Design and Construction of Surface Treatments

Manual 40 Third Edition - February 2021

sabita

excellence in bituminous products

Published by

Southern African Bitumen Association (Sabita)

Postnet Suite 56, Private Bag X21

Howard Place, 7450, South Africa

Tel: +27 21 531 2718

Email: info@sabita.co.za

ISBN 978-1-874968-77-1

DISCLAIMER

While considerable effort has been made to ensure the accuracy and reliability of the information contained in this publication, no warranty, assurance or representation is made in respect of fitness for purpose. Furthermore, neither Sabita nor any of its members can accept liability for any loss, damage or injury whatsoever resulting from the use of this information.

The user of this manual is deemed to have the necessary knowledge, skill and judgment to design bituminous surfacings and to exercise the necessary care and diligence in the application of this knowledge, skill and judgment The information in this publication cannot supplant the user of the information's knowledge, skill and judgment based on the specific site and material conditions and state of the art and the user's exercise of the necessary care and diligence in the application of this knowledge, skill and judgment. Hence neither Sabita nor any of its members can accept liability for any loss, damage or injury whatsoever from the application, or failure to apply such knowledge, skill and professional judgment with the necessary care and diligence by the user of the information in this publication.

The above exclusions apply irrespective of any references in any COTO document to any of Sabita's manuals.

SERIES NAME

SABITA Manuals comprise a series of publications that provide guidelines on various aspects related to flexible pavement engineering. The documents are primarily aimed at ensuring uniform application of best practice methods and procedures throughout South Africa. Users of the documents must ensure that the latest editions or versions of the document are used. When a document is referred to in other documents, the reference should be to the latest edition or version of the document. Any comments on the documents will be welcomed and should be forwarded to SABITA. When appropriate, such comments may be incorporated in future editions of the document.

SYNOPSIS

SABITA Manual 40 provides backgrounds, concepts, guidelines and procedures to assist practitioners with the selection, design and construction of bituminous road surface treatments on roads. This manual provides updates to TRH3 (2007) Design and Construction of Surfacing Seals and replaces the existing Manual 10 and Manual 28.

MANUAL 40 COMPRISES OF THE FOLLOWING EIGHT PARTS:

ACKNOWLEDGEMENTS

SABITA Manual 40 was compiled by Gerrie van Zyl, assisted by experienced practitioners in southern Africa.

We acknowledge the contributions made by the following:

Meisie Beukes
Steph Bredenhann
Gerhard Fourie
Andre Greyling and team from BVi Consulting
Arno Hefer
Wim Hofsink
Philip Joubert
Simon Kotze
Hennie Landman
Herman Mostert
Piet Myburgh
Pieter Molenaar
Barry Pearce
Denniss Rossmann
Herman Wolff

MANUALS PUBLISHED BY SABITA

Manual 1	Technical guidelines: Construction of bitumen rubber seals
Manual 2	Bituminous binders for road construction and maintenance (under review)
Manual 3	(Withdrawn)
Manual 4	(Withdrawn)
Manual 5	Guidelines for the manufacture and construction of hot mix asphalt
Manual 6	(Withdrawn)
Manual 7	SurperSurf – Economic warrants for surfacing roads
Manual 8	Guidelines for the safe and responsible handling of bituminous products
Manual 9	(Withdrawn)
Manual 10	Bituminous surfacing for low volume roads and temporary deviations
Manual 11	(Withdrawn)
Manual 12	Labour Absorptive methods in road construction using bituminous materials
Manual 13	LAMBs – The design and use of large aggregate mixes for bases
Manual 14	(Superseded by TG2)
Manual 15	(Withdrawn)
Manual 16	(Withdrawn)
Manual 17	Porous asphalt mixes: Design and use
Manual 18	Appropriate standards for the use of sand asphalt
Manual 19	Guidelines for the design, manufacture and construction of bitumen rubber asphalt wearing courses
Manual 20	Sealing of active cracks in road pavements
Manual 21	(Superseded by TG2)
Manual 22	Hot mix paving in adverse weather
Manual 23	Code of practice: Loading bitumen at refineries
Manual 24	User guide for the design of asphalt mixes (currently being developed)
Manual 25	Code of practice: Transportation, off-loading and storage of bitumen and bituminous products
Manual 26	Interim guidelines for primes and stone pre-coating fluids
Manual 27	Guidelines for thin hot mix asphalt wearing courses on residential streets
Manual 28	Best practice for the design and construction of slurry seals
Manual 29	Guide to the safe use of solvents in a bituminous products laboratory
Manual 30	A guide to the selection of bituminous binders for road construction
Manual 31	Guidelines for calibrating a binder distributor to ensure satisfactory performance
Manual 32	Best practice guideline and specification for warm mix asphalt
Manual 33	Design procedure for high modulus asphalt (EME)
Manual 34	(A) Guidelines to the transportation of bitumen and (B) Bitumen spill protocol (booklets)

Manual 35	Design and use of Asphalt in Road Pavements
Manual 36	Use of Reclaimed Asphalt in the Production of Asphalt
Manual 37	Sampling Methods for road construction materials (currently being developed)
Manual 38	A Health and Safety Guide for material testing laboratories in the road construction industry
Manual 39	Laboratory testing protocols for binders and asphalt
Manual 40	Design and construction of surfacing seals

TECHNICAL GUIDELINES

TG 1	The use of modified binders in road construction
TG 2	Bitumen stabilised materials
TG 3	Asphalt reinforcement for road condition

SABITA DVD SERIES

DVD 100	Test methods for bituminous products
DVD 200	Training guide for the construction and repair of bituminous surfacing by hand
DVD 300	Manufacture, paving and compaction of hot mix asphalt
DVD 410	The safe handling of bitumen
DVD 420	Treatment of bitumen burns
DVD 430	Working safely with bitumen
DVD 440	Firefighting in the bituminous products industry
DVD 450	Safe loading and off-loading of bitumen

PART A

GENERAL

CONTENTS

LIST OF TABLES

LIST OF FIGURES

A.1 INTRODUCTION

A.1.1 CONTEXT

Manual 40 comprises eight parts:

- **Part A: General (This document)**
- Part B: Materials
- Part C: Performance
- Part D: Seal type and binder selection
- Part E: Design
- Part F: Construction
- Part G: Quality Assurance
- Part H: Repair of premature failures

A.1.2 OBJECTIVES

PART A provides a background to the purpose and functions of surface treatments, the development of the local seal design method and a summary of typical seals used in South Africa. General terms and definitions, applicable to surface treatments are provided.

A.1.3 SCOPE

Important aspects relating to the design of different seal types are addressed under the following headings:

A.2 Definition, functions and basic requirements

A.3 Evolution of seal design in South Africa

A.4 South African Environment

A.5 Surface treatment types

A.2 DEFINITION, FUNCTIONS AND BASIC REQUIREMENTS

A.2.1 DEFINITION

Bituminous surfacings could be divided into surface treatments and asphalt overlays. The surface treatments, in turn, could be further divided into sprayed seals, slurry seals and combination seals.

In its simplest form a sprayed seal consists of a coat of bituminous binder sprayed onto the road surface which is then covered with a layer of aggregate (stone or sand). The aggregate cover is applied immediately after the binder has been sprayed and then rolled to ensure close contact and thus good adhesion between the aggregate and the binder film. Rolling initiates the process of orientating the particles into a mosaic pattern and working the binder into the voids between the aggregate particles. The process is completed by the action of traffic, so that finally a dense and relatively impermeable pavement surfacing is obtained.

Slurry seals consist of a mixture of crusher dust, bitumen emulsion, an active filler, water and chemical additives (in case of microsurfacings) to control the rate of curing.

A combination seal consists of a single seal or single sized aggregate matrix, with the voids filled with a fine graded slurry.

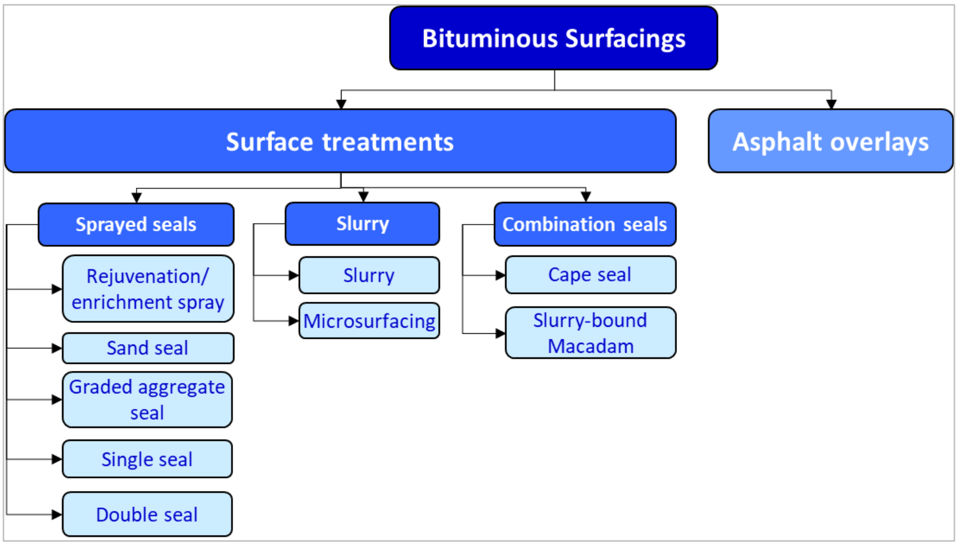


Figure A 1 Bituminous Surfacing Types

The different seal types are described in Section A.5.

The main functions of a surface treatment are to:

- Provide a waterproof cover to the underlying pavement
- Provide a safe all-weather, dust-free riding surface for traffic with adequate skid resistance
- Protect the underlying layer from the abrasive and destructive forces of traffic and the environment.

Where appropriate, slurry seals are used for rut-filling or to improve the riding quality of the road by smoothing out small irregularities.

Since most seals are relatively thin, they have no load distribution properties, whereby stresses in underlying layers are significantly reduces. However, the seal itself should be able to accommodate the horizontal and vertical traffic-induced stresses, not to shear or lose aggregate.

A.2.2 BASIC REQUIREMENTS

A.2.2.1 Skid Resistance

Skid resistance is a measure of the ability of a road surface to prevent a vehicle's tyres from sliding while the vehicle performs typical operational manoeuvres such as turning or braking. Since skid resistance plays a role in determining how a vehicle will respond to sudden braking or turning at speed, it is related to road safety and accident potential. As such, it is one of the most important features to consider during surface treatment selection and to monitor the performance as part of road network surveillance operations.

Road accidents are caused by many factors such as driver behaviour, vehicle and tyre characteristics, vehicle speed, climatic conditions and roadway characteristics (which includes skid resistance properties).

Equipment used for measuring skid resistance are:

- Side-way Force Routine Investigating Machine (SCRIM)
- Grip tester

Suggested readings:

Sections of PART A have been extracted from TMH13 [1]. More detailed information could be obtained from this document

Figure A 2 SCRIM

A smooth thread tyre is dragged at a 20° angle to the direction of travel on a water wetted surface at a speed of 50 or 80 km/h. The friction value is calculated by the force at which the test tyre tries to straighten from the 20° angle. The higher the friction value, the better the skid resistance.

Although no specifications exist for skid resistance in South Africa, international guidelines for different situations are provided in Table A 1 [3].

Table A 1 Skid Resistance Investigatory Levels

Site category and definition		Investigatory levels (SFC)							
		0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65
A	Motorway								
B	Dual carriageway non-event								
C	Single carriageway non-event								
Q	Approaches to and across minor and major junctions, approaches to roundabouts								
K	Approaches to pedestrian crossings and other high-risk situations								
R	Roundabout								
G1	Gradient 5 - 10% longer than 50m								
G2	Gradient > 10% longer than 50m								
S1	Bend radius < 500m - dual carriageway								
S2	Bend radius < 500m - single carriageway								

Notes:

- ***The Side-way force coefficient values given in Table A 1 are not specifications, but merely trigger values to identify potential improvement projects and to assist with the selection of appropriate surfacing types***
- ***The darker shaded cells or range indicate the recommended SFC with the lighter shaded cells the suggested minimum***

Typical SFC values for different surface treatment types, as measured on an existing road network in South Africa [3], are provided in Table A 2. The measured values confirm that surface treatments could provide sufficient skid resistance in any situation.

Table A 2 Typical SFC Values for In-Service Surface Treatment Types

Surfacing type	Condition	Binder type	Range of results at 50km/h	Typical average
Coarse slurry	Sound	Modified	0.6 - 1.00	0.8
7 mm Single seal	Sound	Conventional	0.51 - 0.87	0.7
10 mm Single seal	Sound	Conventional	0.36 - 0.64	0.5
14 mm Single seal	Sound	Conventional	0.29 - 0.65	0.5
	Sound	Bitumen rubber	0.50 - 0.66	0.55
20 mm Cape seal	Sound	Conventional	0.56 - 0.80	0.65
	Severe bleeding	Conventional	0.07 - 0.39	0.2

Skid resistance is influenced by two key components of surface texture: microtexture and macrotexture and are described in the following sub-sections.

A.2.2.1.1 Microtexture

Microtexture is provided by the irregularities on the surfaces of road surface aggregate. It increases friction by creating momentary molecular bonding (known as adhesion) between the tyre and aggregate surfaces. The smoothness or harshness of aggregate and sand in the road surface are the key elements that cause and influence microtexture.

Microtexture is important at most vehicle speeds, and in wet and dry weather. At low speeds, microtexture is the primary contributor to skid resistance. However, microtexture will reduce significantly as the water film between the tyre and road surface increases, and the role that microtexture plays in skid resistance thus depends on how much water can be dispersed by the tyre tread and macrotexture.

A.2.2.1.2 Macrotexture

Macrotexture is caused by protruding aggregate (in the case of surface seals and asphalt) and by grooves or textures (in the case of concrete) in the road surface. Therefore, it is primarily influenced by design and construction aspects of seals, asphalt and concrete surfacings.

Macrotexture contributes to skid resistance in two ways: (a) it deforms the tyre, thereby leading to energy loss (known as hysteresis); and (b) it provides the grooves and unevenness needed to rapidly disperse surface water at higher speeds. At vehicle speeds of more than 100 km/h, macrotexture is the dominant factor in determining skid resistance.

Macrotexture is often referred to simply as texture depth, and different tests are designed to quantify macrotexture:

a) Volumetric Texture Depth (VTD)

In this method as described in SANS 3001-BT11, 50 or 100ml material (sand or glass beads) is spread out with a rubber pad in an approximate circular patch so that only the tops of the aggregate particles are just visible. The VTD is than determined by dividing the volume by the area.

Figure A 3 Circular Sand Patch

b) Mean Profile Depth (MPD)

High frequency laser measurements provide a two-dimensional profile from which the MPD is calculated.

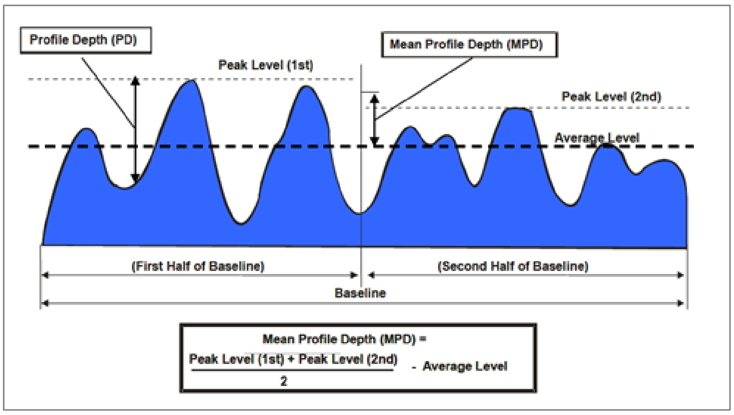


Figure A 4 Mean Profile Depth Calculation

PIARC (1995) [4] developed an equation to relate texture depths obtained from texture profilers, referred to as Mean Profile Depth (MPD), and those measured using the volumetric patch method. MPD is transformed to an estimated volumetric texture depth (ETD) by applying the following equation:

ETD = 0.2 x 0.8 MPD

However, a study in South Africa [5] suggest the following transformation

ETD = 1.35 x MPD

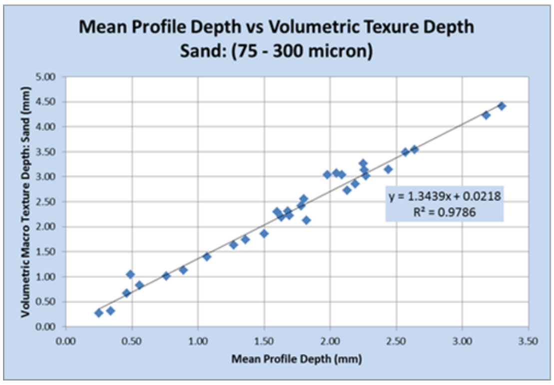


Figure A 5 Correlation between MPD and ETD

***Note**: Different specifications exist for the material used to determine the volumetric texture depth (VTD) e.g. glass beads and sands with different grading specifications. These variances could result in up to 4% difference in the calculated VTD.*

c) Mean Texture Depth

Three-dimensional scanning of a road surface provides a profile, from which the mean texture depth over a selected area is calculated.

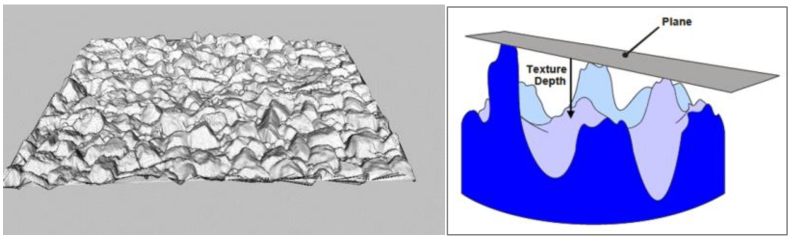


Figure A 6 Three-Dimensional Scanning and Calculation of Mean Texture Depth (MTD)

Typical in-service volumetric texture depths as measured on a rural road network in South Africa are provided in Table A 3.

Table A 3 Typical in-Service Average VTD of Different Seal Types

	Surfacing Type					
	Grit	7 mm	10 mm	14 mm	20+7+7 mm	20+10 mm
Average VTD (mm)	0.9	1.2	1.9	2.5	1.8	2.2

A.2.2.2 Road Noise

Clause 8.3.1.4 of SANS 10328:2008 specifies that the noise level emitted by traffic on roads is to be determined in accordance with SANS 10210:2004: Calculating and predicting road traffic noise.

The procedures for assessing environmental noise, in general, are outlined hereunder.

In accordance with SANS 10328, the predicted impact that noise emanating from a proposed development would have on surrounding land is assessed by determining whether the daytime rating level, LReq,d, and/or the night-time rating level, LReq,n, of the predicted ambient noise would exceed the typical rating level of noise on that land as indicated in Table 2 of SANS 10103. If the rating level of the ambient noise under investigation exceeds the typical rating level, it is probable that the noise is annoying or otherwise intrusive to a community exposed to the noise. This excess is then related to the probable response of a community to the noise as indicated in Table 5 of SANS 10103. Tables 2 and 5 of SANS 10103 are reproduced in part hereunder as Table A 4. Below.

Table A 4 SANS 10103:2008, Table 2 – Typical Rating for Noise in Districts

Type of district	Equivalent continuous rating level (LReq.T) for noise, dBA					
	Outdoors			Indoors, with open windows		
	Day-night LR,dna	Day-time LReq,db	Night-time LReq,nb	Day-night LR,dna	Day-time LReq,db	Night-time LReq,nb
a) Rural districts	45	45	35	35	35	25
b) Suburban districts with little road traffic	50	50	40	40	40	30
c) Urban districts	55	55	45	45	45	35
d) Urban districts with one or more of the following: workshops; business premises; and main roads	60	60	50	50	50	40
e) Central business districts	65	65	55	55	55	45
f) Industrial districts	70	70	60	60	60	50

Table A 5 SANS 10103:2008, Table 5 — Categories of Community/Group Response

Excess (ΔLReq,T) a dBA	Estimated community/group response	
	Category	Description
0 – 10	Little	Sporadic complaints
5 – 15	Medium	Widespread complaints
10 – 20	Strong	Threats of community/group action
>15	Very strong	Vigorous community/group action

A.2.2.2.1 Regulation

In terms of Regulation 3(d) of the Noise Control Regulations (NCR):

“No person shall build a road or change an existing road, or alter the speed limit on a road, if it shall in the opinion of the local authority concerned cause an increase in noise in or near residential areas, or office, church, hospital or educational buildings, unless noise control measures have been taken in consultation with the local authority concerned to ensure that the land in the vicinity of such road shall not be designated as a controlled area.”

Therefore, in areas where the predicted noise level associated with a new road or a change to an existing road exceeds 65 dBA, legislation requires that noise mitigation measures be implemented in order to ensure that the LReq,T on affected land will not exceed 65 dBA.

The World Health Organisation (WHO) recommends a maximum outdoor daytime LAeq of 55 dBA in residential areas and schools "*in order to prevent significant interference with normal activities of local communities*". It further recommends a maximum night-time LAeq of 45 dBA outside dwellings [6]and [7]. No distinction is made as to whether the noise originates from road traffic, from industry, or any other noise source. These recommended maximum levels correspond to the typical daytime rating levels for ambient noise in an urban (residential) district referred to in Table 2 of SANS 10103.

By contrast the NCR does not consider the land use and zoning of the adjacent land such as residential, educational, hospitals and places of worship and explicitly omits the most noise sensitive period between midnight and 06h00.

It is considered important to note that the NCR are not in line with World Best Practice and that the 65 dBA limit specified in the NCR exceeds by a significant 10 dB the maximum level of 55 dBA recommended by the WHO and the SANS 10103 typical level in an urban district. Thus, compliance with the NCR limit of 65 dBA would still cause considerable annoyance to a community exposed to such noise.

The disparities mentioned plus various other shortcomings experienced in implementing the NCR has resulted in these being extensively revised by the Department of Environmental Affairs and Development Planning of the Province of the Western Cape to bring the Provincial NCR in line with SANS 10103. The revised NCR have been published in draft form in Provincial Gazette 6412, 25 January 2007.

In the revised form of the NCR the 65 dBA limit for road traffic noise is removed and replaced by the SANS 10103 typical levels for the particular affected land. However, the existing NCR remain in force until promulgated in revised form.

A.2.2.2.2 Influence of road surface texture

During the rolling of a tyre over the road surface the weight of the vehicle produces a constant deformation of a portion of the tyre called the contact patch. The length of the contact patch, a, is dependent on the tyre "profile" type, tyre diameter and the inflated air pressure. For standard tyres fitted to passenger vehicles the patch length, a, varies between approximately 100 mm and 130 mm as illustrated in Figure A 7 for a 17 inch diameter "normal profile" tyre and an 18 inch "low profile" tyre.

Superimposed on the constant deformation is an alternating deformation due to the macro texture, or profile, of the road surface. The texture wavelength, λ, which is the distance between peaks or troughs of the profile, and the texture depth, h, determine the extent to which the tyre can be deformed. If the wavelength of the profile is very much shorter than the length of the contact patch the tyre rolls over the surface without following the road texture. In practical terms this implies that the wavelength must be less than 1/10th of the patch length. Thus, $\lambda < a/10$. When the profile wavelength is much longer than the footprint the alternate deformation is also small.

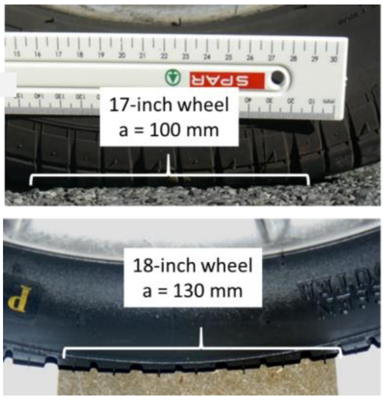


Figure A 7 Tyre Contact Patch Lengths of Two-Wheel Diameters and Tyre Type

Between these two extremes, when the profile wavelength is close to that of the contact patch length, the alternating deformation and hence noise producing vibrations of the tyre are maximised.

The road surface texture descriptors related to tyre contact patch length are summarised in Figure A 8.

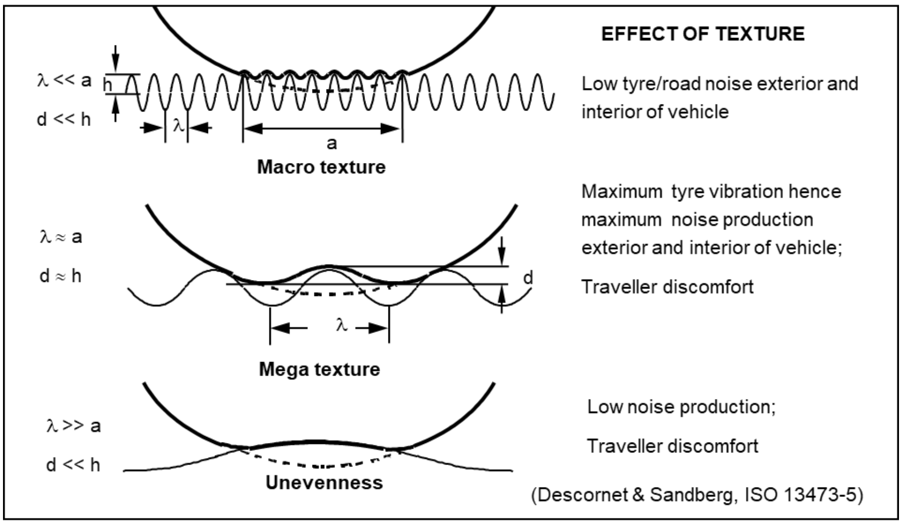


Figure A 8 Texture Descriptors Related to Tyre Contact Patch Length

Where:

a = Contact patch length of tyre with road surface λ = 100 to 130 mm for passenger vehicles

λ = Road texture wavelength – distance between adjacent peaks

d = Vertical displacement of the tyre wall within contact patch

h = Road texture depth (Not volumetric texture depth, but ½ of the wave amplitude)

There is a close positive correlation between texture depth for texture wavelengths from 12,5 mm to 160 mm and rolling noise produced [6]. This is illustrated by the middle diagram of Figure A 8 for $\lambda > a/10$ and approaching contact patch length, a.

Translated into road surface design, for aggregate sizes larger than 12,5 mm an increase in the texture depth of the gaps between the contact surfaces of the aggregates will cause an associated increase in the level of tyre impact noise in the frequency range between 600 Hz and 1 000 Hz. **It is the fundamental, physical reason why surfacing seals produce high levels of rolling noise, or conversely, are inherently unable to produce low levels of rolling noise.**

A.2.2.2.3 Impact on surface treatment selection and construction

All of the following are to be implemented in order to minimise impact noise that is the major contributor to road noise:

- The aggregate exposed to the tyres should be of constant size and, preferably not exceeding 8 mm.
- The aggregates should have a cubical shape to ensure a flat exposed surface after rolling. Stone chips with irregular shape and sharp edges are to be avoided.
- The aggregate particles must be closely packed, referred to as a “dense matrix”.
- They must be well rolled to produce a smooth surface with the flat faces of aggregates exposed.

Omission of any one of these requirements will result in an increase in the level of tyre impact noise.

A.3 EVOLUTION

A.3.1 ORIGIN AND EVOLVEMENT 1935 TO 1985

F.M Hanson [8], was the first to publish his work describing the rational design of single chip seals in 1935. Hanson introduced the concept of partially filling the voids in the covering aggregate and that the volume of these voids is a function of the Average Least Dimension (ALD) of the aggregate.

During the 1950s and 1960s further developments based on Hanson's work were applied in the United States of America, Canada, United Kingdom, Australia, New Zealand and South Africa. These developments incorporated additional variables such as aggregate gradation, pavement condition, traffic volume and type of bitumen binder. Correction factors were also incorporated for binder absorption, existing surface texture and aggregate embedment.

A better understanding developed for the impact of aggregate properties such as grading, shape and durability, while research extended to investigate aggregate retention under varying conditions. The long-term monitoring of trial sections assisted in developing design algorithms to predict the future service life of seals.

Most of the design methods used in South Africa evolved from Hanson's concept of partially filling the voids in the covering aggregate. However, the different provinces in South Africa each made adjustments to suit their particular traffic situations, materials and different climatic environments, resulting in four different design methods, each giving a different recommended application rate for a given situation.

During the 1970s investigations by CP Marais [6] and C Semmelink [10] resulted in a rational design method to incorporate the existing road macro texture, embedment potential and aggregate wear.

A.3.2 TRH3 (1986)

The edition of the TRH3 (1986) [11] included the different design methods of the Provincial road authorities and the rational design method. Design variables included Equivalent Light Vehicles (ELVs), with 1 Heavy vehicle accounting for 20 Light vehicles, existing texture, embedment potential and climate. Further adjustments made allowance for binder absorption, steep grades and construction traffic.

A.3.3 TRH3 (1998)

The Committee of Local Transport Officials (COLTO) identified the need for revision of TRH3(1986) and initiated an investigation whereby only one standard method of seal design would be accepted by the industry of South Africa.

Based on good seal performance in each South African Province, the philosophy adopted was that none of the design methods gave "wrong" answers and that an acceptable National design method should allow designers to obtain similar application rates by applying local provincial approaches and preferences.

The investigation into different preferred application rates for similar conditions revealed the following reasons:

- Majority recommend only one application rate.
- Preferred aggregate matrix differs.
- Preferred texture depth differs.
- Climatic differences.
- Different sources of binder.

The study further highlighted that the rational design method gave much too high application rates, beyond what any Province would recommend.

Through adjustment of the basic assumptions of the rational design method, as described in TRH3 (1998)[13], the envelope of recommended application rates for any given situation, was moved downwards to ensure that Provincial recommendations would fall within the envelope. The principle is shown in Figure A 9.

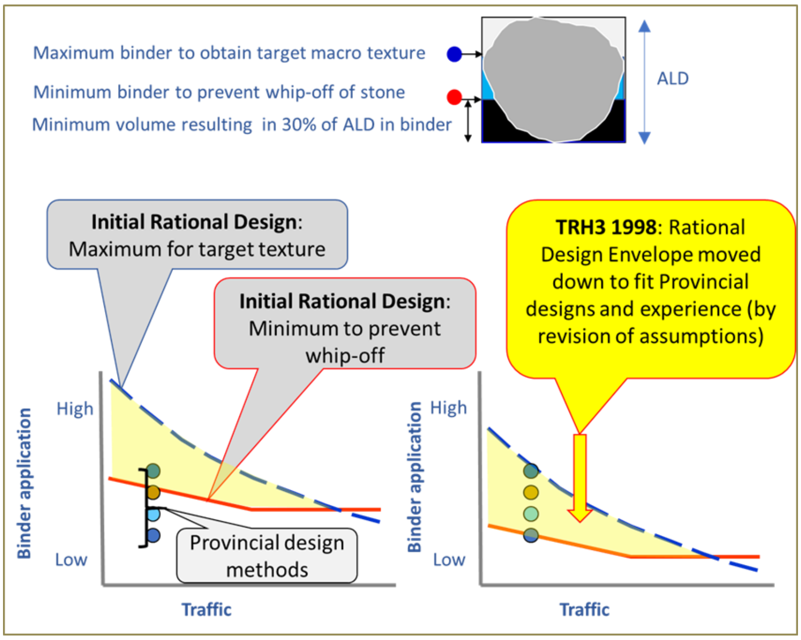


Figure A 9 Adjustment of the Initial Rational Design Method

The red line approximates the "TPA"[1] design application rates as a minimum with the following reasons to substantiate a "lean" design approach:

- More than 50% of vehicles were registered in the centre of the old Transvaal Province (Now Gauteng Province).
- Uncertainty in the attracted traffic after upgrading of roads with the philosophy that it is much easier to add additional binder than to rectify a bleeding seal.
- Annual resealing and rejuvenation contracts, allowing the application of additional binder through diluted emulsions within days of visible or potential aggregate loss.
- Excellent aggregate sources and sealing conditions.

The increase in the heavy vehicle volumes, load and tyre pressures was accounted for by increasing the effect of one heavy vehicle to 40 equivalent light vehicles, compared to the previous assumed value of 20 light vehicles.

[1] Transvaal Provincial Administration

The concept of conversion factors for modified binders was introduced, whereby the Ring and Ball Softening Point of the modified binder and the design traffic (ELVs) was used to derive the conversion factor. The conversion factor made provision for the stone orientation that occurred at a slower rate (assumed to be half that of unmodified binders), resulting in higher void content that requires higher binder application to hold the stone.

A.3.4 TRH3 (2007)

Since publishing TRH3 (1998), a dramatic increase in the use of polymer modified binders for single and double seals was experienced in South Africa and it was soon realized that the conversion factors were not appropriate.

Field experiments and observations since the publication of the TRH3 (1998) suggested that the application rates for bitumen rubber seals were too low, while too high for synthetic polymer modified binders.

Adjustments on sites to obtain good performing modified binder seals were analysed, resulting in conversion factors, related to traffic and degree of polymer modification.

A.3.5 TRH3/ Sabita Manual 40

TRH3 (2007) [13] provided excellent guidelines for more than ten years. However, due to several reasons, the local industry identified the need to update the TRH3 (2007) to minimize risks, highlighting specific issues:

- Several investigations into the cause of premature seal failure since 2007 indicated either poor seal selection, poor design or poor construction practices.
- Significant research work into the performance of surface treatments has been done during the past decade, which should be incorporated in the National guideline document.
- Given the need for development of contractors in the seal industry, much more attention should be given to the selection of “Low Risk Seal Options”.
- Step by step assistance is required for design.
- Practical minimum and maximum application rates are required for different seal types and layers.
- Additional hints and warnings from good practice should be incorporated.
- Summaries are required per Section.
- The latest test methods and standard specifications for road and bridge works in South Africa must be incorporated.

Urgency for new guidelines resulted in Sabita sponsoring the effort to update TRH3 (2007)

A.4 SOUTH AFRICAN ENVIRONMENT

Air and road temperatures are strongly affected by altitude. From the south coast northwards, the temperatures increase little, except in the lowland areas. The duration of sunshine varies from more than 80 per cent of the possible duration in the north western parts to 70 per cent over most of the remainder of the interior and to less than 60 per cent in the coastal areas.

Average annual air temperatures vary from less than 13°C in the central mountain areas to 17°C in the broader central and south coastal areas and to 22°C or more in the western, northern and eastern parts of the country. In all these areas maximum air temperatures may exceed 35°C (40°C in the northern and eastern parts of the country). On the Highveld and in the mountainous regions, minimum temperatures may be as low as -8°C (temperatures of below -10°C have been recorded in places). Minimum temperatures mainly occur during June and July.

Air temperatures influence the road surface temperatures which, in turn, will influence the selection of seal type and binder to be used.

Embargo on seal work during winter periods is enforced by road authorities throughout the world. In South Africa the embargo period generally accepted is from beginning May to end of August due to low day and night temperatures.

The concept of having an embargo period to prevent seal work during winter was introduced due to the high risk of stripping during winter.

In order to maximize seal work throughout the winter, risk levels have been defined to minimize risk (Refer PART D). The most important factors influencing the risk of sealing roads in South Africa during winter are:

- Climatic conditions (Low night time temperatures).
- Traffic volumes.
- Seal and binder type selection.
- Quality of design and construction.

Figure A 10 depicts the minimum road surface temperature that could be expected at night during wintertime, highlighting areas of increasing risk (Red to blue).

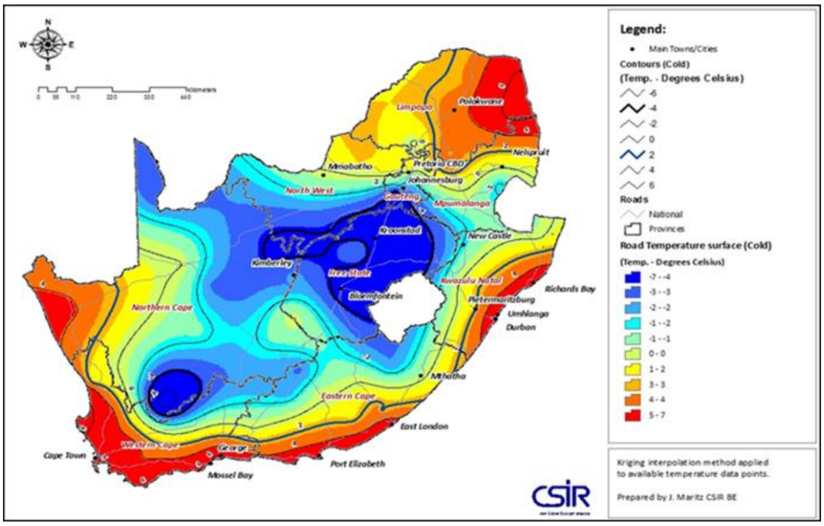


Figure A 10 Minimum Road Surface Temperatures

Notes:

One component of risk not visible from Figure A 10, is the maximum road surface temperatures that could be expected during wintertime. From the figure sealing in the Cape Town area would seem to be less risky than in the Kimberly area. The truth is the other way around for the following reasons:

- ***Road surface temperatures in the Cape Town area, due to cold winds and rain during winter, often do not increase above 20°C. As elaborated upon in PART C: Performance and PART F: Construction, the binder at these temperatures is too stiff to allow orientation of the aggregate into a stable low risk matrix***
- ***In the Kimberley area (summer rainfall), sub-zero road surface temperatures could be expected overnight. However, during daytime the temperatures could easily rise to 40°C, thus allowing the aggregate to orientate quickly.***

A.5 SURFACE TREATMENT TYPES

The most common surface treatment types used in South Africa are described in this section. Table A 6 provides a list of these surface treatment types and abbreviated codes for further use in this document.

Table A 6 Most Common Surface Treatment Types in South Africa – Reference Table

Seal Code	Description
S3 (S <10)	Graded aggregate seals - Single application (<10mm)
S3 (S 10+)	Graded aggregate seals - Single application (10mm or more)
S3 (D <10)	Graded aggregate seals - Double application (<10mm per layer)
S3 (D 10+)	Graded aggregate seals - Double application (10+mm per layer or first layer covered with sand seal)
S7 (<10mm)	Thin microsurfacing or Slurry seal
S7 (>10mm)	Thick microsurfacing or Coarse slurry seal
S1 (7)	Single seal with 7 mm aggregate
S1(10)	Single seal with 10 mm aggregate
S1(14)	Single seal with 14 mm aggregate
S1(20)	Single seal with 20 mm aggregate
S2(10)	Double seal with 10 mm aggregate and sand
S2(14)	Double seal with 14 mm aggregate and sand
S4(10)	Cape Seal with 10 mm aggregate and one layer of slurry
S4(14)	Cape Seal with 14 mm aggregate and one layer of slurry
S4(20)	Cape Seal with 20 mm aggregate and two layers of slurry
S2(14/7)	Double seal with 14 mm aggregate and a layer of 7 mm aggregate
S2(14/5)	Double seal with 14 mm aggregate and a layer of 5 mm aggregate
S2(20/10)	Double seal with 20 mm aggregate and a layer of 10 mm aggregate
S2(20/7)	Double seal with 20 mm aggregate and a layer of 7 mm aggregate
S2(20/7/7)	Double seal with 20 mm aggregate and two layers of 7 mm aggregate
S8(14)	Slurry-bound Macadam seal with 14 mm aggregate
S8(20)	Slurry-bound Macadam seal with 20 mm aggregate
AC	Asphalt layer with suitable grading and thickness

Notes:

- ***Seal codes have been adapted from TRH14 (1985) with S5 (Slurry-fine grading) and S6 (Slurry -coarse grading) combined under S7 with microsurfacing.***
- ***AC refers to an asphalt surfacing (premix). Although not discussed in this document, it is often identified as a more appropriate surfacing than a surface treatment (Refer PART D: Selection).***

A.5.1 GRADED AGGREGATE SEALS

A.5.1.1 General

A graded aggregate seal comprises an application of binder and a layer of graded aggregate. Distinction is made in this document for:

- Single application (<10mm) – Single sand or grit seal.
- Double application (<10mm per layer) – Double sand or grit seal.
- Single application (10mm or more) – Includes the Otta seal of 20mm.

- Double application (>10mm per layer) or first layer covered with sand seal.

A.5.1.2 Thin Graded Aggregate Seals

This seal type, commonly referred to as a sand seal is often used on lower volume roads as initial seals (Double application) or as reseals (Single application), preferably with a soft binder such as MC3000. The term grit seal is applied to a sand with a specific grading (-5mm with not more than 2% less than 0.075 mm).

Thin graded seals are denoted S3 as shown in Table A 4 and summarised in Table A 7 below.

Table A 7 Thin Graded Aggregate Seals

Seal Code	Description
S3 (S <10)	Graded aggregate seals - Single application (<10mm)
S3 (D <10)	Graded aggregate seals - Double application (<10mm per layer)

The typical structure and images for thin graded aggregate seals are shown in Figure A 11.

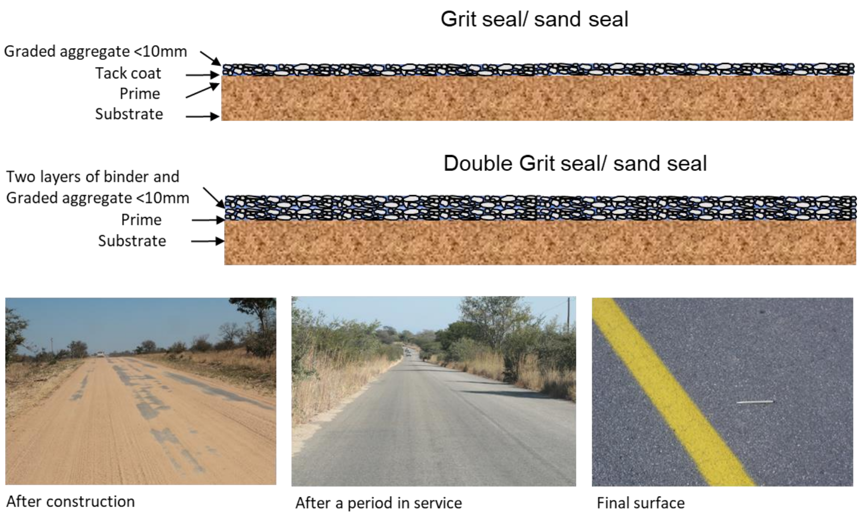


Figure A 11 Thin Graded Aggregate Seals (Sand Seals)

Grit or sand is often used as a blinding layer on single seals constructed with emulsion cover sprays to prevent pickup and to stabilise the seal, locking the large aggregate to handle turning actions or to prevent stripping soon after construction.

Precoated grit is recommended for the repair of stripped seals as discussed in PART H.

A.5.1.3 Thick Graded Aggregate Seals

As per definition, these sprayed seals are more than 10mm thick and could comprise one or two layers e.g.:

- One layer of more than 10mm thick.
- Two layers, each more than 10mm thick.
- One layer of more than 10mm thick plus one layer of less than 10mm thick (A 20mm Otta seal plus a sand seal would fit into this category).

Thick graded seals are denoted S3 as shown in Table A 4 and summarised in Table A 8 below.

Table A 8 Thick Graded Aggregate Seals

Seal Code	Description
S3 (S 10+)	Graded aggregate seals - Single application (10mm or more)
S3 (D 10+)	Graded aggregate seals - Double application (10+mm per layer or first layer covered with sand seal)

The typical structure and images for a thick graded aggregate seal are shown in Figure A 12.

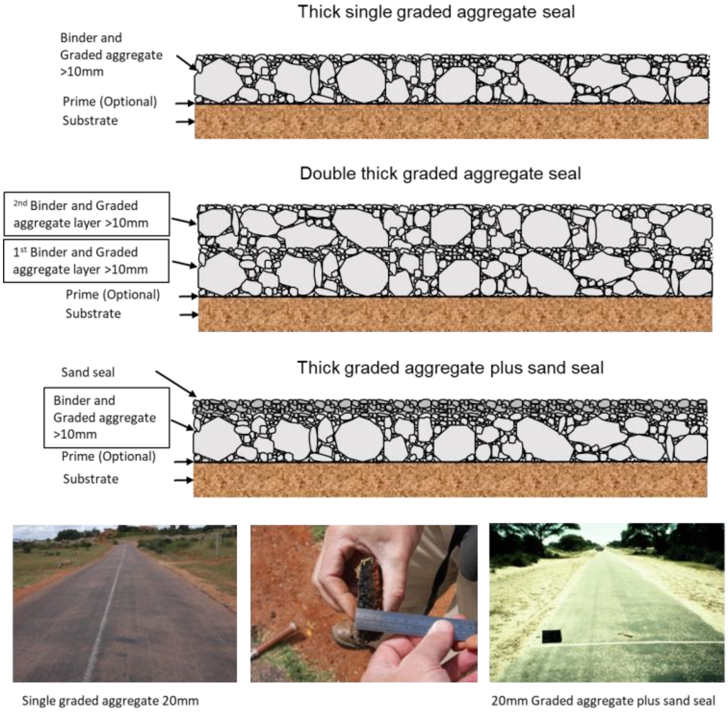


Figure A 12 Thick Graded Aggregate Seals

Excellent performance for more than 15 years has been recorded on very low volume roads in the northern part of the country and in Botswana (neighbouring country north of South Africa).

High application of a soft binder e.g. MC3000 is required, which can migrate upwards through the aggregate with rolling and trafficking.

A.5.1.3.1 Single Seals

A single seal is described as any seal with one application of binder as a tack coat, one application of aggregate. A cover sprays in the form of a diluted emulsion is often done close to, or during wintertime, in cold micro-climates and essential with none-precoated stone and use of emulsion in the tack coat.

Single seals are denoted S1 as shown in Table A 4 and summarised in Table A 9 below.

Table A 9 Single Seals

Seal Code	Description
S1 (7)	Single seal with 7 mm aggregate
S1(10)	Single seal with 10 mm aggregate
S1(14)	Single seal with 14 mm aggregate
S1(20)	Single seal with 20 mm aggregate

The typical structure and images for a single seal are shown in Figure A 18 below.

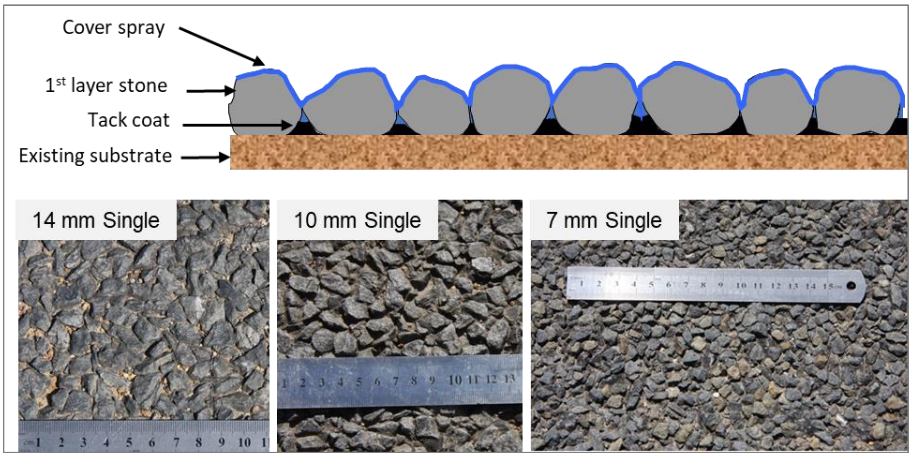


Figure A 13 Single Seals

Due to the risk of nozzle blockage, poor transverse distribution and possible poor base finish, single seals are only recommended for resealing.

A.5.1.4 Double Seals

A double seal for purposes of this document is described as any seal with two applications of binder and two applications of aggregate. Cover sprays in the form of a diluted emulsion on top of the final aggregate is often done close to, or during wintertime and essential with certain type of double seals.

Double seals are denoted S2 as shown in Table A 6 and summarised in Table A 10 below.

Table A 10 Double Seals

Seal Code	Description
S2(10/S)	Double seal with 10 mm aggregate and sand
S2(14/S)	Double seal with 14 mm aggregate and sand
S2(14/7)	Double seal with 14 mm aggregate and a layer of 7 mm aggregate
S2(14/5)	Double seal with 14 mm aggregate and a layer of 5 mm aggregate
S2(20/10)	Double seal with 20 mm aggregate and a layer of 10 mm aggregate
S2(20/7)	Double seal with 20 mm aggregate and a layer of 7 mm aggregate
S2(20/7/7)	Double seal with 20 mm aggregate and two layers of 7 mm aggregate

The typical structures and images for different type of double seals are shown in the figures below.

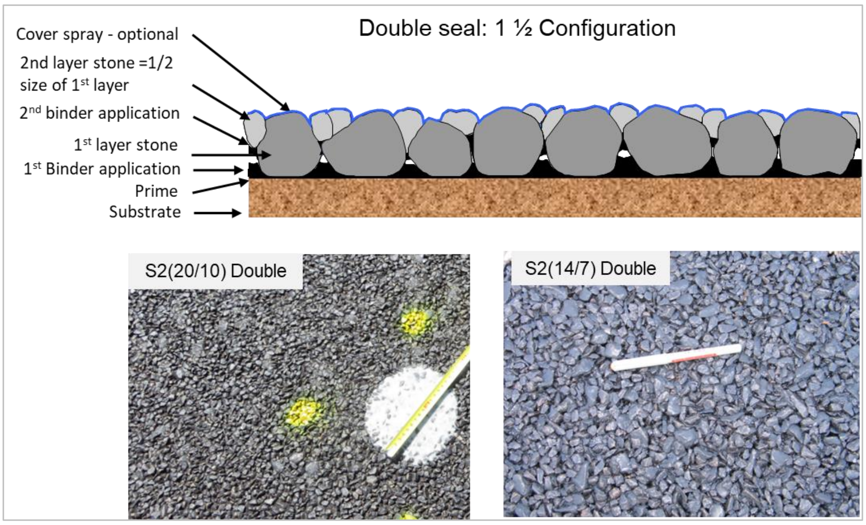


Figure A 14 S2(20/10) and S2(14/7) with 1 ½ Configuration

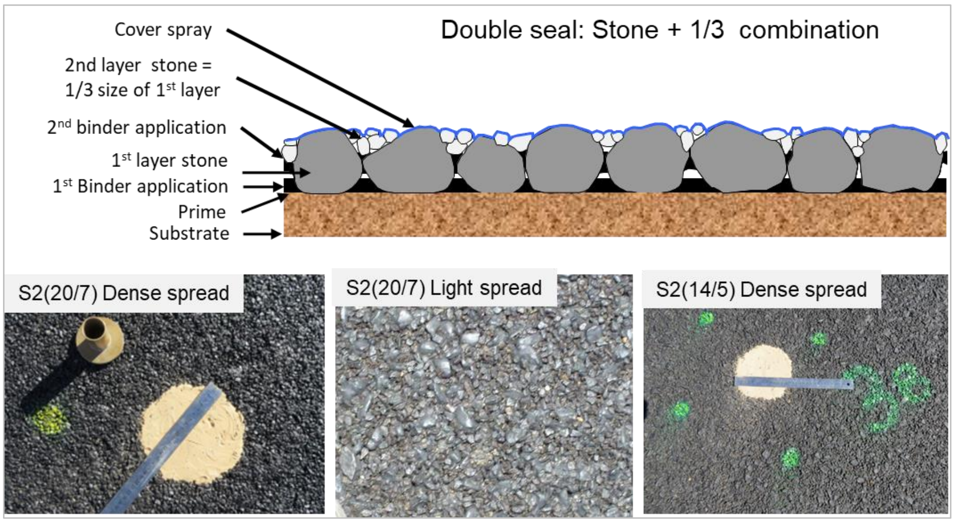


Figure A 15 Stone + 1/3 Combination

As shown, different macro textures could be obtained, suitable for different situations. The small aggregate fills the voids in the structure, making the seal much less sensitive to stripping. A cover spray is recommended for this seal.

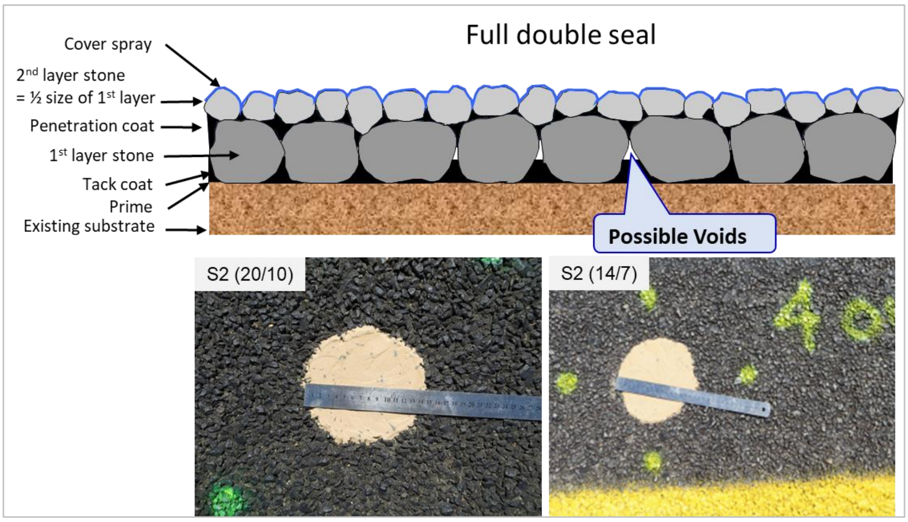


Figure A 16 Full Double Seal Configuration

With high traffic volumes, it is possible that there could still be voids in the structure, requiring the use of a high viscosity binder (e.g. S-E1) as penetration coat. A cover spray is desirable on this seal.

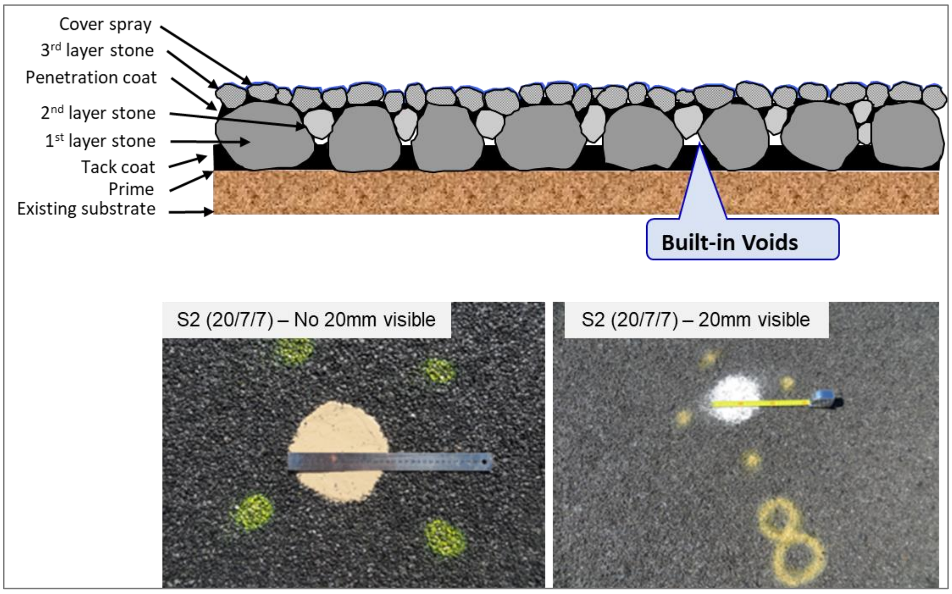


Figure A 17 Split application double seal

As shown, the dry aggregate layer creates voids in the structure. With embedment of the large aggregate, the voids accommodate the resulting upward movement of the tack coat binder, minimising the risk of bleeding.

A.5.1.5 Cape Seals

Cape Seal consists of a single seal of 20 mm, 14 mm or 10 mm aggregate, mostly penetrated with a binder (cover spray) and covered with a slurry seal. If 20 mm aggregate is used, the slurry is applied in two layers.

When hot binders and precoated aggregate are used, a cover spray is usually not applied. However, if emulsions are used as a tack coat with none-precoated stone, a cover spray is essential.

Note: Some practitioners prefer to always apply a cover spray, regardless of whether the aggregate is precoated.

Cape seals are denoted S4 as shown in Table A 6 and summarised in Table A 11 below.

Table A 11 Cape Seals

Seal Code	Description
S4(10)	Cape Seal with 10 mm aggregate and one layer of slurry
S4(14)	Cape Seal with 14 mm aggregate and one layer of slurry
S4(20)	Cape Seal with 20 mm aggregate and two layers of slurry

The typical structure and images for different type of Cape seals are shown in Figure A 18.

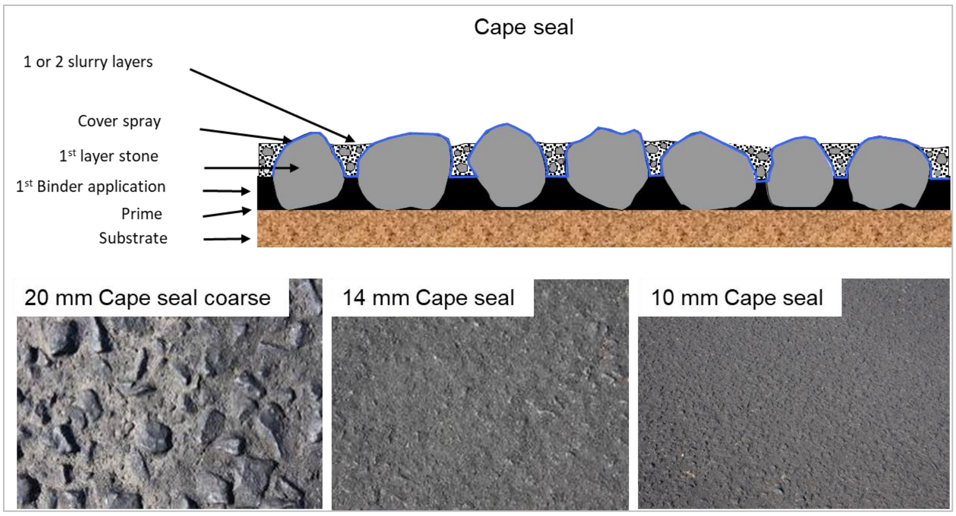


Figure A 18 Cape Seals

The 20 mm Cape seal in Figure A 18 exhibits a very coarse texture that will provide excellent skid resistance but high tyre impact noise. The amount and timing of the second slurry application could result in a much finer macro texture, with much lower tyre impact noise.

A.5.1.6 Slurry-Bound Macadam Seal

Following the preparation of the base layer and priming thereof, single size aggregate (14 mm or 20 mm) is placed on the road surface and levelled to the required thickness (not less than 2 times the ALD of the aggregate) using thickness guides and straight edges. A pedestrian roller, without vibration, is used to orientate and level the aggregate, where after a fine slurry is vibrated into the layer. If necessary, a fine slurry is applied as a final layer.

The Slurry-bound Macadam seal has been constructed with success from 20 mm to 50 mm and is highly effective in maximising labour and accommodating heavy vehicle turning actions.

Slurry-bound Macadam seals are denoted S8 as shown in Table A 8 and summarised in Table A 12 below.

Table A 12 Slurry-bound Macadam Seals

Seal Code	Description
S8(14)	Slurry-bound Macadam seal with 14 mm aggregate
S8(20)	Slurry-bound Macadam seal with 20 mm aggregate

The typical structure and images for Slurry-bound Macadam seals are shown in Figure A 19 below.

As shown, this seal type can effectively be placed on irregular base courses.

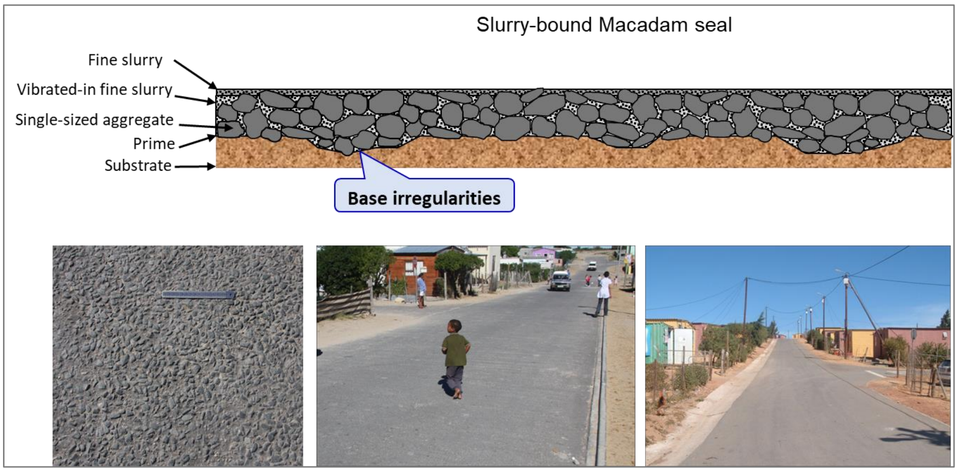


Figure A 19 Slurry-Bound Macadam Seals

A.5.1.7 Slurry Seals and Microsurfacings

Slurry normally consists of a mixture of crusher dust, stable grade bitumen emulsion, cement and water. In the case of microsurfacing, rapid setting cationic emulsions are used, and chemicals are added to control the rate of breaking and curing.

Slurries are used for various purposes e.g.:

- New construction surfacings (Normally > 10mm).
- Resurfacing overlays (Normally > 6 mm).
- Texture pre-treatment (2 – 4 mm).
- Rut filling, edge break and other repairs.

Slurry and microsurfacing are denoted S7 as shown in Table A 8 and summarised in Table A 13 below.

Table A 13 Slurry and Microsurfacing Seals

Seal Code	Description
S7 (<10mm)	Thin microsurfacing or Slurry seal
S7 (>10mm)	Thick microsurfacing or Coarse slurry seal

The typical structure and images for slurry and microsurfacing applications are shown in Figure A 20.

The macro texture obtained is highly dependent on the aggregate grading.

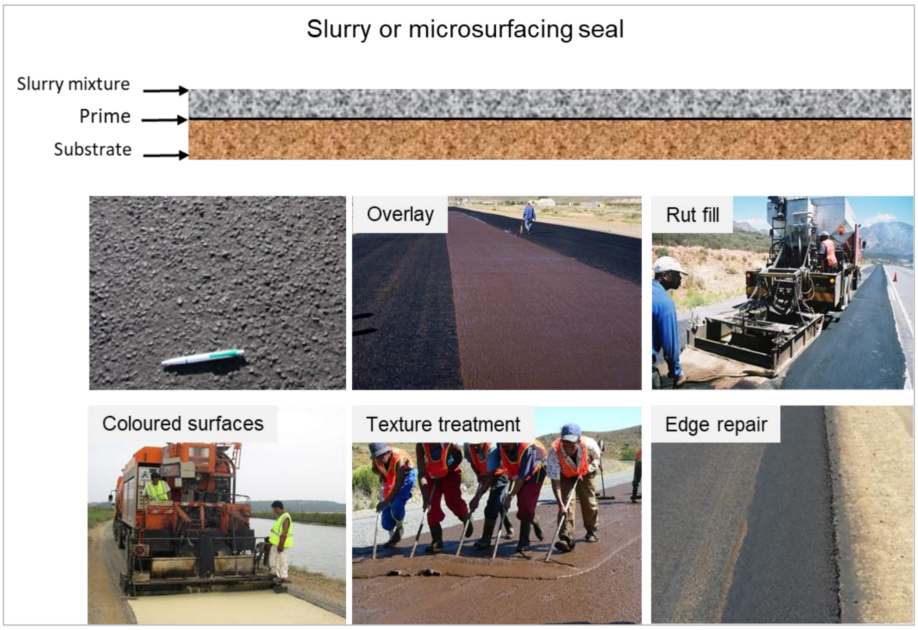


Figure A 20 Slurry and Microsurfacing Applications

A.5.1.8 Other Seal Types

Other seal types used from time to time are:

- Inverted double seals applied in the following situations:
  - A two-phased construction with half-width construction. A 7 mm single seal is applied after construction of the one lane to allow traffic accommodation while the other lane is constructed. Following the completion of the other lane, the road is opened to traffic for a while and then sealed with a 14 mm single seal.
  - The 7 or 10 mm aggregate is applied as an armouring layer on a soft substrate with a very low binder application rate, where after a single seal is applied.
  - The 7 or 10 mm seal is applied only in the wheel track of a rutted road and followed by a single seal over the full width of the road.

Note: Each layer is design as a separate single seal

- Geotextile seals
  - Geotextile seals are defined as bituminous surfacings consisting of a bitumen saturated geotextile and a conventional seal.
  - A geotextile is adhered to the existing surfacing by spraying a bituminous binder tack coat and rolling with a pneumatic roller. Dependent on the application rate of the tack coat and the preference of the engineer, a conventional seal could be constructed directly on the geotextile, adding additional binder to compensate for absorption into the geotextile. Alternatively, a saturation coat could be sprayed onto the geotextile and covered with small aggregate e.g. crusher dust before the conventional seal is constructed.

Note: Good performance has been recorded (refer PART C) and guidelines for the design of this seal type are provided in PART E.

- Choked seals (also referred to as racked-in seals elsewhere).
    - A choked seal can be described as an open single seal, choked with a smaller aggregate, without the application of a binder penetration coat. Several roads have been successfully resealed with choked seals consisting of 14 mm and 7 mm or 20 mm and 10 mm aggregate.

The large aggregate should be placed open and not shoulder-to-shoulder in order to leave room for the smaller aggregate.

<u>Note</u>: Although favoured in New Zealand, this seal type is not often constructed in South Africa. No design guidelines for this seal type are provided in this document.

The typical structures for different above-mentioned seals are shown in Figure A 21.

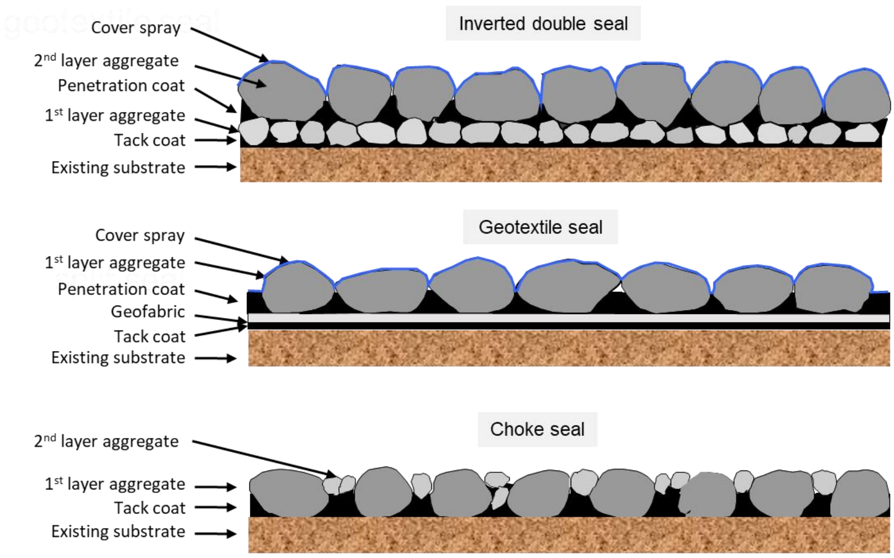


Figure A 21 Inverted, Geotextile and Choke Seals

A 5.1.9 Rejuvenation/ enrichment sprays

Application of a rejuvenation or an enrichment spray to old coarse or open textured single and double seals could extend the effective service life with three to four years. A diluted anionic stable grade emulsion or an invert cutback emulsion is typically used for this purpose.

The effect of rejuvenation or enrichment sprays is shown in Figure A 22.

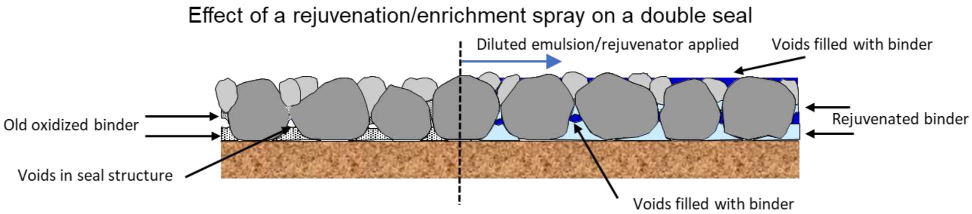


Figure A 22 Effect of rejuvenation and enrichment sprays

A.6 TERMS AND DEFINITIONS

Adhesion properties: The ability of the aggregate to form a strong and lasting bond with the binder.

Aggregate: Inert hard rock-type material which has been crushed and screened to produce the stone, sand or grit used in surface seals.

Aggregate crushing value: A measure of the ability of the aggregate to resist crushing under a compressive load. (See also Hardness.)

Asphalt: A mixture of bituminous binder and aggregate in a prescribed ratio (this includes the terms premix and hotmix).

Average Least Dimension of aggregate (ALD): The overall average of the least dimension for a number of particles (approximately 250) where the least dimension of an aggregate particle is the smallest perpendicular distance between two parallel plates through which the particle will just pass.

Ball penetration test: A test for measuring the penetration resistance of a road surface using a steel ball with a diameter of 19 mm . The result (corrected for temperature and nature of existing surface) is used in the design of surface treatments.

Bitumen: A non-crystalline solid or viscous mixture of complex hydrocarbons which possesses characteristic agglomeration properties. Bitumen, obtained from crude petroleum by refining processes softens gradually when heated and is substantially soluble in trichloroethylene.

Bitumen emulsion: A liquid mixture in which a substantial amount of bitumen is suspended in a finely divided condition in an aqueous medium of one or more suitable emulsifying agents.

Bitumen rubber: Bitumen modified by the addition of approximately 20 per cent rubber crumbs to improve certain properties of the binder. Additionally, 2 to 5 per cent of liquid additive is often added to further improve its properties.

Bituminous binder: A product such as bitumen or derivatives thereof (e.g. cut-back bitumen, modified binder or bitumen emulsion) which acts as a binder for the aggregate in surfacing.

Bituminous surfacing: A surfacing seal or layer of premix asphalt which is directly subjected to traffic forces.

Bleeding: The condition which arises when excess binder is present in the seal, causing a layer of tacky binder to appear above the aggregate.

Blinding: The application of fine aggregate such as crusher sand (not dust) at a low application rate (0,0025 m3/m²) on top of fresh binder, to reduce the tackiness.

Brittleness: The condition which arises when the seal layer fractures, splinters or breaks under traffic impact or as a result of rapid deformation because of its rigidity, caused by ageing and/or thermal effects.

Cape Seal: An application of bituminous binder followed by a layer of stone followed by one or two applications of slurry.

Choked seal: This is an open single seal, choked with a smaller aggregate, without the application of a binder penetration coat.

Cover spray: The application of a diluted emulsion as a final binder application on single or double seals or before application of the slurry, in case of Cape seals (previously referred to as a fog spray)

Cut-back bitumen: A penetration grade bitumen whose viscosity has been reduced by the addition of 5 to 20 per cent of a volatile solvent (kerosene or diesel).

Design Traffic: The total number of expected equivalent light vehicles per lane per day at the time of construction of the surfacing seal.

Diluted emulsion: A mixture of emulsion with water to obtain a lower binder content by volume. It is sprayed to enrich and/or soften the binder of an existing seal (rejuvenation spray, normally anionic stable grade) or a cover spray during seal construction (normally cationic spray grade).

Double seal: An application of bituminous binder followed by a layer of stone followed by another layer of bituminous binder and a layer of smaller stone.

Dryness: The condition which arises when binder loses its elastic, plastic and adhesive properties.

Effective layer thickness (ELT): The volume of stone + voids covering the base of a tray or pan of a given area, divided by the area of the base of the tray or pan. This is used in the original rational design method instead of ALD.

Embedment: The estimated total amount by which the sealing stone will be pressed into the underlying surface during the construction process as well as by traffic using the road after construction.

Estimated Texture Depth (ETD): Refer A.2.2.1.2 for detail

Equivalent light vehicles (ELV): One car or light delivery vehicle per lane per day. Any vehicle larger than a car or light delivery vehicle is taken to be equal to 40 light vehicles.

Flakiness Index (FI): The mass of particles in the aggregate, expressed as a percentage of the total mass of that aggregate, which will pass through the slot or slots of specified width for the appropriate size fraction. The widths and lengths of the slots are respectively half and double those of the sieve openings through which each of the fractions passes.

Flushing: See Bleeding.

Fog spray: See cover spray and rejuvenation spray (A light application of bitumen emulsion binder to the final layer of aggregate of a surfacing seal or to an existing bituminous surfacing as a maintenance treatment).

Geosynthetic: A synthetic material used in contact with natural building materials (soil/gravel/aggregate/bitumen) in civil engineering applications.

Geotextile: A planar, permeable, synthetic textile material, which may be nonwoven, knitted, or woven, used in contact with natural materials used in civil engineering applications.

Geotextile seal: A single or double seal constructed on top of a geotextile material tacked with a bituminous binder to the existing road surface.

Grit seal: A sand seal with a coarse-graded aggregate, defined in PART B: Materials.

Hardness: The ability of the aggregate to resist crushing under a compressive load. (See PART B Materials – 10% FACT). (See also Aggregate Crushing Value.)

Inverted double seal: This is a double seal in which the larger sized aggregate is applied on top of the smaller aggregate.

Invert emulsion: The water is suspended in a finely dispersed state in bitumen. Water in oil compared to oil in water as with emulsion.

Liquid limit: The liquid limit of a soil is the moisture content of the soil at which the soil passes from a plastic to a liquid state.

Macro texture: Refer A.2.2.1.2.

Micro texture: Refer A.2.2.1.1.

Mean Profile Depth (MPD): Refer A.2.2.1.2.

Mean Texture Depth (MTD): Refer A.2.2.1.2.

Modified binder: Any standard bituminous binder which has been modified with polymers to produce a more durable binder with better rheological properties and/or lower temperature susceptibility than the original binder.

Paving fabric: A geotextile used for either stress relief, or waterproofing (when impregnated with selected bituminous binders)

Penetration coat: The second binder layer of the seal which is sprayed after the first layer of stone of a double seal is spread and rolled.

Penetration grade bitumen (bitumen): That fraction of the crude petroleum remaining after refining processes, which is solid or near solid at normal air temperature and which has been blended or further processed to products of varying hardness or viscosity.

Permeable surfacing: The condition which exists when an undesirable amount of water seeps through the surfacing to the base and subbase layers. The degree of permeability can vary.

Plasticity Index (PI): An indication of the clay content of soils or crushed aggregate; the larger the PI, the larger the clay content. Calculated as Liquid Limit – Plastic Limit

Plastic limit: The plastic limit of a soil is the lowest water content at which the soil remains plastic.

Polishing: The tendency of certain stone types to become smooth and rounded under the action of traffic. This should not be confused with attrition or bleeding.

Polishing Stone Value (PSV): Provides a measure of the resistance of aggregate to the polishing action of vehicle tyres under conditions similar to those occurring on a road surface, using a standardised test (SANS 3001 AG 11)

Polymer-modified binder (PMB): Any standard bituminous binder to which a polymer has been added to produce a more durable binder with improved rheological properties.

Porous seal: A seal which contains internal voids such that water can pass through with ease (e.g. honeycomb structure). The degree of porosity can vary.

Precoating: The precoating of the seal stone with a binder (normally bitumen-based) to improve the initial adhesion between the stone and the seal binder.

Prime coat: A layer of binder applied directly on top of the base course to promote and maintain adhesion between the surfacing and the base. This layer also prevents the absorption of surfacing binder by the base and assists in sealing the voids near the surface. It acts as a curing membrane on stabilised bases.

Rejuvenation spray: A mixture of anionic stable grade emulsion with water, generally in a 50/50 ratio, to obtain a lower binder content by volume or, an invert cutback emulsion. It is sprayed to enrich and/or soften the binder of an existing seal.

Reseal: A surfacing seal applied to an existing bituminous surfacing for maintenance purposes.

Residual binder: The residual binder or tar remaining after evaporation of any volatile constituents such as oils in cut-back bituminous binder or water in bituminous emulsion.

SAMI: See Stress Absorbing Membrane Interlayer.

Sand seal: An application of bituminous binder followed by a layer of clean natural and/or crusher sand.

Service life: The period from the construction of the seal to the time when the functionality of the seal ceases.

Sideways Force Coefficient (SFC): Refer A.2.2.1.

Single seal: An application of bituminous binder followed by a layer of stone.

Skid resistance: The ability of a surfacing layer through friction to provide resistance to skidding of a vehicle tyre which is moving over the surface.

Slurry: A mixture of suitably graded fine aggregate, cement or hydrated lime, bitumen emulsion and water.

Slurry seal: A surfacing seal consisting of a layer of slurry.

Split seal: This consists of a double seal in which the top layer of aggregate is split into two applications. The first application of the top layer of aggregate is usually done without a penetration coat.

Spray rate: The rate of application of the bituminous binder expressed in litres per square metre (ℓ/m^2) at a given temperature.

Spread rate: The rate of application of the surfacing stone (chips) expressed in cubic metres per square metre (m^3/m^2) of stone applied at the loose bulk density in the truck or heap.

Stone: A single-sized aggregate used in single or double seals.

Stress Absorbing Membrane Interlayer: A single seal with a polymer-modified binder (usually bitumen-rubber) placed on the existing substrate immediately below an asphalt overlay. Its purpose is to prevent or retard stresses or cracks penetrating into the overlying asphalt layer.

Surfacing: Surfacings consist of two components, namely aggregate and binder. The purpose of a surfacing is to provide a uniform, skid-resistant impermeable coating to the underlying pavement structure.

Surfacing maintenance: Measures which maintain the integrity of the road surface in respect of skid resistance, disintegration and permeability without necessarily increasing the structural strength of the pavement.

Surfacing seal (surface treatment): A thin layer of aggregate and bituminous binder which, being the uppermost pavement layer, is directly subjected to the forces of vehicular traffic.

Surfacing stone: Crushed aggregate with a specified gradation.

Tack coat: First spray of bituminous binder applied during the sealing process. (This should not be confused with a coat of suitable binder applied to an existing surface as a preliminary treatment to promote adhesion between the existing surface and a subsequently applied asphalt layer which is now termed a bond coat.)

Texture depth: A measure of the relative height difference between the troughs and the crests of the aggregate in the seal (Refer macro texture).

Texture treatment: The treatment of an existing seal in order to achieve a more uniform texture or to make a rough texture finer in preparation for resealing. Texture treatment usually takes the form of a thin sand seal or a slurry that is swept or brushed into the existing seal. In the context of this document, texture treatment does not include treatments to increase skid resistance.

Varying texture: A non-uniform texture across the width of the road surface, e.g. where the surface appears smooth in the wheel paths and has a different texture elsewhere.

Viscosity: (resistance to flow).

Dynamic viscosity is the measure of the resistance to flow of a liquid. The ratio between the applied shear stress and the rate of shear is called the coefficient of viscosity, dynamic viscosity, or simply viscosity. The SI unit of dynamic viscosity is the Pascal-second (Pa.s) which is 1N.sec/m^2, and the cgs unit is the gm/cm.s which is the poise (or more conveniently, centipoise cP), such that at a given temperature:

1 Pa.s = 1 000 mPa.s = 10 poise = 1 000cP

The Brookfield model RV with Thermosel system is used in South Africa, measuring the torque required to rotate a SC-4 type spindle immersed in bitumen.

Kinematic viscosity (v) is the ratio of the dynamic viscosity (h) to the density (d) of a liquid such that

v = h / d
Where:
v = kinematic viscosity in mm2/s
h = dynamic viscosity in Pa.s
d = density in kg/l at the temperature under consideration.
The SI unit of kinematic viscos ity is mm^2/s and the cgs unit is cm2/s which is a Stoke or more conveniently, centiStoke (cSt), such that:
1mm2/s = 0,001cm2/s = 1 cSt

Since densities of South African penetration grade bitumen vary between 0.970 and 1.040 kg/l at 60^{0}C, a dynamic viscosity of 1 Pa.s would equate to a kinematic viscosity of between 962 and 1 031 mm^2/s (at 60^{0}C).

Saybolt Furol viscosity, providing a measure of kinematic viscosity, is the efflux time in seconds required for 60 millilitres of a petroleum product e.g. bitumen emulsion, to flow through the calibrated orifice of a Saybolt Furol viscometer, under carefully controlled temperature, as prescribed by test method ASTM D 88.

Volatiles: Solvents used in cutting-back agents and those constituents of bituminous binders which are readily vaporisable at relatively low temperatures.

A.7 REFERENCES

[1] Committee of Transport Officials, 2014. TMH13: Network Llevel pavement surveillance measurements. PART E, Texture and skid resistance.

[2] Design Manual for Roads and Bridges Volume 7 Section 3 Part 1 (HD 28/04), 2004. Pavement design and maintenance. Pavement maintenance assessment. Skid resistance. https://www.standardsforhighways.co.uk/dmrb.

[3] Western Cape Provincial Government, Materials Manual, 2008. Chapter 6, Revison 3. South Africa.

[4] Permanent International Association of Road Conferences. 1995. International PIARC experiment to compare and harmonize texture and skid resistance measurements. Paris, France: PIARC.

[5] Van Zyl, GD and Van der Gryp, A., 2015. Correlation between Mean Profile Depth Estimated Macro Texture Depth. CAPSA.

[6] Descornet & Sandberg, 1980; Sited - Jongens, A.W.D., 2008. Reducing road traffic noise in South Africa. Southern African Transport Conference, CSIR, July 2008.

[7] Legeay, 1990; Sited - Jongens, A.W.D. Reducing road traffic noise in South Africa. Southern African Transport Conference, CSIR, July 2008.

[8] Hanson F.M. Bituminous Surface Treatment of Rural Highways. Ferguson & Osburn,1935.

[9] Marais, C.P. 1979. Advances in the design and application of bituminous materials in road construction. PhD Thesis, University of Natal, Durban.

[10] Semmelink, C.J., 1985. Findings of research on the rational design of single and double seals. Technical Report RP/1, CSIR. ISBN: 0798833181.

[11] Department of Transport, 1986. (Technical recommendations for highways; Draft TRH3). Surfacing seals for urban and rural roads and compendium of design methods for surfacing seals used in the Republic of South Africa. Pretoria.

[12] South African National Roads Agency (SOC) Ltd, , 1998. Technical Recommendations for Highways: Design and Construction of Surfacing Seals (TRH3), Pretoria, South Africa.

[13] South African National Roads Agency (SOC) Ltd, 2007. Technical Recommendations for Highways: Design and Construction of Surfacing Seals (TRH3), Pretoria, South Africa.

PART B

MATERIALS

CONTENTS

LIST OF TABLES

LIST OF FIGURES

B.1 INTRODUCTION

B.1.1 CONTEXT

Manual 40 comprises eight parts:

- Part A: General
- **Part B: Materials (This document)**
- Part C: Performance
- Part D: Seal type and binder selection
- Part E: Design
- Part F: Construction
- Part G: Quality Assurance
- Part H: Repair of premature failures

B.1.2 OBJECTIVES

The purpose of PART B is to provide the currently recommended specifications for materials used in surface treatments. It should be noted that:

- More relaxed standards are now recommended for lower volume roads.
- Several test methods have been adjusted to SANS test methods

B.1.3 SCOPE

PART B provides recommended properties/ specifications for:

- Surface treatment aggregate
- Active fillers for slurries
- Water for diluting emulsions
- Conventional bituminous binders
- Modified bituminous binders

B.2 AGGREGATES

B.2.1 FUNCTION

The aggregate in a seal has four main functions:

- It provides resistance to the abrasion of moving wheel loads and transfers the wheel load to the underlying pavement structure;
- It provides a skid-resistant surface;
- It provides body and a structure to accommodate the visco-elastic and impermeable bituminous binder and has sufficient voids to prevent the binder flushing to the surface under loading, and
- It protects the binder from the harmful ultra-violet rays of the sun.

Note:

Certain aggregate characteristics may have additional functional value, for example:

- *Use of light-absorbing qualities to prevent glare, and*
- *Provision of a different texture or colour to define demarcated areas.*

B.2.2 FACTORS AFFECTING PERFORMANCE

Aggregate-related factors which affect the performance of a seal are:

- Shape, nominal size and grading;
- Spread rate;
- Adhesion characteristics, micro texture, cleanness and dust content;
- Strength, durability and wearing characteristics, and
- Porosity/absorption.

B.2.2.1 Shape, nominal size and grading

The shape of the aggregate affects its interlocking in the compacted layer and, hence, the stability of the seal. The more angular the aggregate, the better the interlock because there are more points of contact. The shape and size also affect the void content in a seal and the ability of the seal to displace surface water (macro texture).

A single-sized stone develops good interlock and provides maximum contact between the tyre and stone surface. This increases the friction area, causes the stone to resist polishing and abrasion and gives good skid resistance, provided the correct quantity of binder is used.

More voids are available with large single-sized aggregates to accommodate a variation in binder application rate than in small single-sized aggregates. The smaller the aggregate size, the greater the possibility of the voids in the layer being filled with binder. This will cause flushing unless very strict control is exercised during construction.

Larger aggregates allow more binder to be used, resulting in a more impermeable, longer lasting seal.

The use of aggregate which does not have a uniform size results in firm tyre contact over a smaller area (which decreases the skid resistance, especially in wet weather), a higher noise level (because the larger particles are spaced further apart), loss of the larger stone by traffic action, and concentrated wear on the larger particles.

***Note**: Design methods, as discussed in PART E of this manual have, to a large extent, been developed and refined while applying strict standards with regard to size, shape and grading. Changing specifications could lead to current design methods not being appropriate to ensure optimal performance.*

B.2.2.2 Spread Rate of Aggregate

The aggregate protects the substrate against traffic abrasion and should be applied at such a rate that complete cover with a uniform mosaic is achieved after construction and traffic compaction. The aggregate should lie shoulder-to- shoulder, in a single layer and in a tightly knit pattern. All design assumptions are made on this basis.

Excessive ultra-violet damage to the binder, ravelling of the seal and subsequent damage of the lower pavement layers may occur if the spread rate is too low. If the spread rate is too high, the aggregate cannot properly orientate, may not be properly covered with binder film, leading to whip-off of the poorly bonded aggregate. Degradation due to crushing and grinding of the aggregate, unnecessary waste of material, and claims for damage resulting from aggregate whip-off and broken windscreens may occur.

B.2.2.3 Adhesion characteristics, micro texture, cleanness and dust content

The aggregate should have good binder adhesion characteristics, which it should retain throughout the life of the seal for it to remain stable under the action of traffic.

Dusty aggregate adversely affects the adhesion between the aggregate and the binder. (The presence of as little as 1 per cent by mass dust may result in a substantial loss of aggregate.) Moist aggregate does not adhere well to binders (except to bituminous emulsions) and, if traffic is allowed to use the seal coat before adequate bonding has occurred, excessive whip-off may occur. Precoating the aggregate with a thin layer of bitumen improves adhesion and obviates the problems associated with hot bituminous binders and aggregates which are not free of dust or moisture.

***Note**: Some granite, felsite and quartzite sources in South Africa are known for poor adhesion (mainly because of smooth micro texture), but have performed reasonably well through careful design, the use of precoating and/ or wetting agents as well as the addition of a cover spray.*

B.2.2.4 Strength and durability characteristics

The aggregate should be hard enough (crushing strength) to allow only minimal breakage during rolling or under traffic and should not weather significantly during the life of the seal. In addition, the aggregate should be inspected visually and tested for the presence of inferior material and harmful minerals. Durability tests should also be carried out.

Apart from this, aggregate exposed to abrasion by traffic will attain a smooth surface in time, i.e. it will polish and/or abrade. The degree of possible polishing depends on its mineral composition and crystal structure. The presence of minerals of similar or different hardness in a rock and their grain sizes therefore determines the potential wearing characteristics of the aggregate and the rate at which wear takes place.

B.2.2.5 Porosity / Absorption

Porous aggregate absorbs the oily components of the bitumen, i.e. maltenes, a process called exudative hardening. This may then result in the binder no longer being suitable (too brittle) to retain the aggregate on the road. If the only aggregate available is a porous aggregate, then the use of modified binders is recommended. In addition, porous aggregates should be precoated prior to use.

B.2.3 SPECIFICATIONS FOR SPRAYED SEAL AGGREGATES

B.2.3.1 General

All the aggregates used in seals, whether stone, crusher dust or natural sand, should, in general, conform to the specifications given in COTO 2019 [1].

B.2.3.2 Relaxation of Specifications

The recommendation to use marginal aggregates in low volume roads was originally made by the Southern African Bitumen Association (SABITA)[2] and is based on the results of a survey carried out in this and neighbouring countries in southern Africa, where high quality aggregates meeting all the requirements of COLTO 1998 [3] are not always available.

It sometimes occurs that, while the available aggregates may comply with the relevant specifications, their dimensional properties (such as ALD or Flakiness Index) may show great variation. This would impact on the design of the seal and may make it necessary to design and apply the seal in many short sections. In such cases, the use of aggregates which are slightly outside the specifications, but whose properties are consistent, may be considered.

If the aggregate comes from a source whose origins and geological properties are not well documented it is essential that they be thoroughly investigated, as there are many recorded instances of apparently suitable aggregates being totally unacceptable and performing very poorly (stripping, disintegration, extremely water sensitive etc.).

It has been found (Wright et al 36) that, by the use of marginal materials, savings of up to 30 per cent in the cost of aggregate alone could be realized, resulting in an overall saving of as much as 7 per cent of the total cost of the seal. Furthering this work through investigations as described in [4] [5] [6] [7] [8] [9] [10] [11] specifications from COLTO 1998 [3] and recommendations in TRH3 2007 [12] have been relaxed for lower volume roads.

***Note*: It is emphasized that relaxation of some of the aggregate standards should not be construed as a lowering of quality or as a means of disposing of sub-standard materials by using these to construct sub-standard roads in communities and suburbs whose roads carry light traffic.**

Three grades of aggregate are defined as appropriate for traffic ranges as provided in Table B 1.

Table B 1 Aggregate Grade Classification

Traffic (AADT)	Less than 300	300 - 3000	More than 3000
Relevant Aggregate Grade	C	B	A

B.2.3.3 Grading

The minimum specifications for single sized aggregates are summarized in Table B 2.

Table B 2 Grading Specifications for Single Sized Aggregate

Sieve size (mm)	Grade	Percentage by mass passing				
		Nominal size (mm)				
		20	**14**	**10**	**7**	**5**
37.5	A & B					
28		100				
20		85 - 100	100			
14		0 – 35*	85 - 100	100		
10		0 – 5**	0 – 35*	85 - 100	100	
7.1			0 – 5**	0 – 35*	85 - 100	100
5				0 – 5**	0 – 35*	85- 100
3.35						0 – 35*
2.0					0 – 5**	0 – 5**
	C	Grading shall comply with the requirements for grades A and B with the following exceptions: * 0 – 50, ** 0 – 10,				
Fines content passing 0,425 mm sieve	A	0.5	0.5	0.5	0.5	1.0
	B	1.5	1.5	1.5	1.5	2.5
	C	2.0	2.0	2.0	3.0	3.5
Dust content: Material passing at 0,075 mm sieve (max)	A	0.2	0.2	0.2	0.5	0.5
	B	0.5	0.5	0.5	1.0	1.0
	C	1.5	1.5	1.5	1.5	1.5

The recommended specifications for sand seals and blinding sand are provided in Table B 3.

Table B 3 Grading Specifications for Sand Seals and Sand Blinding

Sieve size (mm)	Percentage passing by mass
7.1	100
0.300	0 - 15
0.150	0 - 2
Sand Equivalent [%] (min)	35
Plasticity Index: Non-Plastic	

***Note**: It might not always be possible to get aggregate with grading fully within specification. Further relaxation of standards could be considered for very low volume roads i.e. less than 300 vpd.*

Table B 4 Grading Specifications for Grit Seals

Sieve size (mm)	Percentage passing by mass
5	100
2	0 - 100
1	0 - 50
0,600	0 - 20
0,300	0 - 10
0,150	0 - 5
0,075	0 - 2
Sand Equivalent [%] (min)	35

B.2.3.4 Hardness

Whereas aggregates with a maximum ACV of 21 or a minimum 10% FACT of 210 kN were recommended [12], satisfactory results have been achieved on low volume roads (less than 300 vpd) with ACVs as high as 30 (equivalent to a dry 10% FACT value of approximately 130 kN).

In view of the satisfactory performance of aggregates in seals on relatively lightly trafficked roads, the crushing strength requirements for the aggregate have been relaxed.

***Note**: In order to prevent crushing of the aggregate during construction of the seals (single or double) the use of steel-wheeled rollers on irregular substrates should be avoided for Grade B and C aggregates.*

When tested in accordance with SANS 3001-AG10, 10 % FACT values as provided in Table B 5 are now recommended.

Table B 5 Recommended Hardness Specifications

Relevant Aggregate Grade	C	B	A
Dry 10 % FACT [kN] (min)	130	180	210
Wet 10 % FACT [kN] (min)	100	135	160

B.2.3.5 Polishing stone value (PSV)

On high-speed rural roads, the skid resistance of the surfacing is a major functional aspect. For this reason limits are placed on the Polished Stone Value (PSV) of aggregates, since polishing of the stone reduces the skid resistance thereby rendering the surface hazardous at high speeds, particularly in wet conditions, or at locations where braking is likely to take place, such as at approaches to intersections, traffic circles, or at tight bends where there is insufficient super-elevation.

However, risks related to skid resistance are lower on low volume roads, specifically in low rainfall areas with low curvature and flat terrain. Consequently, the PSV requirement has been relaxed for Grades B and C, except, possibly at intersections etc., as described in the preceding paragraph.

The recommended polishing stone values for the different aggregate grades, measured according to SANS 3001-AG11 are provided in Table B 6.

Table B 6 Recommended PSV

Relevant Aggregate Grade	C	B	A
Aggregate position in seal			
Exposed aggregate	48	49	50
Underlying aggregate	45	47	48

B.2.3.6 Shape

B.2.3.6.1 Crushed aggregate

Crushed aggregate is used for single seals, double seals, combination seals and slurries. The ideal is that 95 % percent of the particles should have at least three fractured faces.

B.2.3.6.2 Flakiness

The maximum flakiness index, when tested in accordance with SANS 3001-AG4, should comply with the requirements in Table B 7.

Table B 7 Recommended Minimum Flakiness Index

Relevant Aggregate Grade	C	B	A
20 mm nominal size	30	30	25
14 mm nominal size	30	30	25
10 mm nominal size	35	35	30
7.1 mm nominal size	35	35	30

B.2.3.6.3 Average Least Dimension

Based on experience in South Africa, the recommended Average Least Dimension (ALD) of the relevant nominal aggregate sizes, measured according to SANS 3001-AG2 & AG3, is provided in Table B 8.

Table B 8 Recommended ALD specifications

Relevant Aggregate Grade	C	B	A
Nominal Aggregate Size (mm)			
20	**10.8**	**12**	**12**
14	**7.4**	**8**	**8**
10 single layer	**5**	**5.5**	**5.5**
10 second layer	**NA**	**5**	**5**

B.2.3.7 Durability (Resistance to weathering)

Grade A aggregate used in seals should have a durability index of less than 4 as determined by the Ethylene glycol durability method (SANS 3001-AG14).

B.2.3.8 Additional indicators

The following weathering tests may be conducted on aggregate for seals:

- Sulphate soundness tests;
- Freezing and thawing test;
- Wetting-drying test;
- Los Angeles abrasion test;

***Note*: None of these tests are specified in [1] and it should be noted that not all laboratories possess the facilities to conduct these tests.**

B.2.3.9 Specifications for slurry aggregate

The aggregate used in the manufacture of slurries generally consists of crusher sand or of a blend of crusher sand and natural sand.

The aggregate should preferably be obtained from a parent rock having a 10 % FACT value (dry) of at least 150 kN or a mixture of angular crusher sand and a clean natural sand, where the mixture does not contain more than 25 % of natural sand (by dry mass). Further increase of the natural sand in the aggregate blend could be evaluated using a cationic bitumen emulsion, addition of an adhesion agent and/or addition of polymers.

The gradings of aggregate recommended for slurries are given in Table B 9.

Table B 9 Recommended Gradings for Slurry Applications

Sieve size (mm)	PERCENTAGE PASSING SIEVE, BY MASS				
	Fine slurry			Coarse slurry	
	Fine Grade	Medium grade	Coarse grade	Type 1	Type 2
14					100
10				100	85 – 100
7.1		100	100	85 – 100	70 – 90
5	100	82 - 100	70 – 90	70 – 90	60 – 80
2	90 - 100	56 – 95	45 – 70	45 – 70	40 – 60
1	65 - 95	37 – 75	28 – 50	25 – 45	25 – 45
0.600	42 - 72	22 – 50	19 – 34	15 – 30	15 – 30
0.300	23 - 48	15 – 37	12 – 25	10 – 20	10 – 20
0.150	10 - 27	7 – 20	7 – 18	6 – 15	6 – 15
0.075	1 – 15	4 – 15	2 – 8	4 – 10	4 – 10

The sand equivalent determined in accordance with SANS 3001-AG5, should be at least 35.

The immersion index of briquettes made with slurry aggregate and 70/100 penetration-grade bitumen at the specified net bitumen content for the slurry should be not less than 75.

The slurry for Cape seals shall conform to the specifications in Table B 9 for Fine Slurry, Fine or Medium grade.

The aggregate used in rapid-setting slurries should have the same properties as those specified for conventional slurries. The recommended gradings of the aggregate to be used in rapid-setting slurries are given in Table B 10.

Table B 10 Recommendations for Rapid Setting Slurries and Microsurfacing

Sieve Size (mm)	Type II Percent Passing	Type III Percent Passing	Stockpile Tolerance
	Overlay or Rut fill (up to 12 mm)	Rut fill (more than 12 mm)	
10	100	100	
7.1	100	85 - 100	5%
5	90 - 100	70 - 90	5%
2	65 - 90	45 - 70	5%
1	45 - 70	28 - 50	5%
0.6	30 - 50	19 - 34	5%
0.3	18 - 30	12 - 25	4%
0.15	10 - 21	7 - 18	3%
0.075	5 - 15	5 - 15	2%

***Note**: The compatibility of the binder with aggregates from suitable sources should be evaluated (Refer PART E).*

B.2.4 ACTIVE FILLERS

The purpose of an “active filler” for slurries is not the same as for asphalt. For slurries the main purpose of its addition is to obtain a smooth, creamy consistency and to prevent segregation.

Ordinary Portland cement, Portland blast-furnace cement (PBFC) conforming to SANS 50197 and road lime (Lime for Soil Stabilization) conforming to SANS 824 can be used.

A maximum of 1 - 1,5 % of cement or lime (by mass of dry aggregate) is recommended.

***Note*: Certain aggregates might not react sufficiently with cement or lime. The use of Calcium Chloride could solve this problem and could be tested, starting with 0.5% addition (Refer PART E).**

B.3 BITUMINOUS BINDERS

B.3.1 INTRODUCTION

The behavioural characteristics of bituminous binders and modification thereof are well described in companion documents SABITA Manual 2 and TG1.

For various reasons, the need exists to classify bituminous binders based on its properties and appropriateness of use for specific situations. The following sub-sections describe the classification systems applied in South Africa. The Performance Grade classification has not yet been implemented for surface treatment binders. Therefore, this manual still refers to the various unmodified (conventional) binders as per SANS specifications and modified binders as per SABITA manual TG1 [13].

B.3.1.1 Penetration Grade

The bitumen is classified in terms of the penetration of a standard needle into the bitumen under standard conditions of load, time and temperature. The penetration is expressed in units of dmm (0.1) mm of a standard needle. The standard conditions are a load of 100 g, time of 5 sec and a temperature of 25°C. The higher the penetration the softer the bitumen.

B.3.1.2 Performance Grade

Key aspects of this classification are as follows:

- The specified criteria remain constant, but the temperature at which the criteria must be achieved changes for the various grades.
- The tests specified measure physical properties that can be related directly to field performance by engineering principles and are conducted at temperatures that are encountered by in-service pavements. A central theme of the Specification is its reliance on testing bituminous binders in conditions that simulate the three critical stages during the binder's life:
    - Tests performed on the original binder represent the first stage of transport, storage, and handling.
    - The second stage represents the binder during mix production and construction and is simulated for the Specification by ageing the binder in a rolling thin film oven. This procedure exposes thin binder films to heat and air and approximates the ageing of the binder during mixing and construction.
    - The third stage occurs as the binder ages over a long period as part of the asphalt or surface treatment layer. This stage is simulated for the Specification by the pressure ageing vessel (PAV). This procedure exposes binder samples to heat and pressure in order to simulate years of in-service ageing in a pavement.

South Africa is in the process of changing to Performance Grade (PG) classification, which will be specified in SANS 4001 BT – 10. Currently the specifications are provided in a technical specification (SATS 3208). The classification for asphalt denotes a maximum temperature (Tmax) and a minimum temperature (Tmin) together with a traffic category i.e. Standard (S), High (H), Very High (VH) and extreme (E).

Example: PG 64 -16 H

Where:

Tmax = The maximum pavement design temperature at a depth of 20 mm in asphalt and allowable rut depth of 12.7 mm

Tmin = The actual minimum grading temperature for fatigue related cracking

Important Notes:

- ***The PG binder classification and specifications have been implemented for asphalt (Refer SABITA Manual 35) [14], but not yet for surface treatments.***
- ***Designers, in future, will specify the appropriate binder according to the performance grade required, regardless of any possible modification.***
- ***Different to asphalt surfacings, where the relevant temperatures apply to 20mm from the surface, the critical temperature for surface treatments is at the surface (typically 3°C higher than 20mm below).***
- ***This manual will be updated when PG binder specifications have been finalised for surface treatments.***

B.3.2 UNMODIFIED BINDERS (CONVENTIONAL BINDERS)

Unmodified bituminous binders used in the construction of surfacing seals should conform to the specifications of the latest SANS specifications, which are listed below.

- Penetration-grade bitumen complying with SANS 4001-BT1
- Cut-back bitumen complying with SANS 4001–BT2:
- Anionic bitumen emulsion complying with SANS 4001–BT3
- Cationic bitumen emulsion complying with SANS 4001–BT4

If a decision is made to cut back penetration grade or polymer modified bitumen (to improve aggregate adhesion, facilitate the spraying of bitumen at a low residual binder application rate, reduce the viscosity of the binder or for any other reason), only MC30 (cut-back bitumen) is recommended. (Refer PART E).

Note: The reader is also referred to the Sabita publication: Guide for the control of HSE hazards associated with the field production of medium curing cutback bitumen.

B.3.3 MODIFIED BINDERS

The Technical Guideline for the use of Modified Binders in Road Construction (TG1) describes the different binder classifications and applications thereof in great detail. The product requirements for binders used in surface seals are reproduced in this document. It is important that the reader refers to the latest version of TG1 as the specifications may change from time to time.

A generic system has been developed for classifying modified binders according to four main criteria based on application type and temperature, type of polymer used, and a numerical value. The following codes are used to designate the different classes of modified binders:

- Type of application:
    - Spray seal (S);
    - Asphalt (A);
    - Crack sealant (C).
- Type of binder system:
    - Emulsion – If the product is an emulsion then the letter C would follow directly after the letter indicating the type of application;
    - Hot applied – No letter is used after the letter indicating the type of application.

- Predominant type of modifier used:
  - Elastomer (E) e.g. A-E1;
  - Plastomer (P) e.g. A-P1;
  - Rubber (R) e.g. S-R1;
  - Hydrocarbon (H) e.g. A-H1.
- Level of modification:

  This is indicated by a numerical value. The higher the number the higher the softening point value of the binder, but this does not necessarily imply improved overall performance properties.

An additional code can also be used for classification purposes to indicate whether or not the use of a fluxing agent or cutter is permitted. Should the binder application not permit the use of flux or cutter the letter "t" should be shown in brackets after the classification.

As an example, a classification of SC-E2(t) indicates the following:

- S - The binder is intended to be used in a surfacing seal;
- C - The binder is an emulsion;
- E - The main modifier is an elastomer type;
- 2 - The binder has a higher softening point than an SC-E1;
- (t) - The use of a fluxing agent or cutter is prohibited.

The properties for hot applied polymer modified binder for surface seals are given in Table B 11. Table B 12 contains the properties for cold applied modified binders for surface seals. The properties of bitumen-rubber binders used in surface seals are contained in Table B 13. The test methods with MB pre-script refer to the test methods contained in the TG1 document.

Table B 11 Properties of Hot Applied Polymer Modified Binders for Surfacing Seals

Property	Unit	Test Method	Class	
Before ageing			**S-E1**	**S-E2**
Softening Point[1]	°C	MB-17	50-70	60-80
Elastic recovery @ 15°C	%	MB-4	>50	>60
Dynamic Viscosity @ 165°C	Pa.s	MB–18	≤0.55	≤0.60
Storage Stability @ 180°C[2]	°C	MB-6	≤5	≤5
Flash Point	°C	ASTM D92	≥230	≥230
After ageing (RTFOT)				
Mass change[3]	%	MB-3	≤1.0	≤1.0
Elastic recovery @ 15°C	%	MB-4	>50	>60

Notes:

1. ***The softening point values obtained for bitumen modified with SBS will tend to fluctuate over time and on reheating.***

2. ***Certain base bitumens, when used in the production of modified binders, are prone to cause segregation of the modified binder. The Storage Stability test result should be interpreted as an indicator of the compatibility of the base bitumen and the modifier used. In cases where compliance***

limits are not met, proposals of site agitation procedures of the binder to prevent segregation shall be submitted to the client for consideration. In all cases whenever there is any reason to believe that the composition of the base bitumen has changed, the test shall be repeated to ensure compliance or to determine the need for measures to prevent segregation

3. Mass loss gives an indication of the presence of volatiles in the binder.

Table B 12 Properties of Polymer Modified Emulsions for Surfacing Seals

<table>
<tr><th colspan="2" rowspan="2">Property</th><th rowspan="2">Unit</th><th rowspan="2">Test Method</th><th colspan="4">Class</th></tr>
<tr><th colspan="2">SC-E1</th><th colspan="2">SC-E2</th></tr>
<tr><td colspan="2">Binder content (m/m)[1]</td><td>%</td><td>MB–22</td><td>65-68</td><td>70-73</td><td>65-68</td><td>70-73</td></tr>
<tr><td colspan="2">Saybolt Furol viscosity @ 50°C</td><td>sec</td><td>MB–21</td><td>51-200</td><td>51-400</td><td>51-200</td><td>51-400</td></tr>
<tr><td rowspan="2">Residue on sieving[2]
(/100 ml)</td><td>710µm sieve</td><td rowspan="2">g</td><td rowspan="2">MB-23</td><td colspan="2">≤0.1</td><td colspan="2">≤0.1</td></tr>
<tr><td>150µm sieve</td><td colspan="2">≤0.5</td><td colspan="2">≤0.5</td></tr>
<tr><td colspan="2">Particle charge</td><td></td><td>MB–24</td><td colspan="2">positive</td><td colspan="2">positive</td></tr>
<tr><td colspan="2">Sedimentation after 60 rotations</td><td></td><td>SANS 4001 BT3</td><td colspan="2">nil</td><td colspan="2">nil</td></tr>
<tr><td colspan="2">Recovered binder residue</td><td></td><td>MB-20[3]</td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="2">Softening point</td><td>°C</td><td>MB–17</td><td colspan="2">≥48</td><td colspan="2">≥55</td></tr>
<tr><td colspan="2">Elastic recovery @ 15°C</td><td>%</td><td>MB-4</td><td colspan="2">≥50</td><td colspan="2">≥55</td></tr>
</table>

Notes:

1. For steep inclines, severe cross fall and higher application rates it is advisable to use the higher binder content emulsion to reduce runoff.

2. Pour the emulsion through the larger sieve to remove the skin and larger particles before passing the emulsion through the finer sieve.

3. Either the rotary vacuum or the simple evaporation method can be used. For on-site testing the simple method is more practical and is thus recommended. The simple method retains most of the fluxing oils whereas these are removed in the rotary vacuum method. The latter method renders a better indication of the binder properties after in-service curing.

Table B 13 Properties of Bitumen Rubber for Surfacing Seals

Property		Unit	Test Method	Bitumen Rubber Class	
				S-R1	S-R2
Softening Point		°C	MB-17	55 – 65	65 – 80
Dynamic viscosity at 190°C		dPa.s	MB-13	20 – 40	-
Dynamic viscosity at 170°C				-	10 – 40
Compression Recovery	5 minutes	%	MB-11	> 70	> 70
	1 hour			> 70	> 70
	24 hours			> 40	> 25
Resilience at 25°C		%	MB-10	13 – 35	10 – 40
Flow at 60°C		mm	MB-12	15 – 70	0 – 40

Table B 14 Properties of Polymer Modified Emulsions for Machine-Applied Microsurfacing

Property		Unit	Test Method	Class	
				AC-E1 (Overlay)	AC-E2 (Rut filling)
Binder content (m/m)		%	MB–22	62-65	62-65
Residue on sieving[1] (/100 ml)	**710µm sieve**	g	MB-23	≤0,1	≤0,1
	150µm sieve			≤0,5	≤0,5
Particle charge			MB-24	positive	positive
Sedimentation after 60 rotations			SANS 4001 BT3	nil	nil
Recovered binder residue			MB-20[2]		
Softening point		°C	MB-17	≥48	
Elastic recovery @ 15°C		%	MB-4	≥50	

Notes:

1. ***Pour the emulsion through the larger sieve to remove the skin and larger particles before passing the emulsion through the finer sieve.***

2. ***Either the rotary vacuum or the simple evaporation method can be used. For on-site testing the simple method is more practical and is thus recommended. The simple method retains the fluxing oils whereas these are removed in the rotary vacuum method. The latter method renders a better indication of the binder properties after in-service curing.***

B.3.3.1 Prime Coats

The main function of a prime is to partially penetrate the (granular) layer to which it is applied while leaving a small residue of binder on the surface to:

- Assist adhesion between the base and the newly applied bituminous surfacing or layer;
- Inhibit the ingress of water from rain into the base prior to the construction of the new bituminous surfacing while not hampering the migration of water in the vapour phase out of the base;
- Limit the absorption of binder from the next spray application of bituminous binder into the base;
- Bind the finer particles on the upper zone of the base to accommodate light construction traffic for a limited period until the new surfacing can be placed and to limit damage due to rain.

Standard products available in South Africa are shown in Table B 15.

Table B 15 Standard Products for Prime Coats

Bituminous binder for priming	Specification
MC-10 cut-back bitumen	SANS 4001 – BT2
MC-30 cut-back bitumen	SANS 4001 – BT2
Inverted bitumen emulsion	SANS 4001 – BT5

Various proprietary products have been developed by local suppliers and/or are still in phases of development.

The efforts of suppliers to improve the properties of prime coats and to minimize the use of solvents are acknowledged. Therefore, COTO (2019) allows different products to be evaluated on the completed base against specific criteria. The factors influencing the selection of an appropriate product are:

- Penetration depth
- Drying time
- Softening of the base
- Permeability
- Carbonation (in case of stabilised layers)

***Note*: More detail on prime coats can be obtained from the companion document SABITA Manual 26: Guidelines for primes, bond coats and stone precoating fluids**.

B.3.3.2 Precoating Materials

A precoating fluid assists in reducing the surface tension between the cold surfacing aggregate and the freshly sprayed hot viscous binder during construction of the seal, thereby aiding the initial bond between the aggregate and the binder as the latter cools down

The precoating fluid should have a low enough viscosity to coat damp or dusty surfacing aggregates and be able to dry within a reasonable period to deposit a thin, non-tacky residual film on the surface of the aggregate. The fluid should not cause a deposit of binder to be left on the site that would be harmful to the environment.

***Note*:**

- ***The aggregate should conform to the specifications for dust before precoating.***
- ***Too high application could cause a 'tacky stone" influencing the flow of aggregate through the chip spreader gates.***

Several proprietary products are available on the local market, typically manufactured using a bitumen-based cutback, blended from selected petroleum derivatives and a chemical adhesion agent. The addition of 0.1 - 0,5% amines (chemical adhesion agent) or very low percentage of nano products to the total mass of the typical precoating fluids is used to:

- Enhance the adhesion of aggregate to the binder in the presence of moisture; and
- Improve the adhesion of aggregates that have a poor affinity for bitumen for e.g. quarzitic or siliceous aggregates.

In the absence of a national standard specification, the following recommendation is made based on the successful use of proprietary bitumen-based precoating fluids.

Table B 16 Recommended Requirements for a Cutback Bituminous-Based Precoating Fluid

Property	Requirement	Test method
Density @ 25°C, kg/l	0,922 – 0,928	
Dynamic viscosity @ 25°C, Pa.s	0.075 – 0.13	ASTM D4402
Distillation to 360°C, v/v%		ASTM D 402
To 190°C	0 – 15	
225°C	15 - 55	
260°C	50 - 75	
316°C	80 - 95	
Residue from distillation to 360°C, v/v%	42 - 50	ASTM D 402
Penetration @ 25°C of residue distilled to 360°C	300	EN 1426

B.3.4 WATER FOR DILUTING EMULSIONS

Water used for the dilution of emulsions on site must be suitable potable water and should be tested for compatibility with the emulsion before it is added to the bulk emulsion.

B.3.5 IMPLEMENTATION GUIDELINES FOR PERFORMANCE-GRADE SPECIFICATION

B.3.5.1 General

The new Performance-grade (PG) specification SATS 3208 is a “buyer’s” specification as is SANS 4001:BT1 and related specifications. A “buyer’s” specification is an effort to ensure that different products are compared on an equal footing and the best product is selected for a specific application. With the PG specification the basis for comparison rests on fundamental material properties that can be related to actual performance criteria. A detailed description of the PG specification is given in [15].

The PG specification framework now allows critical factors such as traffic levels and speed, climate (especially temperature ranges) and critical performance characteristics such as excess viscous flow during periods of elevated temperatures or elastic recovery after a load application to be considered.

It was mentioned previously that the PG implementation in SATS 3208 is based on asphalt, it is therefore necessary to look at some definitions and guidelines that must be considered when SATS 3208 is adopted for application in surfacing seal project.

B.3.5.2 Maximum temperature (T_{max})

The maximum pavement temperature for an asphalt layer is the average annual seven-day maximum at 20 mm depth in the asphalt layer, adjusted to reflect a 98% statistical reliability using climatic data from a minimum of 20 years. Surface treatments are obviously not thick enough to satisfy this 20 mm depth definition. Research has shown that road surface temperatures are on average approximately 3,9°C hotter than at 20 mm depth, thus it is recommended to use a shift of 3°C when specifying T_{max}. A PG58-22 would thus become a PG61-19 for a surfacing seal. The choice of a 3°C shift is purely for practical reasons.

In the PG specification the Useful Temperature Interval (UTI), the span between the maximum and minimum temperatures, is maintained at a minimum of 80°C to ensure acceptable rheological properties for a binder over a possible variation in climatic conditions (temperature). An unmodified binder will have a UTI that cannot be changed even although the penetration and SP of bitumen can be changed due to further refining. The UTI can only be increased above 80°C by adding modifiers and the rule of thumb is that a UTI > 92°C indicates modification.

B.3.5.3 Low temperature limits

In the USA research is done on the implementation of a Seal Performance Grade (SPG) specification and the major difference with the PG specification lies in the low temperature requirements. Since a bituminous binder is a viscoelastic material conforming to the principal of the Time-Temperature Superposition (TTS) principle and stiffness and relaxation are critically important to cracking, both at cold temperatures and after ageing, these parameters are essential. The latest proposals from Texas are compared with the SA PG specification in the Table B 17 below.

Table B 17 Comparison of Texas SPG proposal with SA PG specification

Property	SA PG specification	Texas SPG proposal
BBR Stiffness	S(60) ≤ 300 MPa	S(8) ≤ 500 MPa
BBR Relaxation	m(60) ≥ 0.3	m(8) ≥ 0.24
ΔTc	ΔTc ≥ -5°C	ΔTc ≥ -3°C

Texas chose to use the BBR stiffness and relaxation parameters at a shorter application time because the surfacing layer is so thin the frequency of the load application should be higher. The higher stiffness and lower relaxation now compensate for the higher load frequency, due to the TTS principal. At the time of going to press with this document the SPG was not calibrated yet.

The meaning of ΔTc is demonstrated in Figure B below. In the reduced time space, the ΔTc is the gradient between the critical temperatures where S and m reach their respective critical values and is closely related to ductility.

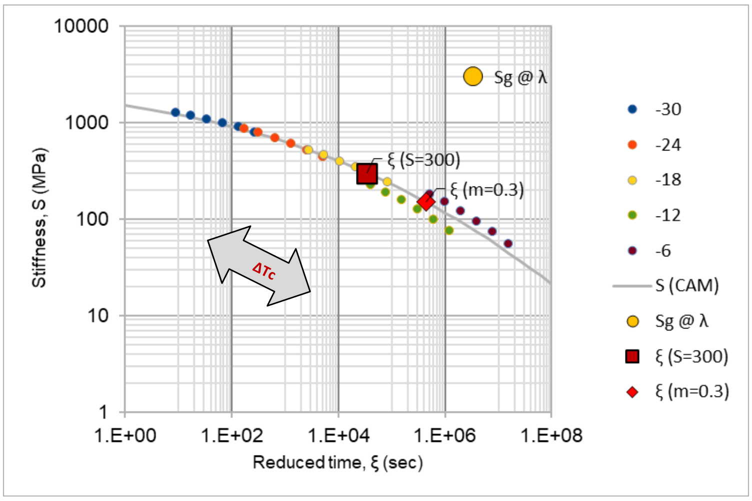


Figure B 1 Master curve of stiffness from BBR test

It is not recommended, at least at this stage, that any adjustments be done to the PG implementation for surface dressings as the TTS principal should take care of any load frequency differences between an asphalt layer and a surfacing seal.

B.3.5.4 South African Binders

Engelbrecht [16] researched the performance grade properties of South African binders and found that all spray grade bitumen and modified binders tested complied with the SATS 3208 specification. Engelbrecht found that a 70/100 pen grade bitumen has a PG58-22 PG-grade, S-E1 a PG70-22 or PG76-22 depending on the base bitumen and an S-E2 PG76-22. No binder was found to show any signs of not complying to the SATS specification.

B.3.5.5 Penetration and Softening Point reference to SANS 4001:BT1

Practitioners in the surface treatment field are used to Penetration and Softening Point parameters. Research on unmodified binders showed that a very good relationship exist between the G*/sinδ parameter from the PG testing and the Penetration and Softening point from conventional tests. Similar relationships exist for the modified binders. Initial testing on binders available for a project should explore these relationships as it will assist in better understanding and acceptance of the PG specifications.

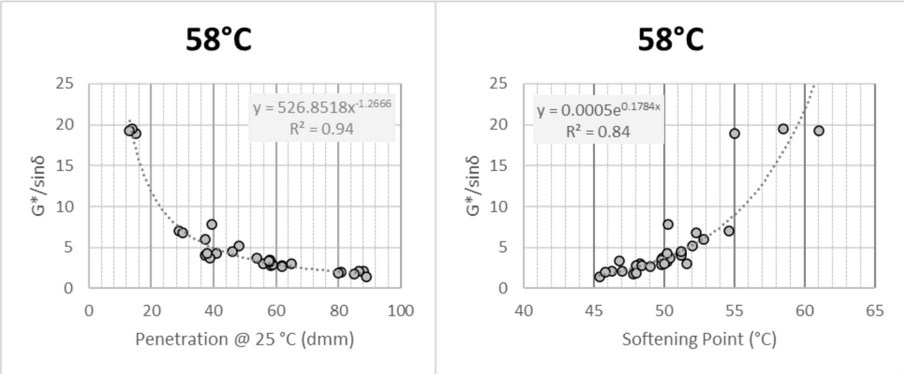


Figure B 2 Relationship of penetration and softening point with G*/sin δ

B.3.5.6 Project Specifications

The SATS 3208, like SANS 4001:BT1, is a buyer specification, allowing the user to compare binders on an equal basis and select a binder that will perform the best. Project circumstances will differ, both in terms of traffic and climate. Climate and traffic may even differ within the project's limits. The Client or Consultant on a project may have the desire to use a specific binder determined by the circumstances on the project. For this reason, it is proposed that a slightly modified designation is used, i.e.

P58H-22(CRM) or PG58H-22(PMB)

The (CRM) and (PMB)would then force the use of crumb rubber modified (CRM) binder or polymer modified binder (PMB). This is acceptable in a project specification.

SANRAL is at present busy preparing new pro-forma project specifications based on the new COTO specification that will be implemented in 2021.

B.3.5.7 Conclusion

There is no compelling reason why the SA PG specification SATS 3208 cannot be used for surface treatment applications. The only important adaptation that is required is the 3°C shift in the maximum temperature. The design engineer should test the available binders and make a judgement from the results from these tests.

B.4 SUMMARY OF TEST METHODS

All materials used in surfacing seals should comply with the relevant specifications mentioned in this document.

In order to ensure compliance with the specifications, all tests on these materials should be carried out according to standard test methods.

Several of the standard test methods have been or are in the process of adjustment to SANS Specifications. Table B 17 and Table B 18 provide lists of relevant tests, the existing/ old test method and the replacement test method.

Note: Tests for modified binders are available the companion document TG1.

Table B 18 Aggregate Tests

Aggregate tests	Test method
Sieve Analysis	SANS 3001-AG1
Aggregate crushing value	SANS 3001-AG10
10% FACT	
Flakiness Index	SANS 3001-AG4
Polished Stone Value	SANS 3001-AG 11/EN 1097
Fines content	SANS 3001-AG1
Magnesium Sulphate soundness tests	SANS 3001-AG12
Los Angeles abrasion test,	AASHTO T96, ASTM C131
Ethylene glycol durability index	SANS 3001-AG14

Sand	Test method
Sieve Analysis	SANS 3001-AG1
Sand equivalent	SANS 3001-AG5

Table B 19 Tests for Conventional Bituminous Binders

Penetration grade bitumen	Test method
Penetration	EN 1426
Softening Point	ASTM D36
Viscosity (before and after Rolling Thin Film Oven Test)	ASTM D4402
Ductility (before and after Rolling Thin Film Oven Test)	ASTM D92
Change in mass after Rolling Thin Film Oven Test	ASTM D2872
Spot Test	AASHTO T102
Cutback bitumen	
Kinematic viscosity	ASTM D2170
Distillation	ASTM D402
Penetration of residue	EN 1426
Cationic bitumen emulsions	
Viscosity	ASTM D244
Binder content	ASTM D244
Fluxing agent content	ASTM D244
Particle charge	SANS 4001-BT4
Residue on sieving	SANS 4001-BT4
Binder deposit on cathode	SANS 4001-BT4
Sedimentation	SANS 4001-BT4
Anionic bitumen emulsions	
Viscosity	ASTM D244
Binder content	ASTM D244
Residue on sieving	SANS 4001-BT3
Sedimentation	SANS 4001-BT3

B.5 REFERENCES

[1]	Committee of Transport Officials (COTO), Committee Draft 2019. Standard Specifications for Road and Bridge Works.
[2]	Southern African Bitumen Association. (SABITA). Manual 10: Appropriate standards for bituminous surfacings for low volume roads. 2011 Cape Town.
[3]	COLTO. 1998. Standard Specifications for Road and Bridge Works for State Road Authorities. Midrand: South African Institution of Civil Engineering.
[4]	Woodbridge, M.E, Greening, P.A.K and Newill, D. 1991. Evaluation of weak aggregates for surface dressing on low volume roads. Trans Res Rec, 1291, Vol 1, pp 263-274.
[5]	Woodbridge, M.E, and Slater, C.W.N. 1995. Development of a reduced specification for surfacing aggregate on low volume roads in Botswana. Crowthorne: Transport Research Laboratory. (Project Report 115).
[6]	Paige-Green, P, 1999. Thin bituminous surfacings for light pavement structures. In Proceedings 7th Conference on Asphalt Pavements for Southern Africa, Victoria Falls, Zimbabwe, Aug 1999, pp 2-116 to 2-123.
[7]	Paige-Green, P. 2001. The use of marginal aggregates in bituminous seals. 20th ARRB Conference, Melbourne, Australia, March 2001. (CD).
[8]	Paige-Green, P. 2004. Aggregate strength for bituminous surfacings for low volume roads: A heavy vehicle simulator experience. 8th CAPSA 04, Sun City, September 2004.
[9]	Paige-Green, P. 2005. Practical Aspects of low cost sealing of roads. Invited paper at Africa T2 Conference, Pietermaritzburg, September, 2005.
[10]	Netterberg, F and Paige-Green, P. 1988. Pavement materials for low volume roads in southern Africa: A review. In: Appropriate materials and methods, (Proceedings of Annual Transportation Convention held at the University of Pretoria, July, 1988), Vol 2D, Paper 2.
[11]	Madu, RM. 1980. The performance of lateritic stones as concrete aggregates and road chippings. Matériaux et Constructions, Vol 13, 78, pp 403-411.
[12]	South African National Roads Agency (SOC) Ltd, Technical Recommendations for Highways: Design and Construction of Surfacing Seals (TRH3), Pretoria, South Africa, 2007.
[13]	Southern African Bitumen Association (SABITA), TG1. Technical Guideline: The Use of Modified Bituminous Binders in Road Construction, 2019. Cape Town.
[14]	Southern African Bitumen Association (SABITA). Manual 35: A Design and use of Asphalt in Road Pavements, 2018. Cape Town.
[15]	S J Bredenhann, P A Myburgh, K J Jenkins, J S O'Connell, G M Rowe, J D'Angelo. Implementation of a performance-grade bitumen specification in South Africa. SAICE Journal of Civil Engineering Vol 61. 2019.
[16]	Engelbrecht, F. Age-related performance of typical seal binders in South Africa. Thesis for the degree of Master of Engineering in Civil Engineering. University of Stellenbosch. 2018

PART C

PERFORMANCE

CONTENTS

LIST OF FIGURES

LIST OF TABLE (*ONE ONLY*)

C.1 INTRODUCTION

C.1.1 CONTEXT

Manual 40 comprises eight parts:

- Part A: General
- Part B: Materials
- **Part C: Performance (This document)**
- Part D: Selection of Seal type and binder
- Part E: Design
- Part F: Construction
- Part G: Quality Assurance
- Part H: Repair of premature failures

C.1.2 OBJECTIVES

The purpose of PART C is to discuss the performance of surface treatments and factors that could influence the expected service life. PART C provides a background to the selection of appropriate seal and binder types and highlights important aspects that should be taken into consideration during design and construction.

C.1.3 SCOPE

PART C first discusses the influence of several factors as listed below and then provides a summary of the main distress types resulting in the “end of service life” being aggregate loss, texture loss, cracking and permeability.

- Pavement structure and condition
- Existing substrate
- Traffic
- Road geometry
- Design
- Materials
- Preparation, pre-treatment and repairs before construction
- Seal structure
- Construction and supervision
- Maintenance
- Physical and social environment

C.2 GENERAL

The main functions of a surfacing as discussed in Part A are to:

- Provide a waterproof cover to the underlying pavement
- Provide a safe all-weather, dust-free riding surface for traffic with adequate skid resistance
- Protect the underlying layer from the abrasive and destructive forces of traffic and the environment.

Since most seals are relatively thin, they have very little load distribution properties. However, the seal itself should be able to accommodate the horizontal and vertical traffic-induced stresses, not to shear or lose aggregate.

Failure of the surfacing to fulfil any one of these functions would indicate the end of its effective service life. Performance is related to both the effective service life and the degree to which the functions are fulfilled.

The performance of a seal is influenced by various factors and combinations thereof. In this PART the most important factors influencing initial and long-term performance are discussed. This chapter also serves as an introduction to materials selection (PART D), design of appropriate surfacings (PART E), and construction (PART F).

Notes:

- ***The first and most important factor influencing the performance of a surface treatment is the selection of the appropriate seal type and binder for a given situation. Any initial surface treatment selected according to PART D should give a service life of at least ten years.***
- ***The expected service life of a reseal is highly dependent on the condition of the existing pavement. However, selecting the appropriate reseal seal type and binder according to the guidelines in PART D will maximise the service life***

The performance of a surface treatment and conditions causing a terminal state (end of life) could be measured in terms of:

- Aggregate loss (stripping).
- Reduced skid resistance influenced by texture loss and polishing of the aggregate.
- inability to retard crack initiation and crack reflection.

Figure C 1 Distress Defining "End-of-Life"

Following discussion on influencing factors, a summary is provided in C.5, highlighting the main risks related to premature failure as well as the best performing seal and binder types for specific situations.

C.3 PAVEMENT STRUCTURE AND CONDITION

The performance of a seal is, to a large extent, governed by the structural adequacy of the pavement layers under the influence of wheel loads. A seal acts mainly as a wearing course resisting the abrasive action of the moving wheel load and it seals the road pavement to prevent the ingress of surface water.

C.3.1 BASE OR EXISTING SURFACE CONDITION

C.3.1.1 Soft Upper Base

C.3.1.1.1 Embedment

The resistance to aggregate penetration into the base could be influenced by:

- The type of material in the base, the degree of compaction and the moisture content.
- A layer of fine material on a crushed stone base (not properly broomed).
- High application of a prime coat with solvents.
- Seal type (structure) and stiffness.

As shown in Figure C 2, the stress concentration with a passing wheel on a single seal (still with a new soft binder) extends to approximately the ALD of the aggregate.

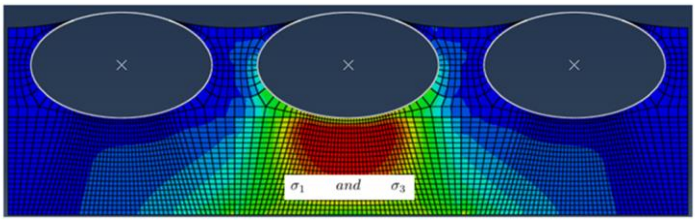


Figure C 2 Stress Concentration [1]

Figure C 3 shows high embedment of a single aggregate layer into a soft wet base during construction.

Figure C 3 Effect of a Soft Wet Base on Stone Embedment During Construction

<u>Notes</u>:

- ***The moisture content in a granular base will increase after application of a prime and seal, resulting in a higher sensitivity to embedment [2]. Figure C 4 highlights the increase in embedment potential due to the increase in moisture content.***
- ***This is also true for emulsion treated or foam treated bases.***

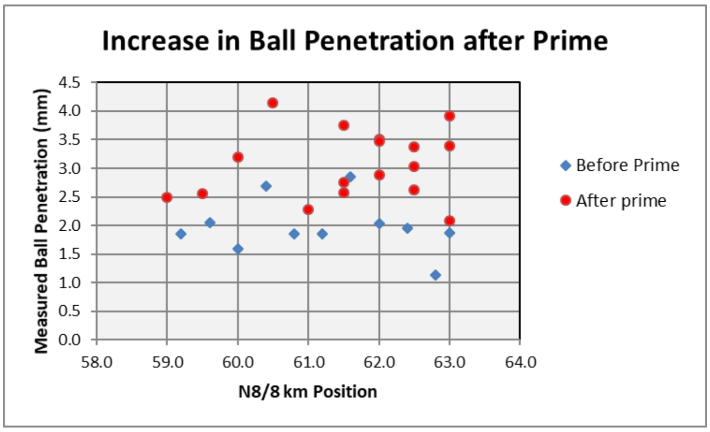


Figure C 4 Increase in Ball Penetration after Prime on a Foam Treated Base

The embedment of surfacing aggregate into the base will reduce the voids in the seal and may result in a fatty or bleeding surface and/or in skidding problems.

C.3.1.2 Flexural Properties of the Pavement Structure

High deflections in the upper part of the pavement structure may result in fatigue of the pavement layers and the surfacing. Rigid seals, cold temperatures and oxidation of the binder will aggravate cracking and ravelling of the surfacing. It is, therefore, important to:

- Ensure that the base (if granular and not stabilised) is at dried out to below 50% of Optimum Moisture Content (OMC) before application of the prime coat and before application of the seal.
- Select a seal and binder suitable for the existing or expected pavement behaviour characteristics.

The degree to which embedment and/or fatigue cracking will occur is a function of the seal structure and stiffness.

As explained in Figure C 5, whereas the individual aggregate of a new single seal would embed in a soft substrate, a stiffer seal (e.g. Cape seal) or an aged seal would rather act as a mat, which would fail in cohesion (fatigue) with repeated loads on a soft layer.

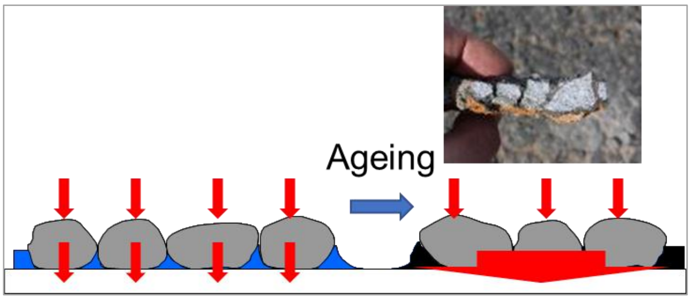


Figure C 5 Effect of Ageing (Oxidative Hardening)

Figure C 6 shows and example of a stiff Cape seal failing on a thin soft layer.

Figure C 6 Cracking of a Cape Seal on a Thin Soft Layer

A thin loose layer or a wet layer directly under the seal will result in a low radius of curvature (ROC) and rapid fatigue of the seal layer. Conducting numerous Road Surface Deflection (RSD) and Falling Weight Deflectometer (FWD) tests on sound and cracked seals resulted in the conclusion that the Radius of Curvature (ROC), or alternatively the difference between the peak deflection and the deflection closest to the impact load, provides a good indication of the expected seal performance [3]

The effect of a wet and dried out upper base layer (50mm) underneath the seal is shown in Figure C 7. Deflection measurements were taken before and after removal of the seal and then, after one and two days after allowing the base to dry out.

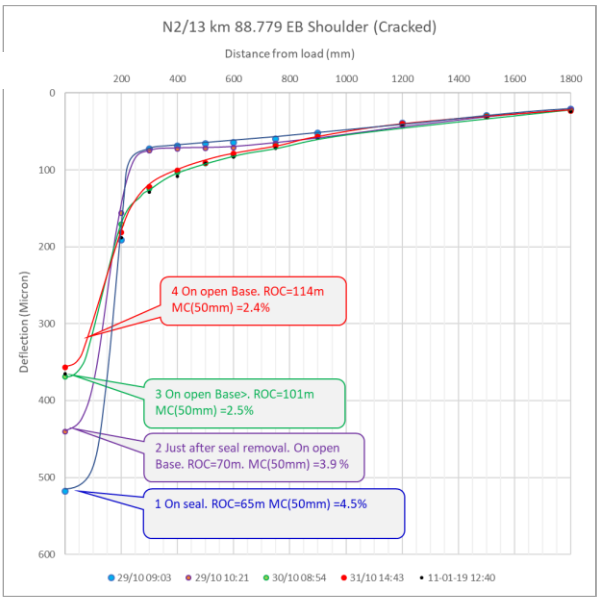


Figure C 7 Effect of Moisture Content in the Upper Base on ROC

Notes:

- ***Cracking only occurred in the seal and not in the base.***

- ***Sound areas (non-cracked) all exhibited ROC of more than 120m and upper base MC less than 2.4%.***

C.3.1.3 Coarse and Varying Substrate Macro Texture

Coarse textures on a new base could result in the base aggregate being in contact with the vehicle tyres as shown in Figure C 8 and Figure C 9.

Figure C 8 Base Aggregate Visible in Seal Structure

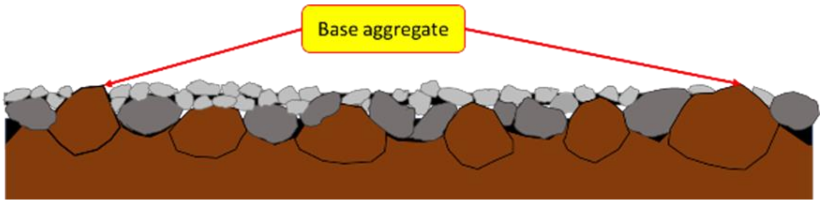


Figure C 9 Base Aggregate Protruding above Seal

Dependent on the seal type this could lead to cracking in the seal, water ingress and failures in the upper base as shown in Figure C 10.

Figure C 10 Base Aggregate in Contact with Tyres and Subsequent Failures

As discussed in PART D and PART E, large aggregate could also bridge on the existing coarse texture, requiring additional binder to fill the voids. The effect is shown in Figure C 11.

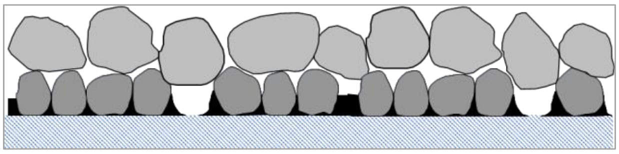


Figure C 11 Bridging of Large Aggregate Reseal

Although not impossible to obtain a good performing seal if the existing texture is uniform, experience indicates that the risk of poor performance could be minimized by applying a void-filling seal (texture treatment) such as a thin slurry seal before the final seal is constructed.

Based on the above discussion, recommended maximum texture depths for different seal types are provided in Table C 1.

Table C 1 Recommended Maximum Texture Before Applying a Texture Correction Layer

Seal Code	Final surfacing type	Max Texture allowed
S1(10)	Single seal with 10 mm aggregate	0.8
S1(10)	Single seal with 10 mm aggregate (with cover spray)	1.0
S1(14)	Single seal with 14 mm aggregate	0.8
S1(14)	Single seal with 14 mm aggregate (with cover spray)	1.5
S1(14)	Single seal with 14 mm aggregate (with Bitumen rubber)	1.2
S2(10/S)	Double seal with 10 mm aggregate and sand	1.0
S2(14/S)	Double seal with 14 mm aggregate and sand	1.5
S4(10)	Cape Seal with 10 mm aggregate and one layer of slurry	1.5
S4(14)	Cape Seal with 14 mm aggregate and one layer of slurry	2.0
S4(20)	Cape Seal with 20 mm aggregate and two layers of slurry	2.5
S2(14/7)	Double seal with 14 mm aggregate and a layer of 7 mm aggregate	1.5
S2(14/5)	Double seal with 14 mm aggregate and a layer of 5 mm aggregate	1.5
S2(20/10)	Double seal with 19 mm aggregate and a layer of 9,5 mm aggregate	2.0
S2(20/7)	Double seal with 19 mm aggregate and a layer of 6,7 mm aggregate	2.0
S2(20/7/7)	Double seal with 19 mm aggregate and two layers of 6,7 mm aggregate	1.5

C.3.1.4 Surface Irregularities

Apart from the effects of coarse and varying macro texture, surface irregularities (small undulations) could result in:

- Accumulation of a low viscosity binder in hollows with bleeding.

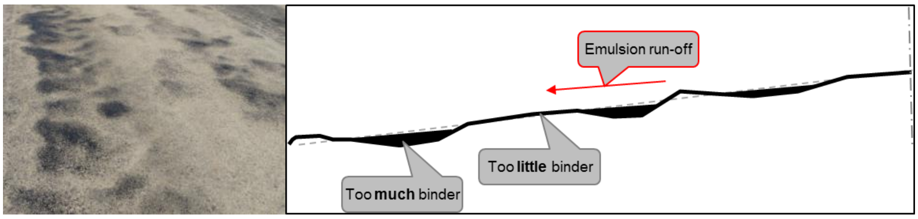


Figure C 12 Undulations Causing Ponding of Binder and Bleeding

- Poor compaction of the seal.

Undulated/irregular surfaces result in flat steel wheel rollers bridging and not able to properly compact the seal layer. It is essential that pneumatic tyred rollers are used for single and double seals.

Figure C 13 Loss of 7 mm Aggregate on a S2(14/7) Double Seal due to Poor Compaction

C.3.1.5 Reflection Cracking

The reflection of cracks through the surfacing can be related to the magnitude and frequency of the movement between the crack walls due to load repetitions, chemical reactions (which cause shrinkage), temperature changes or changes in moisture condition. The greater the crack activity the more quickly crack reflection will occur. However, the binder film thickness and binder rheological properties have a significant influence on the time to crack reflection.

Following a study, using performance data on more than 600 road sections with different seal types and binders [4], calibration factors for use in the HDM4 software have been determined. Figure C 14 highlights the following:

Increase in aggregate size (surrogate for binder film thickness) increases the time before crack reflection

Seals with polymer modified binders perform approximately 25% better than conventional binders to retard crack reflection

Bitumen rubber has the ability to retard crack reflection with 70% - 200% longer than conventional binders

Calculating the calibration factors from study results on the former Transvaal Roads Department network [5], a similar range for bitumen rubber performance was obtained. However, the results from this study [5] showed better performance of the polymer modified binders.

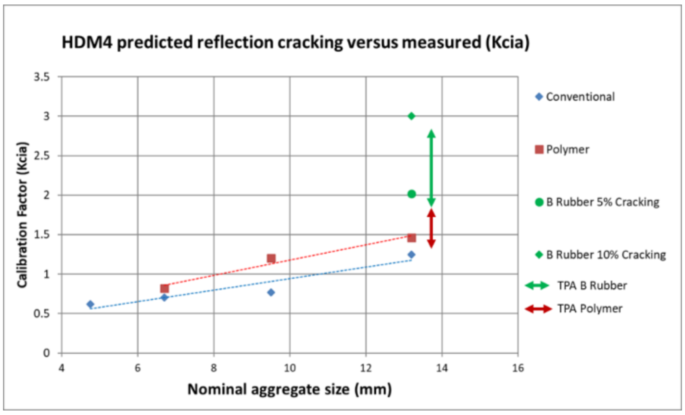


Figure C 14 Effect of Binder Type and Film Thickness on Crack Reflection

<u>Note</u>: The calibration factor Kcia for time to crack initiation in HDM4, is calculated by the measured time to 0.5% crack reflection divided by the HDM4 predicted time to 0.5% crack reflection.

Although mainly used for patching and not on a large scale as full-width seals in South Africa, geotextile seals have shown remarkable resistance to crack reflection. One example highlighted in Figure C 15 shows a geotextile seal with a polymer modified binder, applied on a severely cracked asphalt layer with no crack reflection after 10 years. The section in the foreground shows a 40mm continuous graded asphalt, placed on the same severely cracked asphalt layer at the same time.

Figure C 15 S2(20/7/7) Geotextile Seal with S-E1 Compared with 40mm AC after 10 Years

C.3.2 TRAFFIC

C.3.2.1 General

The number, type and combination of vehicles have a marked influence on the performance of a seal. Heavy vehicles have a much greater influence on the performance of a seal (embedment of aggregate) than light vehicles. In this document, for purposes of seal design, the effect of one heavy vehicle is considered to be equal to that of 40 light vehicles. In earlier guidelines [6] an equivalency factor of 20 was used, but increases in axle loads and tyre pressures have necessitated the use of a higher value.

Although the influence of traffic is interrelated with other factors such as road geometry, the influence of the following traffic parameters is considered important.

C.3.2.2 Volume

The number of vehicles (especially heavy vehicles) greatly affects embedment, with all vehicles contributing to stone orientation, wearing and polishing of the stone. These factors reduce the voids in the seal and could result in flushing and reduction in skid resistance. Although it is believed that a seal requires a minimum number of vehicles per day to keep the binder alive and flexible, a recent study recovering binders from the wheel track and from untrafficked shoulders, suggested no significant difference in binder stiffness development over periods up to twenty-four years [3].

C.3.2.3 Loading

Heavy axle loads cause more rapid embedment of the stone into the existing surface than light vehicle loads. Cognizance should be taken of the continuous increase in axle loads occurring in South Africa.

C.3.2.4 Tyre Pressures

Recent research shows that tyre inflation pressure (or rather contact stress) has a major influence on bleeding and that certain vertical stresses induced on the surfacing can be much higher than the tyre inflation pressures. Heavy Vehicle Simulator tests showed that there was a significant increase in flushing on sections trafficked with similar wheel loads but with higher inflation pressures. It should be noted that the typical heavy vehicle tyre pressures increased over the past two decades from 520 kPa to 700 kPa or more.

C.3.2.5 Vehicle Type and Actions

Vehicles with tandem or tridem axles, turning at intersections, or into/from access roads, cause severe damage to surfacings. Distress typically observed is slippage, scuffing, debonding of the surfacing or ravelling.

C.3.2.6 Speed

Surfacings under slower-moving traffic (typically less than 40km/h) generally do not perform as well as those trafficked by fast-moving vehicles. The reasons for this are the extended period of loading, visco-elastic behaviour of the binder, higher horizontal stresses induced as a result of traction, particularly of heavy vehicles accelerating or braking, and fuel or oil spillage.

C.3.2.7 Traffic patterns?

Traffic which is concentrated in particular wheel paths (typical on narrow roads), or which occurs early on during the life of the seal (when the binder is still soft), or during cold temperatures (when the binder is brittle), will adversely affect the performance of the seal.

C.3.3 ROAD GEOMETRY

Several aspects of the road geometry may contribute to the poor performance of the surfacing seal, as highlighted below:

C.3.3.1 Gradient

Steep gradients may, because of the traction force of vehicle tyres, may result in debonding or slippage of the surfacing, or in flushing. The risk of poor seal performance on ascents and descents increases because of construction difficulties at these sites.

Figure C 16 Shear and Slippage of a Microsurfacing on a Smooth Base

Steep gradients cause slower vehicle speeds and often result in flushing.

Canalized water flow down steep gradients can have a severe erosion effect on stone seals. This is particularly true for roads and streets with kerbs in wet, hilly environments.

Figure C 17 Erosion of a Double Seal in a Wet Hilly Urban Environment

Low viscosity binders, such as standard emulsions (discussed under C.4.2.4.2), after application run off the road surface resulting in too little binder to hold the aggregate and subsequent aggregate loss.

C.3.3.2 Sharp Curves

Sharp curves cause vehicles to induce high horizontal stresses on the surfacing. These may result in ravelling and slippage of the surfacing. Vehicles on lower volume roads "cut" corners, resulting in the outer part of the road becoming dry and brittle, with consequent stone loss. Because of the super-elevation on curves, higher loads are transferred to the inner side of curves, often resulting in fattiness. The situation may be aggravated by excess binder accumulated at these positions, as a result of "run-off" during construction.

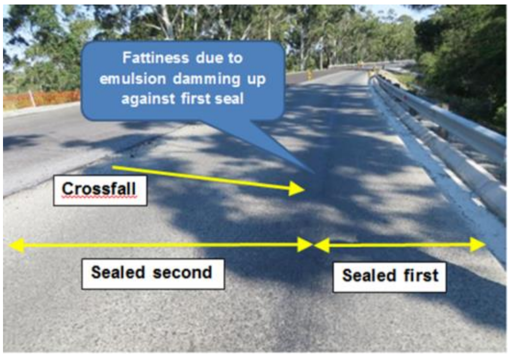


Figure C 18 Run-off on Camber Resulting in Fattiness

C.3.3.3 Intersections

Braking and acceleration, particularly of heavy vehicles, create high horizontal stresses in the surfacing, which may result in the slippage, flushing and deformation of the surfacing. Fuel and oil spillages at intersections aggravate flushing and deformation.

As mentioned in C.3.5.4, turning actions of heavy vehicles, particularly those with tandem or tridem axles, may cause ravelling and slippage of surfacings at intersections.

Figure C 19 Sensitivity of a Single Sand Seal at Intersections

Therefore, sand seals, thin slurries, single and double seals are sensitive to turning actions soon after construction.

Cape seals, double seals and single seals, locked-in with coarse sand or slurry, are much more resistant to raveling.

C.3.3.4 Road width

Concentrated wheel movements occur on narrow roads, usually resulting in fattiness in the wheel tracks, brittleness between the wheel tracks, and in edge breaks. This aspect is accommodated for in the design – PART E.

C.3.4 DESIGN

During the design process care should be taken to allow for all the different situations which might occur on a specific road. The pre-design investigation is, therefore, regarded as very important to ensure proper design and maximum seal performance. During construction the designs may be adjusted to incorporate new information or changed conditions.

C.3.5 AGGREGATE

C.3.5.1 Function

As stated in PART B: Section B.2.2, The aggregate in a seal has four main functions:

- It provides resistance to the abrasion of moving wheel loads and transfers the wheel load to the underlying pavement structure;
- It provides a skid-resistant surface;
- It provides a structure to accommodate the elastic and "impermeable" bituminous binder and has sufficient voids to prevent the binder flushing to the surface under loading, and
- It protects the binder from the harmful ultra-violet rays of the sun.

Notes:

Certain aggregate characteristics may have functional value, for example:

- **use of light-absorbing qualities to prevent glare, and**
- **provision of a different texture or colour to define demarcated areas.**

The factors affecting performance are well described in Section B.2.2.

C.4 BINDER

C.4.1 GENERAL

The service life and performance characteristics of a seal depend on good adhesion between the binder, stone and road surface and on the durability and flexibility of the binder under different climatic conditions. Adhesion is one of the paramount functions of the binder. Loss in retention of the aggregate, the degree of aggregate whip-off and durability are all related to the adhesive strength developed by the binder, which depend on the type, grade and amount of binder applied.

A properly selected binder fulfils two primary functions - it develops both adhesive and cohesive strength. Initially it is fluid to allow time for placing and wetting of the stone and then rapidly becomes harder. The cohesive strength of the binder facilitates opening to the traffic and prevents the stone from rolling over and adhering to vehicle tyres.

The binder should be able to withstand "softening-up" under the higher temperatures encountered in service and to retain the stone under the action of moving wheel loads. On the other hand, at colder temperatures, the binder should stay flexible for as long as possible to prevent reflection cracking, to accommodate road deflections and to prevent, as far as possible, the ingress of moisture into the base.

Notes:

- ***The performance grade classification (PG grades) currently being implemented is, amongst other reasons aimed at selecting a binder that could perform well under expected road surface temperatures.***
- ***Cutback binders such as MC3000 could be extremely sensitive when applied during high road surface temperatures – typically higher than 40°C.***

C.4.2 FACTORS AFFECTING PERFORMANCE

Binder-related factors which affect the performance of a seal are:

- Binder type and properties.
- Grade of binder.
- Binder application rate.
- Viscosity at time of application.

C.4.2.1 Binder Type and Properties

C.4.2.1.1 General

Penetration grade bitumen, cut-back bitumen, bitumen emulsions and modified bitumen are used as binders for the construction of seals. If the appropriate conventional binder type (penetration grade, cut-back bitumen and bitumen emulsion) is selected for the specific conditions, the longer-term performance of seals with these binders should be comparable.

The use of modified binders in South Africa (hot modified binders and modified emulsions) has increased greatly in recent years because of improved performance regarding adhesion, elasticity, lower sensitivity to bleeding and ability to retard crack reflection - even at sub-zero temperatures. Although these products are more expensive than conventional binders, their improved properties can be cost-effective by ensuring extended pavement life, less maintenance and, consequently, lower life-cycle costs.

The selection of the appropriate type of binder for the prevailing conditions and critical binder combinations are discussed in Part D. If these guidelines are followed, the risk of poor performance will be minimized.

The results shown in Figure C 14 above confirm that the rate of crack reflection through a new reseal is a function of the type of binder and the film thickness. [3] The results further indicate that polymer modified binders (S-E1) provide approximately 25%, and the bitumen rubber (S-R1) more than 70% additional service life, when compared to conventional binders.

Macro texture depth data collected over a period of five years on highly trafficked road sections (3500 – 4000 vehicles per lane per day), after sealing with bitumen rubber single seals, were analysed and expressed as texture retention over time [8]. Figure C 20 shows the much slower loss in macro texture of bitumen rubber seals, when compared to single seals with other binders.

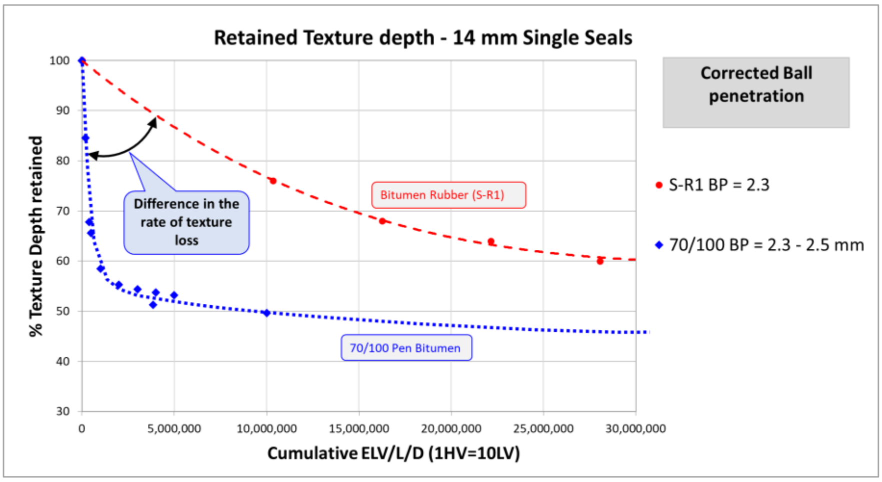


Figure C 20 Macro Texture Retention of Bitumen Rubber Seals Compared With Other Binder Seals

C.4.2.1.2 Ageing characteristics

Several factors contribute to age hardening of bitumen [4] and include:

- Oxidation: Reaction of oxygen with the binder, the rate depending on the character of the bitumen (source) and the temperature
- Volatilisation: The evaporation of the light fractions from binders (Primarily a function of temperature)
- Polymerisation: A combination of like molecules to form larger molecules, resulting in progressive hardening.
- Thixotropy: (Steric Hardening) A progressive hardening due to the formation of a structure within the binder over a period of time.
- Syneresis: A reaction in which the expulsion of thin oily liquids to the surface of the binder film
- Separation: (exudation) The removal of the oily constituents, resins, or asphaltenes from the bitumen caused by absorption into porous aggregates.

The hardening of the binder during the service period of a seal (long term aging) is mainly due to oxidation with the rate of the oxidative hardening a function of the binder properties, the environment and the degree of exposure to oxygen and water within the seal structure.

Measurable changes take place with binder ageing such as a decrease in penetration, an increase in 'softening point', and an increase in viscosity.

Recovering the binder from seventy-four seals, constructed over a period of twenty-four years in different climatic regions [3] confirmed differences in the ageing characteristics of one binder type in different seal structures (refer Figure C 21) and also highlighted a significant difference in stiffness development of different binders as shown in Figure C 22.

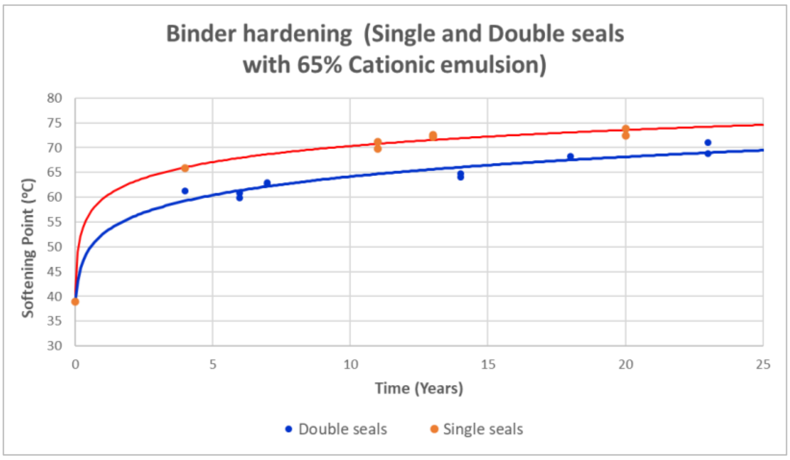


Figure C 21 Difference in Age Hardening of a Binder in a Single and a Double Seal

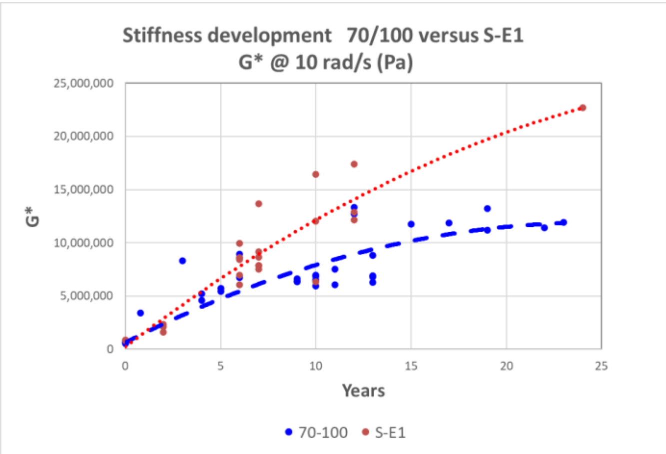


Figure C 22 Difference in Stiffness Development between Conventional and Polymer Modified Binders

Note:

G* = Complex Shear modulus

Figure C 22 suggests that the rate of stiffness development of polymer modified binders (as used in South Africa) is much higher than a conventional 70/100 Pen bitumen. However, when evaluating the initial stiffness development between the two binders, it appears as if the rate of development for 70/100 Pen bitumen during the first five years is higher than the S-E1 (Polymer modified binder).

With reference to the discussion under C.3.1.5: Reflection cracking and the extended life obtained by the use of modified binders, it is clear that **G* by itself does not define ageing or the sensitivity to cracking.**

C.4.2.2 Binder Grade

C.4.2.2.1 General

The selection of the appropriate grade of conventional binder to be used is governed by:

- The expected climatic conditions during construction
- The long-term performance at local ambient temperatures.

Note:

Refer to PART B: Materials regarding the development of Performance Grade (PG) binder specifications

C.4.2.2.2 Penetration grade

Each grade of penetration grade bitumen is characterized by its own temperature/viscosity relationship and has an optimum range over which the bitumen can be sprayed, stored, mixed or pumped. It is essential that the viscosity be kept within the range for spray application in order to obtain optimum performance of the binder, and it is important to refer to the temperature/viscosity curve for the particular binder to determine the temperature range for spray application.

C.4.2.2.3 Cut-back bitumen

Cut-back bitumen is classified in terms of kinematic viscosity and, like penetration grade bitumen, they also have characteristic temperature/viscosity curves for each grade of cut-back bitumen. Because of their lower viscosity, they promote initial adhesion at the time of construction and are generally used under lower temperature conditions.

C.4.2.2.4 Emulsion

Bitumen emulsions are classified according to the percentage by mass of the penetration grade bitumen contained in the emulsion and according to whether the emulsifying agent has imparted a stabilizing positive charge (cationic) or a stabilizing negative charge (anionic) to the bitumen globules in the emulsion.

Cationic emulsions are mostly used in a rapid setting form in spray applications and, are due to its positive charge compatible with most types of aggregate (being negatively charged). Anionic emulsions are not as compatible with certain quartzites and granites to develop quick adhesion (Both materials are negatively charged). However, due to the negative charge and stability anionic emulsion has the benefit that it would easily flow into the seal structure to fill voids and rejuvenate the old bitumen.

The concept is explained in Figure C 23.

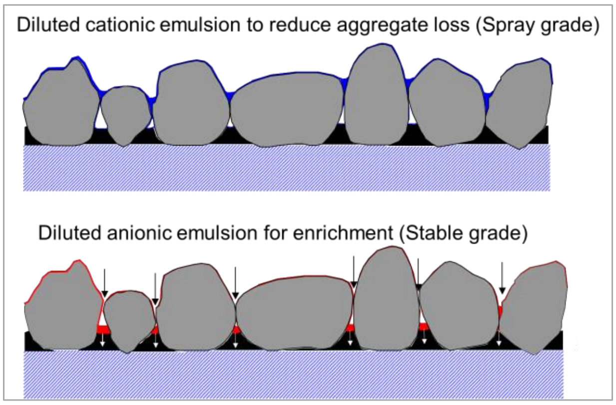


Figure C 23 Effect of Different Emulsions

Invert cutback emulsions are used as prime coats and rejuvenators. Due to the low viscosity and solvents, it has the ability to easily penetrate into a new base or to penetrate and rejuvenate an existing dry/brittle surfacing such as shown in Figure C 24.

Figure C 24 Dry/Brittle Double Seal

Figure C 25 highlights the results of a study on the ability of an invert cutback emulsion rejuvenator to retard crack initiation in a seal.

Detailed assessment of twenty road sections measured initiation of all load associated cracks as 0.4% of the total surface area. Application of a cutback invert emulsion resulted in four years before the same percentage of cracks were visible.

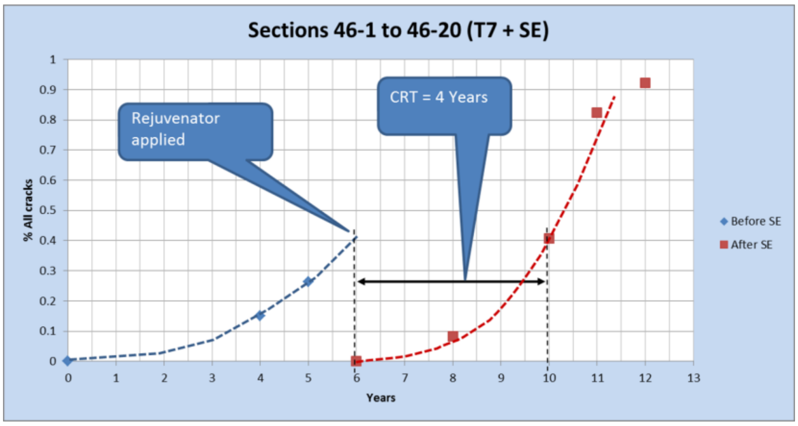


Figure C 25 Four-Year Extended Seal Life due to Application of a Rejuvenator

Notes:

- ***A similar study was carried out using diluted anionic emulsion and resulted in a crack retardation factor (CRT) of 3 years.***
- ***Rejuvenators should be applied when fine cracking (less than 1mm) starts to develop as it becomes less effective when applied on surfaces with wider cracks.***

The addition of up to 5% low flashpoint solvents (LFS) are allowed in cationic emulsions. Although of value for coagulation of the bitumen droplets and use during cold temperatures, the presence of cutters reduces the softening point of the binder and could lead to fattiness or bleeding in Cape seals with high road surface temperatures. Figure C 26 shows the implication of using a binder with LFS (cutter).

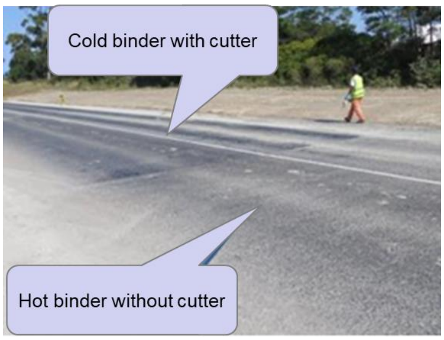


Figure C 26 Bleeding and Fattiness on a Cape Seal due to Solvents in the Tack Coat

C.4.2.2.5 Modified binders

Different grades of modified binders are available in South Africa for application during high and low temperatures. Cognisance should be taken that although modification of binders has numerous benefits, cases have been recorded where highly modified binders performed poorly [11] in Cape seals in cold temperatures soon after construction.

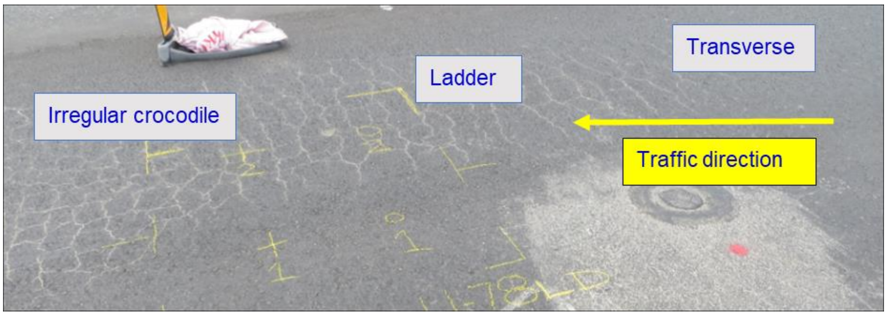


Figure C 27 Crack Development and Progression in Stiff Cape Seal with Modified Binders

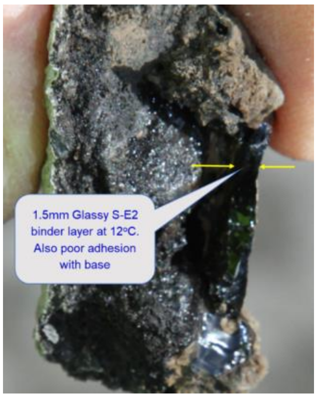


Figure C 28 S-E2 Binder Layer with Poor Adhesion to Base and Seal Aggregate

The mechanism of this distress is deemed to arise from:

- Should bonding between the base and the bituminous be poor or nonexistent, vehicle movement could result in the surfacing forming a wave in front of the wheels, resulting in a small enough radius of curvature (ROC2) to cause the surfacing to crack. The typical pattern is closely spaced "top-down" transverse cracking.
- Moisture/water entering through the cracks, softening the upper base with the effect that the surfacing deflects with a small radius of curvature (ROC1), resulting in the typical irregular crocodile pattern cracking.

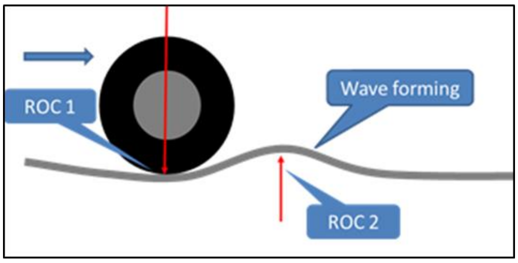


Figure C 29 Cracking as result of Small ROCs

C.4.2.3 Binder Application

For maximum performance the optimum amount of binder should be correctly determined and applied during the construction of seals. A minimum amount is required to hold the stone firmly in place and bind it to the underlying surface. There is also a maximum amount, which, if exceeded, will overfill the voids in the compacted layer, cause flushing and result in reduced skid resistance, particularly in wet weather.

The binder application rate which results in optimal performance is determined by the type of binder selected, volume of the voids in the compacted stone layer, the shape and size of the stone, the amount and type of traffic and the condition of the underlying surface. Adjustments in spray rates are required for steep gradients and other special conditions. These recommendations, as well as construction limitations, are discussed in PART E.

Poor transverse distribution of the binder could lead to tramlining (streaking) as discussed in PART F: Construction.

C.4.2.4 Viscosity at the Time of Application

C.4.2.4.1 General

Uniformity in the application of the binder is a function of viscosity, which varies with temperature. Each grade of binder has its own temperature/viscosity characteristics, which will indicate the optimum viscosity required for the best spray application. Operating outside this range will result in streaking if the binder is too cold and therefore not fluid enough, or will cause binder degradation, run-off on steep gradients, and increased fire risk if the binder is too hot.

C.4.2.4.2 Run-off

Figure C 30 Run-Off of Low Viscosity Emulsions

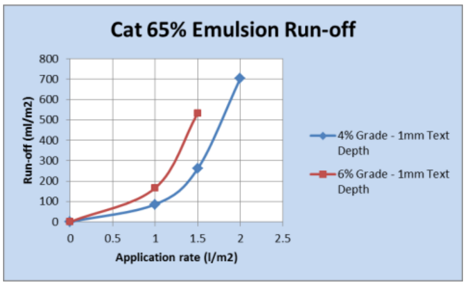
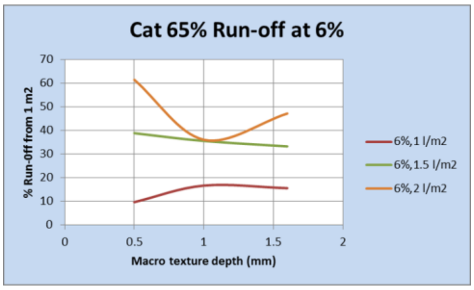


Figure C 31 Increase in Run-Off at Steeper Grades

Previous manuals [12] made recommendations regarding the maximum emulsion application rates, based on macro texture. Research on this topic has shown that this is not valid as the run-off is also influenced by other factors e.g. [13] highlighted the fact that the run-off becomes more at a certain macro texture due to "small rivers" forming with Darcy' s law of flow becoming more effective at lower application rates than on smoother textures.



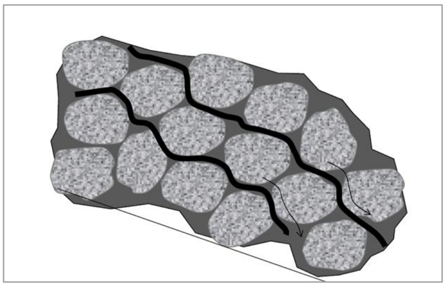


Figure C 32 Increase in Run-off with Texture Depth >1 mm at 2 l/m^2 [13]

C.4.2.4.3 Run-in

The binder application reduces with increase in traffic. Experience indicates that the penetration coat for double seals on high volume roads should always be a high viscosity binder e.g. modified binder. Low viscosity binders, such as emulsions tend to run into the structure of the seal not keeping sufficient binder in the upper structure for the second aggregate layer to adhere properly. Figure C 33 shows the difference in binder retained on the aggregate to adhere the second aggregate layer of a double seal.

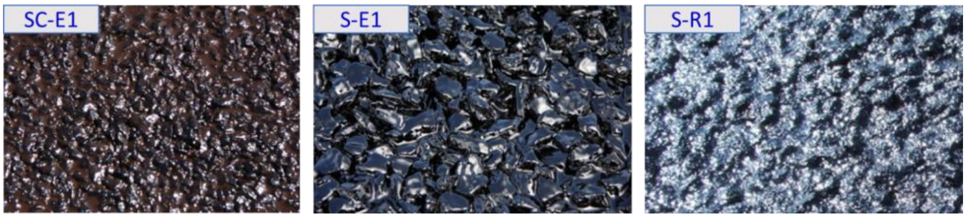


Figure C 33 Difference in Binder Retained

<u>Note</u>: The binder codes are described in PART B: B.3.3, with:

- ***SC-E1 a modified emulsion (elastomer modifier)***
- ***S-E1 a hot modified binder (elastomer modifier)***
- ***S-R1 a hot modified binder (crumbed rubber modifier)***

Figure C 34 below describes the "running-in" effect of an emulsion penetration coat that led to seal stripping.

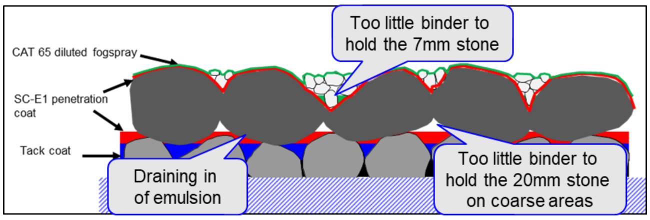


Figure C 34 Effect of Run-in on Double Seals

C.4.2.4.4 High viscosity emulsions

Following good performance of high viscosity emulsions in other countries, local binder suppliers have developed products and processes to overcome the problems with run-off and run-in as discussed above.

Three alternatives are available in South Africa namely:

- Multi-grade rapid setting cationic emulsion (Also referred to as a high shear/Low flow emulsion). The characteristic of this product is that it has a low viscosity under pressure (when sprayed through the nozzles), but gels immediately under normal atmospheric pressure (on the road).
- Double bar spray bar system. Normal rapid setting cationic emulsion or polymer modified cationic emulsion is sprayed through the first bar. Directly afterwards, a catalyst is applied through a second spray bar, resulting in immediate breaking of the cationic emulsion.
- Good experiences have been recoded with imported high viscosity emulsions.

<u>Notes</u>:

With all the benefits related to low flow characteristics, the following aspects could adversely affect the performance of the seal:

- ***Too high viscosity at time of application could result in uneven binder distribution.***

Figure C 35 Too High Viscosity Emulsion

- ***Transverse distribution of the binder must be perfect as the binder will not even itself like the low viscosity emulsions, which could result in tramlining (Refer to PART G: Quality Control).***

- ***It is recommended that the surface be slightly damp before spraying as the surface tension could result in "fish eyes" as shown in Figure C 36, permeability of the seal and/or aggregate loss.***

Figure C 36 Effect of Surface Tension on Flow

Different to standard emulsions, there is quite a difference in curing time after breaking. Breaking of the emulsion occurs rapidly (evaporation of the water in the emulsion). However, it could take some time before proper cohesion and adhesion development (curing). This period is often referred to as a cheesy state.

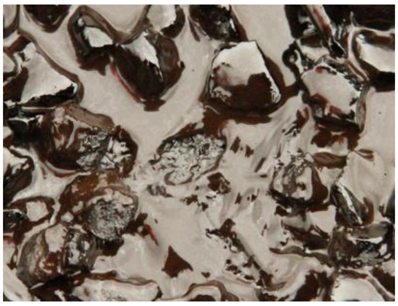


Figure C 37 Slow Development of Cohesion and Adhesion to the Aggregate

C.4.3 SEAL STRUCTURE

The seal structure (also referred to as the seal geometry) has a major influence on the stability of the seal to resist ravelling and to retain macro texture.

As a simple example, the effect of a cover spray and small aggregate blinding on a single seal is shown in Figure C 38.

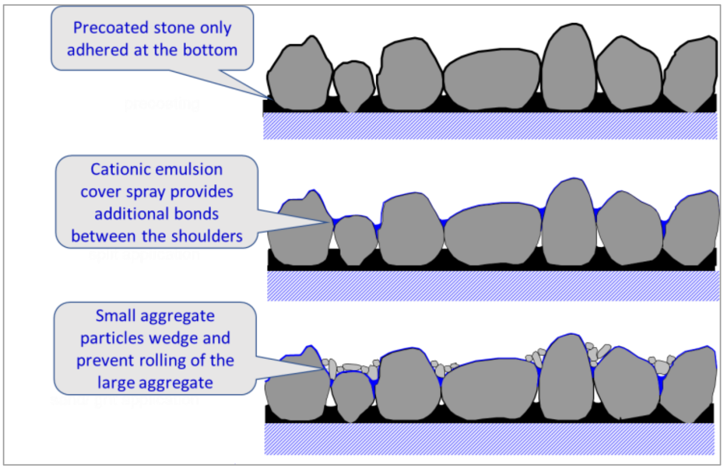


Figure C 38 Increasing Seal Stability with Alternative Seal Geometry

The structure of a double seal reduces embedment and orientation of the large aggregate resulting in better macro texture retention. Even though the texture depth of a single seal is higher, the retention expressed as a percentage of the initial texture, of a double seal is much better as shown in Figure C 39 [5].

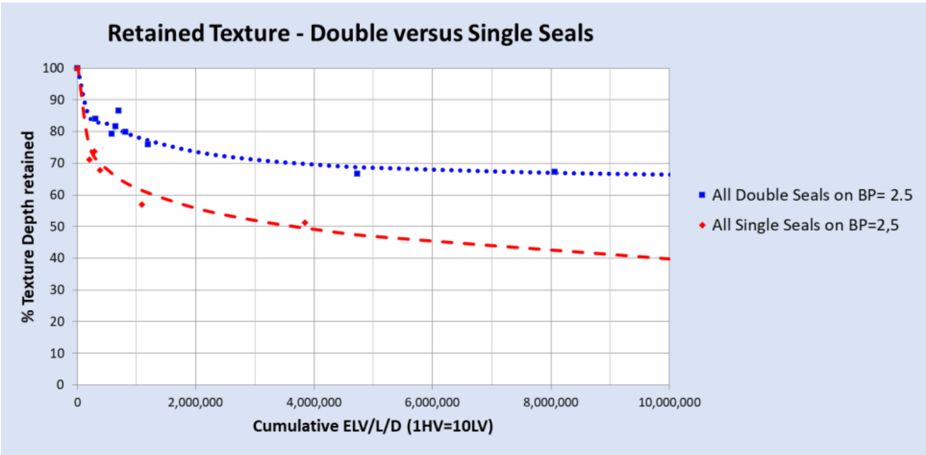


Figure C 39 Texture Retention Between Single and Double Seals

<u>Note</u>: BP refers to the embedment potential (Corrected ball penetration of the existing substrate in mm) as determine through SANS 3001-BT10.

C.4.4 PRE-TREATMENT AND REPAIRS

C.4.4.1 General

Preparation of the road surface, timeous pre-treatment and repair of defects before seal work commences are of vital importance to the initial and long-term performance of a seal.

Failure to provide a clean, uniformly, dense surface will result in a poor bond between the underlying surface and the seal and will add to the risk of aggregate loss or embedment of the seal.

C.4.4.2 Pre-Treatment

If the existing surface texture varies, or if there is any unevenness (small irregularities or rutting), pre-treatment is advisable to ensure a uniform texture and a smooth riding surface for the effective design and construction of the new seal.

Dry or porous surfaces can be treated by:

- Spraying a diluted emulsion or rejuvenator.
- By applying a sand seal or a small aggregate seal.

Coarse textured surfaces can be treated with fine or medium slurry or small aggregate seals to fill the voids in the surface.

Figure C 40 Effect of Sealing on Different Existing Textures

Varying textured surfaces can be treated with slurry before application of a single seal.

Microsurfacing is often used to improve small irregularities or rutting as an alternative to asphalt on roads with lower traffic volumes.

Areas with excess binder should receive special attention to prevent similar problems occurring prematurely on the new seal. The recommended procedure is either to roll aggregate into the existing surface or to do hydro cutting.

Figure C 41 Implication of Not Pre-treating a Variable Existing Surface

C.4.4.3 Repairs

Failure to repair defects such as potholes, sub-surface failures, poorly constructed patches and active or wide cracks will result in these defects reflecting through, or in debonding of the new seal (generally within 3 to 6 months).

One of the most effective ways of treating cracked areas is the application of geotextile patches. Figure C 42 highlights the ability of a geotextile patch, acting as a stress absorbing membrane to retard crack reflection.

Figure C 42 Ability of a Bitumen Impregnated Geotextile to Retard Crack Reflection

C.4.4.4 Timing of Pre-Treatment/Repairs

All repairs should be done well in advance of the construction of the seal, mainly to ensure stability of the treatments so as to minimize embedment of aggregate.

Details and recommendations for preparation, pre-treatment and repairs are discussed in Part F: Construction.

C.4.5 CONSTRUCTION AND SUPERVISION

C.4.5.1 General

Poor performance of seals is often caused by poor construction practices, inadequate plant, inadequate supervision or by lack of attention to detail. Trial sections are required and each section should be inspected and assessed prior to continuation of operations. Good supervision in all aspects of surface preparation and application is essential.

The correct, uniform application of binder and aggregate, as well as rolling and brooming with properly operated, correctly adjusted and calibrated plant and equipment, is essential for the construction of a seal to ensure that it will perform efficiently during its design life.

Check lists, guidelines and practical hints to ensure good performance are given in PART F and PART G.

C.4.5.2 Opening to Traffic

Depending on the binder type and road surface temperature, rolling during construction will not fully orientate the aggregate to the least dimension being perpendicular to the road surface. Therefore, controlled traffic compaction at road surface temperatures still allowing orientation (typically more than 20ºC), is essential to obtain a stable seal with most of the large aggregate on the same plane, in touch with the vehicle tyres.

It is essential to reduce the initial maximum speed of the traffic on a seal to 60 km/h, or, specifically when using emulsions during colder periods, to extend the initial non-trafficked time so that the binder can develop sufficient cohesion to retain the aggregate under traffic.

C.4.6 MAINTENANCE

Some types of seals are much more responsive to timely maintenance than others. Although some problems may be avoided by good design and construction practice, timely maintenance can considerably extend the life of the seal and the pavement structure. A typical maintenance action on a seal is to spray diluted emulsion or inverted cut-back emulsion to increase and rejuvenate the existing binder before loss of aggregate occurs (Refer C.4.2.2.4). Other maintenance actions would be patching of small areas where delamination/debonding of the previous surfacing occurred, or application of fine slurry to isolated areas where ravelling has occurred as a result of turning movements or concentrated water flow.

The role of maintenance capability in the selection of an appropriate surfacing is discussed in Part D.

C.4.7 PHYSICAL AND SOCIAL ENVIRONMENT

Several factors related to the specific environment can adversely affect the performance of the seal and the pavement structure. The majority of these are inter-related with factors already discussed, but are worth mentioning.

C.4.7.1 Climatic Conditions

The climatic conditions in the region where the seal is to be laid should be correctly evaluated to enable the appropriate grade and type of binder to be determined. These include:

- Extremely hot weather, which will reduce cohesion.

- Cold weather, which can result in a brittle, hard binder and subsequent aggregate loss or cracking.
- Variable weather and/or temperature.
- Ultra-violet radiation, which accelerates ageing of the binder.
- Humidity, which influences the evaporation of volatiles.

C.4.7.2 Drainage Systems/Kerbs

Roads are often used to carry storm water, especially in the urban environment. High flow speeds and volumes erode the seal. In this process soil particles and/or detergents are often carried in suspension which aggravates the situation. Research in South Africa has shown that single seals and thin sand seals or slurry seals are particularly vulnerable to erosion and should not be applied on steep gradients with urban-type drainage.

C.4.7.3 Mechanical Damage

Damage to seals is often caused during construction or by agricultural equipment crossing roads, by vehicle wheel rims of flat tyres, or by cargo falling off vehicles at sharp corners. Damaged areas should be repaired as soon as possible to prevent rapid deterioration of the surfacing. Although the damage cannot be prevented by the road authority, in the selection of appropriate seals cognizance should be taken of the likelihood of the occurrence of mechanical damage, and maintenance strategies should be developed to ensure good seal performance.

C.4.7.4 Dust or Wind-Blown Sands

Dust or sand covering a freshly applied bituminous binder has, in many cases, been the cause of poor aggregate adhesion and subsequent poor performance of seals.

C.4.7.5 Fuel Spillage and Organic Matter

Intersections, steep gradients and access roads to fuel depots and filling stations are particularly vulnerable to fuel spillage, which softens up the bituminous binder and results in failures. Guidelines for selection of a suitable binder are given in Part D.

The effects of animal droppings are often visible on surfaced roads in game parks and rural areas. Because of deterioration of the contaminated areas, particularly in the drier parts of the country, seal lives are markedly reduced. The presence of sugar cane, saltwater or detergents also has a detrimental effect on the life of a seal.

C.4.7.6 Developing Areas

Stresses induced on the seal can vary significantly between developing areas and developed areas. Building materials, such as stone, sand, bricks etc. are often found on streets in developing urban areas. Standpipes are often provided next to road/streets in developing areas, resulting in people doing their washing at these locations. The building materials and detergents can damage the seal and result in poor performance of the surfacing.

C.5 SUMMARY

C.5.1 GENERAL

The influence of different factors on the performance of bituminous surfacings has been discussed throughout this document. The purpose of this summary is to highlight the most important distress types and recommended actions to mitigate or to retard the development and progression thereof. Aspects covered are:

- Aggregate loss (Ravelling/stripping)
- Texture loss
- Cracking
- Permeability

C.5.1.1 Aggregate Loss

C.5.1.1.1 Initial loss

The key factors contributing to stripping shortly after construction, reported by [9] are:

- The seal strength (resistance to stripping), which is a function of the seal geometry (structure), the cohesive strength of the binder and the adhesive bond strength between the binder and the aggregate.
- External influences, with the main factors being climatic conditions (temperature and moisture) and traffic.

Recommendations to reduce the risk of stripping focus on:

- Defining high risk situations (Refer Part D: Seal selection – Winter sealing).
- Selection of the correct seal type and binders (Refer Part D: Seal selection – Geometry & Microclimates).
- Design, with specific attention to interpretation of design parameters and compensation for stiff binders which do not allow for quick orientation of aggregate (Refer Part D: Design).
- Construction, with specific emphasis on aggregate spread, rolling and controlled opening to traffic. Key aspects, as discussed in PART F: Construction are:
    - Not to over-apply the aggregate. The designs are based on sufficient binder to hold the stone after orientation. The spread rate should be open enough to allow orientation into a stable matrix.

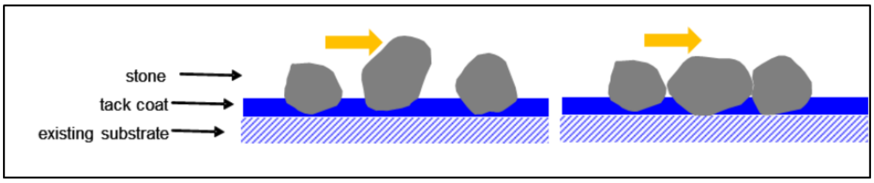


Figure C 43 Open Spread will allow Orientation

    - Controlled opening to traffic. Dependent on the binder type and road surface temperatures, rolling during normal construction does not fully orientate the aggregate. An initial stable matrix could take up to 10000 vehicle passes to develop. Refer case study results in Figure C 44.

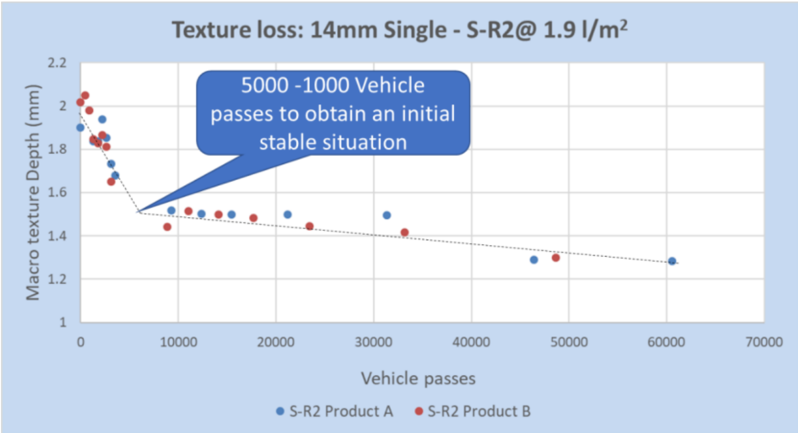


Figure C 44 Impact of Initial Traffic Compaction

C.5.1.1.2 Long-term loss

Loss of aggregate after several years is normally a slow process, easily identified through regular visual inspections (part of Pavement Management System processes) and effectively treated through rejuvenation sprays.

C.5.2 TEXTURE LOSS

Loss of macro texture mainly occurs as a result of:

- Aggregate embedment (Refer C.3.1.1) with the most import aspect to ensure that the base has dried out sufficiently. The degree of potential embedment is taken into consideration during design (PART E). Corrected ball penetration values of more than 3 mm are considered a problem requiring special pretreatment such as an armouring layer (new seals) or, hydro cutting to remove excess binder on the surface before reseal.
- Aggregate orientation (Refer Figure C 20 and Figure C 39) regarding the influence of binder type and the structure of the seal). Adjustment factors are applied during design (PART E) to compensate for slow orientation of aggregate in stiff binders.
- Binder rise. Migration of the binder to the surface could occur as a result of moisture in the base or solvent volatiles.
- Aggregate wear (Abrasion and polishing). Selecting aggregate within specification (PART B) will eliminate this problem.

Figure C 45 Causes of Texture Loss

C.5.3 CRACKING

C.5.3.1 Crack Initiation

Existing performance models predicting crack initiation e.g. as currently described in HDM4 [14] are not providing accurate answers. Even though models could be calibrated, the principle of using a structural number, incorporating the contribution of the total pavement structure, is not considered appropriate when evaluating bituminous surfacings.

Fatigue of the bituminous surfacing as discussed in C.3.1.2 is highly dependent on the radius of curvature (or difference in the deflection under the load and at the first sensor), providing a parameter for deflection high up in the pavement.

Models developed [3], using the above-mentioned deflection contribution, repeated standard axles, environment and age of the surfacing provide more reliable answers. An example of one set of results is shown in Figure C 46.

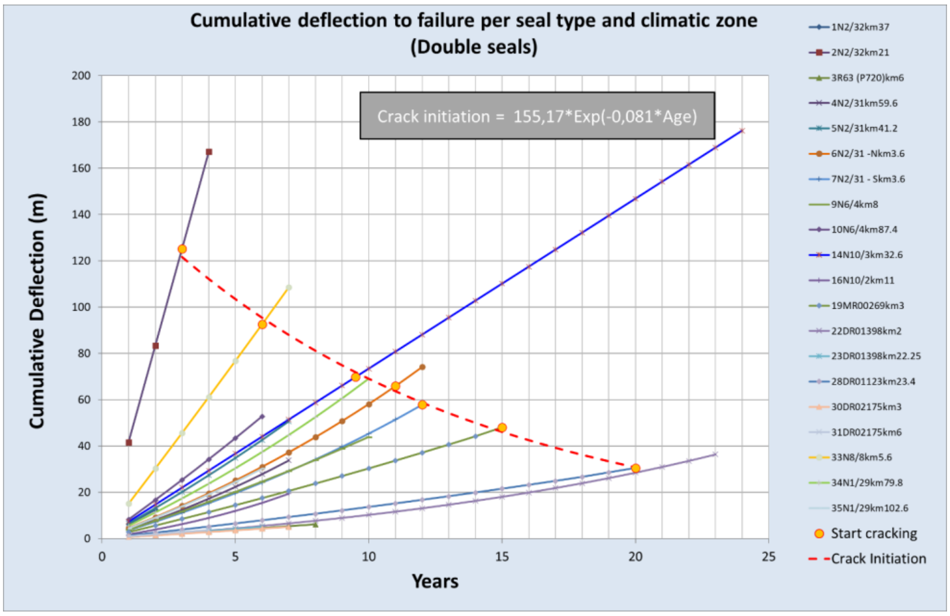


Figure C 46 Tentative Model for Crack Initiation (Double Seals with Conventional Binder)

C.5.3.2 Crack Retardation

The use of cut-back invert emulsions and diluted stable grade emulsion could extend the service life of a single or double seal with four years (Refer C.4.2.2.4).

C.5.3.3 Crack Reflection

The key aspects to retard crack reflection (Refer C.3.1.5) is to use a larger stone size (increase in binder film thickness) and modified binders.

C.5.4 PERMEABILITY

Permeability has been mentioned in this document but not discussed in detail. Investigation of permeability of seals (Aged 1 to 24 years) confirmed an increase with age and oxidative hardening.

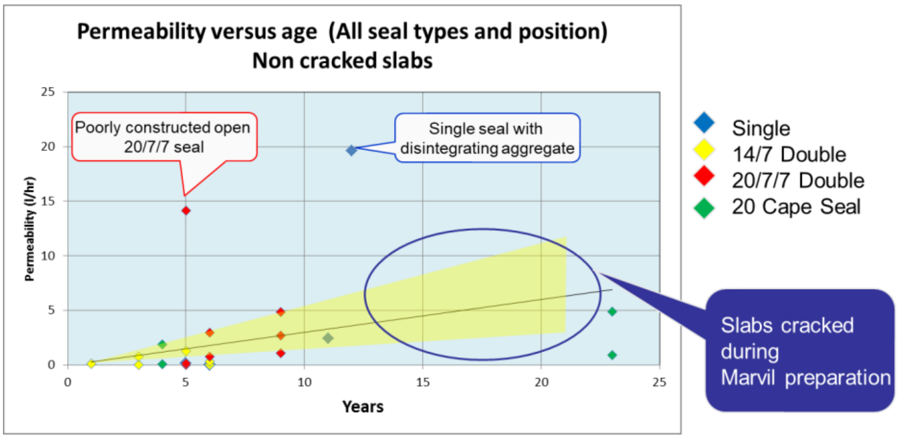


Figure C 47 Increase in Permeability with Age

The true pressure when heavy vehicles pass over a road with a layer of water could be between a 100kPa and 300 kPa (significantly higher than the pressure created with the Marvil permeability meter). Studies by [15] highlighted permeability differences in different seal types, in and out of the wheel tracks and at different applied water pressures. An example is provided in Figure C 48.

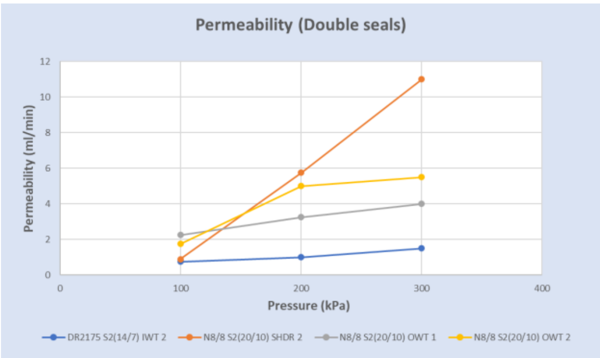


Figure C 48 Increase in Permeability with Pressure Increase

With reference to results highlighted, and discussion in C.3.1.3 regarding the structure of double seals, the following should be noted:

- The principle of determining the binder volume to fill a percentage of the voids in the 20/7/7 split application double seal is not valid (due to the dry aggregate layer).
- For a double seal, such as a 20/10 seal designed for very high traffic volumes, there are still voids underneath the 10 mm aggregate during the orientation and initial embedment phase.

If the above-mentioned seals are constructed on a very coarse textured substrate, the probability is high that there will also be voids underneath the 20 mm, increasing the risk of permeability.

Ingress of water through the seal will soften a granular upper base resulting in a low ROC and rapid fatigue.

C.6 REFERENCES

[1]	Gerber, JAK. 2016. Numerical modelling of performance and failure criteria for surfacing seals. Phd Thesis. University of Stellenbosch.
[2]	Emery, S.J. 1992. The prediction of moisture content in untreated pavement layers and an application in pavement design in southern Africa. CSIR Research Report 644, Pretoria, South Africa.
[3]	Van Zyl, G.D. 2019. Modelling of Surfacing Seal Performance, PhD Unpublished.
[4]	Roberts, F. L., Kandhal, P. S., Ray Brown, E., Lee, D.-Y., and Kennedy, T. W. (1996)."Hot mix asphalt materials, mixture design, and construction." NAPA Research and Education Foundation, Lanham, Maryland.
[5]	Van Zyl GD and Jenkins K. 2015. Overview of Long Term Seal Performance. CAPSA, Sun City, South Africa.
[6]	Renshaw RH, Kleyn EG and Van Zyl GD.1991. The performance of bitumen rubber binders. The South African Bitumen and Tar Association. Proceedings of Modified Binder Seminars. South Africa.
[7]	Department of Transport. (Technical recommendations for highways; Draft TRH3). 1986. Surfacing seals for urban and rural roads and compendium of design methods for surfacing seals used in the Republic of South Africa. Pretoria.
[8]	Committee of Transport Officials (COTO), Committee Draft. 2020. Standard Specifications for Road and Bridge Works.
	Van Zyl G D and Fourie HG. 35 Year's experience. A review of bitumen rubber seal design and performance. Rubberized asphalt and asphalt rubber conference. Kruger Park, South Africa. 2018
[9]	Van Zyl G D, Fourie H G and Rossmann D. 2019. Stripping of seals in South Africa: Case studies and guidelines for an improved approach to mitigate it. CAPSA. South Africa.
[10]	Mukandila E. 2016. Investigation of rheological response cohesion and adhesion fatigue damage of bituminous road seal materials. Doctoral dissertation. University of Pretoria.
[11]	G.D. van Zyl and H.G. Fourie. 2015. Key Aspects Of Good Performing Cape Seals. Conference on Asphalt Pavements for Southern Africa (CAPSA). South Africa.
[12]	South African National Roads Agency (SOC) Ltd. 2007. Technical Recommendations for Highways: Design and Construction of Surfacing Seals (TRH3), Pretoria, South Africa.
[13]	AA Kashya. 2013. Surface run-off behaviour of bitumen emulsions for the construction of seals. M Thesis University of Stellenbosch.
[14]	Morosiuk G, Riley M.J, Odoki J.B. 2002. Highway Development and Maintenance Model (HDM4). Volume 6: Modelling road deterioration and work effects.
[15]	Grobbelaar O R.2016. Towards the development of a standard test protocol: Permeability of chip seals under pressure. Thesis presented in partial fulfillment of the requirement for the degree of Master of Science in Engineering in the Faculty of Civil Engineering at Stellenbosch University.

PART D

SEAL AND BINDER SELECTION

CONTENTS

LIST OF TABLES

LIST OF FIGURES

D.1 INTRODUCTION

D.1.1 CONTEXT AND SCOPE

Manual 40 comprises eight parts:

- Part A: General
- Part B: Materials
- Part C: Performance
- **Part D: Seal type and binder selection (This document)**
- Part E: Design
- Part F: Construction
- Part G: Quality Assurance
- Part H: Repair of premature failures

D.1.2 OBJECTIVES

In this PART the purpose is to assist practitioners with the selection of appropriate seal and binder types for specific situations.

D.1.3 SCOPE

Important aspects relating to selection of seal types and binders are addressed under the following headings:

D.3 Life expectancy of surface treatments

D.4 Relative cost of surface treatments

D.5 New construction (initial surfacings)

D.6 Resurfacing

D.7 Inexperienced/emerging contractors

D.8 Temporary surfacings

D.9 Sealing through winter (embargo periods)

D.10 Surface treatments for labour enhanced construction

D.11 Surface treatments for small airports

D.12 Surface treatments for game parks

D.13 Surface treatments for forestry roads

D.14 Surface treatments for footways, cycle lanes and non-motorised traffic

D.15 Surface treatments for intersections

D.16 Summary of binder selection

D.2 GENERAL

The selection of appropriate surfacings and binders for both new construction and reseals, is discussed in this document.

Although this document deals only with surface treatments, it is important to understand the limitations of a surfacing seal. Recommendations with regard to the most appropriate surfacing type will, therefore, include asphalt surfacings. However, the most appropriate type of asphalt surfacing for given situations will not be discussed. The reader is referred to the companion document SABITA Manual 35 and Manual 27.

The factors influencing the performance of surfacings (discussed in PART C) should be considered in the decision process.

The recommended process for selecting a surfacing or seal is as follows:

- Obtain all relevant information required for decision making.
- Divide the road into uniform sections of similar existing condition and required characteristics.
- Identify appropriate surfacings for each situation.
- Compare the influence of other factors, e.g. institutional capacity.
- Evaluate life-cycle strategies and compare initial and discounted life-cycle costs.
- Final selection.

For surfacings on new construction, the most important influencing factors, which identify those surfacings which will perform well under specific situations are provided in Appendix A. A process is followed whereby inappropriate surfacing types are eliminated. A spreadsheet application is available, assisting the user to make an informed decision for specific situations.

For reseals, decision diagrams are provided in Appendix B to select an appropriate treatment.

D.3 LIFE EXPECTANCY OF SURFACE TREATMENTS

D.3.1 HISTORIC EVALUATION

The life expectancy of surface treatments previously reported in TRH3 (2007) (1) and SABITA Manual 10 were based on opinions from road authority staff and practitioners through questionnaires. The reported life expectancies are provided in Appendix F.

It should be noted that poor performance, governing perceptions, were often related to poor selection, poor design and poor construction.

D.3.2 PERFORMANCE OF SURFACE TREATMENTS

The performance of surface treatments is discussed in PART C highlighting influencing factors and risks. Some of the key aspects influencing performance are:

- The total pavement acts as a system. The seal cannot perform well without proper support.
- The bituminous binder in any surface treatment will oxidise and harden with time, often resulting in increased permeability. The combined effect of traffic loads on a now hard and brittle surfacing with poor support of a moist upper part of a granular base, is failures and potholes.

- The ability of a reseal to retard crack reflection is dependent on the binder film thickness and properties of the selected binder. The larger the seal aggregate, the more binder is required and therefore, increasing the binder film thickness.
- Local studies have shown that the use of homogenous polymer modified binder increase the effective life by approximately 25%, when compared to conventional binders. The non-homogenous modified binder (Bitumen rubber), as manufactured in South Africa, has the ability to increase the effective service life with more than 70%, when compared to conventional binders. The true expected life of a reseal (in years) is therefore, governed by the extent and activity of cracks.
- The loss of macro texture is a function of the substrate softness (embedment potential), the seal structure and the binder properties. The non-homogenous modified binder (S-R1) is the least sensitive to aggregate orientation and therefore, the best binder to maintain a high macro texture. Due to the structure of double seals, the rate at which macro texture is lost, is far less than single seals.

This PART further elaborates on selecting appropriate initial seals as well as reseal types and binders) for typical situations. The purpose is to assist users to understand the benefits and risks of different seal types in specific situations, which could lead to normal or reduced effective surfacing lives.

Using the guidelines in this PART for initial construction seals should result in **effective service lives of 10 years** or more with the proviso that:

- The pavement structure remains sound
- A prime coat is applied
- The seal is well designed and constructed
- Routine maintenance is carried out where and when required

Note:

- ***Apart from Cape seals, two applications of binder and two applications of aggregate are always recommended for initial construction seals.***

D.4 RELATIVE COST OF SURFACE TREATMENTS

D.4.1 COST COMPONENTS

The cost to construct a bituminous surfacing is often broken down into three major components namely:

- Materials;
- Equipment; and
- Labour.

Evaluating the cost components of a normal surfacing project showed that the labour costs and physical cost of aggregate are small when compared to the aggregate haul costs, bitumen cost, and equipment establishment and utilisation costs.

Based on information obtained from contractors, several scenarios have been calculated varying the distance from sources and the sizes of projects. The proportional distribution of costs compared with the average situation for a 14 mm single seal is displayed in Figure D 1.

The contribution of each of these components could vary significantly depending on:

- Size and remoteness of project;
- Haulage of suitable aggregate; and
- Constraints during construction (e.g. standing time and production rate).

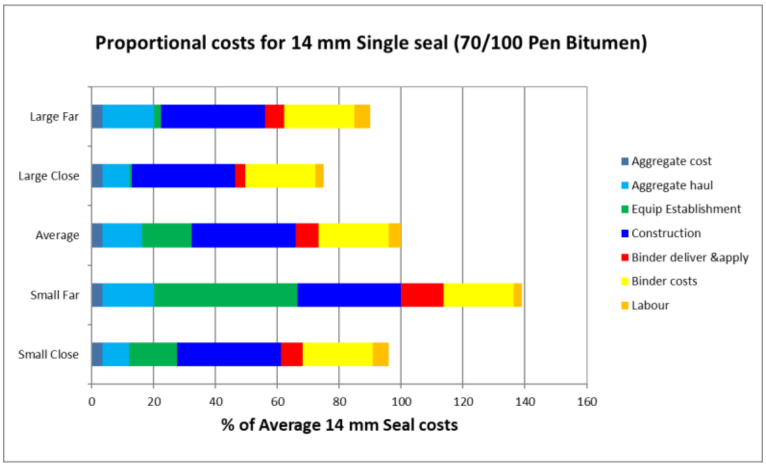


Figure D 1 Proportional Cost of Seal Components

In addition to the above and often not elaborated on, are other activities adding to the total project costs. Examples are:

- Overheads including P&Gs, safety and environmental requirements, traffic accommodation and risks;
- Consultant costs including investigation, design, quality assurance and contract administration;
- Laboratory costs;
- Cost of pre-treatment (e.g. pavement repairs);
- Line marking.

D.4.2 COST COMPARISON

The relative cost of different surface treatment types, relative to a 14 mm single seal with 70/100 pen bitumen, is provided in Appendix E.

Notes:

- ***Item cost for a particular seal type as tendered for in the bill of qualities for a reseal project, often makes up only 50% of the total project cost. Establishment, traffic accommodation, pre-treatment and repairs, line marking etc. could result in the total unit cost for reseal being double that of the tendered item cost.***
- ***As shown in the relative cost table, the cost of a surfacing could vary significantly due to project size, material availability and haul distances. Therefore, the cost ratio for surfacing types, relative to a 14mm conventional binder seal could also vary.***
- ***In the case of graded aggregate seals, the aggregate is often obtained close to the road, resulting in a much lower cost as displayed in the cost table.***

D.4.3 ADDITIONAL COST FOR SEALING DURING WINTER

Expected total additional costs for winter sealing, as indicated by contractors, is in the order of 20 - 25 % when compared to summer sealing. This is due to doubling the construction time as a result of:

- Waiting for road surface temperatures to increase.
- Waiting for the emulsion to break before rolling (where emulsion is used as tack coat).
- Waiting for proper adhesion to develop (particularly where S-E1 on precoated stone is used).
- Waiting for fog spray to reduce tackiness before opening to traffic.

Doubling the construction time result in approximately 65% increase in the construction cost component and a total seal cost increase of 20%, as shown in Figure D 2. However, cognisance should be taken that utilising expensive sealing equipment (e.g. binder distributors) throughout the year might well result in overall reduction of seal costs over the longer term.

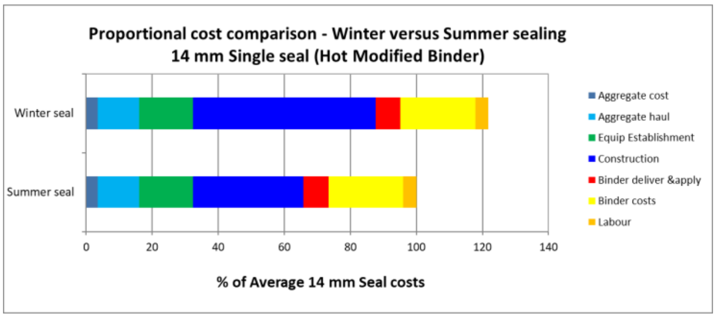


Figure D 2 Typical Cost Proportions for Seals (adapted from Figure D 1)

D.4.4 ADDITIONAL COSTS FOR LABOUR INTENSIVE SEAL CONSTRUCTION

Cognisance must be taken that the cost for labour intensive seal construction is higher than through the normal mechanical processes. However, the additional cost is offset against poverty alleviation and skills development.

D.5 NEW CONSTRUCTION (INITIAL SURFACINGS)

D.5.1 GENERAL

A surfacing on new construction is defined as the first surfacing on a newly constructed road or street. Guidelines for the selection of appropriate initial surfacings are discussed under the following headings:

D.5.3 Traffic volume

D.5.4 Road geometry

D.5.5 Maintenance

D.5.6 Surface texture required

D.5.7 Experience, equipment and work method

D.5.8 Environmental

D.5.9 Quality of the base

D.5.10 Risk of salt damage

D.5.11 Strategy evaluation and final decision

D.5.2 SELECTION PROCESS

Sections D.5.3 to D.5.7 briefly discuss the main factors for initial seal type selection and provide categories that must be selected based on the situation at hand. For each of these factors, tables are provided in Appendix A, highlighting in colour codes which surfacing types will perform well.

Through a process of elimination, one or more surfacing types could be selected for further evaluation as discussed under D.5.8, D.5.9, D.5.10 and D.5.11.

Notes:

- ***The recommended surfacings are based on history of good performance. However, certain seals which are not recommended for specific situations may still perform reasonably well and their performance will depend largely on the skills and experience of local practitioners in the areas in which they are used.***

- ***Because of the simplified process incorporated in the tables of Appendix A, the decision-maker is advised to study PART C: PERFORMANCE and to incorporate additional information obtained during the pre-design investigation.***

The most common seal types used in South Africa and evaluated for appropriateness under different conditions are provided in Table D 1.

Table D 1 Seal Codes and Description

Seal Code	Description
S3 (S <10)	Graded aggregate seals - Single application (<10mm)
S3 (S 10+)	Graded aggregate seals - Single application (10mm or more)
S3 (D <10)	Graded aggregate seals - Double application (<10mm per layer)
S3 (D 10+)	Graded aggregate seals - Double application (10+mm per layer or first layer covered with sand seal)
S7 (<10mm)	Thin microsurfacing or Slurry seal
S7 (>10mm)	Thick Microsurfacing or Coarse slurry seal
S1 (7)	Single seal with 7 mm aggregate
S1(10)	Single seal with 10 mm aggregate
S1(14)	Single seal with 14 mm aggregate
S1(20)	Single seal with 20 mm aggregate
S2(10/S)	Double seal with 10 mm aggregate and sand
S2(14/S)	Double seal with 14 mm aggregate and sand
S4(10)	Cape Seal with 10 mm aggregate and one layer of slurry
S4(14)	Cape Seal with 14 mm aggregate and one layer of slurry
S4(20)	Cape Seal with 20 mm aggregate and two layers of slurry
S2(14/7)	Double seal with 14 mm aggregate and a layer of 7 mm aggregate
S2(14/5)	Double seal with 14 mm aggregate and a layer of 5 mm aggregate
S2(20/10)	Double seal with 20 mm aggregate and a layer of 10 mm aggregate
S2(20/7)	Double seal with 20 mm aggregate and a layer of 7 mm aggregate
S2(20/7/7)	Double seal with 20 mm aggregate and two layers of 7 mm aggregate
S8(14)	Slurry-bound Macadam seal with 14 mm aggregate
S8(20)	Slurry-bound Macadam seal with 20 mm aggregate
AC	Asphalt layer with suitable grading and thickness

D.5.3 TRAFFIC VOLUME

Traffic counts or information from a road authority's Traffic Information System mostly provide the average daily traffic (ADT) or average annual daily traffic (AADT), with the number or a percentage of heavy vehicles. **It should be noted that these reflect the total vehicles in both directions.**

Traffic volume for seal design is currently still expressed as the number of equivalent light vehicles (ELV) per lane per day, and calculated as follows:

ELV = L + 40H

Where

L = Number of light vehicles/lane/day

H = Number of heavy vehicles/lane/day

It is common practice to use surfacing seals for roads carrying from less than about 100 to 40 000 equivalent light vehicles (ELV) per lane per day. For roads carrying more traffic than this, an asphalt surfacing is usually recommended. However, there are surfacing seals, both in this country and elsewhere, which have performed well under much greater volumes of traffic (up to 80 000 ELV). For roads carrying greater traffic volumes, all aspects relating to the materials, design and construction of the surfacing seal should carried out meticulously and with great care.

Lighter types of surfacing seals, such as sand seals, small aggregate seals and slurry seals should only be used as initial seals for roads carrying up to 2000 elv per lane per day. Larger sizes of stone should be used for roads carrying traffic near the top end of the range, since heavier traffic causes greater embedment of the stone.

Recommendations for different seal types are given for the traffic categories as shown in Table D 2.

Table D 2 Traffic Categories

(ELV/lane/day)
< 750
750 - 2000
2000 - 5000
5000 - 10000
10000 - 20000
20000 - 40000
> 40000

Note**: *The validity of designs reduces and risk of poor performance increases above 20 000 ELVs. The use of surface treatments above 40 000 ELVs should only be considered by highly experienced practitioners.***

D.5.4 ROAD GEOMETRY

PART C discusses the influence of road geometry on seal performance under the following headings:

- Gradient
- Sharp curves
- Intersections
- Road width

On steep gradients, at traffic circles or in places where frequent stopping and starting occurs, traffic imposes such great traction/braking stresses on the surfacing that a surfacing seal is at risk to be damaged, particularly in its early life. For these special conditions the choice of surfacing type and the design are most critical. A normal single seal is likely to prove inadequate even for light traffic conditions. Under these conditions, surfacing seals in which binders with higher viscosity than normal (modified binders) are used, together with the use of precoated stone, or seals with a relatively fine texture finished off with a fog spray, or seals in which the stone particles are firmly held in place by slurry or smaller aggregate, will perform better.

Recommendations for different seal types are given for the turning action categories as shown in Table D 3.

Table D 3 Turning Action Categories

Rural with occasional heavy vehicles turning	Infrequent farm accesses
Residential - developed	Mainly delivery vehicles, garbage trucks etc.
Residential - developing	High proportion of building material delivery trucks and risk of spillage
Urban with occasional heavy vehicles turning	Typical close to small shopping centers
Urban/Rural with many heavy vehicles turning	Industrial areas. Large/heavily loaded turning vehicles e.g. mine haulage vehicles

The road gradient affects the constructability of seals and also has a major effect on potential erosion in the urban environment. Where roads or streets are used to carry storm water, single seals or thin seals are not recommended because of the risk of erosion.

Recommendations for different seal types are given for the gradient categories as shown in Table D 4.

Table D 4 Gradient Categories

< 6 %
6 - 8 %
8 - 12 %
12 - 16 %
> 16 %

D.5.5 MAINTENANCE

The majority of surfacing seals will normally lend themselves to simple maintenance techniques, such as the application of diluted emulsions or slurry seals. The application of diluted emulsions and rejuvenators (the latter only for low volume roads) have been found to be cost-effective where the seal is starting to ravel. If this is done before the seal starts to disintegrate, the life of the seal can be prolonged.

Any bituminous surfacing has a limited life, highly influenced by oxidative hardening. If a reseal is not applied in time it will result in complete failure and need for pavement rehabilitation within a short period of time (This is of prime importance with initial seals and even more important for granular base pavements). Therefore, if the responsible authority has a poor or no institutional capacity, the only option is to select more expensive/ stronger seals or a thick asphalt surfacing for new construction.

Recommendations for different seal types are given for the maintenance capability categories as shown in Table D 5.

Table D 5 Maintenance Capability (Institutional Capacity)

High (Can perform any type of maintenance whenever needed)
Medium (Routine maintenance, patching and crack sealing on regular basis, but no formal maintenance management system)
Low (Patching done irregularly, no committed team, no inspection system)
None

D.5.6 SURFACE TEXTURE REQUIRED

Since the skid resistance of smooth-textured (fine) surfaces decreases much more rapidly with an increase in vehicle speed than that of rough-textured (coarse) surfaces, it is more important to provide a rough-textured (coarse) surface for rural high-speed roads than for city streets. Smooth-textured surfaces are also desirable for city streets since they are both easier to clean and generate less noise. Refer PART A for more detail.

There is a limit to the coarseness of texture of the surface because of the nuisance of tyre noise, its effect on riding comfort and the risk of windshield damage by large loose stones.

For single seals the largest size of stone generally recommended is 14 mm (16 mm in exceptional cases).

The higher the operating speed, the greater the texture depth required. Texture depths in excess of 0.7mm are recommended for operating speeds of more than 80 km/h. The greater the risk when braking, the higher the Sideways Force Coefficient (SFC) required (Refer PART A and PART C).

Recommendations for different seal types are given for macro texture categories as shown in Table D 6.

Table D 6 Minimum Macro Texture Required (mm)

<0,7
0,7 - 1,0
1,0 - 1,5
1,5 - 2,0
>2,0

D.5.7 EXPERIENCE, EQUIPMENT AND WORK METHOD

Although seal construction techniques for single and double seals are basically the same, the experience of the construction team should be taken into consideration in the selection of the seal to be used. Also, some types of seal are also more "forgiving" than others, lending themselves more readily to the construction of an acceptable quality wearing surface.

Section D.7 pays specific attention to inexperienced contractors and categorises different seal types into “Risk Classes”

Labour enhance construction is directed towards poverty alleviation and often enforced in road building contracts. This topic is extensively dealt with in SABITA Manual 12 with appropriate seal types discussed in D.10 of this document.

Table D 7 provides the categories for selecting low risk surfacings under the specific situations.

Table D 7 Construction Categories

Experienced contractor
Small or emerging contractor
Labour enhanced: Only aggregate by hand/ light equipment
Labour enhanced: Binder and aggregate by hand/light equipment

D.5.8 ENVIRONMENTAL FACTORS

D.5.8.1 Cold and/or Humid Micro-Climates

The following aspects should be taken into consideration:

- In cold micro-climates (shady areas, in cuttings, under or on bridges), the cold binder prevents orientation of the aggregate, resulting in insufficient bond strength. An additional cover spray and a blinding layer of coarse sand on single seals, or an additional application of a fine slurry would reduce the risk of stripping/aggregate loss.
- Areas with high humidity will negatively affect the curing of emulsions and conventional slurries. Unless opening to traffic could be delayed, alternative binders should be used. Microsurfacings are designed to cure within a short period.
- Sealing during winter periods is discussed under D.9.

D.5.8.2 Social Environment

Several factors could influence the selection of surfacing types related to the social environment. The following aspects, as discussed in PART C, are of importance:

- Children in the urban environment use the street as a playground. Very coarse surfaces are not socially friendly (refer Figure D 3).

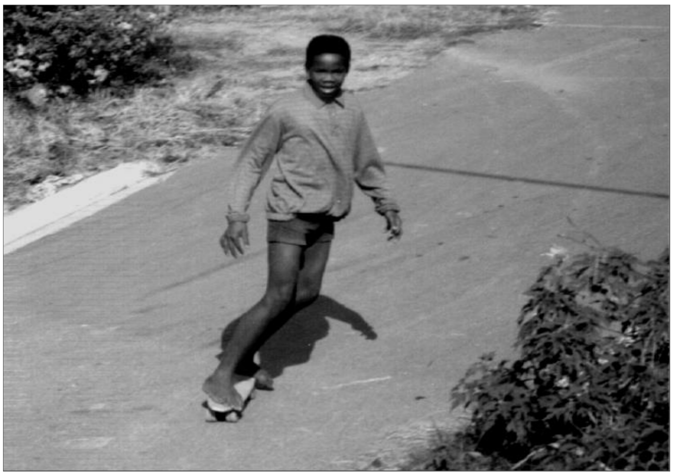


Figure D 3 Streets used as Playgrounds

- Urban environment: Poor maintenance, standpipes next to the road and use of detergents could cause rapid erosion of a bituminous surfacing (Up to 12 mm per annum measured in some cases). Thin surfacings, single and even double seals are not appropriate.
- Developing areas: Building materials are often stockpiled on the road, causing severe abrasion of the surfacing. Only thick microsurfacings, Cape seals and asphalt are appropriate for such conditions.
- Protests, barricades and fires on the road surface eliminate the selection of anything else than thick asphalt layers.

D.5.9 QUALITY OF THE BASE

Since surfacing seals are relatively thin, any imperfections/irregularities in the finish of the base will be reflected to the surface and will have an adverse effect on the uniform compaction of the surfacing layer and the riding quality of the road. This is particularly true of single seals (since the layer is only a single stone thick), and also of sand seals (which could be only 3 mm thick). In the case of multiple seals, minor undulations and depressions in the base may, to a small extent, be evened out (Refer PART F: Construction). Some authorities have had good success in this regard, with the use of inverted double seals (smaller aggregate followed by the larger aggregate).

On relatively soft bases, such as those constructed with natural gravel or emulsion treated gravel where significant embedment of the surfacing stone is likely, good results can be obtained if inverted double seals or large-sized stone is used. The S2(20/7/7) is quite forgiving as the voids within the seal prevent the binder from migrating to the top.

Where a satisfactory finish to the base profile cannot be assured, or where appreciable embedment of the surfacing stone is likely, a surfacing seal should not be used. Consideration should then be given to the use of an asphalt surfacing, or pretreatment with a void-filling seal (texture correction) before applying a seal.

Also refer to D.6.6, PART E and PART C on the effects of embedment and coarse textures.

D.5.10 RISK OF SALT DAMAGE

In cases where the base has a high salt content, a surfacing seal should be selected and designed to be as impermeable as possible and, it should be placed as soon as possible after the base has been primed (Refer SABITA Manual 26). Consideration could be given to seal without priming, minimising the risk of salt migration.

D.5.11 STRATEGY EVALUATION AND FINAL DECISION

D.5.11.1 Alternative Life-Cycle Strategies

Several arguments could be presented regarding the need for full life-cycle analyses between two or more surfacing types. However, as explained in D.3, the future uncertainties incorporating risks, on-time maintenance, overloading etc., makes it extremely complex, resulting in questionable answers.

What is essential as part of a risk management exercise, when funds are extremely limited, is to evaluate and to highlight risks and the implications if:

- Periodic maintenance, in the form of a reseal on time, is neglected, resulting in rehabilitation of the road within five years from the optimum reseal time.
- A single seal or single sand seal is applied as stage construction, with the intention of resealing within three years. If the road is resealed within this three-year period, the next seal could effectively last for another 10 to 15 years. If not done, the pavement might have to be rehabilitated in year five or six.

D.5.11.2 Comparison of Initial Costs

Following the selection process for initial surface treatments, more than one surfacing type might be appropriate. An initial cost comparison would be sufficient to minimise the total project costs.

D.6 RESURFACING

D.6.1 SOUND ASSET MANAGEMENT PRACTICE

Proper road asset management practice requires commitment of the road authority to provide and to maintain the road network to selected levels of service. The process is highlighted in Figure D 4 and activities and the activities summarised in the following sub-sections:

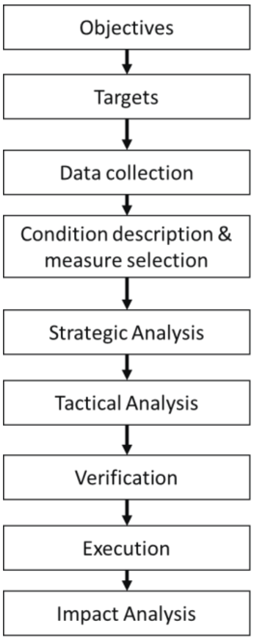


Figure D 4 Asset Management Process

D.6.1.1 Objectives

The objective of a Roads Authority is to manage the road network in accordance with government directives with a view to provide and to maintain appropriate levels of service.

D.6.1.2 Targets

Targets related to the goals and objectives are set to monitor the effectiveness and efficiency of the organisation. A typical target set for the condition of road surfacings is “Not more than 10% in a Poor or Very Poor condition”

D.6.1.3 Data Collection

The type of data collected is controlled by the system models input and reporting requirements. Although guidelines exist regarding the frequency of data collection, which are based on expected rates of change, it is often influenced by funding availability.

The main data sets required for proper road asset management planning with resurfacing in mind are:

- Asset register and inventory (continuously updated).
- Traffic data (continuously updated).
- Climate data (updated as new information becomes available).
- Pavement data (pavement structure and reseal history – continuously updated).
- Pavement condition data.

D.6.1.4 Condition Description and Measure Selection

Various condition indices as calculated in South Africa according to the recommendations in TMH22 [2], with the purpose of monitoring the performance of the road network and to identify the need for periodic maintenance (reseal), based on the degree and extent of functional and structural distress. Appropriate remedial measures are selected for use in the strategic and tactical analyses.

D.6.1.5 Strategic Analysis

Strategic analyses are carried out at network level to achieve and to maintain target levels of service at minimum costs. This then provides the:

- Required optimum funding level
- Optimum distribution of funds to different activities e.g. rehabilitation, reseal, regravel, upgrading
- Impact of reduced funding levels

D.6.1.6 Tactical Analysis

Based on existing condition and expected traffic, different alternative treatments over the life cycle of the pavement are evaluated and the most appropriate strategy for each uniform road section selected to provide "Potential Work Programs"

D.6.1.7 Verification

Typically, all potential periodic maintenance projects are inspected to verify:

- Main cause/s for remedial action and condition category. This information is also used to calibrate condition description and measure selection models.
- Most appropriate remedial measure (pre-treatment, seal and binder type).
- Exact start and end of project.
- Priority and schedule.

D.6.1.8 Execution

Execution starts with more detailed investigation to determine exact quantities of repair, required pre-treatment and appropriate binder and stone application rates.

This is followed by preparation of tender documents, bid evaluation and appointment of suitable contractors to carry out the works.

D.6.1.9 Impact Analyses

Following the execution of works and reassessment, the effects on the network performance become visible.

D.6.2 DECISION TO RESEAL

The decision on whether or not to reseal depends mainly on whether the surfacing is achieving the purpose for which it was applied in the first instance, or on the risk of not achieving this.

It may not be necessary to reseal, as other maintenance strategies, such as patching or crack sealing, may be more cost-effective in certain cases to reinstate the surface to an acceptable condition.

Considering the first aim, the definition of a safe surface is related to the risk of collisions. It does not mean that all roads should have surfaces with high skid resistance, e.g. roads in dry areas, smooth textured roads with low traffic volumes, low posted speed and roads with alignments of a high standard may still have adequate skid resistance.

Provided the pavement layers are not moisture sensitive and the volume of heavy vehicle traffic is low, ingress of moisture can be tolerated to a certain extent before resealing is considered necessary. (For example: cement? stabilization cracks tend to reflect through conventional binder surfacings within three to five years. Experience with stabilized pavements in South Africa indicates that the rate of pavement deterioration is slow until pumping of fines starts to occur. In such cases it is usually more cost-effective to do crack sealing than to apply a new seal.)

Visually assessable types of distress indicating the need for reseal are related to the basic functions of a surfacing, as shown in Table D 8.

Table D 8 Visually Assessable Distress

Basic functions of a surfacing	Surfacing distress	Cause of distress	Visually assessable distress
To prevent ingress of water	Porous surfacing	Dry binder Too little binder	Dry binder
			Voids
			Stone loss
			Poor surface drainage
	Surfacing cracks	Dry binder Premature cracking	Surfacing cracks
			Dry binder
	Structural cracks	Various mechanisms	Structural cracks
			Pumping
To protect base from traffic wear	Loss of stone/ravelling	Surfacing cracks	Surfacing failures
			Surfacing cracks
	Potholes	Dry binder Structural cracks	Dry binder
			Structural cracks
To provide skid resistance	Smooth surface texture	Flushing/bleeding	Flushing/bleeding
		Embedment	Smooth surfacing texture
	Polishing	Tyre abrasion/poor stone	Polishing
	Rutting	Densification of base or pavement failures due to water ingress	Rutting

The following road surface conditions normally indicate that resealing or seal maintenance is required:

- Lean and dry appearance of an old seal caused by ageing of the binder, which has become hard and brittle.

- Loss of aggregate from the seal caused by ageing of the binder, insufficient binder, chemical decomposition of the stone or by the use of dusty stone during construction.
- A seal which is bleeding and has a smooth surface texture caused by excess binder. Such a seal will last a long time and will also have low permeability but, because of its low skid resistance, it may be a hazard to the travelling public. Where a road surface is rich in binder or is only bleeding slightly, the decision on whether or not to reseal should be based on the overall surface texture, skid resistance, geometry, traffic speeds and risk of accidents.
- A seal which is cracked and permits the ingress of water into the underlying pavement. There are several types and causes of cracking, and an understanding of the cause is essential to the selection of an appropriate remedial measure. For example, the road surface may exhibit crocodile cracking caused by fatigue of the pavement layers. In this case a reseal alone may not be effective and partial reconstruction or pre-treatment in the form of structural patching may be necessary. Cracks as such do not necessarily spell disaster, but their causes should be determined, and crack development monitored.
- A seal with low skid resistance and a fine surface texture or aggregates which have polished under traffic.

D.6.3 TIMING OF RESURFACING

The optimum time for resurfacing is critical to prevent rapid deterioration of the pavement. Failing to reseal on time could result in six to eighteen times the cost, within three to five years, to restore the condition to the same level. Early identification of reseal needs is required as it could take up to two years before the contractor could be on site (refer Figure D 5). This requires regular monitoring of all surfaced roads in the network, identifying and recording visual assessable distress as highlighted in Table D 8 and, using these to prioritise reseal work.

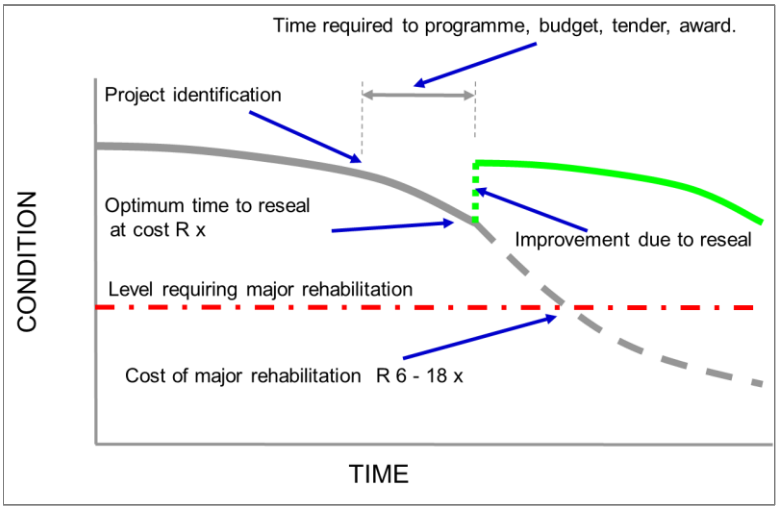


Figure D 5 Early Identification Required

D.6.4 TYPICAL RESEAL TYPES USED IN SOUTH AFRICA

The seal types most commonly used for resealing, and the conditions under which these seals are used, are indicated below:

D.6.4.1 Sand and Small Aggregate Seals (7mm and less)

Provided sufficient macro texture is obtained (Refer PART C), these seal types are the cheapest and very effective if only surfacing related problems require resurfacing e.g. surfacing cracking, ravelling. They are also considered low risk surfacings when used with MC3000 or emulsions on relatively flat grades. Figure D 6 shows a precoated grit seal that had an effective life of more than ten years on a road carrying 3000 ELVs.

Notes:
- ***MC 3000 should not be used when high road surface temperatures (> 40°C) are expected.***
- ***The use of cationic emulsion is preferred with high temperatures and close to the coast***
- ***Refer to PART C for more information.***

Figure D 6 Pre-coated Grit Seal with MC3000 as Binder

D.6.4.2 Single Seals

The greater the traffic volume the larger the stone size used. When 20 mm (seldom), 14 mm or 10 mm aggregate is used with emulsion, a second spray of binder is added, followed by a thin layer of coarse sand, grit or even crusher sand if required to accommodate traffic immediately. This considerably reduces the risk of stone loss and hence the risk of broken windscreens. Precoating of the aggregate is recommended when hot binders are used.

D.6.4.3 Double Seals

Double seals are often used as reseals on high volume roads to reduce the risk of windscreen damage and to reduce road noise. The S2(20/7/7) seal is often favoured due to its low road noise and ability to minimise bleeding. It is also often used with a combination of binders e.g bitumen rubber (S-R1 or S-R2) in the tack coat, homogeneous polymer modified binder (S-E1) as the penetration coat and, a cationic diluted emulsion as a cover spray to retard crack reflection (Refer PART C: Performance).

The S2(20/10) using two layers of bitumen rubber has been used with success as holding actions to postpone pavement rehabilitation for several years.

Double seals with the lowest risk for sealing during cold periods or using inexperienced contractors are those where the size of aggregate for second application is one third or less of the first applied aggregate e.g. S2(10/S), S2(14/S), S2(14/5) and S2(20/7).

D.6.4.4 Slurry Seal and Microsurfacing

Slurry seals can be applied effectively to roads with a varying surface texture, for example where the aggregate has stripped in patches, where the road has been extensively patched, or where only the wheel tracks are fatty. A uniform texture results from a slurry application and it is, therefore, commonly used as a pre-treatment before a stone seal is applied.

Because of their thicker applications, microsurfacings are often used to even out small irregularities and ruts.

Thin slurries or microsurfacings should not be used on very smooth surfaces, bleeding surfaces or as a repair of new seals where aggregate loss occurred.

Warning!

Slurry seals should not be used on smooth-textured surfaces, especially in hilly environments with steep grades and sharp curves or at intersections because of the risk of shoving

Figure D 7 Shoving of Slurry on a Smooth Substrate

D.6.4.5 Surfacing Enrichment

The life of a seal can be extended by the application of a surfacing enrichment spray in the form of a diluted anionic emulsion or invert cut-back emulsion (rejuvenator), provided the texture and voids in the surfacing are such that the mixture can penetrate into the seal and does not remain on the surface (Refer PART C).

Figure D 8 Dry Porous Surfacing Requiring Rejuvenation

High solvent proportions in the rejuvenator could extend the effective life of a seal with up to four years. However, cognisance should be taken that the performance of the next reseal could be compromised if applied within a year. An example of such a case is shown in Figure D 9.

Warning!

- Invert cut-back emulsion rejuvenators should only be used on very lightly trafficked roads as it might take more than two days before traffic can be allowed on the surface
- Resurfacing on a rejuvenated seal should be postponed for at least one year to minimize

Figure D 9 Reseal Applied too soon after Rejuvenation Spray

D.6.4.6 Diluted Emulsion Plus Slurry

When a dry porous seal is treated with a slurry seal, the existing seal should be pre-treated with diluted emulsion to prevent the trapping of air voids in the old seal or loss of binder from the new slurry. This could cause the binder to strip from the aggregate and could result in the failure of the seal.

D.6.5 THE CHOICE OF THE TYPE OF RESEAL

With all the possible pavement distress types, severity and extent of occurrence having been taken into account, a very large number of possible conditions could exist, making the selection of the most appropriate seal very complex.

In many cases one particular type of seal will provide the most effective solution. However, there is often at least one alternative which appears to be equally effective. The final choice will depend mainly on wide experience and engineering judgement, economics and on the construction capabilities of the resealing unit or contractor.

The influence of some of the most important factors is discussed below and recommendations regarding actions currently considered to be the most cost-effective for the specific conditions are given.

D.6.5.1 Rutting

The typical crossfall of paved roads is 2 per cent. This implies that, for a rut width of 1 m, water will start to pond when the depression is deeper than 10 mm. However, roads may be found where the crossfall is inadequate, resulting in ponding of water in ruts less than 10 mm deep. A reduction in the risk of aquaplaning can be achieved by:

- Application of a coarse aggregate seal to dissipate water.
- Application of a coarse slurry (not recommended for all cases because of experience with stripping in wet conditions).
- Where rut depths are greater than 10 mm and there is little evidence of other types of distress, the following measures are considered to be the most appropriate:
  - Application of coarse rapid-setting slurry or microsurfacing. (This is often done in two applications, firstly in the wheel tracks and then over the whole road width.)
  - Application of an asphalt overlay or inlay. The use of asphalt is still regarded as a more reliable measure than that of slurry seals on more important roads with high volumes of traffic.

In cases where deep ruts and cracking occur, it is considered essential to apply a stone seal on top of the slurry as soon as the risk of embedment is negligible.

D.6.6 EXISTING SURFACE TEXTURE

D.6.6.1 Fatty Surfaces

The need to rectify fatty surfaces is dependent on skid resistance risks. If the risk is low it is not considered essential to improve this condition. Where the risk is high, a large aggregate single seal or double seal is often applied, with modified binders. In certain cases, especially where there is a significant amount of excess binder, pre-treatment in the form of hydro cutting is preferred.

D.6.6.2 Medium to Fine Texture

Single stone seals are directly applied on this type of surface, the size of stone being dependent on the traffic volume and on the severity of the type of distress.

D.6.6.3 Medium to Coarse Textures

Depending on the type and severity of distress, various strategies can be followed, e.g.:

- Application of diluted emulsion.
- Small stone single seal such as with 7 mm stone.
- Texture treatments with sand seals, “Grit” seals or slurry seals.

The application of larger aggregate single seals is not recommended unless the surface is pre-treated or modified binders with high application rates are used. (The practical maximum binder application rate is usually insufficient to fill the voids in the existing surface and to bind the new aggregate.) This situation usually results in loss of stone.

D.6.6.4 Varying Textures

In this case "varying texture" refers to a situation where the wheel tracks are fine textured or fatty and the area between the wheel tracks has a coarse texture.

It is not considered essential to reseal just because of this variation. When it becomes necessary to seal a road with varying texture, the choice depends on the ability of the type of seal selected to rectify this specific situation for a reasonable period of time. The choice is highly dependent on the traffic volume and on the risk of low skid resistance.

One strategy is to prepare the surface for the next stone reseal with a texture treatment such as a sand seal or slurry. In this regard the following may be recommended:

- Application of a grit seal where traffic volumes are low, if this is cheaper than a fine slurry.
- Application of a medium or fine slurry on roads with higher volumes of traffic.
- Application of a coarse slurry where skid resistance risks are high.
- Application of a coarse, rapid-setting slurry or microsurfacing on high volume roads, roads with little room for deviations or on roads with small irregularities, such as rutting or small undulations.

Depending on the structural condition of the pavement, these texture treatments may act as seals for several years before further action is required.

D.6.7 LOSS OF AGGREGATE

Three different situations are identified. If very little loss of aggregate has occurred and the situation is stable, there is no real need to improve the current condition. If the situation is not stable, or if there is a potential for further loss of aggregate, e.g. because of dry binder or voids in the surfacing, diluted anionic emulsion is applied to prevent further deterioration. In cases of severe loss of aggregate (coarse texture) the situation can be rectified by the application of a texture treatment as discussed previously.

D.6.8 PAVEMENT CONDITION

As the severity and extent of cracking and patching increase, increased binder film thickness and/or modified binders are needed to retard reflection of the distress. (Refer PART C)

The choice of a reseal as a holding action is often considered by road authorities when major rehabilitation cannot be executed immediately. There are many examples on South African roads where holding actions have extended the service life of pavements by more than ten years. The tendency is to make use of modified binders and/or geotextile seals for this purpose.

However, it should be noted that the pavement must be able to carry the load. If the pavement structure fails due to insufficient bearing capacity, resealing without strengthening and/or proper repairs will be a waste of money.

D.6.9 TRAFFIC

There is general agreement among practitioners that seals have an upper traffic limit, below which seals can be applied cost-effectively. A traffic volume of **40 000 equivalent light vehicles per lane per day is regarded the upper limit,** beyond which asphalt surfacings are usually applied. This limit is not rigid and may be influenced by factors such as road importance, construction quality and sophistication, time delays and the funds available.

In addition, the volumes and types of heavy vehicles, as well as their speed and turning actions, determine whether a seal would be appropriate. Cape seals or asphalt surfacings are often used on roads with much lower traffic volumes, particularly at intersections with stopping and turning actions.

The general trend with lower traffic volumes is to reduce the aggregate size to 7 or 10 mm. This has the effect of reducing the binder application and thus of reducing the costs of the reseal.

Here again other factors often contribute to a final decision of whether to rather use a 14 mm aggregate such as:

- Availability and cost of smaller stone.
- Pavement condition (the greater the severity of the distress, the greater the quantity of binder needed).
- Embedment potential.
- Risk of a sudden increase in traffic volumes.
- Difference in cost effectiveness for the specific conditions.

D.6.10 CONSTRUCTION EXPERIENCE

The risk of premature seal failure is highly dependent on the experience of the contractor and quality of his equipment. When the possibility exists that a seal contract will be awarded to and inexperienced contractor, only low risk seals should be considered (Refer D.7).

Reseal teams of some road authorities, as well as those of some contractors, have built up experience in the construction of specific types of seal only.

In cases where various alternatives are considered, those types of seal with the least risk of construction problems are recommended.

D.6.11 FUNCTIONAL REQUIREMENTS

D.6.11.1 Noise Levels

High noise levels are not acceptable in urban areas or on high speed roads traversing through built-up areas. Surface treatments with the lowest noise levels are those with 7mm or less aggregate in the top layer. Course Cape seals are known for very high noise levels. However, controlled application of the slurry in this type of surfacing through trial sections could result in reduced noise levels.

Additional information is presented in PART A and PART C.

D.6.11.2 Low Risk of Windscreen Damage

Cape seals, slurry, microsurfacing and stone seals with a top layer of 7mm and less, pose a low risk of windscreen damage.

D.6.11.3 Improvement of Road Roughness

The thickness of surface treatments (mostly less than 20mm) cannot significantly improve road roughness (riding quality). However, if surface irregularities or roughness is caused by short wave lengths (corrugation effect), a coarse slurry or microsurfacing (>10mm), applied with a continuous slurry machine, will have a measurable positive effect.

D.6.12 RESURFACING TYPE SELECTION

Selection diagrams are provided as Figures D-1 to D-5 in APPENDIX D and, can be used to select the appropriate types of surface treatments for different situations. The categories are as shown in Table D 9.

Table D 9 Reseal Treatment Selection

Category	Description
Nothing	Nothing required
DE	Diluted emulsion or rejuvenator
TEXT	Texture treatment
STONE	Single or double seal with conventional binder
MOD STONE	Single or double seal with modified binder
TEXT + STONE	Texture treatment plus Single or double seal with conventional binder
TEXT + MOD STONE	Texture treatment plus Single or double seal with modified binder
DE + TEXT + STONE	Texture treatment plus Single or double seal with conventional binder
DE + TEXT + MOD STONE	Texture treatment plus Single or double seal with modified binder

Once a suitable treatment has been selected based on the road condition, external factors could be incorporated for each treatment in Table D 9 to recommend a specific seal type and binder. The additional factors taken into account are:

- Urban or rural environment.
- Traffic volume.
- Traffic actions.
- Gradient.

The second level recommendations are provided in Figures D 32 to Figure D 35.

D.7 INEXPERIENCED/EMERGING CONTRACTORS

D.7.1 GENERAL

The risk of poor performance increases dramatically with inexperienced contractors, often not having proper equipment or experienced staff on site to control the various processes.

Although there is no excuse for poor quality work, the selection of lower risk surfacing types and binders could reduce the risk of construction defects and, thus, premature failures and/or poor longer-term performance.

D.7.2 RISK CLASSIFICATION

Based on experience, Table D 10 provides some guidance regarding the risk levels of different surfacing and binder types for inexperienced contractors.

Table D 10 Risk Classification for Different Seal and Binder Types

Risk category	Seal/ treatment type	Binders
Low	Rejuvenation	Anionic stable grade emulsions or Invert cutback emulsion
	Slurry Texture by hand	Anionic stable grade emulsions
	Sand, grit or graded aggregate seals	Cationic spray grade emulsion or MC3000[1]
	Single seals with cover sprays and grit blinding	Cationic spray grade emulsion
Medium	Single seals with cover sprays	Conventional binders
	Cape seals	Any binder except MC3000 or bitumen rubber
	Double seals (Stone & 1/3 configuration)	Hot homogeneous polymer modified binder
	Precoated single and double seals with additional cover spray	Conventional binders
High	Precoated single and double seals, even with cover sprays	Hot homogeneous polymer modified binder
Very high	Precoated single and double seal	Bitumen rubber
	S2 20/10 double seal	Any binder combination

Note:

[1] If MC3000 is used, it is recommended that the product is applied by an experienced supplier and not by the inexperienced contractor.

D.8 TEMPORARY SURFACINGS

D.8.1 USE OF TEMPORARY SURFACINGS

Temporary surfacings are mostly used in South Africa to accommodate traffic safely on temporary deviations or to protect the base during half-width construction until the final surfacing could be applied over the full width. The latter situation often occurs as a result of seal embargos during the cold winter period (Discussed under D.9).

D.8.2 CONSIDERATIONS

D.8.2.1 Traffic and Safety Issues

Temporary deviations normally carry dual direction traffic managed through "stop-go" control. These deviations are often constructed without a high level of quality control, using local or marginal materials and are normally narrow, not allowing traffic wander. Hence, the damage, especially caused by heavy vehicles, could be much more than on a properly designed and constructed road.

Although the benefits in terms of savings in vehicle operating costs might not warrant the costs of surfacing, the negative effect of dust and loose aggregate on road user safety, vehicle damage and on the main construction activities (e.g. sealing) could dictate a decision to surface the deviation.

It should further be noted that speeds are kept low and that skid resistance is, therefore, not normally a concern.

D.8.2.2 Duration and Traffic Volume

Table D 11 shows suggested surfacing types based on practitioners' feedback (Conservative approach).

Table D 11 Suggested Surfacing Types for Temporary Deviations

Duration of temporary deviation (months)	Traffic Volume		
	500 vpd	2 500 vpd	10 000 vpd
1	Gravel or S3*	S2(10/S) or S4(10)	S2(14/S) or S4(10)
2	Gravel or S3*	S2(10/S) or S4(10)	S2(14/S) or S4(10)
3 - 6	S2(10/S)	S2(10/S) or S4(10)	S2(14/5) or S4(14)
6 - 12	S2(10/S)	S2(14/S) or S4(10)	S2(20/7) or S4(20)
12 - 24	S4(10)	S2(14/5) or S4(14)	Asphalt
> 24	S4(10)	S2(20/7) or S4(20)	Asphalt

***Note* ***

If the seal is only required for a temporary deviation which will be removed after opening of the road, then sand seals and graded aggregate seals constructed with soft binders (e.g. MC3000) are appropriate.

D.8.2.3 Pavement and Base Quality

Previous recommendations suggested the use of modified binders in cases where the quality of the base and pavement layers are suspect. However, experience over the past decade indicates that this recommendation is not valid. The pavement must be able to carry the load for the structural design period.

D.8.2.4 High Stress Wheel Actions

Traffic actions such as turning, braking and acceleration occur on temporary deviations at "stop-go" controls, intersections and accesses. It is recommended that these areas be evaluated for a stronger seal type.

D.8.2.5 Cost

The cost plays a major role in the selection of a temporary seal. In this regard it should be noted that the surfacing life is relatively short and that some specifications for the aggregate could be relaxed to facilitate savings. However, cheap solutions might result in premature failure, vehicle damage and high risk of accidents.

Notes:

- ***Waste fractions from a crushing and screening processes could be evaluated for use.***
- ***Local material could be screened for use in graded aggregate seals.***
- ***Grade C aggregate specifications in PART B could be considered for temporary surfacings.***

D.8.2.6 Practical Considerations and Examples

Poor performance of temporary surfacings Figure D 10 is often observed and has led to the general recommendation that single seals are not appropriate for this purpose.

Figure D 10 Poor Performing Single Seal

Figure D 11 shows a temporary single seal on a widening contract, constructed with an emulsion tack coat but without an emulsion cover spray. Even with an increased binder in the tack coat the seal is still sensitive to traffic abrasion and ravelling.

Figure D 11 Temporary 10 mm Single Seal without Emulsion Cover Spray

Note: Applying the same quantity of net cold binder, but using emulsion in the tack coat, and undiluted emulsion or up to 60/40 (emulsion/water) dilution as a cover spray, eliminated the sensitivity to ravelling.

Some experiments on national routes in South Africa, carrying up to 60% heavy vehicles have shown that even 10 mm single seals with cover sprays or with coarse sand added, and 10mm Cape seals can perform without any defects for more than a year on a properly constructed base and good quality seal construction

Figure D 12 shows a 10 mm temporary single seal on the N1/14, carrying extremely high heavy vehicle traffic for a year. The seal was placed directly on the primed crushed stone base in winter with the following application rates:

- Tack coat - 1.1 l/m^2 SC-E1 (65% Cationic polymer modified emulsion).
- Cover spray - 0.8 l/m^2 65% Cationic spray grade emulsion (Diluted 70/30 – Water/emulsion).

Figure D 12 Single 10 mm Seal with Emulsion Cover Spray (N1/14 after 1 year)

One of the lowest risk temporary surfacings (also suitable for temporary winter seals) is a 10 mm Cape seal as shown in Figure D 13. This seal type is also quite effective in handling heavy vehicle turning actions as shown in Figure D 14. The seal was constructed using precoated stone with 1.0 l/m^2 SC-E1 emulsion as tack coat (cutters omitted), precoated aggregate and one layer of medium-fine slurry with 8% bitumen content.

Figure D 13 Temporary 10 mm Cape Seal after 1 year

Figure D 14 Temporary 10 mm Cape Seal on Intersection

Figure D 15 shows a microsurfacing placed on a foam treated base (road widening), as a temporary seal. The design bitumen quantity was 6.5%. Apart from eliminating irregularities on the foamed base that was damaged by traffic, the microsurfacing assisted in obtaining a surface level with the existing road and provided a smooth-textured surface, similar to the existing road after texture treatment.

Figure D 15 Microsurfacing (8mm)

Figure D 16 10 mm Single Seal with a Cover Spray and a Natural Fine Sand Blinding

Figure D 16 shows the surface of a 10 mm single seal with a sand blinding layer applied after the emulsion cover spray has cured.

Several cases have been mentioned by practitioners where graded aggregate seals such as Otta Seals and coarse sand seals provide excellent service on temporary deviations. The key to good performance with these types of seals on deviations lies in the use of a high application of a soft binder such as MC3000 and, preferably, a high percentage of fines and dust (e.g. 7 – 25% minus 0.425 mm and 3 – 10% minus 0.075mm) as recommended for dense graded Otta seals [1].

D.9 SEALING THROUGH WINTER (EMBARGO PERIODS)

D.9.1 GENERAL

Following a strategic research project by SANRAL [5], the key elements to maximise seal work throughout the year, whilst minimising risk, were confirmed to be:

- Propper planning and scheduling of seal projects.
- Seal type and binder selection for different situations.
- Attention to detail during investigation, design and construction.

Planning and scheduling of seal projects require a risk assessment with the most important influencing factors being:

- Climatic conditions.
- Traffic volumes.
- Seal and binder type selection.
- Quality of design and construction.

Low road surface temperature during and shortly after construction significantly influences the orientation of the aggregate, increasing the risk of stripping/aggregate loss. Figure D 17 highlights minimum road surface temperatures measured throughout South Africa.

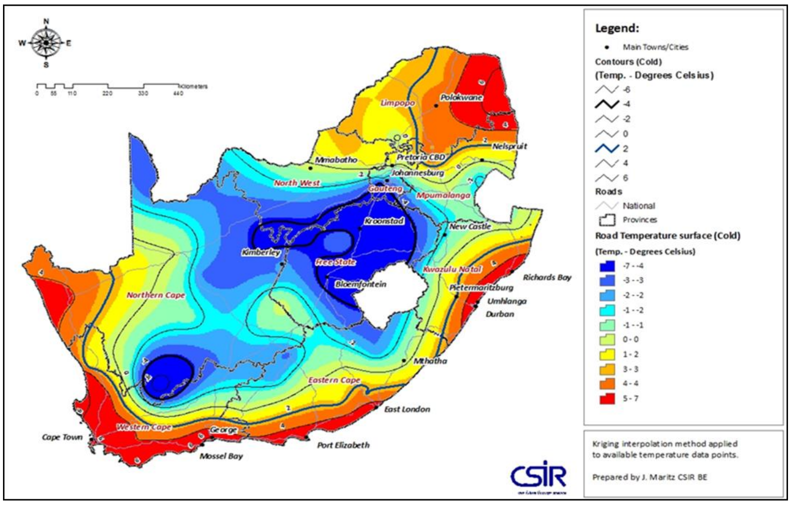


Figure D 17 Minimum Expected Road Surface Temperatures

A conservative risk allocation, as recommended by [5], could be done using Tables D 12, 13 or 14.

Table D 12 Risk Allocation (AADT > 3000)

Traffic	Rainfall Area	Minimum Temperature (°C)	Probability of inexperienced contractor/designer	Risk level (May - Aug)
High (AADT > 3000)	Winter > 150mm	Cold < 0	Yes	High
			No	High
		Mild	Yes	High
			No	High
		Hot > 4	Yes	High
			No	High
	Autumn > 150mm	Cold < 0	Yes	High
			No	High
		Mild	Yes	High
			No	Medium
		Hot > 4	Yes	High
			No	Medium
	Summer	Cold < 0	Yes	High
			No	High
		Mild	Yes	High
			No	Medium
		Hot > 4	Yes	High
			No	Medium

Table D 13 Risk allocation (AADT 1000 - 3000)

Traffic	Rainfall Area	Minimum Temperature (°C)	Probability of inexperienced contractor/designer	Risk level (May - Aug)
Medium (AADT 1000 - 3000)	Winter > 150mm	Cold < 0	Yes	High
			No	High
		Mild	Yes	High
			No	High
		Hot > 4	Yes	High
			No	High
	Autumn > 150mm	Cold < 0	Yes	High
			No	Medium
		Mild	Yes	High
			No	Medium
		Hot > 4	Yes	High
			No	Medium
	Summer	Cold < 0	Yes	High
			No	Medium
		Mild	Yes	High
			No	Medium
		Hot > 4	Yes	Medium
			No	Low

Table D 14 Risk Allocation (AADT < 1000)

Traffic	Rainfall Area	Minimum Temperature (°C)	Probability of inexperienced contractor/designer	Risk level (May - Aug)
Low (AADT < 1000)	Winter > 150mm	Cold < 0	Yes	High
			No	Medium
		Mild	Yes	High
			No	Medium
		Hot > 4	Yes	High
			No	Medium
	Autumn > 150mm	Cold < 0	Yes	Medium
			No	Low
		Mild	Yes	Medium
			No	Low
		Hot > 4	Yes	Low
			No	Low
	Summer	Cold < 0	Yes	Medium
			No	Low
		Mild	Yes	Medium
			No	Low
		Hot > 4	Yes	Low
			No	Low

Recommended strategies to minimise the risk of seal failure are summarised in Table D 15.

***Note*: Almost 45% of the surfaced road network, in summer rainfall areas, carries less than 1000 vpd and falls in the "Low Risk" category.**

Table D 15 Recommended Seal Strategy Based on Assigned Risk Level

Risk	Recommended strategy
High	Schedule reseal projects for summer period. Enforce winter sealing embargo. De-establish May and re-establish September.
Medium	Schedule reseal projects for summer period, but allow for alternative binders and seal types, should the project run into the winter months
Low	Schedule reseal projects for any period and allow for alternative binders and seal types for sealing during colder periods

D.9.2 SEAL TYPE SELECTION

Based on a three-year project by SANRAL, constructing seals during winter in the coldest part of South Africa and recommendations in [5], appropriate seal types per traffic category for sealing during the winter period are shown in the tables below.

Table D 16 Very Low Traffic AADT < 300

Very Low traffic AADT < 300 (Winter strategy)	
New construction	**Reseal**
S4(20)	S2(14/5)
S4(14)	S2(14/S)
S4(10)	S1(14)
S2(20/7)	S1(10)
S2(14/5)	S1 (7)
S2(14/S)	S3 (S <10)
S2(10/S)	S7 (<10mm)
S3 (D <10)	
S3 (D 10+)	
S8(20)	
S8(14)	

Table D 17 Low Traffic AADT 300 - 1000

Low traffic AADT 300 - 1000 (Winter strategy)	
New construction	**Reseal**
S4(20)	S4(20)
S2(20/7)	S2(20/7/7)
S2(14/5)	S2(14/5)
	S2(14/S)
	S1(14)
	S1(10)
	S1 (7)
	S3 (S <10)
	S7 (<10mm)

Table D 18 Medium Traffic AADT 1000 - 3000

Medium traffic AADT 1000 - 3000 (Winter strategy)	
New construction	Reseal
S4(10) Temporary	S2(20/7)
S4(20)	S2(20/7/7)
S2(20/7)	S2(14/5)

Table D 19 High Traffic AADT > 3000

High traffic AADT > 3000 (Winter strategy)		
New construction	**Reseal**	
Cold	**Cold**	**Mild**
S4(10) Temporary	S2(20/7)	S2(20/7)
S4(14) Temporary		
S4(20)		S2(20/7/7)
S2(20/7)		

***Note:* Cape seals could be used as reseals but are normally not practical due to extended construction times**

D.9.3 BINDER TYPE SELECTION

Based on experience with the winter seal trials, performance of seals constructed in winter over the past fifteen years and recommendations from experienced practitioners, Table D 20 has been compiled to select the preferred binder type and combinations for different seal types. "Cold" refers to areas and time of year when sub-zero temperatures are expected at night.

Table D 20 Preferred Binder Type for Winter Sealing

Seal type	Prefered binder type					
	Cold			Mild		
	Tack coat	Penetration Coat	Fogspray	Tack coat	Penetration Coat	Fogspray
20 Cape Seal	SC-E1 (t)	Cat 65(t) or anionic (50/50)		SC-E1 (t)	Cat 65(t) or anionic (50/50)	
				S-E1 (0% LFS)	Cat 65(t) or anionic (50/50)	
20/7 Double	SC-E1 (2-4% LFS)	S-E1 (4% LFS)	Cat 65 (70/30)	SC-E1 (2-4% LFS)	S-E1 (2% LFS)	Cat 65 (70/30)
	S-E1 (2-4% LFS)	S-E1 (4% LFS)	Cat 65 (70/30)	S-E1 (0-2% LFS)	S-E1 (2% LFS)	Cat 65 (70/30)
20/7/7 Split Double	SC-E1 (2-4% LFS)	S-E1 (4% LFS)	Cat 65 (70/30)	SC-E1 (2-4% LFS)	S-E1 (2% LFS)	Cat 65 (70/30)
	S-E1 (2-4% LFS)	S-E1 (4% LFS)	Cat 65 (70/30)	S-E1 (0-2% LFS)	S-E1 (2% LFS)	Cat 65 (70/30)
14/5 Double	Cat 65	Cat 65	Cat 65 (70/30)	Cat 65	Cat 65	Cat 65 (70/30)
	SC-E1 (2-4% LFS)	S-E1 (2-4% LFS)	Cat 65 (70/30)	SC-E1 (2-4% LFS)	S-E1 (2% LFS)	Cat 65 (70/30)
	S-E1 (2-4% LFS)	S-E1 (2-4% LFS)	Cat 65 (70/30)	S-E1 (0-2% LFS)	S-E1 (2% LFS)	Cat 65 (70/30)
14/Grit	Cat 65	Cat 65 (70/30)		Cat 65	Cat 65 (70/30)	
	SC-E1 (0-2% LFS)	Cat 65 (70/30)		SC-E1 (2-4% LFS)	Cat 65 (70/30)	
14 Single	S-R1 (8 % HFS)			S-R1 (4 % HFS)		
	S-E1 (4% LFS)			S-E1 (2% LFS)		
	SC-E1 (2-4% LFS)		Cat 65 (70/30)	SC-E1 (2-4% LFS)		Cat 65 (70/30)
10 Single	S-E1 (2-4% LFS)			S-E1 (2-4% LFS)		
	SC-E1 (2-4% LFS)		Cat 65 (70/30)	SC-E1 (2-4% LFS)		Cat 65 (70/30)
	Cat 65		Cat 65 (70/30)	Cat 65		Cat 65 (70/30)
7 Single	Cat 65		Cat 65 (70/30)	Cat 65		Cat 65 (70/30)
	SC-E1 (2-4% LFS)		Cat 65 (70/30)	SC-E1 (2-4% LFS)		Cat 65 (70/30)
Grit	MC 3000*			MC 3000*		
	Cat 65			Cat 65		
Temp 10 Cape Seal	SC-E1(t) (0% LFS)			SC-E1(t) (0% LFS)		
Slurry/ Microsurfacing						

Notes:

- ***Grit seals - Cat 65 is preferred above MC 3000 in wet coastal areas.***
- ***Cape seals - If stone is pre-coated, no penetration coat/cover spray is required.***
- ***Where ranges are provided, the lower value applies to autumn when temperatures start to fall. The low flashpoint solvent content (LFS) is increased to maximum (4%) during June and July and reduced to the minimum (2%) at start of spring.***

D.9.3.1 Temporary Winter Seals

As a result of the winter seal embargo, temporary surfacings are often constructed during this time. The most appropriate temporary surfacing types on which a stone seal could be constructed after winter are:

- Single 7mm or 10mm single seals using an emulsion tack coat and cover spray, preferably blinded with coarse sand.
- 10mm or 14mm Cape seals.
- Microsurfacings (>8 mm).

Sand seals and graded aggregate seals could still be too soft (high ball penetration) to accommodate the subsequent construction of a stone seal, within a few months.

D.10 SURFACE TREATMENTS FOR LABOUR ENHANCED CONSTRUCTION

D.10.1 GENERAL

Any single or double seal could be constructed by hand using hand spray equipment, applying the aggregate by hand and compaction with light pedestrian type rollers. However, the key to good performance lies in the quality of workmanship, with the risk increasing dramatically with poor base finishing and increase in traffic volumes.

There are excellent examples of good performing seals, constructed by hand and/or with the aid of light equipment. Refer Figure D 18 and D 19.

Figure D 18 Slurry Bound Macadam

Figure D 19 Cape Seal

Guidelines for the construction of various seal types are provided in SABITA Manual 12: Labour Absorptive methods in road construction using bituminous materials.

Table D 21 and Table D 22 highlight the suitability of sprayed seals, slurry and slurry-bound macadam seals for labour enhancement, as published in SABITA Manual 12.

Table D 21 Suitability of Sprayed Seals for Labour Enhancement

Component	Key issue	Suitability for labour enhancement
Spray	Application rate and variability	Suitable for confined areas only; this is critical for performance and plant control is a prerequisite.
Stone	Uniformity and application rate	Reasonable; spread by hand or using walk-behind chip spreaders in demarcated areas; can accept limited variance which can be achieved with appropriate skills training.
Rolling	Coverages	Reasonable; with a pedestrian roller.

Table D 22 Suitability of Slurry and Slurry-Bound Macadam Seals for Labour Enhancement

Component	Key Issue	Suitability for labour enhancement
Manufacture	Mix proportions	Reasonable; mix in concrete mixers; can accept some variances.
Applications	Application rate	Reasonable; can accept some variances; use wheelbarrows and squeegees with appropriate skills training.
Rolling	Coverages	Reasonable; with a pedestrian roller.

D.10.2 RISK CLASSIFICATION

Different risks could be applicable to labour intensive seal construction e.g.

- Safety: The lowest risk is to use cold binders (Emulsions).
- Base quality: Single and double seals cannot be properly compacted with pedestrian type rollers on base layers with surface irregularities. A poorly compacted base will result in premature failure of the seal.
- Seal constructability: Provided safety with handling hot binders could be maintained and the base is properly constructed without irregularities, Table D 23 provides some indication of risk levels related to specific treatments.

Table D 23 Risk Levels for Labour Intensive Seal Work

Risk category	Seal/ treatment type	Binders
Low	Rejuvenation	Anionic stable grade emulsions or Invert cutback emulsion
	Slurry Texture by hand	Anionic stable grade emulsions
	Boxed-in slurry layers with suitable grading for selected thickness	Anionic stable grade emulsions
	Sand, grit or graded aggregate seals	Cationic spray grade emulsion or MC3000
	Single seals with cover sprays and grit blinding	Cationic spray grade emulsion
Medium	Single seals with cover sprays	Conventional binders
	Cape seals	Any binder except MC3000 or bitumen rubber
	Double seals (Stone & 1/3 configuration)	Hot homogeneous polymer modified binder
	Precoated single and double seals with additional cover spray	Conventional binders
High	Precoated single and double seals, even with cover sprays	Hot homogeneous polymer modified binder
Very high	Precoated single and double seal	Bitumen rubber
	S2 20/10 or S2 20/7/7 double seals	Any binder combination

D.11 SURFACE TREATMENTS FOR SMALL AIRPORTS

D.11.1 GENERAL

Recommendations in this section originated from general aviation requirements, a workshop held at the CAPSA Conference 2019, the experience of local practitioners and experience in Australia [6].

Notes:

- ***Due to low traffic movements and high degree of wander the design application rates for surface treatments should be much higher than for roads. In this regard the recommendation is to design for the minimum of ELVs=2000 on the runways and for a target texture dept of 1.0mm for non-trafficked areas (Refer PART E).***
- ***Specific attention should be given during construction to ensure maximum orientation of the aggregate and continuous cleaning of excess material generated from the construction process (Refer PART F).***

D.11.2 AVIATION REQUIREMENTS

South Africa is a subscribed member of the international controlling body ICAO (International Civil Aviation Authority) and the Civil Aviation Authority in SA (CAA), regulating the safety standards that apply for all registered airports in South Africa.

Even though numerous airfields (aerodromes) in South Africa are unsurfaced, strict specifications are applied for surfaced runways, regardless of the type of aircraft (turbo-prop or jet engine aircraft).

In some instances (Mass < 6570 kg) surface treatments are allowed on general aviation airports, provided there is **no loose material after construction** [8]. Cape seals and slurries are mentioned as possible treatments.

Although not yet an established form of runway surface in South Africa, cognisance could be taken that a large portion of regional and remote runways in Australia (two thirds) are surfaced with surface treatments (sprayed seals). Current research and investigations are aimed at providing standards and specifications for small airports [6] and [9].

D.11.3 KEY REQUIREMENTS

Surface friction and macro texture are considered the most important requirements with the current the current ICAO specifications [10] as follows:

Macro texture depth – Minimum 1.0 mm (Also see Table D 25 as recommended by [8].

Table D 24 Friction Requirements

Friction requirements at 1.0 mm water depth						
Device	65 km/h at			95 km/h		
	Minimum	Maintenance planning	New Construction	Minimum	Maintenance planning	New Construction
Mu Meter @ Tyre pressure = 70 kPa	0.42	0.52	0.72	0.26	0.38	0.66
Grip tester @ Tyre pressure = 140 kPa	0.43	0.53	0.74	0.24	0.36	0.64

Table D 25 Macro Texture Requirements [8]

Macro texture requirements (mm)				
Method	Repair within 2 months	Maintenance planning	New Construction	Minimum after retexturing
Volumetric	0.25	0.76	1.14	0.76

***Note**: The material specified for the sand patch method [10] is not exactly the same as the grading specified in SANS 3001-BT11 and could result in up to a 3% difference (refer [11]).*

D.11.4 POSSIBLE SURFACE TREATMENTS FOR SMALL AIRPORTS IN SOUTH AFRICA

D.11.4.1 Cape Seals

More than a hundred workshop attendees (CAPSA 2019) were in agreement that Cape seals could meet all the required specifications with the proviso that:

- Only finely graded slurry be used for the final slurry layer of the 20mm Cape seal or for the only slurry layer in case of a 14mm Cape seal (Refer PART B: Materials). This also means that the coarse aggregate must be spread open (Refer PART E: Figure E 31 Open shoulder-to shoulder matrix), allowing the first slurry of the 20mm Cape seal to penetrate into the large aggregate matrix, with sufficient voids after compaction to accommodate the fine-fine slurry.
- Additional steel wheel and PTR rolling to maximise orientation of the large aggregate before application of the cover spray and slurry. From experience, this would also imply that aggregate hardness must meet the specification of 10% FACT of 210 kN.
- Additional pneumatic tyre roller compaction is required to ensure densification of the slurry.
- Trial sections are essential on non-trafficked areas to obtain the required macro texture.
- Slurry binder content should be high to eliminate any possibility of ravelling.

Examples exist where Cape seals have been used on airports carrying jet aircraft with excellent performance, as shown in Figure D 20.

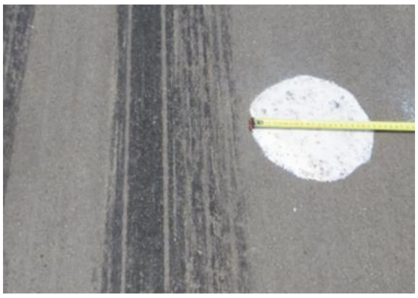


Figure D 20 20mm Cape Seal – Texture Depth 1.32

An example of a poor performing cape seal on an airport is shown in Figure D 21. The main reason for poor performance is a too dry final slurry layer, resulting in disintegration of the slurry and potential tyre damage.

Figure D 21 Loss of Low Binder Content Slurry

D.11.4.2 Thick Slurry/ Microsurfacing

Thick coarse slurry or microsurfacing denoted as S7 (>10mm) with high binder content may be considered on low traffic, small airports provided the base has some macro texture to minimise slippage and shear. Additional PTR compaction and brooming would be required to ensure no loose material after construction.

Microsurfacings have been used with success as a maintenance treatment on small airport runways in the USA to restore ravelling and loss of friction [7].

Note*: *Trials with different design gradings could be required to ensure sufficient macro texture.

D.11.4.3 Single Seals Plus Sand

Good performance of single seals plus sand on runways has been reported by White [6] (Referred to as "locked-down seals").

The 14mm plus sand/grit S2(14) used in South Africa has been proven as a very low risk seal in low temperature conditions and with inexperienced contractors. The use of pre-coated grit (-5 mm graded aggregate) dramatically reduce the need for brooming and removal of loose aggregate. An example of the S2(14) seal is shown in Figure D 22.

Figure D 22 14mm Plus Grit (-5mm)

D.11.4.4 Double Seals (Stone +1/3 Combination)

Experience with this seal type during winter seal trials confirmed a very low risk of aggregate loss. Dependent on the design and construction procedure, different macro texture depths could be obtained as shown below.

Figure D 23 Coarse 20/7 Double Seal

Figure D 24 Fine 20/7 Double Seal

<u>Note</u>: Precoating of both aggregate layers and application of a diluted cationic rapid setting emulsion are recommended

D.11.5 MAINTENANCE REQUIREMENTS FOR SMALL AIRPORTS IN SOUTH AFRICA

Continuous routine maintenance in the form of brooming and rolling of surface treatments on runways is essential, especially in areas where very little traffic is experienced.

D.12 SURFACE TREATMENTS FOR GAME PARKS

D.12.1 GENERAL

Specific considerations pertaining to game parks, as obtained from practitioners, are highlighted in this section.

D.12.2 CONSIDERATIONS

The need for upgrading, the required level of upgrading and the appropriate surfacing type to use depend largely on:

- Volume of traffic;
- Turning and braking actions of buses and other heavy vehicles;
- Environmental sensitivities;
- Gravel wearing course properties and climate during peak seasons (Accessibility and rate of deterioration);
- Availability of suitable surfacing aggregate;
- Maintenance capability and strategy;
- Objectives and preferences of the organisation and involved environmentalists;
- Costs.

Providing it is visually acceptable to the organisation to use a bituminous surfacing, the main consideration for selection lies in the potential actions of heavy vehicles (buses) and the maintenance capability of the organisation. Whereas double sand seals and Otta seals generally perform well on lightly trafficked road sections [12], it is recommended that a layer of loose fine sand on the surface is maintained at intersections, parking areas and look-out points to prevent shearing during turning actions.

D.13 SURFACE TREATMENTS FOR FORESTRY ROADS

D.13.1 GENERAL

Specific considerations pertaining to forestry roads, as obtained from experienced? practitioners, are highlighted in this section.

D.13.2 CONSIDERATIONS

Forestry roads are generally located in wet and hilly areas (Steep gradients and short radius curves), with rural drainage (no kerbs), carrying heavy loaded trucks with tandem or tridem axle configurations (often overloaded).

The decision to surface is dependent on the purpose and function of the specific road section and is normally based on economic considerations. Management of the forestry area and frequency of harvesting specific species dictate the required level of service and the need for temporary or permanent upgrading.

Although these roads are privately owned, the maintenance levels tend to be low resulting in a preference towards stronger surfacing types such as asphalt, thick Otta seals and Cape seals.

***Notes*:**
- ***Smooth base surfaces could result in shoving of the surfacing;***
- ***Due to generally low speeds, a layer of sand on the bituminous surface would reduce the risk of shoving or ravelling.***

D.13.3 INNOVATIVE SOLUTIONS

Due to the remoteness of small projects in forestry areas, the surfacing or resurfacing of roads could be expensive. However, as shown in Figure D 25, De Wet [13] proved that slurry surfacings could be constructed using a simple adjustable spreader box, available equipment and inexperienced staff.

Figure D 25 Small Scale Slurry Operation and Completed Product

D.14 SURFACE TREATMENTS FOR FOOTWAYS, CYCLE LANES AND NON-MOTORISED TRAFFIC

Any surface used by pedestrians or bicycles should ideally be smooth textured. Heavy vehicles are either excluded or limited. Therefore, slurry seals (>6 mm, see Figure D 26), slurry-bound macadam seals, microsurfacing and thin asphalt are considered the most appropriate. Sand seals and graded aggregate seals require vehicle tyre action to create a proper surfacing and are, therefore, not ideal for footways and cycle lanes.

Figure D 26 Slurry Applied on Footway (Sidewalk)

Colored surfacings could be used to demarcate footways and cycle lanes as shown in Figure D 27.

Figure D 27 Colored slurry on cycle lanes and footways (side walks)

Several options for coloring and friction requirements could be evaluated [14].

D.15 SURFACE TREATMENTS FOR INTERSECTIONS

Newly constructed single and certain double seals are sensitive to turning actions occurring at intersections, and property entrances.

The lowest risk option is to apply an asphalt surfacing across the full intersection or area where turning actions occur.

Alternatives that could be considered for lower traffic volumes:

Main surfacing applied	Situation type	Treatment options
Single seal with hot conventional or homogeneous polymer modified binder (no solvents)	Entrances with mainly light vehicles and occasional heavy vehicles (Low volume)	Application of a dry coarse sand layer after the seal construction
		Application of a diluted emulsion cover spray and coarse sand or 5mm aggregate blinding layer
		Application of a fine graded slurry after construction
	Heavy vehicle entrances and rural intersections	Application of a medium graded slurry after construction over the full area where turning actions occur. Note that the binder application rate for the single seal component should be reduced to the minimum (Refer Cape seal design in Part E)
Single seals with bitumen binders containing solvents (including bitumen rubber)	Entrances with mainly light vehicles and occasional heavy vehicles (Low volume)	Application of a dry coarse sand layer after the seal construction
		In case of emulsion seals, a coarse sand or 5mm aggregate blinding layer is applied after the cover spray

D.16 SUMMARY OF BINDER SELECTION

Selection of appropriate binders for different situations have been dealt with throughout this document. The purpose of this section is to highlight the most important recommendations regarding the standard available binders in South Africa.

Table D 26 Summary of Considerations for Binder Selection

Treatment/ application	Binders/ situation	Comments
Rejuvenation	Inverted cutback emulsion	Only use on very low volume roads and not in mid-summer
		Can stay tacky for several days
		Application rate 0.4 -0.5 l/m^2
		Subsequent seal work must be postponed with at least a year for volatiles to escape
		Not effective to fill wide cracks
		Effective for dry and brittle seals with sufficient macro texture
		Could extend the service life of seals for up to 4 years
		Low risk for cold weather application and inexperience contractors
	Diluted anionic stable grade emulsion	Suitable for high traffic volume roads provided sufficient macro texture
		Road surface must be clean
		Typical application rate 0.8 -1.0 l/m^2
		Risk of run-off on steep grades
	Cationic rapid setting emulsion	Not suitable - does not penetrate. Polymer modified cationic emulsions even worse than normal Cat 65
Sand and grit seals	MC3000	Soft binder able to migrate upwards in loos aggregate
		Suppliers not keen to keep on manufacturing - safety hazard
		Do not use when road surface temperatures increase above 40°C
		Sensitive to rain shortly after construction - emulsification
	Cationic rapid setting emulsions	Low solvent content result in thinner seal compared to MC3000
		Preferred above MC3000 close to the see - reason unknown
Tack coat	Double seals	Any binder could be used, except for MC 3000
		All emulsions sensitive to steep grades - run-off
	Cape seals	Do not use any binder with solvents in Cape seals
		Emulsion must cure before application of penetration coat. Polymer modified emulsions (post blended with SBR) forms a skin retarding curing, referred to as a false break
Penetration coat	Low traffic	Any binder could work
	High traffic	Only high viscosity binders preferred due to run-in, not leaving sufficient binder to hold the top stone
Cover spray	Diluted emulsions	Best performance with cationic 65% emulsion diluted 70/30 or 60/40
		Polymer modified diluted cationic emulsions could also be used, but could stay tacky for a longer period
Winter sealing		Refer detailed discussion in Section D.9

D.17 REFERENCES

[1] South African National Roads Agency (SANRAL). 2007. Design and construction of surfacing seals. (Technical recommendations for highways; TRH3). Pretoria. South Africa.

[2] Committee of Transport Officials, Technical Methods for Highways: Manual for the Visual Assessment of Road Pavements (TMH22) Pretoria, South Africa, 2016.

[3] Committee of Transport Officials, Technical Methods for Highways: Manual for the Visual Assessment of Road Pavements (TMH9) - Part B: Flexible Pavements, South African National Roads Agency SOC Ltd., Pretoria, South Africa, 2016.

[4] Jooste K and Van Zyl G. The use and performance of bitumen rubber sprayed seals for holding actions in South Africa. Proceedings 2nd International Sprayed Sealing Conference, Melbourne, Australia, 10-12 October, ARRB Transport Research.

[5] G.D. van Zyl, H.G. Fourie, and S.J. Bredenhann, Recommended Practice for Winter Sealing in South Africa, Conference on Asphalt Pavements for southern Africa (CAPSA). South Africa, 2015.

[6] White, G. Development of an Airport Spray Seal Design Method. Conference: Airfield Pavement and Lighting ForumAt: Sydney, New South Wales, Australia, 2015.

[7] Transportation Research Board. 2011. ACRP Synthesis: Common airport pavement maintenance practices. Washington.

[8] U.S. Department of Transportation Federal Aviation Administration. Advisory Circular, 2018.

[9] White G. Sprayed seals for airports. Fulton Hogan Pty Ltd, Australia 2010.

[10] International Civil Aviation Organization. Airport Services Manual. Part 2. Pavement Surface conditions. Fourth Edition, 2002.

[11] Van Zyl,GD and Van der Gryp A. Correlation between Mean Profile Depth Estimated Macro Texture Depth. CAPSA 2015

[12] Louw K and Schoeman S. 2004. Performance of sand seals in the Kruger national Park. Conference on Asphalt Pavements in southern Africa. Sun City, South Africa.

[13] De Wet F. 2010. Development of a small scale bituminous road surfacing concept . Komatiland Forests, Business Innovation 2009/2010.

[14] Uys JR, Van Zyl GD, Kelfkens R, Jenkins K. 2010. Verification of Performance Guarantee System Criteria for High Friction Colour Surfacing through Accelerated Performance Testing. IRF Conference Portugal.

APPENDIX A

SIMPLIFIED DECISION DIAGRAMS FOR INITIAL SEAL TYPE SELECTION

Table D 27 Suitability of Surfacing Types for Initial Surfacing

TRAFFIC VOLUME	SUITABILITY OF SURFACING TYPES FOR INITIAL SURFACING																					
(elv/lane/day)	S3(S<10)	S3(S10+)	S3(D<10)	S3(D10+)	S7(<10)	S7(>10)	S1(7)	S1(10)	S1(14)	S1(20)	S2(10/S)	S2(14/S)	S2(14/5)	S2(14/7)	S4(10)	S4(14)	S4(20)	S2(20/7)	S2(20/7/7)	S2(20/10)	S8(14)	S8(20)	AC
< 750	x	Y	Y	Y	x	Y	x	x	x	x	Y	Y	Y	Y	Y	Y	Y	Y	b	Y	Y	Y	Y
750 - 2000	x	a	x	a	x	Y	x	x	x	x	Y	Y	Y	Y	Y	Y	Y	Y	b	Y	Y	Y	Y
2000 - 5000	x	x	x	x	x	x	x	x	x	x	a	a	Y	Y	a	Y	Y	Y	b	Y	Y	Y	Y
5000 - 10000	x	x	x	x	x	x	x	x	x	x	x	a	a	Y	x	Y	Y	Y	b	Y	Y	Y	Y
10000 - 20000	x	x	x	x	x	x	x	x	x	x	x	x	a	Y	x	a	Y	Y	b	Y	Y	Y	Y
20000 - 40000	x	x	x	x	x	x	x	x	x	x	x	x	x	a	x	x	a	Y	b	Y	Y	Y	Y
> 40000	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	a	a	b	a	Y	Y	Y

***Notes*:**

a — ***Good performance has been noted in several cases. The use of modified binders and trials on site can reduce risks in these situations. Typical problems expected are bleeding and loss of skid resistance.***

b — ***Sensitive to permeability on coarse base textures due to first 7 applied without a binder.***

x — ***Not recommended.***

Table D 28 Suitability of Surfacing Types for Initial Surfacing

GRADIENT	SUITABILITY OF SURFACING TYPES FOR INITIAL SURFACING																						
	S3(S<10)	S3(S10+)	S3(D<10)	S3(D10+)	S7(<10)	S7(>10)	S1(7)	S1(10)	S1(14)	S1(20)	S2(10/S)	S2(14/S)	S2(14/5)	S2(14/7)	S4(10)	S4(14)	S4(20)	S2(20/7)	S2(20/7/7)	S2(20/10)	S8(14)	S8(20)	AC
< 6 %	h	h	h	h	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
6 - 8 %	x	c,d,f,h	c,d,f,h	c,d,f,h	c,f	c,f	d,e,f	d,e,f	d,e,f	d,e,f	e,f	c,e,f	e,f	e,f	f	f	f	e,f	e,f	e,f	Y	Y	Y
8 - 12 %	x	x	x	x	x	x	x	x	x	x	e,f,g	c,e,f,g	e,f,g	e,f,g	f,g	f,g	f,g	e,f,g	e,f,g	e,f,g	Y	Y	Y
12 - 16 %	x	x	x	x	x	x	x	x	x	x	x	c,e,f	c,e,f	c,e,f	c,f	c,f	c,f	c,e,f	c,e,f	c,e,f	Y	Y	Y
> 16 %	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	Y	Y	x

Notes:

c	***Not on stabilized base-courses constructed with fine material.***
d	***Not if channelling of water flow is expected because of soil wash - common in developing areas.***
e	***Not if urban drainage systems (kerbs) are present.***
f	***Not if communal water systems are present, since these result in detergents being washed onto the road with consequent erosion of the bitumen.***
g	***Not on gradients above 10 per cent if channelling of flow is expected because of soil wash - common in developing and hilly areas.***
h	***Not if urban drainage systems (subsurface stormwater systems) are present.***
x	***Not recommended.***

Table D 29 Suitability of Surfacing Types for Initial Surfacing

MAINTENANCE CAPABILITY OF ROAD AUTHORITY	SUITABILITY OF SURFACING TYPES FOR INITIAL SURFACING											
	S3(S<10)	S3(S10+)	S3(D<10)	S3(D10+)	S7(<10)	S7(>10)	S1(7)	S1(10)	S1(14)	S1(20)	S2(10/S)	S2(14/S)
High (Can perform any type of maintenance whenever needed)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Medium (Routine maintenance, patching and crack sealing on regular basis, but no MMS#)*	x	i	Y	Y	x	Y	x	k	k	j,k	j	j
Low (Patching done irregularly, no committed team, no inspection system)	x	i	Y	Y	x	Y	x	x	x	x	x	x
None	x	x	x	x	x	x	x	x	x	x	x	x

MAINTENANCE CAPABILITY OF ROAD AUTHORITY	SUITABILITY OF SURFACING TYPES FOR INITIAL SURFACING (continued)										
	S2(14/5)	S2(14/7)	S4(10)	S4(14)	S4(20)	S2(20/7)	S2(20/7/7)	S2(20/10)	S8(14)	S8(20)	AC
High (Can perform any type of maintenance whenever needed)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Medium (Routine maintenance, patching and crack sealing on regular basis, but no MMS#)*	Y	Y	Y	Y	Y	Y	j	j	Y	Y	Y
Low (Patching done irregularly, no committed team, no inspection system)	k	k	x	Y	Y	k	k	k	Y	Y	Y
None	x	x	x	x	x	x	x	x	x	Y	Y

Notes:

i	***Performance highly dependent on binder application of only one layer.***
j	***Rural areas only.***
k	***The performance of surface seals is sensitive to design and construction problems.***
x	***Not recommended.***

Table D 30 Suitability of Surfacing Types for Initial Surfacing

TURNING ACTIONS	SUITABILITY OF SURFACING TYPES FOR INITIAL SURFACING																						
	S3(S<10)	S3(S10+)	S3(D<10)	S3(D10+)	S7(<10)	S7(>10)	S1(7)	S1(10)	S1(14)	S1(20)	S2(10/S)	S2(14/S)	S2(14/5)	S2(14/7)	S4(10)	S4(14)	S4(20)	S2(20/7)	S2(20/7/7)	S2(20/10)	S8(14)	S8(20)	AC
Rural with occasional heavy vehicles	x	Y	Y	Y	x	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Residential - developed	x	x	Y	Y	x	Y	x	m	m	x	Y	Y	Y	Y	Y	Y	Y	Y	x	x	Y	Y	Y
Residential -developing	x	x	x	x	x	Y	x	x	x	x	x	x	Y	x	x	Y	Y	Y	x	x	Y	Y	Y
Urban with occasional heavy vehicles	x	x	x	x	x	Y	x	x	x	x	x	x	Y	x	x	Y	Y	x	x	x	Y	Y	Y
Urban with many heavy vehicles	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	Y	Y

Notes:

m	***Only if blinded with coarse sand.***
x	***Not recommended.***

Table D 31 Suitability of Surfacing Types for Initial Surfacing

EQUIPMENT, EXPERIENCE & WORK METHOD	SUITABILITY OF SURFACING TYPES FOR INITIAL SURFACING																						
	S3(S<10)	S3(S10+)	S3(D<10)	S3(D10+)	S7(<10)	S7(>10)	S1(7)	S1(10)	S1(14)	S1(20)	S2(10/S)	S2(14/S)	S2(14/5)	S2(14/7)	S4(10)	S4(14)	S4(20)	S2(20/7)	S2(20/7/7)	S2(20/10)	S8(14)	S8(20)	AC
Experienced contractor	x n	x n	Y	Y	x n	x n	x n	x n	x n	x	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	q	q	p
Small or emerging contractor	x n	x n	Y	Y	x n	x n	x n	x n	x n	x	Y	Y	Y	o	Y	Y	Y	Y	x	x	q	q	p
Labour enhanced: Only aggregate by hand/ light equipment	x n	x n	v	v	x n	x n	x n	x n	x n	x	v	v	v	w	v	v	v	Y	x	x			
Labour enhanced: Binder and aggregate by hand/light equipment	x n	x n	w	w	x n	x n	x n	x n	x n	x	w	w	w	w	v	v	v	o	x	x	qv	qv	p

Notes:

n	***Too high risk for one binder application.***
o	***Only if binder application is well controlled.***
p	***Suitable cold asphalt mixes.***
q	***Reserved for labour enhanced work.***
v	***Only for very low volume roads - risk level "Low".***
w	***Only for very low volume roads - risk level "Medium - High".***
x	***Not recommended.***

Table D 32 Suitability of Surfacing Types for Initial Surfacing

Minimum Macro texture required (mm)	SUITABILITY OF SURFACING TYPES FOR INITIAL SURFACING																						
	S3(S<10)	S3(S10+)	S3(D<10)	S3(D10+)	S7(<10)	S7(>10)	S1(7)	S1(10)	S1(14)	S1(20)	S2(10/S)	S2(14/S)	S2(14/5)	S2(14/7)	S4(10)	S4(14)	S4(20)	S2(20/7)	S2(20/7/7)	S2(20/10)	S8(14)	S8(20)	AC
<0,7	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	u
0,7 - 1,0	x	r	x	r	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	t	Y	Y	Y	Y	Y	Y	Y	u
1,0 - 1,5	x	x	x	x	s	Y	Y	Y	Y	Y	Y	Y	Y	Y	t	t	t	Y	Y	Y	t	t	u
1,5 - 2,0	x	x	x	x	x	x	x	Y	Y	Y	x	Y	Y	Y	x	t	t	Y	Y	Y	t	t	u
>2,0	x	x	x	x	x	x	x	x	Y	Y	x	x	x	x	x	t	t	x	x	Y	t	t	u

Notes:

r	***Dependent on aggregate grading.***
s	***Not if fine-fine grading.***
t	***Dependent on slurry thickness application.***
u	***Suitable asphalt mixes.***
x	***Not recommended.***

Table D 33 Example of Combined Requirements and Suitability

Selected situation		SUITABILITY OF SURFACING TYPES FOR INITIAL SURFACING																						
		S3(S<10)	S3(S10+)	S3(D<10)	S3(D10+)	S7(<10)	S7(>10)	S1(7)	S1(10)	S1(14)	S1(20)	S2(10/S)	S2(14/S)	S2(14/5)	S2(14/7)	S4(10)	S4(14)	S4(20)	S2(20/7)	S2(20/7/7)	S2(20/10)	S8(14)	S8(20)	AC
Traffic Volume (elv)	5000 - 10000	x	x	x	x	x	x	x	x	x	x	x	a	a	Y	x	Y	Y	Y	b	Y	Y	Y	Y
Gradient	6 - 8 %	x	c,d,f,h	c,d,f,h	c,d,f,h	c,f	c,f	d,e,f	d,e,f	d,e,f	d,e,f	e,f	c,e,f	e,f	e,f	f	f	f	e,f	e,f	e,f	Y	Y	Y
Turning actions	Rural with occasional heavy vehicles	x	Y	Y	Y	x	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Maintenance capability	Medium	x	i	Y	Y	x	Y	x	k	k	j,k	j	j	Y	Y	Y	Y	Y	Y	j	j	Y	Y	Y
Experience & work method	Small or emerging contractor	x n	x n	Y	Y	x n	x n	x n	x n	x n	x	Y	Y	Y	o	Y	Y	Y	Y	x	x	q	q	p
Macro texture required	1,0 - 1,5	x	x	x	x	s	Y	Y	Y	Y	Y	Y	Y	Y	Y	t	t	t	Y	Y	Y	t	t	u

APPENDIX B

SIMPLIFIED DECISION DIAGRAMS FOR

RESEAL TYPE SELECTION (1ST LEVEL DECISIONS)

Rutting	Texture	Reference
	Varying coarse to fine	Figure D 29
< 10mm	Medium or coarse	Figure D 30
	Medium-Fine to Fine	Figure D 31
> 10mm		Figure D 32

Figure D 28 Reference to 1st Level Selection Diagrams

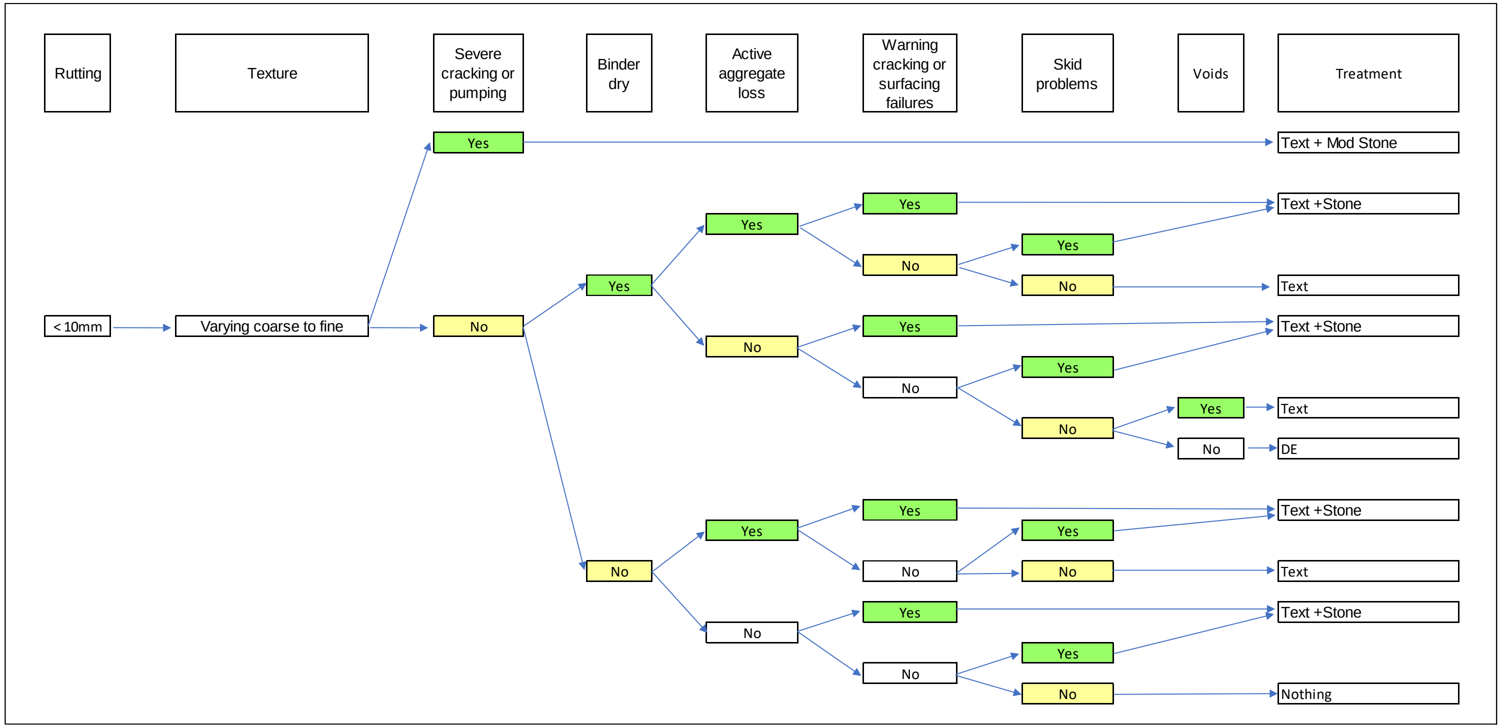


Figure D 29 Varying Coarse-to-Fine Existing Macro Texture

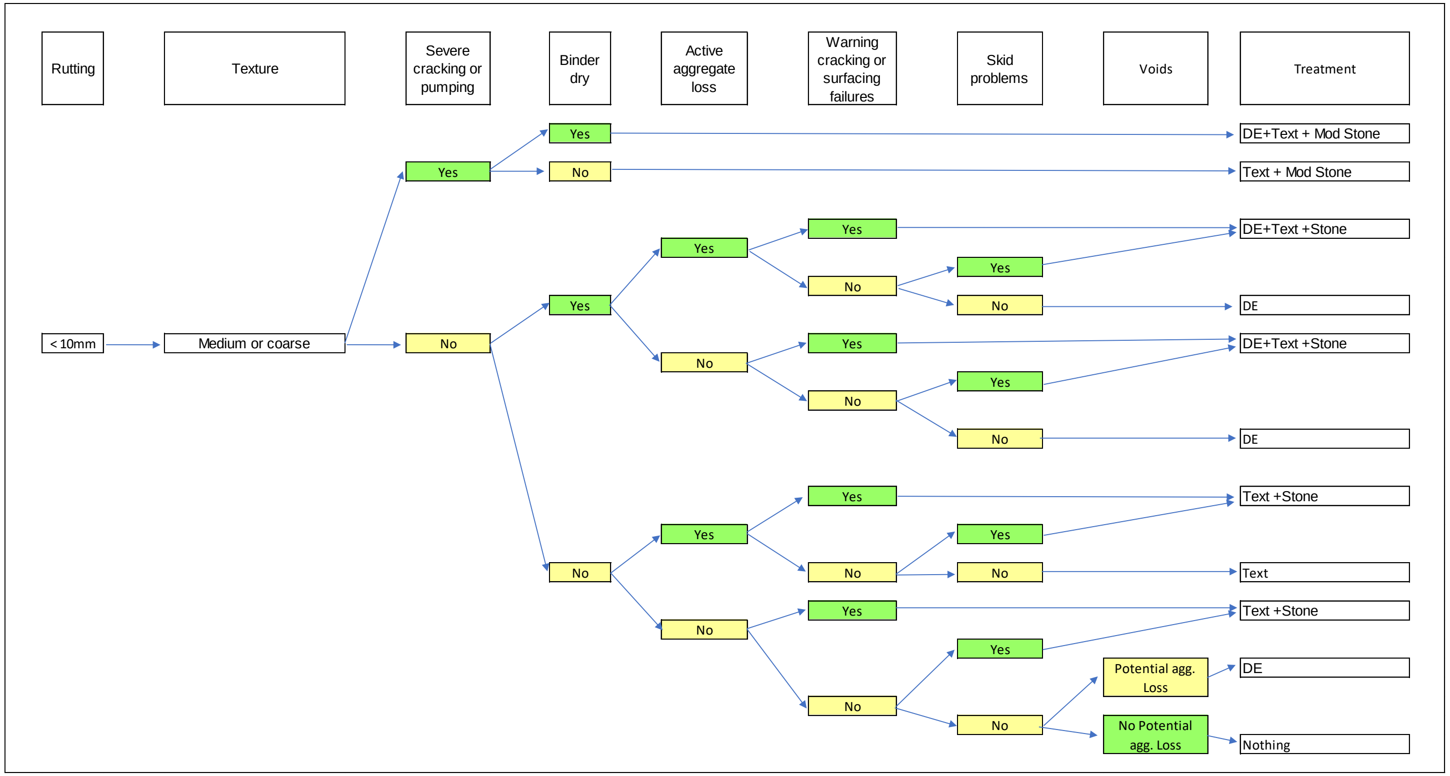


Figure D 30 Medium-to-Coarse Existing Macro Texture

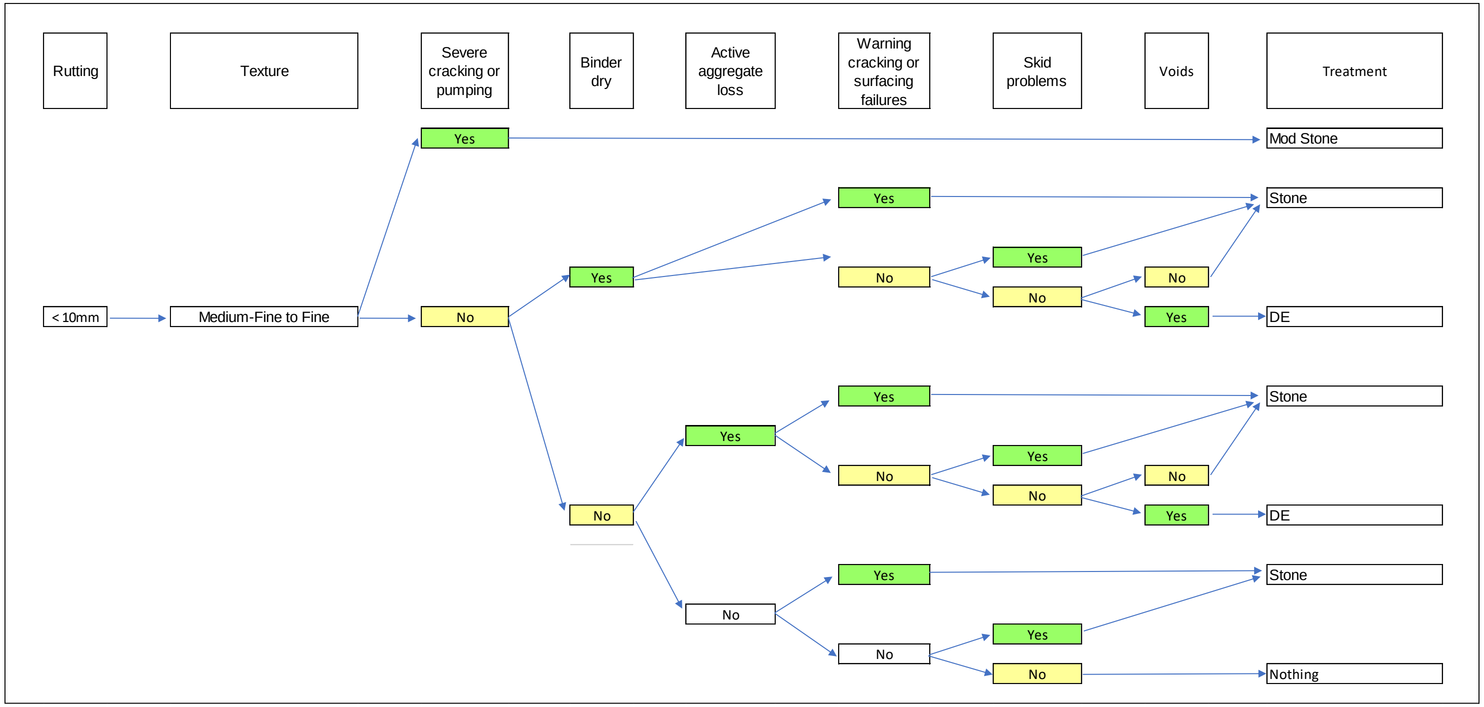


Figure D 31 Medium-Fine to Fine Existing Macro Texture

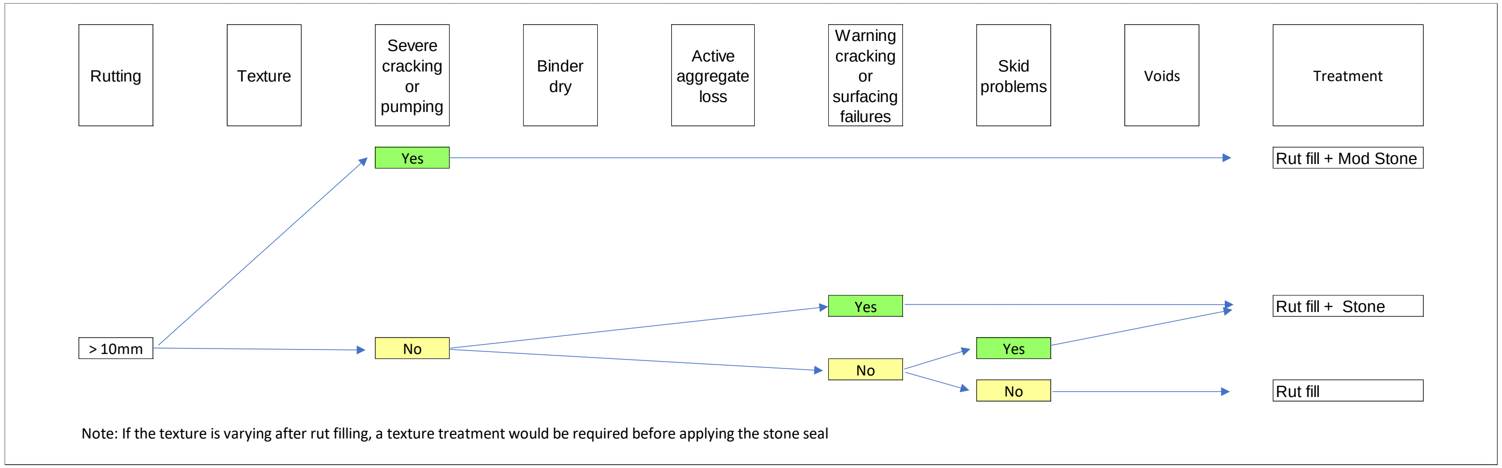


Figure D 32 Rut Depth more than 10 mm

APPENDIX C

SIMPLIFIED DECISION DIAGRAMS FOR

RESEAL TYPE SELECTION (2ND LEVEL)

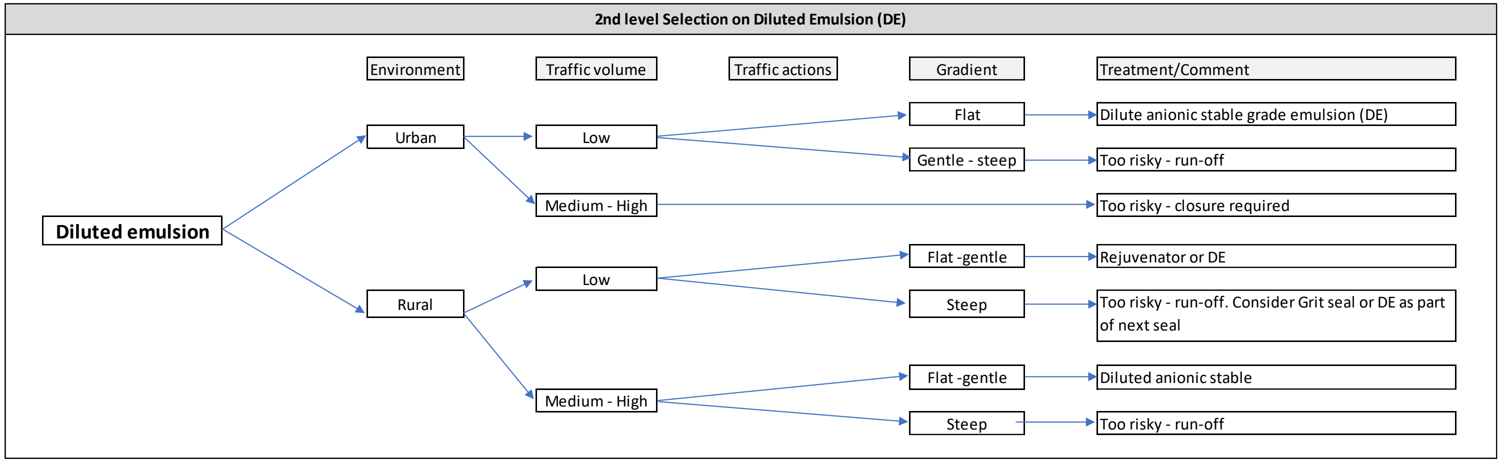


Figure D 33 2nd Level Treatment Alternatives under "Diluted Emulsion"

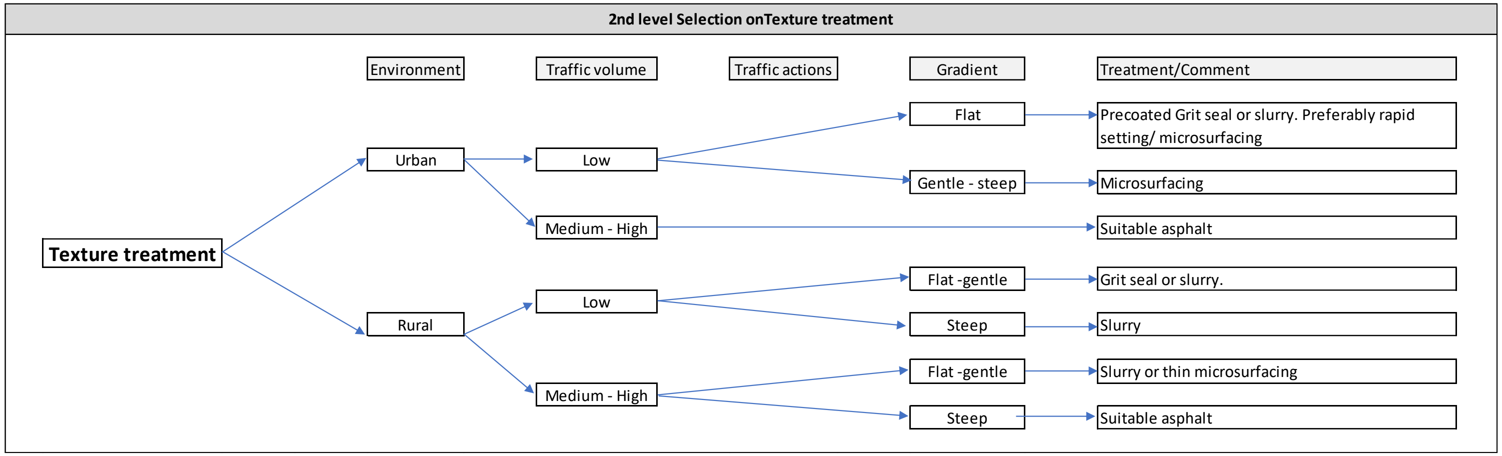


Figure D 34 2nd Level Treatment Alternatives under "Texture Treatment"

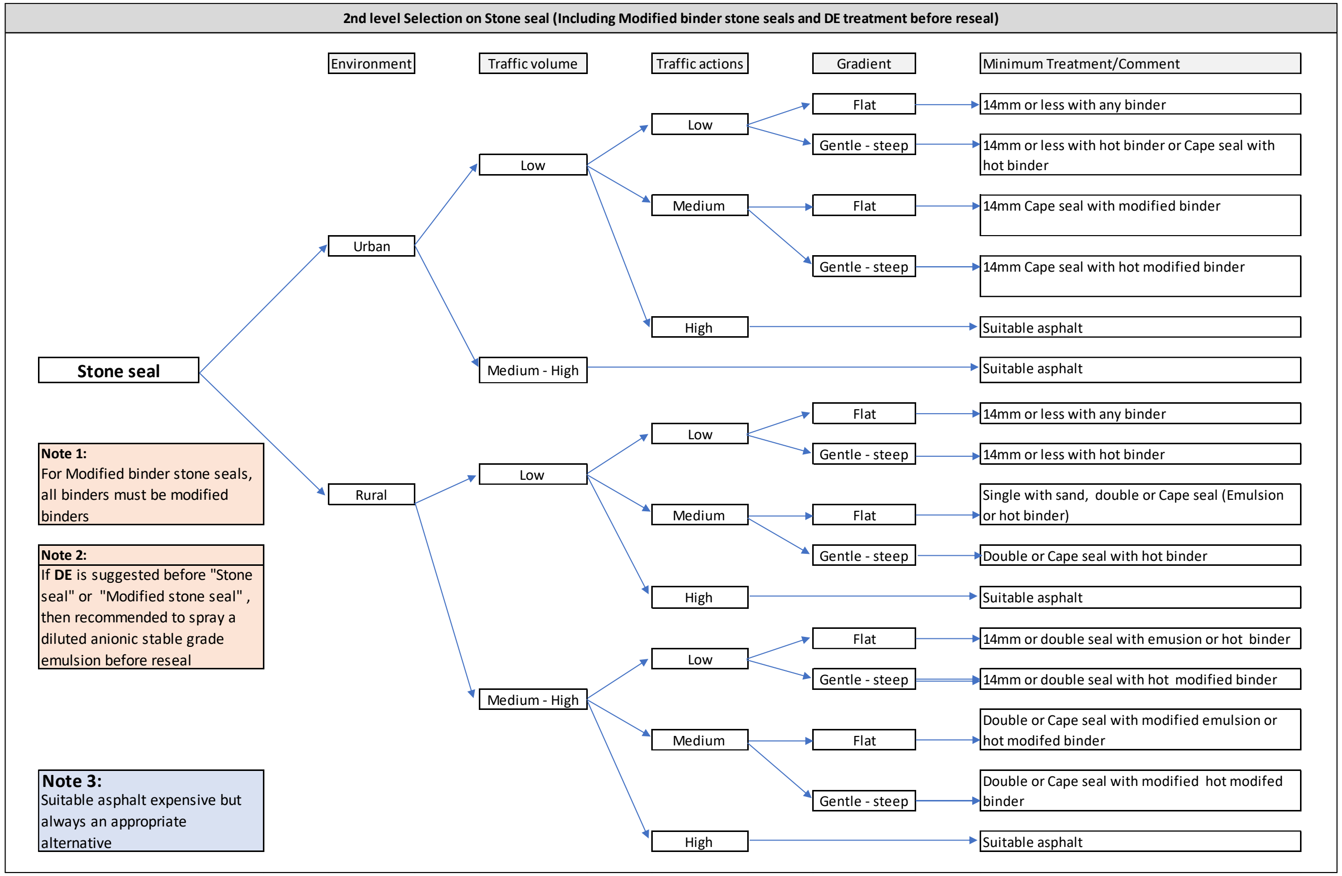


Figure D 35 2nd Level Treatment Alternatives under "Stone Seal"

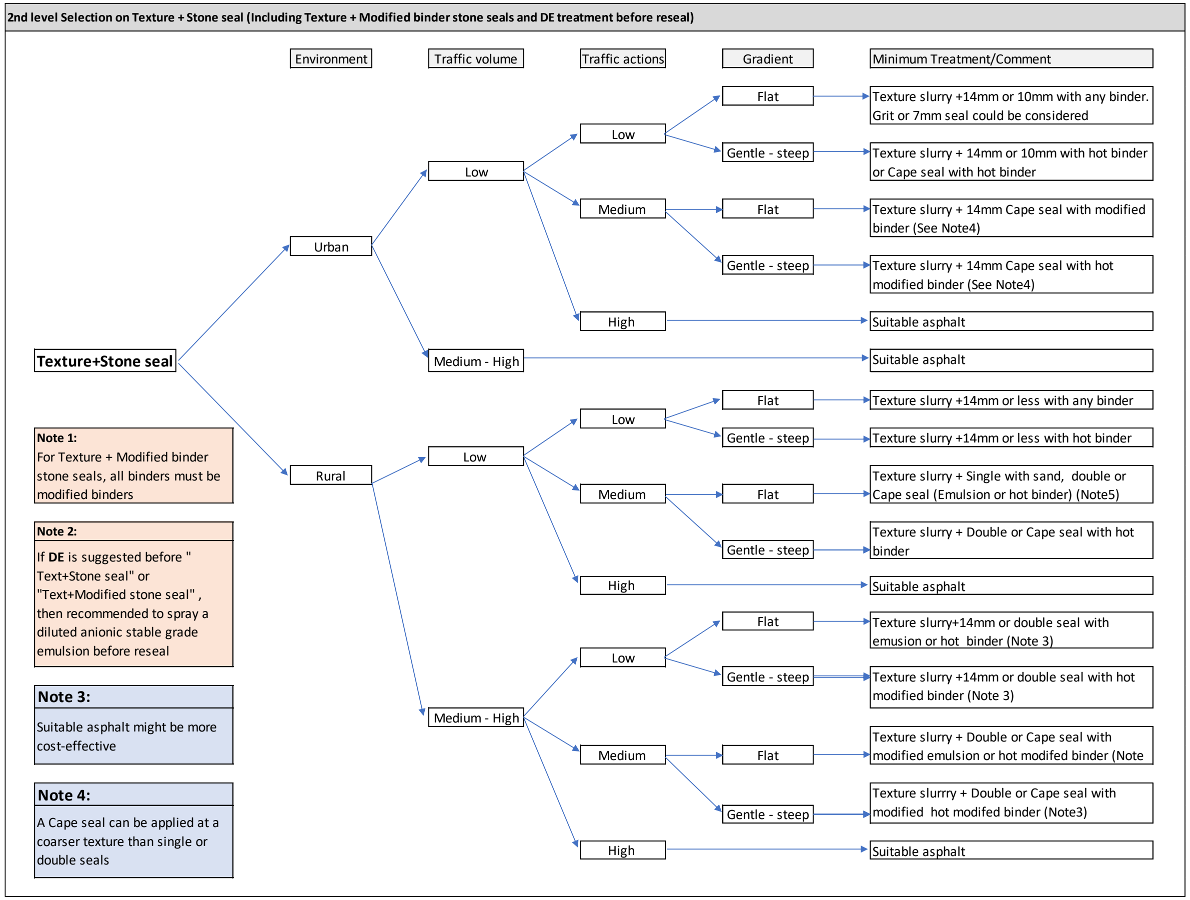


Figure D 36 2nd Level Treatment Alternatives under "Texture + Stone Seal"

APPENDIX D

RELATIVE SEAL COST COMPARISON

Seal Code	Description	Binder	Cost ratio
S3 (S <10)	Graded aggregate seals - Single application (<10mm)	MC3000	0.69
		Cat 65%	0.73
S3 (S 10+)	Graded aggregate seals - Single application (10mm or more) (10mm)	MC3000	1.16
S3 (D <10)	Graded aggregate seals - Double application (<10mm per layer)	MC3000	1.40
S3 (D 10+)	Graded aggregate seals - Double application (10+mm per layer or first layer covered with sand seal)	MC3000	1.80
	Double Otta seal	MC3000	2.00
S7 (<10mm)	Thin Microsurfacing or Slurry seal (3 mm texture slurry)		0.87
	Thin Microsurfacing or Slurry seal (6 mm coarse slurry)		1.32
S7 (>10mm)	Thick Microsurfacing or Coarse slurry seal (10 mm microsurfacing)		2.10
S1 (7)	Single seal with 7 mm aggregate	70/100	0.60
		Cat 65%	0.87
S1(10)	Single seal with 10 mm aggregate	70/100	0.92
		Cat 65%	1.08
		S-E1	1.01
S1(14)	Single seal with 14 mm aggregate	70/100	1.00
		Cat 65%	1.11
		S-E1	1.25
		S-R1	1.49
S1(20)	Single seal with 20 mm aggregate (16 mm)	S-R1	
S2(10/S)	Double seal with 10 mm aggregate and sand	Cat 65%	1.24
		SC-E1	1.41
S2(14/S)	Double seal with 14 mm aggregate and sand	Cat 65%	1.52
		SC-E1	1.61
S4(10)	Cape Seal with 10 mm aggregate and one layer of slurry	SC-E1 (t)	
S4(14)	Cape Seal with 14 mm aggregate and one layer of slurry	Cat 65% (t)	1.65
		SC-E1 (t)	
S4(20)	Cape Seal with 20 mm aggregate and two layers of slurry	Cat 65%(t)	2.21
		S-E1	
S2(14/7)	Double seal with 14 mm aggregate and a layer of 7 mm aggregate	70/100	1.43
		S-E1	1.82
S2(14/5)	Double seal with 14 mm aggregate and a layer of 5 mm aggregate	70/100	
S2(20/10)		70/100	1.60

	Double seal with 20 mm aggregate and a layer of 10 mm aggregate	S-E1	
		S-R1	2.30
S2(20/7)	Double seal with 20 mm aggregate and a layer of 7 mm aggregate	S-E1	
S2(20/7/7)	Double seal with 20 mm aggregate and two layers of 7 mm aggregate	S-E1	2.10
S8(14)	Slurry-bound Macadam seal with 14 mm aggregate (20 - 25 mm)	60% Anionic	2.55
S8(20)	Slurry-bound Macadam seal with 20 mm aggregate (30 -40 mm)	60% Anionic	3.20
AC	Asphalt layer with suitable grading and thickness (Continuous 15mm)		2.55
	Asphalt layer with suitable grading and thickness (Continuous 30mm)		3.32
	Asphalt layer with suitable grading and thickness (Continuous 40mm)		3.90

APPENDIX E

REPORTED EFFECTIVE SEAL LIVES

Table D 34 Reported Expected Seal Lives

LIFE EXPECTANCY OF BITUMINOUS SEALS (Years)				
Seal type	Traffic ** (elv/lane)	New construction seals	Reseal on sound structure	Reseal on structure with fatigue/active cracks
Single 7 mm plus sand	<2000	6	6	4
	2000 -10000	3	3	2
	>10000			
Single 10 mm plus sand	<2000	8	8	5
	2000 -10000	6	6	3
	>10000	3	3	
Single 14 mm plus sand	<2000	12	12	7
	2000 -10000	9	9	4
	>10000	6	6	2
Double 14 + 7 mm	<2000	14		
	2000 -10000	10		
	>10000	8		
20mm Cape Seal	<2000	14		
	2000 -10000	10		
	>10000	8		
14 mm Cape Seal	<2000	12		
	2000 -10000	8		
	>10000	5		
Sand seal	<2000	4	7	3
	2000 -10000	2	3	2
	>10000			
Fine slurry	<2000	4	4	2
	2000 -10000	2	2	1
	>10000			
Coarse slurry	<2000	7	7	4
	2000 -10000	4	4	2
	>10000	2	2	
Single 7 mm	<2000		6	4
	2000 -10000		4	2
	>10000			
Single 10 mm	<2000		10	6
	2000-10000		6	3
	>10000			
Single 14 mm	<2000		12	7
	2000 -10000		9	4
	>10000		6	2
Single 14 mm Polymer modified	<2000		14	8
	2000 -10000		10	6
	>10000		8	3
14 mm Bitumen rubber	<2000		16	10
	2000 -10000		13	7
	>10000		10	5

Source (Provincial road authorities' opinion survey 1994 for TRH3)

PART E

DESIGN

CONTENTS

LIST OF TABLES

LIST OF FIGURES

E.1 INTRODUCTION

E.1.1 CONTEXT

Manual 40 comprises eight parts:

- Part A: General
- Part B: Materials
- Part C: Performance
- Part D: Seal type and binder selection
- **Part E: Design (This document)**
- Part F: Construction
- Part G: Quality Assurance
- Part H: Repair of premature failures

E.1.2 OBJECTIVES

In this PART the purpose is to guide the reader with the design of typical seals used in South Africa.

E.1.3 SCOPE

Important aspects relating to the design of different seal types are addressed under the following headings:

E.2 PRIME COATES

E.3 UNIFORM DESIGN SECTIONS

E.4 SINGLE AND DOUBLE SEALS

E.5 CAPE SEALS (SINGLE SEAL PLUS SLURRY)

E.6 SLURRY SEALS

E.7 MICROSURFACINGS

E.8 INVERTED DOUBLE SEALS

E.9 CHOKED SEALS (RACKED-IN SEALS)

E.10 GEOTEXTILE SEALS

E.11 GRADED AGGREGATE SEALS

E.12 STRESS-ABSORBING MEMBRANE INTERLAYER (SAMI)

E.13 SEALING DURING WINTER (EMBARGO PERIODS)

E.14 DESIGNING FOR VERY LOW AND VERY HIGHT TRAFFIC VOLUMES

E.2 PRIME COATS

Recommendations for prime coats and bond coats are discussed in detail in the companion document SABITA Manual 26 and are summarized below:

- Prime coats are not essential but reduce the risk of failures resulting from small imperfections in the upper part of the base. In addition, they:
  - promote adhesion between the base and the surfacing;
  - help to seal the surface pores in the base;
  - help to strengthen the surface of the base by binding the finer particles, and
  - provide the base with a temporary protection against the effects of weather and traffic.

- The main aspects to be taken into consideration in the selection of the type and grade of prime are the weather conditions, the absorptive characteristics of the base and whether or not the base is chemically stabilized.
- The use of quick-drying primes should be limited to special circumstances, such as when the road has to be surfaced as soon as possible, when cold, wet conditions occur, or when the base is very dense.
- Suitable spray rates vary between 0,65 and 1,2 ℓ/m^2, dependent on the properties of the prime and the bases.
- Priming should not be carried out when the surface temperature is below 10 °C, in strong wind or when rain threatens.
- Priming should be done when the base has dried to less than 50 per cent of optimum moisture content.
- If traffic has to be accommodated on the road before the prime has dried out, the surface should be covered with a blinding layer of small aggregate (5 mm or 7 mm nominal single size without dust).– not single sized fine sand.

Commonly used primes are:

- Inverted bitumen emulsion prime
- MC 30
- MC10

***Notes*:**

- ***Several suppliers manufacture their own proprietary branded primes, some with excellent performance.***
- ***COTO (2020) [6] allows for testing of different products after base construction and the selection of the most appropriate product according to guidelines in SABITA Manual 26.***
- ***Prime coats are permeable and might be omitted, in case of possible salt migration, to allow quick application of the seal (Refer PART C).***
- ***Any product containing coal tar is not allowed in South Africa.***

E.3 UNIFORM DESIGN SECTIONS

A road requiring a bituminous seal or a reseal, as part of periodic maintenance, is seldom uniform in terms of factors influencing the seal design and performance. Therefore, it is considered essential for project management, quality assurance and seal design purposes to identify Uniform Design Sections (UDS).

Any situation requiring a different seal type, design or construction closures should be considered a UDS with a separate design being carried out.

As further discussed in PART G, a layout as shown in Figure E 1 below is valuable to highlight different conditions along the road requiring different designs and to manage the process of design and construction.

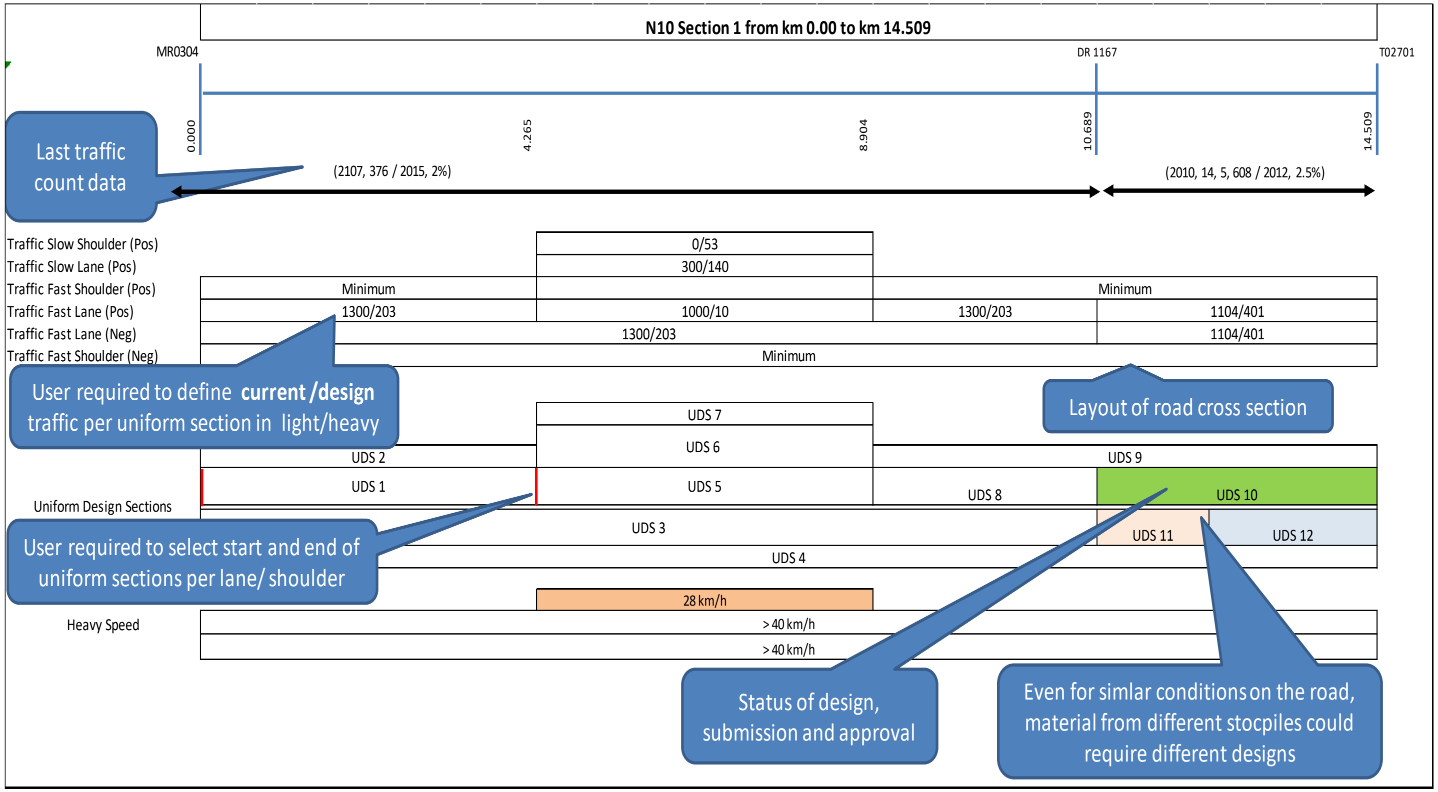


Figure E 1 Project Layout Plan

E.4 SINGLE AND DOUBLE SEALS

E.4.1 BASIC DESIGN PRINCIPLES FOR SINGLE AND DOUBLE SEALS

Most of the seal design methods used in South Africa evolved from a concept of partially filling the voids in the covering aggregate and that the volume of these voids was controlled by the Average Least Dimension (ALD) of the sealing chips. Through formal and informal experiments and experience, different institutions have refined their design methods over a period of 50 years to provide guidance to designers in the design of seals within their areas of jurisdiction [1].

For various reasons, the recommended application rates for similar situations, are different. Several logical reasons were found for these differences. The main reasons are:

- Most design methods recommend only one application rate for a given situation, whereas theory and practice indicate that a range of application rates could be considered.
- Perceptions of the ideal aggregate matrix differ. The more open the aggregate matrix, the more binder can be accommodated (in case of low flakiness aggregate).
- Perceptions of the ideal texture depth differ, which may be related to the maintenance strategy of the authority, the risk of bleeding and poor skid resistance.
- Climatic differences.
- Different sources of binders.
- Variations in stone sources in terms of geological origin.

Adjustments have been made to the original rational design method [1], changing the basic assumptions, to ensure that each Provincial Roads Authority's and the Department of Transport's recommendations would be similar to the calculated application rates using this manual.

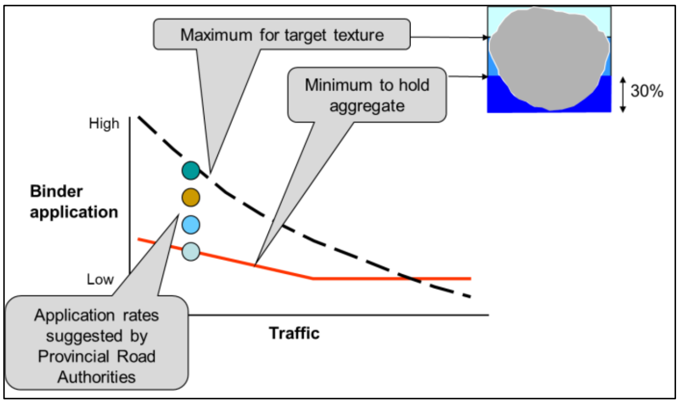


Figure E 2 Adjustment of Assumptions to Fit Provincial Road Authorities' Application Rates

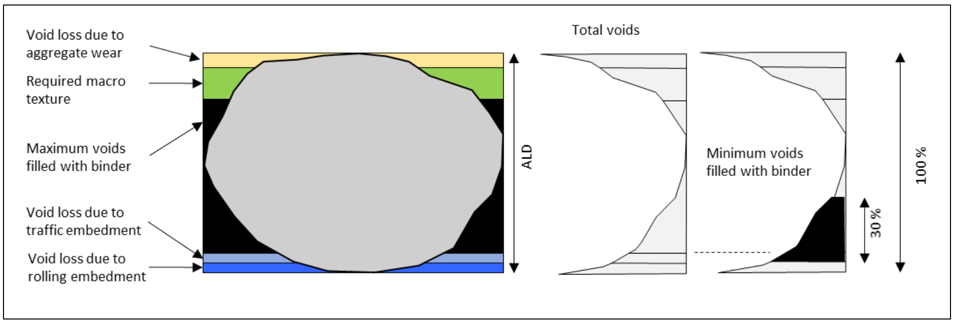


Figure E 3 Principles applied for Design of the Binder Application Rate

- The minimum amount of voids to be filled with binder to prevent stone loss when there is no embedment, is 42 per cent for single seals and 55 per cent for double seals.

(Wetting 30 per cent of the aggregate height in a single seal, as shown in Figure E , requires approximately 42 per cent of the voids to be filled.)

- The amount of void loss due to traffic wear is dependent on the hardness of the stone and defined by the following equation with a maximum ELV = 5000.

$$Where\ (mm) = -0.0011\ x\ (Hardness) + 0.2533\ x\ ELV^{0.1747}$$

Where

Hardness is the Dry 10% FACT value in kN

The impact of void loss over a ten-year period due to wear on the aggregate complying with the 10% FACT specification requirements for various traffic category ranges (refer Table E 1), is relatively small when compared to the impact of other variables.

A soft aggregate (10% FACT=130) on a low trafficked road (1 000 ELVs) will wear approximately 0.7 mm in a ten-year period, while a hard aggregate (10% FACT=210), carrying high traffic (20 000 ELVs), will wear approximately 0.9 mm.

Table E 1 Recommended Hardness Specifications (COTO 2019)

Traffic (AADT)	**Less than 300**	**300 - 3000**	**More than 3000**
Approximate ELVs	< 1500	1500 - 15000	> 15000
Relevant Aggregate Grade	C	B	A
Dry 10 % FACT [kN] (min)	130	180	210

- The required texture depth to provide adequate skid resistance is related to the risk of accidents during wet weather (An increase in texture depth (macro texture of the seal) reduces the risk of aquaplaning and

associated accidents)
- The degree of embedment during construction may vary, but for simple design purposes, it is taken as 50 per cent of the final expected embedment
- The total embedment potential is determined from ball-penetration tests (SANS 3001-BT10).
- The effective layer thickness (ELT) of a single seal is a function of the Average Least Dimension (ALD). If the aggregate is allowed to orientate to its ALD being perpendicular to the road surface, the ELT could be calculated as follows [1]:

$$ELT = 0{,}85679 \times ALD + 0{,}46715 \text{ mm.}$$

The effective layer thickness of a double seal is a function of the sum of the ALDs of the two aggregates.

$$(ELTd) = 0{,}86028 \times (ELT1 + ELT2) + 0{,}19188 \text{ mm.}$$

(The ELT and percentage voids for any aggregate/binder combination may be determined by the modified tray test). (See Appendix A).

- The percentage void content in the aggregate layer is a function of the ELT.
  Estimated void content for a single seal (%) = 45,3333 - 0,333 x ELT.
  Estimated void content for a double seal (%) = 63,01263 + 0,04743 x ELTd2 - 2,41172 x ELTd.

E.4.2 DESIGN PROCESS FOR SINGLE AND DOUBLE SEALS

This section describes the procedure for the design of single- and double seals according to Figure E 4.

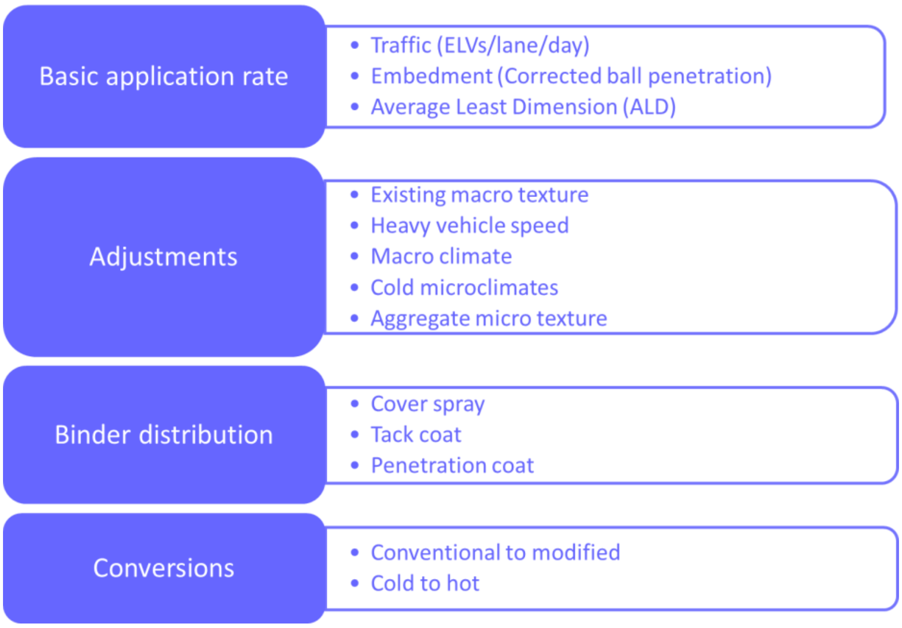


Figure E 4 Design Process (Binder application rate)

E.4.2.1 Basic Application Rate

E.4.2.1.1 Calculation

The minimum and maximum basic application rates for single and double seals could be calculated using the equations provided in Table E 2 and Table E 3.

Table E 2 Design Calculations for a Single Seal (Nominal size 10mm or more)

Single seal design		
Input parameters	**Example**	
Corrected Ball penetration (CBP) in mm	2	If CBP <1.0, then 1.0
Equivalent Light Vehicles per lane per day (ELV)	4000	Design for minimum ELVs of 2000
Average Least Dimention of aggregate (ALD)	8.2	
Macro texture requirement	0.7	
Aggregate hardness - 10%Fact (kN)	210	
Calculations		
Equivalent layer thickness (ELT) = 0,85679 x ALD + 0,46715 (mm)	7.49	
Embedment =((0.1816*LN(CBP)+0.4184)*LN(ELV))-(0.8365*LN(CBP)+2.9284) - Note: Design for Minimum ELV=2000	1.01	
Embedment as fraction of ELT = (Embedment/ELT)	0.13	
Fractional void loss due to embedment =3.0556*(Embedment/ELT)^3-4.5833*(Embedment/ELT)^2+2.5263*(Embedment/ELT)+0.0002	0.26	
Maximum ELV for wear calculation = 5000	4000	
Wear (mm) =-0.0011x(10%FACT)+0.2533x(ELV)^0.1747	0.85	
Wear as fraction of ELT = (Wear/ELT)	0.11	
Fractional void loss due to wear =3.0556*(Wear/ELT)^3-4.5833*(Wear/ELT)^2+2.5263*(Wear/ELT)+0.0002	0.23	
Estimated void content for a single seal (%) = 45,3333 - 0,333 x ELT.	42.84	
Fractional Void loss for macro texture = Macro texture requirement/(Estimated void content%*ELT)	0.22	
Total fractional void loss =Fractional void loss due to (Embedment + Wear + Macro texture requirement)	0.71	
Available void fraction to be filled with binder = (1 - total fractional void loss)	0.29	
% Rolling embedment of total embedment (Assumed 50%)	50%	
Rolling Embed (50% * Total embedment) in mm	0.50	
Rolling Embed as fraction of ELT = (Rolling embedment/ELT)	0.07	
Fractional void loss due to rolling =3.0556*(Rolling embedment/ELT)^3-4.5833*(Rolling embedment/ELT)^2+2.5263*(Rolling embedment/ELT)+0.0002	0.15	
The minimum amount of voids to be filled with binder to prevent stone loss when there is no embedment, is 42 per cent for single seals	42%	
Filled void fraction to hold stone = Min void fraction to be filled with binder - Fractional void loss due to Rolling Embedment	0.27	**Warning 1**
		If the filled void fraction to hold the stone is more than the available void fraction, then the target texture cannot be achieved at end of design period
NCCBmin = (Min void fraction to be filled with binder - Fractional void loss due to Rolling Embedment)*(Estimated void content for a single seal (%) *(ELT)	**0.87**	**Warning 2**
Practical Construction Minimum	**0.72**	Practical minimum NCCB = Maximum of 0.6 and (0.7226ln(ALD) - 0.7976) l/m². If NCCBmin is less than the practical minimum, then a larger stone should be selected, or the practical minimum applied with the risk of too low macro texture
NCCBmax = Estimated void content * Available void fraction to be filled with binder * ELT	**0.92**	**Warning 3**
		If the calculated NCCBmax < NCCBmin, then the target texture will not be achieved for the design period of ten years
Selected practical maximum NCCBmax = 0.1458*ALD+0.1444	**1.34**	**Warning 4**
		If the calculated NCCBmax > selected practical NCCBmax, then select the practical maximum

Commented [GvZ1]: Note this is a corrected table

E.4.2.1.2 Design of 7 mm single seals

The principle of filling the voids in a single layer of aggregate does not apply to 7mm aggregate or smaller. The recommended basic application rate as calculated as follows:

$$NCCB = 0.52\ x\ ALD - 1.17$$

<u>Note</u>: No adjustments should be made for the existing macro texture or for embedment potential

The aggregate is slightly over applied at a spread rate of 180 – 200 m²/m³.

Table E 3 Design Calculations for a Double Seal

Double seal design		
Input parameters	**Example**	
Corrected Ball penetration (CBP) in mm	1	If CBP <1.0, then 1.0
Equivalent Light Vehicles per lane per day (ELV)	5100	Design for minimum ELVs of 2000
Average Least Dimention of 1st aggregate (ALD1)	8.5	
Average Least Dimention of 2ndt aggregate (ALD2)	4	
Macro texture requirement	0.7	
Aggregate hardness (top layer) - 10%Fact (kN)	210	
Calculations		
Equivalent layer thickness (ELT1) = 0,85679 x ALD1 + 0,46715 (mm)	7.75	
Equivalent layer thickness (ELT2) = 0,85679 x ALD2 + 0,46715 (mm)	3.89	Note: In case of the 1 1/2 stone configuration use ALD2/2
Equivalent design layer thickness (ELTd) = 0,86028 x (ELT1 + ELT2) + 0,19188 mm	10.21	
Embedment =((0.1816*LN(CBP)+0.4184)*LN(ELV))-(0.8365*LN(CBP)+2.9284) - Note: Design for Minimum ELV=2000	0.64	
Embedment as fraction of ELT = (Embedment/ELT)	0.06	
Fractional void loss due to embedment =3.0556*(Embedment/ELT)^3-4.5833*(Embedment/ELT)^2+2.5263*(Embedment/ELT)+0.0002	0.14	
Maximum ELV for wear calculation = 5000	5000	
Wear (mm) =-0.0011x(10%FACT)+0.2533x(ELV)^0.1747	0.89	
Wear as fraction of ELT = (Wear/ELT)	0.09	
Fractional void loss due to wear =3.0556*(Wear/ELT)^3-4.5833*(Wear/ELT)^2+2.5263*(Wear/ELT)+0.0002	0.19	
Estimated void content for a double seal (%) = 63,01263 + 0,04743 x ELT_d^2 - 2,41172 x ELT_d.	43.33	
Fractional Void loss for macro texture = Macro texture requirement/(Estimated void content%*ELT)	0.158	
Total fractionl void loss =Fractional void loss due to (Embedment + Wear + Macro texture requirement)	0.49	
Available void fraction to be filled with binder = (1 - total fractional void loss)	0.51	
% Rolling embedment of total embedment (Assumed 50%)	50%	
Rolling Embed (50% * Total embedment) in mm	0.32	
Rolling Embed as fraction of ELT = (Rolling embedment/ELT)	0.03	
Fractional void loss due to rolling =3.0556*(Rolling embedment/ELT)^3-4.5833*(Rolling embedment/ELT)^2+2.5263*(Rolling embedment/ELT)+0.0002	0.08	
The minimum amount of voids to be filled with binder to prevent stone loss when there is no embedment, is 42 per cent for single seals and 55 per cent for double seals	0.55	
Filled void fraction to hold stone = Min void fraction to be filled with binder - Fractional void loss due to Rolling Embedment	0.47	**Warning 1**
		If the filled void fraction to hold the stone is more than the available void fraction, then the target texture cannot be achieved at end of design period
NCCBmin = (Min void fraction to be filled with binder - Fractional void loss due to Rolling Embedment)*(Estimated void content for a single seal (%) *(ELT)	**2.10**	**Warning 2**
Practical Construction Minimum for double seal	**1.33**	Practical minimum NCCB for double seal = maximum of 1.2 and (0.9539ln(ALD1+ALD2) - 1.0792) l/m^2. If NCCBmin is less, then a larger stone should be selected, or the practical minimum applied with the risk of too low macro texture
NCCBmax = Estimated void content * Available void fraction to be filled with binder * ELT	**2.27**	**Warning 3**
		If the calculated NCCBmax < NCCBmin, then the target texture will not be achieved for the design period of ten years
Selected practical maximum NCCBmax = 0.5248*ALD^0.606	**2.43**	**Warning 4**
		If the calculated NCCBmax > selected practical NCCBmax, then select the practical maximum

Commented [GvZ2]: Note this is the corrected table

Commented [GvZ3]:

E.4.2.1.3 Average Least Dimension (ALD) of the Aggregate

ALD determination

Two methods could be used to determine the ALD of an aggregate sample and are summarised as follows:

- SANS 3001 (AG2) – **Recommended**
  Average least dimension of aggregates by direct measurement.

- SANS 3001 (AG3) – **Not recommended**
  Average least dimension of aggregates by computation.

Notes:

- ***SANS 3001 (AG3) was developed as an improvement to international practice, using the median size of the aggregate between the larger and smaller sieve sizes, relevant to the nominal size. However, the calculated ALD becomes less accurate with cubical shaped aggregate.***
- ***At least five samples should be taken and tested.***
- ***Aggregate samples should be taken on site and not from stockpiles at the crusher.***

Design ALD for single seals

The philosophy is to rather have some fattiness with time than aggregate loss tonight. Therefore, since higher ALD implies higher binder contents, it is recommended that the upper 80% percentile of the five or more samples be used as the design ALD.

Design ALD for double seals

The design ALD of the double seal is dependent on the structure selected e.g. "full double", the "1 ½" or the split seal configuration (Refer PART A for definition).

The design ALDs are calculated as follows:

- Design ALD (1 ½ configuration) = ALD of first layer + ½ ALD of the second layer
- Design ALD (full double seal) = ALD of first layer + ALD of the second layer.
- Design ALD (Split application double seal) = ALD of first layer + ALD of the top/final layer

E.4.2.1.4 Equivalent light vehicles (ELV)

The traffic parameter used in this manual is Equivalent Light Vehicles per lane per day (ELV),

Where:

Total ELV/lane/day = Number of light vehicles + (Number of heavy vehicles x 40) per lane, per day.

The most probable traffic scenario for each unique section per lane **directly after construction** of the seal, should be estimated, taking cognisance of:

- Recent traffic counts.
- Construction traffic.
- Attracted traffic.
- Seasonal variations e.g. due to harvesting periods.
- Channelization (lane width). Traffic wander is a function of the lane width, surfaced shoulder width,

gradient as well as the traffic volume, speed and vehicle type distribution. **Based on the evaluation of current best practice, it is recommended that the design traffic volume is increased with 20% for two-lane roads (gravel shoulders), carrying more than 5000 ELVs and with lane widths of 3.5m or less**.

Note:

Current research is focussed on relating traffic induced vertical and horizontal stresses to embedment and aggregate orientation, which will replace the existing concept and calculation of ELVs

E.4.2.1.5 Potential embedment

Potential embedment of seal aggregate is one of the main input parameters in the seal design and estimated using the ball penetration test (SANS 3001-BT10).

High potential embedment results in less binder being required.

A minimum of ten tests within and out of the wheel tracks should be done per uniform road section.

The test requires:

- Road surface temperature measurement (minimum 25°C if sealing on temperature susceptible surfaces).
- Recording of the existing substrate type and binder dryness condition (with photograph).
- A zero reading after placement of the 20 mm ball.
- First blow with the Marshall hammer and first penetration reading (with photograph).
- Second blow with the Marshall hammer and second penetration reading (with photograph).
- Selection of applicable/representative penetration value.

In this regard the following recommendations [2] are made:

- When a "half-moon" indent is created in the existing surface by the 20 mm ball after one blow of the Marshall hammer, without any significant displacement or crushing, it could be assumed that embedment of the stone will take place. In this case, the penetration value after the first blow is used for design purposes.

Figure E 5 Ball Penetration Test Indicating the "Half-Moon" Effect

- When only crushing of the existing surfacing aggregate or only displacement of the substrate is observed, without the "half-moon" effect, then the potential embedment is considered to be very low. In such cases, only the second penetration value (i.e. second reading minus the first reading) is used for design purposes. The first blow is considered a "seating" blow.

Figure E 6 Ball Penetration Test Indicating the "Crushing" Effect

Figure E 7 Ball Penetration Test Indicating the "Displacement" Effect

- When an indent is observed as well as crushing and/or displacement, the recommendation is to use the average of the first- and second blow penetrations

Figure E 8 Ball Penetration Test Indicating the "Crushing and Displacement" Effect

- Unless the tester provides a full report with photographs of each test, the designer should be on site during testing.

- Adjustment to Corrected Ball penetration value.

The expected true embedment is a function of the temperature susceptibility of the substrate and the road surface temperature under which it will operate. Therefore, the measured Ball penetration values at the test temperature must be corrected to the expected penetration (dependent on the substrate type) at the operating temperature.

Suggested design road surface temperatures, TD as described in SANS 3001-BT10, 2013, are shown in Figure E 9.

The temperature corrected ball penetration is calculated as follows:

BPC = BPT1 – k (T1 – TD)

where

- *BPC is the temperature corrected ball penetration value, in millimetres (mm);*
- *BPT1 is the ball penetration value measured at the road surface temperature, in millimetres (mm);*
- *k is the correction value given in Table E 4 in millimetres per degree Celsius (mm/°C);*
- *T1 is the road surface temperature at the time of the test, in degrees Celsius (°C);*
- *TD is the design road surface temperature for the climatic zone in which the road is located, in degrees Celsius (°C).*

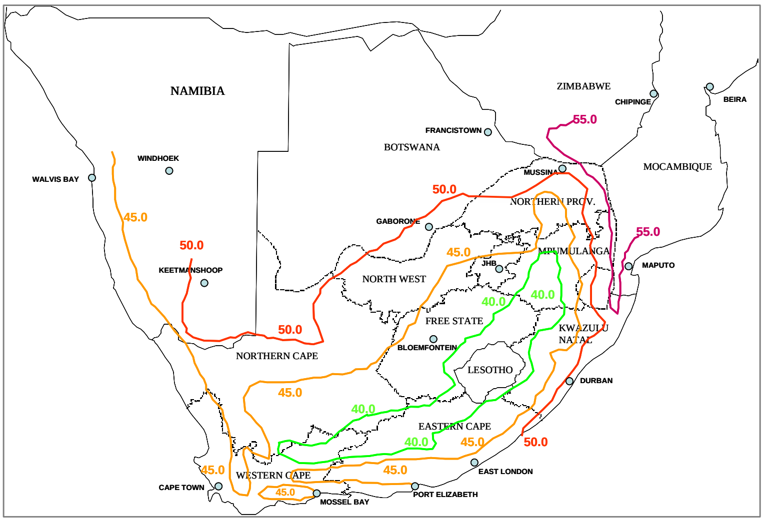


Figure E 9 Isotherms - Design Temperature

Table E 4 Selection of k Value

Existing surface type	k value (mm/°C)			
	Surface defects as described in TMH9 [13]			
	Dry and brittle		Bleeding	
	Degree ≥ 3	Degree <3	Degree 3 - 4	Degree 5
Natural gravel base	0	0	0	0
Crushed stone base	0	0	0	0
Emulsion treated base (< 2 % bitumen)	0	0	0	0
Foamed bitumen base (> 3 % bitumen)	0,02	0,04	0,05	0,08
Single and multiple seals	0	0,02	0,04	0,08
Slurry seals and sand seals	0,03	0,05	0,06	0,08
Cape seals	0,03	0,06	0,07	0,08
Asphalt (sand mastic)	0,05	0,07	0,08	0,08
Asphalt (stone mastic)	0,02	0,04	0,05	0,08

E.4.2.1.6 Minimum and maximum binder application rates

With reference to Figure E 3, an envelope exists with the minimum application rate sufficient to hold the aggregate without stripping. The maximum application rate is a function of the target macro texture selected.

The choice of the final total application rates mainly depends on:

- Risk related to uncertainty regarding attracted traffic. If there is a high level of uncertainty with regards to traffic and the ability exists to add binder (application of diluted emulsion) when necessary, a strategy can be followed of applying the minimum amount of binder.
- Risks related to inclement weather shortly after construction. Sealing close to winter could influence the rate of stone orientation and sensitivity to stripping. Designing for the minimum application rate is not recommended in this case (Refer E.13 for more guidance)
- Existing cracking and need to extend the service life before crack reflection
- Contractor experience and equipment quality. It is essential that the contractor be given a specified application rate for each unique road section. In selecting the target application rate cognisance should be taken of the 5 per cent permissible variation in binder application rates (See COTO specifications [6]). To minimise the risk of early stripping, good practice suggests adding 5% binder if designing on the minimum application rate
- Practical minimum and maximum application rates.
    - Check for practical minimum spray rates (accuracy) = 0,7 ℓ/m^2 (hot).
    - Check for practical maximum spray rates to prevent run-off by evaluating the maximum gradient/cross fall combination, texture and binder viscosity (approximately 1,75 ℓ/m^2 for hot conventional binders and 1.5 ℓ/m^2 for emulsions).
    - Each type of binder has its own minimum practical spray rate. Cognisance should be taken of this. In the case of polymer-modified binders, it should be borne in mind that the use of minimum spray rates will tend to defeat the objective for which the polymer-modified binder was selected in the first place.

E.4.2.2 Adjustments

E.4.2.2.1 Existing texture

Purpose

The purpose of measuring the existing texture depth is to determine the additional binder required to fill existing voids or to determine the need for more appropriate measures e.g.

- Split application of binder.
- Use of a modified binder.
- Texture treatment to obtain a uniform fine texture before application of a stone seal.

Measurement

The Volumetric Texture Depth (VTD) as measured using SANS 3001-BT11 provides the average macro texture depth over an area.

A known volume of sand (50ml or 100ml), consisting of clean dry rounded or sub-rounded particles with at least 98 % passing the 300 µm sieve and not more than 2 % passing the 75 µm sieve, is spread in a circular form so that only the top of the aggregate is visible. The average diameter of the sand circle is determined, and the volume divided by the area to obtain the average texture depth. At least ten measurements in each wheel track and ten in-between the wheel tracks are required.

Figure E 10 Volumetric Texture Depth Measurement

Although glass beads complying with the particle size requirements for the sand may be used, it should be noted that the calculated texture depth would be approximately 3% more [24].

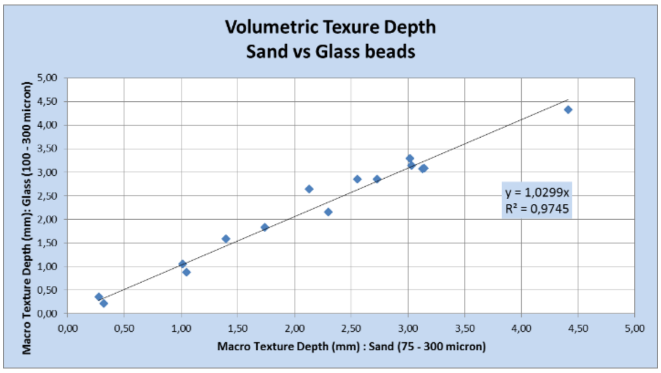


Figure E 11 Correlation between Sand and Glass Beads

Voids within the existing substrate could allow the sand/ glass to trickle into these voids, resulting in a higher measured texture depth. This phenomenon is more likely to occur with glass beads.

Figure E 12 Trickling of Sand into Surfacing Voids

Interpretation and guidelines

The following aspects need consideration [2] [3]:

- Variable texture depth between the wheel track and the adjacent road.

  Information regarding the variation in texture depth transversely across the lane width adds value to decisions regarding the application of a texture treatment or additional cover spray on coarser areas e.g. the centre line.

  Application of a texture treatment is recommended when the macro texture variation exceeds 40%.

Figure E 13 High Variation in Macro Texture Depth

- What seal type will be used on the existing texture?

  The size and shape of aggregate to be used and the characteristics of the existing surface should be taken into account.

  Example:

  Texture depth measurements on an old 10 mm single seal and a 20 mm Cape Seal could result in the same values. (Refer to Figures E 14 and E 15).

Figure E 14 Texture of a Cape Seal

Figure E 15 Texture of an Old 10mm Seal

When sealing with a 14 mm or 10 mm aggregate on the existing 10 mm single seal, additional binder is required or, dependent on the texture depth, a texture treatment would be required. However, when using the same aggregate on the 20 mm Cape Seal, it is possible that the aggregate would be in direct contact with slurry, in which case no additional binder is required. The effect is shown in Figures E 16 and E 17.

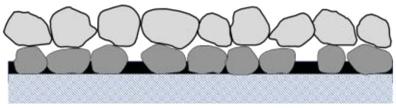


Figure E 16 14 mm Reseal on 10 mm Single Seal

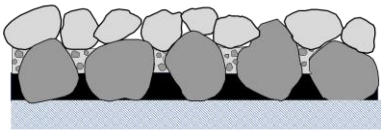


Figure E 17 14 mm Reseal on 20 mm Cape Seal

In addition to the above, the size of aggregate used will influence the additional binder required, the effect as shown in Figure E 18.

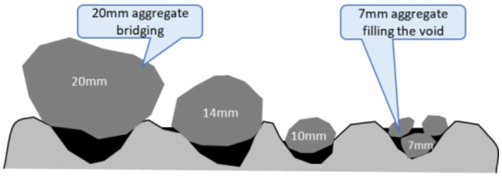


Figure E 18 Variation in Additional Required Binder

Various attempts have been made to quantify the additional required binder, with different guidelines providing significant different values for similar situations.

Until this issue is properly resolved, the following recommendations are provided for design purposes in South Africa:

- A texture treatment (void filling seal) is required if:
  - The average macro texture depth varies by more than 40% within and outside of the wheel tracks.
  - The macro texture is not uniform due to aggregate loss or fattiness across and along the uniform section to be sealed.
  - The macro texture exceeds the guideline values for different seal types as shown in Table E 5.

Table E 5 Recommended Maximum Texture Depth Before Pre-Treatment is Required

Seal Code	Description	Max Texture Depth
S1(10)	Single seal with 10 mm aggregate	0.8
S1(10)	Single seal with 10 mm aggregate (with cover spray)	1.0
S1(14)	Single seal with 14 mm aggregate	0.8
S1(14)	Single seal with 14 mm aggregate (with cover spray)	1.2
S1(14)	Single seal with 14 mm aggregate (with Bitumen rubber)	1.2
S2(10/S)	Double seal with 10 mm aggregate and sand	1.0
S2(14/S)	Double seal with 14 mm aggregate and sand	1.5
S4(10)	Cape Seal with 10 mm aggregate and one layer of slurry	1.5
S4(14)	Cape Seal with 14 mm aggregate and one layer of slurry	1.8
S4(20)	Cape Seal with 20 mm aggregate and two layers of slurry	2.0
S2(14/7)	Double seal with 14 mm aggregate and a layer of 7 mm aggregate	1.5
S2(14/5)	Double seal with 14 mm aggregate and a layer of 5 mm aggregate	1.5
S2(20/10)	Double seal with 20 mm aggregate and a layer of 10 mm aggregate	1.8
S2(20/7)	Double seal with 20 mm aggregate and a layer of 7 mm aggregate	1.8
S2(20/7/7)	Double seal with 20 mm aggregate and two layers of 7 mm aggregate	1.5

- The additional binder for texture adjustment only applies for seals if the aggregate layer size is more than 7mm. Sand seals, grit seals 5mm seals and 7mm seals will fill the voids of coarse textured surfaces.

Re-evaluation of the different recommendations in TRH3 2007 and previous Provincial manuals resulted in the recommended adjustments as provided in Figure E 19.

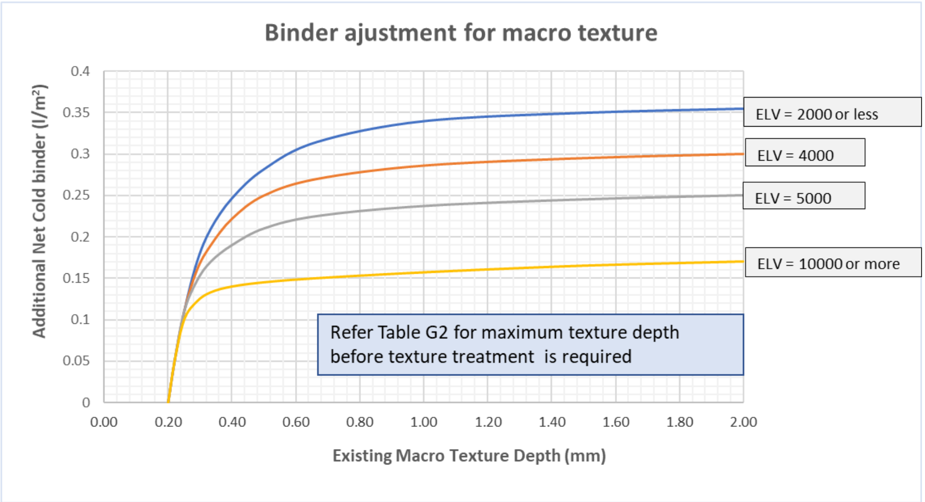


Figure E 19 Adjustment for Macro Texture

E.4.2.2.2 Macro Climate adjustment

Experience [23] suggested an increase in binder application rates in dry areas and a decrease in humid areas. Three climatic zones have been identified over a period of thirty years in this Province, and coincided with the macro climatic areas as defined by Weinert [4] with:

- Weinert N-value < 2 defining the humid zone (10% binder decrease).
- Weinert N-value > 2 and < 5 defining the moderate zone.
- Weinert N-value > 5 defining the dry zone (10% binder increase).

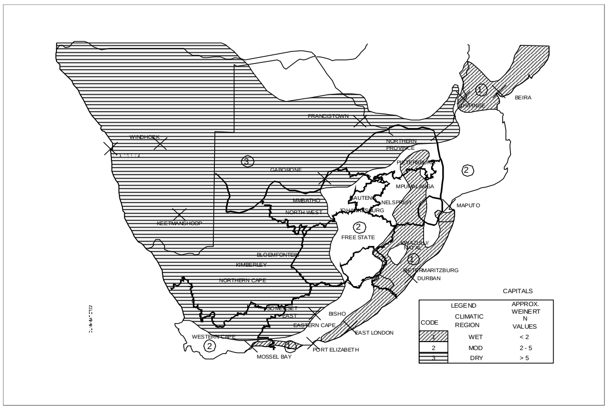


Figure E 20 Macro Climatic Regions of southern Africa

<u>Note</u>: Although incorporated in TRH3 (1994) and TRH3 (2007) for conventional binders, it is no longer recommended until specific research confirms a reason for this adjustment.

E.4.2.2.3 Cold microclimates

Shady or cold areas (under/on bridges or next to trees) are prone to aggregate loss. Current practices to reduce the risk of aggregate loss in these areas are:

- Sensitive areas are constructed separately, close attention being paid to temperatures, application rates and immediate extra rolling.
- Application of an emulsion cover spray and sand blinding.
- Selection of different binder. Hot binders are not recommended unless they are cut back or modified.
- Increase of binder application rates by between 10 to 20 per cent.
- Apply tight control on traffic speed and turning actions for at least two weeks after construction
- Close the new seal overnight and only allow traffic when road surface temperatures increase above 20ºC.

<u>Note</u>: In cases where emulsion is used, sufficient time should be allowed before these areas are opened to traffic.

Orientation of the aggregate during and, within the first two to three weeks after construction is dependent on the viscosity/stiffness of the binder at the prevailing road surface temperature. Figure E 21 highlights a significant difference in road surface temperature due to shade.

Colder areas such as sections in cuttings, under bridges and in the shadow of trees could result in slow or little, if any, aggregate orientation, high stresses on protruding stones and high risk of stripping (aggregate loss), as shown in Figure E 22.

Figure E 21 Temperature Differences (Shade Versus Sun)

Figure E 22 Aggregate Loss due to Cold Shady Area

With Forward Looking Infra-Red (FLIR) cameras available, cold areas could easily be detected as shown in Figure E 23.

Alternatives that could be considered to reduce risk of stripping are:

- Apply the rule of thumb by adding 0.2 l/m² net cold binder either in the tack coat for single seals, in the penetration coat of double seals, or as a cover spray.
- Change the single seal to the "Stone-and-third" double seal configuration (Refer PART C and PART D).
- Design as a Cape seal (Single plus slurry).

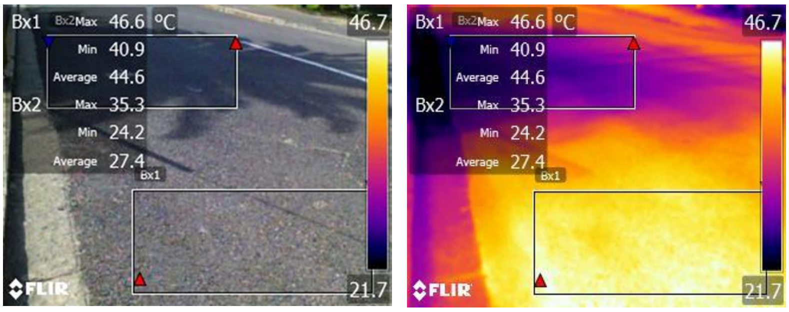


Figure E 23 Forward-Looking Infra-Red

E.4.2.2.4 Adjustment for aggregate micro texture

Accepting that bond strength is highly influenced by the surface area between the binder and aggregate, the surface micro texture and shape of the aggregate should be taken into account when determining appropriate application rates.

Experience indicates that smooth-surfaced aggregate types are more prone to stripping and requires additional binder to ensure proper bond strength.

Figure E 24 Stripping of Quarzitic Aggregate

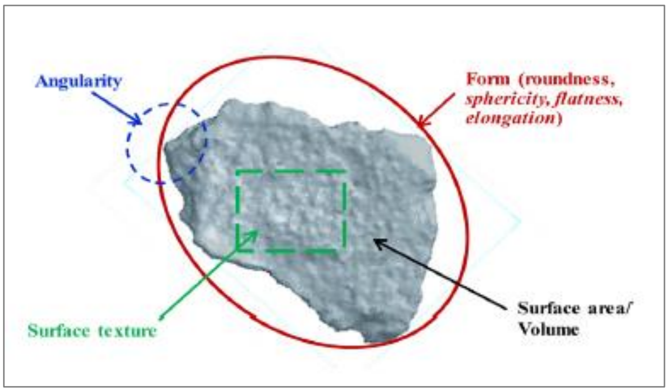


Figure E 25 Aggregate Shape and Surface Texture

Common practice in certain areas of the country, working with smooth textured granite and quartz aggregate suggest up to 0.2 l/m^2 additional binder when sealing with 14mm aggregate (ALD approximately 8mm).

The rationale for the additional binder relates to the aggregate surface area in contact with the binder i.e. the binder level in the seal structure should be higher for a smooth textured aggregate to obtain the same surface area (and bond strength) as for a coarse textured aggregate.

Note*: *Quarzitic stone (i.e. not fully metamorphosed quartzite) is rough textured, very absorbent, and not often used due to failing hardness specifications. The new relaxed specifications for lower volume roads (refer PART B: Materials) might result in some sources being allowed for seal work. Precoating of this material is recommended regardless of the binder being used.

Technology now allows three-dimensional scanning of aggregate and quantifying micro texture. Typical differences in surface area per nominal size for some aggregate types in South Africa are shown in Figure E 26 [5].

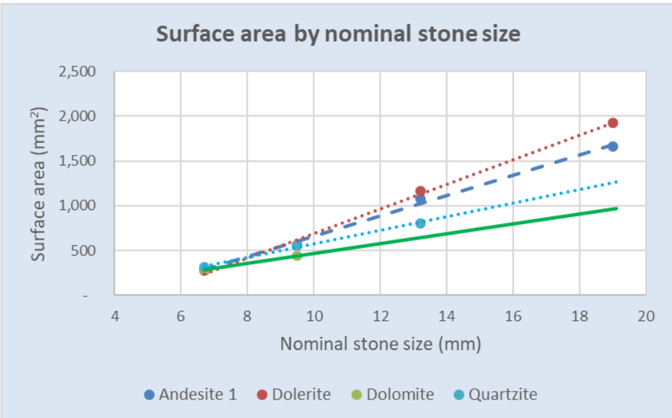


Figure E 26 Surface Area per Nominal Aggregate Size

The visible difference in surface micro texture, as could be observed from Figure E 27, confirms the relative difference as shown in Figure E 26.

Figure E 27 Surface Texture Differences

Notes:

- ***Information presented is based on one study which focused on the total surface area, taking into account the size of the stone, the shape and the micro texture.***
- ***Surface micro texture for one type of aggregate could vary significantly.***
- ***The shape of the aggregate could also influence the surface area and could vary as a result of the mineralogical structure and crusher type and settings.***

For seal design purposes the size and to a certain extent, the shape of the aggregate, are already taken into account. Therefore, further research should focus on the difference in surface contact area (and bond strength) due to the micro texture differences of different aggregate types.

Until quantitative guidelines are available from research on this topic, the following should be considered when working with fine-textured/ smooth aggregate:

- Do not design for the minimum application rate (compensate at least for the 5% contractor's tolerance).
- Precoating of aggregate.
- Application of a diluted cationic emulsion cover spray.

E.4.2.2.5 Slow-moving traffic

Evaluation of occurrence of bleeding /fattiness highlighted that this phenomenon is related to tyre pressure and the speed of heavy vehicles. The typical speed where fattiness starts to develop is below 40km per hour.

The movements and speeds of heavy vehicles should be determined on site. In rolling terrain, vehicle speeds are usually still high at the bottom of steep grades due to the momentum gained on the downhill and are usually low past the crest.

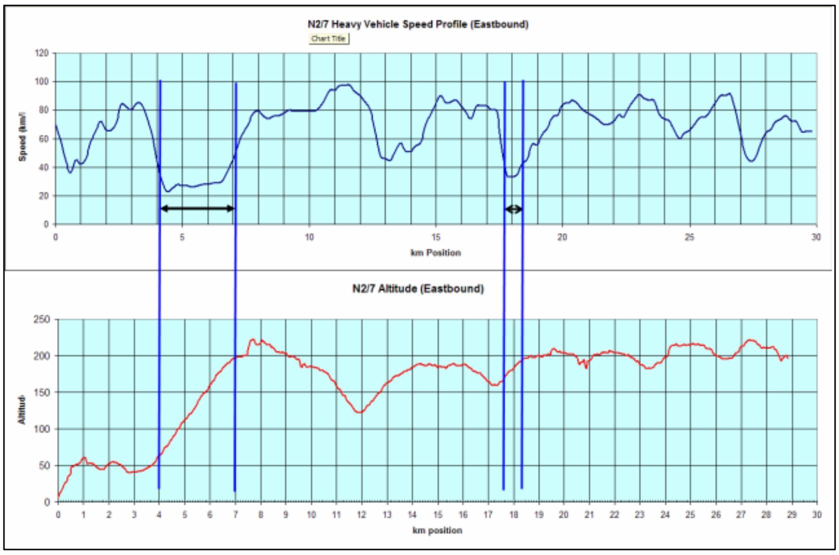


Figure E 28 Occurrence of Fattiness Related to Heavy Vehicle Speed

For reseal projects the existing road sections where fattiness occur should be recorded and could be compared with the typical speed and actions of heavy vehicles e.g. uphills, downhills, stopping places, turning places.

The current recommendation, over and above the effects of low existing macro texture and high embedment potential (Ball penetration), is to reduce the net cold binder application rate with zero to 10 percent for heavy vehicle speeds reducing from 40 km/h to 20 km/h.

***Note*: Downward binder adjustment will be required on downhills as a result of braking actions and slow movement.**

In urban environments where frequent stops occur, heavy vehicles tend to stay in the lower gears. In these situations, binder application rates could be reduced by 5 to 10 per cent.

Straight line interpolation results in the following function for reduction of the net cold conventional binder.

HV Speed binder adjustment (% of Net Cold binder) = 0.5 x HV Speed – 20 (only applicable between 40 km/h and 20 km/h).

***Note*: Sections where binder application should be reduced relate to the speed of heavy vehicles and not the gradient. Reduction of the binder application rate is normally required when the speed of heavy vehicles reduce to below 40 km/h.**

E.4.2.2.6 Aggregate spread rate

Binder application rates as recommended in this manual, based on filling voids within the seal structure, are determined for single sized aggregate with low flakiness (Flakiness Index <10%), already orientated in a dense matrix (refer Figure E 29).

Opening the aggregate matrix for cubical stone in a single seal as shown in Figure E 30, could require additional binder to wet 30% of the stone height. The complexity to calculate appropriate application rates increases as a result of variation in aggregate spread rate and particle shape. Therefore, the current recommendation is to only design for a dense matrix and, to construct single seals to form a dense shoulder-to-shoulder matrix after traffic compaction.

Figure E 29 Dense Shoulder-to-Shoulder Matrix after Construction and Traffic Compaction

The design application rates recommended for Cape seals are based on an aggregate matrix as presented in Figure E 30.

Figure E 30 Open Shoulder-to Shoulder Matrix

E.4.2.2.7 Adjustment for sealing during very cold (winter) periods

As discussed under E.4.2.2.3 for cold micro climates, the sensitivity to stripping (aggregate loss) is mainly due the stiffness of the binder in cold weather when the aggregate has not yet orientated to ensure proper embedment, resulting in high/protruding individual stones that can easily be dislodged when the road is opened to traffic.

Whereas an increase in binder application in the cold micro climatic areas (remaining cooler than the rest of the road throughout the day) results in good performance, a general increase of binder application rate to compensate for slow aggregate orientation during winter, could result in too much binder during the first summer.

Experience with sealing of fifty-four road sections during winter in the coldest parts of the country and monitoring the performance thereof, resulted in the following recommendations:

- Do not design for the absolute minimum application rate (Recommend at least 10% above the minimum to allow for the permissible variation in binder application rate).
- Select a seal type which will result in a relative smooth surface without large protruding aggregate after construction and/or double seals where the smaller aggregate assists in interlocking. Typical examples as discussed in PART D, are 14/Grit, 14/5, 20/7, Cape seals, Grit seals, sand seals, slurry and microsurfacing.

- In case of single and double stone seals select a binder that would allow quick orientation of the aggregate during and shortly after construction. Use emulsions where feasible to do so. Also refer to PART D for cutting back of binders.
- In case of sand, grit or graded aggregate seals select a soft binder such as MC3000.
- Control the opening of the road to traffic, to ensure traffic compaction only when the road surface is warm enough to allow orientation of the aggregate.

E.4.2.2.8 Adjustments for dry and porous surfaces

Porous or dry surfacings tend to absorb binder, often resulting in loss of aggregate from the new seal. Depending on the type of binder used and other factors, this absorption may occur over a period of time. Increasing the application rate for the reseal may result in excess binder and bleeding. It is therefore recommended that porous and dry surfacings be treated with diluted emulsion prior to sealing and that no adjustments be made for loss in binder on account of porosity.

E.4.2.2.9 Adjustments for fatty surfaces

Although there is a tendency to reduce binder application rates on fatty surfaces, it is believed that the corrected ball penetration value already makes provision for this phenomenon. High ball penetration values would indicate that larger aggregate should be used.

***Note**: Areas with excess binder should rather be pre-treated as describe in PART H.*

E.4.2.2.10 Adjustment for no initial traffic

Newly constructed roads are often not trafficked for some time after construction. The recommended practice in such cases is to evaluate the situation just before the road is opened to traffic by driving over the section and observing any loss of aggregate. Application of a diluted emulsion cover spray will assist in preventing loss of aggregate.

***Notes**:*

- ***Care should be taken to differentiate between excess aggregate (over-application) and true aggregate loss.***
- ***Seals on surfaced shoulders should be designed as separate lanes, in which factors such as potential traffic, gradients and whether the shoulders are used as climbing lanes, are taken into consideration.***
- ***As outer areas on curves usually carry less traffic than those on the inside, the application rates may be adjusted upward to prevent loss of aggregate.***

E.4.2.2.11 Adjustment for porous seal aggregates

Aggregate which meets the specifications [6] usually has low binder absorption properties. Where absorptive aggregate is used (water absorption greater than 2 per cent), it is recommended that the aggregated be precoated rather than that the binder application rate be increased.

E.4.2.2.12 Adjustment for construction traffic

A particularly severe condition is encountered when a newly laid surfacing seal is trafficked by heavily loaded trucks engaged in the construction of other parts of the road. This situation should be avoided if possible. However, if construction traffic cannot be kept off the new surfacing, the expected traffic should be incorporated in the calculation of the design traffic.

E.4.2.2.13 Adjustment for stone and sand seal combinations

Single seals are often blinded with a coarse sand or "grit" to prevent initial aggregate loss. Experience indicates that the total binder content, calculated for the single seal, may be increased by between 15 and 20 per cent in such cases. The penetration coat usually consists of an emulsion or diluted emulsion.

E.4.2.2.14 Adjustment for cracked surfaces

As discussed in PART C, the ability to retard crack reflection is a function of the binder film thickness and the type of binder used. Therefore, upward adjustment from the minimum application towards the middle of the allowed envelope is recommended.

E.4.2.2.15 Adjustment for allowed contractor tolerance

Contractors are allowed to spray 5% over or under the specified application rate without penalties being applied and, up to 10% with penalties before the work is rejected. If the design approach is "lean", using the minimum to hold the stone, it is recommended to add 5% to the design application rate to minimise the risk of stripping.

E.4.3 CONVERSIONS

E.4.3.1 Conversion Factors for Modified Binders

In order to utilise the rational application rate design for conventional binders a single function is applied to increase the calculated application rates for each of the hot homogenous and non-homogenous modified binders. Although research on this topic is continuing, the current conversion factors are based on experience and opinions of a panel of current practitioners.

E.4.3.1.1 Non-homogenous modified binders (Bitumen rubber)

Based on initial trial and error to obtain good performing single seals, typical conversions back-calculated from net cold conventional binder to net cold non-homogenous modified binder varied from 1.5 and 1.9 times the application rate appropriate for a conventional binder.

The minimum practical hot application rate to prevent tramlining is 1.8 ℓ/m^2 for the summer grade products (S-R1) and 1.6 ℓ/m^2 for S-R2 and winter grade products. Due to the contractors' allowance for variation, it is recommended that the minimum specified application rates be increased by 5% to 10%.

Notes:

- ***Applying the developed equations could result in unnecessary high application rates on low volume roads. The general consensus is that 3.2 ℓ/m^2 maximum hot application rate is sufficient, even for 20 mm seals to perform well.***
- ***Due to the minimum high application rates, small aggregate e.g. 7 mm cannot be applied in a single***

layer without bleeding. The smallest aggregate recommended is 10 mm.

- ***Aggregate used with non-homogenous modified binders are normally precoated to improve adhesion.***
- ***In case of a double seal where bitumen rubber is only used as the tack coat, the conversion only applies to the tack coat.***

Table E 6 S-R1 Conversion

S-R1 ADJUSTMENT (Conventional to modified binder)			
Traffic (ELV)	**Single seal**	**Double Seal**	**Split application double seal**
< 5000	1.8	1.6	1.6
5001 - 20000	1.9	1.7	1.7
> 20000	2.0	1.8	1.8

Table E 7 S-R2 Conversion

S-R2 ADJUSTMENT (Conventional to modified binder)			
Traffic (ELV)	**Single seal**	**Double Seal**	**Split application double seal**
< 5000	1.7	1.7	1.7
5001 - 20000	1.8	1.7	1.7
> 20000	1.9	1.7	1.7

Note*: *In contrast with homogeneous polymer modified binders, the conversion factors back-calculated from trials, for S-R1 and S-R2 increase with higher traffic volumes.

E.4.3.1.2 Homogenous hot modified binders

Through back calculation of documented guidelines and rationalization of several opinions, conversion factors from conventional to homogenous modified binder of between 1.1 and 1.4 as recommended in Table E 8 and Table E 9 provide appropriate design application rates.

Table E 8 S-E1 Conversion

S-E1 ADJUSTMENT (Conventional to modified binder)			
Traffic (ELV)	**Single seal**	**Double Seal**	**Split application double seal**
< 5000	1.3	1.1	1.2
5001 - 20000	1.2	1.0	1.1
> 20000	1.1	1.0	1.0

Table E 9 S-E2 Conversion

S-E2 ADJUSTMENT (Conventional to modified binder)			
Traffic (ELV)	**Single seal**	**Double Seal**	**Split application double seal**
< 5000	1.4	1.2	1.3
5001 - 20000	1.3	1.1	1.2
> 20000	1.2	1.0	1.1

TRH3 (2007) did not allow for an increase when using polymer modified emulsions. It was contemplated that due to the low viscosity, orientation of the aggregate occurs immediately. Following investigations into the causes and mechanisms of stripping [3] and monitoring further orientation under traffic, it was concluded that some adjustment is required.

E.4.3.1.3 Homogenous cold modified binders

The provisional recommendation is that the conversion for polymer modified emulsion is 50% less than for the hot polymer modified binder. Therefore:

- Conversion for SC-E1 = 50% of the conversion for S-E1 and;
- Conversion for SC-E2 = 50% of the conversion for S-E2.

As an example, using Table E 9, the conversion factor for SC-E2 for a single seal with ELV < 5000 = 1.2.

E.4.3.2 Conversion to Hot-Applied Binder Application

Binder application rates are specified and controlled at spraying temperature. Therefore, the application rate for each binder in the seal structure must be converted to the hot application rate. Table E 10 provides typical conversion factors.

Table E 10 Factors for Converting Net Cold Residual Binder to Hot Spray Rates and Storage and Spraying Temperatures

Type of binder	Conversion factor*** (Net cold to hot)	Spray temperature (°C)	Max. storage temperature (°C)
Cutback bitumen			
MC 3000	1.19 – 1.27	130 - 155	100
MC 70	1.63 – 1.72	60 - 80	Ambient
MC 30	1.88 – 1.99	45 - 65	Ambient
Penetration grade bitumen			
150/200 pen	1.09	145 - 185	115
70/100 pen	1.09	160 - 200	125
Polymer modified bitumen			
S-E1	1.08	175 – 185	150
S-E2	1.06	175 – 185	150
Bitumen rubber (S-R1)	1.07	195 – 210	150-
Bitumen rubber (S-R2)	1.07	180 – 190	150
Bitumen emulsions			
60% emulsion	1.68	50 - 70	Ambient
65% emulsion	1.55	50 - 70	Ambient
70% emulsion	1.44	50 - 80	Ambient

Commented [GvZ4]: Line up

Note:

****** Binders from different sources have different temperature conversion factors. The user should refer to the manufacturer.***

Please refer to TG1 for additional requirements regarding handling, transport and storage of bituminous products.

E.4.4 SENSITIVITY ANALYSIS

It is important to note that variations of input parameter values could occur and that different assumptions used in the design process may be valid. Therefore, it is recommended that the sensitivity of these parameters be analysed to obtain a possible, but realistic range of application rates.

Towards a Minimum:
- Higher expected traffic
- Higher ball penetration (Max: Average corrected ball penetration+1 Standard deviation).
- Smoother texture (Min: Average texture depth - 1 Standard deviation).
- Lower design ALD (Min: Average texture depth - 1 Standard deviation).

Towards a Maximum:
- Lower expected traffic
- Lower ball penetration (Min: Average adjusted ball penetration - 1 Standard deviation).
- Coarser texture (Max: Average texture depth + 1 Standard deviation).
- Higher design ALD (Max: Average texture depth + 1 Standard deviation).

E.4.5 BINDER DISTRIBUTION

E.4.5.1 Decision to Apply an Emulsion Cover Spray

One of the most cost-effective ways to minimize the risk of stripping is to add a final application of binder to the seal in the form of a diluted cationic spray grade (rapid setting) emulsion cover spray.

Due to the fairly coarse texture of the new seal and the need to create a bond between the aggregate as shown in Figure E 31, a rapid setting emulsion is considered appropriate for this situation.

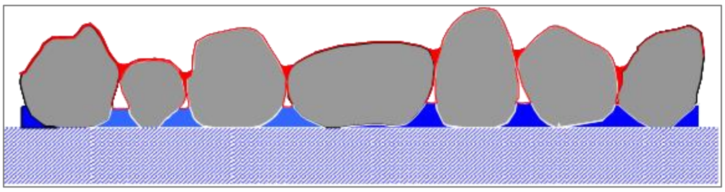


Figure E 31 Bond Created Between Aggregate Particles with Rapid Setting Emulsions

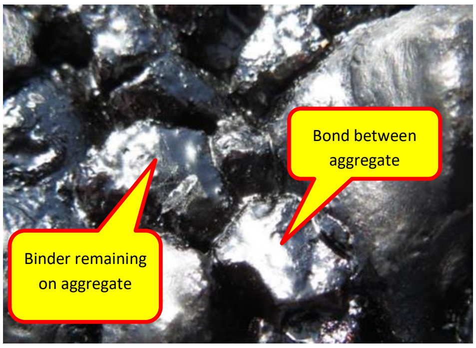


Figure E 32 Effects of Cationic Spray Grade Emulsion Cover Spray

Good practice in South Africa suggests always to apply a cover spray in the following situations:

- Any single seal with emulsion used as the tack coat
- All double seals designed as “full double” seals
- All split application double seals
- All seals constructed close to, or within the winter months

***Note**: Experimentation with different emulsions from different suppliers resulted in the recommendation to use a cationic rapid setting emulsion, further diluted with 30% or 40% water i.e. 70% or 60% emulsion and 30% or 40% water, and sprayed at 0.8 to maximum 1.2 l/m^2.*

E.4.5.2 Design Effects Using A Cover Spray

Dependent on the emulsion formulation, application rate, aggregate properties, road surface temperature etc., proportions of the binder:

- Flow down into the structure of the seal, filling the voids from the bottom.
- Adhere to the aggregate shoulders (reducing the risk of stripping).

- Stay/adhere to the top of the aggregate (driven off with time).

Until more research is carried out to quantify the volume not filling the voids, the rule of thumb is applied to subtract 50% of the net cold binder applied from the total design application.

Therefore, following the decision to apply the cover spray and selection of application rate and dilution, half of the net cold binder must be subtracted from the total net cold binder requirement to be applied as a tack coat in a single seal, or to be split into the tack coat and penetration coat, in case of a double seal.

E.4.5.3 Split of Binder in Double Seals

For double seals, opinions differ regarding the split in binder between the tack coat and penetration coat.

The standard "rule of thumb" distribution between the tack coat and penetration coat was, after subtracting half of the residual binder of the cover spray, to apply 60% in the tack coat and 40% in the penetration coat.

Recent guidelines suggest, due to the more cubical shape of the smaller aggregate, to distribute the total available binder 50/50 between the tack- and penetration coats. This is also the recommended approach for "full" double seals and split application double seals.

Experimentation during winter seal trials confirmed that the risk of stripping is even less if more binder is distributed to the penetration coat e.g. 45/55 distribution between the tack- and penetration coat.

However, it is generally agreed that this split is governed by the minimum application rates required for each layer to prevent whip-off or by the minimum rate that can be sprayed accurately.

The minimum quantity of net cold binder required for the penetration coat depends on the aggregate size of the second layer. (Table E 11 may be used as a guideline.)

If traffic has to be accommodated on the first layer for some time (this is not recommended), it is advisable to revert to a different design approach e.g. a "Stone and Sands" combination.

The minimum quantity of residual binder required for the tack coat depends on the size of the aggregate used in the first layer. (See Table E 12).

Table E 11 Minimum Quantity of Net Cold Binder Required for Penetration Coat

Aggregate size in top layer	**5 mm or less**	**7 mm**	**10 mm**
Minimum net binder required	0,3 ℓ/m^2	0,6 ℓ/m^2	0,7 ℓ/m^2

Table E 12 Minimum Quantity of Net Cold Binder Required for Tack Coat

Aggregate size	**10 mm**	**14 mm**	**20 mm**
No traffic	0,5 ℓ/m^2	0,7 ℓ/m^2	1,0 ℓ/m^2

E.5 CAPE SEALS (SINGLE SEAL PLUS SLURRY)

E.5.1 GENERAL

The Cape Seal originated in the Western Cape Province of South Africa and typically consists of a single seal with the voids between the aggregate filled with slurry. If 20 mm aggregate is used, the slurry is applied in two layers. When 14mm or 10mm aggregate is used, only one layer of slurry is applied. Good performance under most conditions, which include urban and rural environments, low maintenance capability and cold weather construction, resulted in this seal type being selected as the preferred initial seal type on many roads.

E.5.2 DESIGN PROCESS FOR CAPE SEALS

E.5.2.1 Single Seal Component

Several investigations [9] concluded that the main reasons for bleeding of Cape seals are:

- Too soft binder in the tack coat for the prevailing road surface temperatures. The best performing binders in terms of sensitivity to bleeding and cracking are hot polymer modified binder (S-E1) and cold polymer modified binders (SC-E1 and SC-E2 modified with SBR, but without any solvents/cutters).
- Too high tack coat application rates in case of the 20mm Cape seal. The conclusion was drawn that the tack coat application rate for 20mm Cape seals, as determined through TRH3-2007(minimum line) as well as the Western Cape Government design processes (with two layers of slurry), was too high and contributed to bleeding. Yet, 10mm and 14mm Cape seals, with one slurry application performed well with lower and higher application rates, as determined from the TRH3 (minimum line).
- Application of the slurry before proper curing of an emulsion tack coat.

Unless the emulsion content in the slurry is extremely high, the slurry is seldom the cause of bleeding/fattiness.

The application rates applied for Cape seals over a spectrum of traffic situations and substrate softness (Corrected Ball penetration <3.0mm) have been used to back calculate the Net Cold Conventional Binder (NCCB) of good-performing seals [9].

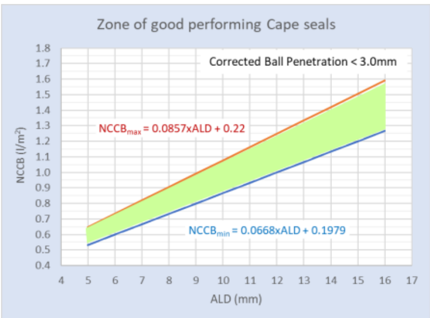


Figure E 33 Zone of Good Performance

Using the basic principles of the rational design method, allowing 30% of the voids filled with binder and simulating the effect of embedment and slurry fill through 30% embedment during construction, provide application rates for the most likely situations within the zone of good performance as shown in Figure E 34.

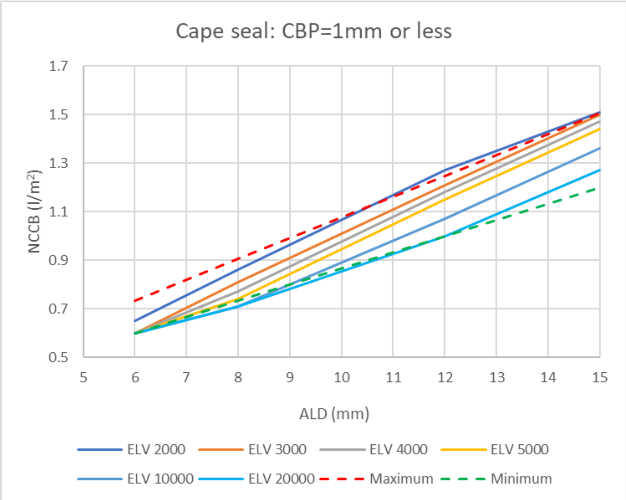


Figure E 34 Simulated Cape Seal Application Rates (Example)

Calculation for the basic Cape seal application rate is provided in Table E 13.

Table E 13 Calculations for Cape Seal Design

Commented [GvZ5]: This is the corrected table

Cape seal design		
Input parameters	**Example**	
Corrected Ball penetration (CBP) in mm	1.5	If CBP < 1.0, then 1.0
Equivalent Light Vehicles per lane per day (ELV)	7300	Design for minimum ELVs of 2000
Average Least Dimention of aggregate (ALD)	12.8	
Macro texture requirement	1	
Aggregate hardness - 10%Fact (kN)	210	
Calculations		
Equivalent layer thickness (ELT) = 0,85679 x ALD + 0,46715 (mm)	11.43	
Embedment =((0.1816*LN(CBP)+0.4184)*LN(ELV))-(0.8365*LN(CBP)+2.9284) - Note: Design for Minimum ELV=2000	1.11	
Embedment as fraction of ELT = (Embedment/ELT)	0.10	
Fractional void loss due to embedment =3.0556*(Embedment/ELT)^3-4.5833*(Embedment/ELT)^2+2.5263*(Embedment/ELT)+0.0002	0.20	
Maximum ELV for wear calculation = 5000	5000	
Design period (Default 10 years)	10	For temporary Cape seals select less than 10 years
Wear (mm) =-0.0011x(10%FACT)+0.2533x(ELV)^0.1747*(10/design life)	0.89	
Wear as fraction of ELT = (Wear/ELT)	0.08	
Fractional void loss due to wear =3.0556*(Wear/ELT)^3-4.5833*(Wear/ELT)^2+2.5263*(Wear/ELT)+0.0002	0.17	
Estimated void content for a single seal (%) = 45,3333 - 0,333 x ELT.	41.53	
Fractional Void loss for macro texture = Macro texture requirement/(Estimated void content%*ELT)	0.21	
Total fractional void loss =Fractional void loss due to (Embedment + Wear + Macro texture requirement)	0.59	
Available void fraction to be filled with binder and slurry = (1 - total fractional void loss)	0.41	
% Rolling embedment of total embedment (Assumed 30% as a result of slurry filling)	30%	
Rolling Embed (30% * Total embedment) in mm	0.33	
Rolling Embed as fraction of ELT = (Rolling embedment/ELT)	0.03	
Fractional void loss due to rolling =3.0556*(Rolling embedment/ELT)^3-4.5833*(Rolling embedment/ELT)^2+2.5263*(Rolling embedment/ELT)+0.0002	0.07	
The minimum amount of voids to be filled with binder to prevent stone loss when there is no embedment, is 30 per cent for Cape seals	30%	
Filled void fraction to hold stone = Min void fraction to be filled with binder - Fractional void loss due to Rolling Embedment	0.23	**Warning 1**
		If the filled void fraction to hold the stone is more than the available void fraction, then the target texture cannot be achieved. For temporary cape seals select a shorter period than 10 years
NCCBmin = (Min void fraction to be filled with binder - Fractional void loss due to Rolling Embedment)*(Estimated void content for a single seal (%) *(ELT)	**1.09**	**Warning 2**
Practical Construction Minimum	**1.04**	Practical minimum NCCB = Maximum of 0.6 and (0.7226ln(ALD) - 0.7976) l/m^2. If NCCBmin is less than the practical minimum, then a larger stone should be selected, or the practical minimum applied with the risk of too low macro texture
Selected maximum NCCBmax = 0.0857*ALD+0.22	**1.32**	**Warning 2**
		If the calculated NCCBmin > selected practical NCCBmax, then select the practical maximum

Note: Adjustments and conversions, as for single seals should still be applied.

Dependent on the conditions, either hot binders or emulsions could be used for the tack coat, provided solvents are omitted.

In all cases where an emulsion is used for the tack coat with un-precoated stone, a diluted emulsion cover spray should be applied.

<u>Notes</u>:

- ***Good practice suggests to always to apply a diluted emulsion cover spray, regardless of whether the aggregate is precoated. In this case, different from single seals, the full residual (net cold) binder component from the cover spray should be deducted from the total binder volume to obtain the tack coat application rate***
- ***The stable mix grade emulsion used in the slurry seal may also be used for the cover spray. If available, this may be the most desirable. A mixture of equal parts of 60% stable grade emulsion and water***

applied at a rate of 0,8 - 1,2 ℓ/m² is recommended.

- ***Compatibility of the water to be used with the emulsion for the cover spray should be checked. Water which is fit for drinking is usually suitable for the dilution of cationic (spray grade and stable mix) and anionic stable mix emulsions. In all cases the water should be added gradually to the emulsion.***
- ***Where emulsion is used for the tack coat, it is possible that the calculated spray rate will exceed the maximum permissible spray rate of 1,5 ℓ/m² .In such cases the first spray should be reduced to 1,5 ℓ/m² and the rest of the binder should be sprayed in the second spray in a ratio of emulsion to water not to exceed 1.2 ℓ/m² .***
- ***The maximum emulsion spray rate should be reduced with steep gradients, smooth surface textures (< 0.5 mm) and very coarse surface textures (>1.5 mm).***
- ***In exceptional cases, where diluted emulsion cannot be used for the cover spray, undiluted emulsion may be used.***

E.5.2.2 Slurry Component

The first important decision is the selection of the slurry grading that could fill the voids in the single seal structure.

As discussed in PART F: Seal Construction, it is essential to determine the appropriate aggregate spread on site. The aggregate should not be over-applied, as this would prevent the slurry to penetrate fully into the seal structure.

As a general rule, the appropriate spread of aggregate would allow the following slurry gradings:

- 10 mm single seal component – One layer of fine slurry, fine grading.
- 14 mm single seal component - One layer of fine slurry, fine grading or medium grading.
- 20 mm single seal component - One layer of fine slurry, medium grading and one layer of fine slurry, fine grading.

Slurry design for Cape seals is discussed in Section 0, highlighting that the minimum binder content (using 60% anionic emulsion) is 8.0% for fine slurry, medium grading and 10% for the fine slurry, fine grading.

Notes:

- ***The original 20 mm Cape Seal design for crusher dust gradings within the fine slurry, medium and fine grading envelopes, required 8,4 – 12,0 % bitumen in the first layer and 12% bitumen in the second layer.***
- ***Permeability specifications for the first layer of Cape seals originated from measurements on the fine slurry medium grading with a minimum of 8.4% bitumen. Reducing the binder content will result in this specification being difficult to meet.***

E.6 SLURRY SEALS

E.6.1 GENERAL

A slurry is a homogenous mixture of fine aggregate, stable-mix grade emulsion (anionic or cationic) or a modified emulsion, water and filler (cement or lime).

Slurry seals are used for new surfacings on roads and airfields, as maintenance treatments (resurfacing) and also to provide a homogenous texture to the existing surface prior to resealing (Referred to as a texture treatment or void-filling seal).

The Cape seal (single seal with the voids filled with slurry) is considered one of the lowest risk seals for new road construction.

E.6.2 MATERIALS

Materials for slurry seals are discussed in PART B.

E.6.3 SLURRY TYPE AND PROPERTY SELECTION

The selection of the appropriate slurry type is discussed in PART D.

Based on the traffic volumes, loads, tyre pressures and conditions, the designer has to formulate his/her strategy and evaluate the impact of a lower or higher binder content e.g. a much higher binder content could be accommodated on a low volume road without the risk of bleeding or deformation.

Key aspects to the design of slurry is that:

- The mixture is easily applied by hand by rubber squeegees or by mechanical spreaders.
- The mixture will have a creamy consistency, which will allow it to flow readily into surface voids and interstices.
- The hardened product will have sufficient binder not to ravel but stable enough to carry the wheel loads without bleeding or deformation.

E.6.4 HISTORICAL DESIGN APPROACHES

The different applications of slurry seals have led to different design approaches, utilized for conventional binder slurry mixes over many years in South Africa.

The designs were either based on asphalt design methods, empirical methods or on experience taking into account:

- Aggregate type and grading.
- Fattiness/ dryness of the existing surface.
- Climatic zones.
- Traffic.

One empirical method which has yielded useful results is to determine the residual bitumen content of the slurry according to the hot-mix Marshall design procedure. The binder mixed with the aggregate is a 70/100 penetration grade bitumen and the optimum bitumen content is taken as the value which gives maximum stability. The residual binder content of the slurry could then be selected in terms of:

- Traffic;
- Aggregate grading; and
- Apparent maximum relative density of combined aggregate.

Notes:

When the Marshall approach is used, it should be borne in mind that the optimum bitumen content is established on a compacted sample. All the slurry seal calculations are based on uncompacted material, e.g.:

- ***If the optimum bitumen content is 8 per cent obtained at a density of 2415 kg/m³, then the quantity of residual binder would be 193,2 ℓ/m³ compacted.***
- ***If the material were loose and a bulking factor of 1,4 were applied, the quantity of residual binder in 1 cubic metre would be 138 litres, i.e 193,2/1,4. This would give 230 litres of 60% emulsion per cubic metre of aggregate (loose).***

The Modified Marshall method, as still used by some South African practitioners is provided in this document as Appendix B.

E.6.5 DESIGN OF CONVENTIONAL SLURRY SEALS

Investigations into the various historical design approaches led to publishing of SABITA Manual 28 (2012)[2], recommending either:

- **Simplified design process**

Determining appropriate binder contents for slurry mixes on low volume roads when aggregates conform to standard COTO specifications), **or**

- **Detailed design process**

Determining appropriate binder contents for slurry mixes on high volume roads and/or when aggregates do not conform to standard COTO Specifications).

E.6.5.1 Simplified Design Process

E.6.5.1.1 Texture treatments (Simplified)

The purpose of a texture treatment is to pre-treat an existing coarse or variable texture surfacing to obtain a uniform fine texture before a single or double seal is applied. A 2 - 4 mm thick layer of fine slurry is applied, preferably by hand. The ideal emulsion content is dependent on the aggregate type and on the grading, the time before the new stone seal will be applied, the traffic conditions on the road and on the thickness and method of application. Table E 14 may be used as a guide in respect of traffic.

[2] Manual 26 has been withdrawn, with its content incorporated into this manual

Table E 14 Binder Content of Texture Slurry

ELV/lane/day	Percentage of residual bitumen in mix by mass of aggregate	Typical emulsion contents for texture treatments
> 10 000	7 - 8	180 - 200 ℓ/m^3
1000 - 10 000	8 - 10	200 - 220 ℓ/m^3
<1000	10 - 12	220 - 260 l ℓ/m^3

Notes:

- ***Percentages given are by mass of loose dry aggregate and not by mass of the total mix.***
- ***The construction of small experimental sections, trafficked for a week, usually provide sufficient information to enable the appropriate emulsion content to be selected. The residual bitumen contents given in Table E 14 are based on the aggregate having a maximum relative density of 2,65. Adjustments to the percentages of residual bitumen can be made for aggregates with different maximum relative densities by multiplying the given bitumen contents by a ratio of (2,65/X), where X is the maximum relative density of the aggregate to be used.***

E.6.5.1.2 Slurry overlays (Simplified)

The recommended simplified method is considered applicable for lower volume roads (typically < 3000 vpd), provided the aggregate is well graded and within the recommended envelopes (Refer PART B: Materials).

This method originated from the Gautrans design method [11], which was developed through experimental work and performance evaluation. An "appropriate binder content" (Stable grade 60% emulsion) for a specific type of grading and traffic situation, within a specific climatic zone, is selected. The climatic zones identified by the former Transvaal Roads Department coincide well with "Wet, Moderate and Dry" macroclimatic regions as defined by the Weinert N values [4] of less than 2, 2 - 5 and more than 5.

The process is summarized as follows:

Steps:

1. Obtain recent and relevant traffic data and convert to Equivalent Light Vehicles per Lane per day (ELV) where 1 Heavy vehicle = 40 Light vehicles. Any vehicle other than light delivery, car or minibus should be considered a heavy vehicle.
2. Assess the existing surface according to TMH9 [13] (Fattiness/ Dry-brittleness).
   a. Dry is defined by a degree of 3 or more.
   b. Recent rejuvenated surfaces are considered as "fatty".
   c. Bleeding or slick surfaces should not be treated with a slurry seal.
3. Verify the purpose and type of slurry mix.
4. Verify material grading within specification.
5. Select the relevant macro-climatic area (Figure E 35).
6. Use Figure E 36 to select the appropriate binder (emulsion) content.
7. Select the appropriate filler content based on the dust (-0,075) content or by the "Mixing and coating test" (Refer E.6.6.1.2).

8. Determine the water demand for the selected application, using the cement that will be used on site (Refer E.6.6.1.1).

<u>Note</u>: Although Figure E 36 could recommend emulsion contents of up to 330 l/m^3 of dry sand, based on real experiments on low volume roads, current recommendations suggest lower upper limits e.g. maximum of 280 l/m^3 for fine slurry on a low volume road. The lower border of areas shaded in red represent maximum emulsion contents currently recommended.

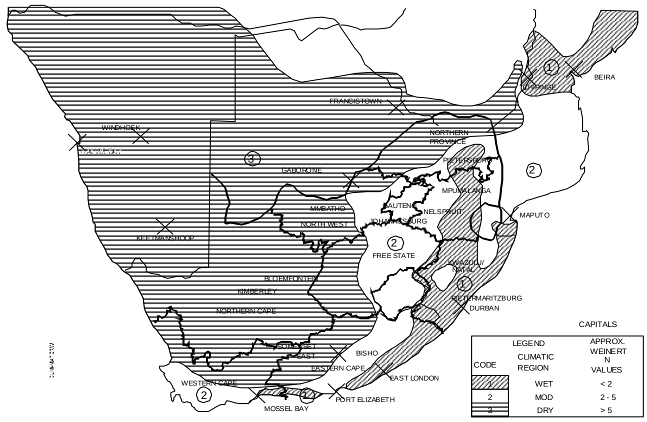


Figure E 35 Macro-Climatic Regions of southern Africa

<u>Example</u>:

For a Medium graded slurry in a moderate to dry environment on an existing dry surface, with 2500 elv/l/d, the appropriate emulsion content would be in the order of 240 l/m^3 (Refer Figure E 36).

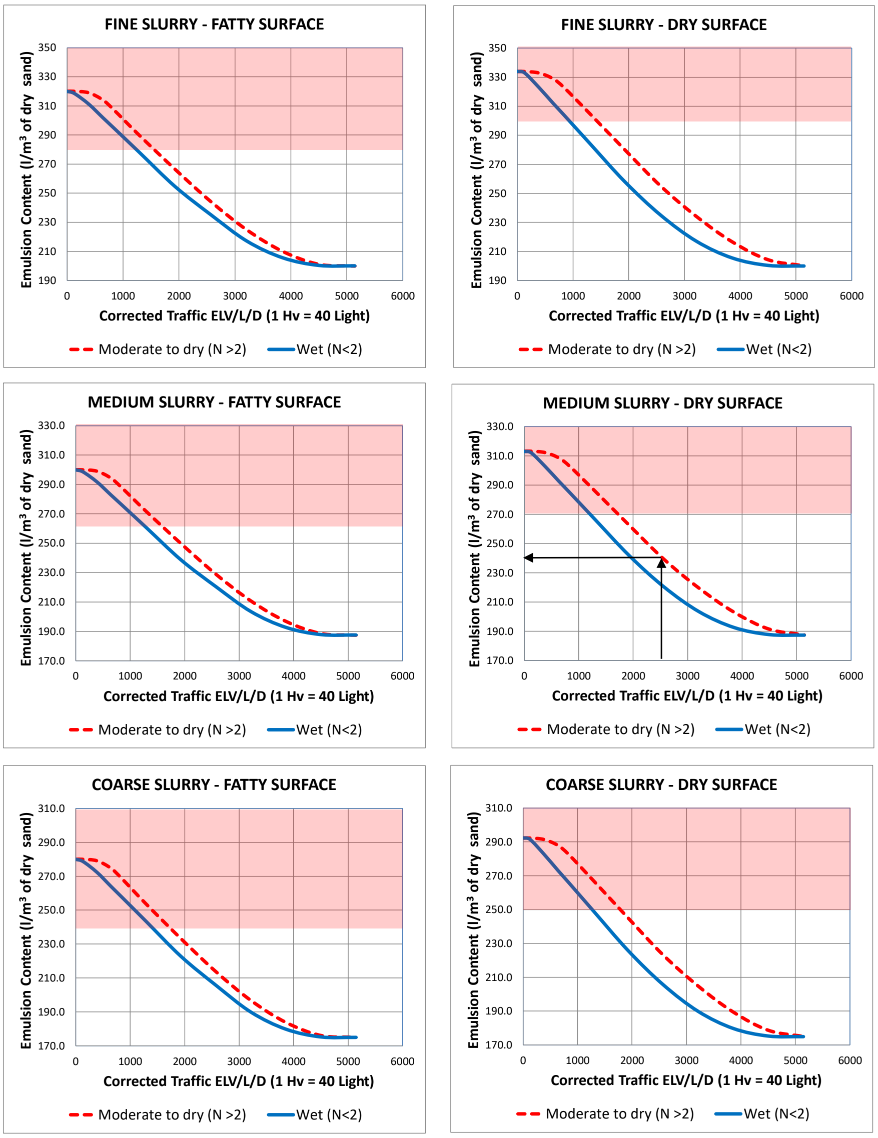


Figure E 36 Simplified Slurry Design

***Note**: Red zones considered as unnecessary high emulsion contents.*

E.6.5.1.3 Cape seal slurry (Simplified)

For low volume roads and aggregates within the COTO specifications, a mix consisting of 100 parts aggregate to 20 parts stable grade emulsion (60 per cent) by mass is recommended. The cement content should be between 1 and 1.5 parts. The water content may be varied, but it will normally be about 15 parts to give a flow of 30-40 mm using ASTM test method D 3910.

Approximate slurry spread rates for the different Cape seal types are provided in Table E 15. This could vary significantly based on the true shape and spread of the single sized aggregate, the softness of the substrate and the construction process. As further discussed in PART F: Construction, the first layer of slurry is levelled off with the top of the stone. Trafficking this layer will result in compaction of the slurry and reducing the volume to approximately 80 – 85%. In the case of an open spread 20 mm aggregate, this will result in a coarse macro texture and high road noise. A final layer of finely graded slurry is then applied, again level to the top of the stone.

Table E 15 Slurry Spread Rates

Single seal size (mm)	1st Layer (m^2/m^3)	2nd Layer (m^2/m^3)
20	185 - 195	360 - 370
14	195 - 205	
10	330 - 340	

E.6.5.2 Detailed Design Process

A detailed design is recommended for high traffic situations and/or non-standard aggregate and requires comprehensive testing. The process is summarized as follows:

- Sample preparation and compaction.
- Preliminary evaluation.
- Abrasion testing.
- Determining of voids filled with binder.
- Evaluation and decision.

Sample preparation

- Several slurry mixtures are made up, varying the emulsion content from 180 ℓ/m^3 to 260 ℓ/m^3.
- The slurry mixtures, each 200g are poured into Marshall briquette moulds to approximately 15 -20 mm in depth.
- Samples are dried overnight at 60°C to allow water evaporation.
- Samples are then compacted using the Marshall hammer - 150 blows (only one side).

In case automatic compaction equipment is used, a spacer would be required to obtain a similar height to a normal Marshall briquette as shown in Figure E 37 and Figure E 38.

Figure E 37 Marshall Mould and Spacer for Mechanical Compaction

Figure E 38 A 20mm Layer of Slurry Poured into the Mould

Figure E 39 Specimen after Compaction (on a spacer)

Preliminary evaluation

During the compaction of the briquettes the extent to which plastic deformation occurs should be recorded After compaction the briquettes are broken in two and the colour and pliability recorded.
The ideal binder content would result in:

- No plastic deformation at the edges (between the hammer and the side of the mould).

- Dark grey to black coloured specimens, slightly pliable when broken in two.

A dull brown colour indicates too low binder content.

Figure E 40 Preliminary Evaluation of Briquettes

Abrasion testing

The visual evaluation of compacted samples could result in a range of binder contents being acceptable (typically three percentages of bitumen e.g. 7%, 8%, 9%). Mixes with the same range of binder contents are then prepared and abraded using the **Wet track abrasion test**.

The apparatus is shown in Figure E 41

Figure E 41 Wet Track Abrasion Test Apparatus

Steps taken in the preparation of the specimens are as follows:

1. Cut 300 mm diameter of suitable material (Felt roof leaking repair material works well).
2. Pour the slurry mix (approximately 800g on the felt material).

Figure E 42 Slurry Poured onto 300mm Felt Material

3. Spread the slurry mix without slushing the fines and emulsion to the top.

Figure E 43 Spread the Slurry Mix Evenly and Allow to Dry

4. Allow the sample to dry for approximately 24 hours and weigh accurately to 0.1 g.
5. Abrade the sample according to ASTM 3910.

Figure E 44 Abraded Specimens

6. Dry the abraded sample in a ventilated oven at 60 ^{o}C to constant weight and weigh accurately to 0.1 g (Typically 24 – 48 hours).
7. The loss of aggregate is then determined and the performance evaluated. The performance in terms of aggregate loss of specimens with different binder contents is mostly quite obvious/visible as shown in Figure E 45.

Determine the voids filled with binder

SANS 3001- AS10 Bulk density and void content (Marshall) is used to calculate:

- Bulk relative density of the briquette.
- Percentage of voids in the mix.
- Voids in mineral aggregate.
- Percentage of voids filled with binder.

Evaluation and decision

Minimum binder content

Figure E 45 shows the mass loss after abrasion on a specific aggregate grading with different binder contents. The arrow depicts the binder content where after an increase in binder does not alter the mass loss significantly. Within a range of appropriate binder contents, this percentage is considered to be the absolute minimum binder required for a slurry (in this case approximately 7% bitumen calculated to the mass of dry aggregate).

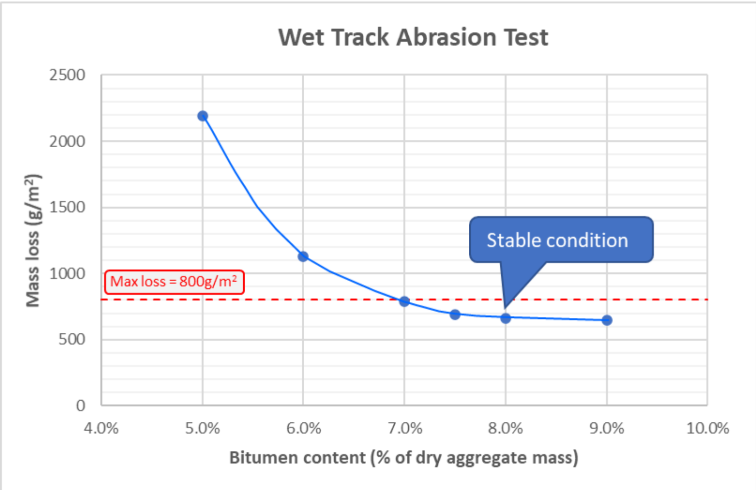


Figure E 45 Mass Loss versus Bitumen Content

WARNING !:

Additional tests should be carried out adjacent to the "turning point" as the test is sensitive to the preparation of the sample before abrasion. As 7% appears to be the critical binder content in many cases to stabilise mass loss, at least three samples should be tested at this binder content.

In addition to the above:

- *The International Slurry Seal Association (ISSA) recommends a binder content resulting in less than 800g/m^2.*
- *Changes in the grading (specifically with increase the fines content) could result in a too dry slurry with risk of ravelling.*
- *The low binder content will result in a high water demand to satisfy flow requirements, which in turn, will*

*result in **higher permeability**.*
- *Also of importance to note that low binder contents result **in stiff mixtures, prone to cracking** (Refer PART C: Performance of Cape seals).*

Figure E 46 highlights the effect of the percentage of fines (-0.425mm) in the slurry mix.

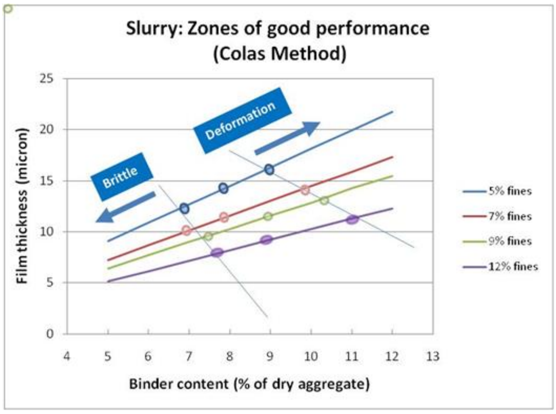


Figure E 46 Percentage Fines Impact on Performance [10]

Samples are often taken of the crusher dust on site at the beginning of a project and submitted to an accredited laboratory for the slurry design. This design is then applied throughout the project without re-evaluation when additional material is delivered to site. Cases have been recorded where the dust content (minus 0.075mm) varied within the acceptable range of 4% to 15% without adjustment of the binder content, resulting in ravelling of the slurry on significant proportions of the project.

Figure E 47 shows a slurry ravelling as a result of too low binder content. It also highlights that bleeding of Cape seals is mainly due to the tack coat binder.

Figure E 47 Bleeding of a Cape Seal through a Ravelling Slurry

Maximum binder content

The maximum binder content is a function of the purpose of the slurry and the conditions under which it has to perform.

Visual evaluation of the briquettes shows a variation from a brown and dull colour at 5% binder to a shining specimen with some plastic deformation at 10%. For this particular grading (aggregate mixture) the material stuck to the Marshall hammer at percentages higher than 10%.

Using SANS 3001 - AS10 the voids filled with binder is determined for each of the prepared briquettes and plotted against the binder content. In addition, the visual observations regarding the briquette condition is added (brittle, normal, fatty) to define the range of "Voids filled with binder" providing a "Normal" performance.

Superimposing the observations on the "mass loss versus binder content" graph (refer Figure E 49), provides a range of binder contents in a "normal" performance category.

Figure E 48 Briquettes with Different Binder Contents (% Bitumen)

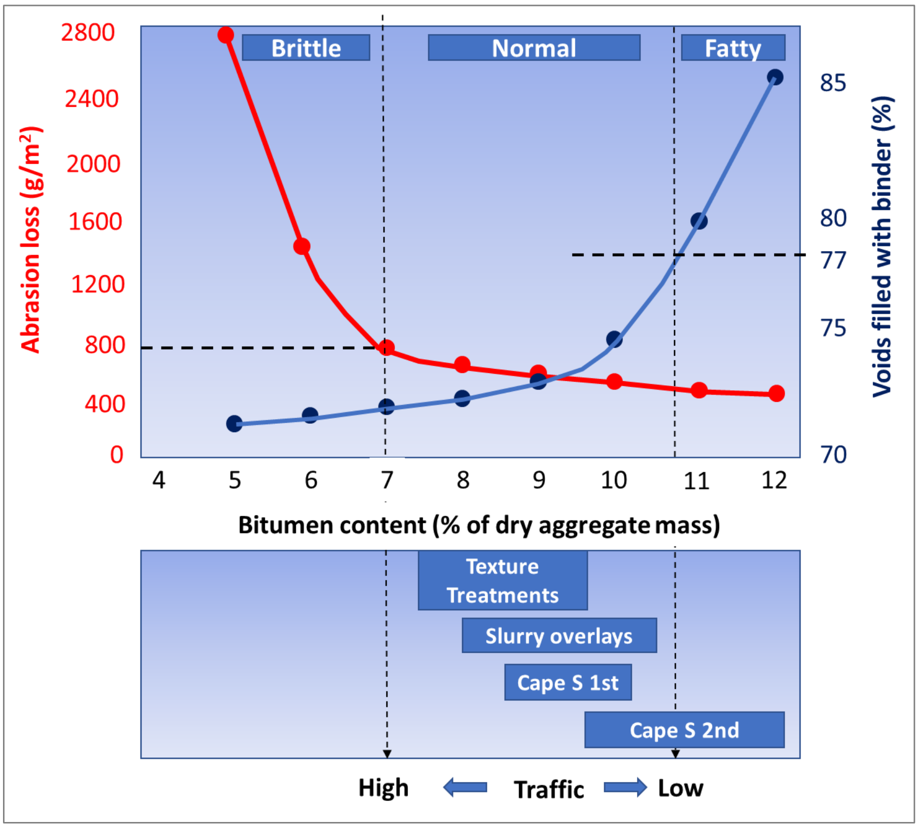


Figure E 49 Combined Information for Decision Making

A final decision is taken at this stage for conventional slurries to select the design binder content, taking account of:

- Traffic conditions.
- Timing of and type of surfacing to follow the slurry application.
- Construction process and technique.
- Traffic conditions.

In terms of Equivalent Light Vehicles (ELV) per Lane per day the following guidelines apply:

- High - > 15000 ELVs
- Low - < 3000 ELVs

***Note**: Risks related to dry/brittle slurry and impact of variability in the grading, suggest not specifying binder contents close to the perceived turning point towards a stable mass loss, even if the mass loss is less than 800 g/m^2.*

Bulking

As further elaborated on in PART F, the mass measuring proportions are often converted into volume. Although volume batching is discouraged, it is still a more practical solution with labour intensive work. Care should be taken on site to determine the moisture content of stockpiles before using, as both the mass and the volume increases with small increase in moisture (Refer Figure E 50). Volume batching, without adjustment of the binder content could result in bleeding/fattiness as experienced in a case, shown in Figure E 51.

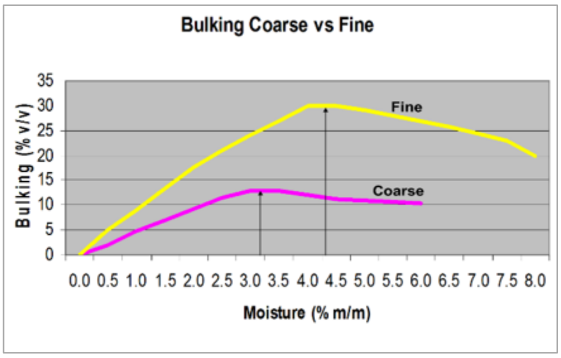


Figure E 50 Effect of Bulking on Slurry Aggregate

Figure E 51 Effect on Slurry Not Compensating for Bulking due to Moisture

Timing and type of surfacing to follow the slurry application

Texture treatment and/or rut filling are often done just prior to resealing operations. The typical minimum curing periods (COTO 2020) [6] are as follows:

- Texture treatments - 6 weeks.
- Rut filling (rapid setting slurry) - 12 weeks.

The higher the traffic and the quicker the follow-on seal must be applied, the drier (less binder) the mix should be.

Note*: *Should circumstances require earlier sealing after the pre-treatment e.g. close to winter, ball penetration testing could be done to monitor the hardening of the slurry. Commencing with seal work is not recommended if the corrected ball penetration is still more than 2 mm.

E.6.6 USEFUL TESTS

E.6.6.1 Water Demand (Consistency Test)

The mixture of crusher dust, cement and emulsion requires additional water to improve the workability. A general rule of thumb suggests an additional water demand of approximately 80% of the total emulsion content. However, the required workability is dependent on the specified procedure and is measured by the flow of the mixture on a plate (ASTM consistency test).

Figure E 52 ASTM Consistency Test

Figure E 53 Slurry Flow Measurement

Typical flows required for different applications are as follows:

Table E 16 Recommended Slurry Flow

Application	Target Flow
Slurry bound macadam	60 mm
Texture treatment or Cape Seals	30 - 40 mm
Slurry overlay	20 - 30 mm
Micro surfacing	10 - 20 mm

Notes:

- ***The number reflects the flow distance from the outside of the cone and not the radius of the slurry on the plate.***
- ***The target flows recommended are not specifications and could be adjusted on site.***

E.6.6.2 Mixing and Coating Test

The purpose of this test is to determine the stability of the mix and appropriate percentage of cement or lime to obtain a creamy mix without segregation.

Notes:

- ***1% filler (cement or lime) is normally sufficient.***
- ***When the dust content (<0.075 mm) is less than 7% of the dry aggregate mix, up to 1.5% filler addition was suggested in previous guideline documents. However, this will result in a stiffer mix, more prone to cracking and therefore, not recommended.***
- ***Some materials are insensitive to cement or lime to obtain the desired creamy consistency. The use of Calcium Chloride could be effective in such cases.***

Figure E 54 Mixing of Slurry Components

Figure E 55 shows a sample with cement (creamy consistency) and one without cement (segregating)

Figure E 55 Effect of Slurry with and without Cement

E.7 MICROSURFACINGS

E.7.1 GENERAL

The design of microsurfacings is considered highly specialised and is therefore, not addressed in detail.

Although the basic principles for design of conventional slurries apply, the selection and addition of additives for different situations complicates the design dramatically. Therefore, it is recommended that the design of microsurfacings be left to the suppliers of these products.

E.7.2 ADDITIONAL TESTING FOR MICROSURFACINGS

E.7.2.1 General

Similar to conventional slurry, the design of microsurfacings require evaluation of the aggregate grading and properties as well as the minimum binder content to prevent ravelling. However, due to the different curing process (chemical), additional testing is required to determine the need for and quantity of chemicals (usually amines) to obtain an appropriate mix that will allow sufficient time to mix before breaking.

E.7.2.2 Effect of additive on mixing and setting time

Depending on the purpose of the microsurfacing, climatic conditions, equipment and traffic accommodation requirements, more or less additive could be introduced in the mix. A balance should be obtained to ensure no early breaking during construction but sufficient additive to open traffic as early as possible. Figure E 56 highlights the effect of an increase in additive on mixing time before breaking.

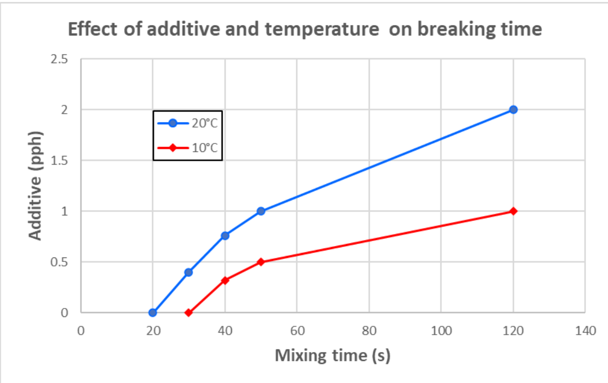


Figure E 56 Mixing Time Before Breaking

Notes:

- ***The mixing time before breaking for a microsurfacing should be at least 90 seconds.***
- ***The formulation of the product should be such that complete curing will take place within a maximum of 4 hours, regardless of the climatic conditions during construction, to allow opening to traffic.***

Figure E 57 highlights the speed at which sufficient curing could be achieved with correct formulation of additives.

Figure E 57 After 5 minutes and 15 minutes

E.7.2.3 Methylene Blue Test

The purpose of this test is to verify the degree of electrostatic attraction between emulsion and the aggregate.

The Methylene blue is positively charged and neutralises the negative charge of the aggregate fines in the prepared solutions. More and more Methylene blue is added until the total charge is neutralised, resulting, thereafter in excess Methylene blue, which creates a halo effect on the filter paper as shown in Figure E 58 and Figure 59.

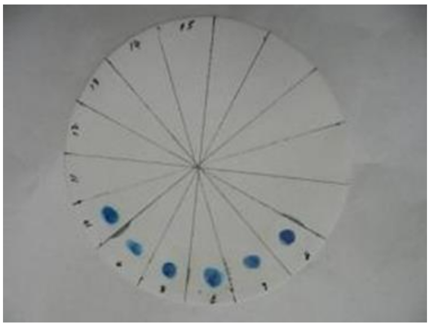


Figure E 58 Effect of Methylene Blue Addition

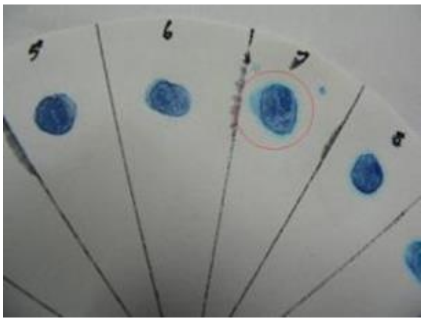


Figure E 59 Halo Effect

In this particular case the value of 7 is recorded.

Experience indicates reaction times with the following values:

- >10 Reaction time too quick
- < 4 Too slow setting
- 6 – 8 Ideal

Note:

More or less positively charged break control additive could be added to obtain a workable mix. (Methylene Blue values of 6 – 8).

E.8 INVERTED DOUBLE SEALS

E.8.1 DESIGN PROCESS FOR INVERTED DOUBLE SEALS

Inverted double seals are constructed by first applying the smaller aggregate and then the larger aggregate. Reasons quoted for the reverse operation are:

- Armor plating of a soft substrate (reduced punching with 7 mm aggregate).
- Base protection during half-width construction. Sealing the new half surface width first with a 7 mm aggregate is considered a lower risk than immediate construction of a double seal or a single 14 mm layer.

The current approach is to design the two layers as individual single seals. However, experience indicate that additional binder might be required to fill up the voids in the first seal e.g. 7 mm or that provision must be made for an additional emulsion cover spray.

E.9 CHOKED SEALS (RACKED-IN SEALS)

E.9.1 DESIGN PROCESS FOR CHOKED SEALS

A choked seal can be described as an open single seal, choked with a smaller aggregate, without the application of a binder penetration coat. Several roads have been successfully resealed in South Africa with choked seals consisting of 14 mm and 7 mm aggregate as well as 20 mm and 7 mm.

Good experience with 20 mm and 10 mm aggregate has been reported in New Zealand and Australia.

***Notes*:**

- ***The performance is highly dependent on the spread of the large (first) aggregate layer.***
- ***Too open a spread results in the smaller aggregate (top layer) forcing the binder to the top with resulting bleeding.***
- ***Too close a spread results in the top aggregate layer not being in contact with the binder, resulting in whip-off.***
- ***Aggregate particles larger than 7 mm can cause cracking of windscreens. Therefore, 10 mm aggregate for the top layer is not recommended.***

The first aggregate layer should be placed open and not shoulder-to-shoulder in order to leave room for the 7 aggregate (Refer Figure E 30).

The quantity of binder is calculated by normal methods, using the ALD of the large aggregate and adjusting the quantity for the percentage of 7 mm aggregate that is anticipated to be used.

It is suggested that a sample be made up of the ideal mix required by placing the large aggregate in a pan, opening it up sufficiently to enable the 7 mm stone to be in contact with the binder.

- The design ALD of the mixture can then be determined.
- The sample may be screened and the application rates of the two aggregates determined.
- The aggregate application rates may be compared with those obtained in the field by adjusting the gates of the chip spreader for a dry run.

From observations, the following comments might be of value:

- If binder is under-sprayed, loss of 7 mm aggregate will be excessive.
- The judgement of opening up the large aggregate matrix in the field to accommodate the 7 mm aggregate is arbitrary and may either cause loss of 7 mm aggregate or flushing.

E.10 GEOTEXTILE SEALS

E.10.1 DESIGN PROCESS FOR GEOTEXTILE SEALS

E.10.1.1 General

Geotextile seals are defined as bituminous surfacings consisting of a bitumen saturated geotextile and a conventional seal. The geotextile effectively absorbs strain to inhibit reflection of cracks.

The geotextile is adhered to the existing surfacing by spraying a bituminous binder tack coat and rolling with a pneumatic roller. Dependent on the application rate of the tack coat and the preference of the engineer, a conventional seal could be constructed directly on the geotextile, adding additional binder to compensate for absorption into the geotextile. Alternatively, a saturation coat could be sprayed onto the geotextile and covered with small aggregate e.g. crusher dust before the conventional seal is constructed.

Experience in South Africa consists mainly of seals constructed on polyester, non-woven fabric, double needle punched (150g/m^2).

Although some experiments are documented, sufficient information regarding the long-term performance on the full traffic spectrum does not exist. Therefore, information provided should only be considered as guidelines for good practice.

E.10.1.2 Design Guidelines

Experience indicates that the required total application is a function of the construction procedure. Lower total application rates could suffice if the seal is constructed in stages allowing traffic compression of the saturated geotextile before application of a large aggregate seal.

E.10.1.2.1 Geotextile tack coat

The purpose of a tack coat is to properly adhere the geotextile to the existing surfacing.

A variety of binders have been used worldwide with hot application rates varying from 0.6 ℓ/m^2 to 1.2 ℓ/m^2. This relates to approximately 0.5 – 1.1 ℓ/m^2 residual bitumen.

The ideal application rate is dependent on the texture and permeability of the existing surface, the viscosity of the binder used for the tack coat, the grade of geotextile used and the traffic. The ideal tack coat application rate is considered one where the geotextile would be saturated, without being tacky, after rolling with a heavy pneumatic roller and 6 - 8 weeks trafficking.

The following minimum and maximum application rates are suggested for the recommended non-woven, double needle punched geofabric with mass of 150 g/m^2:

- High traffic (ELV > 15000) and fine existing texture 0.5 ℓ/m^2 residual bitumen.
- Low traffic (ELV < 5000) and coarse existing texture 1.1 ℓ/m^2 residual bitumen.
- Although a polymer modified emulsion (SC-E1) without solvents is preferred, hot binders could be used, provided the application temperature is below the temperature recommended by the geotextile supplier.

E.10.1.2.2 Saturation coat

Trafficking the road for 6 - 8 weeks would show whether there is a need for additional binder to saturate the geotextile. Areas exhibiting dry/clean geotextile should be sprayed with a diluted emulsion and, if necessary, covered with a washed coarse sand or "Grit" (low fines, minus 4.75 mm coarse sand).

Note:

If the probability of rain is high, the geotextile must be saturated and covered with a coarse sand.

E.10.1.2.3 Aggregate seal application rates

The seal is designed in the conventional way described in this manual.

In the case of stone seals:

- Corrected ball penetration is taken as 1mm.
- No provision is made for additional binder due to texture depth.
- Add at least 30% additional binder if using the minimum to compensate for the vertical movement of the stone on the geotextile (only if not saturated already).

Notes:

- ***Should circumstances not allow for trafficking of the geotextile e.g. concern for low skid resistance or contractual aspects, additional binder would be required to prevent whip-off. Experience indicates an additional 0.3-0.4 ℓ/m² net binder is required to prevent whip-off.***
- ***Due to the movement of the aggregate layer on the geotextile, it is recommended that the total binder calculated is distributed to make provision for a cover spray (minimum hot application rate of 1.0 ℓ/m² diluted emulsion).***

E.10.1.2.4 Additional comments

- Rapid setting slurries applied on geotextiles tend to delaminate.
- Tack coats without cutters are recommended.
- Concerns regarding milling of geotextile seals are only valid on new geotextiles. These products tend to deteriorate within 10 years to such an extent that it could be torn by hand.
- A non-woven geosynthetic fabric, double needle punched with properties as specified in COLTO Chapter 10 should be used.
- The use of steel wheel rollers is not recommended.

E.11 GRADED AGGREGATE SEALS

E.11.1 SAND SEALS

Generally sand seals are not recommended as initial seals for roads on which the traffic exceeds 750 ELV per lane per day. However, as a reseal or texture treatment numerous examples exist where sand seals have performed exceptionally well on roads carrying up to 3000 ELVs per lane per day. The success of sand seals on higher volume roads relates to a coarse grading (2.0 mm - 5 mm) with a low dust content (minus 0.075 mm). The material falling into this category is often referred to as "Grit".

Should a sand seal be selected as the initial seal, it is recommended that a double sand seal be constructed or that provision be made to reseal the road within three years. Timeous reseal, even with another sand seal, could result in a service life of the second seal in excess of ten years.

E.11.1.1 Design

There is no specific design method for sand seals. A nominal bituminous binder application rate of 1,0 ℓ/m^2 residual binder is recommended.

As a rule-of-thumb the hot binder is applied at the following rates:

- Penetration grade bitumen….1,1 - 1,3 ℓ/m^2
- Cut-back bitumen……………….1,2 - 1,4 ℓ/m^2
- Emulsion………………….………….1,4 - 1,6 ℓ/m^2

The selected application is a function of the purpose of the seal, the porosity and texture of the existing seal, the grading of the sand, the prevailing temperature and the expected traffic

Thereafter the sand is applied at a rate of between 200 and 100 m^2/m^3 and rolled. For one to two weeks, depending on the traffic, the excess sand is swept back towards the wheel tracks to prevent fattiness and pick-up.

Notes:

- ***A sand texture treatment differs from a conventional sand seal in that the minimum quantity of binder is applied and the sand application rate is reduced to approximately 300 m^2/m^3.***
- ***Excellent performance on roads carrying up to 3000 ELVs per lane per day has been recorded using coarse graded sands and precoated coarse sand. Precoating eliminates dust during construction, reduces the need for back sweeping and requires a lower rate of binder application.***
- ***Moist aggregate reduces dust during construction and improves adhesion when using emulsions or cut-back bitumen. Refer to construction of sand seals (PART F) to prevent built-in corrugations.***
- ***A higher application rate of aggregate (120 – 100 m^2/m^3) is normally required when applied by hand.***

E.11.1.2 Aggregate

Normally river sand or crusher dust is used for sand sealing. The sand should be screened to eliminate pebbles larger than 7 mm. These pebbles are often quarzitic with large crystals and when applied and rolled, although they partially penetrate the surfacing, they tend to shatter under steel wheel rollers and to form incipient potholes. The recommended grading of the sand is given in PART B.

E.11.1.3 Binder

Typical binders used for sand seals are given in Table E 17.

Table E 17 Binders used for Sand Seals

Summer	Winter
65% or 70% Cationic Emulsion 70/100 pen. bitumen MC 3000 cut-back bitumen	65% or 70% Cationic Emulsion MC 3000 cut-back bitumen

Notes:

- ***Sand seals are highly sensitive to rain within hours of construction.***
- ***Coarse graded precoated sand seals with cut-back bitumens are sensitive during and immediately after construction to road surface temperatures above 50 °C.***
- ***MC 800 cut-back bitumen is not recommended and should only be considered on very low volume roads in very cold areas.***
- ***Several products are marketed in South Africa as bituminous dust palliatives and have been used with success to provide dust-free surfaces. These products are often mixtures of hydrocarbons and cut-back bitumens, applied at approximately 1,4 ℓ/m^2 and blinded with sand. The average effective life of these surfacings is 3 years on lightly trafficked roads.***

E.11.1.4 Additional information on graded aggregate seals

Although numerous graded aggregate seals have been constructed in South Africa over the past thirty years and some case studies have been documented, insufficient information exists to provide guidelines for all traffic spectrums.

General recommendations:

- Softer binders are recommended (e.g. MC3000).
- Recommended binder application rates vary between 1.4 – 1.6 ℓ/m^2 residual binder.
- Preferred aggregate (max 14 mm).
- Dust (max 5% preferred 2%).
- Aggregate spread rate (0.015 m^3/m^2) or 67 m^2/m^3.
- Max traffic (ADT = 1000 vpd in both directions).

E.11.2 OTTA SEALS

Following excellent performance of Otta seals in Botswana using marginal quality material, several road authorities in southern Africa have introduced the use of graded aggregate seals. Although the design, construction and maintenance is well described [14], it has been decided to incorporate the basic information of the Otta seal and local experience with graded aggregate seals into this manual.

E.11.2.1 Otta Seal summary

E.11.2.1.1 General

The Otta seal was developed by the Norwegian Roads Research Laboratory during the early 1960's and refers to the Otta valley where it was first used. The seal consists of graded aggregates (natural gravel or crushed rock) in combination with soft (low viscosity) binders. From experience, three different aggregate gradings have been defined namely "Open", "medium" or "dense".

Dependent of the circumstances a single or double layer of aggregate is constructed after which a sand cover seal is generally applied. The total thickness of a single Otta seal is approximately 16mm. A single Otta seal with a sand cover layer is normally used with ADT < 1000vpd.

Key aspects for a successful Otta seal are:

- Using a soft binder that could work itself up into the aggregate layer.
- Maximum particle size (Preferred 16 mm - Maximum 19mm).
- Dust content (<0.075mm) (Preferred <10% - Maximum 15%).
- After care in the form of brooming material back into the wheel tracks during the first hot season.

E.11.2.1.2 Design of Otta seals

From experience, suitable binder application rates have been determined and provided in Table E 18.

Table E 18 Binder Application Rates for Otta Seals

Hot bitumen spray rates for un-primed base course (ℓ/m^2)					
Type of Otta Seal		Grading			
		Open	Medium	Dense	
				AADT<100	AADT>100
Double	1st layer	1.6	1.7	1.8	1.7
	2nd layer	1.5	1.6	2	1.9
Single with sand cover seal	1st layer	1.6	1.7	2	1.9
	Fine sand	0.7	0.7		0.6
	Crusher dust or coarse river sand	0.9	0.8		0.7
Single		1.7	1.8	2	1.9
Maintenance reseal (single)		1.5	1.6	1.8	1.7

Notes:

- ***Refer to PART B for material properties***
- ***Reduce application rate by 0.2 ℓ/m^2 for the first layer on a primed base course***
- ***Increase application rate by 0.3 ℓ/m^2 if the aggregate water absorbency is more than 2%***

Recommended aggregate spread rates are provided in Table E 19.

Table E 19 Aggregate Spread Rates for Otta Seals

Type of seal	Aggregate spread rates (m^2/m^3)		
	Open grading	Medium grading	Dense grading
Otta seals	77 – 63	77 – 63	63 – 50
Sand cover seals	100 – 83		

E.12 STRESS-ABSORBING MEMBRANE INTERLAYER (SAMI)

E.12.1 DESIGN PROCESS SAMIs

E.12.1.1 General

SAMIs are not, strictly speaking, seals. They are designed and constructed as single seals with modified binders (usually bitumen-rubber). As their name implies, they are applied on an existing surfacing as an interlayer, prior to the application of an asphalt overlay. Their purpose is to accommodate and attenuate strains in the existing pavement and to prevent or minimise their transfer (typically reflective cracking) to the new asphalt surfacing.

E.12.1.2 Design

Typically, a 14 mm single seal is constructed using a bitumen rubber product e.g. S-R1 at application rates between 2.0 and 2.5 l/m^2.

Different to the normal S-R1 single seal, the aggregate spread rate is similar to a conventional binder single seal, resulting in an open matrix (Refer Figure E 30 Open shoulder-to-shoulder matrix) after rolling and before the asphalt wearing course is applied.

E.13 SEALING DURING WINTER (EMBARGO PERIODS)

E.13.1 IMPORTANT CONSIDERATIONS

The highest risk of failure (stripping/aggregate loss) occurs when sealing during cold periods or when temperatures drop significantly shortly after construction.

Key aspects to minimise risk are as follows:

- Plan seal construction on high volume roads for the summer period.
- Add alternative low risk seal types and binder combinations in the bill of quantities, if the probability exists that the project will extend into the winter months.
- Monitor ambient and road surface temperatures on a daily basis and change over to lower risk seal types and binders.
- Low risk seal types (Refer PART D).
- Addition of low flashpoint solvents (LFS) requires specific safety precautions. Only MC30 is recommended with a maximum of 4% LFS during the middle of winter and reducing towards spring to maximum 2%.
- Emulsions could be applied at 10ºC road surface temperature and assist to extend the construction period. Due to the low viscosity, more orientation of the stone could occur during construction than with hot binders and therefore, increased contact area between the stone and the binder. However, once the water has evaporated, it could be very similar in properties to the base binder in terms of allowing/ not allowing further aggregate orientation (Refer PART C) – Therefore, not truly a winter seal binder.
- Always apply a cover spray on seals constructed during or close to winter.
- Specific attention is required during construction to apply and roll the seal as quickly as possible (Refer PART F).
- Traffic compaction at low speeds and when road surface temperatures have increased above 18ºC is perhaps the most important factor to minimize risk of stripping. If necessary, the sealed section must be closed during night-time (at least for two nights) and only opened to controlled traffic during daytime.

***Note*: Ambient temperatures and road surface temperatures during the day and night could be vastly different in different parts of the country.**

E.14 DESIGNING FOR VERY LOW AND VERY HIGH TRAFFIC VOLUMES

E.14.1 GENERAL

Design guidelines in this manual originated from research, investigations and experience over a period of more than fifty years. However, it should be noted that equations developed are based on performance of typical traffic volumes in South Africa (ELVs between 2000 and 15000). Extrapolation beyond these limits pose a certain degree of risk.

Recommendations for very low and very high traffic volumes are discussed in the following sections:

E.14.2 VERY LOW VOLUME ROADS

Based on the best fit of data in the “zone of most experience”, equations increase application rates dramatically for the very low volume roads, resulting in unnecessarily high values.

Monitoring the performance of numerous low volume roads and re-evaluation of old Provincial design manuals, resulted in the recommendation to select 2000 ELVs/lane/day as the minimum design traffic and to use the minimum application rate “to prevent whip-off” (Refer Figure E 60).

E.14.3 VERY HIGH-VOLUME ROADS

The higher the traffic volume and load, the quicker the aggregate orientation and the higher the embedment of large aggregate particles.

Although equations are now provided instead of design charts, the effect of increased traffic and increased embedment is visible on Figure E 60 below. With high traffic (increased embedment), the minimum volume of binder applied to prevent whip-off could be too much to maintain a selected target macro texture.

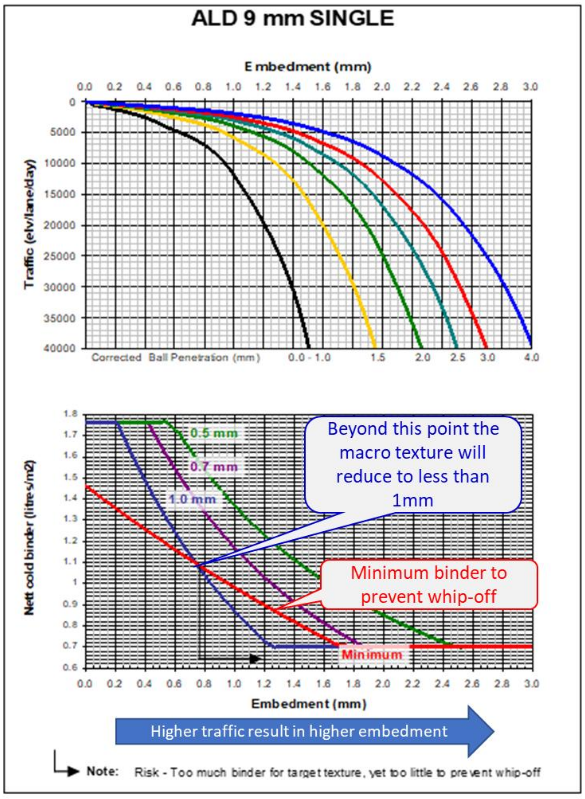


Figure E 60 Sensitivity to High Traffic Volumes

One way to ensure a minimum target texture is to select aggregate with a higher ALD [15] or to use a double seal.

Similar to the discussion under very low volume roads, extrapolation of best-fit curves to very high volume situations might not provide appropriate answers. Therefore, it is recommended that additional effort be applied during the design for high volume roads and that the performance of trial sections be monitored before final design.

E.15 SUMMARY

E.15.1 DESIGN CHECKLIST

Table E 20 provides a summary of the most important data/information required for design. Section references are provided to each component.

Table E 20 Summary of Information Required and Section References

Component	Comments	Reference
Project detail and contacts	See design summary sheet	E.15.2
Uniform design sections (UDS)	Identify. Design required for each	E.3
Traffic volume and distribution	Minimum 7-day count recommended. Obtain information on seasonal traffic	E.4.2.1.4
Seal type, structure and binders	Confirm. See limitations	PART D
Aggregate properties	At least 5 samples per stockpile	PART B
Ball penetration tests	Minimum 10 texture measurements in and between wheel tracks per UDS	E.4.2.1.5
Existing macro texture	Minimum 10 texture measurements in and between wheel tracks per UDS	E.4.2.2.1
Heavy vehicle speed	Identify where < 40km/h. Separate UDS. Reduce binder	E.4.2.2.5
Channelization	Reduce binder for narrow roads	E.4.2.1.4
Aggregate spread	Recommend to only design for closed packing (dense matrix)	E.4.2.2.6
Cold micro-climate	Identify where (Shade, bridges etc). Separate designs	E.4.2.2.3
Grit /sand blinding	Identify where required (access, stop-go, cold micro- climate). Separate designs	E.4.2.2.13
Aggregate micro texture	Increase for smooth textured aggregate unless precoated	E.4.2.2.4
Dry/cracked existing surface	Increase binder	E.4.2.2.14
Macro climatic area	No longer used for adjustment	E.4.2.2.2

E.15.2 DESIGN SHEET

A design sheet summarising the seal design should be prepared, highlighting any assumption and/or changes to recommended values. The rationale for any of these changes should also be described e.g. the designer might decide to ignore the recommended texture adjustment on a coarse Cape seal due to the new 10mm single seal fitting well into the coarse matrix and in touch with the slurry.

Different road authorities require different forms to be completed for this purpose.

Design spreadsheets could be developed using the equations provided in this document to calculate the recommended application rates for each layer and to highlight results might increase the risk of failure/poor performance.

Figure E 61 shows an example of such a spreadsheet, allowing the user to enter project information, displaying values of input parameters entered in separate sheets, displaying comments of relevance when selecting specific cells and providing warnings for situations not in accordance with recommendations.

SEAL DESIGN SUMMARY: SURFACE TREATMENT APPLICATION

Form No ....

Contract:		Contractor:		Consultant:		Designer:		Tel No:	
Road No:		Carriageway:		Lane:		From km:		To km:	
Uniform Design Section:									

Seal Type: **Cape_Seal**

Aggregate size				Binder types				
	3rd Layer	None			Cover spray	None	Dilution	0
	2nd Layer	None			3rd Application	None		
	1st Layer	20	Precoated		2nd Application	None		
					1st Application	Hot: S-E1		

Shading	Note
(green)	Enter data
(blue)	Calculated - Do not change
(grey)	Headings
(yellow)	Selection from Drop-down list
Warnings	Looked up

Traffic

AADT	Min (7 day count)				
Volume Light per lane	1000	Heavy Vehicle speed min (km/h)	60	E80 per Heavy	1
Volume Heavy per lane	100			Average E80/day (dual direction)	200
Equivalency factor	40			Traffic factor (Western Cape)	0.13
ELVs	5000				

Road surface condition

					Average	20th %tile	80th %tile	Warnings
Existing substrate type								Sensitivity analysis required
Crocodile cracking	Degree		Existing texture depth	Smoothest Wheel track	0.50	0.44	0.55	
	Extent			Between Wheel tracks	0.79	0.71	0.84	
				Design Value for Cape_Seal	**0.84**			
Other cracking (not edge)	Degree		Corrected Ball Penetration	Wheel tracks	1.50	2.00	2.00	Sensitivty analysis required
	Extent			Between Wheel tracks	1.00	1.00	1.00	
				Design Value for Cape_Seal	**2.00**			

Climate

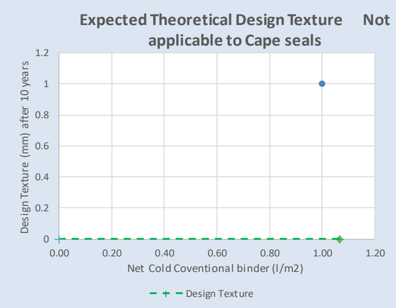
Macro Climate (Weinert N)	5	Micro climate	Normal
Operating Temperature	44	Season of sealing	Summer

Figure E 61 Design Summary Sheet (Part 1)

Aggregate Properties									Warnings
Stockpile position/ name		km 6.5R(b)					0		
Lab Sample No									
Source		OMV	OMV	OMV	OMV	OMV			
Type		Dolorite	Dolorite	Dolorite	Dolorite	Dolorite			
Size		20	20	20	20	20	0	Design ALD	
ALD	Measured	13	13	13	13	13		13.00	
	Calculated	11.9	12.3	12.0	12.4	12.3			
Flakiness		9.0	10.4	10.6	11.0	11.2			
Dust content		0.4	0.4	0.5	0.4	0.3			
Durability (Etylene Glycol)		2	2	2	2	2			
10% FACT	Dry	328	0	0	0	0			
	Wet	220	0	0	0	0			

Binder Application								
		TRH3						
		Min	Cape S Max				W Cape ALD	13
Basic Net Cold Conventional Binder	Calculated	1.07	1.33	N/A	N/A	N/A	W Cape NCCB	1.69

									Warnings
Adjustments	Existing Macro Texture Depth (mm)	0.84	0.23	0.23	0.23	0.23	0.23		
	Select Texture adjustment or ignore		0.23	0.23	0.23	0.23	0.23		
	Heavy vehicle speed (km/h)	60	0.00	0.00	0.00	0.00	0.00		
	Channelization (yes/no)	no	0.00	0.00	0.00	0.00	0.00		
	Aggregate spread (open or closed)	Closed	0.00	0.00	0.00	0.00	0.00		
	ColdMicro Climate (yes/no)	no	0.00	0.00	0.00	0.00	0.00		
	Grit/Sand blinding	no	0.00	0.00	0.00	0.00	0.00		
	Aggregate micro texture	Coarse/precoated	0.00	0.00	0.00	0.00	0.00		
	Dry and cracked existing surface	no	0.00	0.00	0.00	0.00	0.00		
	Macro climate (Weinert N)	Moderate	0.00	0.00	0.00	0.00	0.00		
Total NCCB after adjustments			1.30	1.56					
	Selected NCCB (Design total)		1.30		Effective NCCB		1.07		



					Warnings
Fog/ cover spray	Binder type	None	Dilution	0	
	% Bitumen in Emulsion	0	% Emulsion in dilution	0	
	Hot application rate	0.00			
	% part of seal	50%	NCCB(fog)	0.00	

							Warnings
Seal	Remainder after fog spray	NCCB(seal)	1.30				If emulsion is used for the tack coat, the maximum application rate should be checked for run-off
		Tack coat 1		Tack coat 2		Penetr. coat	
Distribution	% NCCB	100%		0		0%	
Binder Type		Hot: S-E1		0		0	
Modified conversion (factor)		1.3		0		0	Check minimum application rates for modified binders to prevent tramlining
Cold- hot conversion (factor)		1.08		0		0	
Contractor tolerance (%)		0%		0		0%	

Design		Tack coat 1	**Hot: S-E1**	Tack coat 2	0	Penetration coat	0%		Fog/ cover spray	None	Dilution	
Calculated	Total hot binder	**1.83**	l/m²	0	l/m²	**0**	l/m²		**0.00**	l/m²	0	**Warnings**
Specified	Total hot binder		l/m²		l/m²		l/m²			l/m²		

Figure E 62 Design Summary Sheet (Part 2)

E.16 REFERENCES

[1] Department of Transport. (Technical recommendations for highways; Draft TRH3). Surfacing seals for urban and rural roads and compendium of design methods for surfacing seals used in the Republic of South Africa. 1986. Pretoria.

[2] Van Zyl G D, Measurement and Interpretation of Input Parameters Used in the South African Surface Seal Design Method, Conference on Asphalt Pavements for Southern Africa (CAPSA), Gabarone, Botswana, 2007.

[3] Van Zyl G D, Fourie H G and Rossmann D. Stripping of seals in South Africa: Case studies and guidelines for an improved approach to mitigate it. CAPSA. South Africa, 2019.

[4] Weinert HH. 1980. The Natural Road Construction Materials of Southern Africa, CSIR.

[5] Anochie-Boateng J.K, Komba J.J, Gculisile M. Mvelase B. Three-dimensional laser scanning technique to quantify aggregate and ballast shape properties.

[6] Committee of Transport Officials, (COTO), Standard Specifications for Road and Bridge Works for State Road Authorities, Pretoria, South Africa, 2020 (In preparation).

[7] Western Cape Provincial Government, Materials Manual. Chapter 6, Revison 3. South Africa . 2008

[8] South African National Roads Agency (SOC) Ltd, Technical Recommendations for Highways: Design and Construction of Surfacing Seals (TRH3), Pretoria, South Africa, 2007.

[9] Van Zyl G D and Fourie H G. Key Aspects Of Good Performing Cape Seals. Conference on Asphalt Pavements for Southern Africa (CAPSA). South Africa, 2015.

[10] Van Zyl, G.D, Louw J, Labuschagne M. Establishment of appropriate slurry seal design methods for South Africa. Conference on Asphalt Pavements for Southern Africa (CAPSA), South Africa, 2011.

[11] Gauteng Department of Transport (GAUTRANS). 1992. Seal Design Manual. Pretoria, South Africa.

[12] Marais, C.P. 1979. Advances in the design and application of bituminous materials in road construction. PhD Thesis, University of Natal, Durban.

[13] Committee of Transport Officials, Technical Methods for Highways: Manual for the Visual Assessment of Road Pavements (TMH9) - Part B: Flexible Pavements, South African National Roads Agency SOC Ltd., Pretoria, South Africa, 2016.

[14] Republic of Botswana, Roads Department, Ministry of Works, Transport and Communications. The Design Construction and Maintenance of Otta Seals, Guideline No 1. June 1999.

[15] Judd D and Bester A. Pushing the limits of surface seals and its effect of material properties. Conference on Asphalt Pavements for Southern Africa (CAPSA), 2007.

[16] Van Zyl G D, Fourie H G and S.J. Bredenhann, Recommended Practice for Winter Sealing in South Africa, Conference on Asphalt Pavements for Southern Africa (CAPSA). South Africa, 2015.

[17] Transit New Zealand,. Chipsealing in New Zealand. First Edition. Chapter 4, Chapter 12, 2005.

[18] Committee of Land Transport Officials, (COLTO). Standard Specifications for Road and Bridge Works for State Road Authorities, Pretoria, South Africa, 1998.

[19] Southern African Bitumen Association (Sabita), Technical Guideline: The Use of Modified Binders in Road Construction (TG1), South Africa, 2019.

[20] Van Zyl G D and Jenkins K. Overview of Long-Term Seal Performance. Conference on Asphalt Pavements for Southern Africa (CAPSA). South Africa, 2015.

[21] Van Zyl GD, 2010. Synthesis on Cape Seal variations in southern Africa. 2nd International Sprayed Sealing Conference, Melbourne, Australia, 2010.

[22] Clayton RA. 2004. Experience with Cape Seals on heavily trafficked roads leading to improved design and larger aggregate utilization. Conference on Asphalt Pavements for Southern Africa (CAPSA), Sun City, South Africa.

[23] Surface treatment manual. 1994. Pretoria. Transvaal Provincial Administration.

[24] Van Zyl GD and Van der Gryp A. Correlation between Mean Profile Depth Estimated Macro Texture Depth. CAPSA 2015.

APPENDIX A

MODIFIED TRAY TEST

The test equipment consists of a circular tray with an area of 0,05 m^2 and a wall height of 50 mm, and of a shoulder piece which fits snugly on top of the tray, has the same internal diameter as the tray and is fitted to a loose-fitting cloth membrane. The purpose of the membrane is to prevent the "density sand" flowing into the voids between the stones.

Volume of stone plus voids	V_3	=	$V_1 - V_2$
		=	$(M_1 - M_2) / BDS$ *(see Figure E 63)*
where	BDS	=	*bulk density of the sand*
Effective layer thickness (ELT) of the stone layer		=	V_3 / A
where	A	=	*area of tray.*
Void content in stone layer	(V_v)	=	$(V_3 - V_{stone}) / V_3 \times 100\ \%$
		=	$(V_3 – M_S / RDS) / V_3 \times 100\ \%$
where	RDS	=	*relative density of stone*
	M_S	=	*mass of stone sample*

The practical spread rate of the stone and the bulk void content of the aggregate are determined by taking the stone sample from the modified tray test and pouring it into a plastic measuring cylinder (2 000 mℓ capacity) and determining the bulk volume of the sample. Repeat a number of times and determine the average bulk volume of the stone sample.

The practical spread rate of the stone		=	$V_4 / A \times 10^{-3} (m^3/m^2)$
where	V_4	=	*bulk volume of the tray test sample (ℓ)*
	A	=	*area of the tray* (m^2)
The bulk void content	(V_b)	=	$(V_4 – V_{stone}) / V_4 \times 100\ \%$
		=	$(V_4 – M_S / RDS) / V_4 \times 100\ \%$
Theoretical spread rate		=	$ELT(100 – V_v) / (100 – V_b) \times 10^{-3} (m^3/m^2)$

If there is a close agreement between the values of the theoretical and practical spread rates, the test data are most likely correct; if not, there was probably an error in the procedure or calculations.

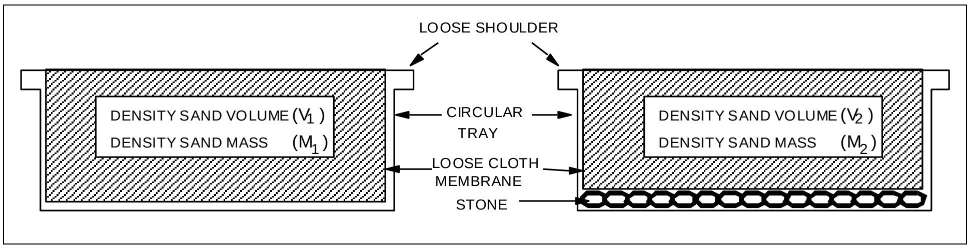


Figure E 63 Schematic Illustration of the Modified Tray Test

APPENDIX B

MODIFIED MARSHALL TEST FOR SLURRY DESIGN

(Documented by P Fourie – Soillab)

Modified Marshal method for slurry design

This method is used to determine an appropriate binder content for use in slurry mixtures. Although this method was derived for coarse mixtures it has also proven to be successful in fine mixtures. This method makes use of the Marshall Method for the compaction of briquettes. Briquettes are formed from materials, of which, the emulsion content is increased in increments of 20 l/m^3.

Stepwise procedure:

1. Create a sufficient quantity of briquettes ensuring that all the Marshall properties are adhered too as well as indirect tensile strength, submersion index and creep properties.
2. The composition of mixtures with different emulsion contents are based on 1m3 loose sand. (Uncompacted / Loose Bulk Density - TMH1: method B9).
3. Assume the loose bulk density is 1 600kg/m3. Calculate the quantity cement that needs to be added, for example 1.5%=24kg. For the purpose of this test, emulsion contents of 160 l, 180 l, 200 l, 220 l, 240 l, are chosen that will be mixed with 1m3 crusher dust.
4. A table can now be put together for use in the creation of briquettes.

Table E 21 Guidelines for the Creation of Briquettes

Emulsion in mixture	(l)	160	180	200	220	240
Slurry Sand 1m^3 (uncompacted)	(kg)	1600	1600	1600	1600	1600
Cement 1.5%	(kg)	24	24	24	24	24
Water	(l)	120	112	104	96	88
Net binder for 60% emulsion	(l)	96	108	120	132	144
Net binder for 60% emulsion Binder head density = 1025kg/m^3	(kg)	98.4	110.7	123	135.3	147.6
Net binder in mixture	(%)	5.71	6.38	7.04	7.68	8.33
Laboratory Mixtures:						
Emulsion	(g)	111.47	124.52	137.38	150.06	162.56
Slurry Sand	(g)	1114.72	1106.82	1099.03	1091.34	1083.77
Cement	(g)	16.72	16.60	16.48	16.37	16.26
Water	(g)	83.60	77.48	71.43	65.48	59.61
Net Binder	(g)	68.55	76.58	84.49	92.29	99.98

5. The amount of water added to attain workability is determined, with the slurry consistency test, in order to achieve the correct consistency. Laboratory mixtures are composed in a such manner as to achieve a mixture of 1200g after the emulsion has broken and the water has evaporated. In the example shown above, to attain an emulsion of 160l the following mix is required, 1114.72g sand, 111.47g emulsion, 16.72g cement and 83.60g water. The mixture is left in a bowl so that the emulsion can break and the water can evaporate. Thereafter the samples are placed in an oven and briquettes compacted when the temperature reaches 135°C (compaction temperature). The briquettes are compacted in a Marshall mould by means of 75 blows with the Marshall hammer on both sides. Briquettes are compacted with all the mixtures as set out in the table above.
6. For each of the binder contents a mixture is made to determine the maximum theoretical relative density. (Method C4 of TMH1).
7. Determine the bulk relative density of the compacted briquettes (Method C3 of TMH1) and calculate the percentage air voids for each of the binder contents.
8. Thereafter the stability and flow of the briquettes are determined according to Method C2 of TMH1. Indirect tensile strength, submersion index and creep property tests are carried out on the surplus briquettes.
9. Record the test results on an appropriate data sheet and compare these against the required specifications.
10. For coarse and medium slurry mixtures the same specifications as for asphalt mixtures should be applied.
11. Once the optimum composition is determined, three sample mixtures are made up (allowing 10 litres less

and 10 litres more than the optimum) and visually inspected for segregation, clotting and colour. Thereafter a thin layer of the slurry mixture is applied on cardboard and left so that the emulsion can break. Take note of the time it takes to break. Allow the mixture to harden. After a day or two the mixture can be tested with the heel of your shoe by making circular movements on it. Check the mixture for complete binder coverage of the aggregate as well as for segregation.

Notes:

- ***1200g slurry is usually too much to create a briquette 63mm thick. Adjust the mass accordingly in order to end as close as possible to a thickness of 63mm.***
- ***In the calculation of the laboratory mixture, a proportionate mixture for 1m3 of sand is used as a basis to compose 1200g laboratory samples.***
- ***After the consistency has been determined for the mixture that contains the least amount of emulsion, the water content of the other mixtures could be calculated by deducting the additional emulsion from the water content of the first mixture.***
- ***As a starting point, we can assume that the quantity of water that needs to be added to achieve workability is approximately 70-80% of the volume of the first emulsion.***
- ***It is sometimes necessary to make minor adjustments on site in order to optimize the mixture.***
- ***The percentage of net binder is calculated for control purposes. Slurry mixtures are allowed to break, then placed in an oven at 105-110°C and allowed to dry.***
- ***Binder extraction can be carried out by means of normal extraction methods (Method C7 of TMH1).***
- ***The accuracy of results depends mainly on the sampling process.***

PART F

CONSTRUCTION

CONTENTS

LIST OF TABLES

LIST OF FIGURES

F.1 INTRODUCTION

F.1.1 CONTEXT

Manual 40 comprises seven parts:

- Part A: General
- Part B: Materials
- Part C: Performance
- Part D: Seal type and binder selection
- Part E: Design
- **Part F: Construction (This document)**
- Part G: Quality Assurance
- Part H: Repair of premature failures

F.1.2 OBJECTIVES

The purpose of PART F is to provide information and guidance regarding the equipment and processes applied during the construction of surface treatments.

F.1.3 SCOPE

PART F discusses equipment and processes during construction under the following headings:

F.2 Equipment

F.3 Preparation

F.4 Pretreatment

F.5 Aggregate management

F.6 Trial sections

F.7 Weather limitations

F.8 Binder application

F.9 Aggregate application

F.10 Rolling

F.11 Brooming and cleaning

F.12 Summary – The spray sealing process

F.13 Opening to traffic

F.14 Slurry mixing and application

F.15 Rejuvenation sprays

F.16 Specific recommendations related to seal types

F.17 Quality assurance and checklists

F.2 EQUIPMENT

F.2.1 BINDER DISTRIBUTOR

F.2.1.1 General

Typical characteristics of binder distributors in South Africa are:

- Tank capacity: 9000 – 20 000 litres
- Spray bar width: 4.2 m
- Nozzle spacing: 100 mm
- Angle of nozzle to bar: 30 Degrees
- Pressure governed by varying pump speed. Pump speed adjusts to change in speed to maintain constant spray rate

Figure F 1 Fixed Angled Flair Distributor

Notes:

- ***Swirling jet systems are not common in South Africa***
- ***Distributors must be purpose-built and certified before allowed on site***

F.2.1.2 Certification

SANS 3001 covers a set of tests for annual certification of a binder distributor as fit for purpose, and includes the following:

- Validation of a dipstick (SANS 3001-BT21).
- Power and road speed (SANS 3001-BT22).
- Pump system performance (SANS 3001-BT23).
- Spray bar transverse distribution (SANS 3001-BT24).
- Spray flair distribution (SANS 3001-BT25).

The binder distributor used for distributing the bituminous binders should:

- Comply with the mentioned SANS 3001 specifications and covered by a valid certificate of compliance, not older than 12 months, issued by an accredited testing organisation
- Not have any fuel, oil or binder leaks:
- Have a straight and clean spray bar, all the spray heads of which should be of the same type which open simultaneously and should not leak when closed;

- Have its spray heads all spraying at the same angle to the spray bar and the height adjusted to the correct level so as to obtain the required overlapping. The uneven application of binder should be unacceptable.
- Have its sieve undamaged and clean;
- Be under the direct control of an operator approved by the Engineer on the grounds of a CV with experience and list of contracts completed with references, in writing or a certificate of competence signed by a representative of a road authority;
- Be fitted with a suitable cut-off spray-head (end nozzles) or fishplates to prevent over spraying onto gravel shoulders or staining of concrete elements on the edge of the surfacing of the road.
- Be capable of spraying the binder at the specified applications rates. The pump of the distributor should be capable of delivering the binder at the spray bar nozzles at the correct pressure to obtain the specified application rates, irrespective of the viscosity properties of the prescribed binder and the number of nozzles open.
- Fitted with a suitable valve or other access gate for taking of samples of the binder for testing purposes.
- The binder distributor, pumps and nozzles, used for non-homogeneous modified binder should be adapted to spray the rubber modified binder satisfactorily. The Contractor should provide proof by way of a test on the site that the binder distributor has sufficient reserve power to maintain the required constant speed up the steepest incline to which spray has to be applied and to obtain a uniform distribution of the binder.

The transverse distribution of the spray bar should be field-verified by means of SANS 3001-BT24. Measurements of transverse distribution ('Bucket test') for a binder distributor. The maximum permissible tolerance permitted between the troughs (excluding the outer 300mm) is dependent on the viscosity of the binder type being applied and should be as follows:

- All emulsions, cutback and penetration grade bitumen – 5 %
- Hot homogeneous modified bitumen – 7 %
- Non-homogeneous binders (bitumen rubber) – 10 %

The spray bar should be of such design as to allow for any adjustments to be made in order to meet the above tolerances. This procedure should be carried out each time the distributor is first established on site and once a week thereafter or when a problem with transverse distribution is suspected. The distributor should thus have a set of troughs available in order to allow the execution of the test.

The transverse distribution of spray flairs should be field verified according to SANS 3001-BT 25. The maximum permissible tolerance permitted for each trough from the average of the nine troughs is 10 %.

F.2.2 CHIP SPREADERS

The chip spreaders should be capable of spreading stone of the specified size uniformly and should be capable of adjustment to permit variation of the rate of application within the specified tolerances and uniform spreading in both the transverse and longitudinal directions.

The chip spreader should be capable of delivering a proper and uniform transverse distribution of chips across the width of application. The chip distribution should be tested by means of canvas patches, each 1,0 m by 1,0 m and placed side by side over the full width of application. The mass of chips spread onto each individual canvas patch should not deviate by more than 10 % from the spread rate determined as part of the trial section and recorded in the approved method statement.

At least two chip spreaders should be provided on site, one of which should be self-propelled.

In cases where the sprayed width exceeds the maximum spread width of the chip spreader, an additional chip spreader should be provided to apply aggregate on the remaining strip within twenty seconds of the first chip spreader.

Spreaders which are not self-propelled should be of a type that can be attached quickly to the rear of trucks and operated while backed over the aggregate being spread.

A non-self-propelled chip spreader may **only** be used in the event:

- Of a breakdown of the self-propelled chip spreader during a pull and should be limited to the completion of that pull. No further application of binder should be permitted until such time as the self-propelled chip spreader is repaired or replaced.
- Of spreading Class 3 aggregate, Graded aggregate, Sand- or Grit seals.

Figure F 2 Self-Propelled and Non-Self-Propelled Chip Spreader

Note:

- ***It is difficult to calibrate and to accurately spread a single layer of aggregate with a non-self-propelled chip spreader easily resulting in over application and poor compaction.***

F.2.3 ROLLERS

F.2.3.1 General

Sufficient operational rollers of each of the following types should be available on the works to maintain the required tempo of work.

- Pneumatic tyred rollers (minimum two).
- Rubber-soled steel wheeled rollers (as and when specified).
- Light steel wheeled rollers of 2 – 5 tons (minimum two).
- Heavy steel wheeled rollers of 6 – 12 tons (as and when specified).

The timing, sequence of rolling and number of passes for each seal type should be in accordance with the approved method statements following completion of the trial sections.

No seal work should continue if the required rollers are not on site or not in an operational condition.

F.2.3.2 Pneumatic-Tyred Rollers

Pneumatic-tyred rollers are used on all surface treatments. They should be of a self-propelled type equipped with smooth flat profile pneumatic tyres of uniform size and diameter. The mass of the roller should not be less than 2 ton per wheel.

The rollers should be equipped with suitable devices for keeping the wheels wet and clean with water or non-petroleum-based products during operation.

The wheels of the roller should be so aligned that one pass of the roller will provide one complete coverage equal to the rolling width of the machine. The total operating mass and tyre pressure should be in accordance with the manufacturer's recommendations. Individual tyre pressures should not differ by more than 35 kPa from one another.

In case of sealing more than 12 000 m^2 per day, using a hot binder, at least three pneumatic-tyred rollers are required.

Figure F 3 Pneumatic Tyre Rollers

F.2.3.3 Rubber-Padded Steel Wheeled Rollers

Rubber-padded steel-wheeled rollers are not commonly used in South Africa but are considered effective for quick orientation of aggregate. It is recommended that they are self-propelled and have a mass of between 6 and 8 tons. It should be equipped with suitable devices for cleaning and moistening the wheels using water or non-petroleum-based products.

Figure F 4 Rubber Padded Steel Wheel Roller

F.2.3.4 Steel Wheeled Rollers

Light steel-wheeled are commonly used for sprayed seals. It is recommended that they are sell-propelled tandem rollers of between 2- and 5-tons mass and equipped with suitable devices for cleaning and moistening the wheels using water or non-petroleum-based products. Heavier rollers (6 – 12 ton) could be used provided that no excessive crushing occurs during construction of the trial section. Steel-wheeled rollers should not be used on the final aggregate layer unless a cover spray will be applied after brooming of the surface.

Figure F 5 Light and Heavy Steel Wheel Rollers

F.2.4 WATER SPRINKLER

The water sprinkler should have efficient spray equipment, capable of spraying a uniform film of water over the whole area to be primed.

***Note*: One spray of water could temporarily reduce the road surface temperature with 10°C**

F.2.5 MECHANICAL BROOMS

F.2.5.1 Rotary Broom

The rotary broom should be height adjustable self-propelled or a towed type supplied together with a suitable pneumatic-tyred towing vehicle. The minimum bristle length allowed should be 70 % of the initial length.

Figure F 6 Self-Propelled and Towed Type Rotary Brooms

Figure F 7 New and Worn Bristles on a Rotary Broom

F.2.5.2 Drag Broom

A drag broom should be provided together with a suitable pneumatic-tyred towing vehicle and capable of being ballasted to distribute the specified seal aggregate size. Drag brooms are made in different forms as shown in Figure F 8 and are effective to spread the aggregate uniformly over the full surfaced area.

Drag brooming:

- Takes out corrugations that may be caused by the chip spreader.
- Improves the final ride quality of the surfacing if too much back chipping occurred.
- Distribute aggregate into open areas.

The drag broom is highly effective on stone seals with smaller aggregate, e.g. 14 mm, 10 mm and 7.1 mm aggregate, and could be used on both layers of a 14/7 mm double seal and on the 10 mm aggregate of a 20/10 mm double seal. The broom is not effective on 20 mm aggregate.

Figure F 8 Drag Brooms

F.2.6 LOADER FOR AGGREGATE

A loader, or equivalent capacity labour force unit, compatible with the needs and capacity of the trucks or mixer, in the case of slurry, should be available at the stockpiling site.

F.2.7 SLURRY EQUIPMENT

F.2.7.1 Batch Mixer for Slurry

A mixer should be in a good working order capable of producing a uniform slurry of the constituent materials. All the constituents of the slurry should be accurately proportioned and due care and attention should be given to the sequence in which the ingredients are introduced into the mixer and to the period of mixing. Mixing should be continued until the materials in each batch are thoroughly blended.

Note: Volume batching is less accurate than weigh batching and therefore, not recommended.

F.2.7.2 Mass-Measuring Device for Large Batch Mixers

Where payment per ton is specified, a suitable gauged mass-measuring device is required. The device should be provided with a printer for printing the mass, the time and date.

F.2.7.3 Continuous Slurry Machine

Self-propelled machines are available and able to:

- Load the crusher sand.
- Carry all raw material components.
- Measure material quantities and feed them to a pug mill.
- Mix the slurry continuously.
- Spread the slurry via an augured spreader box.

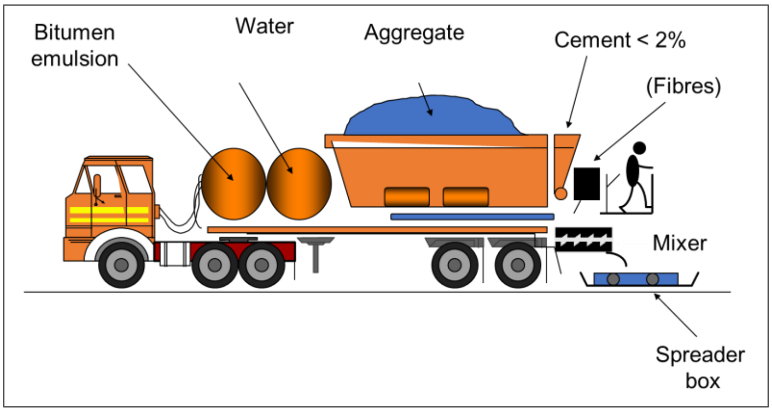


Figure F 9 Continuous Slurry Machine

Aggregate and filler (Cement) contained in separate bins are fed through metering devices at controlled rates to the mixer. Water and bitumen emulsion contained in separate tanks are pumped to the mixer at controlled rates through precise metering devices to enable the various constituents to be combined continuously to the selected or prescribed formulation. The mixing of the slurry should be at a suitable rate adjusted to ensure complete blending of the ingredients and uniformity of mix before depositing into the spreader box.

The spreader box should be so constructed as to distribute the weight onto metal skids in such a way that no damage should be done to the surface when the box is in operation.

Soft rubber belting should be attached to the framework in such a manner as to prevent slurry from being spilt past the sides of the spreader box when the box is in operation.

The spreader box should be capable of spreading a uniform application of the slurry in adjustable widths from 1,5 m to 4,0 m, at specified rates, and it should have efficient mechanical means of adjusting the rates and widths of application specified.

The mixing and application of microsurfacing should be done by a mixer designed to provide a rapid mixing time, and sufficient agitation within the spreading system to prevent segregation or premature hardening. The appropriate workability measured by the flow (Consistency test: ASTM 3910) should be verified during the first application/ trial section and recorded as part of a method statement.

F.2.7.4 Spreader Box for Slurry Rut Filling

A 1.0 m wide spreader box is used in South Africa to spread coarse graded slurry or microsurfacing. The augers in the box assist in moving the coarser particles to the centre to obtain a concave shape (Refer Figure F 10 and Figure F 35).

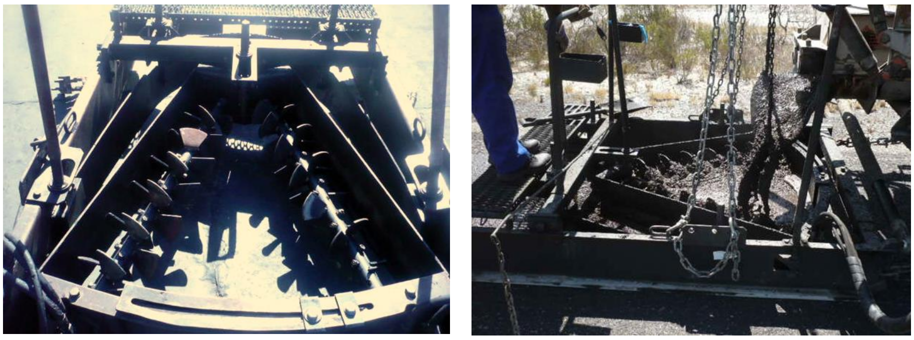


Figure F 10 Slurry Spreader Box for Rut Filling

Just screeding the rut level with the sides as shown in Figure F 11 will result in a rut and because of initial permeability of slurry and microsurfacing, in delamination.

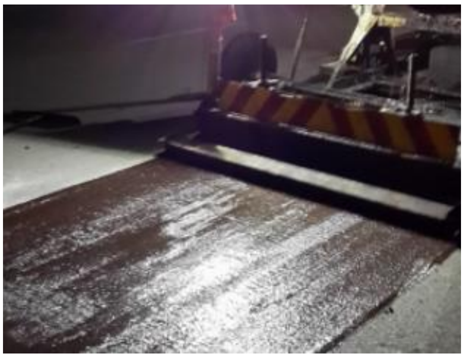


Figure F 11 Rut filling Without Concave Shape

F.2.8 MISCELLANEOUS EQUIPMENT

Sufficient equipment for handling and hauling aggregate, binder and slurry, and blending units for non-homogeneous modified binders, should be provided to ensure prompt and continuous placing and application of bituminous materials as specified.

Ancillary equipment, which should include hand brooms, mat or reinforced paper for joints, string, nails and hand tools to carry out the work efficiently.

Suitable protective clothing should be worn at all times.

Suitable fire-fighting equipment for dealing with fires should be available on site, together with suitable first aid equipment for dealing with injuries and evacuation transport in case of bitumen burns. (Refer to [1] Sabita Manual 8: Bitumen Safety Handbook.)

F.3 PREPARATION

F.3.1 PROJECT PLANNING AND PREPARATION

F.3.1.1 Preconstruction Meeting

The purpose of the pre-construction meeting is to ensure that all parties involved with the project are well informed of the project requirements and timelines.

Good quality seal work is sensitive to climatic conditions, timeous availability of good quality materials, good quality equipment and workmanship. Non-availability of materials at critical times could result in an increase in risk. Therefore, the emphasis is placed specifically on the responsibilities of suppliers and subcontractors to the main contractor.

F.3.1.1.1 Attendance

The meeting should be organized and facilitated by the engineer and specifically attended by:

- Main contractor
- All subcontractors
- Material suppliers
- Equipment suppliers (in case of specialized equipment)
- Laboratory representatives
- Design engineer and supervisory staff
- Site safety personnel

F.3.1.1.2 Specifications

Project specifications are often not well understood by the contractor and/or his sub-contractors and suppliers at the time of tender. This meeting provides the opportunity for the design engineer and supervisory staff to discuss:

- Specific issues and sensitivities regarding the seal design and construction.
- Sensitivities to traffic accommodation and climate.
- Variation to standard specifications.
- Trial section details and method statements.
- Contingency plans.

The responsibility of material suppliers regarding sampling, testing and submission of results must be confirmed.

The higher the traffic volumes, the higher the degree of control is required. In addition, good practice for lower volume roads is not necessarily good practice for very high-volume roads. Appropriate practice must, therefore, be determined for the level of road.

F.3.1.1.3 Volumes

Based on the Contractor’s approved program, the availability of sufficient quantities of materials is essential, in advance, to allow sampling, testing and acceptance. Dedicated stockpiles at the crusher may be required to pre-test construction materials before arrival on site.

It is recommended that suppliers, in conjunction with the Contractor and the laboratory, prepare schedules for production, delivery and testing.

F.3.1.2 Traffic Management

F.3.1.2.1 Planning

Aspects to consider are:

- Peak traffic volumes and policies regarding closures over weekends and public holidays.
- Planning access at interchanges.
- Length and position of closures.
- Flagmen properly trained at critical positions e.g. access roads within closures, and issued with two-way radios.
- Not allowing dual directional traffic on a sensitive new seal by sealing the adjacent lane the following day.
- Treating or blinding intersections to accommodate traffic turning actions.
- Dealing with dust from deviations and haul roads.
- Stop-go positions at steep grades and tight curves, forcing heavy trucks to stop and accelerate on a sensitive new seal, should be avoided.

F.3.1.2.2 Opening

Opening of a new seal to traffic must be done in a controlled way with the following key aspects to consider:

- Complete curing of emulsion binders and slurries.
- In the case of single or double seals, the road surface temperature must be conducive to further orientation of the aggregate (Minimum 18 ºC). Therefore, if cold temperatures or rain are expected, it is recommended to keep the road closed.
- In case of using cutback binders, the road should rather be opened when temperatures have decreased to below 30ºC.
- Traffic speeds should be limited to 40km/h for at least one day.
- If possible, delineators could be used to move traffic transversely over the width of the sealed area.

F.4 PRETREATMENT

F.4.1 SCHEDULING AND COORDINATING REPAIRS AND PRETREATMENT

Provision of a seal necessitates proper management of the total works involved. This includes scheduling of all activities prior to surfacing, which include the following:

- Repair of potholes, pavement and/or surfacing failures and edge breaks.
- Crack sealing.
- Smoothing out of undulations to improve the riding quality.
- Filling of ruts.
- Treatment of dry or porous areas.
- Treatment of fatty areas, e.g. by rolling in chips or hydro cutting.
- Texture treatments to provide a uniform texture.
- Cleaning of existing surfaces.
- Reconstruction of small areas if required, replacement or provision of culverts.
- Provision of sub-surface drainage.
- Reinstatement of service trenches.
- Regravelling of shoulders.

Planning and scheduling of these activities are of the utmost importance. For example, services such as the provision or repair of cable ducts, piping, sub-surface drainage etc, should be completed before surfacing operations begin. Scheduled road-marking should be postponed until the new surfacing has been laid and cured.

F.5 AGGREGATE MANAGEMENT

F.5.1 STOCKPILES

F.5.1.1 Preparation of Stockpile Areas

All stockpile areas must comply with the following:

- Easily accessible to heavy vehicles and plant.
- The distance between stockpiles should be appropriate for the circumstances. A suitable distance between stockpiles is between 4 and 6 km.
- No objects at the stockpile area that hinder movement of plant during loading. Stockpiles under power lines must be avoided to prevent loading equipment from accidentally touching the power line.
- Stockpiles near trees cause problems, especially in autumn and winter with pollution from leaves and branches.
- Stockpiles should not be exposed to dust.
- The stockpile area and floor should be:
  - Well drained. Slopes, hollows or old borrow pit floors must be avoided. The use of side drains for stockpiles must also be avoided. Drains and/or embankments must be shaped in such a way that water drains from the stockpile, without forming ponds around the pile.
  - Cleaned, levelled and all organic material must be removed by means of a grader prior to stockpiling.
  - Well compacted and must have a solid work surface even under wet conditions. A hard surface, such as an old road, is appropriate as a stockpile area and does not require much preparation. Clayey or stony ground must always be avoided.

F.5.1.2 Delivery, Stockpiling and Covering

Aggregates from different sources or crushers should be stockpiled separately. Covering of stockpiles is considered good practice to:

- Keep the aggregate dry
- Prevent contamination by dust, leaves or other matter
- Keep the aggregate temperature compatible with the binder

***Note*: Specifications for minimum road surface temperatures should also apply to the aggregate temperature.**

F.5.1.3 Precoating

F.5.1.3.1 Mixing Process

Precoating should, for environmental purposes, preferably be done at a plant. However, when this is not possible:

- The untreated aggregate stockpile (preferably less than 5m3) is thoroughly sprayed with water and allowed to drain off.
- The damp aggregate is loaded into a bucket of a front-end loader (1.0 m3). The required quantity of an approved precoating fluid is sprayed evenly over the aggregate with a watering can.
- The mixture of aggregate and precoating fluid is dumped on the prepared stockpile area.
- This process continues until a stockpile of approximately 15 to 20 m3 is built up.
- This small stockpile must be turned over with the front-end loader, until the aggregate is uniformly coated with precoating fluid. Three complete turnings of the stockpile are normally required.

F.5.1.3.2 Application

The application (mixing) quantities given in Table F 1 can be used as a guideline for the different aggregate sizes. In addition to these guidelines, the following should be noted:

- Approximately 1.0 to 2.0 ℓ/m^3 less is required when precoating at a plant.
- Different products require different applications. For example, precoated minus 5 mm stone requires 14 – 18 ℓ/m^3 of an appropriate precoating fluid, while minus 14 mm requires significantly less – 12 – 14 ℓ/m^3.
- It is advisable to make up samples with varying precoating fluid application rates, and to visually inspect the coverage of the aggregate.

Table F 1 Nominal Rates for Pre-coating Fluid

Nominal aggregate size (mm)	Nominal precoating application on stockpile or by hand rate (l/m^3)	Nominal precoating application plant precoating rate (l/m^3)
20	12	10
14	14	12
10	16	14
7	18	16
5 or Grit	20	18

F.5.1.4 Allocation of Stockpiles to Road Sections

Although the ideal spacing of stockpiles is approximately 4 to 6 km, compliance with environmental constraints could result in only a few approved stockpile sites, with large volumes and potential high variation in aggregate properties.

For design purposes, the application area of each stockpile must be known, specifically if the properties of aggregate from stockpiles vary. This requires continuous testing of new aggregate delivered to site.

F.6 TRIAL SECTIONS

F.6.1 PURPOSE AND EXECUTION

Trial sections are essential to:

- Confirm the proficiency of the contractor, the equipment, safety, traffic accommodation and the seal process management.
- Verify appropriateness of design application rates and sequence, and aggregate spread rates.
- Verify sampling and testing location and frequency.
- Verify the appropriate roller type, methodology and sequence.

A relatively short section, typically approximately 400 meters, is sprayed with the selected binder at the design application rate. The ability of the distributor to spray the binder evenly, within the prescribed tolerances, over the whole area is checked.

The aggregate is spread at the designed spread rate with a chip spreader. After the aggregate has been rolled with pneumatic tyred rollers and further compacted by traffic, the matrix or spread of the aggregate is visually checked for the selected concentration of application. Adjustments must then be made to the gates of the chip spreader, until the desired spread rate is achieved.

F.6.2 METHOD STATEMENTS

Following the successful construction of the trial section, a method statement regarding the seal construction is compiled describing:

- Equipment required
- Final binder application rates
- Binder application temperatures
- Spread rate of aggregate
- Timing, number and sequence of roller passes and types
- Sampling process
- Management of work zone safety
- Opening to traffic
- Emergency plan

***Note*: Apart from the above, the complete method statement should include:**

- ***Setting out /Demarcation of the work such as lanes, tapers etc. with guide rope.***
- ***The planning of sprays e.g. which lane first etc.***

F.7 WEATHER LIMITATIONS

The following general limitations should apply:

- Whenever the temperature of the road surface falls below the specified temperature for the binder to be applied or is likely to do so before spraying the binder, no binder should be sprayed.
- No bituminous work should be done during foggy or rainy weather and, when a cold wind is blowing, the above temperatures as specified in the sub-sections below, should be increased by 3°C to 6°C.
- When strong winds (more than 30 km/h) are blowing which are likely to interfere with the proper execution of the work, no sealing, especially spraying of binder, should be done.
- No sealing should be done when rain or cold temperature is imminent.
- No sealing should be done when the surface of the substrate is visibly wet, i.e. more than damp.
- No sealing should be done after sunset.

It is recommended that only emulsion products and MC3000 or 70/100 Pen bitumen and S-E1 binders, cutback with MC30, be permitted during the embargo periods. Special formulated winter grade binders should only be allowed if provision is made in the Contract Documentation.

The minimum rising road-surface temperatures at which the spraying of the different types and grades of binder should be allowed are specified in below.

Table F 2 Minimum Road Surface Temperature

Bituminous Binder Type	Minimum Rising Road Surface Temperature
70/100 penetration-grade	25°C
MC 3000	10°C
Cationic emulsion	10°C
Anionic emulsion	10°C
S-E1	25°C
S-E2	25°C
S-R1	25°C
S-R2	25°C
SC-E1	10°C
SC-E2	10°C
S-E1 cut back with 4.5% MC30	23°C
S-E1 cut back with 9.0% MC30	21°C
Any special formulated binder not defined above	As specified in the Contract Documentation

Conventional slurry should not be applied at an air temperature of less than 7°C when temperatures are rising or less than 13°C when temperatures are dropping. During hot weather slurry operations should be suspended when aggregate is being displaced by the spreader box or squeegees or when premature breaking takes place.

Rapid setting slurry or microsurfacing should be sufficiently versatile to be laid in air temperatures of 4°C to 40°C as well as capable of being laid under damp conditions. When the breaking process accelerates to such an extent that it renders the product unworkable to attain the required end result, no further work should be done until adjustments to the composition of the product have been proven through trial sections.

F.8 BINDER APPLICATION

F.8.1 APPLICATION RATE

Accurate application rates are essential for good seal performance. Distributors must be calibrated to achieve a uniform accurate binder application through each nozzle. Following the spray of a section, the total sprayed volume is divided by the sprayed area (Refer Figure F 20 for effective spray width) to obtain the effective application rate.

F.8.2 TRANSVERSE DISTRIBUTION

South Africa typically uses a triple overlap configuration with the three nozzles covering the same area as shown in Figure F 12. Each nozzle sprays and effective width of 300 mm perpendicular to the road centre line and is angled at 15 – 30 degrees.

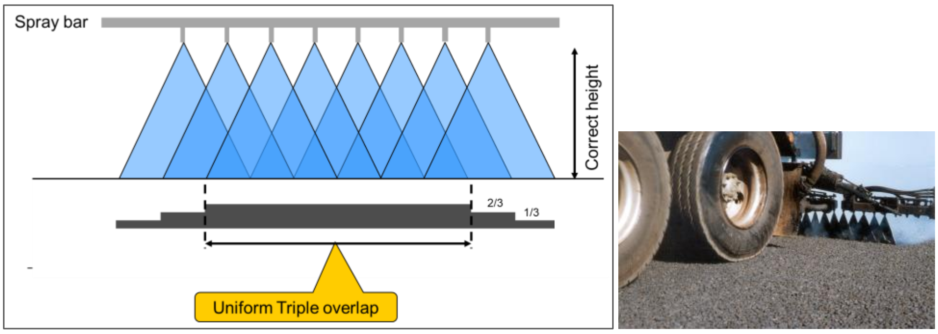


Figure F 12 Correct Bar Height to Obtain a Full Triple Overlap

Poor transverse distribution results in tramlining and risk of poor seal performance as shown in Figure F 13.

Figure F 13 Effects of Poor Transverse Distribution

The main reasons for poor transverse distribution are:

- Incorrect binder temperature, resulting in too high viscosity.
- Incorrect bar height. Figure 14 and Figure 15 shows the effect if the spray bar is too low or too high.
- Incorrect bar pressure.

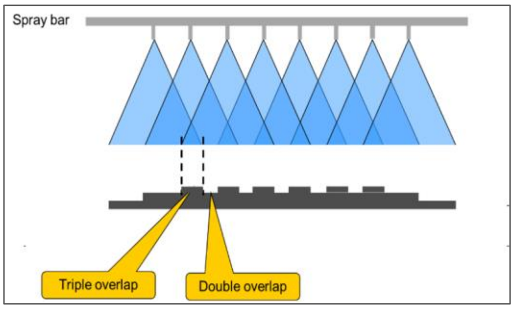


Figure F 14 Effect of "Too Low" Spray Bar

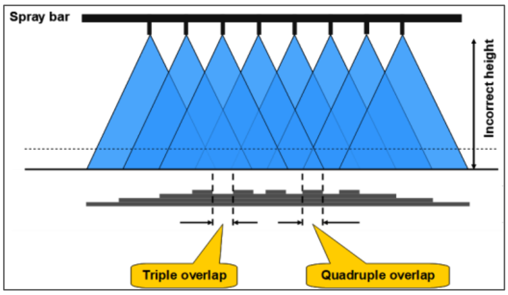


Figure F 15 Effect of "Too High" Spray Bar

Insufficient pressure will result in a poor flair as shown in Figure F 16.

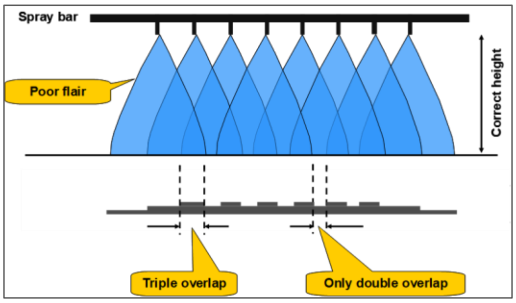


Figure F 16 Effect of Insufficient Pressure in the Spray Bar

Most binder distributors in South Africa are adjustable to provide a selected flow rate through each nozzle, regardless of whether some nozzles are closed off. This allows quick adjustment of the spray bar height to obtain a full triple overlap. A simple process is followed by opening only every third nozzle, spray a short section off the road and adjust the height of the spray bar so that the flairs just meet. The principle is shown in Figure F 17.

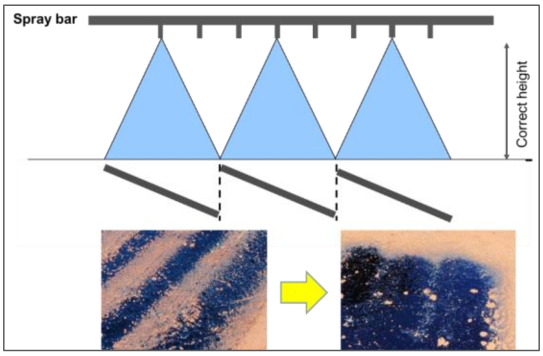


Figure F 17 Adjustment of Spray Bar Height

***Note*: SANS 3001- BT25 requires calibration of the distributor to provide a uniform transverse distribution (per three nozzles) for four different binders. Therefore, if the distributor is properly calibrated for the binder to be sprayed, on-site adjustment would not be necessary**

F.8.3 DEMARCATION

The section to be sprayed must be properly demarcated by means of string lines and reinforced paper to indicate the width and length to be sprayed. Reinforced paper strips must be placed at the beginning and end of sections, on which the binder is sprayed to accurately calculate the actual application rate.

String lines fulfil two purposes namely:

- It guides the driver to accurately apply the binder.
- It assists the cleaning/ removal of stone beyond the "full - 3/3" binder application (Refer Figure F 19). The string line on the joint must demarcate the area sprayed at full application and 2/3 application.

Figure F 18 Guide Marker on String Line

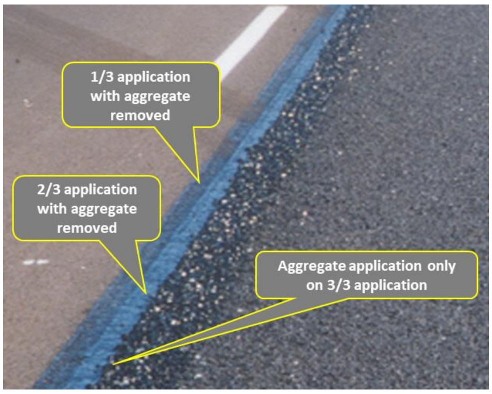


Figure F 19 Aggregate Application Only on Full Application

The string lines positions are illustrated in Figure F 20. The application rate is calculated by dividing the volume of binder sprayed, by the effective area of full coverage. The effective spray width takes into account the reduced binder, due to the flair of the end nozzles. Figure 20 also shows the effective spray width for calculation of the application rate.

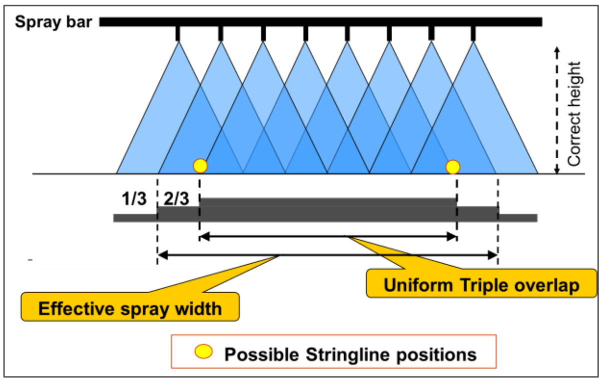


Figure F 20 String Line Positions and Effective Spray Width

F.8.4 TRANSVERSE JOINTS

In order to prevent overlapping at junctions of separate binder applications the previous work along the joint must be covered with removable reinforced paper for a sufficient distance back from the joint to ensure that the sprayer is operating at the required speed before the untreated surface is reached and also to prevent additional binder application onto the previously treated section. The same method should be used to ensure a neat joint at the end of the run.

***Note*: From experience it is recommended that two sheets of reinforced paper (1m each) should be used when spraying bitumen rubber.**

Figure F 21 Transverse Joint

F.8.5 LONGITUDINAL JOINTS

With a triple overlap configuration and the nozzles 100mm apart, the spraying of adjacent strips must overlap by 200 mm i.e. 100 mm of 2/3 application and 100 mm of 1/3 application as shown in Figure F 22.

Good practice also suggests that:

- No turning of the end nozzles or use of fish plates should be allowed at longitudinal joints
- Aggregate should only be applied on the area with full triple overlap binder application
- All aggregate applied on the 2/3 and 1/3 binder application must be broomed back or chipped off in a neat straight line before the adjoining spray
- No longitudinal joints are allowed in the wheel tracks

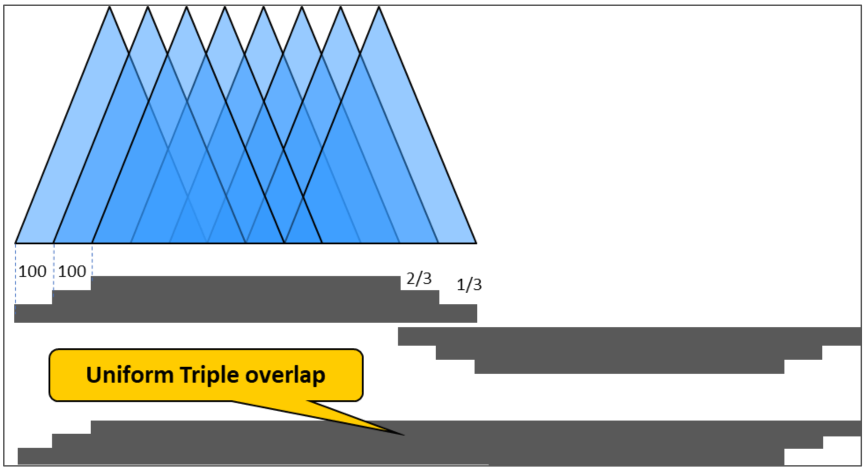


Figure F 22 Normal Longitudinal Joint

Poor centreline joints often result in stripping. Consideration could be given to more overlap on the centreline joint, effectively applying 33.3% more binder as shown in Figure F 23.

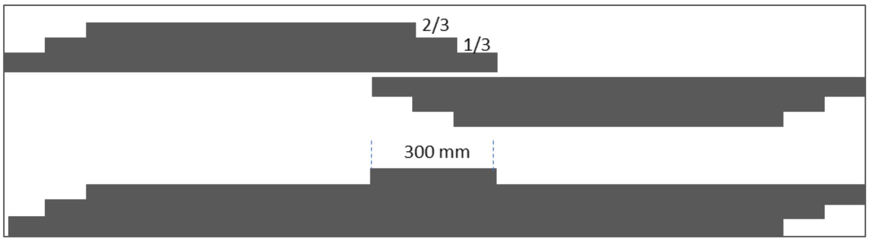


Figure F 23 Additional Joint Overlap on Centre Line

If, for any reason, the longitudinal joint is suspect, a diluted cationic emulsion could be applied by blocking off nozzles to minimise the risk of joint stripping

Figure F 24 Additional Joint Over Spray

F.8.6 EDGE SPRAY

A neat line is required at the edge of the road. For this purpose, a fish plate is attached 50mm from the last nozzle to reflect the 1/3 application back onto the 2/3 application. Whereas a fish plate (Refer Figure F 25) works well with emulsions and cutback binders it is less effective with high viscosity binders. The effect is shown in Figure F26.

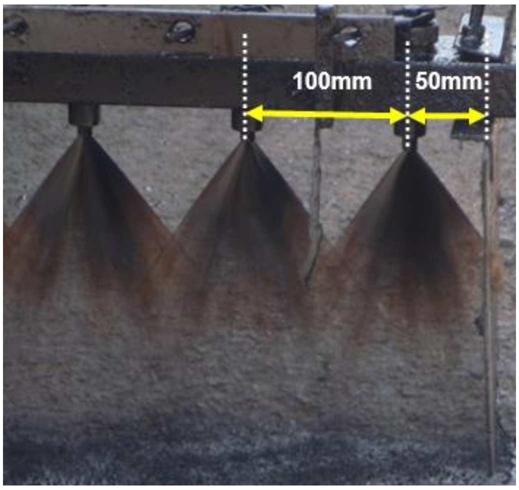


Figure F 25 Fish Plate in Position

Specially designed end-nozzles are recommended for this purpose.

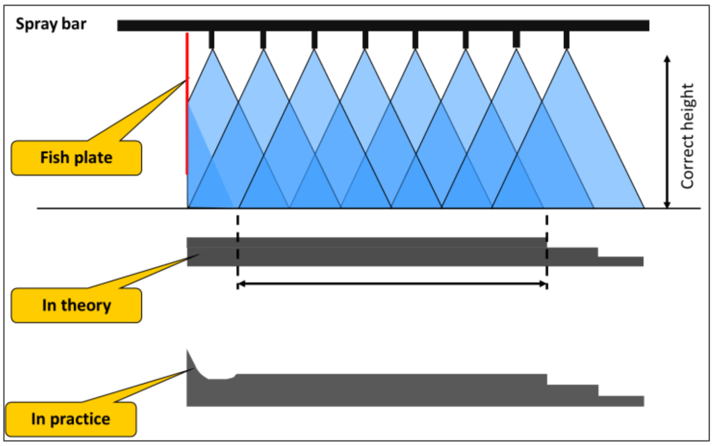


Figure F 26   Effect of Fish Plate with High Viscosity Binders

F.9 AGGREGATE APPLICATION

F.9.1 ESTIMATED SPREAD RATES

The ideal spread rates for aggregate may vary according to the purpose of the seal, shape and flakiness of the aggregate, rolling techniques and personal preferences.

Figure F 27 provides approximate spread rates for aggregate layers in different seal types, based on the ALD and Flakiness Index less than 10.

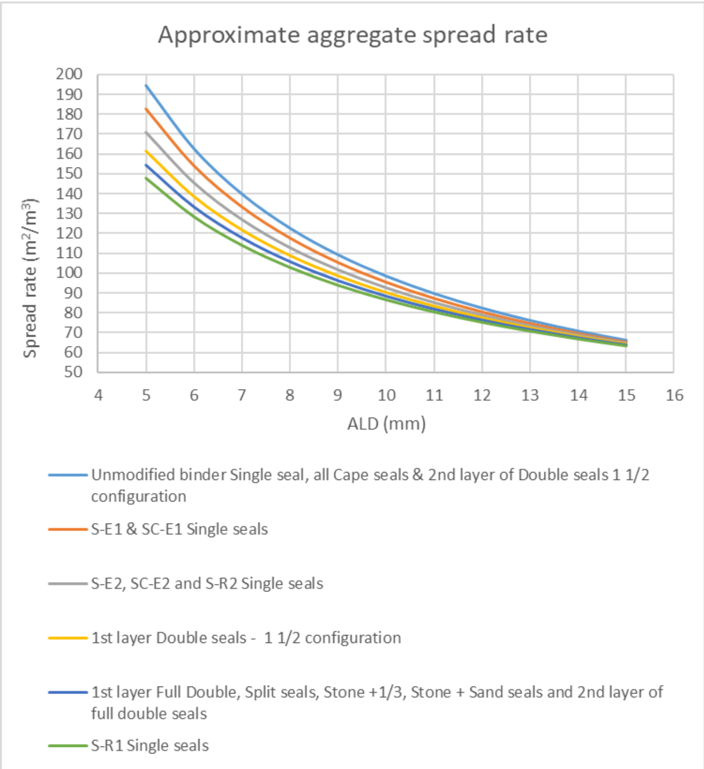


Figure F 27 Approximate Aggregate Spread Rates

<u>Notes</u>:

- ***Information provided only indicates approximate aggregate spread rates and cannot be used as specifications.***
- ***Aggregate spread rates for 7mm single seals, sand seals and graded aggregate seals are not based on the ALD of the aggregate.***
- ***For purposes of ordering and stockpiling aggregate, provision is made in Table F 3 for wastage (approximately 5 per cent).***

The mathematical equation for the approximate spread rates as shown in Figure F 27 is given below with the appropriate constants for the different situations provided in Table F 3.

$$Spread\ rate\ = a\ x\ ALD^{b}$$

With the Spread rate in m^2/m^3

Table F 3 Constants for Approximate Aggregate Spread Rates

Seal Type and Aggregate Position	a	b
Unmodified binder Single seal, all Cape seals & 2nd layer of Double seals 1 1/2 configuration	944.81	-0.982
S-E1 & SC-E1 Single seals	822.21	-0.935
S-E2, SC-E2 and S-R2 Single seals	709.83	-0.885
1st layer Double seals - 1 1/2 configuration	625.6	-0.841
1st layer Full Double, Split seals, Stone +1/3, Stone + Sand seals and 2nd layer of full double seals	565.81	-0.806
S-R1 Single seals	514.85	-0.775

Notes on the 20/7/7 Split seal:

- ***The spread rate of the dry layer is highly dependent on the binder used for the tack coat, the spread rate of the first aggregate layer and the matrix obtained after rolling.***
- ***After spreading the dry layer, the large aggregate of the first layer must be visible to allow adhesion of the penetration coat binder.***
- ***Using a non-precoated dry layer on a precoated large aggregate assists in selecting an appropriate dry layer spread rate as shown in Figure F 28.***

Figure F 28 Large Aggregate Visible after Spread of the Dry Layer

- ***The dry layer spread rate should rather be on the lower side than too high. The lower spread will result in the final surface with initial appearance of an eggshell (small holes) but will disappear with traffic compaction. A too high spread rate (large aggregate not visible) will result in delamination of the final layer***

F.9.2 VERIFICATION ON SITE

Delivered aggregate (preferably not precoated) is spread shoulder-to-shoulder by hand on one square metre with the ALD perpendicular to the road surface and then weighed (Refer Figure F 29).

Figure F 29 Determining Appropriate Aggregate Spread Rate on Site

For Cape seals, using emulsions, 70/100 Pen bitumen and S-E1 binders, the appropriate aggregate spread rate is approximately the same or slightly less than that of a single seal, providing an open "shoulder-to-shoulder" matrix after rolling. Traffic is not allowed before application of the first slurry layer. Therefore, the aggregate does not fully orientate, leaving sufficient gaps for the slurry to fill the voids.

For the higher viscosity modified binders, the design method (PART E) allows for increased application rates, mainly due to much slower orientation of the aggregate during construction and traffic compaction at road surface temperatures. To obtain a good dense shoulder-to-shoulder matrix after construction, the appropriate aggregate spread rate for polymer modified binder and bitumen rubber is higher than for unmodified binders. Cognisance should be taken that the S-R2 bitumen rubber binder contains additives which allows quicker stone orientation than the S-R1 binder, resulting in a required aggregate spread rate less than for S-R1.

Following determination of the ideal spread rate, the chip spreader is calibrated to apply the selected mass of aggregate across the full width (Within 5%).

Figure F 30 Calibration of the Chip Spreader

F.9.3 VISUAL APPEARANCE DURING CONSTRUCTION AND AFTER TRAFFIC COMPACTION

When a dense shoulder-to-shoulder" spread rate, as determined by packing by hand, is applied by the chip spreader on the road, it will appear "open". After rolling, it will still appear slightly open, as shown in Figure F 31. However, after traffic compaction for a couple of days during good weather conditions (appropriate for the specific binder to allow orientation), a dense shoulder-to-shoulder matrix would be obtained.

Figure F 31 Open Matrix after Rolling

Figure F 32 Dense Matrix Obtained after Traffic Compaction/ Orientation

F.9.4 CONSTRUCTION GUIDELINES AND CHECKS

General guidelines as follows:

- The aggregate should preferably be spread with a pre-calibrated, self-propelled mechanical chip spreader in good working condition. Where the chip spreader is hooked onto the back of a truck, the hitch connection should be firm enough to prevent relative movement between the truck and the chip spreader. Excess aggregate that falls onto the road surface during hitching of the chip spreader, should be removed immediately.
- There should be as little lag time as possible between binder application and spreading of chips. **The chip spreader should follow the binder distributor as closely as possible, while the pneumatic tyred rollers follow directly behind, to complete the compaction as quickly as possible.**

- Check the correct line and width of chipping.
- Confirm the aggregate spread rate after chipping and after rolling.
- Due to the large difference in viscosity between conventional, homogeneous polymer modified and non-homogeneous binders (bitumen rubber), the aggregate spread rate and visual appearance of the matrix differ. The appropriate spread rate as determined by hand packing and possible adjustment during trial sections should be checked on a regular basis over the width of application. This could be done by running the chip spreader over the reinforced paper strip and chipping on three 1m by 1m canvas sheets.

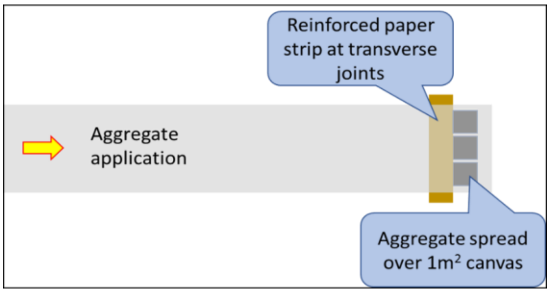


Figure F 33 Checking Aggregate Spread Rate

- Precautions should be taken against excessive application of aggregate. Areas with too much aggregate should be rectified by lightly sweeping off excess aggregate, so that the entire surface is covered by a uniform, continuous layer of aggregate.
- Areas on the surface which show a shortage of aggregate should be supplemented by hand. If required, a back-chipping team should follow behind the chip spreader **only** to fill bare places with aggregate by hand. **Note that these teams tend to spread too much aggregate**.
- Excess stone removal beyond the area demarcated by the string line should be done as soon as possible.
- The spreader box of the chip spreader should not be allowed to run empty, except during the last application of a certain aggregate size for the day. If the spreader box of the chip spreader runs empty or nearly empty, and/or tyre pressures are too high, the chip spreader could start to "bounce", resulting in corrugations on the road.

F.10 ROLLING

F.10.1 INITIAL ROLLING

Immediately after the aggregate has been applied on any hot binder, rolling should commence.

In the case of emulsions, immediate rolling by means of self-propelled 2-4 ton steel wheel rollers can be only permitted if excessive crushing of aggregate does not occur and if another layer of binder will be applied. Pneumatic-tyred rolling must be delayed until the emulsion has been allowed to break sufficiently to firmly secure the aggregate. Rolling must be postponed if there is excessive pick-up of aggregate on the tyres of the pneumatic type roller. Rollers should operate parallel to the centre line of the road from the shoulders inwards towards the crown of the road (or from lowest to highest elevation in case of super elevation) until the entire surface has been covered at least four times with the wheels of the roller.

The process (sequence, timing and roller passes) for each seal type must be finalised during construction of the trial section and documented in a method statement.

F.10.2 ROLLING AND SWEEP COMBINATION WITH LIGHT TYPE OF DRAG BROOMS

Systematically rolling, with simultaneous drag brooming, could be of great value to obtain a uniform shoulder-to-shoulder mosaic.

The combination of rolling and brooming is of particular importance during construction of the second layer of aggregate in double seals, to ensure that a good interlocking action develops between the various aggregate sizes.

F.10.2.1 General Guidelines and Checks

- Check that the roller sequence and minimum number of roller passes comply with the procedure agreed on the trial section.
- Check that rolling is done up to the edge of the constructed seal.
- If it is a new seal, or the surface is smooth, it is advisable to use a light steel-wheel roller to “iron” out the aggregate.
- In case of hot binders, the aggregate should be rolled with pneumatic tyred rollers immediately after it has been applied to the binder.
- For the first roller pass, the drive wheels of the rollers should be in front.
- Rolling should be done systematically, at low speeds, from side to side. Sharp turning movements of the rollers and trucks should be avoided on the fresh seal.
- Rolling with pneumatic tyred rollers should be done as thoroughly as possible. The more the seal is rolled the better.
- The length of road sealed every day should be appropriate to the number of rollers available.
- When excessive aggregate is disturbed and lifted by pneumatic tyred rollers, it is an indication that the viscosity of the binder is too low. Rolling should thus be delayed until the temperature of the binder has dropped, or until more volatiles have evaporated from the binder. The disturbed aggregate can also be a result of the rollers moving too fast.

F.10.2.2 Final Rolling

Final rolling should be done in accordance with the method statement after the trial section construction. Once the brooming is completed, the aggregate should be rolled properly by means of heavy pneumatic tyred rollers.

F.11 BROOMING AND CLEANING

F.11.1 DRAG BROOMING

Once each layer of aggregate has been spread and rolled, it should only be swept with a light drag broom, if necessary, to spread loose aggregate, which has not bonded to the surface, evenly.

The length of the rope used to pull the drag broom must be at least 4.0 meters long, and the broom must be pulled at an easy walking speed, 2 to 3 km/h. The minimum length for the pull rope is necessary to ensure that the front part of the broom is not lifted up during the brooming process. The slow tow speed is necessary to prevent the broom from wobbling on the surfacing.

Final drag brooming could be done early in the morning on the previous day's seal work, when the road temperature is low, and the binder sprayed the previous day is cold and stiff. The broom is dragged to and fro on the surface. Thereafter, when the road surface temperature increases, the seal is rolled with a light steel wheel roller. The broom moves surplus aggregate to areas where there is a lack of aggregate to fill open gaps.

F.11.2 ROTARY BROOMING

When excess aggregate has been applied on any layer, it should be swept off by the rotary brooms in such a way that the underlying aggregate is not disturbed. The brooms can be adjusted and controlled to just touch the surface. This is delicate operation and should be carried out by a skilled operator.

All excess aggregate must be swept off before the seal is opened to traffic. If necessary, rotary brooming should continue to remove loose stone after opening to traffic.

F.12 SUMMARY – THE SPRAY SEALING PROCESS

Once all the checks have been meticulously carried out and the binder distributor correctly placed on the road to be sealed, operations can commence.

The following summarises the key aspects:

- The binder distributor should not commence spraying until it has reached the required speed for the specified application rate for the binder.
- Immediately after the distributor has passed over the reinforced paper joint, the two edges of the paper strip at right angles to the edge of the road are folded over to prevent any spillage of the binder, and the extreme edges of the paper parallel to the centre-line of the road are rolled over towards the centre of the section, picked up in total and placed in a truck or L.D.V. to be disposed of in a suitable manner.
- The chip spreader follows immediately after the jointing material is removed. The reason for this is to avoid holes being punched in the jointing material by the aggregate, which would result in leakage of the binder through the jointing material onto the existing primed surface, which would cause unsightly fatty patches in the surface at a later stage.
- The chip spreader and the truck supplying it should be closely followed by trucks full of aggregate.
- As each truck loading the chip spreader is emptied, it pulls out to face the oncoming traffic. Flagmen are required to control this operation. An experienced truck driver can connect up with the chip spreader in motion, without stopping, and this speeds up the process.
- The binder distributor could spray out its whole load in one operation, provided all the equipment is in sound condition, the operators are experienced and there is sufficient aggregate already loaded in the trucks to cover the whole section. Due to the risks related to equipment problems, this practice is not recommended.
- Immediately behind the loaded trucks, the heavy pneumatic-tyred rollers give the surface one completed pass. One pass of a steel-wheeled roller is often applied to the first layer of a double seal.
- At least two brooms are then brought on in echelon, the second broom overlapping the first broom by ± ½ metre and the rollers follow the brooms systematically. The brooms continue to broom the surface from the centre of the road to the edge and back again. The brooms should be set so that the bristles just touch the aggregate and do not disturb the aggregate in contact with the binder.

***Note**: If emulsion is used, brooming should not take place until the emulsion has broken.*

- The process of lightly brooming and rolling should continue until all the loose aggregate has been placed shoulder-to-shoulder and in contact with the binder in a single layer of stone aggregate.
- If the gates of the chip spreader have been properly adjusted, very little if any back chipping will be required.
- Take steps to avoid over application of chips during back chipping.
- Where the connection of the trucks with the chip spreader occurs, some over-application of aggregate may occur. This over-application of aggregate should be removed by hand brooming the surface before the rollers pass over the area and lock the excess aggregate in the bottom layer of stone.
- The joint on the centre line of the road should be given special attention. A 3 mm twine on the centre line is used as a guide for spraying. The width of the spray should overlap the line by 200 mm. Also refer to F.8.5.
- Immediately after application of aggregate and brooming, the 200 mm overspray should be cleaned of aggregate spillage while the road is still warm and before the binder has set. It is advisable for the rollers to keep within the surfaced area and not to roll across the string line. Once this operation is complete, the string line should be removed.

F.13 OPENING TO TRAFFIC

Opening to traffic is governed by the development of sufficient adhesion between the binder and the stone, cohesion of the binder, prevailing and expected temperatures, as well as the traffic situation. The appropriate time is highly dependent on the binder type. Visual assessment and removal by hand of a few stones, is required to assess the bond strength of the seal.

Traffic speed should be controlled (preferably 40 km/h) and where possible, movement of the traffic transversely over the road width facilitated.

A newly constructed seal should not be opened to traffic:

- When rain or a cold spell is expected overnight.
- When the surface is still wet after unexpected rain.
- Unless proper bond strength has developed (adhesive and cohesive strength). This is specifically relevant when using emulsions or high paraffin content precoating fluids. Tentative guidelines, based on a "Pull-out" test, are available for modified binders [2].
- Until road surface temperatures are conducive to orientation of the stone [3]. As experienced during construction of winter seal experiments, it might be necessary to close the newly sealed lane overnight and only allow traffic during daytime [4].

F.14 SLURRY MIXING AND APPLICATION

F.14.1 PREPARATION OF SURFACE

Before the slurry can be applied to an existing road surface, all distress, potholes and crack treatment should be carefully and efficiently attended to. The road surface should be cleaned of all deleterious material and, if necessary, washed and broomed. Edge failures should also be repaired.

Once the road has been cleaned, the surface is dampened slightly just prior to application of the slurry. There should not be any pools of free water in depressions or in minor cracks which have not been sealed.

F.14.2 TACK COAT

Under normal conditions, a tack coat is not required unless the slurry is being applied to an old porous or oxidised surface. If it is decided to apply a tack coat, a diluted anionic stable grade emulsion spray consisting of 1 part of emulsion to 3 parts of water may be applied at the rate of ± 0,7 ℓ/m². This may be applied either by hand or by a distributor. The use of a motorised hand-sprayer is very useful, especially where extra emulsion is obviously required in particular areas.

F.14.3 BATCH MIXING

Batch mixing can be done in a concrete mixer, of either the tilt or non-tilt type. Small quantities may be mixed in a wheelbarrow.

For large quantities where thick layers of slurry are required, i.e. in excess of 4 mm, mechanical equipment and spreader boxes are used. (This does not apply to Cape Seals where the first layer must be applied by hand.)

The sequence of filling the concrete mixer is:

- Aggregate is put in first.
- Active filler is added slowly, care being taken to ensure that no lumps of cement/lime are added. Mixing continues until a uniform mix of aggregate and filler is obtained.
- Water is added until all the particles have been coated with water - there should be no dry fines in the mix. If this is done efficiently, the risk of balling of the mix is avoided.
- Emulsion is then is added. It may be prudent to dilute this emulsion before it is introduced to the mixer.
- Water is added to obtain the required consistency.

The resultant slurry should be a smooth, creamy, uniform free-flowing mix, free of lumps and balling. ASTM 3910 should be carried out to determine the correct consistency (Refer PART E)

F.14.4 ADJUSTMENT OF EMULSION CONTENT DUE TO EXPANSION OF MOIST SAND

Ideally, the sand used for the slurry seal should be dry before the required volume of emulsion is mixed in. The volume of sand conforming to the grading specifications as provided in PART B, could expand to more than 30 per cent of its dry volume as the moisture content increases, after which, when saturated, it decreases again to approximately its original dry volume. This phenomenon creates a risk of too much binder being added to the slurry mixture.

A practical method of determining the approximate moisture/volume expansion of sand is as follows:

- Fill a container of known volume with sand from the stockpile (tap lightly 10 times).
- Dry the sand by spreading it on a clean surface and heating (e.g. with a gas burner).
- Determine its volume.
- Calculate the moisture content and volume expansion.
- A moisture/volume expansion curve can be derived in a laboratory for a specific sand, by adding water to dried samples and measuring the change in volume.

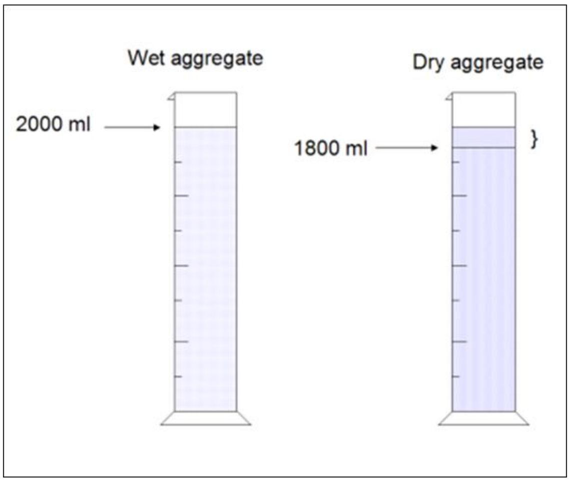


Figure F 34 Determination of the Bulking Factor

Alternatively:

- Fill a container of known volume with sand from the stockpile.
- Saturate the sample with water and
- Determine the reduced volume of sand.

Although not necessarily correct, the saturated volume is taken as being similar to the dry volume for calculation of the required amount of emulsion.

Note**:** ***The method of filling the container is not defined and the packing of the moist sand may be different in the slurry machine.***

F.14.5 WEATHER LIMITATIONS FOR SLURRY APPLICATION

During and soon after placing, slurries could be sensitive to very cold and very hot temperatures, high humidity and rain. Specifications (COTO) and additional guidelines are as follows:

- Conventional slurry should not be applied at an air temperature of less than 7 ^{o}C when temperatures are rising, or less than 13 ^{o}C when temperatures are dropping. When cold winds are blowing, these limits should be increased by approximately 5 ^{o}C. Generally speaking, it should be applied during dry periods and, if these periods occur in winter months, the process should cease 3 hours before the late afternoon drop in temperature
- Experience indicates that conventional slurries should not be applied when the humidity exceeds 70%.
- Rapid setting slurries/ Microsurfacings are normally designed to be applied in air temperatures of between 4 ^{o}C and 40 ^{o}C, as well as in damp conditions.
- During hot weather slurry operations should be suspended. Road surface temperatures in excess of 60 ^{o}C would typically result in the slurry breaking too quickly e.g. in the spreader box. Special measures to reduce the road temperature will be required during hot weather, e.g. a light spray of water could be applied, or work could be carried out in the cool part of the day.
- Care should also be exercised when slurry seals are applied when inclement weather conditions are likely, i.e. rain.

F.14.6 PRECAUTIONS

- The grading selected should be appropriate for the work/problem the slurry is intended to cover.
- If a slurry is too wet it will tend to run off and, if it is too dry, it will be difficult to spread the material uniformly.
- The addition of 1 - 2 per cent of filler (cement or lime) should be carefully controlled and monitored. If too little filler is added, problems of segregation and flotation may occur.
- Fine-graded slurries should not be used for thick applications, or coarse-graded slurries for thin applications.
- The source of the water to be added to the mix should always be checked before work commences.
- The moisture/volume expansion should be checked daily so that the emulsion content can be adjusted if necessary.

F.14.7 MICROSURFACING

Microsurfacings are preferable to conventional slurries in the following cases:

- Where the surface is uneven because of bumps, slacks, etc, i.e., where the riding quality is poor or where rut depths exceed 10 mm. The required thickness will influence the choice of maximum aggregate size.
- Where traffic has to be accommodated on the road soon after application.
- Unpredictable weather conditions.

General guidelines are as follows:

- Microsurfacings should be applied using a continuous slurry machine
- The applied thickness of the product, before compaction, should be 20-25 % more than the desired end thickness. This is of particular importance for rut filling (Refer to F.2.7.4 for suitable equipment)

Figure F 35 Slurry Thickness to Compensate for Compaction

- The formulation of the product should be such that complete curing will take place within a maximum of 4 hours, regardless of the climatic conditions during construction, to allow opening to traffic.
- Rolling should not commence before curing of the slurry.
- Ball penetration (SANS 3001-BT10), corrected for the expected road surface temperature, on the product should reduce to less than 2 mm within a period of 4 weeks.

F.14.7.1 Typical Problems

F.14.7.1.1 Colour variations

Colour variations in slurry seals can occur as a result of any of the following reasons:

- Variation in bitumen content.
- Variation in the grading of the sand.
- The direction of movement of the slurry machine.
- Variation in the quality of the emulsion.
- Rain during or shortly after placement of the slurry.
- Variation in filler content.
- Variation in emulsifier (Phosphoric Acid versus Hydrochloric Acid).

F.14.7.1.2 Balling

Balling as shown in Figure F 36 can occur when rapid breaking occurs and could be caused if the temperature of the aggregate or binder is too high and more so if the fines content is on the high side within the grading envelope.

Figure F 36 Balling of Slurry

F.14.7.1.3 Slow breaking

The breaking of conventional slurries is dependent on temperature and humidity influencing the evaporation of water from the applied product. Experience suggests not to apply conventional slurry when the humidity is more than 70% or the ambient temperature is less than 7ºC.

Micro surfacings are designed for rapid setting with the rate of breaking dependent on the additives introduced for this purpose.

F.14.7.1.4 Too rapid breaking

Apart from aspects mentioned under "Balling", the road surface temperature could also influence the speed of breaking. Experience suggests stopping slurry/ microsurfacing application when the road surface temperature rises above 55 – 60 ºC.

F.14.7.1.5 Segregation

Segregation often occurs during hand application as a result of:

- The mix being moved too far from the point of offload
- Too coarse grading used as a texture slurry or Cape Seal slurry

Segregation of the mix could also occur as a result of an ineffective catalyst (normally lime or cement). During the consistency test, the potential for segregation could easily be observed.

Note:

- ***Cases have been noted where neither lime nor cement is effective. The suppliers of the emulsion should then recommend an alternative chemical compound to be used to overcome the problem***
- ***Calcium Chloride has been used with success instead of cement or lime***

Although rolling with pneumatic tyre rollers is recommended, this must only be done after proper curing of the emulsion. Segregation could occur as a result of too early rolling, forcing the emulsion to the surface. This will result in bleeding on the surface while insufficient binder remains in the slurry/microsurfacing layer as shown in Figure F 37 and Figure F 38.

Figure F 37 Emulsion Forced to the Surface Due to Too Early Rolling

Figure F 38 Emulsion Segregated from Slurry Mix due to Too Early Rolling

F.15 REJUVENATION SPRAYS

F.15.1 DILUTED EMULSIONS

The following construction practices should be kept in mind during the application of diluted emulsions to enrich existing surfacings:

- The areas to be treated should be cleaned of all dust, dirt, dung, oil or any other foreign matter.

Figure F 39 Effect of Spraying Emulsion Before Cleaning

- A water tanker with a pressure distributor should be available on standby for pre-wetting or post-wetting the areas scheduled for rejuvenation sprays.

- Do not use a cationic spray grade emulsion or post blended polymer modified emulsion. These products:
  - Will not penetrate properly and will stay tacky.
  - Tend to form a skin (sometimes referred to as "false break").

Figure F 40 Diluted Cationic Spray Grade Emulsion Not Penetrating

Figure F 41 Skin Forming Retarding Breaking

- Emulsion dilution:
    - The water to be used for the diluting of emulsions should be fit to drink. Water from municipal sources can generally be accepted as suitable. If the suitability of water is in doubt, particularly in remote areas or where the water is derived from sources not normally used for domestic purposes, the water should be tested before use.
    - During the dilution process of the emulsion, the water must be added to the emulsion and not the reverse. Dilution should not be done with water colder than 7 ^{o}C and when the road temperature is below 10 ^{o}C. The diluted emulsion should be applied between 50 ^{o}C and 70 ^{o}C.

- It is advisable to spray diluted emulsions during the colder periods of the year when road temperatures are fairly low. Road temperatures higher than 50 ^{o}C can cause problems, as the emulsion tends to break on the surface before it can penetrate into the existing surfacing.

- Do not add left over diluted emulsion to undiluted emulsion.

- Apply a light spray of water before spraying of the diluted emulsion. In this way, the surface tension of the aggregate of the existing surfacing is broken and allows effective penetration of the diluted emulsion.

- It is advisable to extend the distributor's spray bar so that the application of the binder overlaps by approximately 300 mm on the centre of the road, to obtain a double application of emulsion in the middle. The existing surfacing on the centre portion of roads tend to be much dryer than the rest of the surfacing.

- Existing surfacing:
    - If the existing surfacing is very dry or porous, and the design application rate for the diluted emulsion is in excess of approximately 1.0 ℓ/m2, it is advisable to apply the diluted emulsion in two separate applications. Due to the low viscosity of diluted emulsions, it tends to flow or run off surfacings when the application rate is too high. This normally occurs on curves with high super elevations and roads with steep cross falls.

- Should the strips on the edges and between the wheel tracks be very dry and or porous, the spray bar must be adjusted to enrich these areas first. These areas are normally enriched separately, followed by the full width afterwards.

- Should a road be moderately deformed, and pools of emulsion occur, the emulsion must be removed by means of hard brooms, to prevent bleeding.

- Opening to traffic
  - Treated sections should only be opened to traffic when the emulsion has properly cured, and tackiness has reduced to the extent that no pickup occurs. Should pick-up occur after opening, immediate action is required to stabilise the situation through closure, water spraying or blinding with approved coarse sand.

F.15.2 INVERTED CUTBACK EMULSION

When using inverted cutback emulsion, the following guidelines apply:

- Only use on very low volume roads as the surface could stay tacky for a few days and stop-go traffic accommodation might be required.
- Maximum application rate is 0.5 l/m2.
- Although the service life of the existing seal could be extended for four years, it will not seal wide cracks.
- Do not reseal within one year as the volatiles will soften the new seal binder.

F.16 SPECIFIC RECOMMENDATIONS RELATED TO SEAL TYPES

F.16.1 SINGLE SEALS

The following general guidelines apply:

- Rolling with the heavy pneumatic rollers should continue from the time the binder and aggregate are applied for a minimum of 8 passes per roller width. As a guide, 2½ hrs rolling with one heavy pneumatic-tyred roller is required for every km of single lane 3,7m wide surfaced roadway. (i.e. approximately 8 - 10 passes over each "width of roller" of surfaced width of the roadway).
- It is recommended that the initial rolling (first roll) be completed within 5 min of spreading the aggregate. A minimum of two rollers is recommended for each chip spreader.
- The rollers should be ballasted (20 ton unballasted) and there should be sufficient rollers for the work envisaged. Efficient use of the brooms and rollers makes a significant improvement to the quality of the final finish.
- It is not advisable to use steel-wheeled rollers on single seal reseal projects if the road is deformed, as these will damage the aggregate, riding the high spots and missing the aggregate in the cusps.
- When using a soft binder (cutback binder) in a hot climate it may be necessary to keep the road closed until sunset and even to spray the surfacing with water to cool the surfacing down before it is opened to traffic. If possible, the road should only be opened to traffic the next morning, while the binder is still stiff.
- When cold temperatures are expected during the night, it is recommended that the road only be opened the next morning when the road surface temperature increases above 18oC to facilitate orientation of the stone
- Before the road is opened to traffic, all loose stone should be removed from the surface. The surface should be broomed the day following surfacing to ensure there are no "loose/flying chips" on the road. For wide surfaces exceeding 7,4 m it is advisable to use self-propelled brooms or (preferably) vacuum brooms to remove the loose chips. Back rolling the following day can further improve binder/aggregate adhesion.
- Traffic speeds should be controlled for two to three days to allow the seal to settle.

F.16.2 DOUBLE SEALS

There are two different basic design approaches to the construction of the standard double seal, viz:-

- Full double seal (shoulder to shoulder application of both stone applications).
- One and a half seal (open application of coarse stone and flaky small stone).

In the "one and a half seal" the first application of aggregate does not lie shoulder-to-shoulder and only part of the second application of aggregate is locked into the voids between the coarse aggregate. The balance of the fine aggregate is lost through whip-off as there is not enough binder on the top of the coarse chips to hold the second application.

It is therefore necessary to decide what precise modus operandi is to be used before commencement of the work.

It should be noted that the process described here applies essentially to new construction.

- Once the single layer of large aggregate has been applied, the heavy steel-wheel roller may commence rolling, starting at the lower edge of the surfacing and moving a half wheel at a time towards the centre and back again. The quality of the final finish of the road depends on the efficiency of this operation, which should continue until a tight flat surface has been obtained. A certain amount of crushing/splitting of the coarse aggregate will occur, but the final finish should be "tight", uniform and "flat". On new construction a limited amount of "punching" in of the aggregate into the base will occur, resulting overall in a "tight", flat surface.

- It should be noted that under no circumstances should this layer be opened to traffic before the second application of aggregate has been applied. If this road is opened to traffic for any reason, aggregate loss will occur.
- If slow-moving construction traffic has to use the road, re-rolling would be advisable before the penetration coat of binder is applied.
- Both applications of aggregate may be precoated. The precoating assists in immediate adhesion of the coarse aggregate to the binder and allows effective brooming to take place with minimum delay, without disturbing/turning the aggregate in contact with the binder.
- If emulsion is used as a tack coat, the emulsion should be allowed to break and adhere effectively to the aggregate before brooming commences. Brooming before the emulsion has broken will result in the turning of the aggregate, which, in turn, will result in the aggregate sticking to the rollers and broom bristles.
- It is most important to obtain the correct application of aggregate at initial application so as to reduce brooming and the need for back-chipping as far as possible.
- If emulsion is used for the penetration sprays:
  - And the second application of the aggregate is precoated, rolling with pneumatic tyre rollers might have to be delayed.
  - The quantity of binder calculated for the tack coat should be reduced to the minimum quantity of binder required to hold the first application of aggregate in place and prevent its movement when the surface is broomed. The balance of the binder should be added to the penetration sprays.
  - The application of the second spray should be delayed until all the excess volatiles have evaporated. Under no circumstances should highly cutback binders e.g. MC3000 be used for the tack coat as subsequent sprays lock in the volatiles, which will flush up during the hot season. Heavy to medium traffic using the road under these conditions will cause excessive bleeding of the surface.
- Finishing of the final layer is similar to that for single seals. This is described in the section on the construction of single seals.

F.16.3 CAPE SEALS

The aggregate of the single seal component should be uniformly spread resembling the “Open Shoulder-to-shoulder” matrix (Refer Figure F 42) to allow the slurry to properly penetrate into the voids between the aggregate.

Figure F 42 Ideal Spread of Cape Seal Aggregate

If the aggregate is too closely packed after rolling, the slurry will not be able to penetrate properly, leaving voids in the structure with sensitivity to water penetration and stripping (See Figure 43). In addition to this the 4.75 mm aggregate in a fine-medium grading will tend to segregate, as shown in Figure 44.

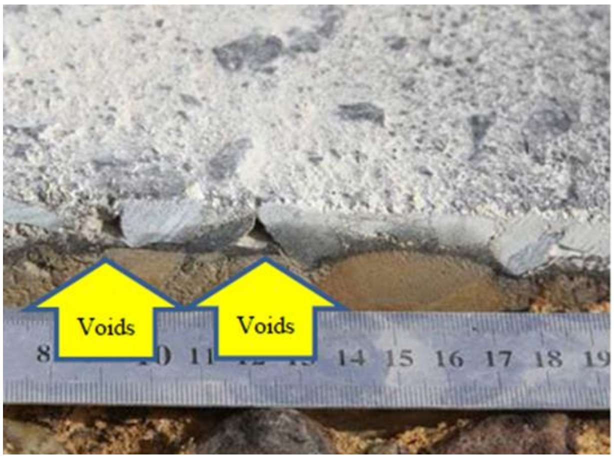


Figure F 43 Voids Created by Too Close Aggregate Packing [3]

Figure F 44 Coarse Particles Segregating from the Slurry Mix

A further impact of a "too-close packing" of a 20mm Cape seal, is that the coarser particles of the second slurry layer will either segregate from the mix or will be driven off, resulting in a bad-looking final seal (Refer Figure 45).

Figure F 45 Effect of Coarse Particle Segregation

***Note**: The coarse particles have a large mass but small surface area. The impact of losing these from the mix is that the binder content of the remaining mix is much higher than what was designed for, making it sensitive to bleeding or fattiness.*

When the aggregate is spread, the perception is often that back-chipping should be done, resulting in a non-uniform matrix as shown in Figure 46, which will negatively impact on the road roughness (riding quality).

Figure F 46 Varying Spread of Aggregate due to Back Chipping

- Rolling with the heavy pneumatic-tyred rollers should continue from the time the binder and aggregate are applied for a minimum of 8 passes per roller width. As a guide, 2½ hrs rolling with one heavy pneumatic-tyred roller is required for every km of single lane 3,7 m wide surfaced roadway, i.e. approx. 8 - 10 passes over each "width of roller" of surfaced width of the roadway.
- All loose stone should be broomed off the surface before the cover spray is applied.

Note:
Sufficient time should also be allowed between application of the tack coat and the cover spray, especially if emulsion is used in the tack coat.

- If emulsion is used as the cover spray, the aggregate does not have to be precoated but has to be clean and preferably moist. Precoating is important in so far as it assists in the application and preparation of the first application of aggregate.
- Before the slurry is applied and the surface has been exposed to the elements and construction traffic, there probably will be some disturbance of the aggregate. It is therefore recommended that the surface

be given one complete pass with a steel-wheeled roller early in the morning before the surface has warmed up.

- If the surface has lain for any length of time, it should be inspected for contamination by dust, mud, vegetable matter or water. Loose material can be removed effectively with compressed air.

After application of the first layer of aggregate the following procedures are recommended:

- Depending on the size of the large aggregate, the slurry grading and texture required for the final surface, either a single or double application of slurry may be required.
- Both the first and second layer of slurry should be spread to the full final width of the primed surface.
- When the slurry is applied in two layers, the first layer of slurry should be struck off level with the tops of the stones in the aggregate layer so that after application, the tops of the stones will be just visible.
- The second slurry layer may be applied either by hand or spreader box, but the mixing should be done in an approved mixer.
- The slurry batch should be discharged onto the road in small increments by means of a chute. When the slurry is applied, the squeegee squad should be allowed to complete the spreading of each batch discharged onto the road, using squeegees (or combination of squeegees and stiff bristle brooms), before the next batch is discharged.
- Care should be taken to determine the bulking of the fine aggregate used (Refer PART E: Design).
- Before slurry is applied, the road surface should be thoroughly cleaned and lightly sprinkled with water but no free water should be present on the surface when the slurry is applied.
- If the slurry is placed with hand labour, 13 mm diameter sisal rope (50 m lengths) should be placed on either edge of the section to be treated with slurry, i.e. at the edge of the surface and on the centre line. Work should be confined to these limits. The slurry should not be over-applied but levelled off neatly to the tops of the aggregate and finished off by dragging a moist burlap over the slurry before the emulsion breaks. If the slurry is applied with a spreader box, it is advisable to work up to approximately 100 mm from the edge and to use squeegees to spread the slurry to the edge.

  ***Note*: A much better result is obtained by hand spreading through criss-cross movement, forcing the slurry into the voids of the underlying aggregate. However, the slurry must not be "moved" too far as segregation could occur.**

- The surface should be well rolled with a heavy pneumatic-tyred roller after the slurry has cured, in order to obtain a dense, well-knit surface.

The rate of application is normally measured by cubic metre of saturated aggregate, contained in the slurry applied per square metre of surfacing.

F.16.4 GEOTEXTILE SEALS

The following guidelines apply:

- Rut filling and patching must be done prior to placing of the geotextile.
- The geotextile should be placed as quickly as possible after application of the tack coat, even if emulsion is used. The use of bogies or manual placement is allowed.
- Geotextile width should be equal to the lane width plus the overlap width/s.
- Overlap on the joints should be 100mm – 200mm.
- Overlap on the transverse joint should be in the direction of traffic flow.
- Do not overlap geotextile in wheel paths.
- Complete application of tack coat and geotextile over full width before sealing.

- Removing of all creases in the geotextile is essential.
- Rolling with a heavy pneumatic roller should commence immediately after placing of the geotextile.
- Four to five passes with a heavy pneumatic roller (20 ton or heavier) is recommended.
- Additional hand spray on the overlap might be required.

Additional comments and concerns from South African practitioners:

- Rapid setting slurries/ microsurfacings applied on geotextiles tend to delaminate.
- Tack coats **without** cutters are recommended.
- Concerns regarding milling of geotextile seals are only valid on new geotextiles. These products tend to deteriorate within 10 years to such an extent that it could be torn by hand.
- Fabric recommended is non-woven, double needle punched, 140g/m2. (Refer PART B: Materials).
- The use of steel wheel rollers is not recommended.

F.16.5 OTTA SEALS

The following general guidelines apply:

- On day of construction:
    - 15 passes with a 12 ton or heavier pneumatic roller and one pass with a heavy steel roller are recommended.
- Each of two days after construction:
    - 15 passes with a 12 ton or heavier pneumatic roller.
- Maximum traffic speed of 40 – 50 km/hour for 2 – 3 weeks after construction and even longer (4 – 6 weeks) if natural gravel with high fines content is used.
- Allow for a minimum period of 8 – 12 weeks between the construction of the first and second layers.
- Accept that bleeding will occur and blinding and additional rolling might be required. Provision must also be made in contracts to establish a team for blinding during the first hot season after construction for up to 8 weeks.
- Back brooming of the sand cover should be repeated regularly until the sand is fully embedded in the first layer of the surfacing. This could be required for up to 4 weeks.
- The surfacing could be sensitive to heavy vehicle turning and breaking actions during the early life. Harder binder and reduced application rate are required for these situations.
- Road markings must be delayed for as long as possible. For safety reasons pre-marking or temporary lines might be required.

F.16.16 SAND AND GRIT SEALS

The success of a sand seal is dependent on the finish of the base and on the construction technique employed. The recommended construction procedure is described below.

- The primed base should be swept clean of all loose and foreign particles.
- The bituminous binder is applied at the required rate and, in case of a hot binder, the sand should be applied immediately to obtain maximum wetting of the sand by the binder.
- As wet sand with high dust and or fines content could be difficult to apply, the preparation of the sand should be done well ahead of the actual construction and the appropriate moisture content determined and tested during construction of the trial section.
- If an emulsion and a mechanical spreader are used, care should be taken to avoid the formation of a wave of emulsion in front of the curtain of sand being spread. This can be done by waiting until the emulsion has started to break before the sand is applied.

Figure F 47 Effect of Spreading Sand in Wet Emulsion

- As soon as a complete layer of sand has been applied, rolling with a 6 to 10 ton pneumatic-tyred roller should commence. During the rolling process, any uneven application of sand should be rectified with a light broom drag or other suitable apparatus.

  ***Note**: Light steel wheel rollers could be used for initial rolling*

- After the entire surface has had four passes of the roller(s), the road could be opened to traffic. While the traffic is using the road, the sand should be continuously broomed back onto the road until the binder has cured sufficiently to retain the sand. This is particularly important on curves and on gradients.
- The sweeping-back process should be done with a rotary broom or manually and may take as long as two months before the surface finally settles down. Tenders should be based on brooming back for five times.
- If a second seal is required, work should not commence until the road has been trafficked for eight weeks or when the first application has cured sufficiently for it to take the traffic without requiring brooming back of the sand. All loose sand on the existing surface should then be removed, and the application of binder and sand and after-care treatment should be resumed as described above. All areas showing signs of distress should be repaired before the second seal is applied.
- Proper maintenance of a sand seal will result in an extension of the functional life of the seal. Scouring of the road shoulders and the growth of vegetation on the road shoulders should be prevented.

Excellent seals have been constructed using precoated Grit. Benefits recorded with the precoated Grit are:

- No dust during construction
- No back-brooming required
- Line marking could commence within a week or two

Figure F 48 Precoated Grit Seal

Sensitivities recorded are as follows:

- Highly sensitive to rain shortly after construction (also applies to unprecoated sand/grit seals).
- To prevent clogging of the precoated sand particles, the precoating on aggregate must still be moist. However, this increases the sensitivity to pickup during warm weather directly after opening to traffic.

F.17 QUALITY ASSURANCE AND CHECKLISTS

PART G compliments this PART by providing guidance on quality assurance and providing checklists through each phase of construction.

F.18 REFERENCES

[1] Sabita Manual 8: Bitumen Safety Handbook.

[2] Southern African Bitumen Association (Sabita), Technical Guideline: The Use of Modified Binders in Road Construction (TG1), South Africa, 2019.

[3] Van Zyl G D, Fourie H G and Rossmann D. Stripping of seals in South Africa: Case studies and guidelines for an improved approach to mitigate it. CAPSA. South Africa, 2019.

[4] G.D. van Zyl, H.G. Fourie, and S.J. Bredenhann, Recommended Practice for Winter Sealing in South Africa, Conference on Asphalt Pavements for southern Africa (CAPSA). South Africa, 2015.

[5] G.D. van Zyl, and H.G. Fourie. Key Aspects of Good Performing Cape Seals. Conference of Asphalt Pavements for southern Africa (CAPSA), South Africa, 2015.

PART G

QUALITY ASSURANCE

CONTENTS

LIST OF TABLES

LIST OF FIGURES

G.1 INTRODUCTION

G.1.1 CONTEXT

Manual 40 comprises eight parts:

- Part A: General
- Part B: Materials
- Part C: Performance
- Part D: Seal type and binder selection
- Part E: Design
- Part F: Construction
- **Part G: Quality Assurance (This document)**
- Part H: Repair of premature failures

G.1.2 OBJECTIVES

The purpose of PART G is to assist practitioners with Quality Assurance on surface treatment works. Aspects of good practice discussed in PART F: Construction, are not repeated and only referred to in PART G. Therefore, PART F should be incorporated in the process of Quality Assurance to ensure good performing surface treatments.

G.1.3 SCOPE

PART G discusses under different headings:

- Forms of contract/procurement
- Components of quality assurance
- Quality requirements of the existing surface
- Quality requirements of equipment
- Quality requirements of materials
- Quality requirements during the construction process

G.2 FORMS OF CONTRACT

The most common forms of contract/ procurement are highlighted in Table G 1 with comments regarding the suitability related to surface treatments. Whereas all forms of contract could be suitable for new construction and rehabilitation, the conventional procurement is still regarded the most appropriate for periodic maintenance (reseal works). In all cases, the contractor remains responsible for constructing the surface treatment according to the design and good practice guidelines covered in this document. As stated under the conventional procurement, current suggestions are that the design of all surface treatments become the responsibility of the contractor. In this form of contract, the client still specifies the type of surface treatment and binder/s and therefore, takes the risk of poor performance if unsuitable for the conditions at hand.

Table G 1 Most Common Forms of Contract (Adapted from SAPEM [1])

Procurement Type	Comment	Suitability for surface treatments
Conventional Procurement	The contractor is appointed by the client to construct the works as designed by the designer. Normally the designer is a consulting engineer. The consulting engineer also administers the contract and monitors that the contractor constructs the Works as designed, and that the works comply with the specified requirements.	Suitable for new construction, rehabilitation and for reseal work. Historically, the responsibility for the design of asphalt and slurry in South Africa lied with the Contractor. **Current suggestions are that the design of all surface treatments become the responsibility of the Contractor**
Product Performance Guarantee System (PPGS)	The contractor includes a guarantee for one of the final products constructed/used in the works, which is normally a proprietary product or for the result of work utilising a proprietary product. Examples are a specific type of final surfacing, such as a UTFC, a type of bridge joint, or, the sealing of joints in concrete pavements utilising a proprietary joint sealant. Therefore, there is a reduced need for monitoring quality during construction on behalf of the client.	Only suitable for new construction or rehabilitation works and **not** for **reseal** work. The performance of the surface treatment is higly dependent on the quality of the pavement structure. COTO 2020 provides specifications regarding the required performance of surface treatments for a period of three years after construction
Design and Construct	The client specifies the works (facility) required and its intended purpose. The contractor employs a designer and delivers a Turnkey solution that must meet the intended purpose of the facility. Turnkey implies the client literally turns the key and takes over the road.	Only suitable for new construction or rehabilitation works and **not** for reseal work. The performance of the surface treatment is higly dependent on the quality of the pavement structure.
Design, Build and Operate (DBO)	The client specifies the works (facility) required and its intended purpose, as well as hand-over conditions. The contractor employs a designer and delivers a Turnkey solution that meets the client requirements. The contractor then operates and maintains the facility for a specified period before handing it over to the client.	Could be suitable for new construction, rehabilitation and reseal work. However, it could be difficult to price the required maintenance effort if the works only require minimal repair and reseal.
Concession	The concessionaire, which is typically a consortium consisting of a contractor, consulting engineer (designer) and financier, provides a complete solution for a section of road for a preset period of time, the concession period. Only the level of service provided to users is audited by the client during the concession period.	The concessionaire takes full responsibility for the performance.

G.3 QUALITY ASSURANCE

G.3.1 GENERAL

Quality assurance can be defined as planned and systematic actions necessary to provide adequate confidence that a product or service will satisfy given requirements for quality. It is a pro-active activity aimed at significantly **reducing or eliminating, non-conformance before it occurs.**

Quality assurance should be applied during all processes i.e. during:

- Surface treatment type selection (Refer PART C and PART D).
- Design investigation and design (Refer PART E).
- Execution (Construction - Refer PART F).

Processes and activities relating to quality assurance during construction are:

- Quality control.
- Quality management.
- Quality system.
- Quality plan.

G.3.2 CONSTRUCTION QUALITY CONTROL

Quality control (management), as carried out by the contractor, is defined in the [2] as **Process Control**. It comprises the continuous control testing and evaluation of test results by the contractor during construction to determine if the construction, methods and material used ensure an end product that complies with the specifications.

The onus rests with the contractor to produce work which conforms in quality and accuracy of detail, to all the requirements of the specification and drawings. The contractor must, at his own expense, institute a quality control system and provide sufficient experienced personnel and equipment to ensure adequate supervision and positive control of the works at all times. On completion of each element of the construction work, the contractor is required to test and check such materials, products and/or elements for compliance with the specified requirements.

Acceptance control is the continuous control testing and evaluation of test results (based on stratified random sampling), carried out on behalf of the client by the supervisory personnel, to determine if the quality of material and workmanship is acceptable and according to the specifications.

G.3.3 QUALITY MANAGEMENT

Figure G 1 summarises the processes and decisions forming part of quality management.

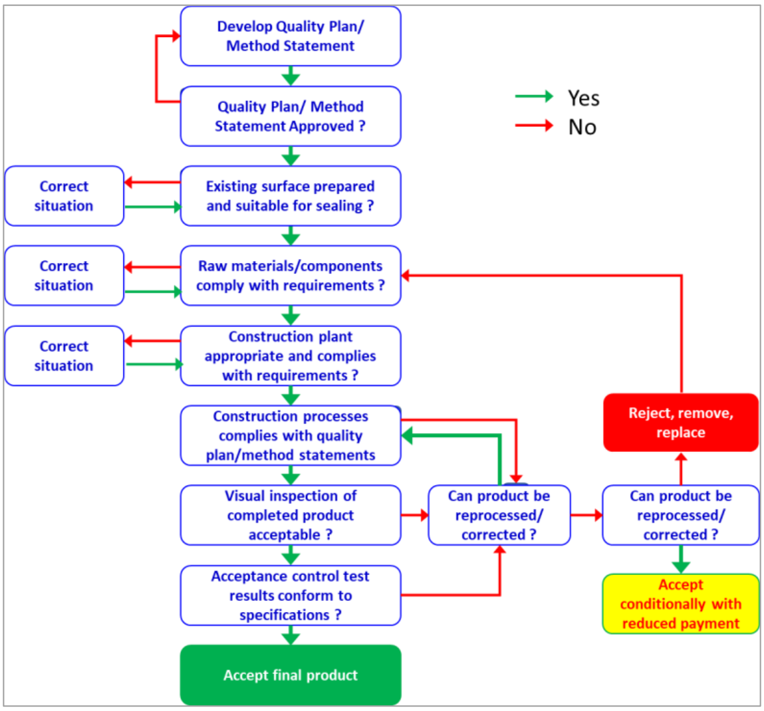


Figure G 1 Quality Management Process

G.3.4 QUALITY SYSTEM

A Quality system is a documented system in which the organizational structure, responsibilities, procedures, processes and resources for implementing quality management are defined. ISO 9000 and SANS 17025 provide an excellent framework and point of departure for the development and implementation of an organizational quality system. A quality system is implemented in a project by the preparation and use of a Quality plan.

G.3.5 QUALITY PLAN

A Quality Plan is a document setting out the specific quality related practices, resources and sequence of activities relevant to a particular project or service. Such a plan should be appropriate to the scope, complexity, and/or risk profile of the works.

Proper planning of the entire project is essential, ensuring sufficient resources to complete the project within the target period, minimising risk of failure and injury. Therefore, the quality plan should also incorporate aspects such as communication, training, contingency plans and dealing with emergencies.

Good practice suggests that all projects should commence with a preconstruction meeting to ensure that all parties involved with the project are well informed of the project requirements and timelines. (Refer PART F – F.3.1.1)

To ensure an acceptable final surface treatment (product), the following components should be evaluated:

- Quality of the existing surface or new base surface (refer PART F: Section F3).
- Quality of raw materials.
  - Quality of aggregate.
  - Quality of binder.
- Appropriate equipment in good working condition (refer PART F: Section F2).
- Quality of construction.

G.4 QUALITY OF THE EXISTING SURFACE OR NEW BASE SURFACE

G.4.1 QUALITY OF THE EXISTING SURFACE BEFORE SEALING

The quality of preparatory work and pre-treatment is discussed in PART F: Section F3.

In addition to the above, recommendations regarding allowable macro texture depths and prime coats are provided in the following sections.

G.4.2 EXISTING TEXTURE DEPTH

Existing surfaces should be pre-treated if the volumetric macro texture depth varies with more than 40% or if the macro texture exceeds the guideline values for different seal types as shown in Table G 2.

Table G 2 Recommended Maximum Texture Depth before Pre-treatment is Required

Seal Code	Description	Max Texture Depth
S1(10)	Single seal with 10 mm aggregate	0.8
S1(10)	Single seal with 10 mm aggregate (with cover spray)	1.0
S1(14)	Single seal with 14 mm aggregate	0.8
S1(14)	Single seal with 14 mm aggregate (with cover spray)	1.2
S1(14)	Single seal with 14 mm aggregate (with Bitumen rubber)	1.2
S2(10/S)	Double seal with 10 mm aggregate and sand	1.0
S2(14/S)	Double seal with 14 mm aggregate and sand	1.5
S4(10)	Cape Seal with 10 mm aggregate and one layer of slurry	1.5
S4(14)	Cape Seal with 14 mm aggregate and one layer of slurry	1.8
S4(20)	Cape Seal with 20 mm aggregate and two layers of slurry	2.0
S2(14/7)	Double seal with 14 mm aggregate and a layer of 7 mm aggregate	1.5
S2(14/5)	Double seal with 14 mm aggregate and a layer of 5 mm aggregate	1.5
S2(20/10)	Double seal with 20 mm aggregate and a layer of 10 mm aggregate	1.8
S2(20/7)	Double seal with 20 mm aggregate and a layer of 7 mm aggregate	1.8
S2(20/7/7)	Double seal with 20 mm aggregate and two layers of 7 mm aggregate	1.5

G.4.3 PRIME COAT

G.4.3.1 Preparation of the base and application of the prime coat

Good practice for the preparation of the base and application of the prime coat is covered in PART F: Construction.

The actual spray rates measured at the spraying temperature should not deviate by more than 8.0% from that specified. According to the latest specifications [2], application rates falling outside this tolerance up to 13% may be accepted at reduced payment, as shown in Table G 3.

Table G 3 Payment Reduction Factors for Conditionally Accepted Prime Coat

Deviation specified spray rate at spraying temperature. (%)	Payment reduction factor of tendered rate.
±8,0	1.00
±9,0	0.97
±10,0	0.95
±11,0	0.90
±12,0	0.85
±13,0	0.80

G.4.3.2 Reporting

Application rates achieved per sprayed section must be reported on a binder application worksheet. This information must then be transferred to the as-built data sheets.

G.4.4 CURING PERIODS BEFORE SEAL APPLICATION

The following curing periods should apply to the various treatments listed in, prior to applying to seal/reseal.

Table G 4 Specified Curing Periods Per Treatment Type (COTO 2020)

Treatment type	Recommended curing period
Texture treatment using fine slurries[1]	6 weeks
Coarse slurry, rapid setting slurry or microsurfacing applied as screed or rut filling[1]	12 weeks
Crack sealing	2 weeks
Asphalt patches for pavement repair	6 weeks
Bitumen treated granular materials	4 weeks
Untreated granular and cement stabilised materials	2 weeks

Note:

[1] Consideration could be given to reduce the specified curing period for slurry, microsurfacing and asphalt application, based on a representative corrected ball penetration (SANS 3001-BT10), at the expected operating road surface temperature of less than 2 mm.

G.5 QUALITY OF CONSTRUCTION PLANT

G.5.1 GENERAL

The equipment required for surface treatments are well described in PART F: Construction – Section F2, highlighting the purpose of each type and general checks to be performed as part of the QA process.

Specific requirements pertaining to the binder distributor are highlighted in the next section.

G.5.2 BINDER DISTRIBUTOR

G.5.2.1 Calibration certificate and general checks

Requirements for certification and general checks are discussed in PART F: Construction – Section F.2.1.2.

G.5.2.2 On-site transverse distribution

Two QA checks are applied namely:

- Transverse distribution over the entire spray bar, referred to as the "Bucket Test" - (SANS 3001-BT24).
- Spray flair transverse distribution (SANS 3001-BT25).

These processes are applied each time:

- A new distributor is used.
- After repairs to the distributor.
- A different binder is applied.
- When instructed by the Engineer.

Several tests and distributor adjustments could be carried out on site for one particular evaluation.

G.5.2.2.1 Input

Information and data required for each of the two tests are provided in Table G5 and Table G6.

Table G 5 Transverse Distribution Test input Requirements

Transverse Distribution Test - "Bakkie Test"															
Contract			Date			Tester					Per Contractor				
Distributor Reg. No.			Pump Speed (l/min)			Pump No.					Per Consultant				
Binder Type			Temperature			Viscosity					Tolerance allowed				
Nozzle set	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Mean
Mass of binder (kg)	10.31	10.56	10.47	9.96	10.36	9.96	10.38	10.26	10.48	10.43	10.59	10.86	10.63	10.58	10.42
Variation from Mean (%)	-1.02	1.38	0.51	-4.38	-0.54	-4.38	-0.35	-1.5	0.61	0.13	1.67	4.26	2.05	1.57	

Table G 6 Spray Flair Distribution Test Input Requirements

Spray Flair Distribution Test							
Contract		Date		Tester		Per Contractor	
Distributor Re. No		Pump Speed (l/mi		Pump No		Per Consultant	
Binder Type		Temperature		Viscosity		Tolerance allowed	
Calibration certificate No		Calibration date		Bar height		Flair Angel	

Spray bar section	Left				Centre				Right				
Nozzle of binder (kg)													Mean
Mass of binder (kg)													
Variation from Mean (%)													

G.5.2.2.2 Processing and reporting

The recorded Temperature, Viscosity, Tolerance and Flair Angle for the specific binder type are recorded and the variations from the mean evaluated against the allowed values as below:

- All emulsions, cutback and penetration grade bitumen – 5 %.
- Hot homogeneous modified bitumen – 7 %.
- Non-homogeneous binders (bitumen rubber) – 10 %.

G.5.3 QUALITY OF OTHER PLANT

The purpose, required quantity and quality of other equipment are well discussed in PART F: Construction

G.6 QUALITY OF RAW MATERIALS

G.6.1 AGGREGATE

G.6.1.1 Stockpiles

The management of stockpiles is well described in PART F: Section F5.

G.6.1.2 Sampling and testing before delivery (Basic properties)

Before aggregate is delivered on site from crushers, samples of all the aggregate to be used must be taken at the crusher for testing in the laboratory. If possible, it is advisable to take two to three conveyor belt samples of each aggregate size. These samples are normally more representative of what can be expected in a stockpile, because they are not segregated.

If it is not possible to take belt samples, all samples must be sampled in accordance with TMH5, at the source of production and from the stockpiles.

Aggregate used for seal work must meet the requirements of the SABS 1083 (Refer PART B: Materials). The recommended tests shown in Table G 7 must be carried out before delivery to site.

Table G 7 Pre-Delivery Sampling and Testing

<table>
<tr><th>Test</th><th>Method</th><th>Sample Size Required</th><th>Testing Frequency</th></tr>
<tr><td>Sieve analyses</td><td>SANS 3001–AG1</td><td rowspan="6">18 kg</td><td rowspan="6">3 per 100 m^3</td></tr>
<tr><td>Fines content</td><td>SANS 3001–AG1</td></tr>
<tr><td>Dust content</td><td>SANS 3001–AG1</td></tr>
<tr><td>Flakiness index</td><td>SANS 3001–AG4</td></tr>
<tr><td>Aggregate crushing value [1]</td><td>SANS 3001–AG10</td></tr>
<tr><td>10 % FACT (Wet and dry)</td><td>SANS 3001–AG10</td></tr>
<tr><td>Polished stone value</td><td>SANS 3001–AG11</td><td rowspan="6">20.0 kg</td><td rowspan="6">1 only</td></tr>
<tr><td>Sulphate soundness test [1]</td><td>AASHTO T04</td></tr>
<tr><td>Freezing and thawing test [1]</td><td>AASHTO T103</td></tr>
<tr><td>Los Angeles abrasion test [1]</td><td>AASHTO T96-45</td></tr>
<tr><td>Deval abrasion rest [1]</td><td>AASHTO T4–35</td></tr>
<tr><td>Ethylene glycol test</td><td>SANS 3001–AG14</td></tr>
<tr><td>Riedel and Weber value before precoating [2]</td><td></td><td></td><td></td></tr>
<tr><td>Riedel and Weber value after precoating [2]</td><td></td><td></td><td></td></tr>
<tr><td>Immersion Index (in case of slurries)</td><td></td><td></td><td></td></tr>
</table>

Notes:

[1] Not essential for QA purposes.

[2] Report only.

G.6.1.3 Sampling and testing after delivery and stockpiling

Once the aggregate is stockpiled on site, it is sampled (Minimum of five samples) and submitted for testing by a laboratory. Tests and results required for evaluation and design are provided in Table G 8.

Table G 8 Post-Delivery Sampling and Testing

Test	Method	Sample Size Required	Testing Frequency
Sieve analyses	SANS 3001–AG1	18 kg	1 per 10 m^3
Fines content	SANS 3001–AG1		
Dust content	SANS 3001–AG1		
Flakiness index	SANS 3001–AG4		
Aggregate crushing value[1]	SANS 3001–AG10		
ALD Measured	SANS 3001 – AG 2		
ALD calculated	ANS 3001 – AG 3		
Loose bulk density			
Sand equivalent (Slurries)	SANS 3001 No AG5		

Note:

[1] Refer to PART B Materials for relevant specifications

The process flow for quality assurance on aggregate is summarised in Figure G 2.

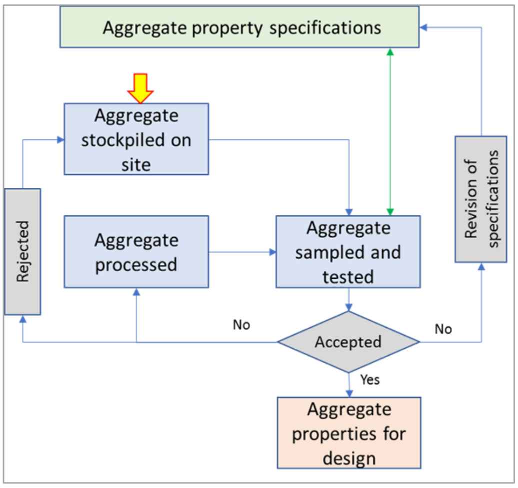


Figure G 2 Process Flow of QA on Aggregate

Aggregate properties related to each stockpile should be recorded together with the evaluation and decision.

Table G 9 Example of Information and Aggregate Properties Reported by Laboratories per Stockpile

Line No	Aggregate Properties					Batch No	
1	Stockpile position/ name		km 6.5R(b)				
2	Test Request No		C2015/6	C2015/7	C2015/8	C2015/9	C2015/10
3	Sample No		km 6.5R(b)/10/12Jan17/1	km 6.5R(b)/10/12Jan17/2	km 6.5R(b)/10/12Jan17/3	km 6.5R(b)/10/12Jan17/4	km 6.5R(b)/10/12Jan17/5
4	Lab Sample No		RL 7653	RL 7654	RL 7655	RL 7656	RL 7657
5	Source		OMV Crushers	OMV Crushers	OMV Crushers	OMV Crushers	OMV Crushers
6	Type		Dolorite	Dolorite	Dolorite	Dolorite	Dolorite
7	Size		10	10	10	10	10
8			SIEVE ANAYSIS (Percentage passing by mass)				
9	Sieve Sizes	37.5	100.00	100.00	100.00	100.00	100.00
10		28	100.00	100.00	100.00	100.00	100.00
11		20	100.00	100.00	100.00	100.00	100.00
12		14	100.00	100.00	100.00	100.00	100.00
13		10	82.00	86.00	82.00	87.00	88.00
14		7	7.00	10.00	8.00	10.00	8.00
15		5	1.00	1.00	1.00	1.00	1.00
16		3.35	0.40	0.20	0.20	0.20	0.20
17		2	0.40	0.20	0.20	0.20	0.20
18		0.425	0.40	0.20	0.20	0.20	0.20
19		0.075	0.20	0.20	0.10	0.10	0.10
20							
21	ALD (mm)	Measured	5.5	5.6	6	5.6	5.7
22		Calculated	0.00	0.00	0.00	0.00	0.00
23	Flakiness (%)		8.96	10.4	10.6	11	11.2
24	Durability (Etylene Glycol)		2	2	2	2	2
25	10% FACT	Dry	429				
26		Wet	324				
27	Polishing stone value		51				
28	Loose bulk density (kg/m^3)		1550				
29	Adhesion (R&W) not precoated		4				
30	Adhesion (R&W) precoated		9				
31	Immersion Index (Slurry aggregate)		(Percentage) e.g. 80.3	(Percentage)	(Percentage)	(Percentage)	(Percentage)
32	Sand equivalent (Slurry aggregate)		(Percentage)e.g 28.2	(Percentage)	(Percentage)	(Percentage)	(Percentage)
33	**Grade specification**						
	Evaluation		**Accepted**	**Rejected**			
				Outright	**Reprocessing**	**Revised Specifications**	
			Engineer: ______	Engineer: ______	Engineer: ______	Engineer: ______	
			Date: ________	Date: ________	Date: ________	Date: ________	

G.6.1.4 Precoating of aggregate

Good practice for precoating of aggregate is discussed in PART F: Construction – Section F.5.1.3

Key aspects for acceptance are summarised as follows:

- The precoating fluid must completely cover the aggregate, without blotches of excess binder.
- Wetting agents. If adhesion remains a problem, a commercial wetting agent can be added to the precoating fluid at a rate of 0.5% of the volume of the precoating fluid.
- Timing before seal construction. Different opinions exist regarding the dryness of precoating before seal work commences, which also varies depending on the binder used. Testing bond strength development with different precoating products and binders highlighted the following:
  - Bond strength development is quickest with products not containing any solvents and dried.
  - Bond strength development could take up to four days during cold periods with products still moist and containing solvents.

The selection of an appropriate product depends on the required time for opening to traffic. More information on this topic in SABITA Manual 26. The key issue is not to open the road to traffic before complete adhesion/ bond strength development.

- Part of the quality assurance process is to ensure that any binder is removed from the stockpile floor after precoating and discarded.

G.6.2 BINDERS

G.6.2.1 General

Although the bitumen manufacturers try to ensure the tanker used to transport the product is free from any form of contamination prior to loading, they do not provide guarantees. This, together with the difficulty in monitoring and controlling the heating protocols for transport and storing, implies that conformance of the product to the relevant SANS standard, when delivered on site, cannot be automatically assumed. The bitumen binder producers are generally required to supply a batch test data sheet with every load dispatched. These should be continuously requested and retained with the site records.

Notes:

- ***Excluding contamination, the factor with the greatest influence on the change in bitumen properties is temperature.***
- ***Excessively high temperatures, poor circulation within the holding tanks, and long-term storage at elevated temperatures all contribute to the degradation of the bituminous binder. Continuous vigilance is therefore required on site to ensure that the storage of hot bitumen binders is within the specified limits and follows good practice.***
- ***Similarly, as the properties of hot-applied binder alter with each heating and cooling cycle, it should be standard practice to take duplicate samples from each tanker load delivered to site, prior to discharge into the site storage tanks. One sample is utilised for testing, the other is retained for further testing, if necessary.***
- ***Dependant on the length of storage time, it may also be necessary to regularly sample the product from the site storage tanks, followed by testing for conformance.***

When the binder arrives on site, it is accompanied (or shortly after) by tested properties of the batch from the supplier. Following confirmation that the correct binder has been delivered, it is heated and general distributor checks are carried out.

When these checks are acceptable the binder is sampled and:

- On-site binder tests carried out (refer Table G 11 for conventional binders)
- The samples submitted to a laboratory for testing (refer Table G 10, Table G 11 and relevant tables for modified binders)

Notes:

- ***Conditions on site may change e.g. weather or breakdown of equipment, resulting in the binder being cooled down to the recommended storage temperature. When the conditions are again favourable, the binder is reheated (re-blended in case of bitumen rubber) and sampled and tested again.***
- ***These cycles could occur several times.***
- ***By the time the binder properties from laboratory tests are available, the product has already been sprayed and the seal (or initial layers) constructed.***

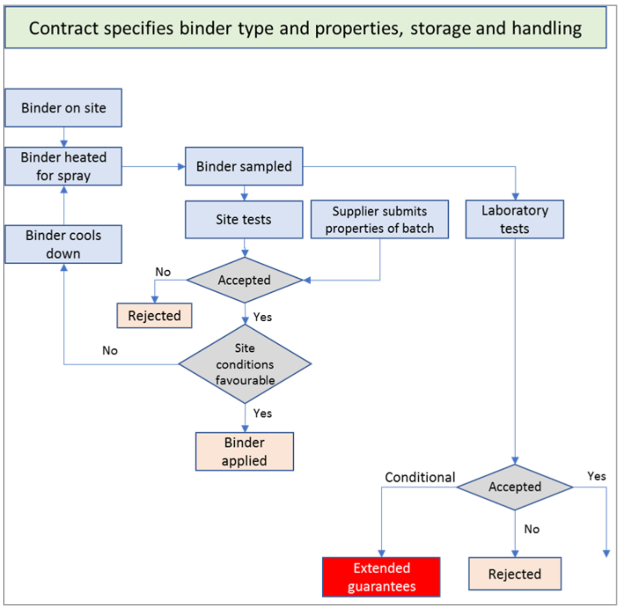


Figure G 3 Process Flow for Binder Acceptance

G.6.2.2 Sampling and testing for conventional binders

Unmodified bituminous binders must conform to the applicable SANS specifications (refer PART B: Materials). As these specifications are frequently reviewed and amended, it is important that the latest applicable specifications are available on site. It is important to be aware the SABS mark only implies conformance at the refinery despatch point.

Table G 10 Recommended Test Frequencies for Penetration Grade Binders

Property	Manufacturer	Haulier	Site Storage	Sprayer	Test Method
Before Ageing					
Softening point	Every batch	Every load	Every day	Every load	ASTM D36
Penetration	Every batch	Every load	Every day	Every 5th load	EN 1426
Dynamic viscosity @ 165°C	Every batch			Every 5th load	ASTM D4402
Flash point	Once, at start of project				ASTM D92
After Ageing (RTFOT)					
Mass change	Every 10th batch			Every 10th load	ASTM D2872
Difference in softening point	Every 10th batch			Every 10th load	

Note**:** ***This test is performed on a frequency basis, or when there is a change in the source of base bitumen or bitumen crude type.***

Note the following regarding testing:

- Frequency of laboratory testing is dependent on available funding and degree of risk, which should be clarified with the client as part of the quality plan.
- Requests for more laboratory testing are dependent on the early performance of the seal.

At minimum, each delivery (truck load) of bituminous binder should be sampled, with 3 x 1 litre samples.

- The samples should be clearly marked, indicating the:
    - Binder type
    - Batch number
    - Source
    - Application position on the road
    - Date
- The samples must be properly sealed to prevent volatiles and/or water evaporating
- One of the samples should be tested on site as per Table G 11. If the laboratory test results indicate that the product does not comply with the specification, tests for compliance with SANS 4001-BT1 should be carried out.
- The second sample is sent to a commercial laboratory for more detailed testing, if so required.
- The third sample is kept as a reference sample.

Table G 11 Tests Required for Conventional Binders

	Penetration Grade	**Cut-Back Bitumen**	**Emulsion**
Laboratory Testing	As per Table G 10	Viscosity @ 60 °C, Pa.s	Binder content
		Flash point, °C	Viscosity (Saybolt Furol)
		Water %	Residue on sieving (g/100 mℓ)
		Distillation and % distillate	Particle charge
			Sediment flux content
			Coagulation value
Site Testing	Penetration @ 25 °C/100 g/5 s		Binder content
	Softening point (Ring and ball), °C		Viscosity (Saybolt Furol)
	Viscosity @ 135 °C, Pa.s		Residue on sieving (g/100 mℓ)

G.6.2.3 Sampling and Testing for Modified Binders (according to TG1)

Due to the specialist nature and time required to complete some of the prescribed tests, it is not feasible to conduct the full spectrum of tests at the point of manufacture prior to dispatch, or on-site prior to application of the binder. The main objective of the quality assurance process is to ensure that product supplied meets the required specification, and that the quality of the binder is maintained until it is applied. From the time the product is dispatched from the blending plant it is exposed to the risk of contamination and degradation, unless the binder is handled in the correct way. This could occur mainly through overheating and shearing at the different stages of handling from loading, transporting, offloading and storage, until it is mixed with aggregate or sprayed.

To ensure that the properties of the applied modified binder have not changed significantly from that of the original product dispatched from the blending plant, the following quality control measures are recommended:

- The supplier must conduct the necessary tests on the product to ensure that it meets the specification requirements before dispatching the product. The supplier must keep retention samples for each batch for a period of 12 months following the completion of the project. In the case of modified emulsions this period can be reduced to 3 months from date of manufacture;
- The supplier should supply a laboratory certificate for each batch stating the binder properties. This might not include all the test requirements but should contain the indicative tests like softening point. The batch certificate should be transmitted to the site electronically or delivered by the haulier driver;
- Samples should be taken from the haulier while the product is being discharged on-site, and these should be retained for further testing in the case of a dispute. This is the responsibility of the receiving party;
- Samples should be taken from the site storage tank **on a daily basis** and tested prior to application. In the case of a sprayer, samples should be taken for every load sprayed;
- Product not applied can be returned to storage and retested for compliance prior to further use;
- All samples must be clearly labelled on the side of the container and NOT on the lid, with all relevant details for ease of identification and traceability;
- To limit the potential for a dispute arising from test results of the manufacturer and the site laboratory, it is recommended that correlation testing be carried out between the laboratories prior to the supply of binder to identify any discrepancies.

On commencement of a contract, the full spectrum of tests should be conducted on the first batch of the product manufactured or delivered on site, to demonstrate the supplier's ability to comply with the specification. Thereafter, the respective tests should be conducted at an agreed frequency unless there is a change in the source of raw material (base bitumen or polymer).

In the case of bitumen-rubber, the supplier must also provide a set of curves showing the changes in the flow, softening point and viscosity with time at various temperatures relevant to the technology stated in the company's method statement.

Table G 12, Table G 13 and Table G 14 provide the recommended frequency level for all the tests required at the different stages.

Table G 12 Recommended Sampling and Test Frequency for Hot Polymer Modified Binders

Property	Manufacturer	Haulier	Site storage	Sprayer
Before ageing				
Softening point	Every batch	Every load	Every day	Every load
Elastic recovery @ 15°C	Every batch			Every 5th load
Dynamic viscosity @ 165°C	Every batch			Every 5th load
Storage stability @ 180°C	Every 10th batch			
Flash Point	Once, at start of project			
After ageing (RTFOT)				
Mass change	Every 10th batch			Every 10th load
Difference in Softening Point	Every 10th batch			Every 10th load
Elastic recovery @ 15°C	Every 10th batch			Every 10th load

Table G 13 Recommended Sampling and Test Frequencies for Polymer Modified Emulsions

Property	Manufacturer	Haulier	Site storage	Sprayer
Binder content (m/m)	Every batch	Sample only	Every day	Every load
Saybolt Furol viscosity @ 50°C	Every batch			
Residue on sieving (/100 ml)	Every batch			
Particle charge	Every 5th batch			
Sedimentation after 60 rotations	Every 5th batch			
Recovered binder residue				
Softening point	Every batch			Every load
Elastic recovery @ 15°C	Every batch			

Table G 14 Recommended Sampling and Testing Frequency for Bitumen Rubber

Property	Spray tanker
Softening point	Every load
Dynamic viscosity[1]	At the start of every load
Compression recovery:	
5 minutes	Every 5th load
1 hour	Every 5th load
Resilience	Every 5th load
Flow	Every load

Note:

[1] Dynamic viscosity is an indicator of the product quality. Attempts should be made for viscosity to be measured at the specified temperature.

If the viscosity is not measured at the appropriate temperature on site, its value at the appropriate temperature can be determined using the relevant temperature-viscosity relationship.

For S-R2, where viscosity is specified at 170°C, products can be certified at the blending source in respect of both softening point and viscosity due to their stability.

G.6.3 SAFE HANDLING AND STORAGE

The most significant hazard associated with bitumen is heat burns. Conventional and modified hot binders are handled at temperatures ranging from 150 °C to 210 °C. Skin contact with bitumen at these high temperatures causes severe burns and shock, which can be fatal. It is important to always wear the required Personal Protection Equipment (PPE), including overalls, heat resistant gloves, face shield and safety boots.

For more detailed information regarding the safe handling of bituminous products see SABITA Manual 8 [4], "*Guidelines for the Safe and Responsible Handling of Bituminous Products*" and Chapter 2 of TG1 [3].

G.7 CONSTRUCTION

G.7.1 TRIAL SECTIONS

The purpose and execution of trial sections are discussed in PART F: Construction – Section F.6.

Part of the trial section planning is to determine/verify the stone spread rate.

<u>Note</u>: Tenders are based on nominal spread rates, without knowing at that stage the true size and shape of the particles.

As discussed in PART F, aggregate (preferably not precoated) is spread shoulder-to-shoulder, by hand on one square metre areas, with the ALD perpendicular to the road surface and weighed.

When this spread rate is applied by the chip spreader on the road and rolled, it will still appear slightly open. However, after traffic compaction for a couple of days during good weather conditions (appropriate for the binder to allow orientation), a dense shoulder-to-shoulder matrix would be obtained.

For QA purposes, it must be confirmed that the process was followed, the ideal spread rate documented, and the target spread rate specified in the "Method Statement".

Similarly, the binder application rate should be evaluated, adjusted by means of submission of a new design and recorded as part of the method statement.

G.7.2 WEATHER LIMITATIONS

Refer PART F: Construction – Section F.7 and Table F 4: Minimum road surface temperature.

G.7.3 TRAFFIC LIMITATIONS

Traffic management is discussed in PART F: Section F.3.1.2.

In addition to the above, traffic should not be allowed:

- On a single seal or double seal prior to application of the cover spray, if designed with a cover spray.
- On the first layer of aggregate of a double seal, second layer of a triple seal (split application double seal) or Cape seal (single seal with slurry).
- On non-completed longitudinal joints.

G.7.4 GENERAL CHECKS AND RECORDS

Detail of each spray section should be recorded on site, which includes:

- Date and time.
- Distributor detail.
- Start and end position.
- Lane (transverse spray configuration).
- Seal aggregate and binder type per layer.
- Binder and aggregate sample references.
- Road surface temperature.
- Aggregate temperature.

- Binder application rate, calculated from the recorded:
  - Effective spray width.
  - Volume binder sprayed (Dip reading before and after).
- Aggregate application.

Mobile weather stations are recommended for all surface treatment projects and the following data recorded for the entire period of sealing and for at least one month thereafter:

- Minimum and maximum air temperature
- Wind speed
- Humidity
- Rainfall

G.7.5 FINAL CHECKS BEFORE SEALING COMMENCES

The following must be checked before the binder is applied:

- All safety regulations adhered to.
- All the required equipment available and checked.
- Confirm weather conditions are appropriate for seal work. If rain threatens, the seal work should be delayed.
- Confirm that all staff are aware of their responsibilities.
- Confirm of binder application and aggregate spread rates.
- Spray area clean. No unwanted material should be carried over on the surface, e.g., mud or loose material dust.
- Where bitumen binder is to be sprayed directly adjacent to existing concrete kerbs, channels, side drains, concrete edge beams, bridge balustrades, and over bridge joints, such concrete elements should be covered with an approved reinforced jointing paper.
- Make sure that the correct type and grade of bituminous binder is in the distributor. The batch certificate should be obtained from the distributor operator, stating the type, grade and batch number.
- Confirm that the binder is at the correct temperature and that the gauges are calibrated.
- Make sure that the contractor has made adequate arrangements and that enough suitable material is available to cover the sprayed area in the specified time.
- The length of each section sprayed should be such that the available aggregate cover the section with the minimum delay.

  Depending on the supply of aggregate to the chip spreader and the available equipment, it is advisable to limit the spray length to:

  - Conventional and homogeneous binders: no longer than 400 meters.
  - Non-homogeneous modified binders, i.e., bitumen rubber: no longer than 200 meters.
- The air, road and binder application temperature should be continuously assessed. The constructed section should be shorter if the temperatures are at the lower end of the accepted ranges.
- Check that there are no obstructions in the line of spray.
- Record the dipstick readings on a level surface, where possible. Take readings after each spray to ensure accurate application.
- Confirm that the road surface temperature is appropriate for the binder.
- Ensure that the specified reinforced paper is available and placed properly at the beginning and end of the section to be sprayed, and that arrangements are made to remove and dispose the jointing material as soon as possible after the seal work is finished. Special “drip trays” may be required when the distributor is parked on the road prior to spraying.

- Make sure that the area to be sprayed is properly demarcated, with string lines held in place with steel nails at 15 meter intervals on straight sections, and at 3 meter intervals on curves, to guide the distributor operator.
- There must be no joints in the wheel tracks.
- Check the alignment of the distributor:
  - Width of spray.
  - Overlap configuration, bar height and fish plate.
  - Position of the guide marker.

G.7.6 BINDER APPLICATION

G.7.6.1 Site QA Process

The process is slightly different for different seal types, dependent on the number of binder applications and ability to correct inaccurate spray applications by altering the application rate of the subsequent binder layer.

Processes are defined for:

- Single seals and Cape seals without a specified cover spray.
- Single seals and Cape seals with a cover spray specified.
- Sand seals and graded aggregate seals.
- Multiple stone seals without a specified cover spray.
- Multiple stone seals with a cover spray specified.

G.7.6.2 Single Seals

The QA processes for single seals and binder application for the large aggregate of Cape seals are provided in Figure G 4 and Figure G 5.

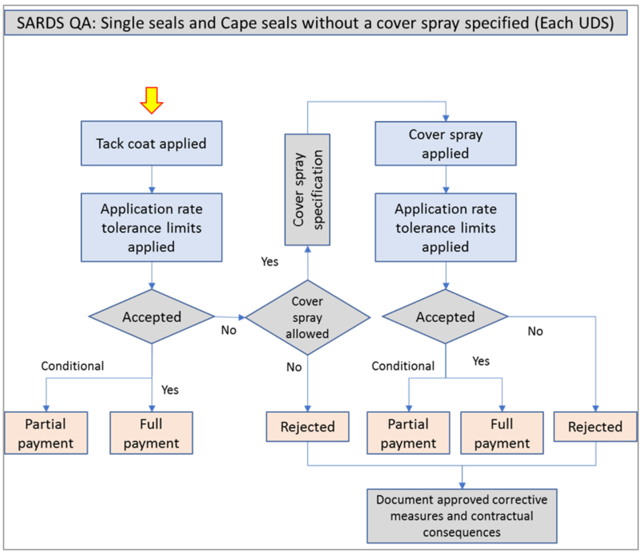


Figure G 4 QA Process for Single and Cape Seals without Cover Spray Specified

Note:
UDS refers to a Uniform Design Section

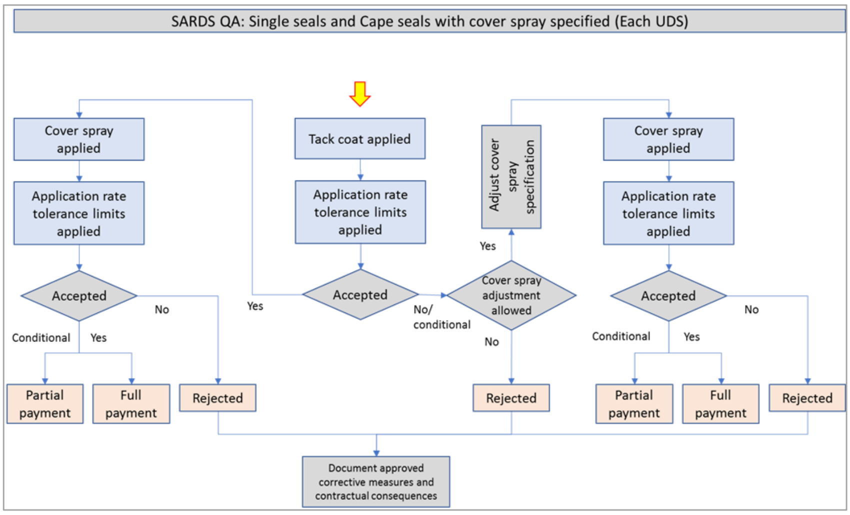


Figure G 5 QA Process for Single Seals and Cape Seals with Cover Spray Specified

G.7.6.3 Sand seals and Graded Aggregate Seals

The QA processes for sand seals and graded aggregate seals are provided in Figure G 6.

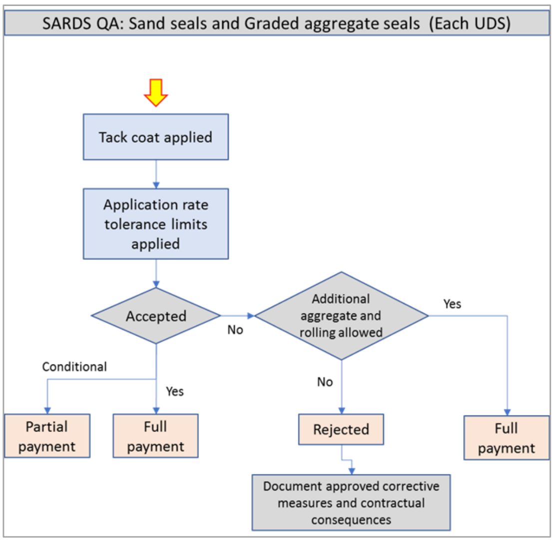


Figure G 6 QA Process for Sand Seals and Graded Aggregate Seals

G.7.6.4 Double Stone Seals

The QA processes for double stone seals, with and without a specified cover spray, are summarized in Figure G 7 and Figure G 8.

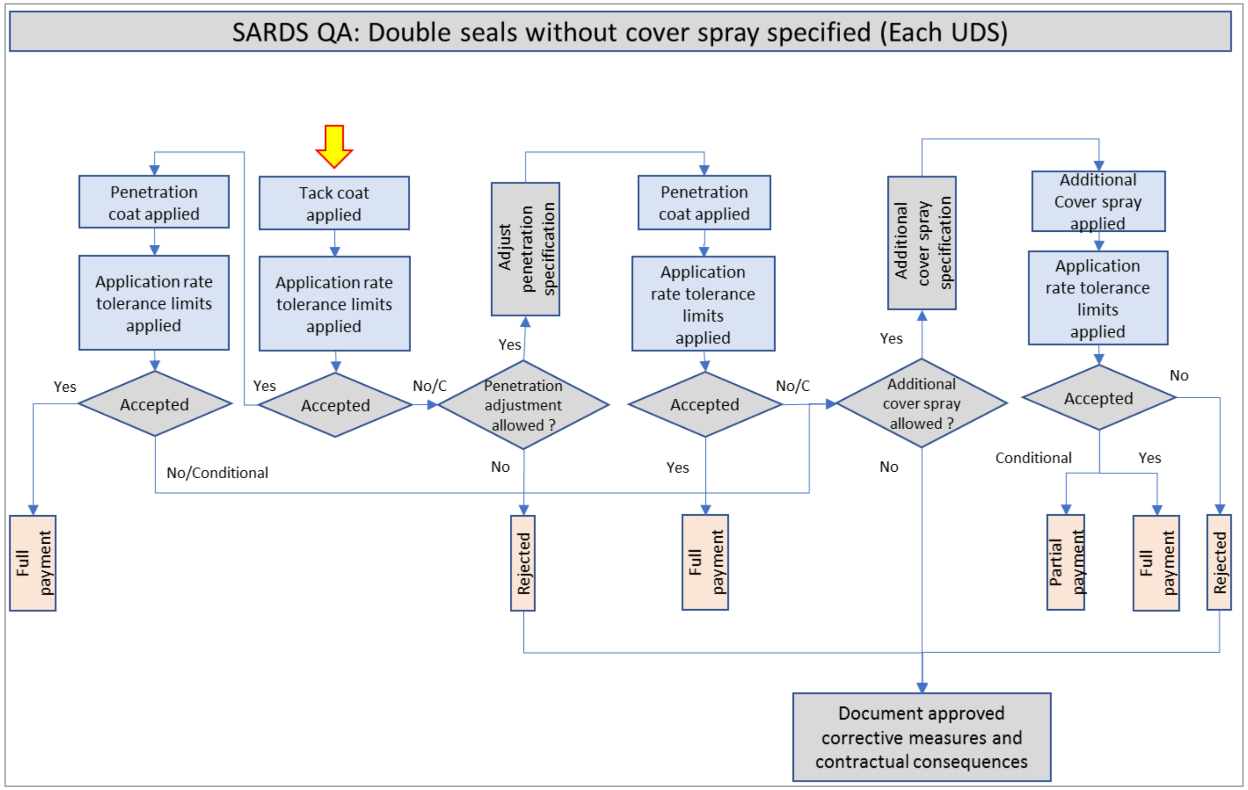


Figure G 7 QA Process for Double Seals without Cover Spray Specified

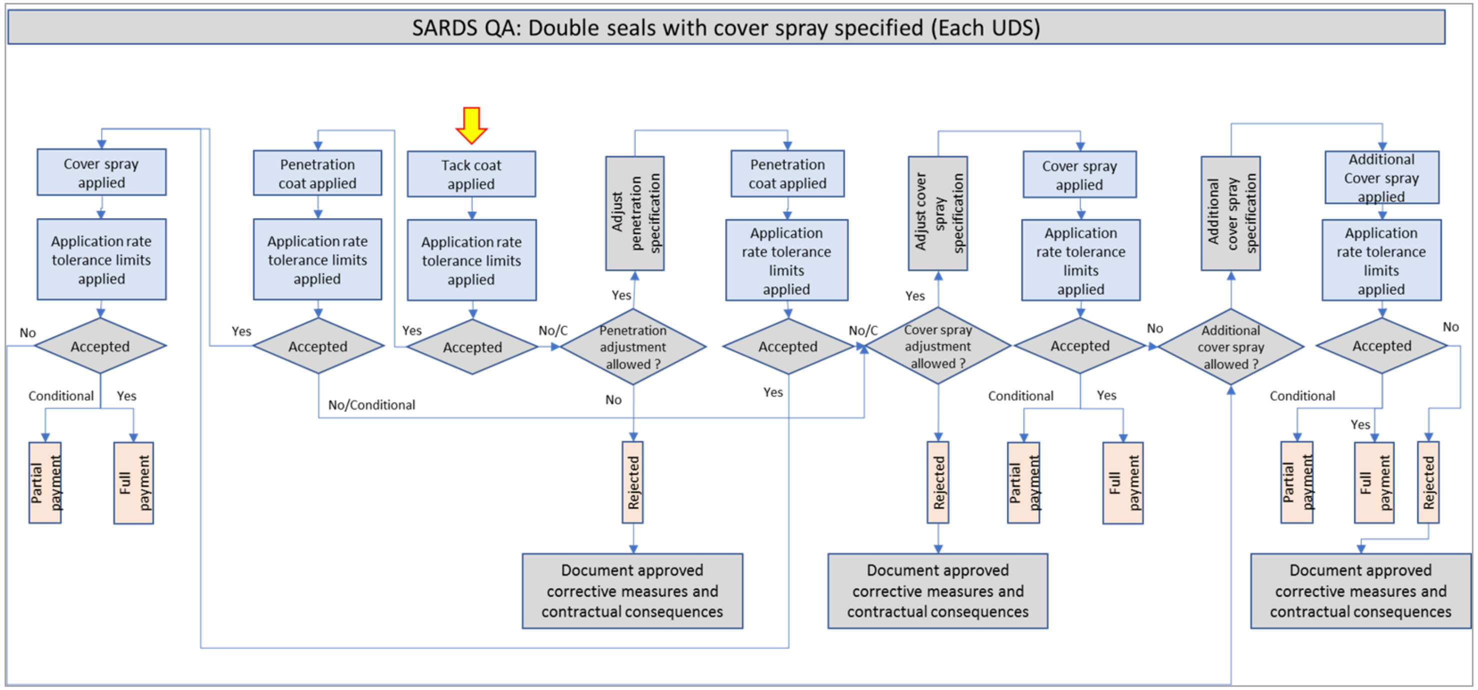


Figure G 8 QA Process for Double Seals with Cover Spray Specified

G.7.7 AGGREGATE APPLICATION, ROLLING AND BROOMING AND OPENING TO TRAFFIC

Guidelines and checks for each activity are well described in PART F (refer Section F.9, F.10, F.11, F.12 and F.13).

G.7.8 REJECTION AND CONDITIONAL ACCEPTANCE

G.7.8.1 General Aspects Related to Quality and Workmanship

The following guidelines are provided regarding acceptable workmanship and reasons for rejection or conditional acceptance:

G.7.8.1.1 Surface tolerances

Where newly constructed base or shoulder areas are to be sealed, the surfaces must be checked for compliance with the surface tolerances and all other requirements specified for the base layer. Any portions that do not meet these requirements must either be corrected or removed and reconstructed before they are sealed.

Surface tolerances specified for the base should also apply to the sealed surface.

As discussed in PART C: Performance, granular/ crushed stone base layers are often coarse textured, resulting in the large base aggregate protruding above the seal aggregate (in touch with vehicle tyres) or allowing ingress of water into the base as a result of voids created within the seal. Corrective texture treatments (void filling seals) should be applied before sealing such bases with surface treatments (refer G.4.2).

The edges of the completed seal should be continuously true to line with a maximum allowable deviation from the specified edge line of 15 mm.

G.7.8.1.2 General appearance

The completed seal should:

- Be free from corrugations or any other wave effect where depressions are preceded and followed by humps or ridges.
- Be of uniform texture without gaps or patches and should be free from longitudinal and transverse corrugations and any loose aggregate or binder spillage.
- Not exhibit any tramlining.

G.7.8.1.3 Aggregate spread rate and binder application

The maximum permissible variation from the rates of application of aggregate, as determined after verification during the trial section, should be plus or minus 5%.

The maximum permissible variation in binder application rate from that specified (measured at spray temperature), should be 5 % for all binders, except diluted emulsions. In case of diluted emulsions, the variation should be calculated in terms of the emulsion before dilution.

A lot for acceptance control purposes should be one comprising the application of at least 600 litres of binder. Lots smaller should be combined with succeeding lots until the minimum lot size is reached. Provided that corrections to subsequent layers (penetration coat and/or cover sprays) could be applied in accordance with good practice (refer G.7.6), out of tolerance variations could be accepted at the reduced rates of payment recommended in Table G 15 (Extracted from [2]).

Variations in binder application rates in excess of those tabled should be rejected. No payment should be made for bituminous binder applied in excess of the rate ordered plus the permitted tolerance.

Rejected sprays should result in rejection of the total seal without any payment.

Conditional acceptance does not relieve the Contractor from his obligations related to the seal performance.

Table G 15 Reduced Payment for Conditionally Accepted Single Binder Application Rates

Diluted emulsion. **Deviation from specified spray rate Net emulsion. (%)**	**Hot applied binder and undiluted emulsion** **Deviation from specified rate. At spray temperature. (%)**	**% Payment of tendered rate for seal**
±5.0	±5.0	100.00
±6.0	±6.0	97.56
±7.0	±7.0	94.32
±8.0	±8.0	90.28
±9.0	±9.0	85.44
±10.0	±10.0	79.80

The equation for determining the reduced payment per binder layer is provided below:

$$= -0.004D^2 + 0.0196D + 1.002$$

Where

P = % Payment of the tendered rate for the seal

D = Deviation from the specified rate

In the case of single seals, where a diluted emulsion cover spray is not specified (refer Figure G 4), the application of a diluted emulsion cover spray in instances where tack coat application rates are below the minimum allowable tolerances could be permitted. In such instances, no additional payment over and above the unit rate tendered for the accepted seal, plus or minus any variation from the nominal to the rate ordered, should be made.

In the case of single seals, where a diluted emulsion cover spray is specified (refer Figure G 5), no payment should be made for bituminous binder in the tack coat applied in excess or at a rate lower than the specified rate, plus or minus the permitted tolerance unless, such overspray or any shortages can be satisfactorily corrected by the adjustment to the application rate of the cover spray, or an additional cover spray.

In the case of multiple stone seals, no payment will be made for any bituminous binder applied in excess of, or at a rate lower, than that specified, plus or minus the permitted tolerance. In such instances adjustment to any subsequent spray applications to achieve the total net binder as determined and specified for the particular seal type could be permitted (refer Figure G 7 and Figure G 8). In the event of under application of binder, the application could be allowed, or an increased application, of an appropriate cover spray if the overall integrity/performance of the surface seal is deemed not to be compromised.

In the latter two cases, where some of the layers are conditionally accepted, a weighted payment adjustment could be calculated based on the payment adjustment for the specific layer and the proportional cost of the binder layer to the total binder cost, as determined from the tendered variation for each binder. An example is provided in Table G 16.

Table G 16 Calculation of Weighted Payment Adjustment

Binder layer		Binder	Specified hot appli-cation rate	Applied rate	% out	Adjust-ment factor %	Accep-tance	Weighted adjustment	Variation (R/l) tendered	Cost of binder (R/l)	%Cost of layer
First application (tack coat)		Hot: S-R1	2.00	2.20	10.00	79.80	Condi-tional	46.49	6.00	12	58.25
Second application (penetration coat)		Hot: S-E1	1.30	1.20	7.69	91.61	Condi-tional	28.91	5.00	6.5	31.55
Cover spray		Diluted Cat 65	1.00	1.10							
% Emulsion in dilution	70	Cold: Cat 65	0.7	0.77	10.00	79.80	Condi-tional	8.13	3.00	2.1	10.19
							% Payment	83.53		20.60	
							Tendered price/m^2	62.00			
							Payment /m^2	51.79			

G.8 REPAIR OF DEFECTS

Any areas which show signs of bleeding, aggregate loss, non-uniformity of texture and surface irregularities after the section has been opened to traffic should be corrected as recommended in PART H. Corrective work should be carried out in such a manner as to blend in colour, texture and finish with adjacent work.

In case of Cape seals, slurry or microsurfacing, any damage to the slurry by rain or traffic before the slurry has cured should be rectified by the Contractor at his own expense.

G.9 REFERENCES

[1] SANRAL 2014. South African Pavement Engineering Manual (SAPEM).

[2] Committee of Transport Officials (COTO), Committee Draft 2020. Standard Specifications for Road and Bridge Works.

[3] Southern African Bitumen Association (Sabita), Technical Guideline: The Use of Modified Binders in Road Construction (TG1), South Africa, 2019.

[4] Sabita Manual 8: Bitumen Safety Handbook.

PART H

REPAIR OF PREMATURE FAILURES

CONTENTS

LIST OF TABLES

LIST OF FIGURES

H.1 INTRODUCTION

H.1.1 CONTEXT

Manual 40 comprises eight parts:

- Part A: General
- Part B: Materials
- Part C: Performance
- Part D: Seal type and binder selection
- Part E: Design
- Part F: Construction
- Part G: Quality Assurance
- **Part H: Repair of premature failures (This document)**

H.1.2 OBJECTIVES

The purpose of PART H is to highlight the most common types of premature seal failures and to provide guidance regarding appropriate repair methods. Although premature cracking and delamination occur from time to time, the most problems are related to aggregate loss and bleeding.

H.1.3 SCOPE

PART H discusses the main causes of premature aggregate loss and bleeding and focusses on repair in the following sections:

H.2 Most common types of premature seal failure
H.3 Repair of aggregate loss
H.4 Bleeding repair

H.2 MOST COMMON TYPES OF PREMATURE SEAL FAILURE

The most common types of premature seal failure are:

- Aggregate loss (Also referred to as stripping).
- Bleeding/Fattiness.

Other types of premature failures such as cracking and delamination occur from time to time and require detailed investigation into the causes and appropriate remedial measures.

H.2.1 AGGREGATE LOSS

H.2.1.1 Main Causes

Several factors could contribute to stripping during the early life of a seal. Figure H 1 highlights the various components affecting the development of seal strength and stresses influencing the early life performance.

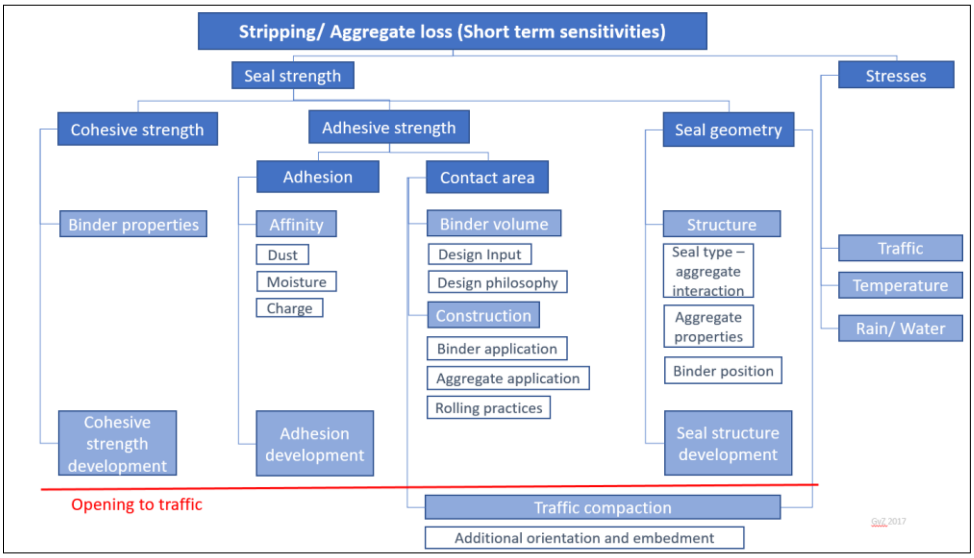


Figure H 1 Short Term Sensitivities to Stripping

The main causes and mechanisms of stripping are well described in PART C: Performance, with good practice guidelines to prevent this mode of failure, provided throughout the various parts of this manual.

The most common cause of failure reported from investigations in South Africa is "cold temperatures" experienced soon after construction. The mechanism, as described in Section C.5.1.1 of PART C, could be summarised as follows:

- Design of binder application rate is based on the ALD of the aggregate particles being perpendicular to the road surface providing the maximum stone area in contact with the binder.

- The aggregate, during construction, does not orientate fully, resulting in insufficient bond strength to resist the horizontal forces on proud-standing particles.
- When high road surface temperatures are experienced (>20ºC for binders without solvents), the soft binder adhering to the aggregate allows further orientation when opened to traffic. However, with low road surface temperatures (<15ºC) the aggregate cannot orientate, resulting in high stresses on individual proud-standing particles

The effect is shown in Figure H 2 with stripping only occurring in the shaded areas.

Figure H 2 Striping Occurring Only in Shady Areas

With the above in mind, effective repair of stripped areas would require either:

- Applying additional binder to increase the bond strength.
- Application of a cationic rapid setting emulsion in isolated areas and replacing lost aggregate with one standard size smaller than the stripped aggregate.
- Increase the seal strength and minimise proud-standing aggregate by applying emulsion and adding a smaller, interlocking aggregate.
- Prepare the surface by replacing single-sized stone on bare patches and add an additional layer (e.g. small aggregate, slurry of asphalt).
- Complete removal and replacement of the seal.

H.2.2 BLEEDING AND FATTINESS

H.2.2.1 Main Causes

Main causes for bleeding reported during forensic investigations are:

- High embedment of aggregate due to a soft substrate, high traffic loads and too much binder for the prevailing conditions.
- Using too soft binders in areas prone to very high road surface temperatures.
- Using cut-back binders as the tack coat in cape seals.
- Sealing on granular bases with high moisture content.
- Sealing too soon on seals treated with cut-back invert emulsions.

Examples of bleeding due to different causes are shown in the figures below. Recommended repair methods are provided in H.4.

Figure H 3 Bleeding as a Result of High Base Moisture

This emphasises the need for granular bases to dry out to less than 50% of the optimum moisture content before sealing.

Figure H 4 Bleeding as a Result of Volatile Evaporation from Rejuvenation Treatment

The above situation confirms that reseals should be postponed for preferably two years after application of high solvent content rejuvenators.

Figure H 5 Bleeding Cape Seal – 70/100 Pen Bitumen at 80^{o}C Road Surface Temperature

As discussed in PART C, stiffer binders should be used in areas prone to high surface temperatures.

H.3 REPAIR OF AGGREGATE LOSS

H.3.1 GENERAL

The most appropriate repair method depends on:

- Seal type and layer affected.
- Degree of stripping and sensitivity to further deterioration.
- Speed of remedial work.
- Availability of suitable materials.
- Traffic accommodation, traffic volumes and risk of vehicle damage.
- The effectiveness of the repair method to stabilise the condition and to ensure a good performing and visually acceptable surface.

Alternative repair methods, as mentioned in H.2.1.1, are described in the following sections:

H.3.2 ADDING ADDITIONAL BINDER

Only adding additional binder in the form of a diluted emulsion should only be done if:

- The existing texture is uniform.
- Still acceptable in terms of visual appearance, adequate chip distribution and noise levels.

Although diluted anionic stable grade emulsion could be used, the preference for repair/ reducing sensitivity to stripping is to use a diluted cationic spray grade (rapid setting) emulsion. The effects and differences of the two products are described in Section C.4.2.2.4 of PART C.

<u>Notes</u>:

- ***Cationic spray grade emulsion could stay tacky for a while, but allows some penetration to fill voids in the structure and to create bonds between the shoulders of the aggregate particles.***
- ***Anionic stable grade emulsion will tend to flow deeper into the seal structure, with less tackiness. However, depending on the seal type and voids, the top aggregate of a double seal could still be sensitive to stripping.***
- ***Polymer modified emulsions could stay tacky for an extended time, not penetrate at low application rates and form a skin at the top.***

An example of a 14/7 double seal is shown in the following figures with:

- Figure H 6 showing the intended surface finish (non-stripped section).

Figure H 6 Non-Stripped 14/7 Double Seal Texture

- Figure H 7 showing the 14/7 double seal sprayed with a (70/30) diluted cationic spray grade emulsion at 0.8 l/m², after some stripping of the 7 mm aggregate occurred.

Figure H 7 Treated Stripped 14/7 Double Seal

<u>Note</u>: Several cases have been recorded where the top 7 mm of a 20/7/7 seal stripped during cold weather and where it was considered a lower risk just to add an additional diluted cationic cover spray, than to add additional binder and aggregate. Application rates of the diluted cationic emulsion of 1.0 – 1.2 l/m² provided acceptable results.

H.3.3 ISOLATED REPAIRS – REPLACING LOST AGGREGATE

When stripping only occurs in small areas, it is not considered feasible to treat the entire road or large sections as discussed in H.3.4.

A practical method to repair small areas such as joints and slightly stripped areas is to:

- Clean the area.
- Apply cationic emulsion or polymer modified emulsion by hand (approximately 0.8 l/m²).
- Fill the voids with a precoated stone, on standard size smaller than the stripped aggregate.
- Roll with pneumatic tyre roller.
- Broom off excess aggregate.
- Apply a dilute cationic emulsion cover spray at approximately 0.8 l/m², if necessary, by hand on the repaired area or, if sensitivity exists on the full width by distributor.

Figure H 8 shows the effect of a treated small stripped area.

Figure H 8 Replacement with smaller size precoated aggregate

H.3.4 INCREASE THE SEAL STRENGTH AND MINIMISE PROUD STANDING AGGREGATE

In cases where the top layer of a 20/10 double seal stripped or slight losses of a single 10 mm or 14 mm seal occur, the recommended treatment is to add binder and to fill the voids with a small aggregate such as a 5 mm, 7mm or application of a fine slurry (Fine or medium grade – Refer PART B: Materials).

Figure H 9 Slight Losses but Uniform and Ideal for Small Aggregate Filling

The effects of the different alternatives are discussed by means of examples where several experiments were conducted.

H.3.4.1 Example 1: Very coarse and open textured surface of a stripped 20/10 double seal.

Figure H 10 shows the condition of a 20/10 double seal after stripping during a cold spell.

Figure H 10 Stripped 20/10 Double Seal

Several repair experiments were carried out as discussed in the following sub-sections.

H.3.4.1.1 5 mm Precoated Grit with 60% anionic emulsion (undiluted) at 0.9, 1.0 and 1.1 l/m²

Figure H 11 Trials with different binder application rates (close-up of 1.1 l/m²)

Figure H 12 Before and After (Slow Lane at 0.9 l/m²)

<u>Note</u>: The large double seals tend to have many voids for binder to run into – visible when circular sand patch is done (Refer Figure H 13). The situation requires more binder and very quick application of Grit. Recommended to test different applications and procedures on a small scale as shown in Figure H 11.

Figure H 13 Sand Trickle into Porous Surfacing

H.3.4.1.2 7 mm Precoated Aggregate

The following repair procedure was applied:

- Application of 70/100 pen bitumen at 0.7 l/m^2.
- Application of precoated (16 – 18 l/m3) 7 mm aggregate at 180 m^2/m^3.
- First two passes with light steel wheel roller (2 ton) followed by heavy pneumatic rolling (eight passes).
- Closed overnight, broomed and opened to traffic.
- Slight loss of the 7mm occurred.
- Anionic emulsion fog spray (No cationic emulsion available) of 1.0 l/m^2 and 50/50 diluted with water, applied over the full width to reduce risk of further aggregate loss.

The final surface after a few weeks of trafficking, is shown in Figure H 14.

Figure H 14 Repair Using 7 mm Aggregate – Final Surface

H.3.4.1.3 Fine slurry (Fine grade)

Figure H 15 shows the final surface after application of a fine slurry (Fine grade – Refer PART B: Materials) by hand using squeegees.

Figure H 15 Repair Using a Fine Slurry

<u>Note</u>: Slurry should not be applied on bare areas without aggregate as the free binder will migrate to the top, resulting in severe bleeding.

H.3.4.2 Example 2: Very coarse and open textured surface of a stripped 20/10 double seal

Figure H 16 shows an example of a 20/10 double seal constructed during winter, opened to traffic and exposed to high traffic volumes the next morning at sub-zero temperatures.

Figure H 16 Stripping of the 10mm Aggregate From a 20/10 Double Seal

The seal was repaired by:

- Applying a cationic spray grade emulsion at 1.0 l/m^2.
- Application of a precoated 7mm aggregate.
- Application of a (50/50) diluted cationic emulsion at 0.8 l/m^2.
- Rolling with pneumatic tyre rollers.
- Closed during the night and opened during morning when road surface temperatures increased above 15°C.

This section, as shown in Figure H 17 did not deteriorate during an eight year monitoring period.

Figure H 17 Repaired 20/10 Double Seal

***Note*: An adjacent section with exactly the same design and construction process was closed overnight (for three nights) and only opened to traffic during day time when road surface temperatures increased above 18°C. Even though sub-zero temperature were experienced for several weeks after construction, no aggregate loss occurred over a monitoring period of eight years. This emphasises the importance of controlled opening to traffic to complete the orientation of the aggregate.**

Figure H 18 N1/14 Section 4b – 20/10 Double Seal

H.3.4.3 Example 3: Varying textured stripped single seal

A heavily patched road was sealed with a single 14 mm seal and polymer modified emulsion (SC-E1). Although the binder could be sprayed at 10°C, the road surface temperature did not increase above 15°C for several days after construction.

Stripping occurred to various degrees. Some areas exhibited stripping outside of the wheel track with isolated fattiness due to embedment in the wheel tracks.

Figure H 19 Stripping and Fattiness on a Newly Constructed 14 mm Seal

Following several successful repairs with emulsions and pre-coated grit or 5 mm aggregate, trials were conducted using undiluted anionic and cationic emulsions, as well as 70/30 and 50/50 dilutions with water, all applied at 0.8 l/m^2 and covered with pre-coated grit.

Figure H 20 Different Dilutions of Anionic Emulsions Applied

Figure H 21 Different Dilutions of Cationic Emulsions Applied

The 50/50 dilutions performed best for the combination of stripped and fatty areas on this road during hot conditions.

H.3.4.4 Conclusions and recommendations

Although several repairs were successfully done using 7mm aggregate and fine slurries, the lowest risk option for repairs is the application of conventional emulsions and pre-coated 5 mm aggregate.

From lessons learnt in different conditions, it was concluded that the ideal binder and application rates for the 5 mm pre-coated aggregate repair are functions of:

- Existing macro texture and voids within the structure.
- Traffic volume and load.
- Road surface temperature just/soon after construction.
- Time available before opening to traffic.
- Whether the aggregate is spread into the wet emulsion or only when breaking of the emulsion starts to occur (recommended to apply in wet emulsion).
- **Note that stable anionic emulsion is less tacky but could, also with the effect of pre-coating, take significantly longer than a spray grade cationic emulsion to cure properly.**

Based on experiences, Figure H 22 has been developed as an initial guideline for the net bitumen requirement when a stripped seal is repaired with a pre-coated grit or pre-coated 5 mm aggregate.

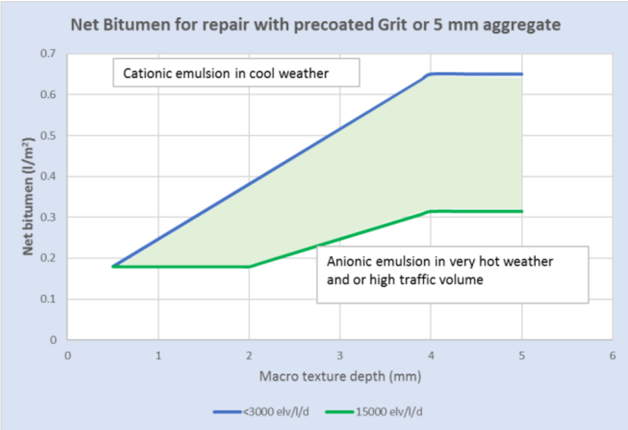


Figure H 22 Approximate Net Bitumen Requirement

Notes:

- ***The minimum relates to a 60% anionic emulsion, diluted 50/50 with water and sprayed at 0.6 l/m^2.***
- ***The aggregate spread of 250 m^2/m^3 results in a layer on which the pneumatic tyres can roll without pick-up.***
- ***Excess aggregate is driven off without damage to vehicles.***

H.3.5 PREPARE SURFACE AND ADD ADDITIONAL LAYER

Situations occur, typically with single seals, where large areas exhibit severe or complete loss of aggregate as shown in Figure H 23.

Figure H 23 Severe and Complete Loss of Aggregate

Due to the free binder already on the surface, the recommended treatment as described in H.3.4.4 will result in a fatty or bleeding surface.

Before application of the 5 mm pre-coated grit, large bare patches must first be treated by:

- Application of 0.8 l/m^2 65% Cationic emulsion or polymer modified emulsion (SC-E1), preferably using a distributor. Nozzles could be closed off if stripping only occurred in the wheel tracks.

- Application of a similar sized aggregate e.g. 14 mm pre-coated aggregate at a rate approximately 10% higher than the original seal spread rate (reason being that the aggregate will not fully orientate).
- Initial rolling with a light steel wheel roller.
- Final rolling using a pneumatic tyred roller.
- Brooming off excess loose aggregate.

The pre-coated 5 mm is then applied in accordance with the recommendations in H.3.4.4.

Examples and effect of this treatment are shown in the figures below.

Figure H 24 Before and After repair

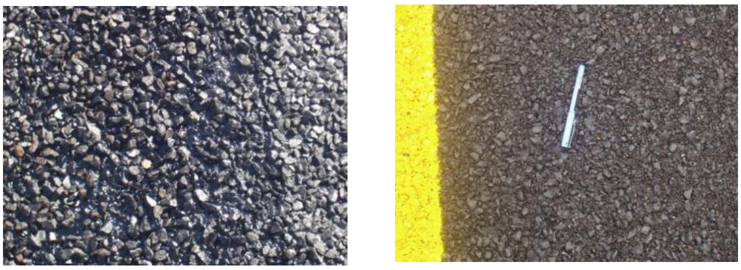


Figure H 25 After Application of Coarse Aggregate and the Final Repaired Surface

H.4 BLEEDING REPAIR

H.4.1 SHOULD WE DO ANYTHING?

Degrees of bleeding/fattiness, as defined in TMH9 are shown in Table H 1. Although a road could look fatty, it does not mean that is has poor skid resistance. General consensus is that Degree 1 and Degree 2 bleeding, as shown in Table H 1, are not considered a distress requiring any action and actually preferable in situations where the institutional capacity of the authority is not of a high standard.

Table H 1 Degree of Bleeding/Fattiness (TMH9 [1])

Degree	Description		
1	Surfacing is slightly rich in excess binder. Stones well proud of binder.		
2	Surfacing is rich in excess binder. Stones well proud of binder.		
3	Surfacing rich in excess binder. Smooth appearance, but stones visible in the binder.		
5	Surfacing very rich in excess binder giving pavement surface a wet look. Film of excess binder covering all stones in wheel paths. Surface is tacky during hot weather, and/or wheel prints are visible in binder with possible pick-up of binder.		

From a quality assurance perspective, the surface texture should be uniform after construction. However, as discussed in PART C: Performance, embedment and orientation of the aggregate continues after construction, which could result in significant differences in texture depth within and outside of the wheel tracks.

Provisional specifications for performance-based contracts require:

- Initial macro texture measurement between 7 and 14 days after opening to traffic in both wheel paths and in-between the wheel paths per 10 m.
- The initial measured surface macro-texture must meet the acceptance criteria presented in Table H 2 (Table D10.1.6-3 in COTO [2]).
- The measured surface macro texture after one year and two years must meet the acceptance criteria presented in Table H 3 (Table D10.1.6-4 in COTO).

Table H 2 Acceptance Criteria (Minimum) for Initial Surface Macro-Texture

Seal Type	10 mm	14 mm	14/7	20/10	20/7/7	20/7	20 Cape	14 Cape
5th Percentile MPD	1.8	1.95	1.5	1.8	1.55	1.7	NA	NA

Notes:

- ***The average MPD value per km lot becomes the reference MPD for performance measurement.***
- ***The volumetric texture depth as determined by SANS 3001-BT11 = 1.35 times the Mean Profile Depth.***

Table H 3 Acceptance Criteria for Surface Macro-Texture Performance – Double Seals

Time	**Percentage retention of initial Mean profile depth (%)^2**	**Maximum (%) of 1 km segment with surface macro-texture retention worse than limit value**
Year 1^1	85.0	20 %
	80.0	5 %
	75.0	0 %
Year 2^1	80.0	20 %
	75.0	5 %
	70.0	0 %

Table H 4 Acceptance Criteria for Surface Macro-Texture Performance –Single Seals

Time	Percentage retention of initial Mean profile depth (%)[2]	Maximum (%) of 1 km segment with surface macro-texture retention worse than limit value
Year 1[1]	70.0	20%
	60.0	5%
	55.0	0%
Year 2[1]	60.0	20%
	55.0	5%
	45.0	0%

Notes:

[1] Time in years after the issuing of the Performance Certificate.

[2] Mean Profile Depth value over 10 metres.

H.4.2 CONCLUSIONS

Any situation which could result in tackiness, pickup or poor skid resistance, should be repaired immediately.

Depending on the contractual requirements a decision will have to be made whether remedial work is required, e.g. for a performance-based contract, it is highly unlikely that the measured macro texture, as displayed in Table H 1 for Degree 1 and Degree 2, will satisfy the macro texture requirements.

H.4.3 REPAIR METHODS

Bleeding could be corrected by one or more of the methods described in the following sub-sections:

H.4.3.1 Rolling in of aggregate

Application and rolling in of heated aggregate with, or without, softening of the existing surfacing with a heating apparatus has been an accepted practice for a long time.

The type of binder, road surface temperatures and available equipment could vary. Therefore, it is recommended to test different options on site.

Trial sections could be constructed to determine the most effective process using:

- 10 mm and 7 mm aggregate.
- Pre-coated and un-pre-coated aggregate.
- Heated aggregate.
- Heating of the road surface.
- Steel wheel and pneumatic-tyred rolling.

If the binder of the existing surface has an oxidised film or if the road has been used by traffic for some time, the surface should be softened by heating apparatus. The heating apparatus should not expose the road surface to open flames. This work should only commence when the road temperature exceeds 30°C.

The aggregate, heated to 60°C at the time of application must be applied to the surface and immediately rolled with a flat wheeled (steel) roller as well as a pneumatic-tyred roller having a mass of at least 2t per wheel, until the aggregate is firmly embedded. All loose aggregate not embedded must be broomed off the road before it is opened to traffic.

The road should only be opened to traffic if the road surface temperature has cooled off sufficiently to minimise tackiness and pickup, usually in the late afternoon. When opening the road to traffic, the treated areas must be demarcated with traffic cones and speed limit and "loose stone" signs for at least the first two days. All loose aggregate should be broomed off and removed at least twice per day until full adhesion of the aggregate has been achieved.

All efforts should be made to ensure that the applied aggregate finish in a neat line.

Figure H 26 shows the rolling process and a typical finished treatment

Figure H 26 Rolling-in of Aggregate and Finished Treatment

H.4.3.2 Hydro-Cutting

As a result of risks related to skid resistance and pickup of tacky binder, all areas with excess binder, Degree 3 or more according to TMH9 Part B (Refer Table H 1), and/or insufficient macro texture, according to performance-based specifications of a contract, should be marked out.

The hydro cutter as shown in Figure H 27 comprises a truck mounted high pressure water pump and vacuum recovery system and offers the flexibility to treat widths from 0,75 m to 3,45 m. The high velocity vacuum system allows the cutting pressure as well as the texture depth to be determined while the machine is in operation. Water energy is focused in fine streams at high speed via five rapidly rotating blasting heads. The water streams physically cut the binder from the stone with the energy of each 'needle' of water dissipated upon contact.

Figure H 27 Hydro Cutter

Examples of the improvement in macro texture are shown in Figure H 28.

Figure H 28 Examples of the Effect of Hydro-Cutting

Although the service providers are knowledgeable, it is recommended that trials be conducted with the approved apparatus using different pressure settings and jets to obtain the target macro texture for the particular type of seal according to Table H 2.

Before opening any rectified work to traffic, any excess waste on the road surface should be properly cleaned and the waste material spoiled at an approved dump site.

Note*: *Experience indicates better effectiveness at road surface temperature below 20°C.

H.4.4 WHAT WE SHOULD NOT DO!

Several cases have been recorded where bleeding (free binder) on an existing seal, rapidly migrated through:

- Fine sand and crusher dust applications.
- Slurry and microsurfacing.
- Up to 40 mm continuous graded asphalt.

Figure H 29 shows bitumen from a bleeding cape seal, migrating through a 30 mm continuous graded asphalt within a month.

Figure H 29 Bitumen from Bleeding Cape Seal Migrating through 30mm Asphalt

H.5 REFERENCES

[1] Committee of Transport Officials, Technical Methods for Highways: Manual for the Visual Assessment of Road Pavements (TMH9) - Part B: Flexible Pavements, South African National Roads Agency SOC Ltd., Pretoria, South Africa, 2016.

[2] Committee of Transport Officials (COTO), Committee Draft 2019. Standard Specifications for Road and Bridge Works.