Advanced Testing and Characterization of Bituminous Materials –
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Key characteristics of materials stabilised with foamed bitumen

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ABSTRACT: The first properly-engineered equipment for producing foamed bitumen was launched in Germany in 1996. Since then, foamed bitumen treatment has seen a remarkable increase in usage, worldwide. However, thirteen years later, there is much ignorance as to what a foamed bitumen treated material actually is, what it is not and, most importantly, the performance characteristics of such a material.

The way the bitumen disperses amongst the aggregate particles when treated at ambient temperatures dictates performance. Similar to a granular material that has been treated with bitumen emulsion, particle coating is confined to the smaller fractions leaving the larger ones untouched. Consequently, these materials are very different from conventional hot-mixed asphalt and cold mixes. Pavement layers constructed from bitumen stabilised materials therefore behave differently under applied loads.

The results of research carried out over the past decade, coupled with long-term pavement performance data are used to highlight the in-service behavioural characteristics of these materials and their failure mode. The development of design methodology (both mix- and pavement-design) is reviewed along with recent research programmes to obtain reliable indicators of performance. This includes the outline of a newly developed “intelligent Structural Number” approach to pavement design.

The publication on Bitumen Stabilised Materials that was recently released in South Africa is reviewed, focusing on material classification that is based on the characteristics of the pre-treated material, the inclusion of active filler and the type/application rate of bitumen used in the stabilisation process.

1 INTRODUCTION

A variety of in situ pavement materials have been successfully treated with bitumen emulsion for over thirty years, proving that such treatment is a cost-effective way of improving the strength, as well as reducing the detrimental effects of water. In addition, a pavement layer constructed from a bitumen stabilised material is relatively flexible compared to using cement to stabilise the same material. The inevitable shrinkage cracks associated with cement treatment are absent from a bitumen stabilised material. In South Africa, several pavements with bitumen treated base layers have provided service lives in excess of 20 years and are still performing well today (Long et al. 2007a).

There are currently two agents used for bitumen stabilisation, bitumen emulsion and foamed bitumen. One problem often experienced when stabilising in situ materials with bitumen emulsion, however, is material saturation during construction. Although most bitumen emulsions are comprised of 40% water suspending 60% bitumen droplets (by volume), they are 100% fluid. Applying 3% (by mass) of residual bitumen to achieve the required stabilisation implies that 5% fluid (bitumen emulsion) needs to be added to the material. Adding this amount of fluid to an in situ pavement material with a moisture content approaching the optimum is often sufficient to cause saturation, thereby preventing the material from being compacted. Pore pressures that develop when compaction energy is applied to the material cause instability (the well-known heaving phenomenon), making it impossible to construct a pavement layer. This phenomenon tends to limit the use of bitumen emulsions for stabilisation.

In the mid-1950s, foamed bitumen was identified as an alternative bitumen stabilising agent. One of the primary attractions of using foamed bitumen in place of emulsion was the elimination of the added water with the bitumen. Foamed bitumen and bitumen emulsion have one common characteristic: both reduce the viscosity of the bitumen, allowing it to be mixed with cold moist materials that are encountered when recycling an existing pavement. Early laboratory test results indicated that foamed bitumen offered similar performance benefits as those achieved with bitumen emulsion, but without the compulsory addition of unwanted fluid (Twagira et al. 2006). An additional attraction was the lower cost of the bitumen stabilising agent.

Unlike bitumen emulsion that is manufactured under factory conditions using expensive chemicals (emulsifiers), foamed bitumen is produced by injecting a small amount of water into Penetration-grade bitumen at elevated temperatures (>160°C). Since the foaming state is short-lived, the foamed bitumen has to be produced on site in a purpose-built spraybar immediately before stabilising. However, whether it is introduced in an emulsified or foaming state, the end product is a bitumen stabilised material with similar characteristics that are discussed in the following section.

2 CHARACTERISTICS OF BITUMEN STABILISED MATERIALS (BSMS)

Unlike hot-mix asphalt, a material stabilised with bitumen is not black in appearance and does not have a sticky feel. This is because the larger aggregate particles are not coated with bitumen. The bitumen disperses amongst the finest particles only when the temperature of the aggregate is at normal summer temperatures (15°C to 25°C). The reason for such dispersion is different for bitumen emulsion and foamed bitumen. Being charged, the bitumen droplets in an emulsion are drawn to the smaller particles that exhibit the maximum opposite charge. Tiny bitumen particles produced when the foam bubbles burst have only sufficient heat energy to warm tiny aggregate particles sufficiently to permit adhesion. The resulting mix sees the bitumen confined to the fines fraction, or the mortar between coarse particles, as shown by the black spots in Figure 1 (Wirtgen, 2004). The colour of the material therefore only darkens slightly after treatment.

Regardless of whether bitumen emulsion or foamed bitumen is used, small amounts of active filler (cement or lime) are normally added in conjunction. In addition to improving the retained strength under saturated conditions, such active filler assists in dispersing the foamed bitumen particles by increasing the fines fraction for foamed bitumen, whilst it assists in extracting the water phase from a bitumen emulsion, causing separation (break). Research has,

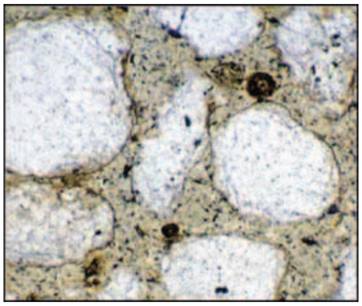

Figure 1. Bitumen dispersion.

however, shown that small amounts of active fillers (1% by mass of hydrated lime or cement) do more than assist the bitumen to disperse (foamed bitumen) or break out of the emulsified state. Adding or omitting the active filler can have a significant effect on the treated material's ability to maintain strength under saturated conditions (Jenkins et al. 2007).

2.1 *Primary characteristics*

BSMs are different from all other pavement materials, primarily due to the "spotty" nature of the bitumen dispersion that creates a non-continuously bound material. The following summarises the main features of these materials:

- the bitumen droplets are not joined to each other;
- when compacted, the cohesion of the material is increased by between 5 and 10 times without a significant reduction in the internal angle of friction;
- the material acquires significant flexural strength as a result of the visco-elastic properties of the dispersed bitumen;
- since the individual bitumen droplets are not interlinked and the coarser aggregate particles remain uncoated, the treated material reflects the granular characteristics of the untreated material. It is therefore stress dependent and not prone to cracking when subjected to tensile stresses (induced by applied or thermal forces);
- since the bitumen is dispersed only amongst the finer aggregate particles, they are encapsulated and immobilised. Such materials are not prone to pumping when load is applied under saturated conditions (Paige-Green et al. 2004 & Collings et al. 2008).

The effective stiffness of a layer of BSM in a pavement structure and its behaviour under load is a function of the parent material, the density of the material in the layer, the amount of bitumen added (and how well it is dispersed), active filler, temperature, moisture content and support characteristics (Asphalt Academy 2002 & Long et al. 2007b).

Although they are flexible and have a tensile strength, their mode of failure within a pavement structure as a consequence of repeated loading is permanent deformation. The shear properties of these materials are therefore of paramount importance.

BSMs are used for the construction of base or subbase layers. They are therefore always surfaced and protected from the direct effects of environmental and traffic forces. Under such conditions the bitumen droplets are protected from UV bombardment and the ageing effects of oxidation and high temperature. They can therefore be expected to retain their elastic properties for extended periods, especially the droplets located in the lower portion of thick layers where tensile stresses develop when the pavement structure is loaded.

2.2 *Fundamental performance properties of BSMs*

Structural design procedures anticipate fatigue cracking (bottom-up) as the failure mechanism for a continuously bound material (asphalt concrete and cement stabilised aggregates) caused by repeated load applications. Such repeated load applications cause unbound granular materials (graded crushed stone and natural gravels) to consolidate, or permanently deform as a consequence of the applied shear forces rearranging the individual particles relative to each other. When the confining pressures within the body of the material are insufficient to resist high levels of applied stress, lateral movement of the material occurs (shoving).

A non-continuously bound BSM behaves in a similar way to a granular material when subjected to load. However, it is the increase in cohesion as a result of the dispersed bitumen that allows these materials to withstand relatively high levels of stress before failing in shear and causing permanent deformation.

Recycled materials combine the influences of mineral aggregates, bituminous binders, active fillers and water to create complex visco-elasto-plastic material with anisotropic characteristics. The matrix of a BSM is "*neither fish nor fowl*" showing stress dependency similar to granular materials (see Figure 2) and dependency on frequency of loading similar to asphalt (see Figure 3).

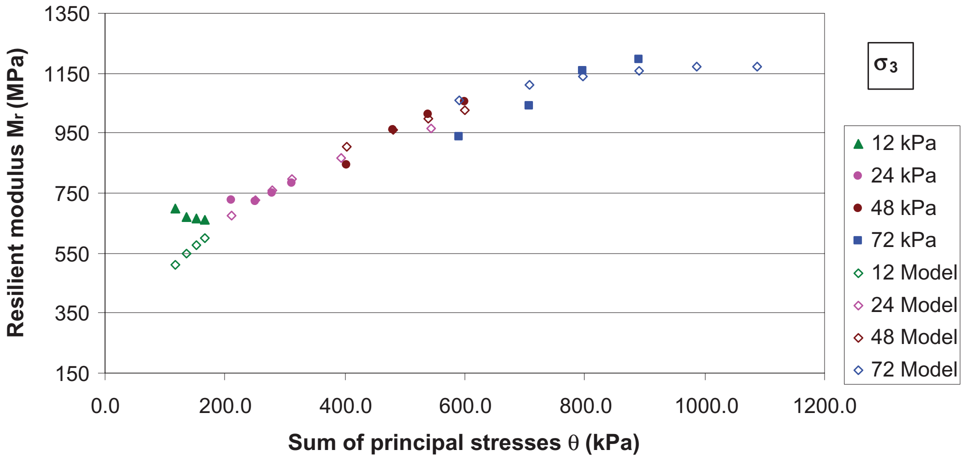

Figure 2. Resilient modulus of recycled mixed granulate with 2% foamed bitumen (Jenkins et al. 2002).

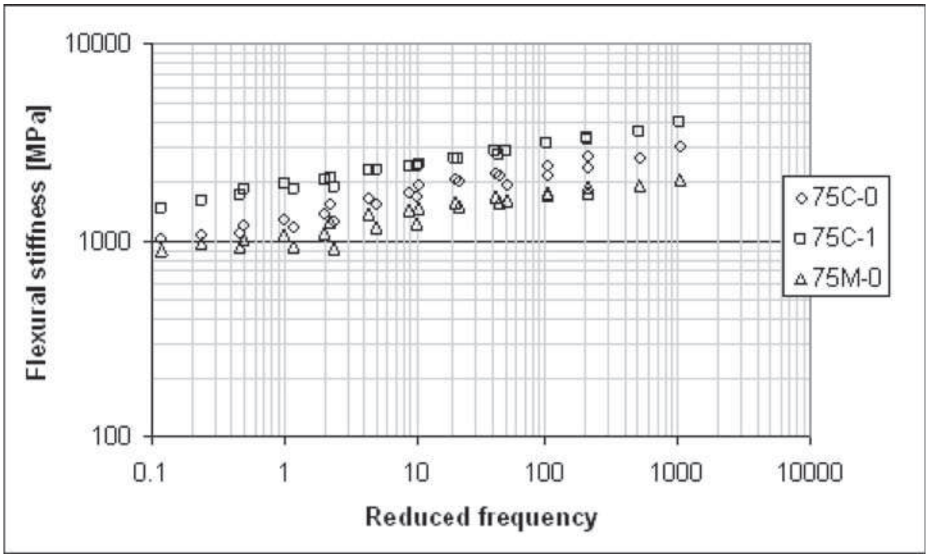

Figure 3. Flexural modulus of crushed limestone and RAP (reclaimed asphalt pavement) stabilised with emulsion, reference temperature 20ºc (Twagira et al. 2006).

Note: 75C-0 = 75% Crushed Limestone with 25% RAP, no cement.
75C-1 = 75% Crushed Limestone with 25% RAP, with 1% cement.
75M-0 = 75% RAP with 25% Crushed Limestone, no cement.

Gathering the available knowledge generated through research and laboratory testing begins to create a two dimensional matrix representing the link between material behaviour and the type and amount of binder, as shown in Figure 4. It assists in understanding the typical failure mechanisms of the cold recycled materials, including BSMs.

The modelling of BSMs needs to look beyond just the binders and must take cognisance of the moisture in the material. It is this added dimension that sets BSMs apart from HMA, and poses challenges for characterisation and design of cold recycled mixtures (BSMs). The initial knowledge gathered from laboratory testing and APT (Accelerated Pavement Testing) on

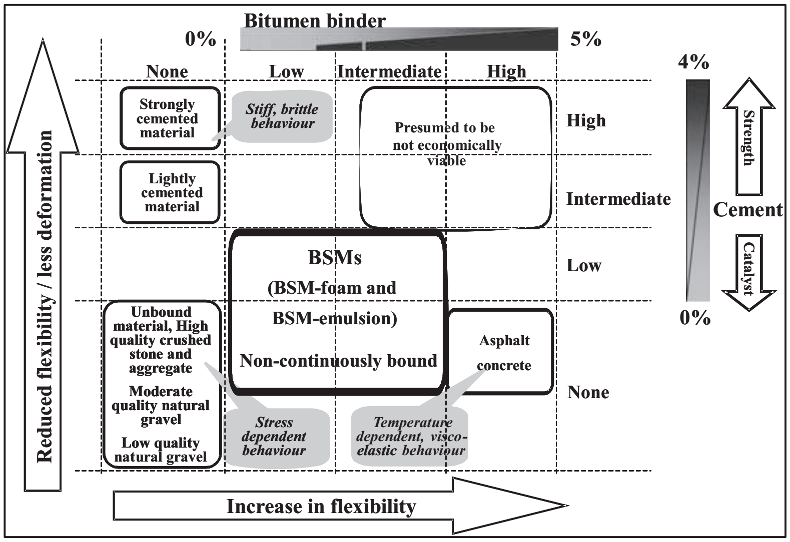

Figure 4. Matrix of bituminous and mineral binder influence on BSM behaviour after (Asphalt Academy, 2002).

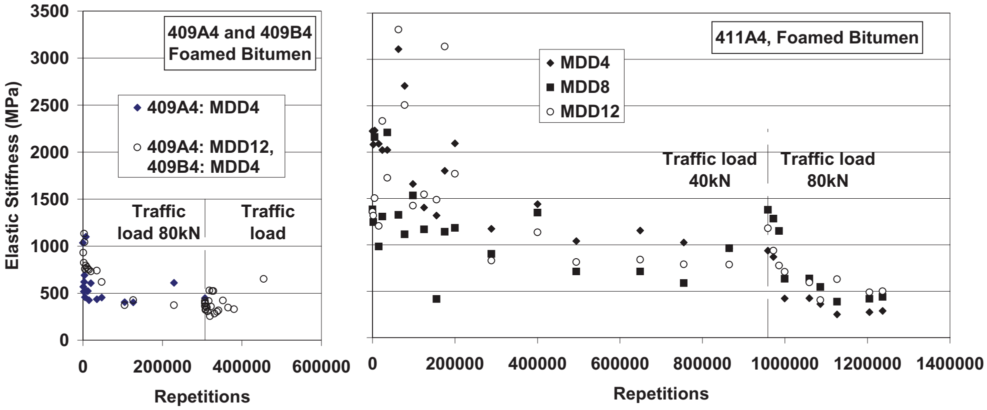

Figure 5. Change of resilient modulus of foamed BSM (2.3% Bitumen and 1% cement) with axle loading of heavy vehicle simulator (HVS) (Long et al. 2004).

BSMs pointed towards a reduction in stiffness of the material during short duration dynamic loading, as shown in Figure 5. However, numerous projects over the past 15 years have provided evidence of an increase in stiffness of the BSM layer with time, under traffic. An example is provided in Figure 6, where FWD deflection analyses on a Greek Highway recycled with foamed bitumen prior to the 2004 Athens Olympics, showed that the stiffness could continue to increase for up to 4 years after construction. Besides a small contribution from the cement, the predominant influence of stiffness accumulation is curing, i.e. moisture reduction in the BSM. This raises the question: how does one develop design tools to take account of the change in stiffness with time? This will be addressed under pavement design in Section 3.

In addition to understanding the behaviour of BSMs, is the need to develop the right tests to be able to critically analyse the mixes, specify them and carry out reliable quality control. The granular nature of BSMs with added bitumen of less than 4%, has led researchers to

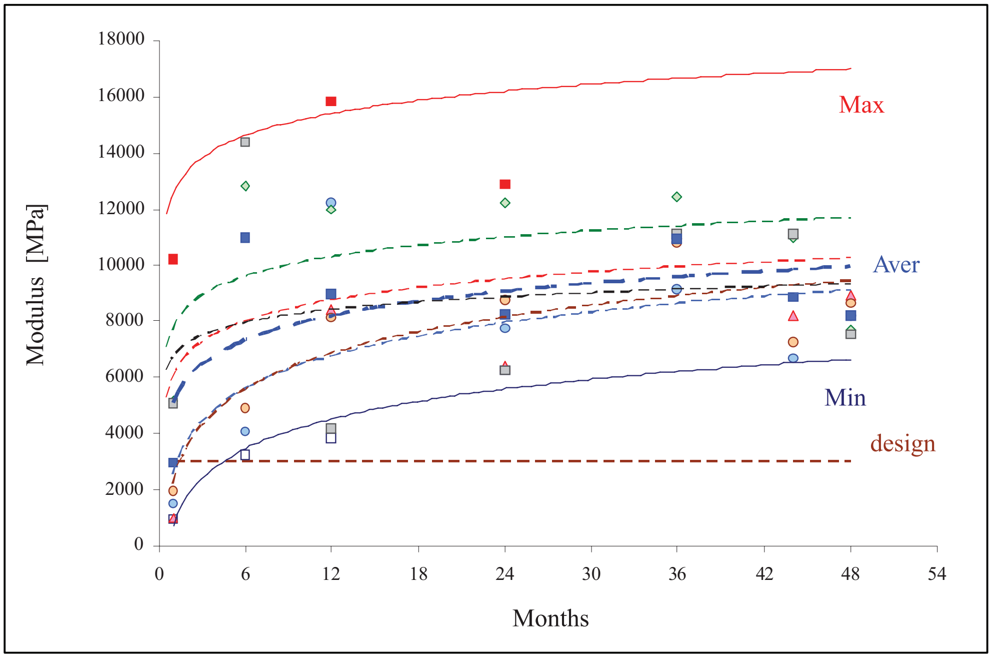

Figure 6. Evolution of resilient modulus from FWD back-analysis of foamed BSM (2.1% bitumen and 1% cement) on a Greek highway (Loizos et al. 2007).

use triaxial tests for the analysis of the shear parameters of the mixes and establish a link to performance. Back in 1974 (Shackel et al. 1974), triaxial tests were used to good effect to understand foamed BSMs. More recently, triaxial testing has become a standard testing procedure for analysing mix performance in terms of moisture sensitivity, durability and resistance to permanent deformation (Jenkins et al. 2008). In fact, the project to rewrite the South African Guidelines for BSMs (TG2) has undertaken 2 tasks under the mix design phase to improve the triaxial testing procedures:

- Task 1 includes the development of a standard research triaxial testing protocol so that research institutes in South Africa can provide interchangeable results.
- Task 2 focuses on the development of a "simple triaxial test" that would make this procedure more accessible to commercial laboratories.

The development of more appropriate triaxial testing procedures has created a need for improved laboratory compaction procedures of the specimens and accelerated curing protocols before testing. These issues, amongst others, are discussed in a separate paper at this conference.

Modelling of BSMs and in particular foamed BSMs, has reached the levels of sophistication where image analysis of Fracture Face Asphalt Coverage (FFAC) is being analysed and modelled at UC Davis (Fu et al. 2007) so that the imaging can provide insights into mix performance. This area is likely to develop further in the future.

3 STRUCTURAL CONTRIBUTION OF BSMS

Probably the greatest challenge in stabilising recycled materials in creating BSMs, is dealing with the variability. Jooste et al (2007) developed a classification system for pavement materials as part of the pavement design portion of TG2. This includes BSMs and takes account of relative certainty of test procedures and numbers of tests in a cumulative updating method.

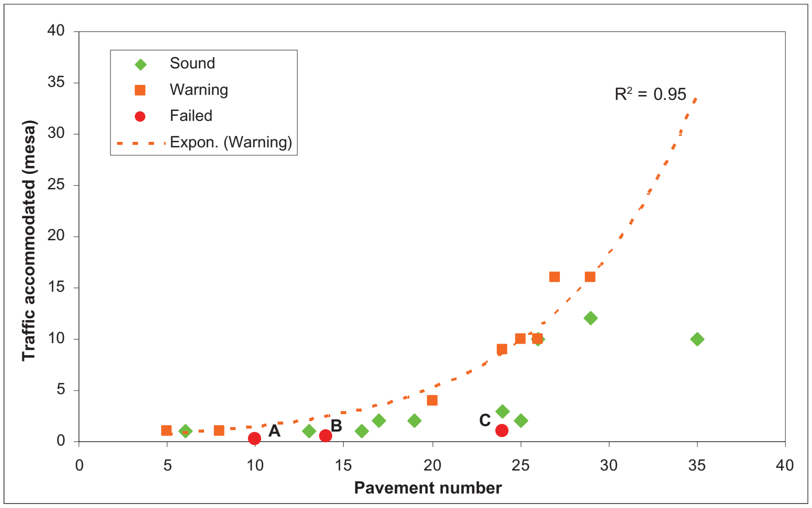

Figure 7. Pavement number design system based on a data set of 15 LTTP sections, and HVS sections with BSMs (Long et al. 2007b).

It provides an indication of the ultimate certainty of the classification of a material given all available information, which can be linked to a level of confidence. This method is discussed in a separate paper at the conference and highlights how the level of confidence in a material can be improved by increasing the number or quality of the classification tests.

The second major challenge associated with the design of pavements incorporating BSMs, is integrating the findings of laboratory, APT and LTPP data from research. As was noted with the stiffness versus time relationship of BSMs, the laboratory and APT trends are often divergent from the LTPP trends. Laboratory tests show that fatigue properties can be evaluated as a failure mechanism of these mixes; however, the increasing stiffness of the mix with time, as observed with LTPP sections, indicates to the contrary. Long et al (2007b) have developed a useful and realistic pavement design system (without a deformation or fatigue phase) using LTPP data collected from BSM pavements of more than 7 years old, based on information of the pavement condition. The system uses a Pavement Number approach, with some similarities to the AASHTO Structural Number, but incorporates modular ratio requirements and long term stiffness values linked to material classification, that ensures a realistic pavement balance. This is also discussed in a separate paper at the conference.

4 CLOSING REMARKS

In summary, BSMs possess some properties of granular materials and some of asphalt, namely stress-dependency and visco-elasticity respectively. Nevertheless, BSMs need to be prepared and analysed using test protocols that are suited to the specific behavioural characteristics of the materials.

In particular, the tests used in the mix design procedures for BSMs need to focus on the shear properties as a differentiator in the performance of these materials. Aspects such as laboratory-compaction and curing of specimens before testing require special attention. Research has shown the BSMs experience an increase in stiffness for several years after construction, and this phenomenon needs to be simulated in laboratory testing protocols.

Improved models for the structural design of BSM-foam and BSM-emulsion have been developed based on LTPP data. Pavements incorporating layers of BSM have sustained more than 30 million ESALs according to some of the data that has been collected. The structural design method uses an "intelligent structural number" type of approach, which includes modular ratios between layers to maintain a realistic pavement balance with regard to layer stiffness.

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