SIMPLE TESTS TO ENHANCE THE SOUTH AFRICAN HMA DESIGN GUIDELINES

B L PEARCE

Cape Peninsula University of Technology, Department of Civil Engineering and Surveying
P O Box 652, Cape Town, 8000
Phone: (021) 460-3045, Facsimile: (021) 460-3710, E-mail: pearceb@cput.ac.za

ABSTRACT

This aim of the paper is to propose simple, inexpensive laboratory tests that could be introduced into the 2001-version of the South African hot-mix asphalt (HMA) design guidelines (SA HMA design guidelines) to determine the effects of the filler. Additional limits for the filler-to-binder (f:b) ratio based on the increase in the ring and ball (R&B) softening point temperature are also proposed for possible inclusion into the SA HMA design guidelines.

Most international specifications include strict controls over the filler related to its fineness and the f:b ratio. The SA HMA design guidelines are not sufficiently specific on these issues.

At present, the test used to determine the grading of the filler is the hydrometer test. There are inherent problems with this test method, which will be highlighted in the paper. The proposed alternative test method is the Rigden voids test. The benefits of this method will be discussed in the paper.

To determine the effect of the filler on the stiffening of the binder, conventional R&B apparatus can be used. The increase in the R&B softening point temperature can then be plotted against the Rigden voids. The increase in R&B softening point needs to be contained to below a certain maximum temperature to ensure that binder stiffness is not excessively increased. The results can to be used to further increase the understanding of the stiffening effects on the mastic, which significantly affect the compactibility of a HMA layer.

Key Words. Bitumen; HMA; filler:binder ratio; compaction; increase in R&B temperature, Rigden voids.

1. INTRODUCTION

International specifications tend to place a fair amount of emphasis on control measures for the filler fraction in relation to the amount of binder in HMA. This is referred to as the filler-to-binder ratio (f:b ratio). Shape, grading and f:b ratio all seem to get a fair amount of attention whereas the 2001-version of the South African hot-mix asphalt design guidelines (SA HMA design guidelines) only refer to the f:b ratio, which is limited to a maximum ratio of 1,5:1 by mass. This is a very broad and simplistic guideline for all HMA mixes that can lead to an over- or under-filled mastic for continuously graded HMA due to other characteristics that are not taken into account but are present in the local fillers found around the country. There is a need to obtain a greater amount of information about the filler to make a more accurate assessment of the filler characteristics for continuously graded HMA before recommending a maximum f:b ratio applicable to a specific region. This paper will motivate two simple tests that can assist in providing this information specifically for continuously graded HMA layers.

2. THE BELGIUM SPECIFICATIONS – ONE OF THE INTERNATIONAL SPECIFICATIONS

The Belgium specifications (1997) brings the following three aspects into contention when specifying the filler that is acceptable in HMA, namely Rigden voids, f:b ratio and the range of increase in temperature for the ring and ball (R&B) softening point test when tested with the filler added at predetermined f:b ratios. This type of additional testing is not onerous and can easily be undertaken in most HMA laboratories at minimum additional cost.

The Ridgen voids provide information on the air voids in the filler that can accept binder due to its packing ability. Figure 1 illustrates the concepts of fixed and free binder (asphalt) as determined by Rigden. These concepts will be described in more detail later in the paper. Take note that the sketch refers to asphalt that is the American term for binder.

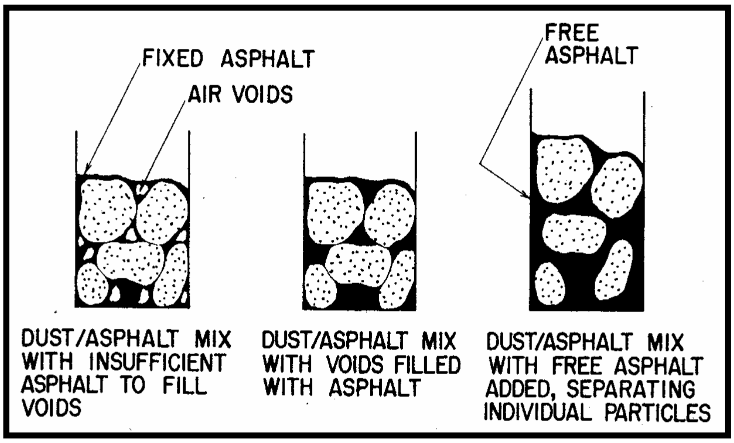

Figure 1: Fixed and free binder illustration as determined by Rigden

The increased R&B softening point as a result on the addition of filler gives an indication of the stiffening effect of the filler when mixed with the binder.

Finally, the design f:b ratio is determined by limiting the increase in temperature of the R&B softening point to between 12 and 16 °C. Most literature refers to it being more ideal to accept a f:b ratio that restricts the increase in R&B softening point to around the 12 °C mark, rather than the higher value of 16 °C (Cooley et al, 1998).

It is these types of simple, inexpensive control tests that are being proposed for incorporation into the SA HMA design guidelines.

3. 2001-VERSION OF THE SOUTH AFRICAN HOT MIX ASHALT DESIGN GUIDELINES

The SA HMA design guidelines devote little attention to the f:b ratio by only mentioning the effects of too high a f:b ratio on the stiffening effects of the mastic paste. An investigation was conducted by Wright (1999) into the stiffening effects of the f:b ratios. The findings of this investigation were used as the basis for the SA HMA design guidelines. Much research has been conducted on the effects of the f:b ratio internationally and the resultant stiffening of the bitumen. Tunnicliff (1962), Kandhal (1981), Anderson (1987) and Cooley et al (1998), among others, have looked into this aspect since the beginning of last century.

As a result of that research, much emphasis has been placed on the fact that it is now common knowledge that too high a f:b ratio can adversely effect the compaction of HMA.

4. EXPERIMENTAL INVESTIGATION

A variety of tests were undertaken to obtain data for this research project. These included:

- Sampling of 4,75 mm dust fractions from HMA supplier and quarries;
- Hydrometer testing;
- Rigden void testing;
- R&B softening point testing.

Samples where collected to determine the variation in the grading of the dust fraction (i.e. aggregate passing the 4.75 mm sieve) as used in HMA in the Western Cape. The sampling took place over a six-month period to determine the extent of the variability of the dust fractions at the various sources. Samples were collected from the three HMA manufacturing plants in the Western Cape, as well as from the quarries that supply them. These samples where all wet sieved (TMH 1:A1(a), 1986) to determine the standard grading for the dust fractions sampled. These samples where then sorted from the finest to the coarsest, based on their grading and fineness modulus (GM & FM).

The samples where then graded using the hydrometer test method (TMH 1:A6, 1986) to get an actual grading for the fractions finer than 0.075 mm. These results where then compared to the finest and coarsest samples as determined by the standard grading based on the GM & FM.

The finest and coarsest samples of the 0.075 mm fractions, as determined by the hydrometer test and the GM & FM, where then tested using the Rigden voids apparatus. This test was used to obtain the voids left within the sample after compaction or, in other words, to assess it's packing ability.

The original binder was tested in the conventional manner to determine the R&B softening point temperature as per SABS 307. The same fine and coarse fractions of the –0.075 mm filler were then combined in various ratios with the original binder. The ratios used were as given in Table 1. Both 60/70 and 80/100 penetration grade bitumen was used in the experimental investigation. Only the absolute coarsest and finest gradings were used to determine the extreme increases in R&B softening point temperature for each source.

Table 1: Filler:binder ratios used

Binder type	Filler : binder (f:b) ratios by mass			
80/100 pen bitumen	1 : 1	1,3 : 1	1,6 : 1	2: 1
60/70 pen bitumen	1 : 1	1,3 : 1	1,6 : 1	2: 1

5. THE EXISTING HYDROMETER TEST METHOD – PRESENTLY IN USE

This section of the paper will discuss the inherent problems encountered as a result of the test method and its theoretical approach. The question that is asked is whether the hydrometer accurately calculates the actual grading of different shaped particles in the filler fraction.

The hydrometer test (TMH 1:A6, 1986) is used in South Africa to provide a grading for the finer particles that cannot be sieved through the conventional meshed sieves. This constitutes the fraction smaller than 0.075 mm. The calculation of the settlement times is based on a spherical particle with the tendency for the smaller particles to settle slower than the larger particles due to the principles of Stokes Law. Although the concept used in the hydrometer test is correct in theory, in reality the particle shapes differ based on the origin of the material being tested. It is very rare if not non-existent to have spherical filler particles in the filler fraction.

The particle shape in reality is in most cases angular, flat or flakey i.e. pin-like. This difference in the shape of the particles has an effect on the settlement times due to the manner in which they will settle through the fluid.

- An angular particle is most likely to settle in the most similar manner to the theoretically shaped spherical particle resulting in a fairly accurate grading result.
- The flat shaped particles are more likely to float from side to side through the fluid in a manner similar to a leaf. As a result of its shape it will tend to move slower as it tries to find a way through the fluid. This settlement action will tend to slow down the time of settlement resulting in the calculation of a finer overall grading result.
- On the other hand, the pin-like particles would tend to realign themselves to fall quickly with their length vertical so as to create the least resistance and hence fall faster than the above two examples. This will result in a coarser grading result due to the increased rate of settlement.

As can be seen from the above examples the shape of the filler can result in different grading results as a result of the manner in which it settles through the fluid. If all the gradings where identical, the hydrometer test could give different grading results as a result of the differing shapes of the various samples.

The graded material as determined by the conventional sieving action differed in some instances to the hydrometer results obtained. In some instances the hydrometer results showed large differences between the two test methods around the 0.075 mm fraction. That is the point at which the conventional sieve testing ends and the hydrometer grading results take over. In some instances there was a big drop-off while in other instances there was an increase in the percentage passing as represented by the hydrometer results. Table 2 illustrates this tendency. The hydrometer results where used from the 0.075 mm fraction as represented in Table 2.

Figure 2 illustrates two examples from Table 1 to highlight the questionable information as obtained due to the combination of the two grading methods. It can clearly be seen that the resultant plot is incorrect due to the increase in the values at the 0.075 mm. The plot should give an ever-decreasing values as it moves from right to left.

Another issue regarding the hydrometer test is the disturbance that occurs when the hydrometer is inserted and removed for taking readings at the predetermined times. These actions result in turbulence in the fluid that will disrupt the settlement process no matter how carefully the hydrometer in inserted and removed. In the case of the flat particles there could be a greater effect on the settlement due to the shape of these particles in relation to the turbulence created. A manner to prevent this turbulence would be to leave the hydrometer in place for the duration of the test. This would however create other issues around particles having to settle past the bulb of the hydrometer that would also delay the settlement process and crowd the particles to the sides around the flask thus further delaying the settlement and resulting in an inaccurate result.

Although it may seem that the credibility of the hydrometer test is being questioned in essence what is being highlighted are the inherent problems that can be encountered when making use of a grading resulting from such a test. The accuracy of the grading result is critical in determining the fineness of the filler.

Table 2: Variations in gradings around 0.075 mm fraction

		Source 1				Source 2	Source 3	Source 4	
		dust	dust	dust	dust	dust	dust	dust	dust
% PASSING	6.7 mm	100	100	100	100	100	100	100	100
	4.75 mm	100	100	100	99	98	93	92	97
	2.36 mm	76	68	75	65	69	55	54	69
	2.00 mm	72	63	71	60	64	51	51	64
	1.18 mm	59	49	52	43	45	36	35	44
	0.850 mm	51	40	42	34	35	29	28	33
	0.600 mm	43	33	35	28	28	23	23	26
	0.425 mm	35	27	28	23	22	18	19	21
	0.300 mm	22	17	23	20	18	15	16	18
	0.250 mm	19	15	21	19	16	14	15	16
	0.150 mm	13	11	16	15	12	10	12	14
	0.075 mm	**8**	**7**	**11**	**11**	**10**	**8**	**9**	**11**
	0.06 mm	**16**	**10**	**15**	**12**	**12**	**10**	**11**	**12**
	0.05 mm	14	9	13	10	10	7	9	11
	0.03 mm	12	9	12	8	9	5	8	11
	0.02 mm	11	8	11	7	8	4	7	9
	0.01 mm	9	6	7	6	6	3	5	7
	0.006 mm	7	4	5	4	4	2	4	4
	0.005 mm	6	4	5	4	3	2	4	4
	0.002 mm	2	2	4	3	2	2	2	3

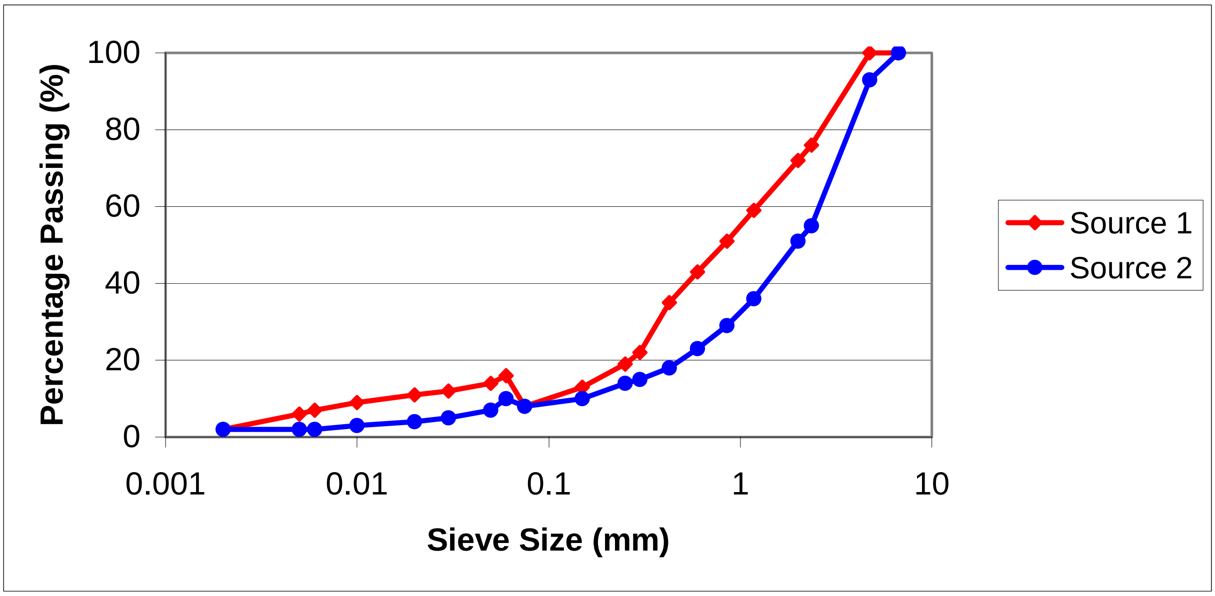

Figure 2: Plot of typical variations for the combined sieve & hydrometer plots for dust gradings

6. RIGDEN VOIDS TEST – PROPOSED ALTERNATIVE #1

This simple test developed by Rigden (1947) is being proposed to replace the hydrometer test. This easily manufactured apparatus works very effectively in determining the voids that are present in the filler fraction giving an indication of its packing ability. Although the results do not provide an actual grading as with the hydrometer test, the results obtained are far more applicable and effective in HMA design.

The test method assists in determining how much binder will be needed to fill the voids within the filler, referred to as fixed binder (asphalt). The remaining percentage, referred to as free binder (asphalt), would be used to coat and lubricate the remaining aggregates (Figure 4).

In this regard the Rigden voids test is far more applicable from a practical perspective than the hydrometer test. The results of the Rigden voids can be utilised far more effectively in determining how much binder is required by the filler i.e. the fixed binder and the resultant free binder that remains to lubricate the larger aggregate fractions. This information is far more valuable to the designers of HMA than the grading itself.

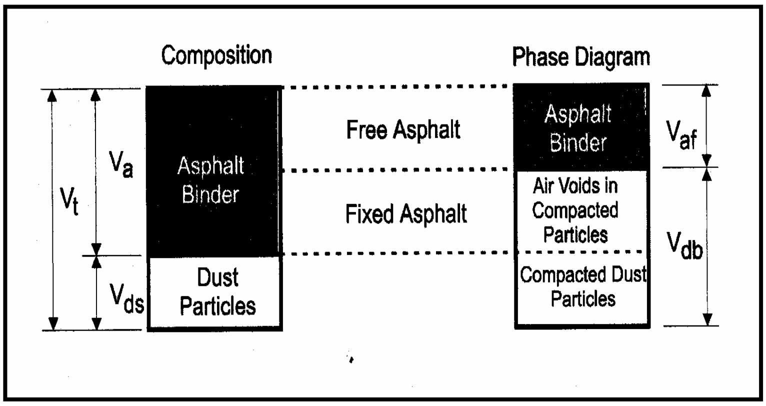

Figure 3: Concepts of Rigden voids

7. INCREASE IN SOFTENING POINT TEMPERATURE – PROPOSED ALTERNATIVE #2

This existing test method can easily be used to include testing of the f:b ratios effect on the stiffening of the mastic.

The original penetration binder is tested according to ASTM D35-95 (1998) to obtain the R&B softening point temperature. The filler is then added in fixed ratios as given in Table 1. The increase in the R&B softening point temperature is determined using the same apparatus and the same testing procedure. If the R&B softening point is expected to be above 80 °C, glycerine is used instead of water as the fluid medium. The reason for this is that the glycerine has a higher boiling point than water. This is also a standard condition mentioned as part of the standard test procedure. A R&B softening point above 80 °C is more likely to occur as the result of higher f:b ratios, which have a tendency to increase the R&B softening point temperature to above 80 °C. The f:b ratio that results in an increase in R&B softening point temperature of approximately 12 °C would be the best ratio to use in the HMA mixture.

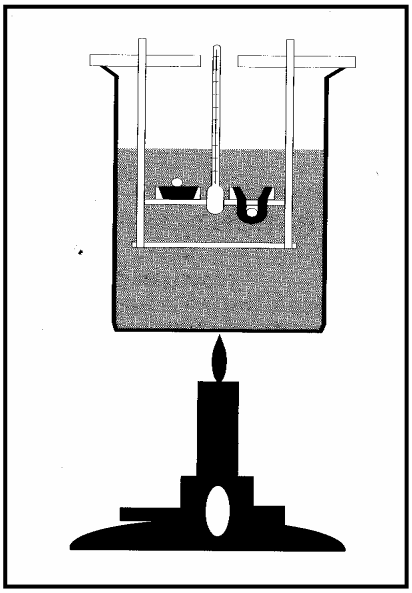

Figure 4: Ring and Ball softening point apparatus

8. RESULTS ANALYSIS

In this section, the various test results will be analysed, giving clear indications of the trends that were observed. Brief explanations of the impacts of the effects will also be presented.

The R&B softening point test results gave a clear indication that an increase in filler increases the stiffness of the mastic. This is indicated by the increase in the temperature required to soften the mastic. The finer fraction from each source also resulted in a stiffer mix at the same f:b ratio than the coarser fraction. This further confirms the fact that a change in the filler grading represented by the Rigden voids value has an effect on the compactibility of the HMA. Regular checks will need to be undertaken on the filler fractions obtained from the various sources to determine the variability of these critical characteristics related to the filler and its effects on the binder and mastic.

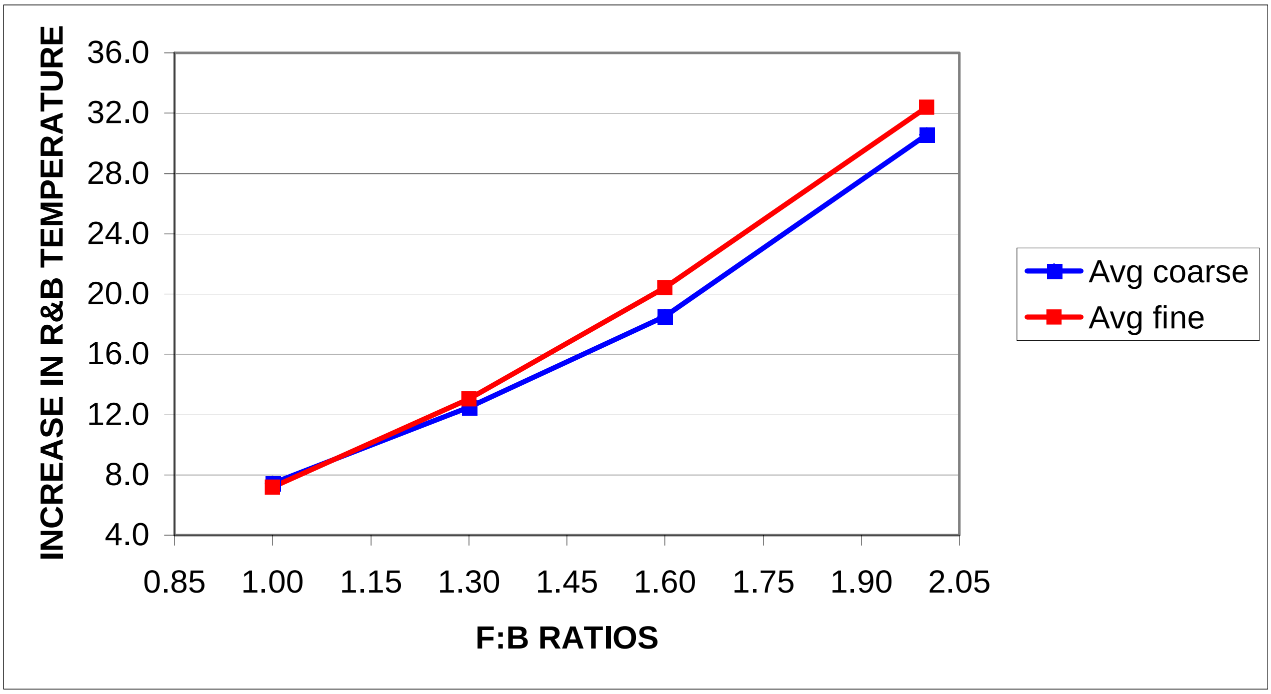

Figure 5: Average increase in R&B softening point temperature

The results obtained from the Rigden tests suggest that each supplier should plot a specific graph for their plant to determine the increase in the R&B softening point temperature based on the specific characteristics of the filler found at that site, together with its specific variations. Although, at present, the graphs plotted do not conform perfectly to the graph as given in the Belgium specification (1997, pg 50), there seems to be some correlation when plotting each sites results on separate graphs. More extensive testing over a wider range of samples for each source is required to confirm this.

It can clearly be seen from Figure 6 that there is a trend in the Rigden voids. The finer fractions have a greater percentage of voids than the coarser fractions. This clearly indicates that the finer the grading, or the higher the Rigden voids, the greater the percentage of binder required to fill these voids. This will result in less binder being available for the lubrication of the aggregates in the mix. Therefore, should there be a variation in the Rigden voids due to a change in the fineness of the filler, there would be a resultant change in the amount of binder available to lubricate the remaining aggregate. As a result of the variations found in each suppliers dust fractions, it is imperative that such information be available to the suppliers so that changes can be effected in line with the variations observed.

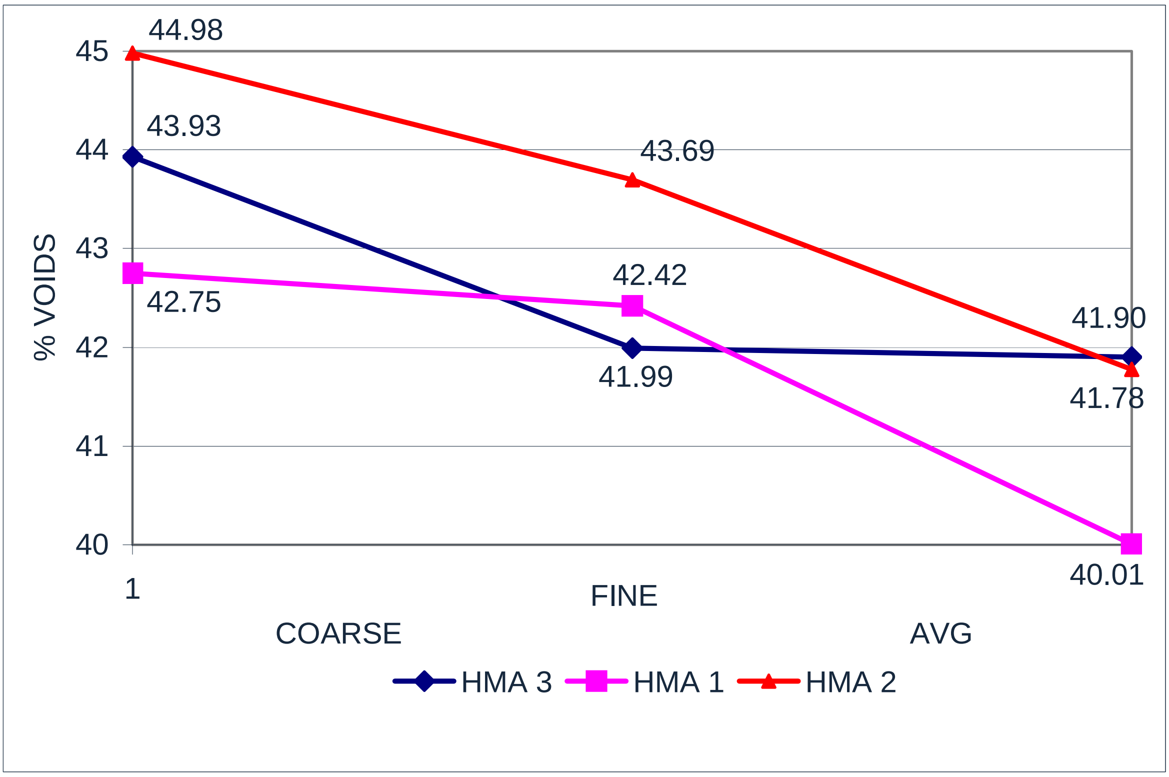

Figure 6: Rigden results for HMA suppliers

Figure 7 reflects the relationships between the fine, coarse and average grading from each of the three sources. Although the plots are not based on the actual sieve sizes, one can see the variation between the 3 sources based on the three broad categories. Looking at the Rigden voids for HMA 3 and the average Rigden voids for HMA 2 it can be seen that the results are very close, 43.93 & 43.69 respectively. Similarly the average result for HMA 3 and the coarse value for HMA 1 & 2 are also very close namely 41.99 & 41.90 & 41, 78 respectively. This indicates that what one source classifies as fine another would classify as average. One manufacturer therefore cannot use the mix proportions from another source and expect to have the same mix characteristics when using different materials.

9. CONCLUDING REMARKS

The intention of this paper is to motivate the inclusion of Rigden voids and the increase in R&B softening point into the SA HMA design guidelines.

Firstly, it has been confirmed that there is a large variation in the dust gradings between sources. This needs to be taken account of in standard mix design and the gradings in the standard specifications. Furthermore, there is an alarming variation at each source for the same dust grading over time. These variations needs to be identified and managed so as to enable the amount of filler to be adjusted in line with the variation in dust grading.

Secondly, the Rigden voids test has proved to be more accurate in determining the characteristics more applicable to HMA design criteria then the hydrometer test. Although a physically plotted grading is easy to visualise, the information provided by the Rigden void test is of greater assistance in designing HMA that is more likely to react as intended. The compatibility of the mix will be more consistent and the engineering properties required more likely to be obtained in the field.

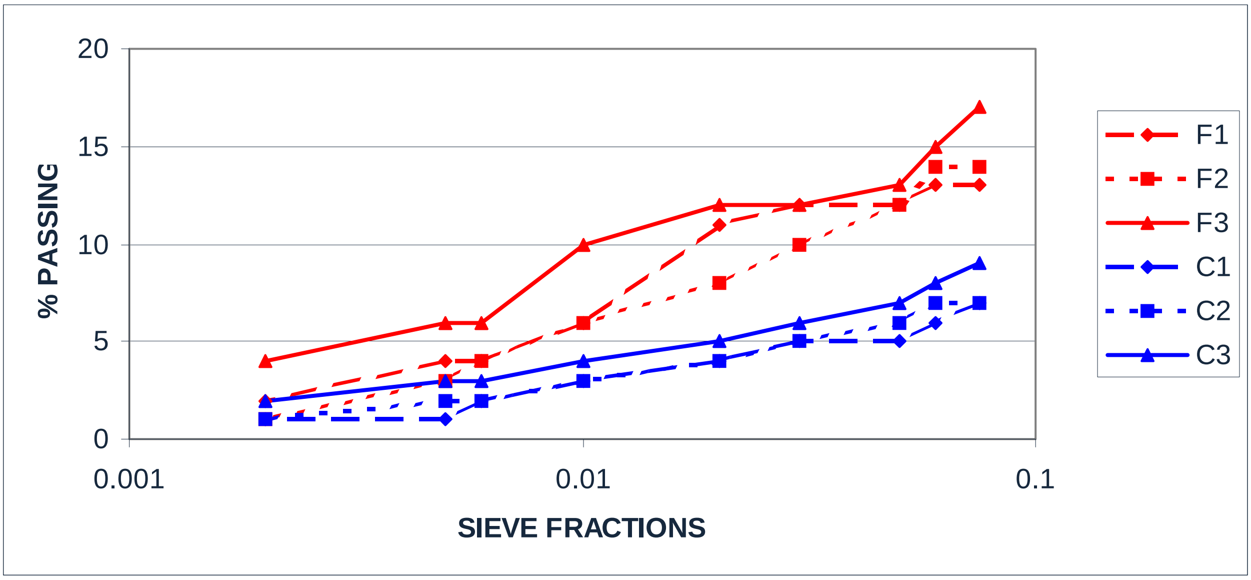

Figure 7: Fine (F) and coarse (C) fractions from 3 sources for 0.075 mm fractions

Finally, the increase in the R&B softening point temperature can be used effectively to demonstrate the stiffening effect of the filler. This simple test pulls together all the other information and it can be conducted on its own, without the Rigden void test, if necessary.

From the results of this research, it became apparent that it would be beneficial to have a database developed at each HMA plant to get a clearer picture of each regions' or suppliers' filler characteristics, particularly with regard to the effects on the increase in R&B softening point as well as on the Ridgen voids. This will allow the individual suppliers to have greater control in providing a more consistent product specifically related to the workability of the mix without sacrificing the resultant engineering properties. Such a database will also assist in determining how the specific material varies from day to day and how it reacts in various ratios with the binder.

In conclusion, the SA HMA design guidelines only recommend a maximum filler-to-binder ratio of 1.5:1 by mass that relates to all types of HMA. This paper has shown that such a ratio for continuously graded HMA's, particularly in the Western Cape, could be too high, possibly resulting in poor workability and compaction failures. The results indicated that the material tested from the Western Cape conformed to a maximum f:b ratio limited to between 1.35 and 1.45, rather than the 1.5:1 as recommended in the SA HMA design guidelines. This range takes account of the variation in the dust between suppliers and is based on an increase in R&B softening point temperature of 12 °C. Such limits for the f:b ratios should be made more explicate and research for each source supplying HMA based on the SA HMA design guidelines.

It is recommended that research into the variability of the dust fraction be extended countrywide. Coupled to this would be the undertaking of Rigden and increased R&B softening point testing at each supplier to ascertain whether the presently recommended maximum f:b ratio for continuously graded HMA in the SA HMA design guidelines is not possibly too high.

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