# A STUDY INTO THE MECHANICAL PROPERTIES OF FOAMED BITUMEN STABILISED MATERIALS

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## 1 INTRODUCTION

Foamed bituminous materials have been used to a limited extent on a global scale before the early 1990's when the lapse of the patent rights Mobil Oil Australia obtained in 1968 occurred. South Africa has also seen a number of projects involving foamed bituminous stabilisation being completed since 1994, with much success (Lewis, 1994).

The design of foam mixes have not received as much attention as Hot Mix Asphalt (HMA) and the approaches used by the various users of the product have been secretive over the years due to the patent rights. To be more specific, over the past 10 years the HMA mix design approach has shifted from the Marshall mix design to methods that focus on investigating the fundamental material properties and relates test values to performance. Compaction of HMA has been the focus of many studies and the concept of using a standardised compaction effort for the design of different mixes have become obsolete. With the renaissance in the use of foam mixes, comes a need to establish sound compaction guidelines.

Compaction methods used in the study were Marshall, Hugo, Kango, Superpave Gyratory compaction and a pedestrian roller. Marshall and Hugo compaction methods has have been used for a number of years in the design of HMA mixes in South Africa. The Kango hammer compaction method, involving the use of the Refusal Density equipment, was developed at the University of Nottingham (Brown et al, 1991). The Superpave Gyratory Compactor (SGC), one of the developments of the Strategic Highway Research Programme (SHRP), was used in this study (McGennis et al, 1995). Penetration grade bitumen used to produce foamed bitumen included 80/100 and 150/200 grades. Mechanical tests used in the project included the Indirect Tensile Strength Test (ITS), Indirect Tensile Test (ITT) and the Semi-Circular Bending (SCB) test.

## 2 BACKGROUND

A research program focussing on the mix design of cold mixes has been undertaken at the University of Stellenbosch. Cold mixes can be described as mixes where no heating of the aggregate and/or binder are necessary in the production of these mixes. This paper reports on a study into the suitability of four laboratory compaction methods for the mix design of foamed bituminous materials. The main objectives of the project were to determine and compare the influence of the different compaction methods on the volumetric and mechanical properties of foam bitumen mixes and make recommendations regarding the suitability of the different compaction methods for use in the mix design of foamed bitumen mixes.

The paper starts with a description of the experimental (laboratory) work, including the mix design, preliminary work, compaction, curing and mechanical testing. A layout of test results follows, with the discussion, conclusions, and recommendations concluding the paper.

## 3 EXPERIMENTAL WORK

Experimental work started off with the mix design. Compaction of slabs at the optimum binder content was the next step. The constructed slabs were cored and the volumetric properties determined, whereafter they were cured and mechanical tests performed. Preliminary compaction with each of the laboratory compaction methods followed with the purpose of determining the compaction effort to achieve laboratory compacted specimens with the candidate materials having volumetric properties equivalent to the slab cores. Final laboratory compaction was carried out based on the output of preliminary compaction. Curing and mechanical testing of specimens fabricated during the final laboratory compaction phase concluded the laboratory work. Figure 1 below outlines the overall test programme.

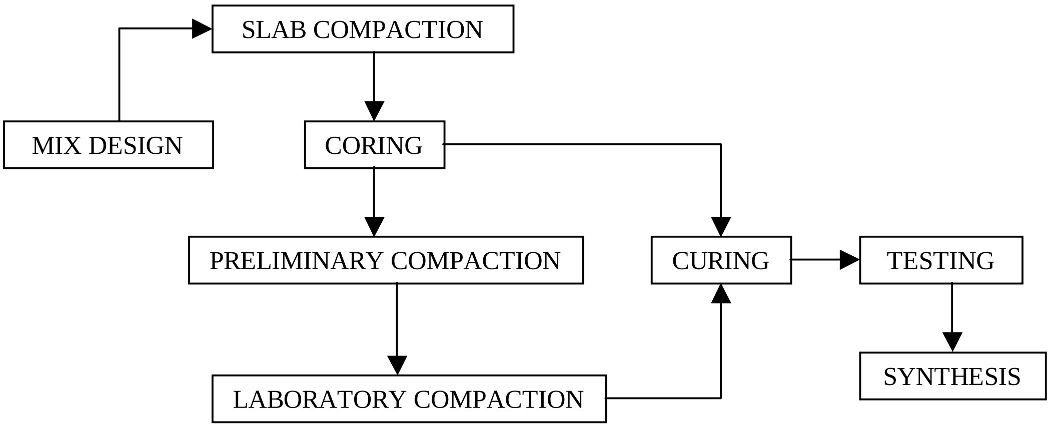


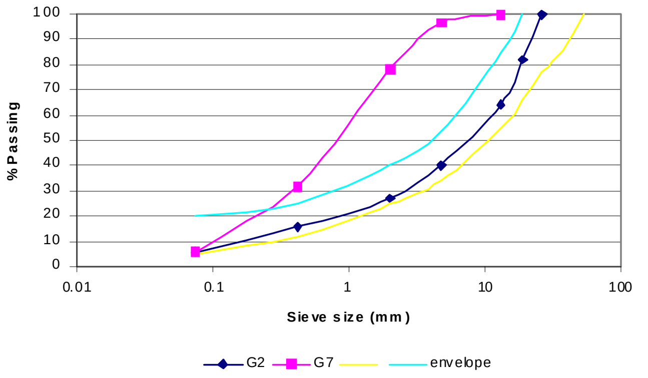
**Figure 1: Overall test programme**

### *3.1 Mix design*

The first step in the mix design process was to determine the material properties (in accordance with TMH 1) and assess whether the material was suitable for foamed bitumen stabilisation. Table 1 summarises the gradations and Table 2 shows the material properties as well as the guidelines applicable to foamed bitumen stabilisation. The G2 material (TRH14 classification) consisted of a blend of crushed Malmesbury Shale and natural sand and was supplied by a local aggregate supplier (CSRA, 1987). The G7 material consists of a blend of light grey brown, fine to coarse natural gravel, found in Sir Lowry’s Pass Village, and 10% Phillipi sand. The G7 material had to be modified by adding 3% filler and 1% cement (due to low CBR value) to satisfy the criteria of minimum filler content of 5%. The mix design procedure employed entailed compacting aggregate samples (75 blows/ side using 150mm diameter moulds) of the candidate specimens at varying foamed bitumen contents (1% to 5%) with a 10.438 kg Marshall Hamer. The optimum binder contents were determined by evaluating retained ITS strengths after doing soaked and un-soaked ITS tests, and the volumetric properties. It was decided to only use 150/200 bitumen and ignore the effect of binder type

### Table 1: Aggregate gradations

| Sieve Size (mm) | G2 % Passing | G7 % Passing |
|---|---|---|
| 26.5 | 100 | 100 |
| 19 | 82 | 100 |
| 13.2 | 64 | 100 |
| 4.75 | 40 | 96.8 |
| 2.0 | 27 | 78 |
| 0.425 | 16 | 32 |
| 0.075 | 6 | 6 |



### Table 2: Properties of parent materials

| Properties | G2 | G7 | Guidelines |
|---|---|---|---|
| Grading Modulus | 2.5 | 2.2 | 1.8 (min) |
| Optimum Moisture Content (%) | 6.1 | 7.0 | N/A |
| Maximum Dry Density (kg/m$^3$) | 2263 | 2118 | N/A |
| Fine fraction (<0.075) | 6 | 6 | 5% min |
| CBR @ 90% Mod | 91 | 12 | 20 (min) |
| Plasticity index | SP | NP | 10 max |

Caltex Refinery bitumen was used in the project. A Wirtgen® WLB10 foam plant was used. Optimum Half-life and Expansion Ratios were determined by injecting varying amounts of water into bitumen and measuring the aforementioned properties. Table 3 below summarises the optimum water content, as well as the Half-life and Expansion Ratio used for the two penetration-grade bitumen types.

### Table 3: Foamed bitumen characteristics

| Bitumen grade | Water content | Expansion Ratio | Half-life (seconds) |
|---|---|---|---|
| 150/200 | 2 | 13 | 15 |
| 80/100 | 2 | 12 | 14 |

Optimum foamed bitumen content for both the materials was determined at 3.5% after considering the volumetric properties and Indirect Tensile Strength (dry and soaked) test results.

## *3.2 Preliminary laboratory work*

Preliminary compaction was one of the cornerstones of the laboratory work, as well as the overall strategy of the project. This part of the project started with slab compaction, the results of which were used as a yardstick for final laboratory compaction. The main objective was to establish how many blows, gyrations or compaction time using a certain laboratory compaction method was necessary to obtain densities and voids equivalent to field compaction.

Square wooden frames being 850 x 750mm and 110mm deep were constructed and seated into the ground with the top of the frames being level with the natural ground level. The frames were secured by means of steel pegs as wedges. The material was mixed in predetermined batches in the laboratory, placed in the frames and compacted with a 750kg hydrostatic double drum vibrating roller after leveling off (Refer to Table 4 for the number of roller passes). Compacted slabs were left to cure for a period of 4-6 weeks before extraction by means of coring with a 150mm $\phi$ core drill. Figures 2 and 3 depict coring in process, a cored slab, and typical G2 cores. Cores were trimmed to the required thickness by means of a diamond saw blade and cured.

Figure 2: Coring in progress

**(a) G2 slab after coring** **(b) Typical G2 cores**

**Figure 3: Typical G2 cored slabs and cores**

The second part of the preliminary compaction comprised the determination of the compactive effort required by each of the compaction methods to obtain equivalent densities and voids to the compacted slabs. Compaction curves were constructed for each of the materials to depict densification during compaction with each of the laboratory during compaction methods. Densification during Superpave Gyratory compaction is automatically measured during compaction. An automated Marshall/Hugo compaction device which has a Linear Voltage Displacement Transducer (LVDT) incorporated to the top of the compaction hammer has been developed at the University of Stellenbosch. Figure 4 depicts a typical unedited compaction data for two faces of a Marshall/Hugo briquette. Compaction curves for Kango hammer compaction were developed by varying the compaction time between 30-120 seconds.

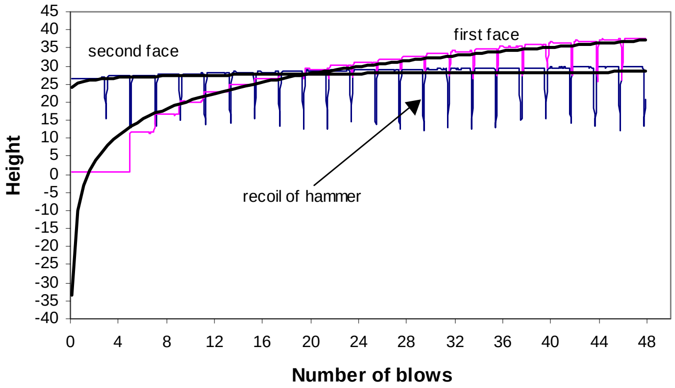


**Figure 4: Unedited compaction data for Marshall/Hugo briquette**

Table 4 summarise the details of each of the compaction methods used in the project.

**Table 4: Details of compaction methods**

| Method | Compaction Load | Compaction mechanism |
|---|---|---|
| Marshall | 10.438kg, height = 456 mm | Dropweight (impact) |
| Hugo | 10.438kg, height = 456 mm | Dropweight (impact, kneading) |
| Kango | 7.5 kg, 7mm | Vibration - frequency 45 Hz |
| Gyratory | 600 kPa | Kneading (gyratory) action, 30/minute |
| Slab | 750 kg | Vibration, static |

Compaction efforts during the preliminary and final compaction stages for each of the respective compaction methods are summarised in Table 5 below.

**Table 5: Compaction efforts**

| Compaction method | Preliminary compaction trial | | Final compaction | |
|---|---|---|---|---|
| | G2 | G7 | G2 | G7 |
| **Marshall** | 200 blows | 200 blows | 175 blows | 60 blows |
| **Hugo** | 200 blows | 200 blows | 150 blows | 50 blows |
| **Kango** | 30 – 120 seconds | 30 – 120 seconds | 45 seconds | 30 seconds |
| **Gyratory** | 200 gyrations | 200 gyrations | 30 Gyrations | 5 Gyrations |
| **Slab** | N/A | N/A | 20 passes | 16 passes |

Samples for the determination of actual binder contents were sent to an industrial laboratory. Actual foamed bitumen contents varied between 3.0% and 3.8%. A particular problem encountered was that the G2 specimens collapsed during trimming with the diamond blade saw for SCB tests. Partial coating of large aggregates and low binder contents may be the main causes for this collapse.

Marshall, Hugo and Slab G2 with 80/100 grade binder were rejected after it became known that the binder supplied did not conform to the SABS specifications applicable to 80/100 bitumen. Due to time constraints, it was decided not to include the 80/100 test results in the paper. Therefore, the variance due to binder type was only considered for the G7 material.

### *3.3 Curing*

Curing can be simply defined as the process during which cold mixes develop strength through evaporation, particle charge repulsion or pore pressure induced flow paths (Jenkins, 2000). The appropriate curing technique for foam mixes has not been developed as yet and has been the topic of much discussion over the years. The approach followed in the curing process was not to obtain strengths representing specific curing periods in the field, but rather to be consistent in the treatment of all specimens. The curing technique used in this study comprised the placement of specimens in sealed containers in a draft oven for three days at 40°C.

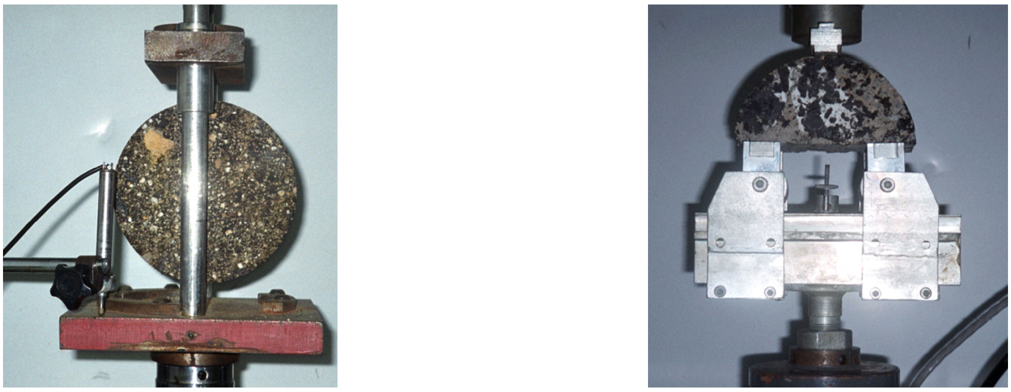
Slabs were cored after an average period of about 4 weeks. Cores were cured immediately after removal from the slabs. Average slab moisture contents at coring were determined by oven drying moisture samples (as per TMH1 method) taken from slabs after coring. Laboratory compacted specimens were allowed to lose moisture at ambient temperature for about two(2) days to reach equivalent moisture levels as the slabs, before they were cured. The effect of the different air temperatures and humidity to which the slabs were exposed outside the building could not be simulated in the laboratory.

### 3.4 *Mechanical testing*

Mechanical testing was undertaken in the servo-hydraulic Materials Testing System (MTS) at the University of Stellenbosch. The MTS is able to provide a compressive load of approximately 10 tons. Test conditions for the respective tests are summarised in Table 6 below. Figure 5 depicts ITS and SCB test setup and the formulae used are summarised in Table 7.

**Table 6: Mechanical properties and test conditions**

| Test | Mechanical property | Load/temperature setting |
|---|---|---|
| ITS | Tensile strength | 50mm/minute at 25° C, displacement controlled |
| ITT | Stiffness (resilient modulus) | 30% maximum ITS load at 25° C, haversine signal, 10 Hz, 80 precondition cycles |
| SCB | Tensile strength | 20mm/ minute at 25° C |



**(a) ITS test setup** **( b) SCB test setup**

**Figure 5: ITS and SCB test setup**

ITS and ITT testing has been used extensively in South Africa. Krans et al (1996) reported on the background of the SCB test.

**Table 7: Formulas applicable to tests**

| ITS | ITT | SCB |
|---|---|---|
| Formula:<br>$\sigma_t = \dfrac{2 \cdot P}{\pi \cdot t \cdot D}$<br>where :<br>P = maximum load at failure<br>$\sigma_t$ = maximum tensile stress<br>t = thickness of specimen<br>D = diameter of specimen | Formula:<br>$M_r = \dfrac{3.59 \cdot P}{\Delta V}$<br>where:<br>$M_r$ = resilient modulus<br>P = applied load (N)<br>$\Delta V$ = vertical displacement (mm)<br>**(the formula is derived by elimination of the horizontal deformation**) | Formula:<br>$\sigma_x = \dfrac{4.263 \cdot P}{D}$<br>where:<br>$\sigma_x$ = maximum tensile stress (kPa)<br>P = maximum failure load per specimen thickness<br>D = diameter of specimen |

## 4 TEST RESULTS

### 4.1 *Volumetric properties*

Table 8 and 9 below summarise the number of specimens compacted and volumetric properties respectively.

Table 8: Compaction matrix showing the number of specimens compacted

| Compaction method | G2 | G7 | |
|---|---|---|---|
| | 150/200 | 80/100 | 150/200 |
| **Marshall** | 14 | 15 | 15 |
| **Hugo** | 14 | 14 | 15 |
| **Kango** | 13 | 15 | 14 |
| **Gyratory** | 15 | 15 | 15 |
| **Slab (cores)** | 9 | 13 | 13 |

Table 9: Volumetric properties

| Compaction method | Bulk Relative Densites | | | Voids content (%) | | |
|---|---|---|---|---|---|---|
| | G2 | G7 | | G2 | G7 | |
| | 80/100 | 80/100 | 150/200 | 80/100 | 80/100 | 150/200 |
| **Marshall** | 2.248 | 2.042 | 2.080 | 17.7 | 17.8 | 16.3 |
| **Hugo** | 2.263 | 2.017 | 2.065 | 12.1 | 18.8 | 16.9 |
| **Kango** | 2.249 | 2.036 | 2.051 | 12.7 | 18.1 | 17.5 |
| **Gyratory** | 2.219 | 2.073 | 2.037 | 13.8 | 16.6 | 18.0 |
| **Slab** | 2.284 | 2.010 | 1.997 | 11.3 | 19.1 | 19.7 |

Figures 6 and 7 depict the average values for the volumetric properties. All of the laboratory compaction techniques provided higher air voids than the field compaction with the pedestrian roller.

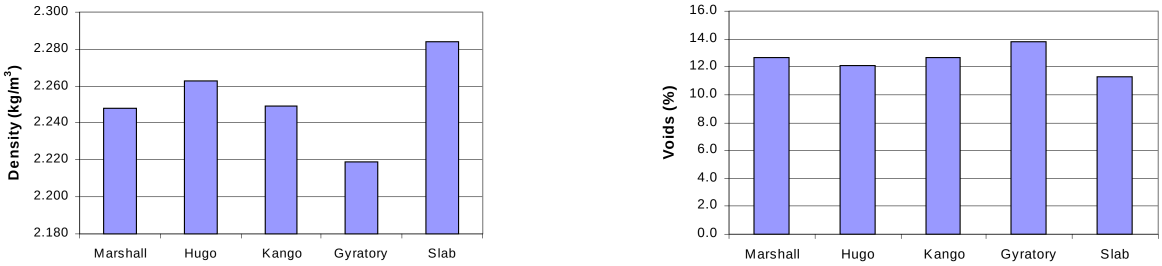


Figure 6: G2 150/200 density and voids (averages)

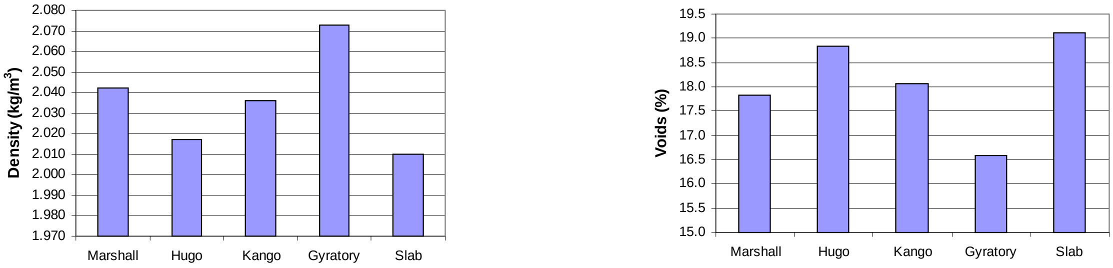


Figure 7: G7 80/100 densities and voids (averages)

Overall G2 material Bulk Relative densities varied by a maximum value of 1.4%. Maximum and minimum voids contents recorded were 11.3% and 12.75 respectively. Overall G7 material densities had a greater variation, some 6.5% maximum. Void contents ranged between 16.3% and 19.7%.

## *4.2 Mechanical test results*

Figures 8 – 13 below depict the mechanical test results.

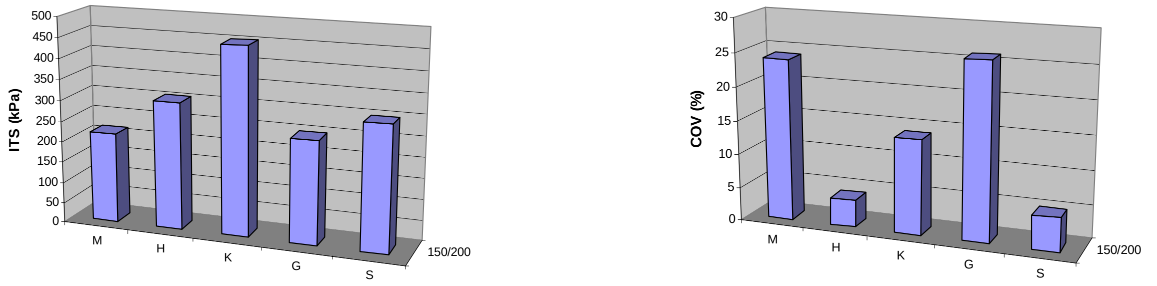


**Figure 8: G2 ITS and COV values**

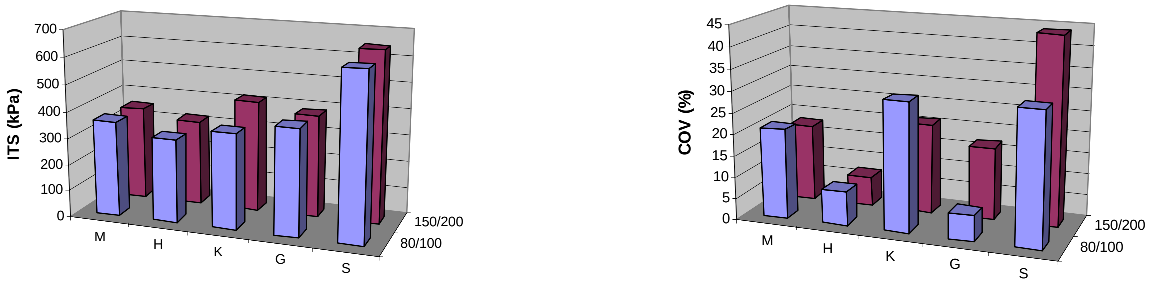


**Figure 9: G7 ITS and COV values**

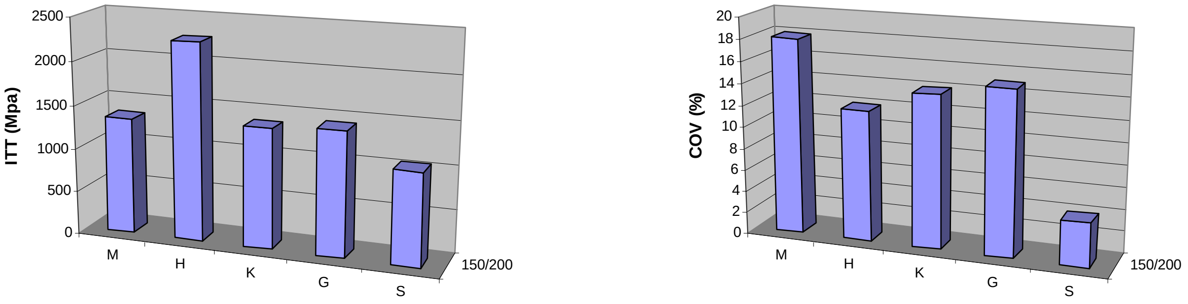


**Figure 10: G2 ITT and COV values**

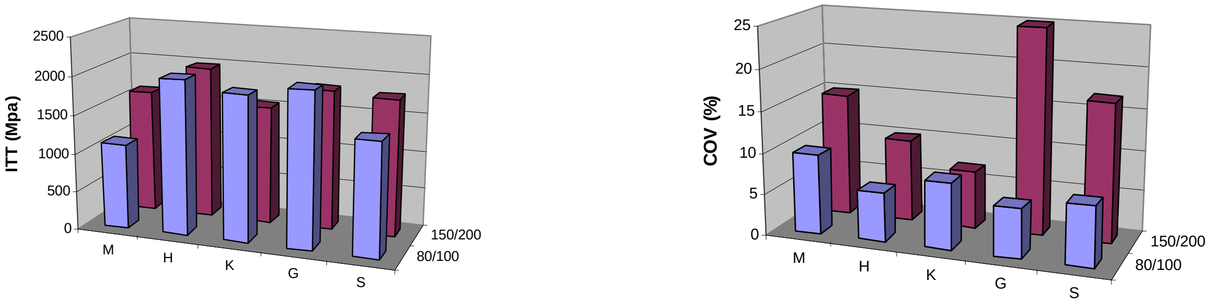


**Figure 11: G7 ITT and COV values**

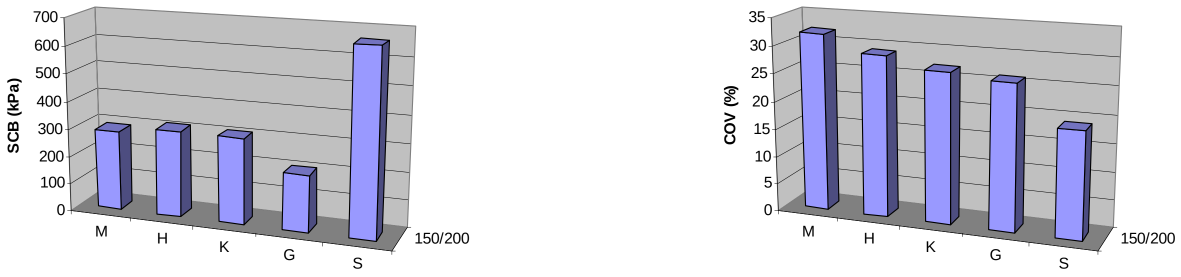


Figure 12: G2 SCB and COV values

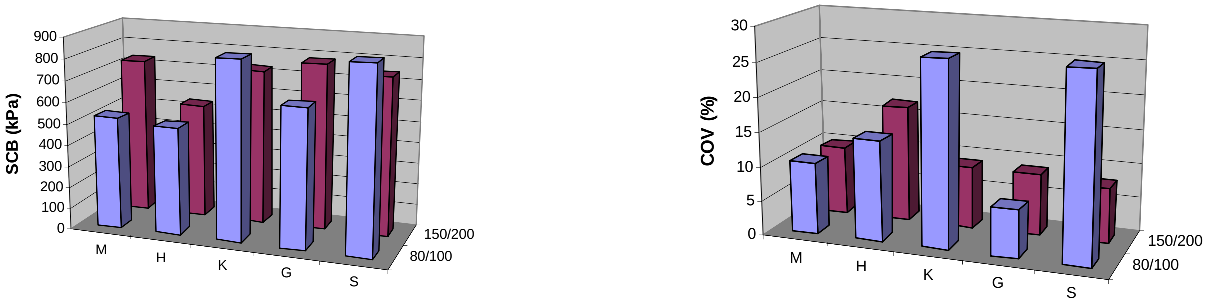


Figure 13: G7 SCB and COV values

## Discussion

Except for Kango values being much higher than the rest (Figure 8), G2 material ITS values ranged between 200 kPa and 450 kPa. The influence of the cement in the G7 material was indicated by the high tensile strength and stiffness values. Overall variations recorded had a minimum and maximum value of 4% and 26% respectively. Variations for Marshall and Gyratory compaction results were the highest overall. Slab ITS values were the highest for the G7 material. The rest of the values ranged between 250 and 400 kPa. Also, the highest (44%) and lowest (4%) variations were recorded for slab ITS strengths. These high variations can be ascribed due to an outlier being recorded with the 150/200 results and only a few tests being done.

Figure 10 indicates that Hugo G2 material compaction had the highest ITT stiffness values. COV values ranged between 3% (min) and 17%(max). Apart from the Marshall G7 material (80/100 bitumen), the rest of the G7 stiffness values ranged between 1400 and 2100 MPa with variations up to a maximum of 24%.

G2 material SCB results were in the same region as the ITS values. The ratio between SCB and ITS strength values for HMA is generally 2.5:1. Lower values can be ascribed due to the brittleness of the material as the binder content (average 3.5%) of the specimens was lower than the general >4% used in HMA mixes. High variability in G2 material results is an indication of the unsuitable semi-circular specimens. Partial coating of the large aggregates may also be a factor.

In contrast to G2 material specimens, the G7 material briquettes stayed intact during halving. G7 material SCB results recorded were much higher than the ITS values (approximately 2×ITS). SCB values ranged between 500 and 800kPa. Variations for Slab and Kango results were the highest with both being 27%. The rest of the variations had a maximum and minimum value of 17% and 7% respectively.

# 5 SYNTHESIS

## 5.1 *ANOVA*

An analysis of variance was carried out to establish whether significant differences existed between the volumetric and mechanical properties of the materials under consideration. Sources of variation were either binder type or compaction method.

A statistic, indicating the significance of mix variables at the 95% confidence level (0.05) was calculated. A null hypothesis that a mix variable did not have a significant influence on the mechanical properties was considered. If the probability of this null was very small, the conclusion was that the mix variable has a significant effect. Table 10 summarises the ANOVA results.

**Table 10: Summary of ANOVA results**

| Material | Source of Variation | Volumetric properties | | Mechanical properties | | |
|---|---|---|---|---|---|---|
| | | Density | Voids | ITS | ITT | SCB |
| **G2** | Comp. method | No | No | Yes | Yes | Yes |
| **G7** | Comp. method | No | No | Yes | No | No |
| **G7** | Binder type | No | No | No | No | No |

## 5.2 *Compaction energy analysis*

Part of the investigation was to compare the energies required by each of the methods to obtain equivalent level of compaction. Research has shown that whilst two compaction methods may be able to produce equivalent compaction levels, the mechanical properties may differ. Compactive efforts and energy are shown in Table 11 and Figure 14 below.

**Table 11: Compactive efforts and energy**

| Compaction method | G2 | | G7 | |
|---|---|---|---|---|
| | Compactive effort | Energy (kJ) | Compactive effort | Energy (kJ) |
| Marshall | 175 blows | 7.8 | 60 blows | 2.7 |
| Hugo | 150 blows | 6.7 | 50 blows | 2.2 |
| Kango | 45 seconds | 1.1 | 30 seconds | 0.7 |
| Gyratory | 30 gyrations | 2.4 | 5 gyrations | 0.4 |
| Roller | 20 passes | 4.3 | 16 passes | 3.5 |

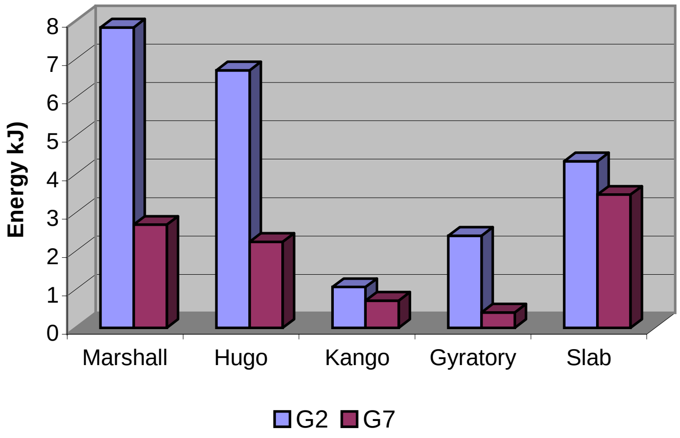


**Figure 14: Compaction energy applied**

## 6 CONCLUSIONS and RECOMMENDATIONS

### *6.1 Conclusions*

Based on the findings of this investigation, the following conclusions can be drawn:

- The type of binder used seems to have no significant effect on the mechanical properties of foamed bituminous material.
- Compaction method has a significant influence on ITS and ITT test results.
- SCB test results are not sensitive to compaction method.
- The SCB test should not be considered for mixes with low binder contents as sawing of the specimens results in spalling.
- No specific trends were visible for all mechanical test results recorded, which may be an indication of poor repeatability. The influence of compaction method and bitumen penetration grade was also not clearly visible from the results.

### *6.2 Recommendations*

The investigation was limited to only two material types and a limited number of tests were on. The recommendations are therefore focused on future work.

- All the laboratory compaction methods were able to produce specimens with volumetric properties comparable to field simulated compaction. More insight into the mechanical properties is needed. A database of the influence of the compaction methods on mix properties needs to be established to extend this work to other materials.
- The SCB test is currently only carried out at the University of Stellenbosch and should be investigated for inclusion in the design of foam mixes with binder contents higher than 4.5%.
- The possibility of incorporating robust test methods in the design of foamed bituminous mixes. The brittle nature of foamed bitumen stabilized materials, especially at low binder contents calls for test methods, which do not necessitate the gluing of strain gauges to specimens.
- Factors like aggregate temperature and curing did not receive attention. More work is needed in these areas.
- A simplistic analysis of the compactive effort for the different compaction methods to achieve the same density and voids was done in this study.
- The Kango hammer could be a useful tool in the compaction of foamed bituminous material and shows potential to be used on site. However, manual operation of the hammer induces human error.
- Standardisation by means of automating the compaction method would reduce the human factor. Energy applied during Kango compaction needs to be assessed in more detail.

## 7 ACKNOWLEDGEMENTS

The work on which this paper is based forms part of a post graduate study towards an M. Tech Degree at Peninsula Technikon. The authors wish to thank the following people and companies: J Muller, University of Stellenbosch (Soils and Water Engineering Laboratory), Institute for Transport Technology, Mr. A de Fortier Smit, Colas South (Pty) Ltd and La Farge.

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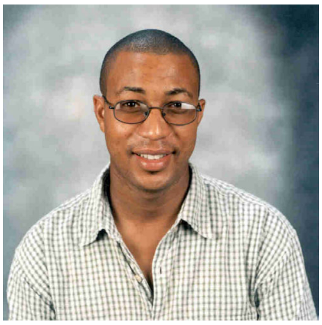
## CURRICULUM VITAE



| | |
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Carl Weston has experience in water engineering, construction entailing municipal services. He was involved in various research projects entailing asphalt, compaction of asphalt, Stone Mastic Asphalt, foamed bitumen and accelerated pavement testing at the Institute for Transport Technology at the University of Stellenbosch. He further did rehabilitation designs for a number of roads, involving Dynamic Cone Penetrometer and Failing Weight Deflectometer measurements. His experience covers testing of pavement materials, rehabilitation designs for roads, cost analysis for rehabilitation projects, seals design and supervision of road projects.

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