Characterisation of Foam Bitumen Quality and the Mechanical Properties of Foam Stabilised Mixes

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ABSTRACT: The use of foam bitumen stabilisation is rapidly growing worldwide because of its environmentally friendly benefits and its high field performance properties. The foam bitumen quality is assessed by two empirical parameters, namely, half life time and expansion ratio. Despite the simplicity of measurements of these two parameters, several discrepancies between the classification of the foam and its actual quality were observed. Such inconsistencies in the current classification system have led to the proposal of a new method to characterise the quality of the foam, which was developed in this study. The proposed method uses the Brookfield rotational viscometer to measure the viscosity of foam at different time intervals. The average foam viscosity over the first 60 seconds of foaming is used as a measure of the quality of the foam. This parameter is analogous to the foam index. Foam index combines both expansion ratio and time of decay of the foam, while the new parameter combines foam viscosity over the first 60 seconds of foam decay. The foamant water content that provides the lowest average viscosity is considered the optimum foamant water content. In addition to foam characterisation, the mechanical properties of foam stabilised mixes were measured and compared to those of hot mix asphalts.

KEY WORDS
Foam, Characterisation, Mechanical, Fatigue, Modulus

1 INTRODUCTION

As the demand for a cost-effective and environmentally friendly pavement stabilisation method increases, so has foamed bitumen stabilisation started to gain broad acceptance worldwide.

The research presented here is part of three-phase research project funded by the Land Transport New Zealand (formerly Transfund New Zealand) aimed at the investigation of the properties and the expected performance of foamed bitumen-stabilised mixes. The first stage investigated the feasibility of using foamed bitumen as a potential stabilising technique (Saleh and Herrington 2003). Some preliminary tests were carried out to evaluate the properties of these mixes (Saleh and Herrington 2003, Saleh 2004a, Saleh2004b). In the second phase of the research, a comprehensive testing programme has been conducted to inspect and characterise the behaviour of the foam-stabilised mixes. Different bitumen sources and grades were investigated to study the effect of bitumen source and rheology on its foamability (Saleh 2004a). The third phase of this research is still under planning and will investigate the field performance of these mixes by constructing different pavement sections in the Canterbury accelerated test track facility (CAPTIF).

The work presented here in this paper is part of the second phase and covers the foamability tests using the current characterisation tests and the newly proposed characterisation method in addition to investigating the mechanical properties of foam stabilised mixes.

2 MATERIALS

2.1 Bitumen Sources and Grades

Nine bitumens from seven different bitumen sources were collected and examined for their foamability properties in this study. Five bitumens were obtained from three sources (SHL, VEN, and DLT, with different penetration grades) that are currently used in New Zealand, three were from three sources in California in the United States (AR2000, AR4000-1, and AR4000-2), and the seventh source was imported from Australia, C170. The sources of the New Zealand samples are denoted by letters, and the grades are indicated by numbers (80, 180) using the penetration grade system. Thus, the five samples are SHL80, SHL180, VEN80, VEN180, and DLT80. Samples from the US are graded with the “Aged Residue” (AR) method. The numerical values of this grading system describe the viscosity (in poises) of these samples at 60°C after being aged in the Rolling Thin Film Oven Test (RTFOT). Thus, the three US samples are AR2000, AR4000-1, and AR4000-2. For the Australian bitumen, the numerical value of C170 is the viscosity of the original bitumen (in Pa.s) measured at 60°C.

2.2 Aggregates and Mineral Fillers

Two aggregate gradations were used, which are the upper limit of the gradation band of the AP-40 (all passing the 40 mm sieve) and the mid-point of AP-20 (all passing the 20 mm sieve) gradation curve. These two gradations are commonly used as base courses in New Zealand. They are reasonably close to the mid-point of the ideal zone for foamed bitumen mixes, as discussed in a previous study by Saleh and Herrington (2003). Four types of mineral fillers: fly ash type C, pond ash, hydrated lime, and Portland cement were used to adjust the amount of fines. Portland cement was used at 1.0% and 2.0% with fly ash type C.

3 FOAM BITUMEN CHARACTERISATION

The Wirtgen WLB10 unit, a laboratory-scale foamed-bitumen plant, was used to determine the foaming properties of the different types of bitumens, and to produce foamed bitumen mixes. In evaluating the foam characteristics, the expansion ratio (ER) and half life time (HLT) values were used. The bitumen temperature was maintained at 170 °C during the foaming. Table 1 contains the foaming parameters and the results of all bitumen types used in this study. In addition, the foam index (FI) was calculated according to Jenkins et al. (2000).

It is obvious from Table 1 that the FI to optimise the percentage of foamant water is not achievable in most tests because very few bitumen types show a peak. This may be attributed to the fact that the FI was developed assuming that the rate of decay of the foam follows a certain exponential decay curve, which may not be valid for all bitumen types. In addition, the FI value is a function of the expansion ratio and the half-life, which are both empirical parameters. Therefore, FI is also an empirical parameter. Because of the empirical nature of the current parameters that are in use to characterise the foam quality, several discrepancies in classification of the different sources of foam bitumen can be detected. For example, although DLT80, SHL80 and AR4000-2 were classified as poor or unsuitable for foam stabilisation according to the South African Guidelines (see Table 2), they both mixed and dispersed effectively with the aggregate matrix in the laboratory without any problems. However, C170 did not mix.

According to Table 1, VEN180 provides the best quality foam and C170 gives the lowest quality foam. It was not possible to mix the foam created from C170 since the foam formed clots and strings and, therefore, no foam stabilised specimens could be prepared with it.

Examining Table 2, the optimum percentage of foamant water for each sample is within the range of 1 to 3.5 that was recorded in the literature (Maccarrone et al. 1994, Mohammad et al. 2003, Ramanujam & Jones 2000). Under the same testing conditions, the effect of bitumen source is also obvious. For instance, AR4000-1 and AR4000-2 are supposed to have similar physical properties and yet they have different foamability parameters.

4 NEW APPROACH TO CHARACTERISING FOAM BITUMEN QUALITY

The lack of a consistent methodology that employs fundamental parameters to classify the quality of the foam, prompted the proposal of another procedure to quantify the foam quality. In this new approach, the Brookfield rotational viscometer (Figure 1) was connected to a computer, and the rotational viscosity of the foam was measured every half second interval, for about three to four minutes. Figure 2 shows the relationship between the rotational viscosity of a foam, which was created by the addition of 2.5% water to SHL80 bitumen, and the elapsed time in seconds. The average foam viscosity over the first 60 seconds was calculated, and is shown in Figure 2. This value is considered a relevant parameter to quantify the foam quality. The first 60-second interval represents the mixing time in the laboratory.

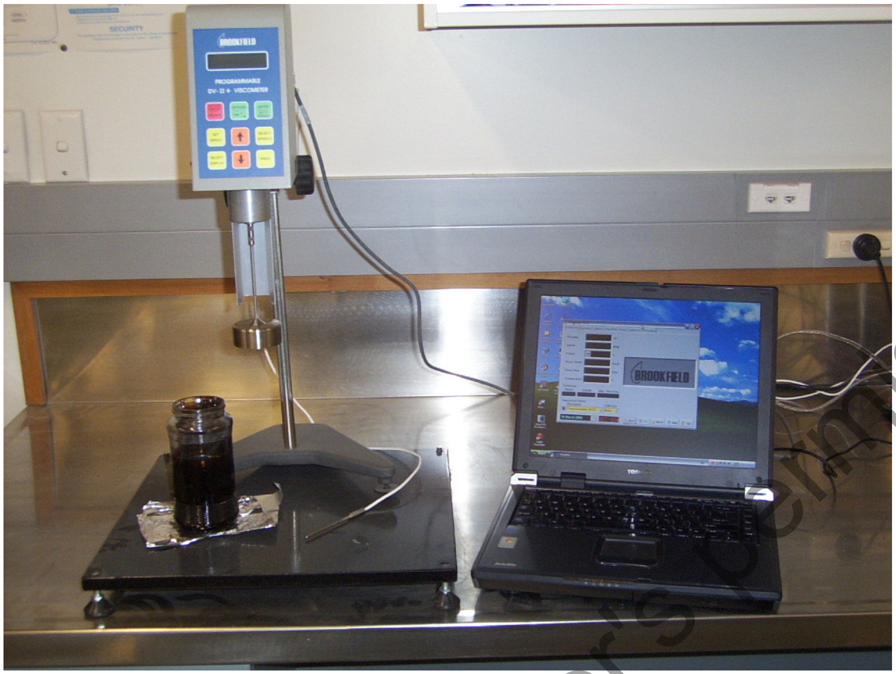

Figure 1: Brookfield rotational viscometer used for quantifying foam quality.

For the purpose of characterising the quality of the foam bitumen, this approach is likely to be more appropriate than the current approach, which relies on empirical parameters such as expansion ratio, half-life and FI. Because viscosity of the foam is a fundamental property, this new approach will provide a direct measurement of the viscosity of the foam and, therefore, will provide a good understanding of the workability and the mix quality. The current empirical parameters only provide an indication about the viscosity of the foam, but do not give an exact figure about its value. In addition, the current empirical parameters may provide inconsistent measures. For example, two different sources of bitumens may have the same expansion ratio and half-life, but might have very different foam viscosity values, which makes the mixing quality and workability of the two different mixes completely different.

Table 1: Foaming properties of the nine different bitumen types.

%W$_c$	**ER**	**HLT**	**FI**	**%W$_c$**	**ER**	**HLT**	**FI**
	SHL80				**SHL180**		
2.0	6	12.7	40.0	2.0	5.8	10.4	37.4
2.5	7.7	6.2	53.4	2.5	7.6	9.5	56.4
3.0	9.7	4.7	72.8	3.0	9.3	8.8	77.3
3.5	11	3.5	88.4	3.5	11.3	7.6	99.1
4.0	12	4.0	93.4	4.0	13.9	7.2	130.7
4.5	12	3.2	97.5	4.5			
%W$_c$	**VEN80**			**%W$_c$**	**VEN180**		
2.0	12.0	10.3	119.7	2.0	9.7	23.7	123.5
2.5	12.5	8.0	115.6	2.5	15.3	16.0	218.4
3.0	13.3	7.5	124.6	3.0	18.0	6.3	176.6
3.5	15.3	5.7	141.9	3.5	20.0	5.7	196.7
4.0	17.7	4.9	163.5	4.0	24.0	5.0	237.9
4.5	20.0	4.3	185.1	4.5	24.0	5.2	240.2
%W$_c$	**DLT80**			**%W$_c$**	**AR2000**		
2.0	7	8	48.4	1.5	11	8.9	94.4
2.5	10	3	78.2	2.0	12	10.3	119.9
3.0	11	3	87.7	2.5	16	5.5	134.4
3.5	12	4	97.0	3.0	17	3.6	127.1
4.0	14	5	121.0	3.5	18	3.6	135.9
4.5	17	5	155.2	4.0	18	3.2	132.4
				4.5	19	3.1	142.2
%W$_c$	**AR4000-1**			**%W$_c$**	**AR4000-2**		
1.5	11	23.8	152.2	1.5	10	7.3	69.63
2.0	14	8.8	137.0	2.0	11	6	80.06
2.5	17	5.7	155.3	2.5	11	4.7	77.35
3.0	18	4.6	160.5	3.0	12	6.7	96.38
3.5	18	5.2	168.6	3.5	13	6.4	100.32
4.0	21	5.5	201.2	4.0	14	5.2	104.87
4.5	23	5.1	229.4	4.5	16	4.6	121.36
%W$_c$	**C170**						
2.0	3	32	22.1				
2.5	6	27.3	45.5				
3.0	7	30.4	68.8				
3.5	8	12.8	66.2				
4.0	9	9.7	74.5				
4.5	11	3.0	89.4				

Note:

ER	Expansion Ratio	HLT	Half-life in seconds
FI	Foam Index		

Table 2: Optimum foamant water content, FI, and Foam Classification* of the nine bitumen types (in order of decreasing FI, or decreasing suitability for foaming).

Bitumen Type	**%,Optimum Foamant Water**	**Foam Index**	**Foam Classification**
VEN180	2.6	224	Very Good
AR4000-1	2	143.5	Good
AR2000	2	118.6	Moderate
VEN80	3	114.9	Moderate
SHL180	3.5	109	Moderate
AR4000-2	2	89.7	Poor
C170	3.5	66	Unsuitable
SHL80	2.5	55.7	Unsuitable
DLT80	2	48.4	Unsuitable

* The quality of foam and its suitability to be used and mixed with aggregates.

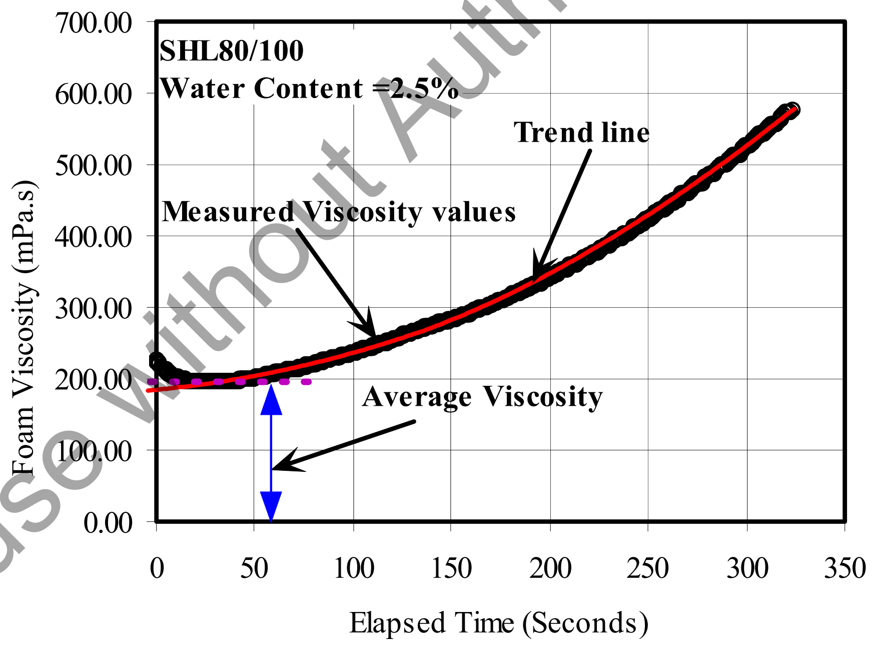

Figure 2: Relationship between foam viscosity (mPa.s) and elapsed time (seconds).

5 DETERMINING OPTIMUM FOAMANT WATER CONTENT

This new approach assumes that the optimum foamant water is that which produces the lowest rotational viscosity (measured by the Brookfield rotational viscometer) of the foam bitumen. The average viscosity over a period of 60 s was computed for different foamant water contents. The relationship between the percentage of water content and average viscosity was then plotted as shown in Figures 3 and 4. The water content that produces the minimum viscosity is then considered the optimum foamant water content. As shown in Figures 3 and 4, the relationship between foam viscosity and water content has a minimum value for viscosity. Sometimes two minima can be detected. In such cases, the absolute minimum was considered the one of interest.

With this new approach, some explanations for the discrepancies in the current empirical systems can now be given. For example, according to the empirical parameters (expansion ratio, half-life, and FI), SHL80 was classified as poor, although it was possible to mix it effectively with the aggregate matrix without any problems. Examining Figure 3, the foam viscosity of the SHL80 is about 190 mPa.s, which is good enough to ensure effective mixing (for HMA the mixing viscosity range is 170±20 mPa.s). In addition, comparing the foam viscosities of SHL80, SHL180, and VEN180, there is no significant difference between them (Saleh, 2004a). However, according to the empirical parameters (expansion ratio and half-life) VEN180 was found to be superior compared to SHL80 and SHL180. The same argument can be made for AR4000-2 which was classified as producing a poor foam according to the FI value, although it was later found to mix nicely with aggregate, which can be explained by its reasonable foam viscosity of 250 mPa.s. This new approach appears to be more reliable as it is based on a fundamental parameter, namely viscosity.

A comparison between the optimum foamant water contents of the current and new approach has been made and it was found that there are some similarities and differences between the results of the two methods for some bitumens. This research indicates that the measurements of average foam viscosity may be a reliable indicator of the quality and suitability of foamed bitumen for mixing. Further research is required to investigate its repeatability and reliability, and the impact of typical field mixing temperatures on bitumen foam viscosity.

6 OPTIMUM MIXING MOISTURE AND MIXING FOAM CONTENTS

The approach using simultaneous determination of optimum mixing moisture (OMMC) and optimum mixing foam (OMFC) contents, which was discussed in (Saleh & Herrington 2003, Saleh 2004a, Saleh 2004b), was used. The contour lines of the resilient moduli for specimens prepared with different combinations of water and foam contents were plotted. The mix combination that maximised the resilient modulus was considered the optimum combination.

7 MECHANICAL PROPERTIES OF FOAM-STABILISED MIXES

After determining the optimum mixing moisture content (OMMC) and the optimum mixing foam content (OMFC) for the different aggregate gradations and types of mineral fillers, several specimens were prepared at these optimum values to test their mechanical properties.

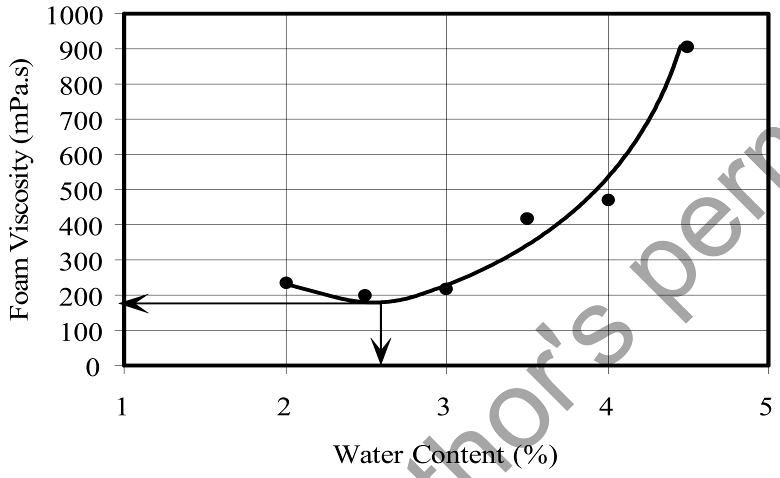

Figure 3: Relationship between foam viscosity (mPa.s) and % foamant water for SHL80 bitumen.

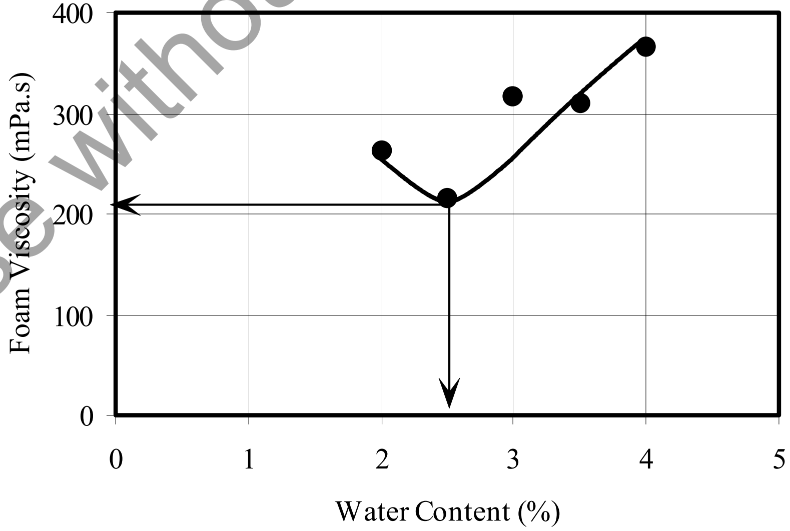

Figure 4: Relationship between foam viscosity (mPa.s) and % foamant water for SHL180 bitumen.

The aggregate temperature was about 20 °C, which is the same as room temperature at the time of testing. The properties that were analysed for these mixes are resilient modulus, temperature susceptibility, moisture susceptibility, indirect tensile strength, fracture energy, California Bearing Ratio (CBR) and fatigue life. Only fracture energy is shown here in this paper due the size limitation but the complete results can be found in Saleh (2004a).

7.1 Fracture Energy

The fracture energy of foam-stabilised mixes was computed by calculating the area under the force displacement curve using the indirect tensile test as shown in Figure 5. This parameter is highly correlated to the fatigue life of the mix. Figure 5 shows a comparison between the force displacement curves of the AC10 HMA and M20FA1C foam-stabilised mix. The M20FA1C is a foam stabilised mix made of AP-20 gradation with fly ash type C and 1.0% cement as mineral filler. The AC10 hot mix asphalt is a dense graded mix with a maximum nominal aggregate size 10 mm. It is clear from this graph that the fracture energy of the HMA is much higher than that of the foam-stabilised mixes. In addition, the AC10 HMA shows much more flexibility than the foam-stabilised mixes since the amount of deformation before failure for the HMA is much higher than that for the foam-stabilised mix.

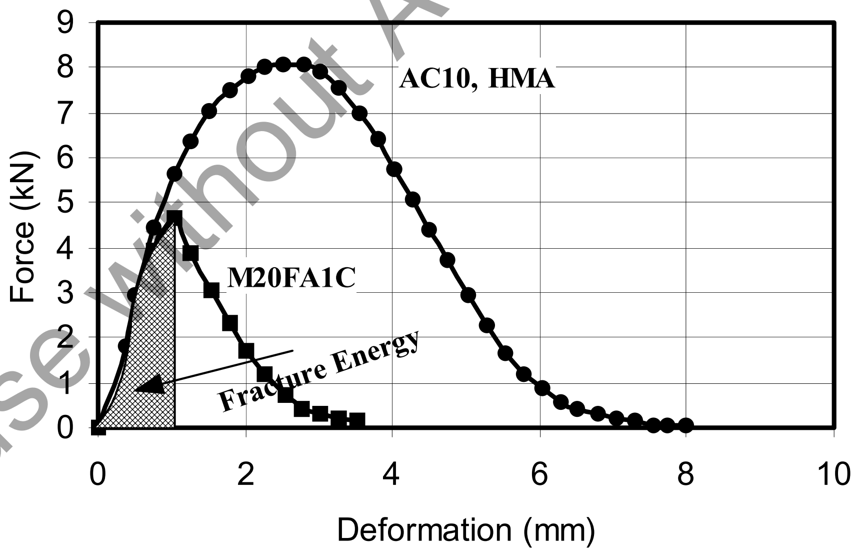

FIGURE 5: Comparison between fracture energy for M20FA1C foam-stabilised and dense graded hot mix asphalt (AC10HMA) mixes.

8 CONCLUSIONS

The current foamability test parameters showed discrepancies in characterising the foam quality of the different bitumen types due to the empirical nature of the tests. A new characterisation system based on the average viscosity of the foamed bitumen obtained over a period of 60 seconds has been introduced and examined for different bitumen types. In addition, the suggested new system provides a way to optimise the foamant water content, and provides a direct measurement of the actual viscosity of the foam. The newly proposed system could provide some explanations to the discrepancies in the current system. The fracture energy of the foam bitumen mix has been evaluated and compared with that of the HMA. It was found that, fracture energy of the foam stabilised mix is less than that of the hot mix asphalt. This indicates that the fatigue life of the foam stabilised mixes is likely to be less than of the hot mix asphalts.

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