THE USE OF RIGDEN VOIDS AND VARIATIONS OF THE RING AND BALL TEST TO DETERMINE THE EFFECT OF FILLER SIZED MATERIAL IN SAND EMULSION MIXES

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Abstract

Soil treated with emulsion (STE) experimental road sections were constructed in Mozambique. The good performance of hot sand asphalt constructed in the 1960s and 1970s in Mozambique prompted renewed interest in this type of asphaltic material by emulating it with a cold process, emulsion treatment. Bitumen emulsion was added to the windblown type sand to emulate the original hot sand asphalt mixes. The characteristics of the filler sized material (smaller than 75μm) in the soil were identified as having a significant influence on the performance of the hot sand or soil asphalt pavements in the past. A parallel laboratory study was launched to quantify the influence of the filler sized material in the STE mixes. The Ring and Ball test and a variation thereof, The Wilhelmi variation, were found to be the most distinguishing test in this regard in combination with the Rigden voids of the filler sized material in the filler binder mastic.

1 INTRODUCTION

Normally good quality rock or gravel quality materials are sourced for pavement layers in road building. In large areas of Southern Africa soil and sand is the only available road building material. Even though such sand does not meet normal road building material standards, as described in TRH14 (CSRA, 1985), the challenge for the road designer and constructor is to make optimum use of such available materials.

In Mozambique and Zimbabwe (formally Northern Rhodesia) considerable success was achieved with the use of sand in surfaced road construction (Mitchell, 1959 and Silva, 1959). Hot sand asphalt road construction was used up to the early 1970s in Mozambique before the War of Independence and subsequent civil war (van Wijk and Carvalho, 2003). During these war periods and associated civil unrest, road infrastructure experienced considerable deterioration due to neglect and destruction. The collective knowledge on the use and construction of sand asphalt also virtually disappeared due to the associated social upheaval and migration of the Portuguese back to Portugal. The alternative of using cement or lime stabilisation in these regions has proven to be costly due to the high cement content requirement and recent associated failures. Research on the use of cement stabilisation has also been ongoing in Mozambique, associated with accelerated pavement testing. (Hugo et al, 2008)

Recently a renewed interest was shown by road authorities in Mozambique for hot sand asphalt, due to the good performance of these roads and the continued scarcity of other good road building material. However, the focus now was to try to construct this sand asphalt layer by means of a cold process which is more people friendly and therefore with a high labour intensive potential and resultantly high job creation potential, whilst also providing durable surfaced roads (van Wijk and Cavelho, 2002, Hartman et al, 2005 and Guiamba, 2010)

A project involving machine intensive and labour-intensive construction of soil treated with emulsion (STE), was initiated to act as demonstration of this cold sand asphalt construction at Marracuene close to Maputo (Hartman et al, 2005). STE is often also referred to as Bitumen Sand Mixes (BSM). These various BSM or STE experimental sections were monitored by means of various innovative field testing equipment (Guiamba et al, 2010). The original hot sand asphalt mix was emulated by the addition of emulsion and no other stabilisers or active fillers in the cold asphalt mix with sand as aggregate.

This STE mix is different from a gravel emulsified mix (GEM) or emulsion treated base (ETB) used and developed in South Africa (Liebenberg, 2004; Theyse, 1998 and SABITA, 1999) in that the GEM and

ETB mixes are normally associated with the addition of small percentages of either lime or cement (about 1%) (SABITA, 1993, 1996 and 2009). Such ETB or GEM materials are normally designed to meet indirect tensile strength (ITS) and unconfined compressive strength (UCS) test criteria which are dependent on the cement and lime presence in the mixes (Liebenberg, 2004). However, in the case of the STE mixes strength is dependant mainly on the bitumen binder and the sand characteristics.

The filler sized material (minus 75 micron) in the original hot sand asphalt was identified as an important material structural component linked to the good performance (Silva, 1959) of the hot sand asphalt pavements. The focus of this research therefore was to find a way to quantify the role that this filler portion has on the strength of the STE mix. A literature survey indicated that Rigden voids could be a useful and practical basis for the quantification of the filler sized material in the STE mix. A suite of tests were identified for this more detailed laboratory investigation on the specific sand and STE mixes from Maraccuene (in Mozambique), using standard laboratory tests such as penetration, viscosity, ductility, ring and ball and Wilhelmi Ring and Ball measurements of the mastic of filler and binder variations.

2 SAND ASPHALT MIXES

A literature review on hot sand asphalt use in Southern Africa revealed that the minus 75µm (filler portion) of sand plays a significant role in the behaviour and good performance of the hot sand asphalt layer (Silva, 1959 and Mitchell, 1959). It was also determined that a filler percentage around 15% gives good sand asphalt behaviour in performance evaluations. Different binder mixing-in technologies were used with success in practice in the past. These included:

- hot sand asphalt (van Wijk and Carvelho, 2002),
- cold binder (cutbacks and low viscosity tars) mixes with sand/soil (van der Merwe, 1959; Mitchell, 1959 and Viljoen, 1979),
- foamed sand asphalt (Acott and Myburgh, 1983; Viljoen, 1979; Jenkins et al, 1999a,b &c; Marais, 1965 and Joubert et al, 1989) and
- emulsion sand asphalt (Hartman et all, 2005 and Viljoen, 1979).

A lot of detail is available on all these technologies, but this investigation focused on the use of soil/sand treated with emulsion (STE) based on the good performance of hot sand asphalt previously constructed in Mozambique. As mentioned before experimental sections using STE mixes were constructed by machine and by labour-intensive methods at Marracuene, close to Maputo, Mozambique, and various field tests done on the constructed road (Guiamba et al, 2010). Hartman *et* *al* (2005) described the typical sand properties for the Marracuene STE road sections as shown in Table 4.

Table 4: Typical properties of Marracuene sand used for low-volume roads constructed with soil treated with emulsion (STE) (Source: Hartman *et al*, 2005).

Pavement layer	**Property**	**Range of Values**
Base	Maximum dry density (kg/m^3)	1912-1999
	Optimum moisture content (%)	5.3 – 7.8
	PI	Non plastic
	% passing 75µm	8 – 14.4
In situ	Maximum dry density (kg/m^3)	1743 – 1998
	Optimum moisture content (%)	8.2 – 11.9
	PI	Non plastic
	% passing 0.075mm	3.7 – 31.8

3 LABORATORY TESTS

3.1 Soil/sand classification tests

Gradings were done on the Marracuene sand samples supplied. A more detailed grading of the filler sized material was done by means of the hydrometer apparatus as well as with an ultrasonic apparatus. These two test methods determined that the average percentage passing the 75µm was 16%, with the majority of the filler material size being between 75µm to 50µm. This average size is the same as the mean particle sizes determined by Cooley et al (1998) from a selection of filler material used in asphalt hot mixes in the USA.

A number of standard classification tests were done on the Marracuene sand/soil. The results from these tests concluded:

- Colour: The sand had a reddish colour. Also known as a type Berea red sand in SA.
- Plasticity: The plasticity index (PI) was found to be non-plastic
- Sand Equivalent: The sand equivalent value (SE) determined was 32.
- Shape: A shape factor (SF) of 1.0856 was determined using an electron microscope.
- Fineness: A fineness modulus (FM) of 0.96 was determined.

Generic sand/soil selection criteria proposed by Theyse and Horak (1987), are shown in Table 5 for successful application in sand/soil asphalt mixes in the Southern African region. The Marracuene sand can be classified as good and a suitable sand for sand asphalt mixes when compared to these criteria.

Table 5 Guidelines for soil selection for use in sand/soil asphalt mixes (Theyse and Horak, 1987)

	Classification		
Criteria	**Good**	**Fair**	**Poor**
% Passing 75µm sieve	3-20	20-30	>30
Sand equivalent	>25	15-25	<15
Plasticity index	<5	5-7	>7

3.2 Rigden void determination

The effects of varying the filler size and quantity on hot mix asphalt are known to influence the behaviour of the hot asphalt mixes (NAPA, 1999). It can stiffen the mix; extend the binder mastic, alter the moisture resistance of the mix; affect the aging characteristics of the mix; and influence the workability and compaction characteristics of the hot asphalt mix (Anderson, 1987). The Rigden voids test is recommended by Anderson (1987) and NAPA (1999) to help quantify the filler binder mastic characteristics.

The Ridgen voids (Rigden, 1947) of filler from the Maraccuene sand were assessed using a modified Rigden voids procedure (Anderson, 1987). Rigden voids (RV), and the percentage Rigden voids (% RV) were determined. The average Rigden void volume was calculated as 45% of bulk volume. In the Rigden voids calculations volumetric ratios are used. In order to convert this volumetric ratios to mass ratios, the specific gravity of the binder and the filler material were used. The specific gravity of the Marracuene sand filler was determined as 2.5886 and the specific gravity of the bitumen binder was 1.025.

3.3 Filler/binder mastic ratios used

NAPA (1999) and Anderson (1987) determined a 60% filler volume versus Rigden voids values as reference line for evaluation of filler asphalt stiffness for constructability. This value was determined to be of value for the evaluation of the binder fines mastic to show actual stiffness behavior that can be assumed to allow for a stiff sand asphalt mixture. A sensitivity investigation around this reference value was therefore done on the Marracuene sand filler to emulate such final stiffness values in the road. The filler volume of the Marracuene sand was varied with 25% up and down from this suggested 60% reference value. These volume based ratios and converted mass ratios are all listed in Table 6. A second set of values were added by variation of 10% filler around 60% to fill in the sensitivity analysis from the extreme of 25% variation, as presented in Table 6. Therefore five filler to bitumen ratios were used in the preparation of the various tests on the mastic as shown in Table 6.

Incidentally Jenkins *et al* (1999) presented three f/b ratios by mass (2.2/1, 1.2/1, and 0.6/1) as a possible limit range of filler to bitumen proportion in the mortar or mastic. As stated before, Anderson (1987) recommended that the percentage of free binder in the mastic should be maintained at 40% or more, while NAPA (1999) stated that the bulk volume filler should be equal to or less than 60%. This should result in hot mix asphalt without excessive stiffness and brittleness. NAPA (1999) and Anderson(1987) recommended a maximum filler/binder (f/b) ratio of 1.2 to 1.5 based on mass.

Table 6. Filler/binder ratios converted from volume to mass.

%$V_{\text{bulk filler}}$ [V_{db}]	**%$V_{\text{free bitumen}}$ [V_{bf}]**	**%$V_{\text{solid filler}}$ [V_{ds}]**	**%V_{bitumen} [V_b]**	**f/b ratio by volume**	**%Filler by mass**	**% Bitumen by mass**	**f/b ratio by mass**
85	15	47	53	0.88/1	69	31	2.2/1
70	30	38	62	0.63/1	61	39	1.6/1
60	40	33	67	0.49/1	55	45	1.2/1
50	50	27	73	0.38/1	49	51	1.0/1
35	65	19	81	0.24/1	38	62	0.60/1

The STE construction process is a cold process in which bitumen binder is added to the soil in an emulsified form. Once the emulsion has broken and the mix fully cured, it is only bitumen binder that remains in the sand asphalt mix. Therefore the end result should be the same as for hot sand asphalt. The original binder used in the manufacturing of the emulsion used on the Marracuene site was an 80/100 penetration binder (Hartman et al, 2005). The laboratory tests with the filler mastic were not made up with binder in the emulsified form, but rather with the original binder. Test procedures do not allow for emulsions being used. Therefore, by using the original binder instead, the end result of the mastic and binder in the mix (once the emulsion has broken) are comparable.

In order to determine the possible influence of the binder hardness on the engineering properties of the f/b mastic samples, three different binder hardness's were used to cover the spread from a "hard to a soft" binder used in practice in SA:

- 40/50 penetration
- 80/100 penetration
- 150/200 penetration

4. MASTIC TESTS AND DISCUSSION

The test results from available tests which can accommodate the stiffening behaviour of the filler binder mastic are discussed here. The most suitable test apparatus available were identified as the Brookfield viscometer, Ring and Ball test and modified Ring and Ball (Wilhelmi) tests. However normal penetration and ductility tests were also done and are reported here as they are also standard tests available assumed to indicate stiffness changes with filler binder ratios variance.

4.1. Brookfield viscosity

The increase in filler content leads to a stiffening of the mastic. In order to quantify this, a stiffening ratio was determined by using the Brookfield viscometer at varying f/b (mass) ratios.

This stiffening ratio (SR) is defined as: $SR=(\mu-\mu_o)/\mu_o = \Delta\mu/\mu_o$. Where:

- μ_o= viscosity of original binder [mPas];
- μ=Viscosity of mastic at a given f/b ratio [mPas]; and
- $\Delta\mu$= difference in viscosity between that of the mastic at a given f/b ratio and original binder.

The Brookfield viscosity apparatus was obviously not designed for testing mastic, but it was nevertheless used to measure the mastic viscosity at 60°C, 135°C and 175°C. During the tests, the readings tended to fluctuate a lot. This variability is assumed to be related to the heterogeneity of the mastic. The Brookfields viscosity measurements became increasingly erratic as the f/b ratio increased and became undeterminable at the higher ends of f/b ratios. This phenomenon was most notable at the lower test temperatures (60°C).

For all the tests there was an increase of stiffening ratio with the increase of f/b ratio. This increase could be expressed as an exponential function $y=a*e^{bx}$. The stiffening ratio for the 135°C versus the variance in f/b (mass), is shown in Figure 1 to illustrate such relations obtained. It is significant that the stiffening ratio increases exponentially from an f/b ratio of 1.2 and upwards. This tends to tie in with the criteria set by Jenkins et al, (1999c) and Anderson (1987).

The exponential function and coefficient of correlation (R^2) for the 60^oC and 175^oC results are as follows:

- At 60^oC : $Y = 0.22e^{0.2471x}$; $R^2= 0.9741$
- At 175^oC; $Y = 0.0114e^{0.46386x}$; $R^2 = 1$

As mentioned before, the 60°C viscosity determined stiffening ratios were the most influenced by the filler presence and became indeterminable more or less after f/b ratios of 1 to 1.2. The Brookfield viscosity stiffening ratios at 135°C became indeterminable when the f/b (mass) ratio reached 1.6. The values determined for the variance in binder hardness are also shown in Figure 1. The binder hardness did not have a major influence on the mastic behaviour as they tended to follow the same trend for varying f/b ratios.

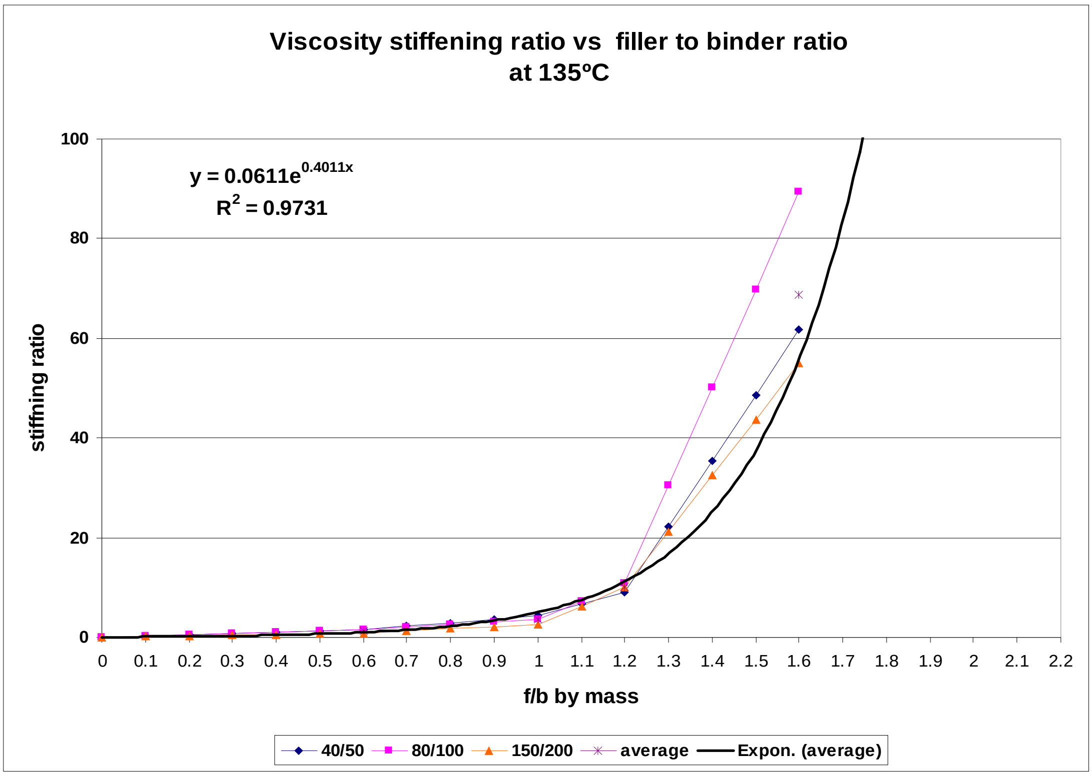

Figure 1: Viscosity stiffening ratio versus f/b (mass) values at 135°C

4.2. Difference in Ring and Ball temperature

Normal Ring and Ball and Wilhelmi Ring and Ball tests were done over the range of f/b (mass) ratios to determine the stiffening effect of the increase in filler content on the mastic. In each case the temperature difference of the Ring and Ball tests was measured with the original binder as reference point. The difference in the normal Ring and Ball , as well as the Wilhelmi Ring and Ball temperature (or softening point) measurement ($\Delta_{R\&B}$), is defined by:

$\Delta_{R\&B} = (t-t_o)$. Where:

t_o= Ring and Ball temperature of original binder; and

t= Ring and Ball temperature of mastic at a given f/b ratio.

The Ring and Ball tests clearly assessed the mastic behaviour better than the Brookfield viscosity test determined stiffening ratios. The Wilhelmi Ring and Ball apparatus gave an even better accuracy and more repeatable measurement as it is obviously better suited for mastic mixes with the larger ring and ball diameter (Pearce, 2004). The $\Delta_{R\&B}$ versus f/b (mass) ratio graphs for both tests are shown in Figures 2 and 3 to follow.

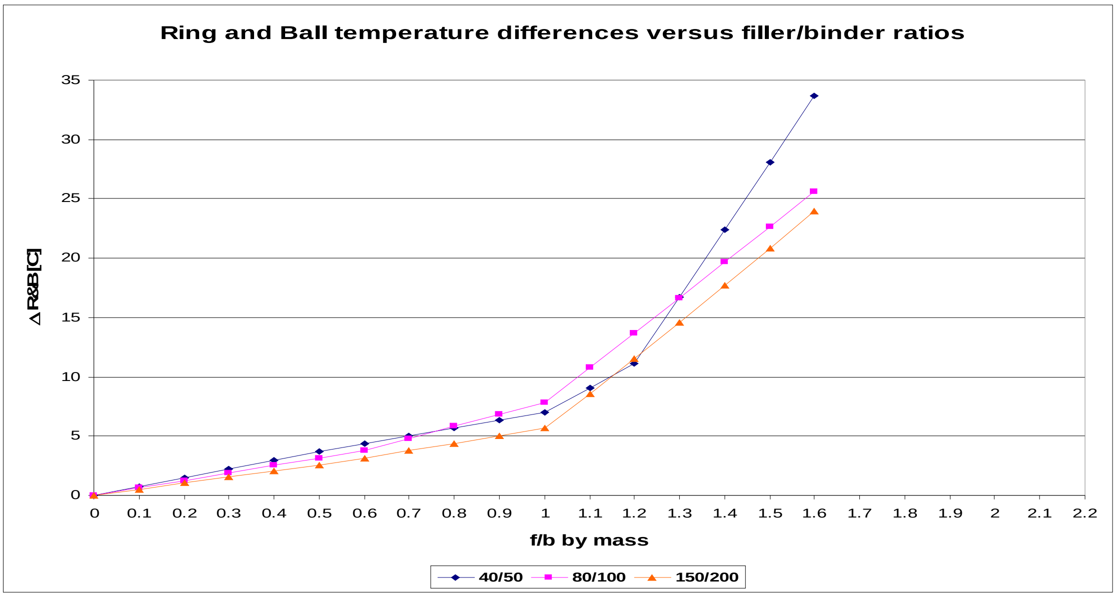

Figure 2: Ring and Ball temperature differences versus filler/binder ratios

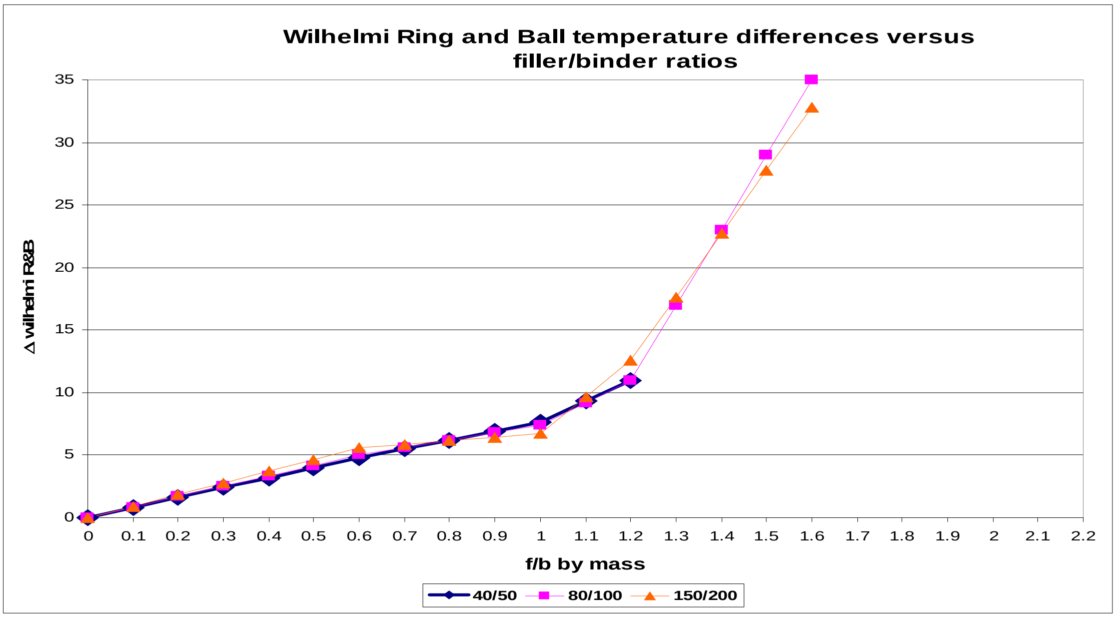

Figure 3. Wilhelmi Ring and Ball values versus filler/binder ratios

The $\Delta_{R\&B}$ of the Wilhelmi Ring and Ball are almost the same at each f/b ratio for all the different mastic binder hardness's (40/50, 80/100, and 150/200 penetrations). In both the normal and

Wilhelmi Ring and Ball tests it was found that $\Delta_{R\&B}$ increased with the increase of the f/b ratio. Even at a 2.2 f/b (mass) ratio the mastic did soften enough to allow the ball to sink through the ring.

However, it can be seen that the first significant jump of rate of increasing $\Delta_{R\&B}$ also tended to occur at an f/b ratio of 1.2 for both the normal Ring and Ball (Figure 2) and for the Wilhelmi Ring and Ball (Figure 3). It should be added that the value of $\Delta_{R\&B}$ at 1.2 f/b ratio was in the range of 11°C which was originally suggested (NAPA, 1999 and Cooley *et al*, 1998) as limiting value in general mastic stiffening behaviour. It therefore seems that the 1.2 f/b (mass) ratio could also be suggested as a design value of mastic stiffness for the Marracuene sand filler.

4.3. Penetration stiffening ratio

Normal Penetration testing with the original binders and with the mastic was also done to possibly determine the stiffening behaviour with increase in filler content. The penetration stiffening ratio (SR_p) was used in this case. SR_p is the ratio of the difference between the penetration of original binder and the mastic at a given f/b ratio and the penetration of the original binder and is formulated as follows:

$SR_p = (p_o - p) / p_o = \Delta p / p_o$

Where:
- Δp is the difference between the penetration of original binder and the mastic at a given f/b ratio (measured in units of 0.1mm) ,
- p_o is the penetration of the original binder (0.1mm); and
- p is the penetration of the mastic at a given f/b ratio (0.1mm).

In Figure 4 the penetration stiffening ratio, $SR_{p,}$ is shown versus the changes in f/b (mass) ratios for the various hardness binders (40/50 pen, 80/100pen and 150/200 penetrations. The test results showed that the stiffening effect increased in a linear relationship with the increase of the f/b (mass) when measured with the Penetration test. This correlation relationship is given by the function:

$Y = 0.0335x - 0.025$, with $R^2 = 0.9976$.

The binder hardness did not make any difference as they all seem to follow the same trend line. It is clear that the penetration test is sensitive to the change in f/b (mass) ratio, but the linear relationship may imply that it will not be able to discern when unacceptable or adequate stiffening may take place.

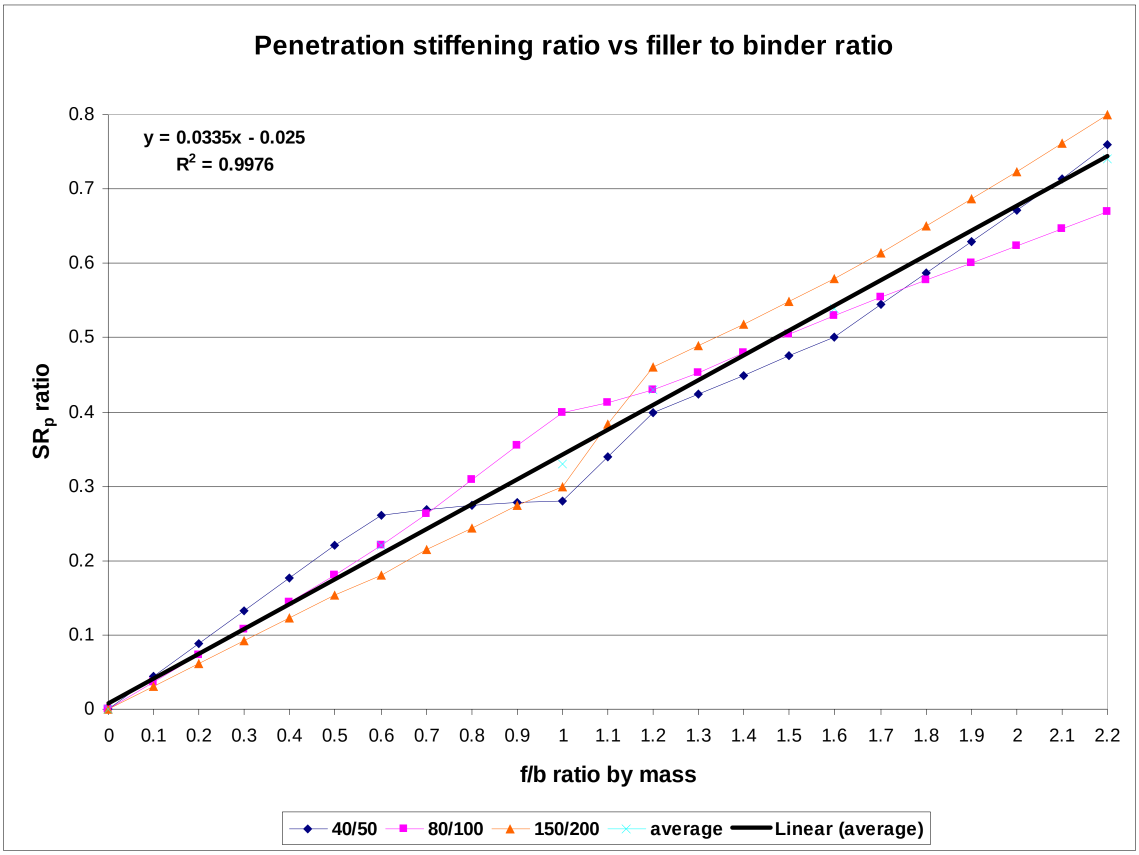

Figure 4: Penetration stiffening ratio versus filler/binder ratios (mass)

4.4. Difference in ductility:

The difference in ductility (ΔD) with changing f/b (mass) ratio was determined with a ductility meter. The difference in ductility (ΔD) is defined by:

$\Delta D = (D_o - D)$

Where:
- D_o is the ductility of original binder [cm]; and
- D is the ductility of a mastic at a given f/b ratio.

The difference in ductility (ΔD) is shown in Figure 5 to follow. The difference in ductility seems to level off after the f/b ratio (mass) value of 0.6 has been reached. Thereafter, changes in f/b ratio (mass) have a reduced influence on ductility. The initial change in the 40/50 penetration binder was much less than the other softer binders (150/200 and 80/100 penetrations) and the difference in ductility (ΔD) tended to level off from a f/b ratio (mass) of 0.6.

The softer binder types (80/100 and 150/200) had ductility difference (ΔD) values which levelled off at approximately an f/b ratio of 1.2. This is more in line with the previous results with the Ring and Ball and viscosity measurements. The hardness of the binder seems to have an influence though on the ductility measurements and therefore, as in the case for difference in penetration, the difference in ductility cannot be seen as a useful test to determine possible unacceptable stiffening behaviour of the mastic due to increased filler presence in a mix.

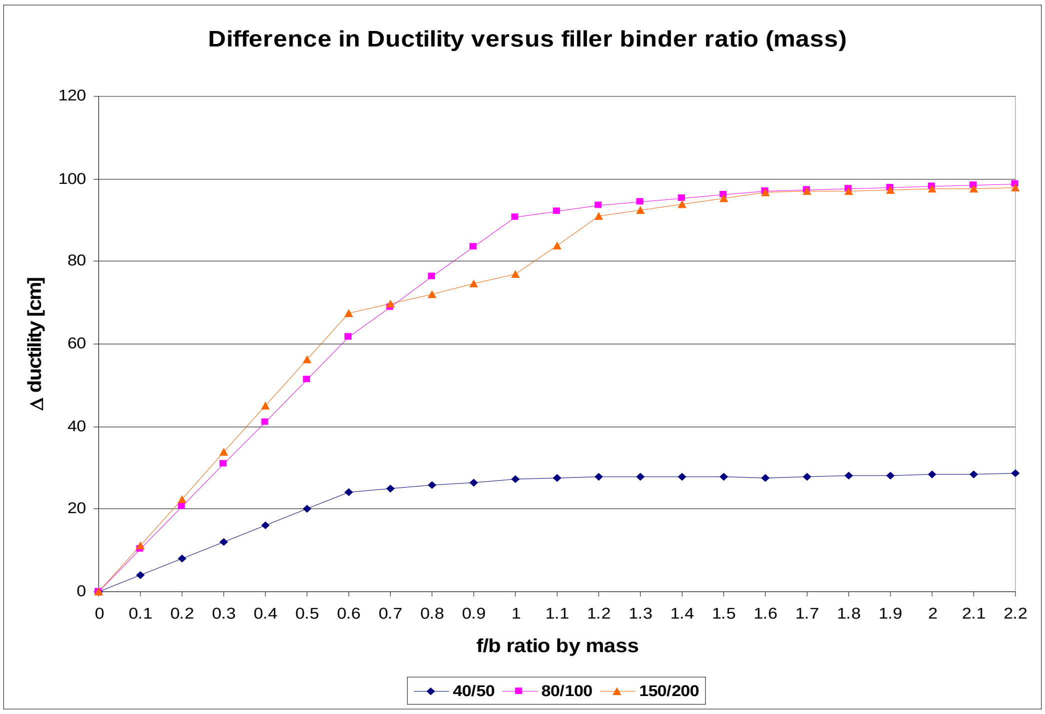

Figure 5: Difference in Ductility versus filler binder ratio (mass)

5. CONCLUSIONS AND RECOMMENDATIONS

Various technologies were successfully used in the past to construct sand or soil asphalt in regions of Southern Africa where sand and soil are the only viable road building material. A literature study identified and confirmed that the minus 75µm (known as the filler portion) of sand/soil plays a significant role in the strength and behaviour of hot sand asphalt.

The good performance of hot sand asphalt in Mozambique served as main motivation to emulate this original hot sand asphalt mix by a cold process which is person friendly and suitable to labour-intensive construction. Therefore the process described by van Wijk and Carvalho and (2002) and Hartman et al (2003) formed the basis of the further investigations (Guiamba et al ,2010).

The Marracuene sand, which was used as test material, has an average filler content of 16%. This sand met the interim specification suggested by Theyse and Horak, (1989) as shown in Table 5. It is suggested that these criteria are valid to identify sands and soils suitable for sand asphalt.

STE mix design is based on other guidelines developed for emulsion treated materials (SABITA, 1993 and 1996). Normally tests like unconfined compression tests, indirect tensile tests and elastic moduli are done to design the mix. However, in most cases small percentages of lime or cement are added to these mixes. This is not the case for STE mixes as no additional filler material is added. Therefore the investigation focused on the value and character of the filler material in the sand or soil used.

Some of the basic volumetric test based on the filler content can be used in designing and ensuring the STE mix will have stiffness and adequate elastic moduli. In this case the criteria normally used to determine unacceptable stiffening of the premix is used in reverse.

In the STE stiffening of the cured emulsion sand matrix, and therefore high effective elastic moduli, is the objective. Tests on the filler binder mastic were done to determine such stiffening behaviour. The Rigden voids test can be done to determine basic volumetric ratios of the filler portion. In this case a 60% filler/binder ratio should be exceeded to ensure adequate stiffness will be reached. A filler/binder ratio (mass) exceeding 1.2 could also be used as threshold value for the Marracuene sand.

It is suggested that the Wilhelmi Ring and Ball test should be the primary test based on Rigden void ratios in determining mastic stiffening effects by varying the binder content. The Wilhelmi Ring and Ball test seems to give more accurate results while the Brookfield viscometer displayed fluctuations in viscosity readings. The Brookfield viscometer can be used as additional test to help verify stiffening behaviour though. The normal Penetration and Ductility tests proved to be insensitive to the variation in filler content of the mastic and cannot be used as a mix design test for STE mix designs.

ACKNOWELEDGEMENTS

Appreciation and thanks for Mr Pedro Carvalho of ANE who initiated and championed the research on STE. Dr Frank Netterburg, who provided access to his personal library and shared his vast knowledge on various aspects of sand asphalt. Mr Bob Kingdon is thanked for his sharing of knowledge and experience on sand asphalt.

REFERENCES

Acott, S.M., Myburgh P.A. 1983. ***Design and Performance Study of Bases Treated with Foamed Asphalt.*** Transportation research record 898. Transport Research Board, Washington, USA.

Anderson D., A. 1987. ***Guidelines for Use of Dust in Hot-Mix Asphalt Concrete Mixtures.*** Proceedings of Association of Asphalt Paving Technologists, Technical Session. Reno, Nevada.

Committee of State Road Authorities (CSRA) (1985) *TRH 14*. ***Guidelines for road construction materials.*** Technical Recommendations for Highways (TRH), CSIR, Pretoria.

Committee of State Road Authorities (CSRA) (1987) **Standard methods of testing road construction materials**. TMH 1. CSIR, Pretoria,

Cooley, L., A., Stroup-Gardiner, Brow, E., R., Hanson, D., I., & Fletcher M., O. 1998. ***Characterization of Asphalt-Filler Mortars with Superpave Binder Tests.*** National Center for Asphalt Technology and South Carolina Department of Transportation.

Guiamba D, Horak E and Visser AT (2010). **Comparative studies of non-destructive field testing devices on BSM-emulsion.** Proceedings of the 29th Annual Southern African Transport Conference and Exhibition (SATC), Pretoria, South Africa.

Hartman, A. M., Van Wijk, A., Carvalho, P., Horak, E. (2005). ***Emulsion Treated Sand for Lo Volume Roads in Mozambique – the STE Research Section.*** T2 Kwa-Zulu Natal Conference, Oct. 2005. Pietermaritzburg.SA

Hugo F de Vos E, Tayob H, Kannemeyer L and Partl M (2008) **Innovative application of the MLS10 for developing pavement design systems.** Proceedings of the Third International Conference on APT, Madrid, Spain, 2008.

Jenkins, K.,J., Van de Ven, M.,F. 1999. ***Mix Design Considerations for Foamed Bitumen Mixtures***.7th CAPSA. Victory Falls, Zimbabwe.

Joubert G., Poolman S., & Strauss P. J. 1989. ***Foam Bitumen Stabilised Sand as an Alternative to Bases for Low Volume*** *Roads.* Proceedings of the 6th Conference on Asphalt Pavements for Southern Africa (CAPSA) , South Africa.

Liebenberg JJE 2004. ***A structural design procedure for emulsion treated pavement layers***. Master of Engineering dissertation, Department of Civil and Biosystems Engineering, School of Engineering, University of Pretoria, Pretoria, South Africa, 2004.

Marais, C. P. 1965. ***Report on a Full-scale Road Experiment to Test Bases of Bituminous-Stabilized Sand on the Tsumeb – Ondangua Route,*** *South West Africa, Constructed in May 1965.* National Institute for Road Research. South Africa.

Mitchell, R.L.1959. *Road* ***Construction on Aeolien Sands****.* Proceedings of the 2nd African regional Conference on Soil Mechanics and Foundation Engineering. Lourenco Marques, 1959.

National Asphalt Pavement Association (NAPA). (1999). ***Evaluation of Badhouse fines for Hot Mix Asphalt***. Information Series 127.

Rigden, P. 1947. ***The Use of Fillers in Bituminous Road Surfacing****.* Journal of the Society of Chemical Industry, Volume 66, September.

Pearce BL (2004) ***Comparison of temperature variations for softening point apparatus with varying filler:binder ratios****.* Proceedings of the 8th Conference on Asphalt Pavements for Southern Africa (CAPSA) Sun City, South Africa.

SABITA. 1993. *GEMs* ***The design and use of granular emulsion mixes****.* Manual 14 SABITA Ltd. Roggebaai . RSA.

SABITA. 1996. ***Appropriate Standards for the use of Sand Asphalt*****.** Manual 18, SABITA Ltd. Roggebaai . RSA.

SABITA. 1999. *ETB:* ***The design and use of emulsion treated bases****. Manual 21, SABITA, Cape Town, South Africa.*

SABITA 2009**. Bitumen Stabilised Materials. A Guideline for the Design and Construction of Bitumen Emulsion and Foamed Bitumen Stabilised Materials.** Technical Guideline 2 (TG2). May 2009 Second Edition.

Silva, A.C. 1959. ***Soil Stabilization with Resins***. Proceedings of the 2nd African regional Conference on Soil Mechanics and Foundation Engineering. Lourenco Marques, 1959.

Theyse, H., Horak, E.1987 ***A Literature Survey on Bituminous Stabilized Sand Bases****.* Technical Note TN/45/87. National Institute for Transport and Road Research (NITRR), CSIR.

Theyse HL 1998. ***Towards guidelines on the structural design of pavements with emulsion treated layers**.* Transportek, CSIR, (CR-97/045), Pretoria, South Africa.

Van der Merwe, C.P., 1959. *Stabilization of Aeolien sand*. Proceedings of the 2nd African regional Conference on Soil Mechanics and Foundation Engineering. Lourenco Marques, 1959.

Van Wijk, I., & Carvalho, P. 2002, ***Innovative Use of Sands in Pavement Layers: Experience in Mozambique**.* 2nd World Engineering Congress, Sarawak, Malaysia, 22-25 july 2002

Viljoen, A.W. 1979. ***Bitumen Stabilisering van Sand**. Jaarlike Kursus oor Materiale en Ontwerp*. Nasionale Instituut vir Vervoer- en Padnavorsing. WNNR, Pretoria

KEY WORDS

Rigden voids, penetration, ring and ball, viscosity, ductility, filler, sand treated with emulsion, filler binder ratio