Technical Memorandum

Updating Bituminous Stabilized Materials
Guidelines: Mix Design Report, Phase II

Interim Progress Report

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1. BACKGROUND AND INTRODUCTION

The Mix Design Inception Study that was published as Phase I of the updating of the Bituminous Stabilised Material BSM Guidelines (2006) identified the main inadequacies of current guidelines and practice in this field. In particular, the cold mix design procedures for foamed bitumen mixes were inadequate in a number of areas and are listed below. These shortcomings are also areas of concern in the mix design of bitumen emulsion mixes making it expedient to address both types of cold mix in the proposed review undertaken in this inception study.

- The lack of a suitable laboratory curing method that is adequately linked to field curing.
- Use of both the UCS and ITS tests for mix design and classification (applicable to foamed bitumen).
- The need for more appropriate tests for assessing mix properties and performance, such as flexibility, shear strength and durability.

Twelve tasks were identified in the BSM mix design inception study for further investigation through research so as to address the main inadequacies of the previous guidelines. The objective of this report is to provide an update of progress in terms of the research conducted on each of these subjects and the implications of the findings in shaping the proposed new guidelines for the mix design of foamed and emulsified bitumen stabilized materials. This report should be viewed as a DRAFT INTERIM report, as new data will come available in almost every task before the report is finalized; so the recommendations will be updated.

1.1. Project Objectives

The summary of the Mix Design Inception Study identified five key areas of research from which the twelve tasks emanated:

- Mechanical Testing,
- Flexural Testing,
- Accelerated Curing,
- Durability,
- Compaction

At the time of the inception study, the tasks were broadly defined with several objectives being identified for each. Table 1 to Table 5 provide an outline of the tasks and their appurtenant objectives.

These tasks outlined in the tables below were further refined at the start of Phase II of the project. This report is structured to provide a Synthesis of each of the progress and findings of each refined task in Section 2. This section first defines the objectives that were set just before commence of the research, for each of the tasks. Thereafter, a summary of the research findings and implications on the revised mix design approach is provided.

Section 3 follows, which covers the Classification of BSM’s as applicable to the draft report, ahead of the final Phase 2 report which is due in mid 2008. Finally, references are provided in Section 4.

The individual, draft progress reports of Task 1 to Task 12 are appended in Appendices A to L. These reports each provide a detailed account of the background, literature, methodology, findings and conclusions for each of the tasks.
Table 1. Tasks Identified for Improved Mechanical Testing of BSM

<table>
<thead>
<tr>
<th>Task</th>
<th>Key Objective</th>
<th>Sub-tasks</th>
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| Standardise the sample preparation procedures for triaxial testing of BSM | Provide a protocol that will produce repeatable and reliable specimens of BSM for testing in a triaxial setup, that provide representative in-service material behaviour | • Establish a forum where institutions with triaxial setups can discuss specimen preparation protocols  
• Draw up a South African procedure |
| Standardise the monotonic testing procedures for triaxial apparatus | Provide repeatable and reproducible results for shear properties of BSM from triaxial testing | • Establish a forum where institutions with triaxial setups can discuss current methods and proposed standard procedures  
• Investigate confinement application type, loading rate, temperature etc  
• Identify useful features from Texas Triaxial Test and others to incorporate  
• Draw up a South African test procedure |
| Investigate development of improved UCS test with 2:1 height : diameter ratio | Provide fundamental compressive properties without confounding friction effects, that will also provide static modulus information | • Develop a UCS test using specimens of 2:1 height : diameter ratio  
• Perform correlation tests between UCS tests and triaxial tests at very low confinement pressures  
• Draw up a South African test procedure |
| Investigate correlation between UCS $E_{tan}$, monotonic triaxial $E_{tan}$, dynamic triaxial $M_r \theta$ and flexural stiffness from four point beam | Provide fundamental stiffness (resilient) properties for use in mix design testing and pavement design inputs | • Gather data for several BSM from modified UCS, monotonic and dynamic triaxial  
• Correlate resilient properties from the three tests given differences in loading rate, temperature etc  
• Discern which method of testing is most reliable and whether a simple reliable alternative exists |
| Investigate an advanced classification system using limited results from a repeated load triaxial test | Provide highly reliable BSM classification for important projects by means of repeated load deformation testing | • Test several more BSM using plastic strain versus repetitions in triaxial testing to enhance current database  
• Establish reliable models for permanent deformation based on stress ratio  
• Discern whether a limiting stress ratio could be used to classify the performance of BSM, as identified using only limited plastic strain versus number of repetition data |
**Table 2. Tasks Identified for Improved Flexural Testing of BSM for Incorporation in the Mix Design**

<table>
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<th>Sub-tasks</th>
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| Identification of possibility of a standardised specimen preparation procedure for beams | Select a suitable procedure that will result in repeatable and reproducible beams, that provide representative in-service material behaviour. Without this a flexibility measure for mix design is futile. | • Decide whether commercial devices such as Shear Box Compactor are viable  
  • If not, refine current methodologies to develop a protocol for SA |
| Identify the potential of beam testing for moisture sensitivity analysis | Determine the most reliable (at the same time affordable) beam testing procedure for moisture sensitivity analysis | • Develop correlations between fatigue ratio, flexural modulus ratio and strain at break ratio (condition/unconditioned)  
  • Analyse the influence of BC on fatigue and fatigue ratio for different aggregates |

**Table 3. Tasks Identified for Improving Accelerated Curing Protocol**

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<tr>
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<th>Sub-tasks</th>
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| Identify a curing protocol for mix design of BSM suitable for implementation in standard (commercial) laboratories - mixes WITHOUT cement | Curing procedure should provide material properties that reflect field behaviour of the material with resilient modulus being the key parameter | • Investigate potential curing protocols (already identified as providing EMC) in terms of resilient modulus reflective of field stiffness  
  • Use a range of materials (sands, gravels, crushed stone).  
  • Validate the protocol in terms of Mr for known field sections  
  • Identify boundaries of applicability (if any) for foam and emulsion binder types  
  • Identify possible differences between emulsion and foam protocols |
| Identify a curing protocol for mix design of BSM suitable for implementation in standard (commercial) laboratories - mixes WITH cement | Curing procedure should provide material properties that reflect field behaviour of the material with resilient modulus being the key parameter | • As above |
### Table 4. Tasks identified for durability testing with respect to moisture damage

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<tr>
<th>Task</th>
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<th>Sub-tasks</th>
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| Investigate potential refinements to DMI and AIV tests so that these may assist in aggregate classification or selection | Identify appropriate adaptations to current DMI and AIV tests for use on natural aggregate before cold mix treatment | • Establish correlations between DMI or AIV indicators and moisture susceptibility from lab tests  
• Validate for field sections and known materials |
| Investigate potential of wet-dry durability test for BSM             | Establish an appropriate adaptation of current wet-dry durability test (for cemented materials) to provide desirable sensitivity for BSM | • Investigate variations of wet-dry durability test, some without brushing (just conditioning)  
• Validate behaviour with known field performance |
| Investigate potential of rotational cylinder submersed specimen durability test (van Wijk) for BSM | Establish an appropriate adaptation of rotational cylinder submersed specimen durability test for BSM to provide desirable sensitivity for BSM | • Investigate adaptations to current method for cemented materials that would make it suitable for BSM  
• Validate behaviour and classification with known field performance |
| Investigate conditioned beam testing to identify moisture sensitivity | Develop a protocol for beam production, conditioning and testing to classify moisture resistance of a cold mix | • Identify a standard beam production and conditioning protocol  
• Test a variety of BSM with strain-at-break, flexural stiffness and fatigue methods to determine moisture sensitivity  
• Validate results and classification with known field performance |
| Investigate the role of wheel tracking and scaled APT in benchmarking field performance in terms of moisture | Establish reliable relationships between the Erosion Test and field performance, and MMLS3 and field performance in terms of moisture damage | • Refine the correlations between Erosion Test and known field performance.  
• Establish an appropriate test protocol and relationships between MMLS3 and field moisture damage |

### Table 5. Tasks identified for durability testing with respect to ageing of binder

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<tr>
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<th>Sub-tasks</th>
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| Investigate binder ageing characteristics for emulsion and foamed bitumen mixes | To identify whether ageing of binder is a key consideration in performance analysis of BSM | • Identify appropriate road sections that have been in service for 5 to 15 years  
• Investigate differential ageing (if any) for emulsion and foamed mixes using recovered samples from road sites |
2. **SYNTHESIS**

The twelve tasks that comprise the Mix Design project of Phase II of the “Updating the Bituminous Stabilised Materials Guidelines” report, are incorporated in the appendices of this draft report. The purpose of this chapter is to summarise the pertinent outcomes of each of the dozen tasks individually and to provide a synthesis of the findings and recommendations, so that a coherent perspective can be obtained of the impact of the research on the proposed BSM mix design guidelines that will follow.

2.1. **Task 1: Standardising the Research Triaxial Protocol**

There are only two institutions that carry out triaxial testing as a (research) analytical tool for evaluation of BSM’s, namely Stellenbosch University (SU) and the Council for Scientific and Industrial Research (CSIR). A discussion forum between these two institutions was established as part of this task.

A proposal was put forward to standardise the three types of tri-axial testing, i.e. monotonic testing to obtain shear parameters, dynamic testing to obtain resilient modulus and dynamic testing (long duration) to obtain permanent deformation behaviour. In the draft test procedure, some references are made to the equipment and data acquisition system requirements.

A number of international standards on tri-axial testing have been scrutinised for useful features to incorporate in the new South African test procedure.

The effects of the type of confinement application, loading rate and temperature were not investigated under this task. A draft protocol for the “Determination of Shear Parameters, Resilient Modulus and Permanent Deformation Behaviour of Unbound and Bound Granular Materials Using Tri-Axial Testing on 150mm Ø x 300mm High Specimens” was compiled under this task by Ebels and Jenkins. More details are provided in Appendix A of this report.

Subsequent to the commencement of Task 1, discussion between the clients of this project and the project team led to the decision that the work under Task 1 of Phase II of “Updating the BSM Design Guidelines” would be completed under the SANRAL project “Updating the South African Pavement Design Method”. Nothing further will be reported on this task under the BSM project.

2.2. **Task 2: Development of Simple Triaxial Test**

The need for a more reliable testing procedure for the characterisation and QA/QC of BSMs, besides UCS and ITS testing, has long been recognised by the roads industry. In fact, at CAPSA 2004 and CAPSA 2007, discussions of improved test methods for granular materials i.e. possible replacement tests for CBR procedures, were conducted in workshops. Triaxial testing for the evaluation of shear parameters is widely recognised as a reliable method of measuring these critical performance properties of granular and bitumen stabilised materials. However, the triaxial test in its current state as a research test has little chance of extensive use by practitioners and commercial laboratories, because of complexity, cost and time issues. Major adaptations to the research triaxial test are necessary, therefore, if such a useful test can have a chance of being accepted by road practitioners.

The main aim of this task is to investigate possibilities of developing a simple, economical, reliable and robust test for characterizing granular and bitumen stabilized materials, with a link to performance. This is achieved through innovative design and manufacture of a prototype triaxial cell capable of accommodating 150 mm diameter by 300 mm deep specimens. The cell should be simpler than the research (geotechnical) triaxial cell and the operational protocols
need to be streamlined, thereby reducing the time and steps required in assembling specimens and testing them.

In order to ensure the development of an appropriate triaxial cell for industry, a survey was conducted aimed at investigating currently available facilities, testing capacity and resources within civil engineering laboratories in the South Africa. Findings from the survey (see Appendix B of this report) have provided guidance with regard to the nature and sophistication of any new tests to be developed. The survey highlighted some of the limitations and lack of sophistication of the current loading frames used for CBR and UCS testing i.e. lack of electronic LVDTs, limited overhead space, limited loading capacity etc. Most laboratories would need to invest in new loading facilities to carry out triaxials.

A review of the test procedure for monotonic triaxial test showed that two main factors contribute to the complexity of the research (geotechnical) triaxial cell namely time taken to assemble the specimen accurately in the cell and secondly the inherent design of the cell which makes it water and/or air tight at relatively high pressures.

The design of the Simple Triaxial Test therefore was aimed at overcoming the drawbacks of research triaxial test e.g. fitting a membrane to each specimen to be tested, through considerable simplification by means of a new structure design and procedure of assembly of specimen into the cell. The advantage of addressing these issues would be reduction in the number of steps required in the test procedure and therefore reduction in testing time. The design of the cell particularly was preceded by a conceptualization process (section 3.3) that involved investigation of numerous options. Concepts such as the bottle, encapsulated-tube, bottle and sandwich concepts were considered and given reality checks. In addition, currently available triaxial procedures of a similar nature e.g. Texas Triaxial, needed evaluation and analysis of pro’s and con’s.

Ultimately, with some trials and innovation, a design was developed for a simple triaxial cell comprising a steel casing with a latex tube glued to it which is then introduced around the specimen sitting on a base plate. It is based on the ‘tube concept’ in which the specimen acts like a ‘rim’ and the cell acts like a ‘tyre’ providing confinement to the triaxial specimens for testing, within the tube. This approach eliminates the use of O-rings and membranes for the specimen and tie-rods for the triaxial cell, thus reducing testing time considerably. The overall dimensions of the cell are 244mm diameter by 372mm height.

The cell is currently being manufactured. Thereafter monotonic triaxial tests are scheduled to be conducted using the simple triaxial cell; results obtained will be correlated through calibration and validation with those obtained using the research triaxial. The specimens to be tested in the triaxial set-up will be manufactured using the compaction technique developed in Task 12 of this study, see Appendix K.

2.3. Task 3: Correlation of BSM Stiffness: Part I (Existing Data)

The stiffness of an engineering material is an important material property that is widely used for the design of structures (including pavements) incorporating such materials. The stiffness (resilient modulus) of a material can accurately be measured in a short duration dynamic tri-axial test, but this requires sophisticated monitoring equipment such as LVDTs. This raised the question whether a simple and reliable alternative exists to provide fundamental stiffness properties that can be used as input in mix design testing and pavement design.

The objective of this task was therefore to gather data for several cold mixes from monotonic and dynamic tri-axial as well as flexural stiffness from Four Point Bending Test from various research institutes e.g. Su and the CSIR. The next step entailed correlation of resilient properties from the three tests taking account of the differences in loading rate, temperature, etc, comparison of stiffness values with representative mix stiffness for equivalent materials in field conditions and discernment of which method of testing is most reliable and whether a simple reliable alternative exists.
From the analysis in this task, the following conclusions were drawn:

- Data for BSMs is available from both Stellenbosch University and the CSIR. This includes information in the shear strength of the mixes, stiffness derived from the monotonic tri-axial test (tangent modulus), stiffness from the dynamic tri-axial test (resilient modulus) and flexural stiffness from the four-point beam test.

- The tangent modulus shows stress dependency, i.e., at higher confinement pressures higher tangent moduli are measured. The tangent modulus can also be used to rank different BSM mixes in a similar order as when the resilient modulus is used. The absolute value of the tangent modulus is however a factor of 10 lower than that of the resilient modulus.

- The tangent modulus and resilient modulus from the same mixes as tested at the CSIR show a good linear correlation, confirming the factor of 10 difference. This correlation is however based on limited data and average moduli. It is recommended that this correlation be extended with more available data.

- At this stage, it is however not recommended to use the tangent modulus alone to characterise stiffness of BSMs and one should be careful when ranking BSMs based on the tangent modulus.

- The flexural stiffness values of BSMs tested at the Stellenbosch University using the four-point beam apparatus fall within the range of resilient moduli of the same mixes determined using a tri-axial test. Although the mechanism of the tri-axial test and the four-point beam tests are different (hence the type of stiffness, i.e., compression vs. bending) the resilient modulus values may provide a rough estimate for the bending stiffness. The latter is normally used in structural design calculations.

- The monotonic tri-axial test is an easy to perform test, but the tangent modulus is less accurate and may show inconsistencies. The resilient modulus dynamic tri-axial test is an extremely difficult test to perform accurately, but the outcome is less variable and fairly reliable. The four-point beam test in itself is an easy to perform test, however, the beam specimen fabrication and preparation is a difficult process. In addition, the variation in the test results of the four-point beam test is generally high due to issues around specimen preparation and quality.

### 2.4. Task 4: Correlation of BSM Stiffness: Part II (Additional Tests)

Progress has been made with additional stiffness measurement of BSMs and their evaluation in the light of the findings of Task 3. This will be reported on in conjunction with the test results of the “Simple Triaxial Test”, once the latter become available in the following two months.

### 2.5. Task 5: Advanced BSM Classification System: Part I (Existing Data)

The General Permanent Deformation Law, as originally developed by Francken (1977) and as later adjusted by Huurman (1997), Jenkins (2000) and van Niekerk (2002) for unbound and bound granular materials, has been used in this task as a basis for the analysis of permanent deformation behaviour of BSM in the repeated load tri-axial test. Selected BSM mixes tested at the Stellenbosch University have been analysed to this extend. This includes determining the model parameter of the Permanent Deformation Law, as well as the stress dependency thereof. Templates showing the permanent deformation curves as a function of the stress ratio have also been developed, an example of which is shown in Figure 1.
The permanent deformation behaviour of BSM’s consists of three phases, i.e. a initial bedding-in phase, a stable secondary phase with steady accumulation of permanent strain and a tertiary flow phase with accelerating strain accumulation. The material may be considered to have failed if tertiary flow occurs. The tertiary flow phase is initiated by the flow point. This is defined as the number of load repetitions at which the rate of strain accumulation is minimal and after which the strain accumulation starts to accelerate again.

The occurrence of a flow point and tertiary flow depends on the level of applied stress. When the applied deviator stress ratio is low enough, tertiary flow does not occur and the permanent deformation of the mix remains stable. When the applied deviator stress ratio exceeds a certain critical ratio, tertiary flow does start to occur. Critical stress ratios for a number of selected BSM mixes have been determined. These vary, depending on the type of mix, from 0.30 to 0.60. When BSM’s are loaded in excess of a deviator stress ratio of 0.60, tertiary flow sets in almost immediately, i.e. within the first 10,000 load repetitions.

It has been identified that the permanent deformation behaviour of BSM’s are to a large extent determined by the Model Parameters A, B and D of the General Permanent Deformation Law. A good correlation appears to exist between the initial strain and initial strain rate as defined by Ebels and Jenkins (2007) and the Model Parameters A and B respectively. The values for the initial strain and initial strain rate can be obtained early on during the permanent deformation test (after 1,000 load repetitions). With some knowledge of Model Parameter D, the permanent deformation behaviour of the BSM can now be predicted. Model Parameter D is, to a large extent, related to the critical stress ratio.

A flow chart (see Figure 2) with most likely scenarios of permanent deformation behaviour depending on Model Parameters A, B and D has been developed. This could serve as the basis for classification of BSM material categories for as far as permanent deformation is concerned.
As can be seen, significant progress has been made with the advanced classification system of BSMs using the available data from current mix design testing as well as research testing. The new data has been processed and will be reported on once additional CSIR data is added to the database and reviewed in conjunction with the current data.

2.6. Task 6: Advanced BSM Classification System: Part II (Additional Tests)

Some of the additional dynamic triaxial tests for the advanced classification system of BSMs have been completed and the additional testing is underway. The additional tests will include variations in temperature, loading frequency, loading wave configuration and rest period. In addition, selected permanent deformation triaxials will be carried out with a variation in confining pressure. All of these triaxial results will be incorporated into the final report.

2.7. Task 7: Curing Protocol: Part I (Improvement)

The Inception Study of this project concluded that current methods of simulation of curing of BSMs are unsatisfactory due unrealistic simulation of filed conditions. Recent research publications have primarily focused on ways of refining and improving the curing protocols for individual types of BSMs for specific field conditions. Despite many concerted attempts, the focus has primarily been on either foamed or emulsion mixes, but rarely on developing a unified approach for both types of BSMs. This research project, possibly ambitiously, is aimed at developing a unified protocol for foamed and emulsion BSMs.
The curing improvement process has been shaped by laboratory investigations outlined in Task 7, to obtain a better understanding of what is achievable through laboratory curing, guided by field validation process described in Task 8. This in particular, triaxial sized specimens of 150mm diameter and 250mm to 300mm high needed to be the focus of the curing protocol.

**Foamed BSMs**

The first step of the curing investigation was focussed on the rate of curing under laboratory conditions. Laboratory tests show that foamed BSM briquettes, when compacted at 80% of OMC, reach an average of 50% of OMC after 10 – 15 hours of curing at both 30°C and 40°C when unsealed in a draft oven, see Figure 1. Results confirm that during the first 12 hours of curing, at both 30°C and 40°C unsealed cured specimens, treated with either cement, lime or without active filler, cure at a very similar same rate. Both temperature and active filler influences begin to play a role after 12 hours of curing.

Moreover, as would be expected, specimens cured at 30°C retain more moisture with time than specimens cured at 40°C. Overall, at the same curing temperatures, there appears to be little difference in moisture trends between active filler and non active filler treated samples.

In the case of foamed BSMs, observed trends may be attributed to the fact that curing is predominantly achieved by water repulsion rather than water consumption, so the inclusion of active filler does not significantly influence the process. This is also the case for emulsion BSMs.

| % OMC of Unsealed Foam Binder Briquettes versus Number of Curing Days at 30 and 40 Degrees |
|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| % OMC of Briquettes             | % OMC of Briquettes             | % OMC of Briquettes             | % OMC of Briquettes             |
| 1% Lime Briquettes: 40°C        | 1% Cement Briquettes: 40°C      | No Active Filler Briquettes: 40°C |
| 1% Lime Briquettes: 30°C        | 1% Cement Briquettes: 30°C      | No Active Filler Briquettes: 30°C |

![Figure 3](image3.png)

*Figure 3 N7 Graded crushed rock- Foamed BSM Moisture (% OMC) versus Laboratory Curing Time at 30°C (dashed lines) and 40°C (solid lines) - unsealed*

Due to similar moisture trends, stiffness trends were also comparable across the spectrum. Figure 4 illustrates the moisture content, shown as a percentage of OMC, versus Resilient Modulus for both curing of specimens at both 30°C and 40°C.
Due to rapid curing taking place at 40°C (unsealed), the rapid loss of moisture yields higher stiffness values with time. The most important observation in Figure 4 is that only when sufficient time and curing conditions to enable the moisture content to reduce to less than 30% of OMC, will BSM specimens incorporating active filler begin to outperform non active filler treated specimens, in terms of stiffness.

Draft Accelerated Laboratory Curing Protocol – Foamed BSMs

Moisture content values of 40% of OMC generally correspond to a maximum 3 day curing period out of the 7 days over which the laboratory stiffness were evaluated. Furthermore, the 40% of OMC or 3 day period yields approximately 60 to 80% of the final stiffness values of the laboratory trends. Consequently, the empirical approach seemed reasonable and consistent for both field and laboratory trends.

In order to achieve the 50 to 60% of OMC as the target, it is necessary to cure samples at 30°C (unsealed) for roughly 10-15 hours. This is subsequently followed by 2 days or 48 hours curing at 40°C (sealed). Final moistures of samples are then in the vicinity of 50 to 60 % of OMC. Any possible adjustments to the draft curing protocol for foamed BSMs that incorporate active fillers are currently being reviewed and will be reported on in the next 2 months.

Emulsion Mixes

Laboratory tests show that emulsion briquettes compacted at 80% of OMC reach an average of 50% of OMC after 20 to 24 hours of curing (unsealed) at 40°C and 30°C respectively, see Figure 5. Contrary to foamed BSMs, the emulsion BSMs’ results confirm that both 30°C and 40°C (unsealed) cured specimens treated with cement, lime or without active filler do not cure at the same rate from the onset. With emulsion BSMs therefore, both temperature and inclusion of active fillers plays a role in the early curing process i.e. immediately after compaction.
Generally, emulsion BSMs including lime lose moisture at a slower rate than emulsion BSMs with either cement and non active filler, for both 30ºC and 40ºC (unsealed) curing. Cement treated specimens lose moisture at a much more rapid rate.

Contrary to the behaviour of foamed BSMs, temperature has a profound impact on the rate of moisture loss of emulsion BSMs. Figure 5 shows that the average difference in final moisture content after a 7 day cure, shown as % of OMC, for temperatures of 30ºC and 40ºC curing, is in the order of 10%.

The influences of different active fillers on moisture trends can be clearly noted by the impact on stiffness performance of specimens in Figure 6. Although specimens cured at 40ºC lose moisture at a more rapid rate, the specimens cured at 30ºC yield higher stiffness values. Temperature effects on stiffness values associated with different active filler types yield complex behaviour in the case of emulsion BSMs.
Figure 6 N7 Graded crushed rock-Emulsion Mix Resilient Modulus versus Moisture Content (% of OMC) during 7 day Laboratory Curing (unsealed) at 30°C (dashed lines) and 40°C (solid lines).

Draft Accelerated Laboratory Curing Protocol - Emulsion Mixes

Moisture content values of 40% of OMC generally correspond to a maximum 3 day curing period out of the 7 days over which the laboratory stiffness were evaluated. Furthermore, the 40% of OMC or 3 day period yields approximately 60 to 80% of the final stiffness values of the laboratory trends. In order to achieve the 50 to 60% of OMC target, specimens need to be cured at 30°C (unsealed) for approximately 20 to 24 hours.

This is subsequently followed by 2 days or 48 hours curing at 40°C (sealed). Final moistures of samples are then in the vicinity of 50 to 60% of OMC, as in the case of foamed BSMs. Any possible adjustments to the draft curing protocol for foamed BSMs that incorporate active fillers are currently being reviewed and will be reported on in the next 2 months.

2.8. Task 8: Curing Protocol: Part II (Validation)

The validation of curing protocols in BSMs through the correlation and validation of trends in moisture and stiffness in the laboratory and the field, is considered to be vital to this project. Extremely limited research data is available in this field, so monitoring of a CIPR project in the Western Cape (N7) was incorporated into this project.

Field moisture monitoring was undertaken through physical sample extraction and moisture buttons installed in the emulsion BSM layer. In terms of trends in moisture content, as observed in Figure 8, the moisture content as a percentage of OMC begins at 58% to 80% of OMC during construction and reduces to 50 to 60% of OMC after 7 months of in-service traffic.
Using the field data, the laboratory moisture trends should target final moisture contents after accelerated curing of 55% of OMC i.e. the 50 to 60% of OMC range is applicable. To achieve this, initial compaction moisture in the laboratory should be maintained at the 75 to 80% of OMC to aim at representing field conditions.

In terms of field stiffness performance, the emulsion BSM with G2 aggregate and 1% of cement that was monitored, yielded an increase in the field stiffness of up to three times the initial value within 7 months of field curing, see Figure 9. The PSPA device (Portable Stiffness of Pavement Analyzer), which uses analysis of surface waves, was used to evaluate the field stiffness.

Due to conflicting methods of acquiring stiffness measurements in both field and laboratory environments, it was difficult to reconcile the laboratory and field stiffness values. The following limitations need to be considered:

- Field material characteristics versus laboratory prepared specimens
Method of stiffness measurements i.e. short-term dynamic loading analysis in the triaxial mode versus high frequency wave measurements in the field using the PSPA.

In order to reconcile field and laboratory stiffness data, investigation and analysis of historical field stiffness data on BSMs projects in South Africa is currently being investigated and will be addressed in the final report of this project.

Critical to Accelerated Laboratory Curing Protocol

Analysis that is currently in progress, indicates that field extracted cores of BSMs, tested in the laboratory, generally yield 75% of field stiffness-values analyzed using a PSPA. Following the trends of Figure 7, a value of 75% of final field stiffness i.e. 75% of 3000 MPa = 2250 MPa, after 7 months of field curing, could be expected from laboratory measurements on the same material using a dynamic triaxial test. On the time axis, 75% the final stiffness value corresponds to 85 days of field curing or roughly 40% of the 220 days i.e. effectively 3 months of field curing.

These ratios can be applied to the trends of the laboratory cured specimens over a 7 day period, as reported above. Implementation of the above empirical approach makes it possible to reconcile field and laboratory stiffness trends. In conclusion, if a 40 % time ratio is applied to the 7 days required in the laboratory to reach a plateau moisture content and stiffness, then 3 days of accelerated laboratory curing are required. This makes it possible to validate the accelerated laboratory curing protocol. Currently more data is being analysed to validate the values provided above.

2.9. Task 9: Moisture Sensitivity: Part I (Improvement)

Several procedures have been developed for the laboratory identification of BSMs mixes with unacceptable moisture sensitivity. Generally the moisture conditioning for mix assessment has been carried out using vacuum saturation of the compacted and cured specimen, in order to accelerate any possible moisture damage. The conditioned and unconditioned specimens are then compared in terms of retained strength e.g. TSR obtained after ITS, or from UCS or ITT tests. Although this method provides an empirical measure of moisture damage, it yields both variable and unreliable results. Task 9 presents the development of new laboratory-based representative testing procedure and analysis protocol for the evaluation of moisture damage which can be distinguished from current over-simplified procedure.

It is clear that simulations of moisture damage in a laboratory will always be an idealised representation of reality; nevertheless, a reliable, cost effective procedure is required to distinguish between research and classification (standard) testing for moisture susceptibility. Although the laboratory simulation cannot be an exact replication of mechanisms that manifest in service, it should represent the fundamental or key failure mechanism for the BSM mixes. A testing and evaluation framework based on the MIST (Moisture Induction Sensitivity Test) device for moisture conditioning and mechanical testing (short dynamic and static tests), is proposed for determining the level of moisture damage in the mixture. Different saturation levels are investigated with experimental determination of stiffness ratio (Mr) and Shear Parameters (C and ø) which are critical parameters for the performance of the BSM. Different types of aggregate blends, with and without RAP, with foamed bitumen or bitumen emulsion binders are being investigated. The rating of the severity of moisture induced damage in these mixtures, using the MIST test, is discussed and the results validated with accelerated pavement testing using a laboratory MMLS3 device. The influence and effect of the addition of active filler (cement or lime) into these mixes is also investigated.

From the preliminary results, it can be seen that the accelerated moisture induction process using MIST device shows potential for use as a tool to condition specimens for tests that will determine the relative moisture susceptibility of different stabilized materials. Mechanical testing at different saturation levels shows better ranking of mixture in term of moisture damage than for example a TSR test.
2.10. **Task 10: Moisture Sensitivity: Part II (Validation)**

Moisture is known to have a detrimental influence on BSM’s, both in terms of stiffness and strength of the material. In order to develop more reliable laboratory testing techniques, a more robust link between laboratory properties of the material and field performance needs to be established. Accelerated Pavement Testing (APT) with devices such as the MMLS3 can serve to provide that link.

Task 9 has outlined the development of the Moisture Induced Sensitivity Test (MIST) apparatus that has been developed for the conditioning of triaxial specimens for the evaluation of the resistance to moisture of these materials. The objective of Task 10, in short, is therefore to validate the findings of the moisture damage that has been observed through MIST conditioning. The setting for loading pulse duration and pressure of the MIST apparatus have been influenced by the load duration and stresses of the wheel loads applied to the materials by the MMLS3 APT device, so a rational analysis should be possible.

In terms of the APT validation tests, first of all a test protocol required development for BSMs with moisture conditioning. A procedure was developed using the MMLS3 whereby a row of 9 BSM (compacted and cured) specimens could be trafficked in a water bath i.e. under saturated conditions. As part of the initial tests carried out with the MMLS3, the BSM materials required some protection at the surface to prevent abrasion and ravelling of the material in contact with the wheel loads, which is not representative of layers of BSMs in the field that have a protective surfacing. This was successfully solved as part of the research project, with the use of a thin layer of vinite that does not reduce the stresses applied to the BSM, but prevents ravelling, see Appendix I.

Four materials have evaluated to date, namely:

1) 2% Emulsion and 0% Cement (accelerated lab curing)
2) 2% Emulsion and 1% Cement (accelerated lab curing)
3) 2% Foam Bitumen and 0% Cement (accelerated lab curing)
4) Emulsion with >9 months ambient curing in the laboratory

The following findings have emerged to date:

- All of the BSM specimens, with both foamed and emulsified binders, conditioned using accelerated curing procedures in the laboratory, failed before 1000 wheel load repetitions had been applied i.e. approximately 4mm of rutting occurred in the specimens.
- The specimens conditioned using accelerated laboratory curing procedures did not show any significant improvement in resistance to moisture damage from “wet” MMLS3 trafficking with the addition of cement.
- Extended ambient curing of an emulsion BSM i.e. a period of greater than 9 months, provided a significant improvement to moisture resistance. This mix withstood 100 000 “wet” MMLS3 wheel load repetitions with only negligible permanent deformation.
- Tensile Strength Retained (TSR) tests on unconditioned and conditioned BSM specimens for all four mixes provided results that did not correlate well with the MMLS3 test results. In particular, the emulsion BSM without cement (Mix 1 above) after accelerated curing, provided the highest TSR value, even higher than the long term cured emulsion BSM (Mix 4). Yet Mix 1 could not even withstand 1 000 MMLS3 “wet” axles, where Mix 4 withstood 100 000 “wet” MMLS3 axles. It would appear that TSR is not a sufficiently sensitive measure of the moisture resistance of BSMs.

Following the preliminary findings outlined above, more MMLS3 will be carried out as part of Task 10 in order to verify the moisture conditioning using the MIST device. These results will be included in the final report.
2.11. Task 11: Durability: Ageing of Bituminous Binder

The durability or resistance to ageing properties of the bitumen binder, is the key factor for the binder characterization in asphaltic mixes and hence pavement performance. Limited research in the past has indicated that BSMs appear to age significantly during in-service pavement life. This phenomenon has been of concern to the practitioners in terms of ensuring sound material durability and behaviour. Task 11 presents in depth studies on the ageing behaviour of bituminous stabilised materials in various pavements. The methodology describes the investigation of binder ageing potential of foamed bitumen and bitumen emulsion for short term (during production, mixing and compaction) and long term (during pavement in-service) period. As such, investigating the differential ageing (if any) for the foamed bitumen and bitumen emulsion assists in identifying possible procedures for incorporation into the mix design of BSMs.

Under real in-service conditions an asphalt pavement undergoes two distinct hardening phenomena. The first is short term hardening, which occurs during mix production and construction. Second hardening refers to in-situ field ageing over long time of in-service pavement.

The short term ageing has been investigated in this study using different types of bitumen from different refineries. The straight-run and foamed bitumen types were tested for their rheological properties i.e. viscosity, penetration and softening point with respect to time of circulation of bitumen in the laboratory foam plant (WBL10). The same rheological properties were performed on the residual bitumen from an emulsion (after evaporation of moisture). The long-term ageing was investigated from cores extracted from the pavement, after five to ten years of in-service conditions. The recovery of bitumen from the cores for both foamed bitumen and bitumen emulsion was done using Abson method according to ASTM D1856-95a.

The findings indicate that maintaining bitumen at elevated temperatures, in circulation in the laboratory plant, contributes significantly to the ageing of the binder. However the trend follows that of the age hardening of the base bitumen.

The research into this task has shown that ageing behaviour of the foamed bitumen and bitumen emulsion binders in BSMs requires considerations during mix design and long term performance. A reduction in penetration of on average of 10 to 30dmm and an increase in viscosity at 60°C to a stiffness that resists flow during in-service conditions, can significantly influence the mechanical properties of these mixes. The preliminary results have not yielded a clear trend on the age hardening between foamed bitumen mix and bitumen emulsion, however foamed bitumen appear to yield more severe age hardening than bitumen emulsion mixes for the BSMs incorporating RAP. The final report will incorporate guidelines for the possible ageing simulation of BSM binders and how effects such as the circulation of bitumen at elevated temperatures should be controlled in order to limit laboratory ageing of the foamed binder.

2.12. Task 12: Laboratory Compaction

There are currently well established compaction methods being used in laboratories globally to prepare specimens for material testing; however, none of these methods presents the exact repeatability and reproducibility, ease of execution or simulation and correlation to field compaction desired by engineers. The research presented in this task is aimed at the development of a new compaction method for bituminous stabilised materials (BSMs) i.e. with both foamed bitumen and emulsion binders, that would address the aforementioned factors, by making use of a vibratory hammer. Along with this, a new protocol was to be established.

The initial investigation incorporated research using a Kango 637® vibratory hammer. This specific vibratory hammer suffered damage to the gear box under the 20kg surcharge load during the research and replacement parts could not be acquired in South Africa, nor could a
replacement Kango hammer be purchased locally. Therefore a substitute hammer was purchased i.e. a Bosch GSH 11E®, for which back-up service and replacement parts are readily available throughout South Africa.

Significant progress had been made with the development of a laboratory compaction protocol for BSM’s using the Kango Hammer before the replacement of this hammer was necessary. The specifications showed the Bosch® hammer to be superior in terms of power, weight and other technical features, so comparative testing had to be carried out initially to allow for adaptation of the results achieved to that point.

Extensive experimentation was then carried out using various types of BSM’s i.e. both foamed BSM (using 80/100 penetration binder) and bitumen emulsion BSM (using 60/40 Stable Grade Anionic) treated material. The initial material used for the experimentation was a G2 quality graded crushed stone acquired from the Lafarge Tygerberg quarry. Additional material was also obtained from a recycling project taking place along the N7 near Cape Town; this N7 material was used to perform a correlation experiment so as to determine whether or not the compaction procedure developed on a clean granular material could be applied to material from the field.

The results of the experiments showed that the vibratory hammer is capable of producing samples for testing in the laboratory as well as providing a possible benchmark method for accurately controlling the quality of work on site i.e. field density control. In order to use the vibratory hammer as a benchmark method for site compaction, experiments regarding the moisture curve of material need to be carried out on a G4 and a G7 material using the specifications obtained from the G2 material compaction results. The vibratory compaction protocol includes a specification for the type of hammer, guide-frame, surcharge weight, compaction moisture and number of layers. Vibratory compaction can be used to prepare specimens of 150mm diameter and 300mm high for triaxial testing or 150mm diameter and 125mm high for laboratory testing.

Experimentation showed that the material properties prove to have an influence on the compactability of the material, as is to be expected. Although both materials were of a G2 quality, the fact that the material from the N7 recycling project had been milled out thus altering the grading, this had an effect on the compactability of the material. This result also showed that as opposed to using time to compact a layer, the layer thickness of the material should rather be the determining factor as to when the target dry density is obtained. Moisture also was found to be an important factor, showing that at higher moisture contents material becomes easier to compact. The results also showed that the variability of the vibratory hammer was well below the specified variability of 15%.

A recommended procedure for the compaction of BSMs was developed following the current results of the experiments, see Appendix K. This procedure incorporates:

- Compaction hammer and guiding framework specifications,
- Compaction mould specifications,
- Number of layers for compaction (depending on specimen height),
- BSM moisture content considerations,
- Compaction time per layer,
- Layer scarification requirements, and
- Other details.
3. **CLASSIFICATION OF BSMS**

3.1. **Background and Objective**

The objective of this section is to provide a method for the consistent assessment of BSM pavement materials using routine tests and indicators, as well as the new tests developed as part of this research project. The method was specifically developed for use as part of a knowledge-based design method for pavements that incorporate bitumen stabilized materials, which is described in detail in Jooste and Long (2007b). It should be noted, however, that the approach outlined in this document can be of use in any pavement rehabilitation context.

After analysis of a significant amount of test data available on BSMSs and taking cognisance of the BSMS structural design framework developed by Jooste and Long (2007a), it was decided that three different classes of BSMSs would suffice for structural design purposes, namely:

- **Class BSM1**: This material should be designed to have high shear strength, and would typically be used as a base layer for design traffic applications of more than 6 million equivalent standard axles (mesa). For this class of material, the source material would typically be a well graded crushed stone with limited amounts of reclaimed asphalt pavement (RAP).

- **Class BSM2**: This material should be designed to have moderately high shear strength, and would typically be used as a base layer for design traffic applications of less than 6 mesa. For this class of material, the source material would typically be a graded natural gravel or RAP.

- **Class BSM3**: This material will typically consist of soil-gravel or sand stabilized with higher bitumen contents. As a base layer, the material would only be suitable for design traffic applications of less than 1 mesa.

With this as a backdrop, a materials classification system, with tests and interpretation limits, is outlined in this section for implementation in the framework and method presented by Jooste and Long (2007a).

3.2. **Classification Indicators for the Untreated Component Material of BSM**

**Table 6: Interpretation of California Bearing Ratio (CBR)**

<table>
<thead>
<tr>
<th>Test Density</th>
<th>Soaked CBR (%)</th>
<th>Possible Design Equivalent Material Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>98 % Mod. AASHTO or In-Situ Density</td>
<td>&gt;80</td>
<td>BSM1</td>
</tr>
<tr>
<td>95 % Mod. AASHTO or In-Situ Density</td>
<td>25 to 79</td>
<td>BSM2</td>
</tr>
<tr>
<td>93 % Mod. AASHTO or In-Situ Density</td>
<td>15 to 24</td>
<td>BSM3</td>
</tr>
</tbody>
</table>

Note: Interpretation ranges are based on BSM1 = G1 to G4, BSM2 = G5 to G6 and BSM3 = G7

**Table 7: Interpretation of Percentage Passing 0.075 mm Sieve**

<table>
<thead>
<tr>
<th>Percentage Passing 0.075 mm Sieve</th>
<th>Possible Design Equivalent Material Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 to 10</td>
<td>BSM1</td>
</tr>
<tr>
<td>5 to 15</td>
<td>BSM2</td>
</tr>
<tr>
<td>5 to 20</td>
<td>BSM3</td>
</tr>
</tbody>
</table>
### Table 8: Interpretation of Relative Density

<table>
<thead>
<tr>
<th>Relative Density</th>
<th>Possible Design Equivalent Material Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥ 0.98</td>
<td>BSM1</td>
</tr>
<tr>
<td>0.94 to 0.979</td>
<td>BSM2</td>
</tr>
<tr>
<td>0.93 to 0.939</td>
<td>BSM3</td>
</tr>
</tbody>
</table>

### Table 9: Interpretation of DCP Penetration Rate

<table>
<thead>
<tr>
<th>Penetration Rate (mm/blow)</th>
<th>Possible Design Equivalent Material Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 3.69</td>
<td>BSM1</td>
</tr>
<tr>
<td>3.70 to 9.09</td>
<td>BSM2</td>
</tr>
<tr>
<td>9.1 to 13.99</td>
<td>BSM3</td>
</tr>
</tbody>
</table>

**Note:** To quantify a DCP refusal result, a penetration rate value of -1 is recommended to denote refusal.

### Table 10: Interpretation of FWD Backcalculated Stiffness

<table>
<thead>
<tr>
<th>Backcalculated Stiffness (MPa)</th>
<th>Possible Design Equivalent Material Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥ 300</td>
<td>BSM1</td>
</tr>
<tr>
<td>150 to 299</td>
<td>BSM2</td>
</tr>
<tr>
<td>100 to 149</td>
<td>BSM3</td>
</tr>
</tbody>
</table>

### Table 11: Rating of Visible Moisture

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Moisture Content Description</th>
<th>Moisture Content Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crushed Stone</td>
<td>Dry</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Slightly Moist</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Moist</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Very Moist</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Wet</td>
<td>5</td>
</tr>
<tr>
<td>Natural Gravel</td>
<td>Dry</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Slightly Moist</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Moist</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Very Moist</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Wet</td>
<td>10</td>
</tr>
<tr>
<td>Sand, Silty Sand, Silt, Clay</td>
<td>Dry</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Slightly Moist</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Moist</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Very Moist</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Wet</td>
<td>5</td>
</tr>
<tr>
<td>Sand, Silty Sand, Silt, Clay</td>
<td>Slightly Moist</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Very Moist</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Wet</td>
<td>8</td>
</tr>
</tbody>
</table>

**Note:** BSM1 = Ratings 1 to 4, BSM2 = Ratings 2 to 6 and BSM3 = Ratings 5 to 7

### Table 12: Rating of Plasticity Index

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Plasticity Index Measured on Fraction Passing 0.425 mm Sieve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crushed stone</td>
<td>&lt; 4 4 and 5 6 and 7 8 to 10 10 to 12 &gt; 12</td>
</tr>
<tr>
<td>Natural gravel</td>
<td>&lt; 5 6 and 8 10 to 12 &gt; 12</td>
</tr>
<tr>
<td>Gravel-silt</td>
<td>&lt; 11 11 or 12 13 to 15 &gt; 15</td>
</tr>
<tr>
<td>Sand, Silty Sand, Silt, Clay</td>
<td>&lt; 12 12 to 14 14 to 20 &gt; 20</td>
</tr>
<tr>
<td>PI Rating</td>
<td>1 2 3 4 5 6 7 8 9 10</td>
</tr>
</tbody>
</table>

**Note:** BSM1 = Ratings 1 to 4, BSM2 = Ratings 2 to 6 and BSM3 = Ratings 5 to 7

### Table 13: Rating of Relative Moisture Content

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Moisture Content as Percentage of Optimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crushed stone</td>
<td>&lt; 60 60 to 65 66 to 80 81 to 90 91 to 100 &gt; 100</td>
</tr>
<tr>
<td>Natural gravel</td>
<td>&lt; 65 65 to 70 71 to 80 81 to 100 &gt; 100</td>
</tr>
<tr>
<td>Gravel-silt</td>
<td>&lt; 85 80 to 89 91 to 100 &gt; 100</td>
</tr>
<tr>
<td>Sand, Silty Sand, Silt, Clay</td>
<td>&lt; 90 90 to 100 101 to 120 &gt; 120</td>
</tr>
<tr>
<td>Relative Moisture Rating</td>
<td>1 2 3 4 5 6 7 8 9 10</td>
</tr>
</tbody>
</table>

**Note:** BSM1 = Ratings 1 to 4, BSM2 = Ratings 2 to 6 and BSM3 = Ratings 5 to 7
Figure 10. Interpretation of Grading to Quantify Conformance to BSM Grading

Table 14: Rating of Grading Assessment

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Conformance to Grading Envelope</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS (use TRH 14 G1 to G3 Spec)</td>
<td>1 2 3 4</td>
</tr>
<tr>
<td>NG (use TRH 14 G4 Spec)</td>
<td>1 2 3 4</td>
</tr>
<tr>
<td>GS (use TRH 14 G4 Spec)</td>
<td>1 2 3 4</td>
</tr>
<tr>
<td>Grading Rating</td>
<td>1 2 3 4 5 6 7 8 9 10</td>
</tr>
</tbody>
</table>

Note: BSM1 = Ratings 1 to 4, BSM2 = Ratings 4 to 7 and BSM3 = Ratings 5 to 7

Table 15: Rating of Grading Modulus

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Grading Modulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gravel</td>
<td>2.6 to 2.0, 2.5 to 1.5, 2.7 to 1.2, &lt; 1.2</td>
</tr>
<tr>
<td>Gravel-Sand Blend</td>
<td>2.5 to 1.2, 2.7 to 0.75, 2.7 to 0.75, 2.7 to 0.75, &lt; 0.75</td>
</tr>
<tr>
<td>GM Rating</td>
<td>1 2 3 4 5 6 7 8 9 10</td>
</tr>
</tbody>
</table>

Note: BSM2 = Ratings 4 to 7 and BSM3 = Ratings 6 to 8

For the interpretation of Grading Modulus (GM), reference should be made to Jooste and Long (2007b).

Table 16: Rating of Aggregate Crushing Value (ACV)

<table>
<thead>
<tr>
<th>Material Type</th>
<th>ACV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crushed Stone</td>
<td>&lt;28, 28 or 29, &gt;30, &gt;30</td>
</tr>
<tr>
<td>Natural Gravel</td>
<td>&lt;29, 29 or 30, &gt;30</td>
</tr>
<tr>
<td>ACV Rating</td>
<td>1 2 3 4 5 6 7 8 9 10</td>
</tr>
</tbody>
</table>

Note: BSM1 = Ratings 1 to 4 and BSM2 = Ratings 3 to 6

Table 1: Rating of Number of Fractured Faces

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Number of Fractured Faces of +4.75 mm Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crushed Stone</td>
<td>All Faces, 2, 1, &lt;1</td>
</tr>
<tr>
<td>Natural Gravel</td>
<td>2, 1, &lt;1</td>
</tr>
<tr>
<td>Fractured Faces Rating</td>
<td>1 2 3 4 5 6 7 8 9 10</td>
</tr>
</tbody>
</table>

Note: BSM1 = Ratings 1 to 4 and BSM2 = Ratings 3 to 5

Table 17: Interpretation of Durability Mill Index

<table>
<thead>
<tr>
<th>DMI (%)</th>
<th>Possible Design Equivalent Material Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Values to be determined</td>
<td>BSM1</td>
</tr>
<tr>
<td>Values to be determined</td>
<td>BSM2</td>
</tr>
<tr>
<td>Values to be determined</td>
<td>BSM3</td>
</tr>
</tbody>
</table>
3.3. Classification from Shear Properties

Based on the “Simple Triaxial Test” that will become part of the mix design procedures for BSM, the classification of the BSMs according to shear properties as outlined below, will be followed.

<table>
<thead>
<tr>
<th>Friction Angle $\phi$ ($^\circ$)</th>
<th>Possible Design Equivalent Material Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\geq$ 40</td>
<td>BSM1</td>
</tr>
<tr>
<td>30 to 44</td>
<td>BSM2</td>
</tr>
<tr>
<td>27 to 40</td>
<td>BSM3</td>
</tr>
</tbody>
</table>

**Note:** The values for the limits are interim and currently under review

<table>
<thead>
<tr>
<th>Cohesion C (kPa)</th>
<th>Possible Design Equivalent Material Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\geq$ 150</td>
<td>BSM1</td>
</tr>
<tr>
<td>75 to 250</td>
<td>BSM2</td>
</tr>
<tr>
<td>50 to 175</td>
<td>BSM3</td>
</tr>
</tbody>
</table>

**Note:** The values for the limits are interim and currently under review

3.4. Classification from BSM Stiffness

Based on monotonic “Simple Triaxial Test” that will become part of the mix design procedures for BSM, the classification of the BSMs according to the $E_{\tan}$ stiffness as outlined below, will be used.

<table>
<thead>
<tr>
<th>$E_{\tan}$ (MPa)</th>
<th>Possible Design Equivalent Material Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\geq$ 300</td>
<td>BSM1</td>
</tr>
<tr>
<td>250 to 400</td>
<td>BSM2</td>
</tr>
<tr>
<td>100 to 300</td>
<td>BSM3</td>
</tr>
</tbody>
</table>

**Note:** The values for the limits are interim and currently under review

3.5. Classification from UCS and ITS Tests

Unconfined Compressive Strength (UCS) and Indirect Tensile Strength (ITS) values carried out on BSM specimens of 100mm or 150mm diameter, can be used in the classification method. In order to use these values, the standard curing procedures outlined in Task 7 and 8 need to be followed.

<table>
<thead>
<tr>
<th>ITS (kPa)</th>
<th>Possible Design Equivalent Material Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 to 600 (300 to 750)</td>
<td>BSM1</td>
</tr>
<tr>
<td>120 to 300 (200 to 450)</td>
<td>BSM2</td>
</tr>
<tr>
<td>75 to 200 (100 to 300)</td>
<td>BSM3</td>
</tr>
</tbody>
</table>

**Note:**
1. The values for the limits are interim and currently under review
2. The values in parenthesis are applicable to 100mm diameter specimens. The other values apply to 150mm diameter specimens
Table 22: Interpretation of Unconfined Compressive Strength (UCS) Tests

<table>
<thead>
<tr>
<th>UCS (kPa)</th>
<th>Possible Design Equivalent Material Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥ 1 200 (≥ 1 400)</td>
<td>BSM1</td>
</tr>
<tr>
<td>500 to 1 500 (550 to 1 600)</td>
<td>BSM2</td>
</tr>
<tr>
<td>400 to 1000 (450 to 1100)</td>
<td>BSM3</td>
</tr>
</tbody>
</table>

Note: 1. The values for the limits are interim and currently under review  
2. The values in parenthesis are applicable to 100mm diameter specimens. The other values apply to 150mm diameter specimens

3.6. Classification from Moisture Resistance Tests

In the new mix design procedures, it is envisaged that a Level 1 and Level 2 analysis. For less important projects i.e. where the design traffic does not exceed 1 mesa, then TSR testing can be used. For all other cases, moisture conditioning using the MIST apparatus followed by Simple Triaxial Testing, is required.

Table 23: Interpretation of Tensile Strength Retained (TSR) Results

<table>
<thead>
<tr>
<th>TSR (%)</th>
<th>Possible Design Equivalent Material Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥ 75</td>
<td>BSM1</td>
</tr>
<tr>
<td>≥ 60</td>
<td>BSM2</td>
</tr>
<tr>
<td>≥ 50</td>
<td>BSM3</td>
</tr>
</tbody>
</table>

Note: 1. The values for the limits are interim and currently under review

Table 24: Interpretation of Retained Cohesion (RC) Results from Simple Triaxial Tests after MIST conditioning

<table>
<thead>
<tr>
<th>RC (%)</th>
<th>Possible Design Equivalent Material Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Values to be determined</td>
<td>BSM1</td>
</tr>
<tr>
<td>Values to be determined</td>
<td>BSM2</td>
</tr>
<tr>
<td>Values to be determined</td>
<td>BSM3</td>
</tr>
</tbody>
</table>

Note: 1. The values for the limits are interim and currently under review

3.7. Classification according to RAP Component

Table 25: Interpretation of RAP Component in BSM Aggregate

<table>
<thead>
<tr>
<th>RAP (%)</th>
<th>Possible Design Equivalent Material Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 75</td>
<td>BSM1</td>
</tr>
<tr>
<td>&lt; 95</td>
<td>BSM2</td>
</tr>
<tr>
<td>-</td>
<td>BSM3</td>
</tr>
</tbody>
</table>

Note: 1. The values for the limits are interim and currently under review
4. CLOSING REMARKS

It is envisaged that the new mix design process for BSMs incorporating either foamed bitumen or emulsified bitumen binders, will adopt a Level 1 and Level 2 approach to determine the tests that are required. The general process will follow the steps outlined below:

**Level 1 Analysis (for all cases)**

- Granular Material Type Testing for Classification, see Section 3.2
- Determination of Maximum Dry Density and OMC using Mod.AASHTO and Vibratory Compaction
- Determination of Binder Type, Binder Content, Active Filler Type and Content using UCS or ITS
- Determination of TSR

**Level 2 Analysis (>1 mesa design traffic)**

- Aggregate (untreated) Durability Testing i.e. Durability Mill Index
- Simple Triaxial Testing (monotonic) on 150mm diameter x 300mm high specimens (vibratory compaction)
- Simple Triaxial Testing (monotonic) after MIST conditioning
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