EFFECT OF CEMENT DUST ON COHESION AND FATIGUE-RESISTANCE OF HOT-MIX ASPHALT

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ABSTRACT

This paper describes the physical influence of adding cement dust on the cohesion of asphalt-aggregate mixtures and improvement of detects in fatigue resistance. The physical effect was measured mainly by the indirect tensile strength of cylindrical specimens of hot-mix asphalt (HMA). Cohesion of two asphalt-aggregate mixtures was measured. The mixes differed in the source of aggregate (A and B), but with both gradations according to Marshall method. The effects would thus be related only to the cement dust and the aggregate characteristics. These effects were quantitatively evaluated by the changes in the values of cohesion when cement dust was added at medium and high temperatures. On the other hand, the effect of cement dust on the fatigue resistance was assessed by the changes in the flow. Additionally, the values of mastic film thickness corresponding to cohesion required to resist fatigue micro-cracks were predicted for each mixture. The results of the investigation showed that addition of 2 % cement dust increases cohesion as well as cohesion ratio at the two temperatures while reducing flow of asphalt-aggregate mixtures, in effect increasing stiffness and fatigue resistance. Regarding the aggregate characteristics, the response of the mixtures to the same amount of cement dust differed due to aggregate source. Based on the mixture physical properties gained after addition of cement dust, Mix-B proved to be more cohesive and resistant to fatigue than Mix-A. The cohesion and film-thickness relationship was found useful in predicting the ideal zones where micro-cracks are resisted. The cohesion ratio may be considered analogous to tensile strength ratio used to measure the stripping potential of a mixture. Hence, cement dust can be used as additive to improve fatigue-resistance and reduce stripping potential.

Keywords: *cement dust; cohesion; hot-mix asphalt; fatigue resistance; indirect tensile strength; aggregate characteristics; Marshall Method; film thickness*

1. INTRODUCTION AND LITERATURE REVIEW

Cohesion is the molecular attraction by which the particles of a body are united throughout the mass. In compacted hot mix asphalt (HMA) mixtures, cohesion may be considered as the overall integrity of the material when subjected to load or stress. On a micro scale as in the binder-filer mastic that surrounds the aggregate, cohesion can be regarded as the resistance to micro-cracks leading to disintegration and deformation under different types of loading. In case adhesion between aggregate and asphalt film or binder-filer mortar is adequate, cohesive forces will develop in the asphalt mixture. Quantitatively, cohesion is the magnitude of the intercept of the Mohr Diagram. Loss of cohesion is typically manifested as softening of the asphalt-aggregate mixtures. Cohesive forces are affected by mix properties such as the aggregate source, binder viscosity, film thickness of the binder-filer mastic and temperature with cohesive forces being inversely proportional to mix temperature. Typically, Marshall Stability, resilient modulus or tensile strength test measures cohesive resistance. Recent studies used indirect tensile and unconfined compression tests to determine the cohesive strength of HMA mixtures (Christensen and Bonaquist, 2002). By analyzing indirect tensile test and compression data the cohesion strength (c) and angle of internal friction (φ) were directly obtained from the relationship

$$\tau_{max} = c + \sigma_N \tan(\varphi) \qquad (1)$$

Where τ_{max} is the shear stress at failure (kPa) and σ_N is the normal stress (kPa). Zaniewski and Srinivasan (2004) found that cohesion is linearly related to indirect tensile strength as depicted in Figure 1.

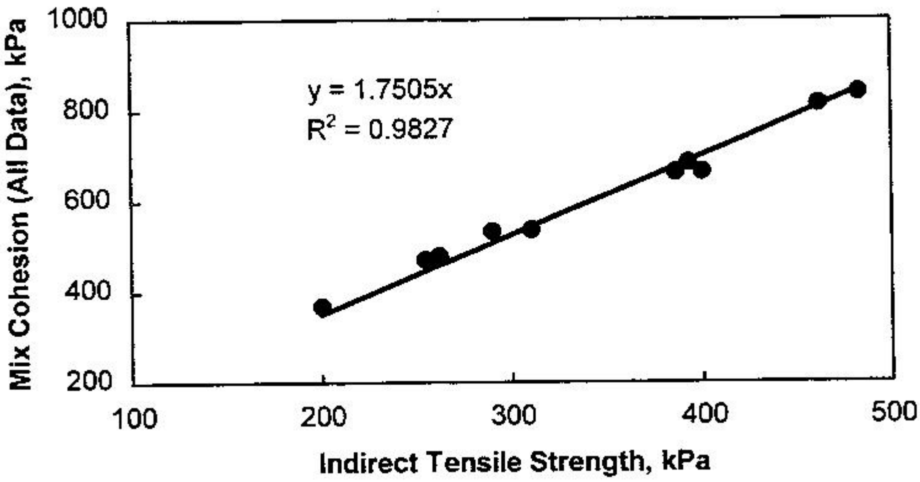

Figure 1. Relationship between cohesion and indirect tensile strength of mixtures - After Zaniewski and Srinivasan (2004)

The above relation shows that the indirect tensile strength is an indicator of mixture cohesion. The intercept in the relationship is considered zero and as such the mixture cohesion can be estimated as 1.75 times the indirect tensile strength with a high correlation coefficient R^2 of 0.98. An important phenomenon related to asphalt concrete mix and asphalt pavement behaviour is fatigue. Fatigue cracking is one of the main distresses that occur in hot mix asphalt (HMA) concrete pavements. It is load-induced distress resulting from tensile strain and leading ultimately to the structural collapse of the pavement requiring rehabilitation (Planche et al, 2003; Ofori-Abebresse, 2006). Attempts have been made to estimate fatigue resistance of hot mix asphalt concrete using approaches ranging from empirical methods through mechanistic-empirical procedures to purely mechanistic methods (Seibi et al, 2001; Ali et al, 2001; Lytton et al, 2005). A study concluded that there exists a relationship between the mixture indirect tensile strength and its estimated fatigue life and rutting potential (Khosla and Harikrishnan, 2007). For fatigue resistance of a mixture, they recommended a minimum tensile-strength criterion for different traffic levels. It was found that a minimum tensile strength corresponding to a given equivalent single-axle load is given by an ascending second-order polynomial curve. This paper had as objective to present the results of a research study to describe the physical influence of adding cement dust on the cohesion of asphalt-aggregate mixtures and improvement of fatigue resistance as well as reducing striping potential. Although the investigation considers the general performance of HMA mixtures when cement dust is added, the chemical influence of adding cement or lime to asphalt is equally important. Al and Youssef (1983) recommended use of cement-modified, bitumen-stabilized silt to be used as subbase material or improved subgrade for low-volume roads. Lytton and co-workers (2005) have recently conducted significant research in this field. Their findings resulted in using hydrated lime In South Africa to improve stripping resistance and cohesion rather than cement.

2. THEORETICAL BACKGROUND

2.1. Cohesion and indirect tensile strength

The cohesion, c, of asphalt-aggregate mixture is thus related to the indirect tensile strength, ITS, as follows: $c = ITS$ (2)

$$ITS = (2P) / (\pi * t * h) \quad (3)$$

Where P is the compressive load (kN) applied on a cylindrical specimen along its diametric axis, t is the specimen diameter (mm) and h is the height of the specimen (mm).

The effect of temperature on cohesion was measured by comparing two sets of specimens tested at two different temperatures. For comparison, use was made of cohesion ratio, CR in per cent, expressed as in equation (4)

$$CR = [C_H/C_M][100\%] \quad (4)$$

Where C_H and C_M are mixture cohesion at high and medium temperatures, respectively

2.2. Binder-filler mastic thickness

The effect of cohesion on mixture fatigue can be obtained by relating cohesion to the mastic film thickness, F_t. The relation was found to be a parabola, defining both routes of increasing and decreasing fatigue resistance. The film thickness affects fatigue in two ways: by adhesion failure and cohesion failure. The first one is the de-bonding of the film from the aggregate surface with micro-cracks developing due to repetitive traffic loads. This type of failure occurs when the film thickness tends to be thinner. On the hand, cohesive failure is also manifested in the form of micro-cracks occurring in the mastic film itself as it tends to be thicker as illustrated in the results and analysis section.

The mastic film thickness F_t is given by

$$F_t = [(P_{be})(G_{mb})] / [(G_b)(A_s)] \quad (5)$$
$$P_{be} = [(P_b) - (P_{ba})(P_s)/(100)] \quad (5\text{-a})$$
$$P_{ba} = [(1/G_{sb}) - (1/G_{se})][G_b][100\%] \quad (5\text{-b})$$
$$G_{se} = [P_s]/[(100/G_{mm}) - (P_b/G_b)] \quad (5\text{-c})$$

Where P_{be} is the % effective asphalt content in the mixture (by weight of mix), G_{mb} is the specific gravity of the compacted mix, G_b is the specific gravity of the asphalt binder, A_s is the surface area of the combined aggregate of the mixture (cm^2), P_b is the % asphalt content of the mixture (by weight of mix), P_{ba} is the % asphalt absorbed by the aggregate, P_s is % of aggregate in the mixture, G_{sb} is the specific gravity of the combined aggregate in the mixture, G_{se} is the effective specific gravity of the aggregate and G_{mm} is the maximum specific gravity of the mixture.

3. EXPERIMENTAL WORK

3.1. Materials and mix design

Asphalt-cement of grade 60/70 was used to prepare two mixture types (Mix-A and Mix-B). Two percent of cement dust was added to the aggregate of each mixture, thereby replacing 2 % of the mix-design mineral filler of 6 %. The difference between the two mixes was limited to the sources of aggregate, the following factors being kept the same:

- Aggregate-gradation specification limits, percent cement dust and asphalt grade;
- Preparation process (mix design method); and
- Testing conditions (conditioning, loading rate etc.)

The values of the optimum asphalt content were determined to be 5.2 and 5.5 %, respectively, for Mix-A and Mix-B using Marshall method of mix design (ASTM D1559; AASHTO T245) and the Asphalt Institute MS-2 (1993). Figures 2 and 3 depict the aggregate gradations of Mix-A and Mix-B, respectively.

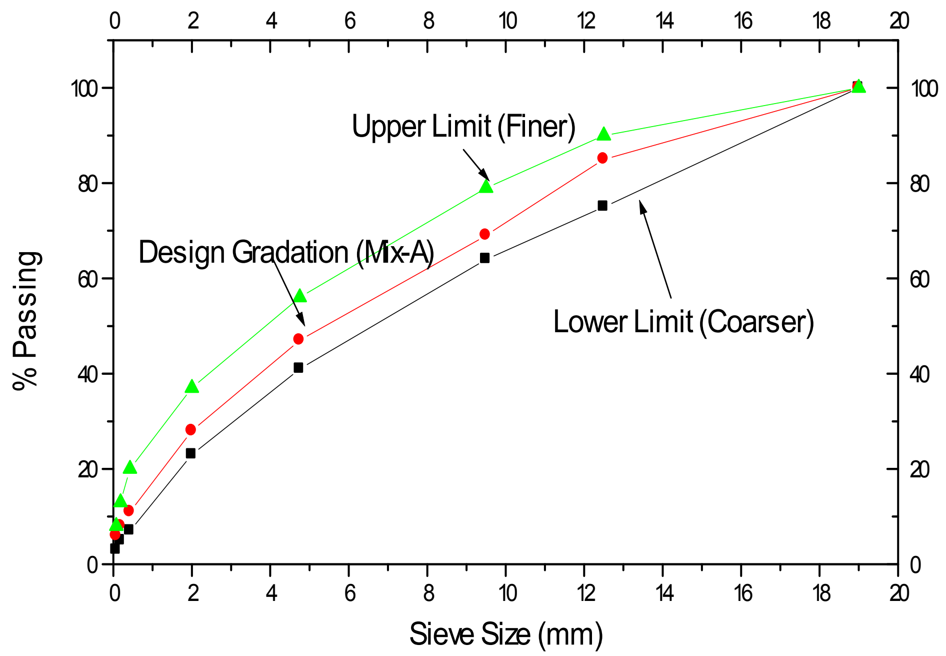

Figure 2. Aggregate gradation: Mix-A

3.2. Laboratory testing and analysis

The combined aggregate specific gravity G_{sb} for both aggregate sources A and B were determined along with that of the bitumen. For each mix type, six specimens of 101.6 mm in diameter and 63.5-mm height were prepared in the laboratory to measure the compacted specific gravity of the mix following ASTM standard method of testing (AASHTO T166), indirect tensile strength and flow. The ITS and flow were conducted by soaking 3 specimens for half an hour in a water bath at 25 ºC (medium temperature); the other 3 specimens were soaked before testing for 24-hours at 60 ºC (high temperature). The maximum specific gravity was determined for each mixture in accordance with Rice method (AASHTO T209). The computations were then carried out following equations (5-c), (5-b) and (5-a) to determine the mix characteristics G_{se}, P_{ba} and P_{be}, respectively. The results of the mix design and volumetric analysis are summarized in Table 1 for G_{sb}, P_{ba} and absorbed water, Table 2 for compacted mixes and Table 3 for loose mixtures.

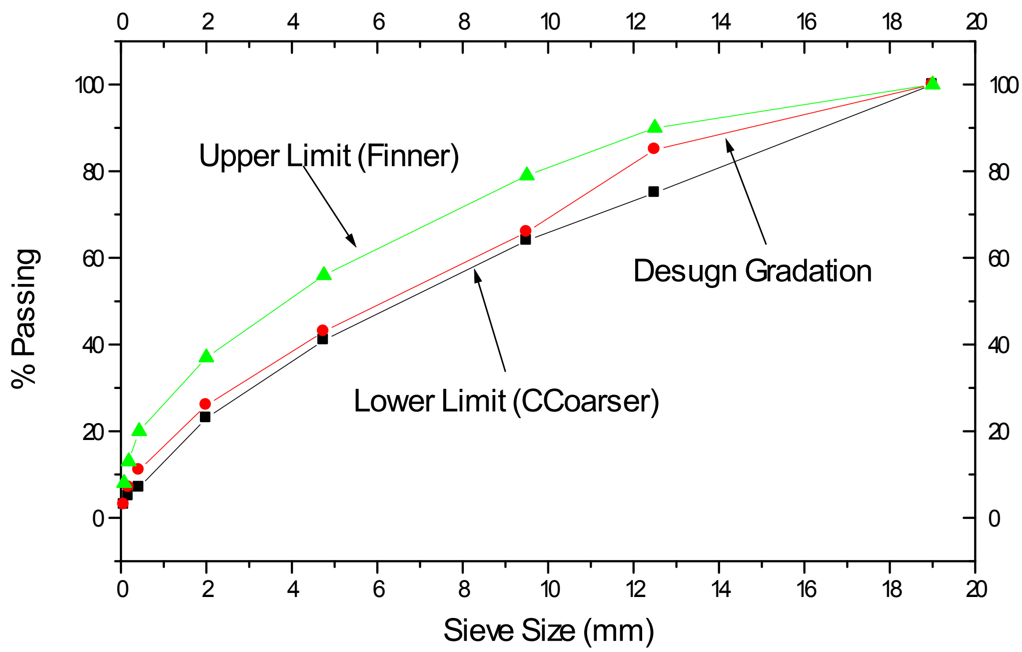

Figure 3. Aggregate gradation: Mix-B

Table 1: Combined aggregate specific gravity, absorbed water and absorbed bitumen

Mix Type	G_{sb}	P_{wa}	P_{ba}
	---	%	%
Mix-A	2.726	1.889	1.086
Mix-B	2.593	1.905	1.469

Table 2: Volumetric properties of compacted mixtures

Mix Type	G_{mb}	P_a	G_{mm}	F_t
	-----	%	% Comp	Micro m
Mix-A	2.45	4.854	95	9.96
Mix-B	2.349	4.98	95	9.41

Table 3: Volumetric properties of loose mixtures

Mix Type	AC	G_b	G_{mm}	G_{se}	P_{ba}	P_{be}
	%	----	----	-----	%	%
Mix-A	5.2	1.026	2.575	2.807	1.086	4.17
Mix-B	5.5	1.026	2.472	2.693	1.469	4.112

4. RESULTS AND DISCUSSION

The values of the mastic film thickness, F_t, shown in Table 4 were determined using equation (5). Statistical analysis was carried out applying modern techniques (Montgomery et al, 2007) and program Origin (1999). Analysis of variance (ANOVA) for the means and related parameters was conducted at 5% significance level for difference in the cohesion of the mixtures before and after addition of cement dust (Montgomery, 2005). Table 5 presents a summary of the analysis.

4.1. Influence of cement dust on mix cohesion and cohesion ratio

Figures 4 and 5 show medium-temperature cohesion and cohesion ratio, respectively, for both mixes with (W) and without (W/O) cement dust. It is observed from Figure 4 that the values of cohesion with cement dust are greater than those without cement dust by about 12.3 % for Mix-A and 11.5 % for Mix-B. Figure 5 indicates that the values of cohesion ratio, CR, with cement dust are greater than CR without cement dust by 46 % for Mix-A and 10.5 % for Mix-B. It is apparent that both the values of cohesion and cohesion ratio with cement dust are significantly larger than those without cement dust, although the difference is less for Mix-B, particularly for CR.

Table 4: Cohesion and film thickness of the mixtures

Mix-A		Mix-B	
Cohesion (kPa)	Film thickness (μm)	Cohesion (kPa)	Film thickness (μm)
44	8	58	6
57	9	71	7
69	10	85	8
76	11	94	10
80	12	100	10
Ü	Ü	105	12

Table 5: Analysis of variance for cohesion of mixtures

Statistical parameter	Cohesion (kPa)			
	Mix-A		Mix-B	
	W/O	W	W/O	W
Mean	56	65	76	85
Std Dev	15		18	
At 0.05 Sig. level	Means are significantly different		Means are significantly different	
(With/Without) %	87		89	

4.2. Effect of aggregate source on mixture cohesion and cohesion ratio

Since the experimental study was designed so that the main variables were inclusion of cement dust and the aggregate type, the effect of aggregate source can be determined on cohesion and cohesion ratio whether cement dust was used or not. From Figure 4 it can be seen for the mixes without cement dust that Mix-A has more cohesion than Mix-B by 7.0%, while the effect was 6.3 % more for Mix-B when dust was used. However, the effect of aggregate type was more pronounced in the values of cohesion ratio (see Figure 5). Mix-B showed cohesion ratio higher than that of Mix-A by 46 % but only 10.5 % higher CR when cement dust was used. These results indicate that the behaviour of the two aggregate types were different in the mixture without cement dust due to variation in aggregate characteristics as reflected by the difference in CR values. However, addition of cement dust reduced that effect since both aggregate types were affected by the addition of cement dust. Eventually, addition of cement dust affected cohesion and cohesion ratio of both aggregate types.

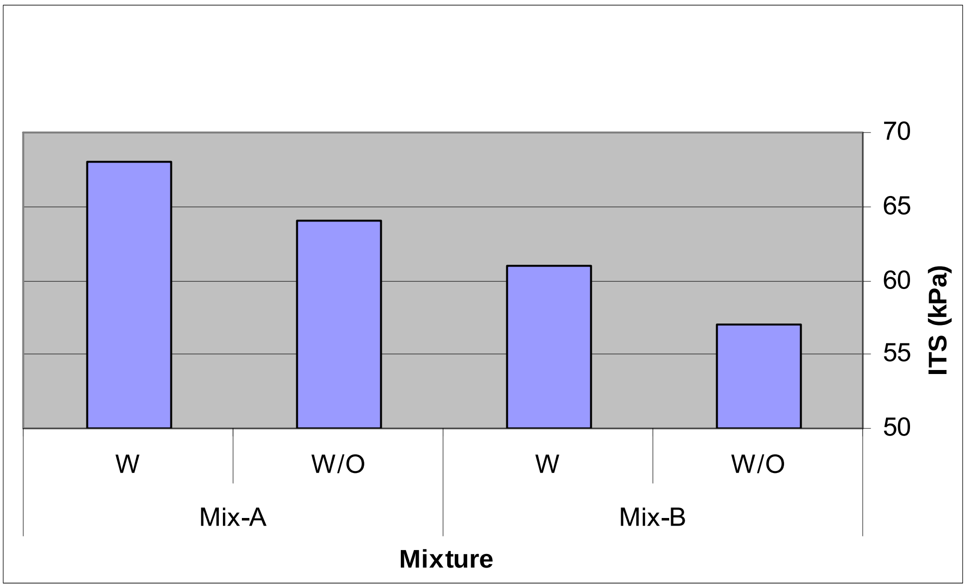

Figure 4. Effect of cement dust on medium temperature cohesion: Mix-A and Mix-B

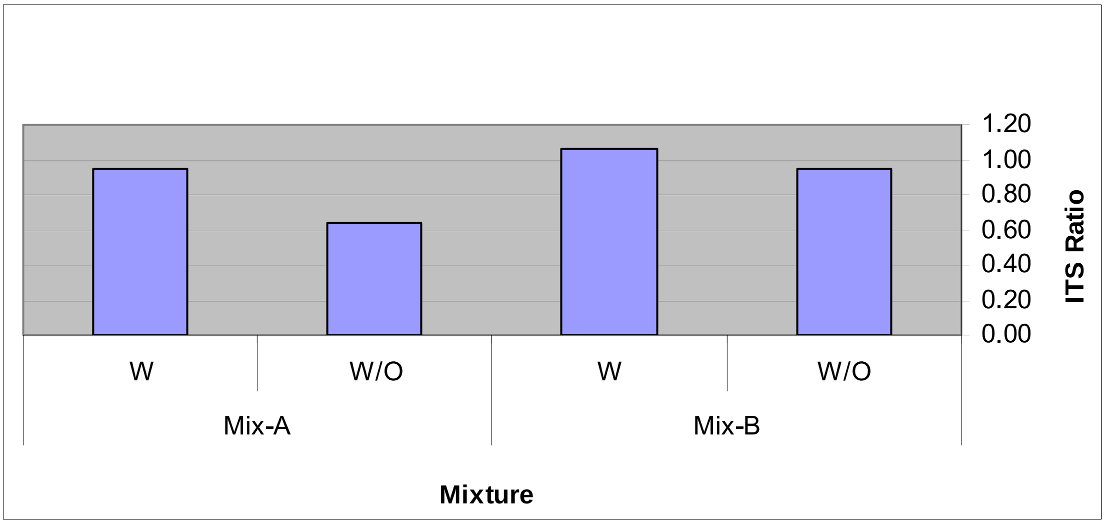

Figure 5. Cohesion ratio with and without cement dust: Mix-A and Mix-B

4.3. Influence of cement dust on fatigue resistance of mixtures

Pavement engineering designers and researchers have recently focused with great concern on incorporation of fatigue and permanent deformation as failure criteria into mechanistic-empirical design methodologies .A simple approach is presented in this paper to estimate fatigue resistance of binder-filler mastic in hot mix asphalt concrete using the relation that exists among cohesion, flow of mastic film thickness and fatigue cracking.

Figure 6 reflects the effect of cement dust on flow associated with cohesion at medium temperature. The figure shows that flow values without cement dust (W/O) are greater than flow with cement dust (W) by about 15.4 % for Mix-A and 12.9 % for Mix-B. The results indicate that fatigue resistance of both mixes increased after addition of cement dust by gaining more stiffness and resistance to flow. Figure 7 compares variation of flow between the two mixtures whether or not cement dust is used. After addition of cement dust, the results show only small difference between the mixes, while before addition the flow of Mix-A is larger than that of Mix-B by 3.1%. Hence, it can be estimated relatively that Mix-A is slightly more prone to fatigue cracking than Mix-B.

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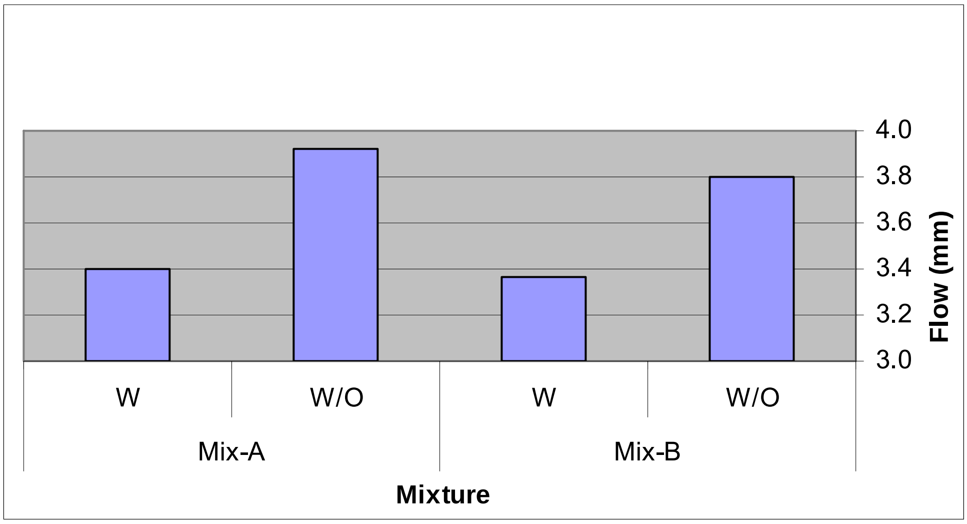

Figure 6. Effect of cement dust on flow at medium temperature: Mix-A and Mix-B

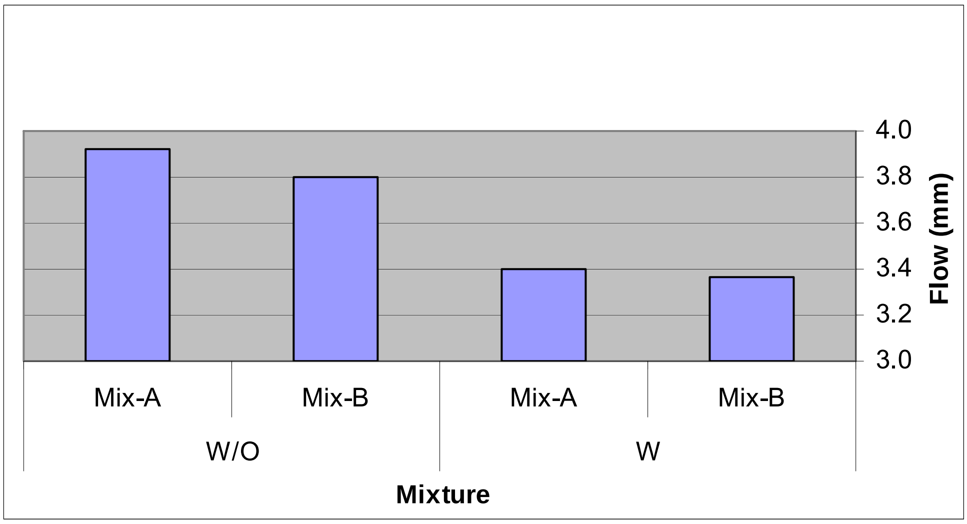

Figure 7. Comparison of flow with and without cement dust: Mix-A and Mix-B

Figures 8 and 9 for Mix-A and Mix-B, respectively, show two significant phenomena: the ideal zone (IZ) of fatigue resistance and the pattern of increase and decrease of fatigue resistance (IOFR and DOFR) with respect to film thickness and cohesion. The regression equations modeling the curves and the values of the corresponding correlation coefficient, R^2, are provided in equations (6) and (7), respectively, for Mix-A and Mix-B. The figures illustrate that the IZ is situated between the c values corresponding to F_t at optimum asphalt content of ± 0.3 (OAC ± 0.3). The value 0.3 is the tolerance of OAC adopted in Marshal method. This means that whenever the F_t value is behind the minimum point of the IZ (i.e. at OAC - 0.3), micro cracks might occur due to separation of aggregate particles from each other because of thinner F_t. On the other side of the figures, where the F_t increases beyond the maximum point of IZ (at OAC + 0.3), fatigue resistance reduces because F_t increases to the extent that the internal friction between the aggregate particles decreases. Consequently, the shear strength or cohesion of the mixtures also decreases leading to probable plastic failure such as shoving, corrugation, permanent deformation, etc.). The values of F_t at OAC ± 0.3 can be found in the laboratory by fabricating cylindrical molds at two values of OAC (i.e. at ±0.3) to measure the compacted specific gravity (G_{mb}), then equations 5 can be used to compute Ft. The c values can be calculated from equations 6 and 7 of the c- F_t relationship.

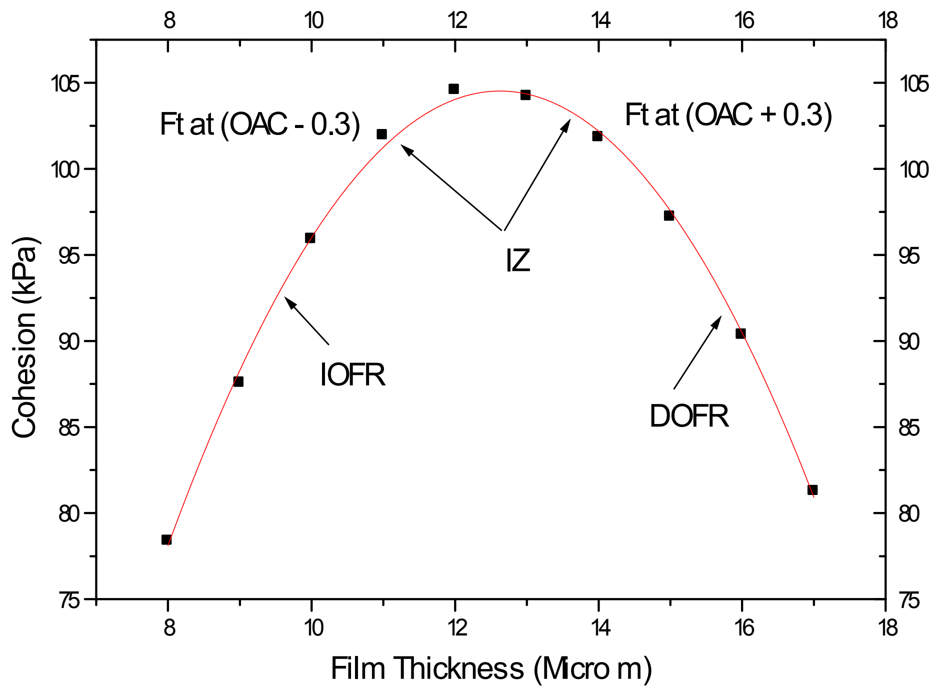

Figure 8. Relation between mastic film thickness and cohesion: Mix-A

$Y = -187 + 42\,X - 1.6\,X^2$ (6) ($R^2 = 0.97$)

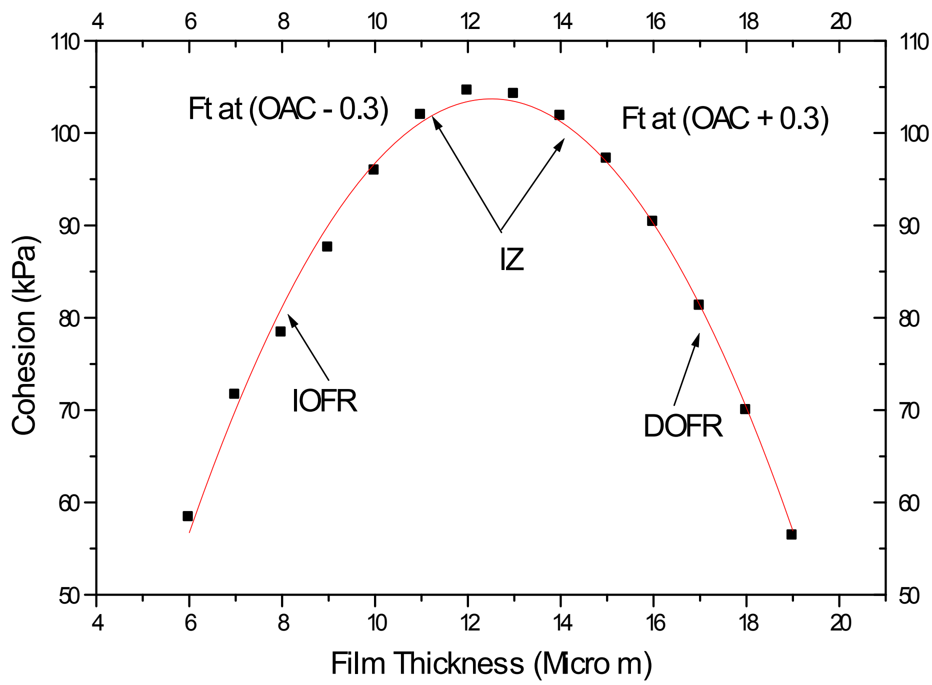

Figure 9. Relation between mastic film thickness and cohesion: Mix-B

$Y = 2.75 + 2.92X - 0.17X^2$ (7) ($R^2 = 0.95$)

5. CONCLUSIONS AND RECOMMENDATIONS

Within the scope of this investigation, the results presented and discussions made, the following conclusions and recommendations may be drawn:

Replacement of 2 % mineral filler by the same amount of cement dust increases cohesion and the cohesion ratio, while decreases the flow of the mixtures. However, the response of the mixture to the same amount of cement dust differs according to aggregate source. Further, addition of cement dust decreases flow of asphalt-aggregate mixture and increases stiffness hence increases the fatigue resistance. It was also determined that the ideal values of cohesion and film thickness resulting from c-Ft curves represent the ideal values for fatigue resistance. Based on the mixture properties of cohesion, cohesion-ratio and flow acquired from addition of cement dust, Mix-B (containing aggregate type B) was found more cohesive with relatively high resistance to fatigue than Mix-A of type B aggregate. Thus, the film thickness-cohesion relationship can be used to determine typical values for these parameters to resist micro cracking. Additionally, cohesion ratio may be considered as analogous to tensile strength ratio used as a measure of stripping potential of a mixture. Hence, cement dust can be used as additives to improve the fatigue resistance, stripping potential, as well as to improve the gradation of aggregate especially when the limit of the finer side does not achieved.

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