



Bituminous products for road construction and maintenance

Manual 2 (PG) – April 2022



excellence in bituminous products

Bituminous products for road construction and maintenance

Manual 2

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This 9th edition has been revised to take account of changes in the crude oil refining scenario and, hence, sourcing of bitumen since 2021.

Introduction

A thorough understanding of the behaviour and performance of bituminous binders is an essential prerequisite for anyone involved in the manufacture, use, design and application of bituminous binders. Therefore the main objective of this manual is to familiarise the practitioner with the important engineering properties of these binders, and to illustrate the significance of the relevant properties in practice.

Consequently this publication serves as an introduction to bituminous binders used in road construction and maintenance in South Africa. Their manufacture, properties, types and grades, handling and application are described, and applicable specifications and test methods are included.

It should be noted that this edition differs from previous editions of this manual in that it covers and focuses on bitumen properties as identified, tested and specified in a performance graded (PG) specification. At the time of this revision the publication by SABS of SATS 3208: 2019 – **Performance Grade (PG) specifications for bitumen in South Africa** has come about. The purpose of this edition is to familiarise practitioners with the background, concepts employed and compliance criteria developed.

It is recommended that this manual be read in conjunction with Sabita Manual 30: *A guide to the selection of bituminous binders for road construction* which gives valuable guidance to the optimal application of various bituminous binder types in road applications. Guidance is given on the safe handling of these products to mitigate the risk of injury or loss. However, the reader is referred to the Sabita manuals and DVDs specifically dealing with this aspect.

In the interests of worker safety and environmental conservation and sustainable practice there is no reference to coal tar in this document. It should also be noted that, in accordance with global nomenclature, the term "bituminous" refers exclusively to binders and mixtures of binders and aggregate containing bitumen.

The year 2021 has seen the closure of a refinery in Durban and the cessation of the production of bitumen at a refinery in Cape Town, with some uncertainty as to whether the manufacture of bitumen at this site would be resumed. During 2022 the ongoing function of another refinery in Durban has been put on hold, pending further investigations regarding its sale. Consequently the scenario regarding the sourcing of bitumen has changed considerably, with imports of bitumen likely to become the norm, as only one refinery in SA is currently producing bitumen. This edition has been revised to take these factors into account.

1. Manufacture and properties of bituminous binders

Manufacture

Origins and use of bitumen

Bitumen is a dark brown to black viscous liquid or solid, consisting essentially of hydrocarbons and their derivatives. It is soluble in trichloroethylene, is substantially non-volatile, and softens gradually when heated. Although solid or semi-solid at normal temperatures, bitumen may be readily liquefied by applying heat, by dissolving it in petroleum solvents, or by emulsifying it in water. Bitumen is obtained by refining petroleum crude oil, although it is also found as a naturally occurring deposit. There are some 1 500 different types of crude oil in existence, with bitumen yields ranging from approximately 60% to zero.

As a binder, bitumen is especially valuable to the engineer because it is a strong, readily adhesive, highly water proof and durable material. It also provides some flexibility to mixtures of mineral aggregates with which it is usually combined. It is highly resistant to the action of most acids, alkalis and salts. Bitumen is also used in many applications not related to traditional construction and transport industries. However, approximately 90% of the bitumen refined from petroleum is used as a paving material - as shown in Figure 1.

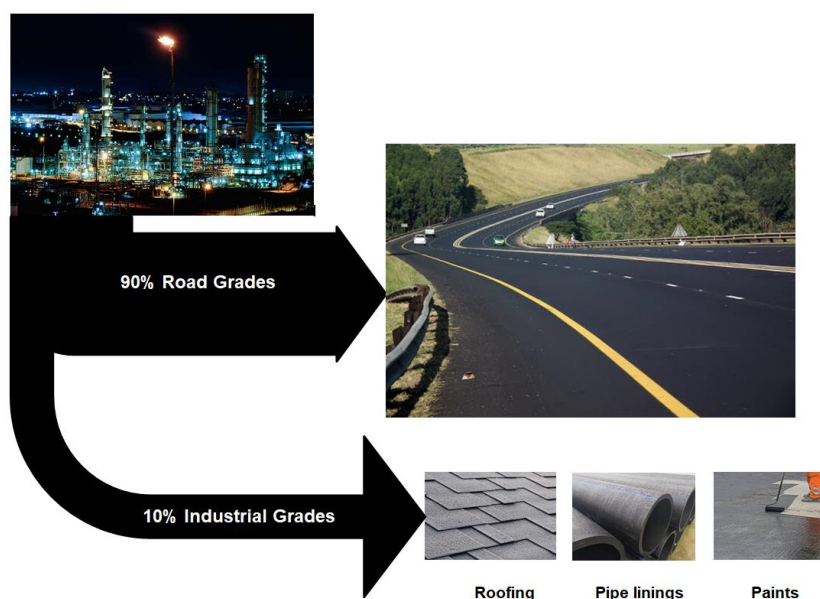


Figure 1: Use and application of bitumen

The properties of bitumen, both chemical and physical, are dependent on the crude oil source from which it is derived, and also on the manufacturing processes adopted in the refinery. Refineries generally use consistent sources of crude which result in consistent bitumen properties. However, there remains a need to evaluate bitumen through laboratory testing to assess its compliance with prescribed standards and performance characteristics.

The distillation process

Figure 2 illustrates the flow of crude oil through a typical refinery, with emphasis on the processes relating to the production of bitumen.

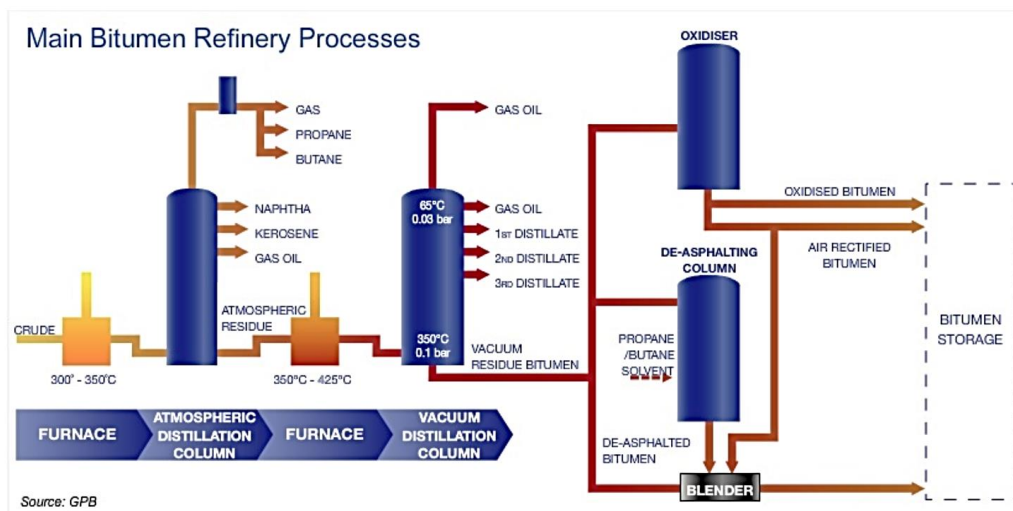


Figure 2: Simplified flow diagram of manufacture of bitumen

The crude oil is heated and delivered to an atmospheric distillation column, where the lighter fractions are vaporised and drawn off, leaving a residue of heavy oil. This residue is processed, by further distillation under vacuum, into “vacuum bottoms”. Treatment under vacuum enables oil fractions to be drawn off in vapour form at relatively low temperatures.

These "vacuum bottoms" are used to produce “straight-run bitumen”. Sometimes it is further treated by air blowing to produce harder bitumen. The vacuum bottoms not used in bitumen manufacture are further processed to produce marine or furnace fuel oil. Additional bitumen production sometimes takes place by precipitation from residual fractions by propane or butane-solvent de-asphalting. Blends of straight run bitumen, blown or de-asphalted bitumen is referred to as “conventional bitumen” in this document.

Recent technological advances in refinery processes make it increasingly possible to produce bitumen by choice. Consequently, production of high margin products is facilitated, resulting in increased pressure on the profitability of bitumen.

Figure 3 shows the typical distillation yield of crude oil products. Bitumen represents about 2.5% of the total barrel.

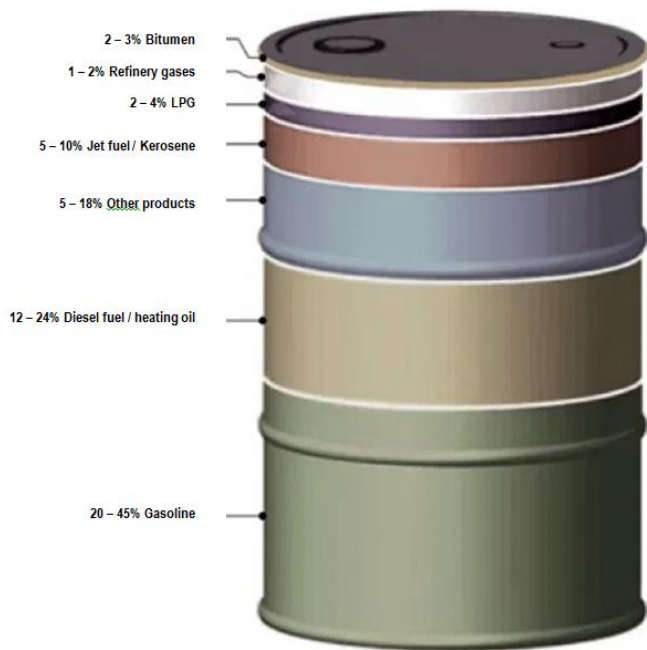


Figure 3: Crude oil distillation products

Note:

Owing to its high viscosity, almost all bitumen and bituminous products must be heated to make them sufficiently fluid for handling and application. Contact with bitumen or the equipment involved in transporting, storing or applying it can cause severe skin burns at the recommended handling temperatures.

It is therefore essential that anyone working with bitumen or bituminous products is familiar with the necessary health, safety and environmental considerations. Users are advised to always refer to product Material Safety Data Sheets (MSDS) for a full description of hazards associated with the use of bitumen products.

This aspect is dealt with in more detail in Chapter 4: Handling of bituminous binders.

Properties of bitumen

Composition

Bitumen is a complex combination of hydrocarbons with small quantities of heteroatoms such as sulphur, oxygen, nitrogen and trace quantities of metals such as vanadium, nickel, iron, magnesium and calcium. Crude oils normally contain small quantities of polycyclic aromatic hydrocarbons (PAHs), a portion of which end up in bitumen. Although some of these PAHs are suspected of causing cancer in humans, the concentrations are extremely low and no causal link to cancer in humans has been established.

Bitumen is mostly manufactured from a range of crude oils and contains the following substances in the proportions indicated:

Carbon	80 – 88%
--------	----------

Hydrogen	8 – 12%
Sulphur	0 – 9%
Oxygen	0 -2%
Nitrogen	0 - 2%

The precise elemental composition and colloidal structure of bitumen varies according to the source of crude oil used in manufacturing it, the manufacturing processes adopted by the refinery, and the type and amount of ageing accumulated during use

The chemistry of bitumen is complex due to the presence of many different chemical constituents, which number from about 300 – 2000 for unaged bitumen. The number of components increases as oxidation products form with ageing. Bitumen must be thought of as a chemical continuum with a gradual increase of molar mass, aromatic content and polarity in its constituents. For categorisation purposes, bitumen can be divided into component classes derived through chemical separation techniques. It is convenient to separate bitumen into two broad chemical groups based on their solubility in n-heptane, known as *asphaltenes* (non-soluble) and *maltenes* (soluble). Solubility is defined as not generating a precipitate and not as molecular solubility. Based on solvent extraction/elution/adsorption, maltenes can be further subdivided into *saturates*, *aromatics* and *resins* (see Figure 4). Hence the composition of bitumen is typically given in terms of its *SARA* (**S**aturates, **A**romatics, **R**esins and **A**sphaltenes) fractions. The values obtained for the SARA components differ according to the method used for determination.

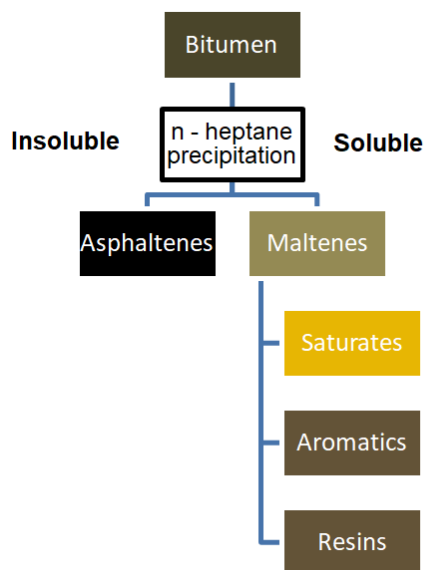


Figure 4: Broad chemical components of bitumen

Asphaltenes

Asphaltenes have relatively high molecular weight compared to the other bitumen constituents. They are n-heptane insoluble solids that are black and glassy. They are largely responsible for the black colour of the bitumen. They make up 5 - 40% of the bitumen, depending of the state of ageing. They have a complex fused aromatic ring structures and more polar groups. The asphaltene aggregation forms the basis of the colloidal structure of bitumen, whereas the asphaltene content has a significant influence on the rheological properties of bitumen. Increasing the asphaltenes content produces a harder, more viscous binder.

Maltenes

Maltenes are the n-heptane soluble phase of the bitumen, and can be further separated into resins, aromatics and saturates, based on chemical separation techniques. The gradual increase of molar mass, aromatic content and polarity is from saturates; to aromatics; to resins; to asphaltenes.

Resins

Resins make up 30 - 50% of the bitumen. They are dark brown solids or semi-solids at room temperature, and they act as a stabiliser (e.g. in dispersing, peptising) for the asphaltenes. Given their polar nature, they are strongly adhesive. The properties of resins characterise to a degree the type of bitumen, i.e. "solution" (SOL) or "gelatinous" (GEL) (see *Bitumen structure* below).

Aromatics

Aromatics, also called naphthene aromatics, are brown/yellow/red fluids at room temperature. They have a lower molecular weight than resins, making up 15% - 65% of the bitumen. They are the most abundant constituents (together with the resins). The aromatic content of the bitumen determines to a significant extent its compatibility with polymers used for modification.

Saturates

Saturates are straw coloured or white, viscous oils with a molecular weight slightly lower than that of aromatics. They contain both waxy and non-waxy saturates and make up 1 - 15% of the bitumen.

Bitumen structure

The structural arrangement of bitumen constituents is generally regarded as a colloidal model. The early models suggested a system consisting of the high molecular mass asphaltenes micelles with an adsorbed sheath of higher molecular weight resins, dispersed or dissolved in the lower molecular weight oily medium of maltenes.

In the presence of sufficient quantities of resins and aromatics of adequate solvating capacity, the asphaltenes are fully dispersed, or peptised, and the resulting micelles have good mobility within the bitumen. In such cases the bitumen is known as a "solution" type (SOL) bitumen as shown in Figure 5.

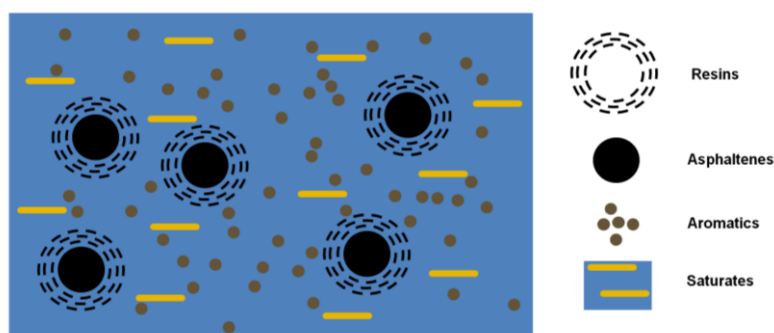


Figure 5: SOL type bitumen

When the aromatic or resin fraction is not present in sufficient quantities to peptise the micelles, or has insufficient solvating capacity, the micelles can associate together. This leads to structures of linked micelles, and these types of bitumen are known as "gelatinous" (GEL) types and are depicted in Figure 6. The non-Newtonian behaviour of bitumen was thought to occur due to the gel structure, as a result of the interacting asphaltenes micelles.

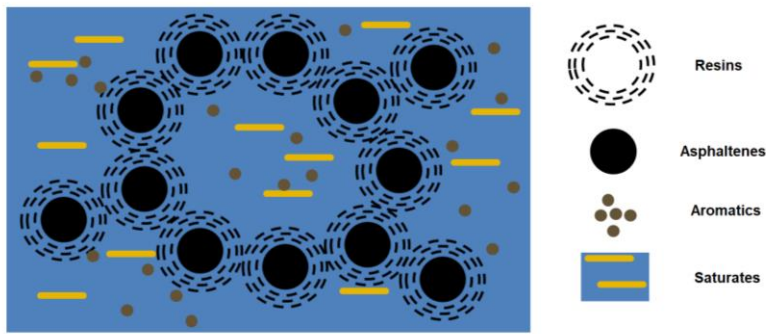


Figure 6: GEL type bitumen

Examples of GEL type bitumens are oxidised grades used for roofing purposes.

In practice, most bitumens are of intermediate character, in which the relatively weak chemical bonds that hold the molecules together can be destroyed by heat or shear stress, giving bitumen its viscoelastic characteristics.

Although these early models serve as useful illustrations, they do have scientific limitations. Most notably is the lack of an elastic plateau for GEL bitumens. Hence modern colloid science has explored more complex models to understand bitumen microstructure and rheology.

Factors influencing bitumen characteristics

The consistency of bitumen depends strongly on the asphaltenes content. At a given temperature an increase in the concentration of asphaltenes will cause an increase in viscosity.

Air-blowing of bitumen from a given vacuum residue results in a significant increase in the asphaltenes content, as well as a significant decrease in aromatics, while saturates and resins content remain largely unchanged.

Also, significant changes in viscosity and the relative proportions of the bitumen constituents take place during the construction and service life of hot mix asphalt layers.

The constitution of the bitumen occurs in an equilibrium which has a significant effect on its performance. Furthermore, too little or too much of a particular constituent can lead to poor bitumen characteristics.

It is important to note that there is no formula for the ideal proportions of saturates, resins, aromatics and asphaltenes; rather it is the interaction between these fractions that will characterise the rheology of bitumen.

Note:

While it is known that the chemical composition of bitumen will determine its physical properties and performance characteristics, its complex and variable constituents make it extremely difficult to measure and define bitumen chemical composition to assure the required performance.

Therefore, historically, specifying bitumen in terms of its chemical constituents has been extremely limited. With advanced colloidal models and analytical techniques, it may ultimately become increasingly feasible to link constituents to bitumen behaviour and performance. However, practical implementation in specifications remains a challenge.

Behaviour of bitumen

Bitumen displays both *viscous* and *elastic* behaviour, depending largely on temperature and loading duration or frequency. This *visco-elastic* character of bitumen results in a variable response behaviour under varied loading times and temperatures changes.

Elastic behaviour

This behavioural characteristic of bitumen can be divided into three categories:

- At low temperature and short duration loads bitumen tends to act as an elastic solid, returning to its original position after removal of the load;
- Excessively low temperature in conjunction with rapid loading may cause brittle failure and cracking; and
- Prolonged low temperature can cause a build-up of internal stress resulting in thermal fracture

Viscous behaviour

At elevated temperatures and / or low frequency loads associated with slow moving traffic, bitumen acts as a viscous fluid. Under such circumstances it will undergo plastic deformation i.e. the deformation is not fully recovered. Pavement layers bound with bituminous materials will tend to deform (i.e. rut or flow) under repeated applications of wheel loads depending on the temperature and rate of loading. It is important to note, though, that this plastic behaviour of the bitumen at high temperatures can be offset by the interlocking action of the aggregate in a bituminous layer, which serves to resist permanent deformation.

Measurement of viscosity

Flow in the binder takes place as adjacent bitumen molecules slide past each other, the resulting friction or resistive force being related to the relative velocity of sliding. The relationship of this resistive force and the relative velocity (of sliding) is termed “viscosity”.

Dynamic viscosity

Dynamic viscosity (or coefficient of viscosity, or simply viscosity) represented by the symbol η , is a measure of the resistance to flow of a fluid, expressed as:

$$\eta = \frac{\text{Resistive force}}{\text{Relative velocity of sliding}}$$

The SI unit of dynamic viscosity is *Pascal second* (Pa.s)

Fluids like water and conventional bitumen above 60 - 100°C show a linear relationship of:

$$\frac{\text{Resistive force}}{\text{Relative velocity of sliding}}$$

The value of viscosity is therefore constant, irrespective of the magnitude of the applied shear stress, and this behaviour is termed Newtonian behaviour. Such materials are known as Newtonian fluids.

Kinematic viscosity

Kinematic viscosity is expressed as the ratio:

$$\frac{\text{Dynamic viscosity}}{\text{Density of the fluid}}$$

The SI unit of kinematic viscosity is mm²/s or centiStoke (cSt).

Given that the densities of SA conventional bitumen generally falls within the range of 0,97 - 1,04 kg/l, a dynamic viscosity of 1 Pa.s equates to a kinematic viscosity of 962 - 1 031 cSt.

Visco-elastic behaviour

To illustrate how viscoelastic materials respond to applied loads it is convenient to represent material behaviour by a system of springs to simulate the elastic components, and dashpots to simulate the viscous behaviour as follows.

- Spring – Elastic deformation
- Dashpot – viscous deformation
- Spring-dashpot in parallel – delayed elastic deformation and recovery

Burger's model is often used to characterise the response of bitumen to imposed stresses. The model is shown in Figure 7, and the components are described in Table 1.

Table 1: Components of Burger's model

Model component		Type of deformation under constant load
Spring	Maxwell	Elastic deformation – not time dependent, no permanent deformation
Dashpot		Viscous deformation – time dependent, permanent deformation
Spring-dashpot in parallel	Kelvin-Voigt	Delayed elastic deformation – time dependent, no permanent deformation

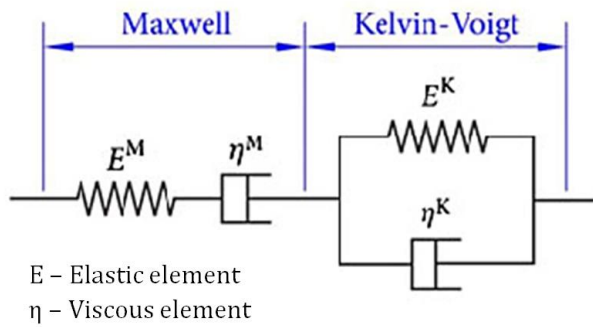


Figure 7: Burger's model

The load and associated deformation of an asphalt mixture subjected to a constant stress is illustrated schematically in Figure 8. After an instantaneous elastic response to the application of the stress, a gradual increase in deformation (or strain) takes place until the load is removed. This ongoing deformation is caused by the viscous behaviour of the material. Upon removal of the stress, the elastic strain is recovered instantaneously and some additional recovery occurs with time – known as delayed elasticity. Ultimately a permanent residual deformation remains, which is non-recoverable and is directly caused by viscous behaviour of the binder.

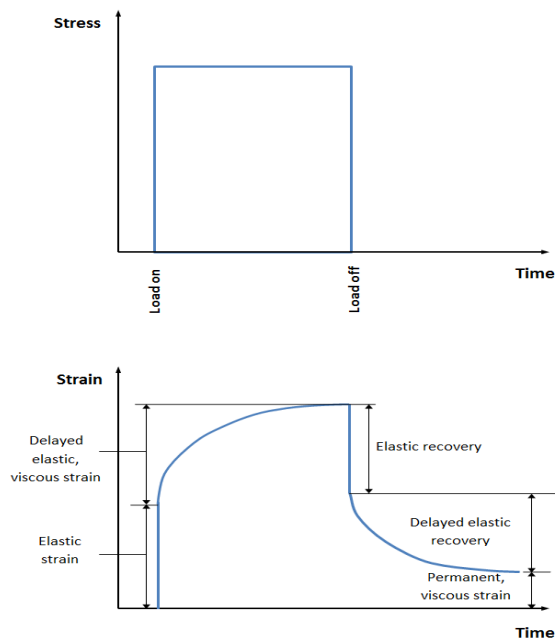


Figure 8: Response of bitumen to constant stress

The results of laboratory creep tests on a terpolymer modified binder compared to modelling using the Burger's model is shown in Figure 9.

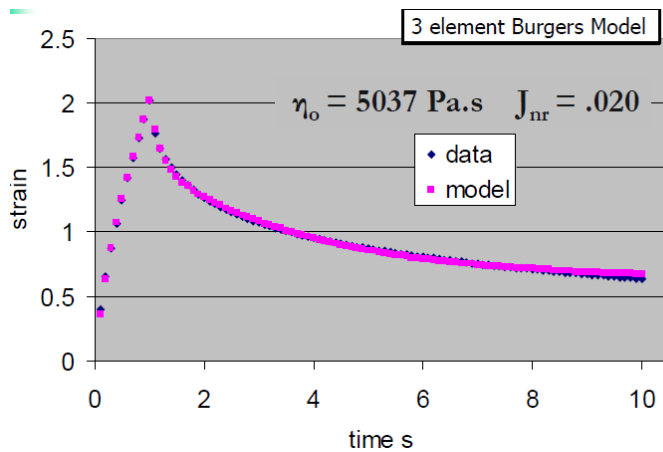


Figure 9: Estimates of creep behaviour using Burger's model

Rheometry

Rheology is the study of the flow and deformation of matter, including soft solids under conditions in which they flow rather than deform and recover fully. The fundamental engineering properties of bituminous binders, as influenced by temperature, chemical composition and the structure – or physical arrangement – of the binder molecules, are well described by rheological principles.

Rheometry refers to the laboratory measurement techniques to determine the rheological properties of materials. For bituminous binders, this entails the measurement of both elastic and viscous behaviour under varied conditions, primarily the type and frequency of loading and temperature of the specimen being tested. Two types of instruments in general use globally will be covered in this document:

- Dynamic shear rheometer
- Bending beam rheometer

Dynamic shear rheometer

Measurements through the use of the Dynamic Shear Rheometer (DSR), shown in Figure 10, are the cornerstone of performance grade specifications. It illustrates important components of viscoelastic behaviour and compliance limits based on tests carried out with this apparatus have been incorporated into SATS 3208: 2019 – *Performance Grade (PG) specifications for bitumen in South Africa*.



Figure 10: Dynamic Shear Rheometer

Specimen configuration

Absolute measurements require that the sample shape is well defined. The specimen is subject to shear between a fixed and moving surface. Absolute measuring systems, illustrated in Figure 11 include concentric cylinder (A), cone & plate (B), and parallel plate (C).

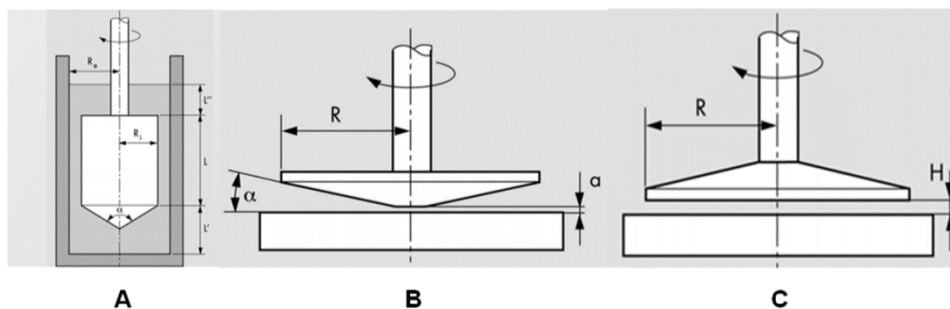


Figure 11: DSR Measuring Systems

Two categories of measurement are afforded by the DSR:

- Fundamental rheological properties
- Creep behaviour of a bituminous binder

Fundamental rheological properties

The DSR testing regimen, described in ASTM D7175, is capable of quantifying both elastic and viscous properties of bituminous binders within the in-service pavement temperature range (e.g. 10 – 70°C). The operation of a DSR is illustrated in Figure 12.

The basic DSR test uses a thin asphalt bituminous binder sample sandwiched between two circular plates. The lower plate is fixed while the upper plate oscillates across the sample at a selected frequency to simulate the shearing action corresponding to a selected traffic speed.

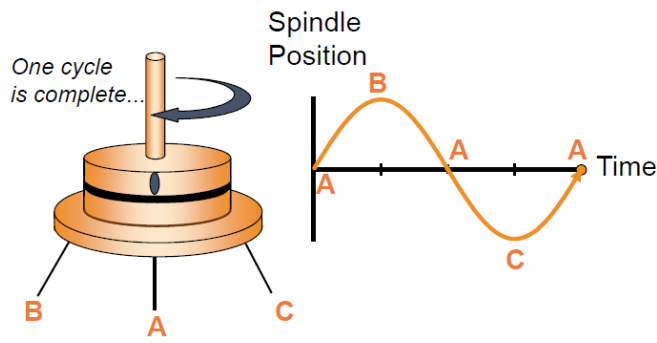


Figure 12: Operation of the DSR

Both viscous and elastic behaviour is assessed by measuring the **complex shear modulus, G^*** (G-star) and the **phase angle, δ** (delta).

G^* is a measure of the total resistance of a material to deformation when exposed to shear load pulses.

The phase angle, δ , represents the time lag (expressed in radians) between the maximum applied shear stress and the maximum resulting shear strain and is indicative of the relative proportions of recoverable and non-recoverable deformation.

The DSR measurement to determine a specimen's complex shear modulus (G^*) and phase angle (δ), is indicated in Figure 13.

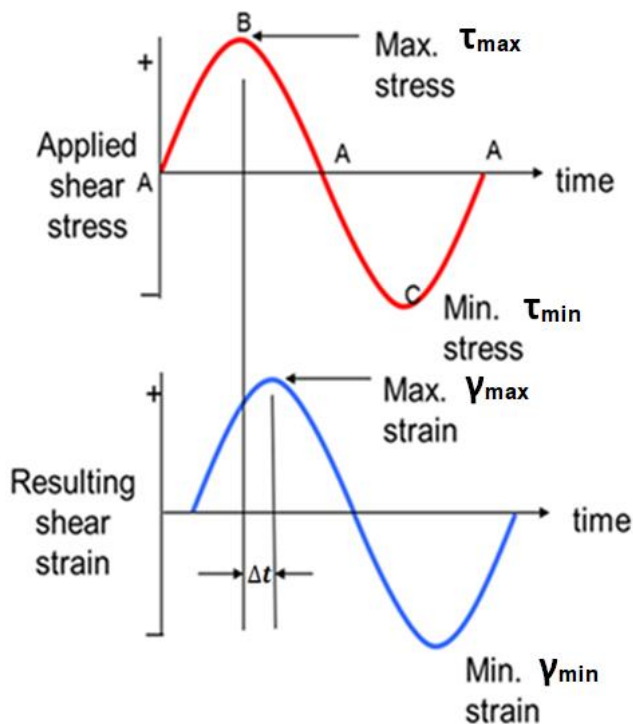


Figure 13: DSR measurements

Test conditions

DSR equipment can be used either in controlled stress or controlled strain modes. In controlled stress mode a predetermined torque is applied to move the oscillating plate from point A to point B (see Figure 12). The required torque to move the plate at the chosen frequency will vary according to the stiffness of the bituminous binder being tested. In controlled strain mode the oscillating plate is moved from point A to point B at a specific frequency while the torque required is measured. When testing in stress control mode, within the linear visco-elastic range of the bituminous binder, the following equations are used to determine properties such as maximum shear stresses and strains as well as complex shearing modulus G^* :

$$\tau_{max} = \frac{2T}{\pi r^3}$$

$$\gamma_{max} = \frac{\theta \cdot r}{h}$$

Where

T is the maximum applied torque

r is the radius of the specimen

θ is the angle of rotation

h is the specimen height

$$G^* = \frac{\text{Total shear stress}}{\text{Total shear strain}} = \frac{\tau_{max} - \tau_{min}}{\gamma_{max} - \gamma_{min}}$$

Δt is the phase lag – often expressed as a phase angle, δ in degrees.

Limiting values of δ are:

- For purely elastic material: $\delta = 0$ degrees
- For purely viscous material: $\delta = 90$ degrees

The phase angle for neat (unmodified) bitumen is typically about $88 - 89^\circ$, indicating that the material behaves almost completely in a viscous manner, while some modified binders can have phase angles as low as 60° , i.e. they behave in a more elastic manner.

Although the magnitude of G^*_1 and G^*_2 (of Bitumen₁ and Bitumen₂, respectively) depicted in Figure 14 are of similar magnitude, they represent binders that are significantly different in visco-elastic behaviour. For instance, Bitumen₂ has a smaller phase angle and, hence, a larger elastic component and will recover better from applied loading. Thus G^* alone cannot describe the behaviour asphalt; δ is also required.

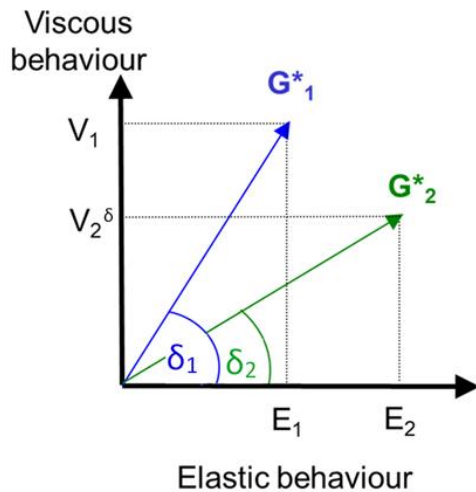


Figure 14: Visco-elastic behaviour

Since bitumen properties are temperature dependent, rheometers are equipped with precise means of controlling the test specimen temperature. This is achieved by employing either a circulating fluid bath or a forced air oven. DSR testing is performed on fresh or aged binders.

Test regimens can be cyclical, dynamic or monotonic.

Cyclical test modes

Recurring cycles of imposed stress or strain are often used in DSR testing to characterize material behaviour and to study resistance to predefined damage. These repeated cycles, also referred to as “sweeps” mostly comprise the following:

- The specimen is subjected to either strain or stress repetitions over a number of cycles until either a predetermined number of cycles have been carried out or until a predetermined degree of damage (e.g. a reduction in G^*) is observed. This type is referred to as a *time sweep test*. (See Figure 15 (A)).
- In *stress or strain sweep tests*, the applied stress or strain is progressively increased, either continuously or in steps to effect the required damage. The temperature and frequency is kept constant. (See Figure 15 (B)).
- *Frequency sweep tests* are carried out to measure the time-dependent behaviour of a sample in the non-destructive deformation range. High frequencies are used to simulate fast motion on short timescales, whereas low frequencies simulate slow motion on long timescales or at rest. The test is carried out at a constant temperature and strain. (See Figure 15 (C)).

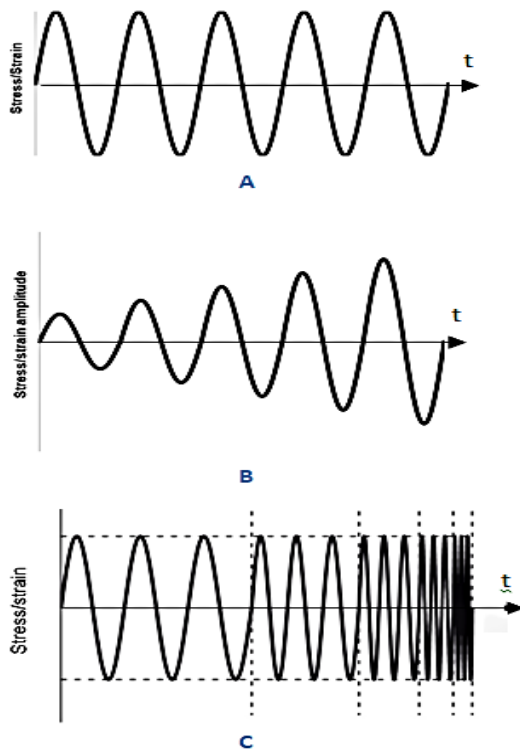


Figure 15: Cyclical test types

Dynamic test mode

In this category, a DSR is used to carry out creep tests at elevated temperatures to assess the extent to which a bituminous binder will recover after the relaxation of an applied torque load. It is especially significant when considering the permanent deformation (rutting potential) of asphalt layers and the flushing / bleeding of spray seals.

The Multiple Stress Creep Recovery (MSCR) procedure, which is described in more detail in *Resistance to permanent deformation (viscous creep behaviour)* on page 47, measures the recovery and non-recoverable creep of bituminous binders.

The response of a bituminous binder during one cycle of this test is illustrated Figure 16.

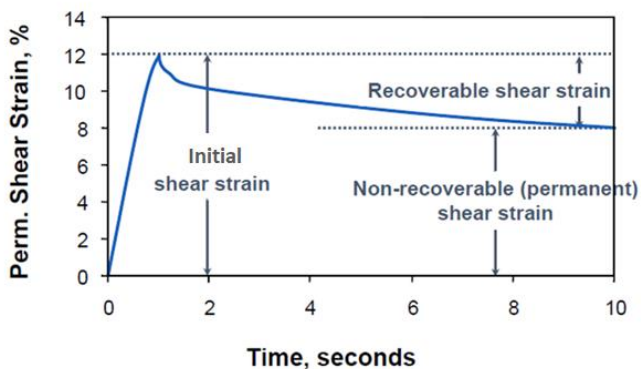


Figure 16: Binder creep and recovery per cycle

Bending Beam Rheometer

To measure the binder's ability to resist fracture due to fatigue and (non-load associated) low temperatures, use is made of measured low temperature stiffness and stress relaxation properties of binders. For this purpose the Bending Beam Rheometer (BBR) is used to measure how much a binder undergoes permanent deformation (or creep) under a sustained load at a given temperature. The test temperatures selected relate to the pavement's lower range of service temperature, when the bituminous binder acts more like an elastic solid. The test is usually carried out on binders that have been aged to simulate the hardening that takes place during asphalt manufacture and paving as well as in-service ageing.

A schematic of the apparatus is shown in Figure 17.

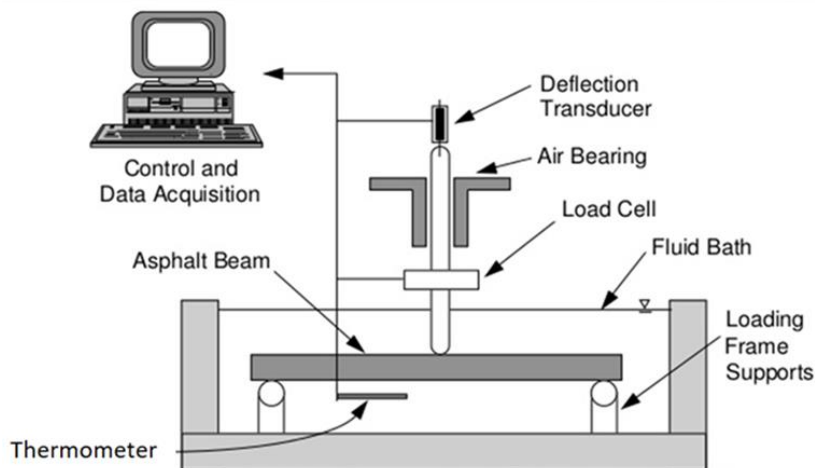


Figure 17: Schematic of the BBR

The method uses beam theory to calculate the stiffness of the bituminous binder under a constant (creep) load, based on measurement of the central deflection of the beam throughout the duration of the test. The BBR software performs the calculation of the stiffness (S) and creep rate (m) with respect to time during the test. S is a measure of the resistance of the binder to creep loading and m is the change in binder stiffness with time during loading – also called the stress-relaxation factor. (See *Resistance to fracture* on page 50)

The computed stiffness over time is shown in Figure 18 below, from which the stiffness at a particular time (60 s), as well as the slope of the curve, m , at the same time is determined.

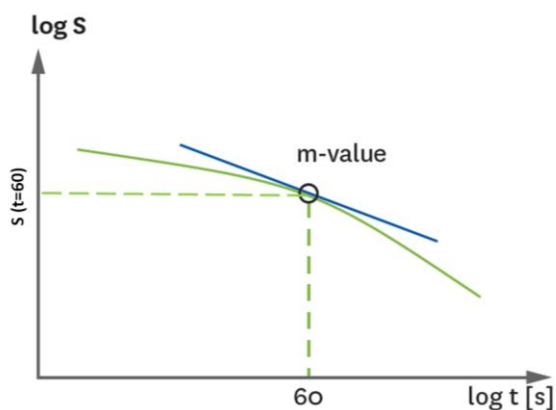


Figure 18: Bending Beam Rheometer test

Durability

For a bituminous surfacing to achieve its design life it is important that no excessive hardening of bitumen takes place during bulk storage, processing (e.g. manufacture and paving of asphalt or spraying) and on the road i.e. when in service.

In thin layers, where exposure to the environment is severe, hardening can have a detrimental effect on the performance of the layer through an increase in brittleness, leading to fracture (cracking), fretting and stone loss.

It should be noted that in some cases, e.g. in asphalt bases, some hardening can be beneficial. It may increase the stiffness of the layer and hence improve its load spreading capability. This hardening is generally termed “curing”, and has the capacity to extend pavement life. While this may be so, it is considered better practice to rely on the significant contribution of stone interlock to these attributes, rather than relying entirely on the hardening of the bitumen, which brings with it other disadvantageous properties and consequences.

Hardening

As many as fifteen factors that influence the hardening of bitumen have been recorded; the dominant mechanisms b:

- Oxidation;
- Loss of volatiles (volatilisation);
- Physical (steric); and
- Exudation.

Oxidation

Hardening due to oxidation at the molecular level is irreversible and is considered to be the main cause of ageing of bitumen. As with most other organic substances, bitumen is slowly oxidised when in contact with oxygen in the atmosphere. This leads to an increase in viscosity, as well as hardening and a loss of flexibility.

The degree of oxidation is highly dependent on:

- temperature;
- the thickness of binder films; and
- time

The rate of oxidisation doubles for each 10°C increase in temperature above 100°C.

Inadequate compaction of asphalt layers or excessively thin binder films adopted in the design of asphalt or spray seals will advance the rate of oxidative hardening during in-service life, especially in warmer climates.

Excessive oxidative hardening can be prevented by ensuring:

- Adequately thick binder films;
- Proper compaction of e.g. asphalt layers

Loss of volatiles

The evaporation of volatiles depends mainly on the exposure to sunlight and prevailing temperatures. Conventional bitumen, being relatively involatile, is not prone to significant loss of volatiles; hardening as a result of this feature is thus slight.

Physical (steric) hardening

Physical hardening occurs at ambient temperatures and is caused by the re-orientation of bitumen molecules and the formation of waxy crystals. This type of hardening is reversible upon reheating and agitation.

Exudative hardening

Exudative hardening is caused by the absorption of oily components of the bitumen, i.e. maltenes, into porous aggregates. Although this phenomenon is widely acknowledged, little research has been carried out to quantify its extent or identifying aggregates that are particularly prone to this type of absorption.

Hardening during use

During use bitumen is exposed to a range of conditions under which hardening can occur, the most important ones being:

- Hot bulk storage;
- Asphalt manufacture;
- Handling of asphalt (i.e. hot storage, transport and laying);
- In-service.

Hot bulk storage

During bulk storage the bitumen is kept at elevated temperatures for a period varying from days to weeks. Very little hardening actually occurs during this phase, as the surface area exposed to oxygen is generally small relative to the volume of the bitumen.

Asphalt manufacture

During this phase a thin film of bitumen is exposed to the high temperatures of heated or superheated aggregates in the presence of oxygen for a relatively short period of time.

Typically bitumen film thickness during mixing with aggregates is between 5 and 15 μm . Given the elevated temperatures, conditions are ideal for oxidation and loss of volatiles.

This process of hardening is well known and should be taken into account when selecting the grade of bitumen to be used. The hardening during warm mix asphalt manufacture and application will be less than with conventional hot mix asphalt.

Handling of asphalt

Asphalt is either stored in hot silos or loaded into delivery vehicles prior to being applied to the road surface. In both instances some hardening occurs, principally through oxidation by contact of the binder films with entrained air. Little or no further oxidation occurs during laying and compaction.

In-service hardening

Hardening of the binder will continue on the road until a limiting value is reached. The main factor influencing the extent of in-service hardening is the exposure of binder films to the atmosphere as

determined by e.g. the air void content of asphalt mixes. Studies have shown that, while very little hardening of bitumen in asphalt occurs at void contents of less than 5%, a significant degree of hardening was observed at air void contents in excess of 9%.

Bitumen content of asphalt mixes as represented by bitumen film thickness is also a prominent factor influencing in-service hardening. Asphalt design methods specify a minimum film thickness of for satisfactory performance of asphalt mixes

Figure 19 illustrates the ageing of bitumen in asphalt during mixing, hot storage, transport and in-service. The ageing is expressed as an ageing index, being a ratio of the viscosity to that of the original binder.

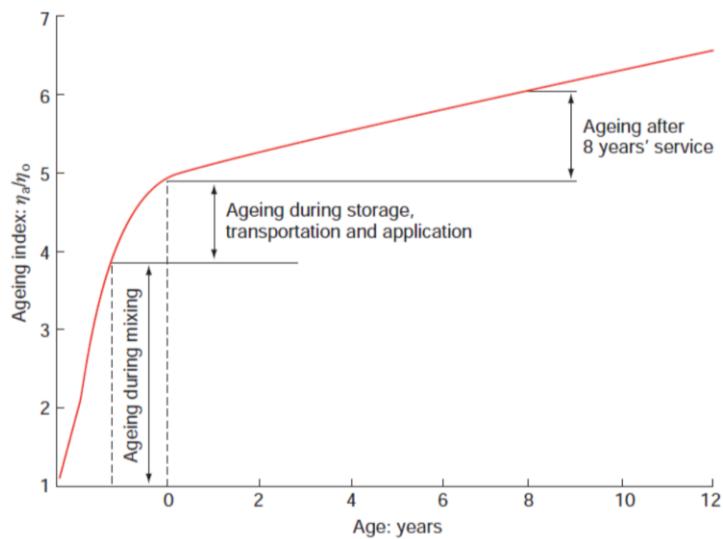


Figure 19: Ageing of binder in asphalt during mixing, storage, transportation, application and service

Source: Shell

Note:

Heating in laboratories:

Small samples of bitumen or asphalt mixes are heated or reheated in laboratories to test either compliance of the products with the relevant specifications, or to assess their performance characteristics.

Care should be taken in the laboratory heating processes to ensure that bituminous binders are not subject to hardening through oxidation in excess of what would normally occur in actual practice. Such hardening would yield results that are not realistic and lead to errors in judgement.

2. Types of bituminous binders

The types of bituminous binders in common use are:

- Conventional bitumen
- Cutback bitumen
- Modified bitumen
- Bitumen emulsions

Conventional bitumen

This binder is manufactured by straight-run distillation or by blending two base components (one hard, the other soft to achieve the desired viscosity). Conventional bitumen is used either as a primary binder or base bitumen for the manufacture of cutback and modified bitumen as well as bitumen emulsions.

Cutback bitumen

Cutback bitumen is a blend of conventional bitumen and petroleum solvents. The solvents are added to reduce the viscosity of the binder for ease of handling or to enhance its function. The choice of solvent determines the rate at which the bitumen will "set up" or cure when exposed to air. A rapid-curing (RC) solvent will evaporate more quickly than a medium-curing (MC) solvent. The viscosity of the cutback bitumen is determined by the proportion of solvent added – the higher the proportion of solvent, the lower is the viscosity of the cutback. The solvent used in cutback bitumen is sometimes also referred to as the "cutter" or "flux".



When the solvent has evaporated, the binder reverts to the original consistency. The advantage of cutback bitumen is that it can be applied at lower temperatures than conventional binders because of its lower viscosity. A disadvantage is that cutback bitumen consumes non-renewable energy resources which are ultimately lost through evaporation.

In South Africa only medium-curing cutbacks are specified.

Modified bitumen

The rheological properties of conventional binders may be significantly modified by the introduction of modifiers. While this adds to the cost of the binder, it may prove to be a cost-effective means of improving the performance of bituminous layers and, thereby, prolonging pavement life.

Very often performance requirements for routine situations can be met with the use of appropriate conventional binder grades. However, increased traffic volumes and loading, accompanied by increased tyre pressures, in recent decades, has seen the increased use and application of modified binders in road construction and maintenance.

Improved performance can be achieved in three ways:

- An increase in the elastic component of the complex modulus, for improved durability; (See Figure 14).
- Stiffening of the bitumen to increase the flexural stiffness and load distribution properties of asphalt layers
- Reduced susceptibility of viscosity to temperature changes.

Particular situations where modified binders could offer cost-effective solutions are¹:

- Conditions of high stress such as heavy traffic, areas of low speeds (steep inclines, busy intersections and sharp curves);
- Regions experiencing large daily/seasonal temperature fluctuations or high ambient temperatures for long periods;
- Special applications to attenuate crack propagation or render surface resistant to fuel spillages
- Remote, not readily accessible areas where improved durability is required.
- Upper layers of relatively highly flexible (and cracked) pavements;
- Layers requiring a high binder film thickness.

To deal with the special requirements necessitated by these circumstances, the primary aim of the modification of bitumen is to:

- Enhance the resistance of bituminous layers to permanent deformation (excessive viscous flow) at high road temperatures
- Improve the resistance of the layer to brittle behaviour fatigue
- Prevent thermal cracking of layer in areas of very low temperatures.

Improved performance can be achieved in two ways, both of which are aimed at reducing the permanent strain:

- An increase in the elastic component of the complex modulus, with an associated reduction in the viscous component; and
- Stiffening of the bitumen to reduce the total viscoelastic response of the layer.

¹ The reader is referred to the Sabita publication TG1: *Technical Guideline: The use of modified bituminous binders in road construction* for more details.

In addition to the primary aims above, a wide range of properties improved include:

- Durability;
- Aggregate retention
- Elasticity;
- Improved load spreading capacity, particularly in asphalt layers.

Modification agents

Modification of bitumen is generally accomplished by the introduction of polymers (including crumb rubber), and hydrocarbon substances. Polymers can be broadly categorised as "elastomers" (sometimes referred to as thermoplastic elastomers) for enhancing the elastic behaviour of a binder, or as "plastomers" (sometimes referred to as thermoplastic polymers) for increasing the viscosity of the bitumen. Hydrocarbon substances used in the modification of bitumen comprise "synthetic waxes" and "natural hydrocarbons". The classification is depicted in Figure 20.

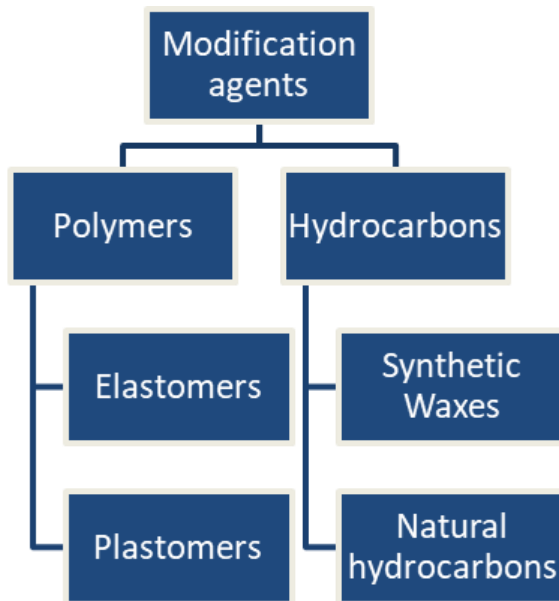
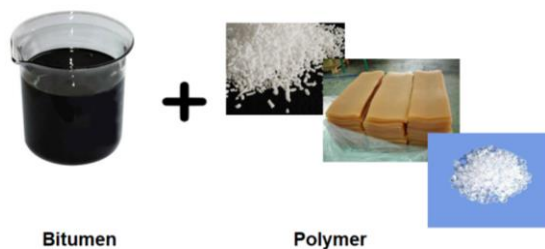


Figure 20: Classification of modifying agents

Polymers



Elastomers

In South Africa the types of elastomers are in general use:

- Styrene-butadiene-rubber (SBR) latex;
- Styrene-butadiene-styrene (SBS);
- Reactive Elastomeric Terpolymer (RET)

1. Rubber crumb.²

Thermoplastic elastomers derive their strength and elasticity from a physical cross-linkage of the molecules into a three-dimensional lattice. The effect of the addition of elastomers on the rheological profile of a binder is illustrated in Figure 21.

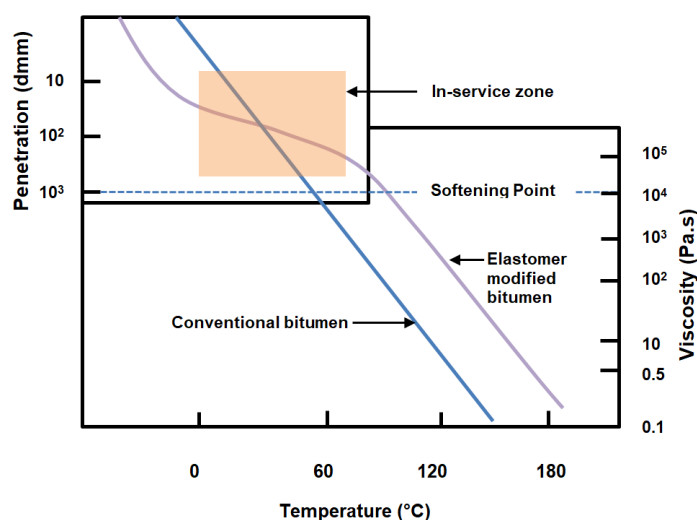


Figure 21: Effect of an elastomer on the rheological profile of binder

At elevated temperatures, say 50 - 60°C, the elastomer modified binder has a significantly higher viscosity than conventional, hard grade bitumen and is therefore much stiffer. In conjunction with the elastic nature of the polymer network, such modified binders will exhibit a significantly higher resistance to permanent deformation. Also, at lower service temperatures, the elastomer modified binder is more flexible than the unmodified bitumen and hence would be less prone to brittleness. Increased flexibility and, hence, resistance to fatigue distress, has also been shown to result from elastomer modification.

As illustrated in Figure 22, the fatigue life of bitumen can be increased by a factor of at least three. The material would therefore offer improved performance in areas where high tensile strains are likely to occur in asphalt layers.

² Although not classified as a polymer, bitumen modified with crumb rubber displays characteristics similar to those associated with elastomers.

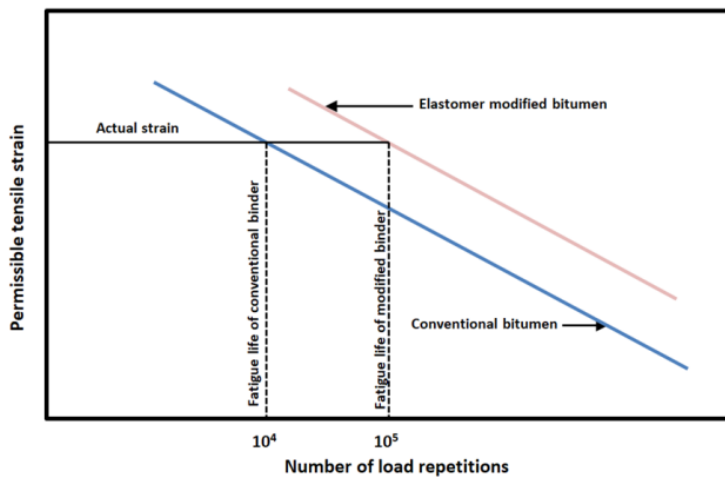


Figure 22: Effect of elastomer on fatigue life

Styrene-Butadiene-Rubber (SBR)

SBR is available in the form of anionic or cationic latex, which makes blending with bitumen emulsion easier. It is also used to modify hot bitumen, but the water phase in the latex must first be removed by boiling or foaming during the controlled addition of latex to the hot bitumen. SBR modified bitumen has been used extensively in southern Africa as a cold applied bitumen emulsion in spray seals and micro-surfacing, as well as a hot applied binder in spray seals and asphalt. The modified binder exhibits elastic properties which make it ideal for surfacing lightly cracked pavements.

Styrene-Butadiene-Styrene (SBS)

SBS polymers are available in powder, crumb or pellet form for modifying hot bitumen. Linear as well as radial copolymers can be used depending on the end properties sought. High shear mixers are recommended for blending high polymer content binders, particularly for industrial applications.

Depending on the concentration of this polymer, it increases or improves:

- Resistance to viscous flow
- Cohesive strength;
- Elasticity;
- Low temperature flexibility

SBS modified bitumen is used in both spray seals and asphalt applications to enhance the bitumen's all-round performance characteristics.

RET (Reactive Elastomeric Terpolymer)

Reactive terpolymers can form chemical bonds with some bitumen components. These polymers form a network around the asphaltenes in the bitumen to form an integral compound and produce a chemical reaction with the bitumen. Asphalt mixes made with bitumen modified with RET have the ability to provide improved rutting resistance and improved resistance to the adverse effects of fuel spillages.

RET consists of three polymers (and also goes under the name of ENBAGMA).

- Ethylene
 - being a hydrocarbon it is compatible with bitumen;
 - provides stiffness and viscous properties to prevent rutting.
- n-Butyl Acrylate
 - provides elastomeric properties to prevent cracking and rutting;
 - improves adhesion to aggregates.
- Glycidyl Methacrylate
 - reacts with bitumen to provide a homogeneous, storage-stable modified binder.

Rubber crumb

Approximately 20% of ground tyre rubber or alternative rubber compounds (with a specific, grading, morphology and composition) are blended with bitumen at a temperature of 170 - 210°C for a period of approximately one hour.

In addition, some products may contain varying levels and / or types of additives and modifiers to enhance the ease of handling through lower handling and application temperatures and to extend storage life

During this time the aromatic oils in the bitumen are absorbed by the rubber particles, causing them to swell. After mixing and reaction the blend, known as “bitumen-rubber”, must be applied within six hours as the product has a restricted shelf life. It is much more viscous than unmodified bitumen, and is not a homogeneous binder, requiring special equipment for pumping and spraying.

Bitumen rubber is widely used in South Africa in spray seals, and asphalt wearing courses. It has also been used as part of a stress absorbing membrane interlayer (SAMI).

The carbon black contained in the rubber also acts as an anti-oxidant, thereby increasing the durability of the binder.

Plastomers

One type of plastomer in general use in South Africa is ethylene vinyl acetate (EVA). Semi-crystalline EVA copolymers are available in pellet form and are easily dispersed in hot bitumen. EVA modified binders are thermally stable at normal handling temperatures. The two properties of the EVA copolymer that have the most pronounced effect on the binder's end properties are its molecular weight and vinyl acetate content. EVA modified bitumen is used mainly as a plastomer in hot mix asphalt to increase binder stiffness and elasticity at high service temperatures and low loading frequencies, improve resistance to permanent deformation e.g. rutting and to reduce the temperature susceptibility of its consistency.

Hydrocarbon substances

These types of modifiers can be divided into two categories – aliphatic synthetic waxes and naturally occurring hydrocarbons.

Aliphatic synthetic wax

Long-chain hydrocarbons produced by the Fischer-Tropsch (FT) fuel synthesis process are used to extend the plasticity range of bitumen. Bitumen modified with FT wax displays unique properties in that it has a lower viscosity than unmodified bitumen above 100°C, but on cooling, the viscosity is higher. This enables hot mix asphalt with bitumen modified with FT wax to be mixed and placed at lower temperatures than those mixes using conventional bitumen. (See Figure 23)

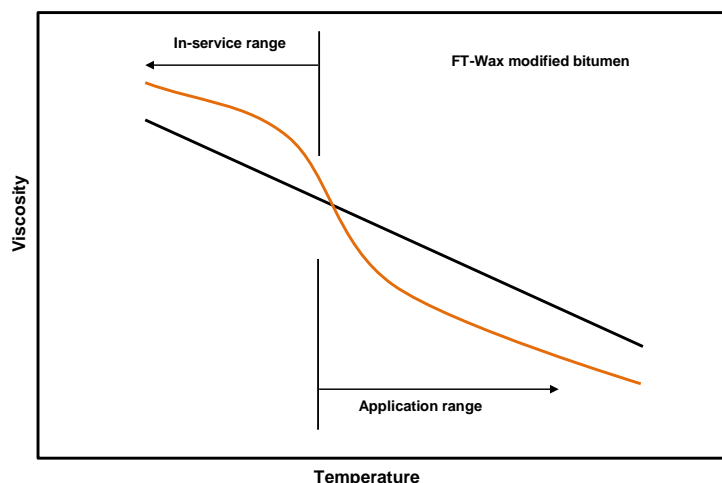


Figure 23: Temperature - viscosity relationship FT-Wax modified binder

Natural hydrocarbons

Naturally occurring hydrocarbons used for bitumen modification occur as natural deposits in North and South America, and are known as *Gilsonite* and *Durasphalt*, respectively. These materials have high asphaltene contents, generally in excess of 70% and can be used to enhance the performance of asphalt in the following ways:

- Increased flexural stiffness of asphalt for improved load spreading capacity
- Reduced temperature susceptibility of viscosity
- Improved resistance to permanent deformation

Table 2 summarises the various types and varieties of modification agents discussed above.

Table 2: Types and varieties of modifiers

Modifier type		Varieties
Polymers	Elastomers	Styrene-butadiene-styrene (SBS)
		Styrene-butadiene-rubber (SBR) latex
		Reactive Elastomeric Terpolymer (RET)
		Rubber Crumb
	Plastomers	Ethylene-vinyl-acetate (EVA)
Hydrocarbon substances	Aliphatic synthetic wax	Fischer-Tropsch (FT) wax
	Natural occurring hydrocarbons	Gilsonite
		Durasphalt

Bitumen additives

These additives are not intended to modify or improve the rheological properties of bitumen; rather the intention is to improve certain performance characteristics to extend the service life of asphalt, in particular.

Table 3 lists additives in common use in asphalt manufacture and their general purpose. Although no specifications for the materials are readily available, examples of generic types are listed to guide the user.

Table 3: Common types of binder additives

Additive type	General purpose	Examples
Extender	<ul style="list-style-type: none"> Substitutes a portion of bitumen to decrease the amount of bitumen and/or polymer required; Improves the storage stability of SBS modified binders. 	Sulphur
Fibre	<ul style="list-style-type: none"> Improving the tensile strength and cohesion in asphalt; Allows higher binder content with reduced risk of drain-down in open-graded asphalt and SMA; Allows increased binder film thickness for improved durability 	Rock wool Polypropylene Polyester Fibreglass Mineral Cellulose
Antioxidant	<ul style="list-style-type: none"> Increases the durability of HMA by retarding oxidation 	Carbon black
Anti-stripping agents	<ul style="list-style-type: none"> Reduce stripping of binder from aggregate. 	Amines Lime
Fuel resistance	<ul style="list-style-type: none"> Improves the resistance of the HMA to fuel spillages. 	FT Wax Selected grades of EVA

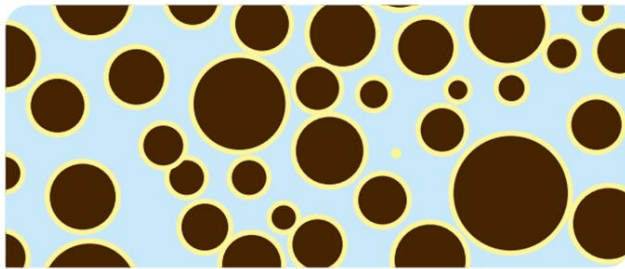
Classification of modified binders

In the previous issue of this manual, reference was made to the various classes of modified in terms of the generic type of modifier used, its application, type of binder system and level of modification – all as set out in the Sabita publication TG1: *Technical Guideline: The use of modified bituminous binders in road construction*. While the purpose of this system of classification was aimed at aiding the user to select an appropriate modified binder for a specific application, it was essentially an empirical and, sometimes, arbitrary system. As it is the aim of this issue to promote rational decisions as to the assessment of binders, selection based on the PG specification framework is advocated – one that differentiates between products on the basis of performance characteristics, rather than their components.

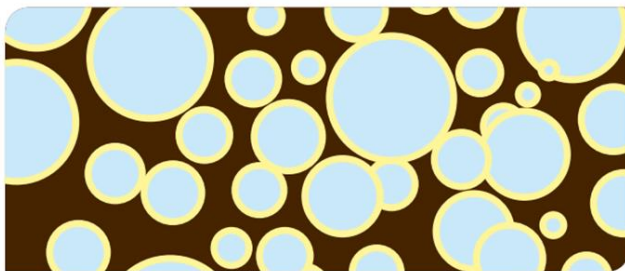
Bitumen emulsions

Bitumen emulsions are two-phase systems consisting, in most cases, of a dispersion of bitumen droplets in water containing an emulsifier. Emulsification of bitumen is a means of reducing the viscosity of a binder so that – at relatively low temperatures – it behaves as a fluid during handling and application. The emulsifiers are added to assist in the formation of the emulsion, to render it stable, and to modify its properties.

Two systems of emulsification are generally used are illustrated in Figure 24. Oil-in-water (O/W) emulsions are those in which the continuous phase is water and the dispersed phase is bitumen. Water-in-oil (W/O) “inverted” emulsions are those in which the continuous phase is bitumen and the disperse phase is water.



Oil-in-water emulsion



Water-in-oil emulsion

Figure 24 Emulsion phases

In a *conventional* emulsion, i.e. O/W type, bitumen is dispersed throughout the water as discrete globules, typically of 0.1 to 50 μm in diameter, held in suspension by electrical charges. The net bitumen content of emulsions typically varies between 60% and 70%.

Inverted emulsions, i.e. the W/O type are manufactured with cutback bitumen and have water contents of less than 20%. This type is more rarely used than the O/W types, mainly as prime coats.

With viscosities in the range 0.5 – 10 Poise at 60°C, bitumen emulsion has a considerably lower viscosity than bitumen permitting used at lower temperature, as mentioned above. There are, of course, benefits to construction and maintenance techniques at lower temperatures e.g. reduced emissions, energy consumption and oxidation of the bitumen and a reduction of hazards associated with heated bitumen.

The use of bitumen emulsions is also more economical and environmentally friendly than cold techniques using cutback bitumen.

As emulsions are water-based, they can generally be diluted further with water for special applications. They are also compatible with hydraulic binders like cement and lime as well as water-based polymer dispersions such as natural and synthetic latex.

Manufacture of emulsion

Bitumen emulsions are normally manufactured in a continuous process using a colloidal mill. This equipment consists of a high speed rotor revolving at 1000 - 6000 rpm in a stator. The clearance between the rotor and stator can usually be adjusted between 0,25 and 0,5 mm. The two phases,

bitumen and chemically-treated water, pass through the narrow clearance between the rotor and stator of the colloidal mill, where the bitumen is sheared into microscopic particles.

A typical emulsion plant schematic is shown in Figure 25.

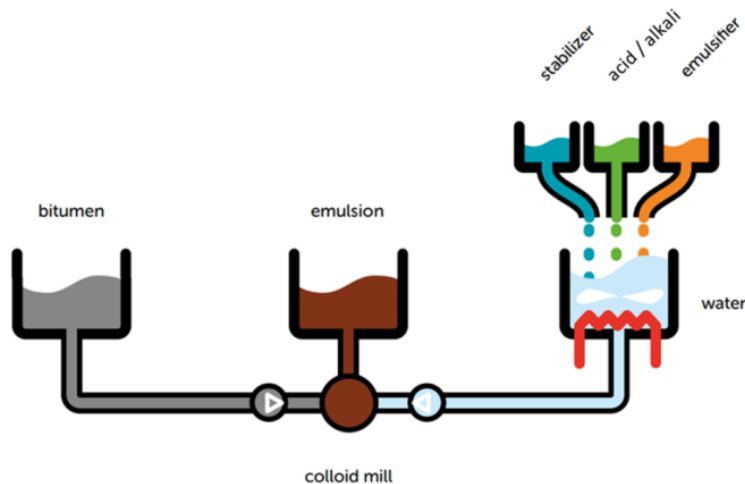


Figure 25: Manufacture of emulsions

The water phase is prepared by dissolving the emulsifier chemicals in heated water. These are then saponified with alkali in the case of anionic emulsions, or acidified with inorganic acids for cationic emulsions. Emulsion manufacturers have distinct anionic and cationic water phase systems.

The temperature of the bitumen phase should be strictly controlled to ensure that its viscosity is within the appropriate range for emulsification, and to prevent boiling of the emulsion on exit from the colloid mill. The base bitumen normally used is (a relatively soft) PG58 grade. Some emulsion types contain a small percentage of solvent flux, which is varied on a seasonal basis to assist with the setting or "breaking" of the emulsion once applied.

On discharge from the mill, the newly formed emulsion is allowed to cool in the storage tanks, which are individually dedicated to particular types and grades of emulsion.

Classes of emulsion

There are two different ways to classify bitumen emulsion:

- Based on surface charge of the bitumen globules
- Based on setting (breaking) time

Based on surface charge

Depending on the type of surface charge, bitumen emulsions are primarily classified into the following two types:

- Anionic Bitumen Emulsion
- Cationic Bitumen Emulsion

The terms cationic and anionic derive from the electrical charges on the bitumen globules. (See Figure 26)

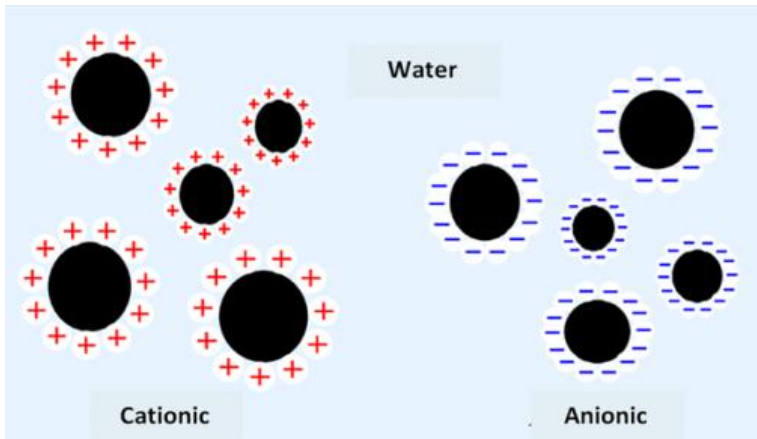


Figure 26: Cationic and Anionic emulsions

Anionic emulsions

In an *anionic bitumen emulsion*, bitumen particles are electro-negatively charged. These particles would adhere to an anode.

Cationic emulsions

In *cationic emulsions*, bitumen particles are electro-positively charged. These particles would adhere to a cathode. Currently cationic bitumen emulsions are most commonly used in road applications.

The choice of bitumen emulsion (i.e. whether anionic or cationic) to be used depends primarily on the mineral composition of aggregate used for construction. In the case of silica rich aggregates, the surface of the aggregates are electro-negatively charged. Therefore a cationic emulsion should be used. This will promote adhesion of bitumen to the aggregates. The repulsion between bitumen droplets with a positive surface charge (as is the case in a cationic emulsion) and potential for attraction to a negatively charged (e.g. silica rich) aggregate is illustrated in Figure 27.

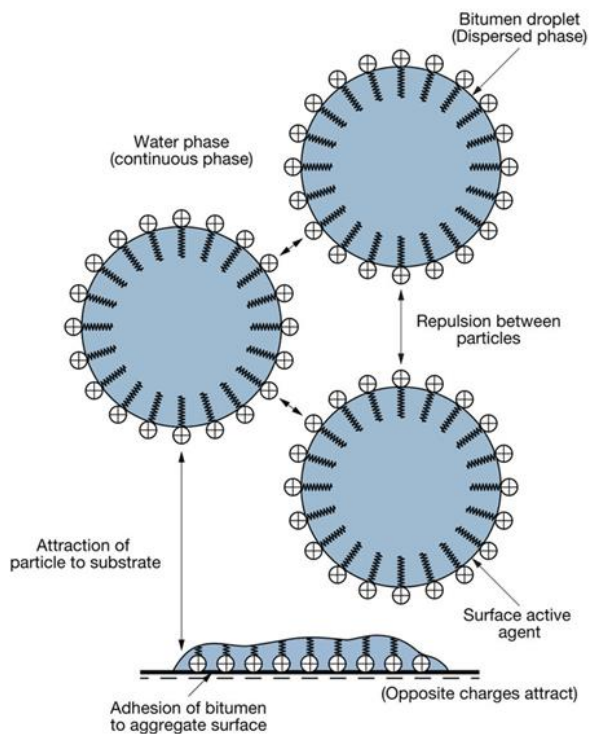


Figure 27: Bitumen dispersion in an emulsion

Mixing any anionic emulsion with any cationic emulsion in any proportion will cause the mixture to "break", i.e. separate into water and bitumen, almost immediately. Clearly such situations should be avoided during both manufacture and handling of the products (e.g. transport and application).

Inverted emulsion

Another type of emulsion, termed *inverted emulsion*, is distinct from normal oil-in-water emulsions in that the water is dispersed in the binder phase. These types of emulsions are manufactured with cutback bitumen and have water contents of less than 20%. This type is more rarely used than cationic and anionic types; mainly as a prime coat.

Based on setting (breaking) time

"Setting" or "breaking" is the separation of water from the bitumen in an emulsion. The stability of the emulsion i.e. is the time lag before separation, is determined primarily by the type and quantity of the emulsifying agent used.

Cationic emulsions break via a physical-chemical reaction, through the evaporation of the water phase and through mechanical action such as rolling.

Anionic emulsions break predominantly when the bitumen particles agglomerate with the evaporation of the water and through mechanical action such as rolling.

When bitumen emulsions are applied on aggregates, water starts to evaporate causing separation of bitumen from water. Subsequently bitumen spreads on the surface of the aggregate and acts as a binding material and slowly attains its strength.

Depending upon the speed at which water evaporates and bitumen particles separate from water, it is classified into following three types.³

1. Rapid setting emulsion
2. Medium setting emulsion
3. Slow setting emulsion

Note that the term "*setting*" does not mean attainment of strength; rather it means the time taken by the bitumen to separate from water.

Rapid setting emulsions

This type of emulsion sets and cures rapidly and is generally used in chip spray applications where the emulsion comes into contact with clean aggregate and no mixing with aggregate is required prior to application on the binder. They are also referred to as ***Spray grade*** emulsions.

Another type of rapid setting emulsion is specially formulated for use with microsurfacing where a quicker setting of the aggregate / binder blend is required. These are termed ***Quick setting grade***.

Medium setting emulsions

Medium setting emulsions do not break spontaneously when in contact with aggregates. It is suitable for mixing with medium or coarse graded aggregate with the percentage aggregate passing the 0,075 mm sieve not exceeding 2%. This type is also referred to as ***Premix grade*** emulsion.

³ In some literature the term "breaking" is used instead of "setting".

Slow setting emulsions

Slow setting emulsions are manufactured by using a special type of emulsifier, which makes the setting process very slow. These types of emulsion are relatively stable and are suitable for mixing with fine aggregates, e.g. sand and crusher dust. This type is also referred to as **Stable grade emulsion**.

In addition to the above four emulsion grades, **SBR latex modified emulsions** are available for specialised applications such as crack-sealing, reseals on lightly cracked surfaces, geotextile seals and rut filling or rapid-setting microsurfacing overlays. These are three phase cationic emulsion systems, where SBR latex is introduced as a third component in the normal bitumen water two phase system

Mode of setting

Setting (or breaking) entails the process whereby the bitumen emulsion reverts to a continuous bitumen film to fulfil their role as a binder in road building materials.

The bitumen globules in the emulsion have a small charge derived from the emulsifier, as well as ionisable components in the bitumen itself. These small charges on the droplets provide an electrostatic barrier to their close approach to each other (like charges repel). However, when two droplets do achieve enough energy to overcome this barrier and come into close contact, they adhere to each other (flocculate). This flocculation may sometimes be reversed by agitation, dilution, or addition of more emulsifier.

Aggregates take up a characteristic surface charge in water which depends on their chemical characteristics and the pH. So-called “acid” aggregates, high in silica, tend to take up a negative charge, whereas basic aggregates like dolomites can take a positive charge.

Over a period of time the water layer between droplets will diminish and the droplets will coalesce. This coalescence cannot be reversed. Factors which force the droplets together such as settlement under gravity, evaporation of the water or shear will accelerate the flocculation and coalescence process. Bitumens with lower viscosity coalesce more rapidly than those with high viscosity.

Over a period of time, which may be hours or much longer, the bitumen phase will separate from the water. Since bitumen is insoluble in water, breakdown of the emulsion involves the fusion of droplets (coalescence). See Figure 28.

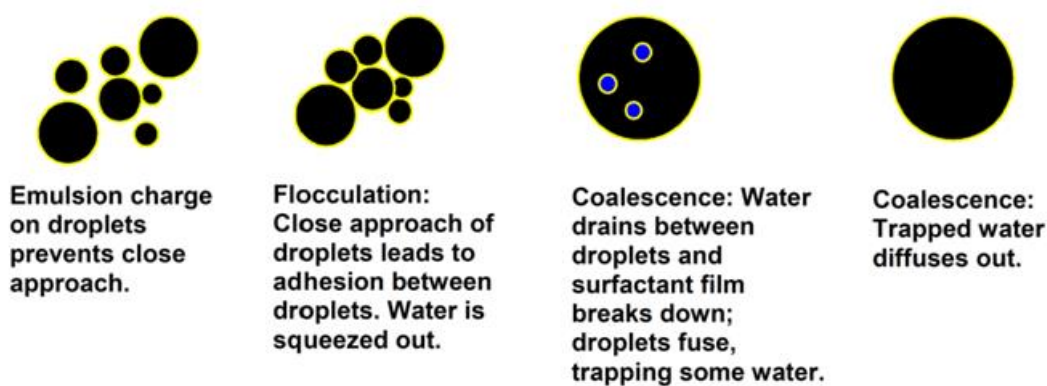


Figure 28: Flocculation and coalescence of bitumen emulsion

All in all the breaking of emulsions is a complex process – not fully understood – and more than one factor influences the process.

The speed of this setting and curing process can, in general, be ascribed to a number of factors listed below:

- Water absorption of aggregate
- Surface texture of aggregate
- Amount of mineral dust in aggregate
- Aggregate gradation
- Mineral composition of aggregate
- Intensity of charge on aggregate surface
- Type and quantity of emulsifier used
- Atmospheric / climatic conditions
- Wind velocity & altitude
- Drainage conditions at construction site

Source and packaging

Following announcements by some of the local refineries of their intention to either cease or pause with local production, the need has arisen for increased volumes of imported bitumen to meet local demand. Sourcing and importing bitumen may pose some challenges to assure consistent, acceptable quality.

Bitumen is imported by sea in the following modes:

- bulk liquid cargo in relatively small tankers with capacities ranging from 2 000 – 10 000 tons.
- specially designed containers manufactured to ISO 1496, typically of 20 – 29 ton capacity
- drums in various dimensions and capacity ranging from 40 – 240 kg.
- bag systems with storage capacity up to 1 000 kg of bitumen.

The reader is referred to Sabita Manual 41: *Best practice for guide for the procurement and importing of bitumen* which gives valuable guidance on quality assurance, import logistics and compliance with legislation in terms of import regulation and health and safety aspects.

Bituminous binders are usually supplied to manufacturing or construction sites in bulk road tankers for ease of handling and economic reasons. Delivery can be made to:

- Storage at asphalt plants and manufacturing plants for modification emulsification;
- Construction sites; or
- Bulk-spray distributors, for direct application to the road surface.

Bulk road tankers are generally fitted with liquid petroleum gas or oil heating systems. The heating system is only used when the road tanker is stationary to maintain or increase the bitumen temperature to the desired handling temperature.

Bitumen (particularly emulsions) is also supplied in non-returnable drums of 210 litre nominal capacity, but to accommodate the change in volume of bitumen when heated, they are never filled to capacity. Usually the mass of the contents is about 200kg (the unit in which it is sold).

In specific instances bitumen is transported and stored in bulk in special ISO type containers, holding about 25 tons of product. Although the product is transported as a solid, these containers have special heating systems, which enable the bitumen to be liquefied for pumping.

Bitumen emulsions are manufactured in numerous fixed plants around South Africa. All or most of the grades are available in bulk or in 200 litre drums, depending on local demand. Emulsions are sold by volume.

A number of modified binders and emulsions are also produced by manufacturers at plants spread around the country. These include:

- **Homogenous types** – SBS (styrene-butadiene-styrene), SBR (styrene-butadiene-rubber), RET (Reactive Elastomeric Terpolymer) and EVA (ethylene-vinyl-acetate).
- **Non homogenous type** – bitumen-rubber
- **Hybrid types** – Blends of different polymers types, blend of Polymers and Rubber Crumbs, blend of polymers and warm mix asphalt (WMA) additives, blends of Rubber Crumbs / WMA Additives and/or Polymers

Bitumen-rubber is usually blended on site in specially designed, high-speed mixing plants, transferred into a distributor and sprayed immediately. When used in the so-called “wet-blend” asphalt mix process, the bitumen-rubber is blended and then fed into the asphalt-mixing plant. Bitumen rubber is, therefore, only available wherever the required volumes are economic to produce.

Supply to a contract is typically by bulk road hauling, although SBR modified emulsions in drums and crack sealants in boxes, pails or special paper bags are often used for small maintenance jobs.

Some blending of modified binders, typically with FT wax and naturally occurring hydrocarbons also takes place at asphalt manufacturing plants.

3. Specifications and test methods

As stated in Section 1, while it is accepted that the chemical composition of bitumen will determine its physical properties and performance characteristics, the complex and variable chemical and molecular structure of bitumen makes it extremely difficult to define chemical composition of a bituminous binder that will ensure adequate performance. It should also be noted that bitumen derived from different crude sources (and hence of different chemical composition) can have similar physical properties.

For this reason it has become general practice, worldwide, to make use of performance-related physical properties as the primary means for specifying and selecting bituminous binders. This section will cover performance-related physical properties for binders as well as a set of tests and specifications to ensure that binders, including bitumen emulsions, can be handled safely and with relative ease, during the actions required prior and during its application in a bituminous layer in a pavement.

Specifications for bituminous binders are intended to ensure that:

- The binders are manufactured to certain accepted standards that will ensure uniformity of quality and satisfactory performance
- They will not be adversely affected during normal handling, transport and storage, even when heated
- Changes in binder properties during correctly controlled application will not exceed certain limits

The key feature of a performance-grade (PG) specification is to define a quality whereby the potential of the binder to contribute to permanent deformation, fatigue cracking and (non-load associated) low temperature cracking of a bituminous layer for a specific set of conditions is minimised. The term PG provides for binders to be graded in terms of their use and application to perform in specific environments defined by climate (particularly temperature ranges) and the intensity and rate of traffic loading.

The specification does not explicitly differentiate between neat and modified binders. Rather, it imposes requirements to meet traffic and climatic conditions – the need for modification and the type of modification rests with the binder suppliers.

The list of requirements is formulated to ensure that the binder will resist damage imposed by the operating conditions. Although these requirements are derived from fundamental, performance related rheological properties of bituminous binders, the compliance limits are based on empirical evidence of their validity in terms of actual field performance.

It is also important to note that the PG specification developed in South Africa was strongly influenced by the USA SHRP binder specifications and consequently the framework developed to date is based on the performance of bituminous binders in asphalt mixes. There is no evidence why such a specification should not be suitable to specify binders for chip seals given the commonality of a number of performance requirements. Also, to have two specifications for binders in two disparate applications would be totally impracticable, given the size of the bituminous product market in South Africa. Hence the approach has been to launch the PG specification as based on

explicit asphalt behaviour and performance characteristics with the proviso that, should it become evident that the framework and adopted parameters fall short of safeguarding adequate binder performance in seals, steps would be taken to add specific requirements as and when appropriate.

Performance criteria

Measurement of the rheological properties of bituminous binders in a DSR and BBR enables the formulation of criteria that would ensure adequate performance and limit their contribution to:

- excessive permanent deformation (viscous flow) at elevated temperatures
- fatigue failure (durability cracking) at intermediate temperatures
- thermal fracture due to large fluctuations in layer temperatures

In considering the development of appropriate criteria to assure adequate binder performance quality, it should be borne in mind that the characteristics of the binder *alone* will not ensure optimal performance of an asphalt layer or a spray seal. Design methods covering these types of application should safeguard adequate performance of the layer through optimal configuration of its components.

What can be achieved in the formulation of this specification is to ensure that the quality of the binder – the glue that holds aggregate particles together – is suitable **to augment the role and function of the other components of the layer** to perform adequately in a set of traffic and environmental conditions.

Safety and handling

Although not directly linked to performance characteristics, three requirements related to safety, ease of handling and the stability during storage are covered in the specifications:

- Safety – flash point
- Handling – flow characteristics (viscosity) of the binder at elevated temperatures to give reasonable assurance that it can be pumped, sprayed, mixed with aggregate and the resulting asphalt compacted.
- Storage stability – for modified binders this requirement serves as an indicator of the compatibility of the base bitumen and the modifier used and whether special procedures of agitation during site storage is required.

PG specification framework

The specification framework provides for a range of operating conditions and performance requirements and safety and handling aspects. A more detailed description of the performance requirements within the context of the operating categories is given in terms of:

- Operating categories;
 - Climate
 - Traffic
- Resistance to viscous flow;
- Resistance to fracture

- fatigue / durability cracking;
- Low temperature cracking;
- Mandatory reporting of G* and δ frequency sweeps at intermediate temperature on original binder as well as RTFO and PAV aged binder;
- Storage stability;
- Safety;
- Pumping and handling; and
- Ageing simulation

Operating conditions

Two key elements of conditions taken into account in the PG specification framework are climate and traffic.

Climate

The effect of climate is taken into account by a grading designation component related to:

- the average seven-day maximum pavement design temperature at a depth of 20 mm below the road surface
- the minimum pavement design temperature.

These maximum pavement design temperatures adopted for South Africa are 58°C, 64°C and 70°C. Figure 29 illustrates the isotherms, with the main isotherm bands based on two 7-day mean maximum temperature zones grading classifications: 58°C and 64°C. The north-western region falls within the 64°C max zone; the south-eastern half being within the 58°C max region. It is expected, based on road surface temperature measurements, that within the 64°C region areas exist with a maximum temperature higher than 64°C, therefore provision is made for a 70°C region.

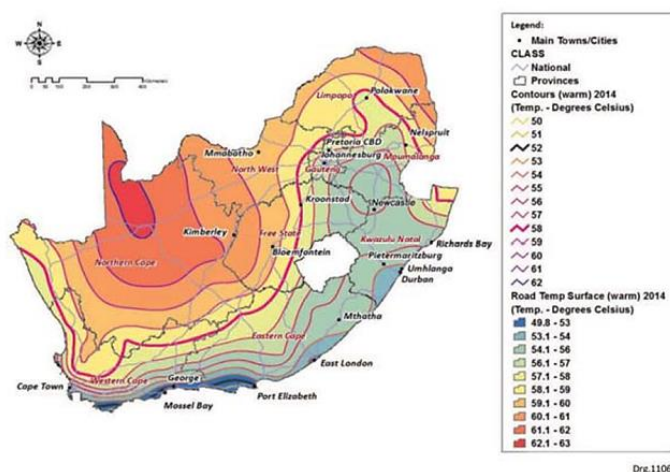


Figure 29: Maximum pavement temperature zones

Source: CSIR

While the minimum temperature in SA rarely falls below -10°C, the minimum temperatures adopted for grading purposes are considerably lower, to align the specification to the US standard and to

determine the temperatures at which other tests are carried out, e.g. intermediate temperatures for fatigue (durability) and the low temperatures for thermal cracking. The three minimum temperatures associated with 58°C, 64°C and 70°C are -22°C, -16°C and -10°C, respectively i.e. an 80°C difference in all cases.

Traffic

Traffic is classified in terms of *Standard*, *Heavy*, *Very Heavy* and *Extreme* categories with the associated symbols of S, H, V and E, respectively. The classification is based on both *traffic volume* and *traffic speed* as shown in Table 4. The reason for including speed is that, at low speeds, heavy traffic exerts stress durations that will have to be countered to some extent by the binder's resistance to viscous flow.

Table 4: Traffic categories

Design traffic (million E80) ^a	Traffic Speed (km/h)		
	< 20	20 - 80	>80
< 0.3	S	S	S
0.3 - 3	H	S	S
>3 - 10	V	H	S
>10 - 30	E	V	H
>30 - 100	E	E	V
> 100	E	E	E

Binder classification

The binder classification system, in terms of both traffic and climate (temperature) according to which compliance requirements will be determined is as shown in Table 5.

Table 5: Binder classification system

Classification	58S - 22	58H - 22	58V - 22	58E - 22	64S - 16	64H - 16	64V - 16	64E - 16	70S - 10	70H - 10	70V - 10	70E - 10
Maximum pavement design temperature, T _{max} (°C)	58				64				70			
Minimum grading temperature, T _{min} (°C)	-22				-16				-10			

In determining the specification framework and, hence, prescribing the temperatures at which tests are to be performed, the following benchmarks have been established:

- **Maximum temperature, T_{max}** : the applicable maximum pavement design temperature, e.g. 58°C, 64°C, 70°C
- **Minimum grading temperature, T_{min}** : minimum temperatures adopted for grading purposes
- **Intermediate temperature, T_{IT}** : a temperature midway between T_{max} and the minimum grading temperature T_{min} plus 4°C, i.e. $\left[\frac{T_{max}+T_{min}}{2} + 4\right]^{\circ C}$
- **low temperature: T_{LT}** : 10°C above the minimum grading temperature, T_{min} , i.e. $[T_{min} + 10]^{\circ C}$ ⁴

Conditioning (Ageing)

Ageing of a bituminous binder is classified in two phases: during handling, manufacture, storage, transport and placement termed *short-term ageing* (STA) and over the in-service life of the layer, termed *long-term ageing* (LTA). STA is a high temperature process which would favour high energy oxidation mechanisms.

For the purposes of correlation with laboratory simulated ageing procedures, for adoption into a specification, LTA is deemed as the ageing a binder undergoes during a period of 5 to 10 years after placement. LTA is a medium temperature process ranging between - 5°C and 70°C in South Africa. It would favour lower energy oxidation mechanisms and volatilisation would not be a major factor, unless the bituminous binder has been cut back with solvents or oils.

Ageing has a significant impact on the behaviour of a bituminous binder and, hence, the layer in which it is incorporated. Ageing of bituminous binders manifests itself as an increase in bitumen stiffness which may have an adverse influence on the fatigue life of a layer, or, conversely, it may have a positive effect by increasing the pavement bearing capacity due to the stiffer material.

It is important to note that ageing tests cannot simulate the actual in-service conditions accurately; the effects on selected performance parameters after either STA or LTA should be regarded as the susceptibility of the binder to the adverse effects of ageing and a tool for assessing, or rating, binders as to its suitability.

In the PG specification the Rolling Thin-film Oven (RTFO) is used to simulate STA and the Pressure Ageing Vessel (PAV) test was selected to simulate LTA. (See below)

RTFO ageing

This procedure, described in ASTM D2872, simulates ageing and hardening due to the effect of heat and oxidation in the presence of air as would occur in an asphalt manufacturing plant and during storage, handling and compaction.

In the RTFO procedure a series of glass containers rotate in a vertical plane so that a fresh surface of bitumen is continuously being exposed to air. This exposure (at 163°C) is continued for 75 minutes

⁴ See footnote 5

and a controlled flow of air is blown over the surface of the bitumen from a single nozzle. (See Figure 30)

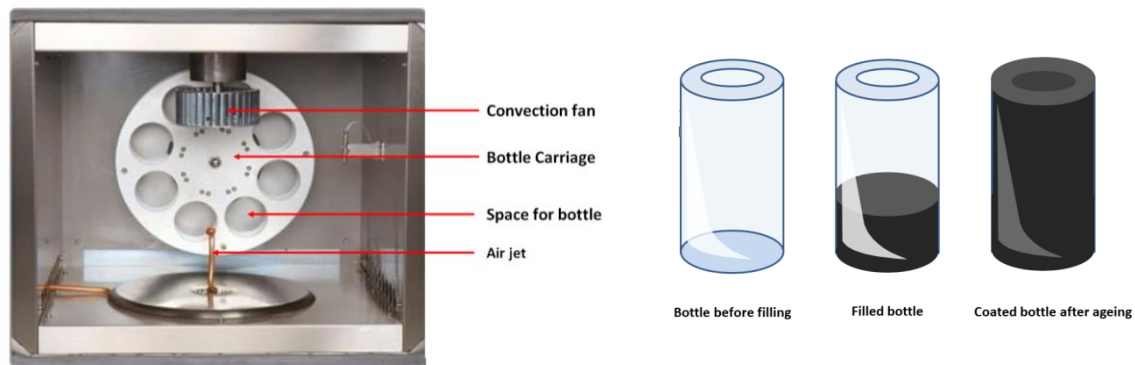


Figure 30: Rolling thin film oven

Tests conducted on binder after this ageing procedure gauge chemical changes during these processes which may alter the generic composition of the binder, as reflected by:

- a mass change
- changes in rheological parameters.

The resistance of the binder to viscous flow is conducted at this stage thereby not allowing the potentially beneficial effects of longer term ageing to come into play.

Compliance limits for the following properties of the short-term aged binder are set in SATS 3208:

- Mass change
- J_{nr} at T_{max}
- Ageing ratio: $\left[\frac{G^*_{after RTFO}}{Original G^*} \right]$ at 10 radians per second

PAV ageing

This ageing process is carried out in accordance with ASTM D6521. In this procedure ageing is carried out on specimens at a pressure of 2.10 ± 0.10 mPa at a temperature of $100 \pm 10^\circ\text{C}$. Specimens subjected to PAV ageing would have been aged in the RTFO and immediately prepared for PAV testing before samples are allowed to cool.

Samples consisting of 50 ± 0.5 g of RTFO aged binder are poured into stainless steel pans of 140 ± 1 mm inside diameter, yielding a binder thickness of approximately 3.2 mm. Pans containing binder are placed in the pre-heated pan holder, with the unused slots with empty pans. (See Figure 31) The pan holder is then inserted into the pressure vessel. (See Figure 32)

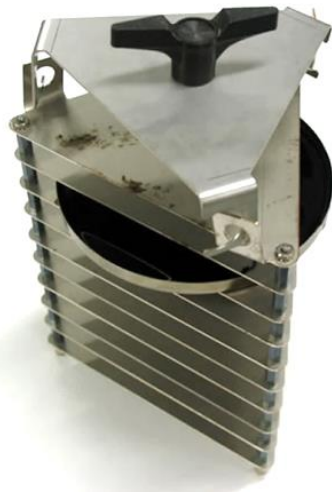


Figure 31: Specimen pan in pan holder

The specimens are aged for inside the pressure vessel for $20\text{h} \pm 10\text{ min}$ while the temperature and air pressure are being maintained.



Figure 32: Pressure vessel with pan holder (not inserted)

Once the test is complete, the internal pressure of the PAV is slowly released within 15 minutes. The pan holder is removed and the pans holding specimens are placed in an oven at 168°C for 15 ± 1 minutes. If the binder is aged in multiple pans, it is decanted into a single container and stirred to blend the binder.

If tests on PAV-aged specimens are not to be performed immediately, samples are covered and stored appropriately for future testing.

Performance tests

In the PG specification, as articulated currently in SATS 3208, all bituminous binders for application in either asphalt layers or chip seals, are assessed by testing their resistance to:

- excessive permanent deformation (viscous flow) at elevated temperatures
- fatigue failure (durability cracking) at intermediate temperatures
- thermal fracture due to large fluctuations in layer temperatures

Resistance to permanent deformation (viscous creep behaviour)

This property is assessed by determining the *non-recoverable creep compliance* J_{nr} with the Multi-Stress Creep Recovery (MSCR) test according to ASTM D7405, using the DSR (described on page 15) as defined in ASTM D7175. The test is carried out on RTFO-aged binder – to simulate the condition of the binder after mixing and paving. The test specimen should reach thermal equilibrium at the test temperature which is equal to T_{max} .

The MSCR test also provides a means of assessing the elastic recovery and stress dependency of bituminous binders.

In the process of placing the binder between the two plates, care is taken to ensure that:

- Specimen is carefully trimmed to match diameter of plates
- The gap between plates is carefully controlled

The process of trimming the specimen is illustrated in Figure 33.



Figure 33: Preparing DSR specimen

In the DSR, one cycle of testing comprises the application of a one-second creep to the binder sample between two parallel plates, then released whereby the sample is allowed to recover for 9 seconds. In the SA PG specification provision is made for two sizes of plates – a 25 mm diameter parallel plate, with a 1 mm gap and an 8 mm diameter plate with a 2 mm gap. (See Figure 34)

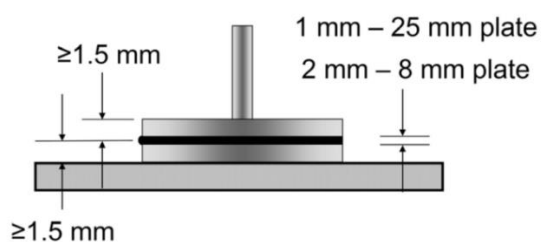


Figure 34: DSR parallel plates

Using the DSR, a one-second creep load is applied to the binder sample, then released and the sample is allowed to recover for 9 seconds. The test is started with the application of a low stress (0.1 kPa) for 10 creep/recovery cycles after which the stress is increased to 3.2 kPa and repeated for an additional 10 cycles. Figure 35 shows a typical creep recovery plot of the MSCR test.

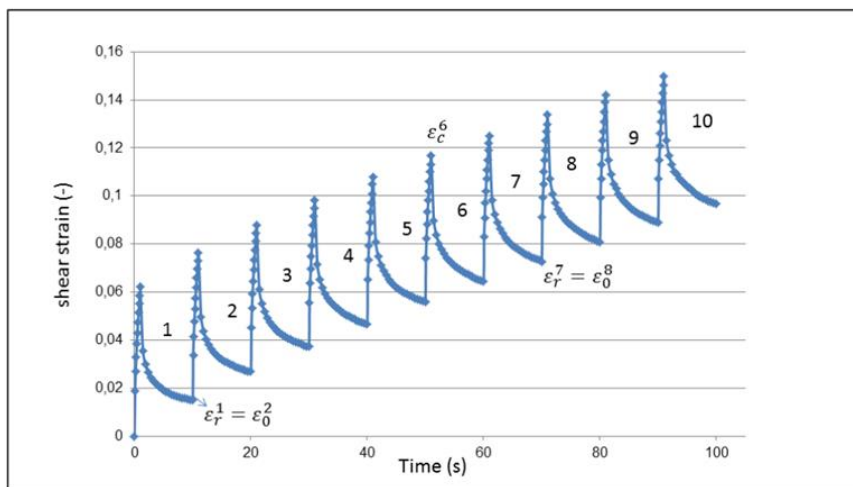


Figure 35: Ten cycles of creep recovery at constant stress

Source: De Visscher

Normalising this plot, as illustrated in Figure 36, facilitates the determination of the non-recoverable compliance – J_{nr} – calculated as:

$$J_{nr} = \varepsilon_u / \tau$$

where

ε_u is the average unrecovered strain from the end of the 9-s recovery portion of the creep and recovery test, over 10 cycles

and

τ is the shear stress applied during the 1-s creep portion of the creep and recovery test.

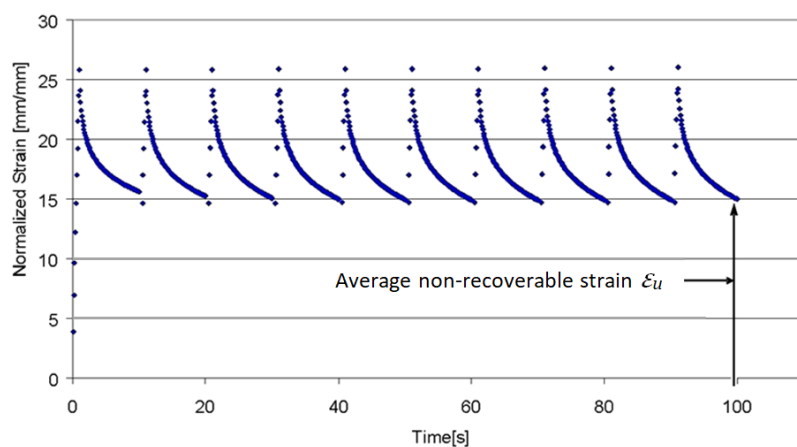


Figure 36: Normalised creep recovery plot

Stress dependency

It is also a requirement in ASTM D7405 that $J_{nr,diff}$ be reported where:

$$J_{nr,diff} = \left(\frac{J_{nr,3,2kPa} - J_{nr,0,1kPa}}{J_{nr,0,1kPa}} \right)$$

This parameter is regarded as indicative of the stress dependency of a binder; if the ratio is greater than 0.75 the asphalt binder is regarded to be stress sensitive. In AASHTO M 332, a maximum ratio of 0.75 is permitted.

Elastic recovery

It is worth noting here that the MSCR test also gives valuable insight into the elastic behaviour of a binder. While the compliance value J_{nr} provides an indication of the binder's resistance to viscous flow associated with rutting of asphalt layers, the amount of recovered strain (percent recovery) from the test identifies the presence of an elastomeric polymer and also the quality of the blending of the polymer in the binder. Elastic recovery associated with elastomeric modified binders is usually significantly higher than is the case with conventional binders, which display very little elastic response, especially at typically elevated road pavement temperatures. See Figure 37.

This test is sometimes used to select binders for special applications where elastic response is useful, for instance in binders used for crack sealing or bituminous surfacing on slightly fractured, highly flexible pavements.

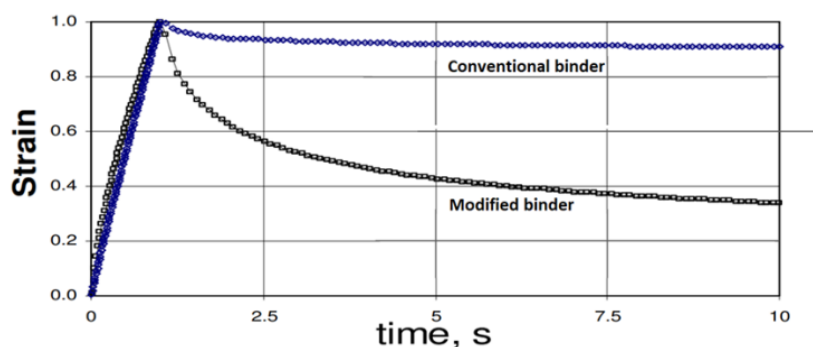


Figure 37: Comparative elastic recovery

The determination of Percent Recovery is illustrated in Figure 38.

$$\text{Percent Recovery} = \frac{\varepsilon_c - \varepsilon_u}{\varepsilon_c} \times 100$$

where

ε_c = is the maximum strain in the creep stage

ε_u = final unrecovered strain

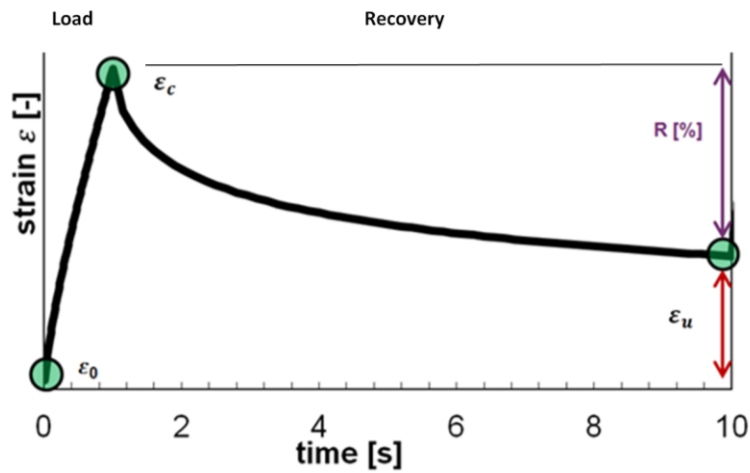


Figure 38: Elastic recovery

Additionally, AASHTO 322 provides a means of assessing the presence of elastic response and stress dependence of polymer modified and unmodified asphalt binders. Figure 39 may be used as an indicator of the presence of an elastomeric polymer.

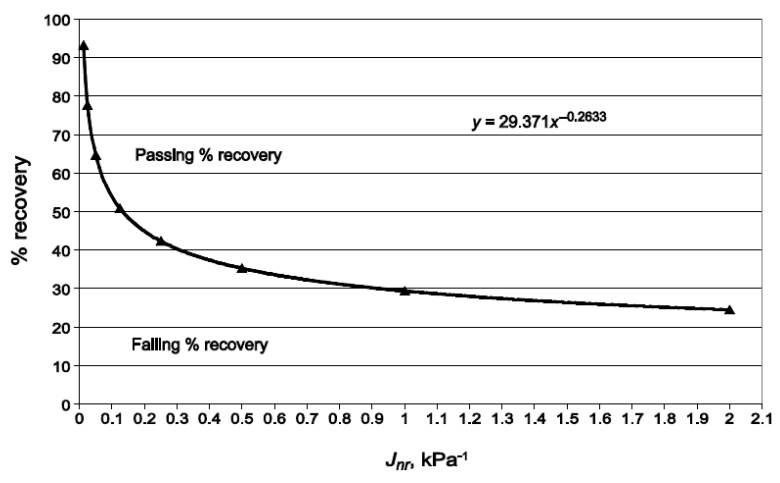


Figure 39: Non-recoverable creep compliance vs. % recovery

Resistance to fracture

Fracture in bituminous layers can occur due to a number of factors, singly or in conjunction with each other. The most common identified sources of fracture, associated with the properties of the binder are:

- Thermal contraction and expansion due to temperature fluctuations
- Fatigue arising from stress or strain reversals due to:
 - repeated traffic loading
 - daily pavement temperature fluctuations
- Loss of pliability due to ageing.

Various parameters, based on studies into the rheological behaviour of binders, have been put forward to evaluate the contribution of the bituminous binder to the susceptibility of the binder to fracture as a result of a combination of the factors listed above.

For the time being the bending beam rheometer (BBR) is employed in SATS 3208 to establish the criteria for resistance to thermal cracking and susceptibility to fatigue cracking as a result of loss of durability.

Thermal cracking

As surrounding temperatures drop, pavements contract and build up internal stresses. Two situations may cause fracture:

- high stiffness of the binder may give rise to high stresses which may initiate fracture
- If the thermal contraction occurs fast enough the fracture may occur due to the fact that induced stresses could not relax sufficiently.

These types of cracks usually run transverse to the direction of travel.

The test to assess the binder's susceptibility to induce this type of fracture is carried out on RTFO and PAV aged binder in accordance with ASTM D6648: *Determining the flexural creep stiffness of asphalt binder using the bending beam rheometer*. The test is conducted at T_L i.e. $T_{min} + 10^\circ\text{C}$.

In this test a moulded bitumen specimen with dimensions 6.35 mm thick, 12.7 mm wide and 127 mm long is simply supported at two points 102 mm apart in a controlled temperature fluid bath the temperature of which is at equilibrium at the desired temperature within a range of $\pm 0.1^\circ\text{C}$. (See Figure 17) A force of 981 ± 5 mN is applied at the midpoint of the beam specimen. The beam deflection is measured at 8, 15, 30, 60, 120 and 240 seconds. The BBR test is done on two beam samples.

Using elastic beam theory – and the elastic-viscoelastic correspondence principle – the beam stiffness, referred to here as “creep stiffness” in relation to time is calculated at the above intervals as follows:

$$S_t = \frac{PL^3}{4bh^3\delta_t}$$

Where

S_t is the creep stiffness at time t

P is the applied constant load

L is the distance between beam supports

b is the beam width

h is the beam depth

δ_t is the deflection at time t

A stiffness curve is then fitted to these points, as illustrated in Figure 40.

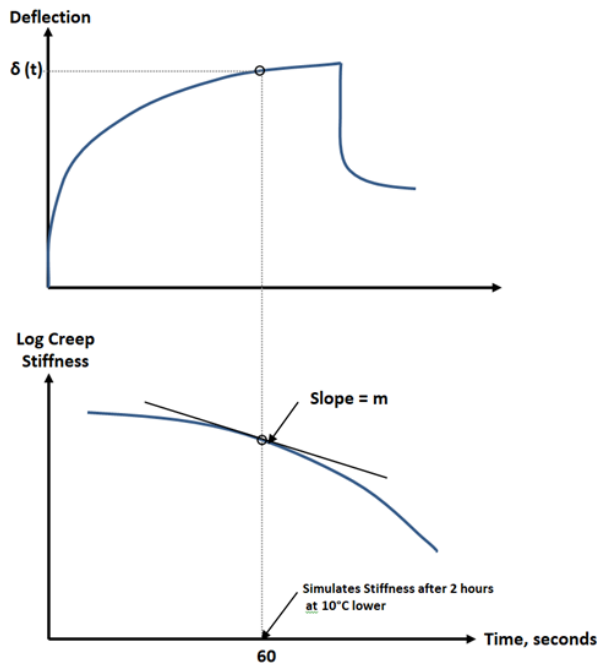


Figure 40: BBR outputs

Both the creep stiffness at 60 seconds, $S(60)$ and slope of the creep stiffness vs. time plot at 60 seconds, $m(60)$ are specified as low temperature cracking criteria.⁵ It was concluded by researchers that neither parameter is solely indicative of a deficiency of a binder. Data indicated that should the creep stiffness not exceed 300 MPa and m is greater or equal to 0.300, this type of distress is infrequent, as illustrated in Figure 41. Hence both parameters, i.e. $S(60) \leq 300$ MPa and $m(60) \geq 0.300$ are specified

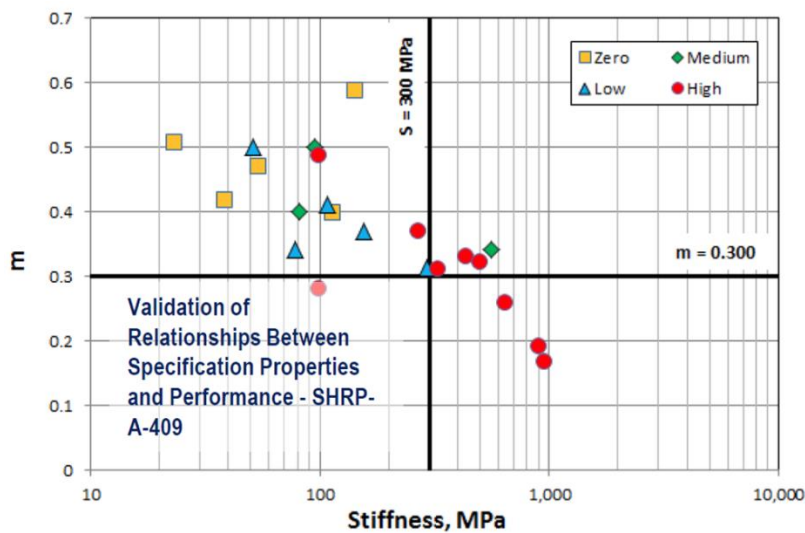


Figure 41: Field data of thermal cracking distress

⁵ Whereas originally it was considered that these critical values should be determined at T_{min} for 2 hours loading time, the test duration was deemed to be impracticable. Hence the principle of time-temperature superposition was used to obtain similar values at a temperature of $T_{min} + 10^{\circ}C$ and 60 seconds loading time.

Fatigue (durability) cracking

To evaluate the potential of a binder to contribute to aged related cracking, ASTM D7643: *Determining the Continuous Grading Temperature and Continuous Grades for PG Graded Asphalt Binders* is specified in SATS 3208.

Researchers have found that ΔT_c – the difference in temperature at which the binder stiffness, $S = 300$ and the slope of the creep curve, $m = 0.3$ – quantifies the loss of relaxation properties and, hence, its susceptibility to progressive pavement ravelling and cracking.

$T_c.S$ is the critical temperature at which $S(60) = 300$ MPa and $T_c.m$ is the critical temperature at which $m(60) = 0,3$ MPa/s. $S(60)$ and $m(60)$ are determined at more than one temperature until $S(60) = 300$ and $m(60) = 0,3$ are both covered within the ranges of test temperatures. These regions for S and m may differ. Consequently $T_c.S$ and $T_c.m$ may only be established by interpolation; extrapolation is not allowed.

$$\Delta T_c = T_c.S - T_c.m$$

where:

$T_c.S$ is the critical temperature at which $S(60\text{ s})$ is 300 MPa

$T_c.m$ is the critical temperature at which $m(60\text{ s})$ is 0.3 MPa/s

$$T_c.S = T_1 + \left(\frac{((T_1 - T_2)(\log 300 - \log S_1))}{\log S_1 - \log S_2} \right) - 10$$

$$T_c.m = T_1 + \left(\frac{(T_1 - T_2)(0.300 - m_1)}{m_1 - m_2} \right) - 10$$

Example

BBR tests at two test temperatures:

- **-18°C** – Stiffness = 243 MPa; m-value = 0.309
- **-24°C** : – Stiffness = 400 MPa; m-value = 0.256

Using these results, the low continuous grade temperatures are

- for the stiffness criteria: $T_c.S = -18 + \left(\frac{(-18+24)(2.4771-2.3856)}{2.3856-2.6021} \right) - 10 = -30.5^\circ C$
- for the m-value criteria $(T_c.m) = -18 + \left(\frac{(-18+24)(0.300-0.309)}{0.309-0.256} \right) - 10 = -29.0^\circ C$

and hence:

$$\Delta T_c = -30.5 - (-29.0) = -1.5^\circ C$$

The binder therefore complies with the compliance requirement:

$$\Delta T_c \geq -5^\circ C$$

Resistance to Ageing

SATS 3208 lists requirements to ensure that bituminous binders are not unduly susceptible to ageing. It therefore stipulates compliance limits for an Ageing Ratio which gives an indication of the sensitivity of the binder to ageing during handling and construction – termed short term ageing – and in-service, termed long term ageing.

Two compliance requirements are specified:

- The short term ageing ratio of G^* (after RTFO) to G^* of original material, i.e. $G^{*RTFO}/G^{*Original}$ tested in accordance with ASTM D7175 at T_1 and 10 radians/second. The compliance limit of this ratio is ≤ 3.0
- The longer term (in-service) ageing ratio of G^* (after PAV ageing) to G^* of original material i.e. $G^{*PAV}/G^{*Original}$ tested in accordance with ASTM D7175 at T_1 and 10 radians/second. The compliance limit of this ratio is ≤ 6.0

Tests for safety and ease of handling

Safety

Bituminous materials release volatiles at high temperatures depending upon their type and grade. These volatiles, when mixed with air can catch fire causing a flash. This tendency is measured in a standard test as the *flash point* of the binder which is the lowest temperature at which flash occurs when a small flame is brought in contact with the vapours of bituminous product, gradually heated under standardised condition.

The flash point, being a measure of the temperature to which bitumen can safely be heated under certain conditions, is usually monitored at the point of manufacture. It is used in shipping and safety regulations relevant to flammable and combustible materials to formulate precautions that are necessary during transport and application of the product. It is only one of a number of properties which must be considered in assessing the overall flammability hazard of a material. Since cutback binders are generally handled at temperatures above the flash point temperature of the solvents (cutters), it is a pertinent requirement for this type of binder.

If the bituminous material is further heated to a more elevated temperature beyond its flash point, the material itself catches fire and continues to burn. The lowest temperature at which this ignition of the material occurs is the *fire point*.

Flash Point temperature

In the interests of safety, flash point temperature is a requirement set out in SATS 3208 for bitumen, although it also applies to other binders, e.g. cutback bitumen.

The flash point temperature is determined according to ASTM D92: *Standard Test Method for Flash and Fire Points by Cleveland Open Cup Tester*. In this test a test cup of the apparatus (usually brass) is filled to a certain level with the binder. The temperature of this chemical is increased rapidly and then at a slow, constant rate as it approaches the theoretical flash point. The increase in temperature will cause the binder to produce increasing amounts of flammable vapour. The lowest temperature at which a small test flame passing over the surface of the liquid causes the vapour to

ignite is considered the binder's flash point. Temperature range of this apparatus is 120 to 250°C. The apparatus is depicted in Figure 42.

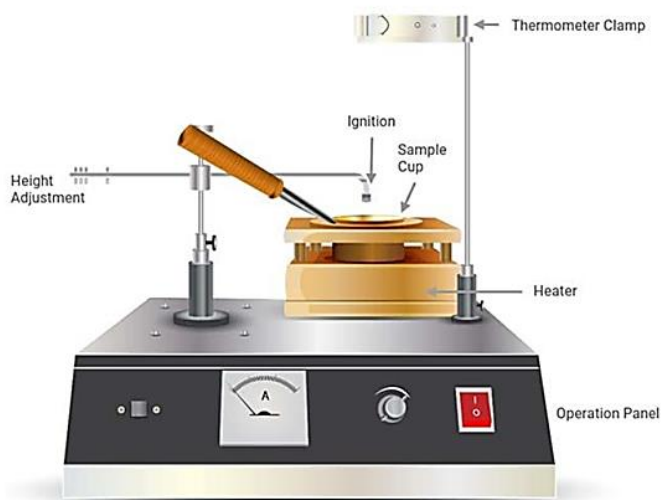


Figure 42: Cleveland Open-cup Flash Point apparatus

Ease of handling

Two tests are stipulated in SATS 3208 to ensure that the binder can readily be pumped and stored for use: pumpability and storage stability.

Pumpability

In SATS 3208 pumpability is ensured by specification of an upper limit for the dynamic viscosity of the binder at 165°C, determined in accordance with ASTM D4402: *Standard Test Method for Viscosity Determination of Asphalt at Elevated Temperatures Using a Rotational Viscometer*.

In this test the dynamic viscosity, or resistance to shear, of a bituminous binder is determined by measuring the torque required to rotate a spindle immersed in bitumen in a temperature-controlled thermal chamber within the range of 38 to 260°C. The viscometer used is the Brookfield model RV with Thermosel system using SC-4 type spindles.

By varying the spindle size, the viscosity can be determined over a large range of bitumen grades - from very viscous to very liquid materials. The SI unit of dynamic viscosity is the Pascal second (Pa.s). In the cm/gm/s (CGS) system, the unit of viscosity is the poise, such that 1 Pa.s = 10 poises.

Viscosity can be measured over a wide range of temperatures, including maximum bitumen application and operating temperatures, enabling the susceptibility of viscosity to temperature to be assessed.

The test apparatus is depicted in Figure 43.

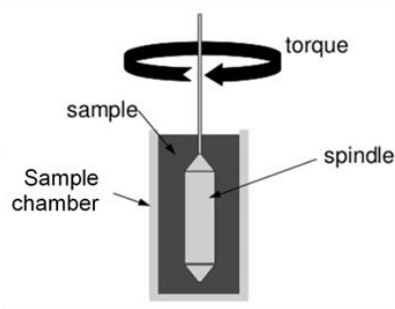


Figure 43: Brookfield rotational viscometer

Storage stability

This property of a binder is assessed by determining the complex modulus, G^* , of the top and bottom portions of a cylindrical specimen. The DSR testing is carried out according to ASTM D7175.

An open ended 300 mm long glass tube with an internal diameter of 12.5 mm is filled with the binder to be tested and placed vertically in an oven at $180 \pm 2^\circ\text{C}$ for three days. The glass tube is then cooled to about 0°C to enable cutting the tube transversely into three equal sections. The top and bottom portions of the specimen are then prepared for DSR testing at T_{MAX} and 10 rad/sec.

The storage stability is determined from the values of G^* of the selected portions as the difference in G^* (highest value minus lowest value) divided by the highest G^* value:

$$(G_{\text{HIGH}}^* - G_{\text{LOW}}^*) / G_{\text{HIGH}}^*$$

Performance grade (PG) specification

The current PG specification is published by SABS as a technical specification SATS 3208 (as precursor to a standard specification). It is the intention that this specification will be implemented on a trial basis for a number of years, during which period the standard specification for bitumen, SANS 4001-BT1 would remain in force.

The compliance criteria presented in SATS 3208 are shown in Table 6.⁶ The columns indicate the 12 binder grades for the three maximum pavement design temperatures and associated minimum grading temperatures for each of the four traffic intensity categories.

It was noted during the development stage of this specification framework that conventional bitumen produced at SA refineries would in all probability comply with the requirements of grades 58S, 58H and 64S. Compliance with higher grades, i.e. for more severe conditions of climate and traffic would most likely require modification by the secondary binder industry.

As imports of bitumen to meet the local market needs are likely to increase, the implementation and use of a PG specification is bound to provide more of a safeguard against receiving inferior product complying with a conventional empirical specification based on penetration etc.

⁶ Only the compliance criteria are reflected here. Other requirements e.g. the compulsory reporting of values of G^* and δ at T_{IT} of original and aged binder as well as $G^*/\sin\delta$ of unaged binder listed in SATS 3208, for further research purposes, are not presented here.

Table 6: Performance grade specification – compliance criteria

Test property	Performance grade											
	58S -22	58H -22	58V -22	58E -22	64S -16	64H -16	64V -16	64E -16	70S -10	70H -10	70V -10	70E -10
Maximum pavement design temperature, T_{max} (°C)	58				64				70			
Minimum grading temperature, T_{min} (°C)	-22				-16				-10			
Original binder												
Viscosity @ 165°C, $\geq 30 \text{ s}^{-1}$, (Pa.s)	≤ 0.9											
Storage stability at 180°C (% diff, G^*_{HIGH} and G^*_{LOW}) at T_{max}	≤ 15											
Flash Point (°C)	≥ 230											
After RTFO ageing												
Mass Change (m/m), (%)	≤ 1.0											
J_{NR} @ T_{max} , (kPa^{-1})	≤ 4.5	≤ 2.0	≤ 1.0	≤ 0.5	≤ 4.5	≤ 2.0	≤ 1.0	≤ 0.5	≤ 4.5	≤ 2.0	≤ 1.0	≤ 0.5
Ageing Ratio, $G^*_{RTFO}/G^*_{Original}$	≤ 3.0											
After RTFO and PAV ageing												
Creep stiffness, S (60s) at $T_{min} + 10^\circ\text{C}$, (MPa)	≤ 300											
m (60s) at $T_{min} + 10^\circ\text{C}$, minimum, (MPa/s)	≥ 0.300											
$\Delta T_c = T_c S - T_c m$, (°C)	≥ -5											
Ageing Ratio, $G^*_{PAV}/G^*_{Original}$	≤ 6.0											

Tests on cutback bitumen

The current specification covering medium curing cutback binders is SANS 4001-BT2. In terms of this specification, the base bitumen should comply with the relevant SABS standard. (Currently SANS 4001-BT1, but likely to revert to a PG framework, as set out in SATS 3208, in the near future.)

Compliance of a number of properties is presented in the standard specification, with those unique to cutback bitumen discussed below.

Kinematic viscosity test (ASTM D2170)

This test of consistency is used to classify cutback binders. The measurement of kinematic viscosity is made by timing the flow of the cutback bitumen through a glass U-tube capillary viscometer at a given temperature. Each viscometer is calibrated, and the product of efflux time and viscometer calibration factor gives the kinematic viscosity in stokes.

The U-tube reverse flow viscometer for measuring kinematic viscosity is shown in Figure 44.

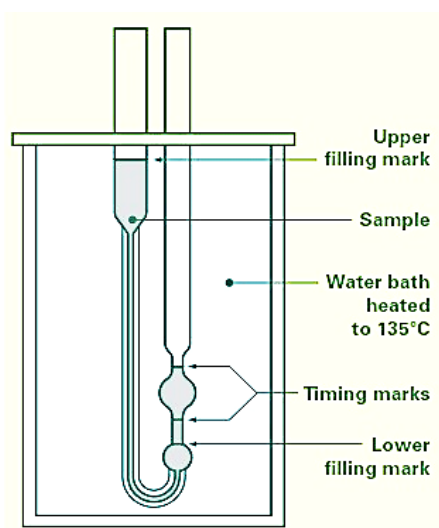


Figure 44: U-tube reverse flow viscometer

Cutback bitumens are classified by their kinematic viscosity at 60°C, expressed in centistokes (cSt) and the type of solvent used is associated with this, either medium curing (MC) or rapid curing (RC). The lower limit of the viscosity range is used in the grade designation, while the upper limit is double this lower figure, e.g. MC30 has a viscosity at 60°C in the range of 30 - 60 cSt.

As is the case with conventional bitumen, the temperature/viscosity relationships of cutback bitumens can be used to determine the correct spraying, mixing and pumping temperatures.

Distillation test (Test method IP27)

This test indicates the rate at which the binder will cure through the evaporation of volatile fractions. The proportion and type of solvent present in cutback bitumen is determined by heating the material, condensing the vapours and noting the volume of the condensate collected at various specified temperatures up to 360°C. The undistilled portion remaining constitutes the binder content of the cutback, typical values of which are shown in Table 7. The apparatus for this test is shown schematically in Figure 45.

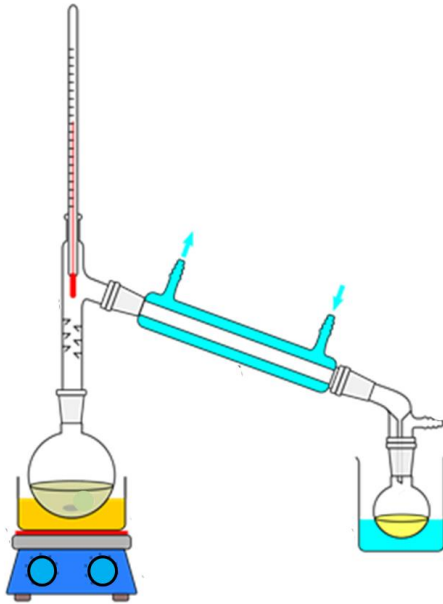


Figure 45: Distillation apparatus

Table 7 : Typical bitumen content of cutback bitumen

Grade	Bitumen content by % volume
MC-10	40
MC-30	50
MC-3000	80

The residue from the distillation test is tested for compliance to a specification. It may well be slightly softer than the original base bitumen, as the distillation process, no matter how carefully performed, may not remove all of the very heaviest constituents of the solvent.

Tests on bitumen emulsions

While it goes without saying that bitumen emulsions are manufactured with base bitumen complying with the PG specification, further tests, particularly associated with the composition and consistency of the emulsified binder are required. These tests are as specified in SANS 4001-BT3, BT4 and BT5 for the anionic, cationic and inverted bitumen emulsions, respectively. Tests for conventional emulsions (i.e. bitumen droplets dispersed in a continuous water phase as given in SANS 4001-BT3 & 4) are given below. Inverted bitumen emulsions are less frequently used, and some test methods for this product differ from those for conventional bitumen emulsions. SANS 4001-BT5 should be consulted for tests for inverted bitumen emulsions.

Binder content (ASTM D402)

Bitumen emulsions may contain up to 40% of water by volume, and it is essential that the quantity of residual bituminous binder (which may include cutters) actually applied to the road surface is accurately determined. The bitumen content is determined by means of a distillation procedure

using equipment commonly referred to as the Dean and Stark apparatus, illustrated schematically in Figure 46.

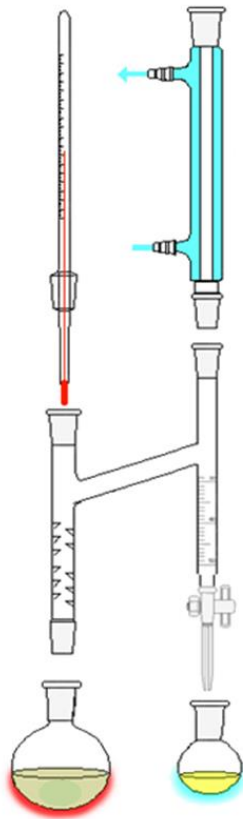


Figure 46: Dean and Starke apparatus

An organic liquid immiscible with water (xylol is usually used) is added to the sample and the flask is heated. The organic liquid distils into the receiving flask, carrying with it the water, which then separates into a lower layer. The volume of water is measured and, by difference, the residual binder content determined.

Particle charge (ASTM D244)

This test distinguishes between cationic and anionic emulsions. Two electrodes are immersed in a sample of emulsion and connected to a low power direct current source. If, at the end of the specified period, bitumen deposits are observed on the cathode, i.e. the electrode connected to the negative side of the current source, the emulsion is identified as a cationic bitumen emulsion.

Viscosity at 50°C (ASTM D244)

The viscosity of an emulsion is monitored to ensure that its flow properties are appropriate to the application, e.g. steep gradients and high super elevation. The viscosity of bitumen emulsion is measured by means of the Saybolt Furol viscometer. This test measures the time of efflux of a specified volume of emulsion at 50°C through the standard orifice.

Residue on sieving (IP 91)

Method IP 91 is varied whereby a sieve of height 50 mm, diameter approximately 80 mm, and nominal aperture size 150 μm is used. The emulsion should first pass through a sieve size of nominal

aperture 710 µm and then through a nominal aperture size 150 µm. Thereafter determine the mass of the dry residue on both sieves.

Upper limits for the residue on sieving (g/100 ml) are given for the two sieves for each class of emulsion, i.e. rapid setting (spray grade), medium setting (premix type) and slow setting (stable mix type).

Coagulation value (SANS 4001-BT3)

This test determines the ability of a stable mix grade emulsion not to break prematurely in the presence of cement or lime. There are two methods for determining this value: mixed with standard dolerite chippings or when mixed with cement.

Using standard dolerite chippings

A bottle, containing standard chippings and emulsion is rotated in a mixer end-over-end 140 times. Boiled distilled water is added to the mixture and rotated end-over-end. The wash water and residual emulsion is strained off through a sieve of nominal aperture size 710 µm. The agitation with 200 ml quantities of the boiled distilled water is repeated until the washings are clear.

After thorough draining of the water the bitumen is dissolved in exactly 100 ml of xylol and placed into the original bottle. A further washing of the sieve and beaker with 100 ml of xylol is carried out and the washings added to the bottle which is rotated again to dissolve the coagulated bitumen.

After standing the bottle to permit dispersed water and stone dust to settle, the xylol is evaporated from an aliquot of the supernatant xylol. The mass of bitumen residue is determined. The amount of bitumen coagulated, as a percentage of the total bitumen originally present is calculated:

$$C_{VS} = \frac{b \times 8 \times 100}{20 \left(1 - \frac{M}{100}\right)}$$

Where

C_{VS} is the coagulation value when chippings are used, expressed as a percentage

b is the mass of bitumen in 25 ml of xylol solution in grams

M is the water content of the original emulsion, % by mass as determined in accordance with ASTM D244

Using cement

A sample of 50 g of the cement sifted through a 180 µm sieve is placed in a plastics beaker. An amount of water to prepare 100 ml of an emulsion having a 50% fraction by mass of water is added at a temperature of approximately 25°C. A predetermined amount of emulsion is added to the beaker and stirred, following which 150 ml of water is added and stirred for a further period.

The mixture is washed through a 1.40 mm sieve with water. After drying the sieve and pan the total mass (i.e. pan and sieve containing residue) is determined.

The coagulation value is calculated as follows:

$$\text{Coagulation value} = \frac{(M_2 - M_1) \times 10}{M_3}$$

where

M_1 = mass of the empty sieve and pan, g

M_2 = mass of the sieve and the pan and the materials retained in the pan and on the sieve, g

M_3 = mass of binder in 100 ml of diluted emulsion, g (calculated from the water content determined in accordance with method ASTM D244)

Sedimentation test (SANS 4001-BT3)

Approximately 10 g of emulsion is centrifuged in a jar for 5 min at a predetermined speed, following which a soap solution is added and the closed jar placed in a mixer. The jar is steadily rotated at a rate of one revolution per second. After every 5 rotations the apparatus is stopped for 10 s in such a position so as to allow the washings to drain down and the presence of sediment at the bottom of the jar to be observed. This procedure is repeated until the sediment has been completely removed from the bottom of the jar.

The number of complete rotations required to effect complete removal of the sediment from the bottom of the jar is recorded.

Test Frequencies

When testing bitumen for compliance with the requirements of SATS3208, it is recommended that the sampling and testing frequencies as set out in Table 8 be adopted.

Table 8: Test frequencies for testing for compliance with SATS 3208

Test	Test Method	Sample Size & Container Type	Sampling Frequency	Acceptance Test Frequency	Remarks
Original Binder	ASTM D7175 – G*/sinδ ASTM D4402 – Viscosity. @ 165°C	1-litre double seal metal tin	Each Load (New Production run from supplier)	Tender submission, Production start-up evaluation and 1 random sample per 5 samples	Certificate of compliance required for each load
Original Binder	ASTM D92 – Flash Point ASTM D7175, MB-6 (depending on binder type) - Storage stability at 180°C (% diff in G* at Tmax)			Tender submission, Production start-up evaluation and 1 random sample per 10 samples	
RTFO –aged Binder	ASTM D2872 ASTM D7405 – MSCR Jnr			Tender submission, Production start-up evaluation and 1 random sample per 5 samples	
PAV aged Binder	ASTM D6521 ASTM D6648 – BBR S & m			Tender submission, Production start-up evaluation and 1 random sample per 10 samples	
Ageing Ratio – Original,, RTFO– and PAV aged Samples	ASTM D2872 ASTM D6521 ASTM D7175 – Intermediate Temperature Frequency Sweep – G* & δ			Tender submission, Production start-up evaluation and 1 random sample per 10 samples	
Base Bitumen properties	SATS 3208			Production start-up evaluation and change in binder supply	

4. Handling of bituminous binders

Bitumen presents a low order potential hazard as long as sound and responsible practices are observed during the handling of the product.

These practices as well as advice on handling, emergency treatment and disposal are described in detail in Sabita Manual 8: *Guidelines for the safe and responsible handling of bituminous binders*.⁷

Users of the product should be aware that there is an obligation on the part of the supplier of bituminous binders to compile and issue Material Safety Data Sheets (MSDS) for each product in accordance with the regulations governing hazardous chemical substances. The MSDS is the primary source of information and advice on the safe handling of the specific product.

The carriage of dangerous goods by road creates risks to drivers, other road users, the public, emergency services and, in the case of some substances, to the environment. The transportation of classified goods and substances is therefore regulated by legislation and also by international protocols and treaties when such transportation involves cross-border operations.

Guidance to assist in the understanding of and compliance with the relevant legislation is covered in Sabita Manual 34: *Guideline to legislation on the transportation of bitumen and bitumen spill protocol*. This manual indicates the UN number in terms of the United Nations Recommendations on the Transport of Dangerous Goods: Model Regulations, under which bituminous binders should be transported by road, either in bulk road tankers or in drums or bags. It also covers the emergency information documentation that should accompany the transport vehicle.

An important aspect associated with bitumen imports is compliance with enhanced health, safety and environmental management practices (driven by strict International Safety Codes) and logistical challenges associated with off-loading the bitumen tanker and storage and handling of the landed bitumen.

In response to these concerns Sabita has produced a best practice guide to assist potential importers of bitumen to deal with these issues as well as assuring a quality product. This document – *Best practice guide for the procurement and importing of bitumen* is available on the Sabita website.

⁷ As it is not the intention to cover the topic in detail in this manual, it is strongly recommended that the reader be familiar with the contents of Manual 8 to ensure that the exposure of personnel to hazards when working with bitumen is mitigated

5. Selection and application

It is not the intention of this manual to instruct readers in road construction techniques, since these are well documented in other Sabita manuals and technical guideline documents. It will, however, be useful to link the ranges of products previously discussed with conventional structural and functional layers of roads where they serve as binding, waterproofing and stabilising agents. The applications refer to both new road construction and maintenance practices.

In chip seals the chippings are bound to the base or existing surfacing by the sprayed binder to form an all-weather surface which is dust free, has the required surface texture and skid resistance, resists the scuffing action of traffic and seals off underlying layers from the ingress of surface water.

In the case of asphalt the binder is mixed in the manufacturing plant with heated aggregates. Asphalt surfacings perform the same functions as chip seals and, if of sufficient thickness, as is the case with asphalt base layers and surfacings thicker than 30 mm, add measurably to the load-bearing capacity of the pavement structure. When applied to uneven surfaces, an asphalt overlay can provide a significant improvement in riding quality.

Stabilisation of pavement layers by means of bituminous binders (either as an emulsion or foamed bitumen) improves the load-bearing capacity of these layers. They help to resist the ingress of water and thus prevent damage to these layers due to the softening effects of excessive moisture and, in extreme climates, damage due to freezing and thawing.

Bitumen-bound layers are relatively flexible and will, within limits and subject to the correct selection of grade of binder, accommodate movements in underlying layers without excessive cracking.

Selection of bituminous binders

The classification of binders in terms of performance characteristics dictated by climate, on the one hand, and traffic loading on the other, as articulated in Section 3 *Specifications and test methods*, greatly assists in selecting an appropriate binder grade for a particular application in a specific region. Whereas it is noted in this section that the PG specification developed in South Africa is biased towards the performance of bituminous binders in asphalt mixes, there is currently no reason to believe that binders conforming to these requirements would not serve well in chip seals and slurries. While this matter is being investigated further, some ad hoc measures may need to be taken to formulate the appropriate specifications for binders in these applications in contract documentation.

There is no substitute for extensive experience and knowledge in this regard, and the following comments can only serve as a general guide.

The selection of bituminous binders for specific applications is dictated by several factors. These include:

- The configuration and type of material that has to be treated or bound together;
- Prevailing environmental conditions of climate (both during construction and in service), topography and traffic loading;

- The position and function of the layer;
- Construction methods required; and
- Costs and budgets

Selection criteria

An indication of typical applications of the various binders is given below. The reader is referred to the following publications by Sabita for more comprehensive guidance on the selection, use and application of bituminous binders:

Spray seals and slurries:

- Manual 40: *Design and Construction Of Surface Treatments*
- TG1: *The use of modified binders in road construction*
- *Asphalt*
 - Manual 35: *Design and use of Asphalt in Road Pavements*
 - Manual 33: *Design procedure for high modulus asphalt (EME)*
 - Manual 22: *Hot-mix paving in adverse weather*
 - Manual 27: *Guideline for thin layer hot mix asphalt wearing courses of residential streets*
 - Manual 17: *Porous asphalt mixes – design and use*
 - Manual 19: *Guidelines for the design, manufacture and construction of bitumen-rubber asphalt wearing courses*
 - Manual 26: *Guidelines for primes, bond coats and stone precoating fluids*
- *Bitumen stabilised materials*
 - TG 2: *Bitumen stabilised materials*
- *Primes, bond coats and stone precoating fluids*
 - Manual 26: *Guidelines for primes, bond coats and stone precoating fluids*

6. Glossary

Asphalt – A mixture of inert mineral matter, such as aggregate, mineral filler and bituminous binder in predetermined proportions.

Binder, Bituminous – any bitumen-based material used in road construction to bind together or to seal aggregate or soil particles. The term explicitly excludes coal tar products

Binder, Modified – bitumen modified by the addition of substances to enhance performance. Examples of modifiers are polymers and natural or synthetic rubbers.

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

Bitumen, Cutback – a liquid bitumen product obtained by blending penetration grade bitumen with a volatile solvent to produce rapid curing (RC) or medium curing (MC) cutbacks, depending on the volatility of the solvent used. After evaporation of the solvent, the properties of the original penetration grade bitumen become operative.

Bitumen, conventional – 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 produce products of varying hardness or viscosity.

Bitumen Emulsion - An emulsion of bitumen and water with the addition of an emulsifier or emulsifying agent to ensure stability. Conventional bitumen emulsion most commonly used in road works has the bitumen dispersed in the water. An inverted bitumen emulsion has the water dispersed in the bitumen. In the former, the bitumen is the dispersed phase and the water is the continuous phase. In the latter, the water is the dispersed phase and the bitumen is the continuous phase. The bitumen is sometimes fluxed to lower its viscosity by the addition of a suitable solvent.

Bitumen Emulsion, Anionic – An emulsion where the emulsifier is an alkaline organic salt. The bitumen globules carry a negative electrostatic charge.

Bitumen Emulsion, Cationic – An emulsion where the emulsifier is an acidic organic salt. The bitumen globules carry a positive electrostatic charge.

Bitumen Rubber – A blend of bitumen and approximately 20% by weight of crumb rubber, containing where necessary extender oil and/or diluent.

Bituminous Surfacing – A layer consisting of a bituminous binder and aggregate with which traffic makes direct contact. (See “wearing course”)

Bitumen-stabilised material – A base layer consisting of granular material mixed together with a bituminous binder.

Chip Seal / Spray seal - One or more spray applications of bituminous materials to a pavement surface with a cover of mineral aggregate.

Filler – Mineral matter composed of particles smaller than 0,075mm and consisting of cement, lime or rock flour.

Fog Spray – A light application of diluted bitumen emulsion to the final layer of stone of a reseal or chip seal spray seal or to an existing bituminous surfacing as a maintenance treatment.

Hydrocarbon – A chemical compound consisting mainly of hydrogen and carbon.

Polymer – A chemical compound consisting of molecules formed by a large number of repeated units of one or more compounds of low molecular weight.

Polymer-Modified Bitumen – bitumen with improved physical properties obtained by the addition of a polymer.

Reseal – A surface treatment spray seal or treatment applied to an existing bituminous surface.

Seal – A term frequently used instead of “reseal” or “surface treatment” or “chip seal” or “spray seal”. Also used in the context of “double seal” and “sand seal” where sand is used instead of stone.

Surface Treatment – A general term incorporating chip seals, pray seals, micro surfacing, fog sprays or tack coats.

Wearing Course – The upper layer of a road pavement on which the traffic runs. (See “bituminous surfacing”)