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Determination of Binder Film Thickness for Bituminous Mixtures prepared with various Types of Fillers

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Abstract: Roads form the lifeline of any country. It is considered to be an engineered structure and the pavement is expected to serve its designed life and meet the performance criteria for better economy. Various materials constitute the different layers of the pavement and their characterization becomes important for durability. In spite of these considerations however, many factors contribute to early pavement failure and improper material characterization is just one of them.

The Bituminous mix which is used for the surface and binder courses is formed as a conglomeration of the binder, graded aggregates and voids which forms a stable mixture which can resist wear and tear as well as heavy wheel loads when used in the field. The bituminous mix needs to meet the volumetric requirements to attain stability. When bitumen is mixed with aggregates in a heated condition, the binder forms a coating around the aggregate particle which is termed as Asphalt film thickness (AFT) which is not measured but calculated. Bitumen due to its visco-elastic nature should be used at the optimum and the specified temperature to provide a minimum uniform film thickness to ensure proper bonding in the Bitumen mastic.

Fillers play a major role in determining the properties and the behaviour of the mixture, especially the binding and aggregate interlocking effects. The filler has the ability to increase the resistance of particle to move within the mix matrix and/or works as an active material when it interacts with the asphalt cement to change the properties of the mastic. Mineral fillers serve a dual purpose when added to asphalt mixes, the portion of the mineral filler that is finer than the thickness of the asphalt film blends with asphalt cement binder to form a mortar or mastic that contributes to improved stiffening of the mix.

In the present study the film thickness was determined by Hveem method by determining the total surface area and the effect of fillers thereon is discussed. The effect of types of fillers in varying percentage, in the performance of hot-mix-asphalt is also studied. Three types of fillers namely, Hydrated lime, Ordinary Portland Cement, and Fly ash were used as fillers in the present study. Their percentage by weight of aggregates was varied as 2%, 4% and 6% to study their effect on the mix prepared for BC Grade II. The optimum binder content was determined for the various fillers and moisture susceptibility of bituminous mixtures was evaluated..

The results of film thickness determination reveals that an average film thickness of 6 μm is obtained for all fillers which is necessary for durability of the mixes. The Fatigue results show that Lime at 4% can be used for enhanced performance and 2% is recommended, when cement or fly ash is used as filler material.

Keywords: Asphalt Film thickness, volumetric properties, aggregate surface area, Stone binder interaction, durability, fillers

1. Introduction

In recent years, many countries have experienced an increase in truck pressure, axle loads, and traffic volumes. Tire pressure and axle load increases means that the bituminous layer near the pavement surface is exposed to higher stresses. High density of traffic in terms of commercial vehicles, overloading of trucks and significant variations in daily and seasonal temperature of pavements have been reasonable for development of distress indications like ravelling, undulations, rutting, cracking, bleeding, shoving and potholing of bituminous surfaces. Appropriate material combinations of aggregates, binders and fillers have been found to results longer life for wearing courses depending upon the percentage of filler and type of fillers used [8].

Fillers, in particular, as one of the ingredients in HMA, have only been thought to fill voids in the aggregate. However, studies indicated that the role of fillers in bituminous mixture performance is more than filling voids depending on the type used. The filler also influences the optimum binder content(OBC) in bituminous mixtures by increasing the surface area of mineral particles and, at the same time, the surface properties of the filler particles modify significantly the rheological properties of asphalt such as penetration, ductility, and also those of the mixture, such as resistance to rutting. In order to improve the pavement performance, it is necessary to ensure that adequate behavior of the bituminous mixtures is achieved, which depends essentially on their composition. Therefore, selecting the proper type of filler in bituminous mixtures would improve the filler's properties.

It is generally believed that asphalt paving mixes should have an adequate asphalt film thickness around the aggregate particles to ensure reasonable durability of the mixture. The minimum asphalt film thickness generally recommended ranges from six to eight microns [1].

2. Objectives of Present study

i. To study the effect of the different types of fillers on increase in surface area and film thickness.
ii. To evaluate the mechanical properties of the Bituminous mixes by Marshall Mix design.
iii. To study the effect of varying filler type & content on the mechanical and volumetric properties of bituminous mixes.
iv. To study the change of moisture sensitivity with varying filler type and content.
v. To evaluate the performance enhancement of the mixes with the use of varying filler type and content as an effect of variation in film thickness.

3. Literature Review

3.1 Boris Radovskiy, et.al., [2] reviewed the history of VMA and average film thickness where he stated that the minimum VMA requirement has been a property proposed since 1950's for use in bituminous mix design provisions, but problems in achieving VMA in mixtures have led to several new research studies. Some researchers recommend using the average binder film thickness to supplement the minimum VMA criteria in the volumetric mix design and the conventional calculation of the film thickness does not require any information on porosity of mixture or on degree of compaction. He concluded that a new definition of film thickness is proposed. A model for film thickness calculation is developed. The results of calculations are logical and agree with some important data reported in previous publications.

3.2 Kandhal ,et.al [3] in their review of literature stated that thicker asphalt binder films produced mixes which were flexible and durable, while thin films produced mixes which were brittle, tended to crack and ravel excessively, retarded pavement performance, and reduced its useful service life. On the basis of the data they analysed, average film thicknesses ranging from 6 to 8 microns were found to have provided the most desirable pavement mixtures. They calculated average film thickness by dividing volume of asphalt by surface area of aggregate. Surface area of aggregate depends on the gradation of aggregate being used in the mixture and surface area factor for each sieve, where surface area calculated by multiplying per cent passing of aggregate for a certain sieve by surface area factor of that sieve. Asphalt Institute proposed surface area factors to be used in calculating surface area of aggregate. They also concluded that the film thickness decreases as the surface area of the aggregate is increased. Studies have shown that asphalt mix durability is directly related to asphalt film thickness.

3.3 Satish Chandraand Rajan Choudhary, et.al[4],in their study have made an attempt on the possible use of three industrial wastes such as marble dust, fly ash and granite dust along with hydrated lime and conventional stone dust from quartzite, as filler in bituminous mix preparations. Bituminous concrete (BC) mixes were designed according to the Marshall method at four different percentages for the five types of fillers. The performances of bituminous concrete mixes were studied through moisture susceptibility, static creep, flexural fatigue, and wheel-tracking tests. The results suggest that marble dust, granite dust, and fly ash can be used as filler in bituminous mixes. Among the three industrial wastes, marble dust shows most potential filler and will shows very economical also, as mixes with marble dust have the least optimum binder content (OBC).

3.4 Talal H. Fadhil, et.al [5] in their study White Cement Kiln Dust was used as filler in Hot Mix Asphalt (HMA) production which results in more economy and leads to maintain the environment clean and healthy. In this research, various percentages of WCKD taken from Fallujah cement plant were used in addition to two filler types such as Cement and Limestone powder to prepare bituminous concrete mixes. Five tests were carried to evaluate the performance of these different bituminous concrete mixes, standard Marshall Test at 60^{0}C and 70^{0}C, to test immersed samples for four days in water at room temperature (24^{0}C), Indirect Tensile Strength (ITS) to test conditioning and un-conditioning samples. All the test results were satisfactory and within the AASHTO and Iraqi roads specifications. The results showed that using WCKD as a filler could save the environment and give confidence to the HMA producers to use this cheap material in their works.

3.5 Debashish Kar, Mahabir Panda and Jyoti Prakash Giri, [6], in their study cement and stone dusts are used as filler material in bituminous mix. A study has been carried out in this study to investigate the use of fly ash, a by-product of a coal based thermal power plant in bituminous paving mixes. For comparison, conventional mixes with cement and stone dust have also been considered. Marshall Test has been adopted for the purpose of mix design as well as evaluation of bituminous mixes. Other performance tests such as indirect tensile strength and retained stability have also been conducted. It was noticed that the mixes with fly ash as filler show slightly inferior properties compared to conventional mixes and full fill the desired criteria as per specifications. Therefore, it has been suggested to utilize fly ash wherever accessible, not only lowering the cost of execution, but also somewhat resolve the fly ash utilization and dumping problems.

3.6 B.Durga Priyanka, et.al[7], studied the likelihood of using fly ash as filler in Bituminous mixes where in general cement, stone dust are used. For comparison, stone dust also used to prepare conventional mix. Marshall stability test is adopted to obtain the properties like stability, flow value, % air voids, voids in mineral aggregate (VMA), voids filled with bitumen (VFB) for a Dense Bituminous Macadam (DBM) mix of Grading I. The tentative work is carried out by using specifications from MORTH. By substituting the stone dust with fly ash at various percentages like 4%, 8%, 12% the results were analyzed. The variation of mechanical properties, optimum bitumen content and fly ash contents were evaluated. It was observed that the mixes with fly ash as filler not differ much in properties when compared with conventional mix and satisfy desired criteria specified by a much higher margin. Hence, it has been recommended to utilize fly ash wherever available, not only reducing the cost of execution, but also partly solve the fly ash utilization and disposal problems.

Based on the above literature review, it was understood that film thickness has to be adequate for better durability, and to reduce the ageing effect. When the mix gradation tends to be open with more permeability, the air voids would increase, having thinner bitumen film thickness and results in excessive ageing. The portion of mineral filler that is finer than the thickness of bitumen film blends with bitumen to form a mortar that contributes to improved stiffening of the mix. This study is intended to evaluate the effect of different fillers namely ordinary Portland cement, hydrated lime and fly ash passing 0.075mm sieve in varying contents on the bitumen film thickness calculated by the empirical method given by Hveem. The Marshall and Moisture susceptibility tests were used to investigate the mixture in the laboratory.

4. General

In this present investigation, the adopted gradation was Bituminous Concrete Grade II as per MORTH specification and the BC mixes were prepared using VG30 grade binder with different types of fillers with varying percentage.

4.1 Material Characterisation

a. Aggregate: The aggregate test results were determined and are tabulated in Table 4.1

Table 1: Test values of aggregates

Sl. No.	Test	Method of Test adopted	Results Obtained	Specification Requirement as Per MORTH (V Revision)
1	Impact value in %	IS:2386 part 4	26.5	Max 24%
2	Loss Angeles abrasion in %	IS:2386 part 4	28.76	Max 30%
3	Combined index in %	IS:2386 part 4	34.7	Max 35%
4	Specific gravity			

	a. 9 mm down aggregates b. 12.5 mm down aggregates c. 6.3 mm down aggregates d. Quarry Dust 4.75 mm down	IS:2386 part 4	2.625 2.600 2.610 2.680	-------- -------- -------- --------
5	Water absorption	IS:2386 part 4	0.65	Max 2%

b. Bitumen: For the present study bitumen VG30 grade was used in the preparation of HMA mixture. The bitumen was tested for its basic properties and found satisfactory according to IS.

c. Filler: The fillers which are finer than 75 micron in size used in the study were hydrated lime, ordinary Portland cement and fly ash. The filler content added in three different percentages (2, 4 and 6) by weight of aggregate for the preparation of BC mixes. The fillers are checked for specific gravity test using density bottle or specific gravity bottle and the results are tabulated in table 4.2

Table 2: Specific gravity of the fillers

Type of filler used	Specific gravity
Hydrated Lime	2.3
Ordinary Portland Cement	3.10
Fly ash	2.09

4.2 Procedure

The specimens were prepared using different types of fillers at varying percentages. The different fillers used were Lime, Ordinary Portland cement and fly ash at 2%, 4% and 6% by weight of aggregates. Marshall Method of mix design is used for the present study and accordingly the specimens were prepared. Compaction of specimen is done by giving 75 blows on either side of the mould. Specimens prepared were then subjected for stability and flow test using Marshall Stability equipment at test temperature of 60^0C. After that the test values were used for density voids analysis to determine OBC.

For moisture damage evaluation the specimens were prepared at OBC. Compaction of the specimen is done at 7% air voids. Then the prepared specimens were subjected to freezing and thawing cycle and followed by testing the specimens for Indirect Tensile Strength test.

Repeated indirect tensile strength test was carried out for studying the mixes for their fatigue behavior.

Asphalt film thickness calculations were done to study the effect of fillers on asphalt film thickness for the durability of the bituminous mixes.

The Marshall Test results obtained are as tabulated below in Table 4.3, 4.4, 4.5

Table 3: Marshall Properties at Optimum Binder Content – Lime Filler

Filler type/ Properties	Lime			Requirement as per MORTH
	2%	4%	6%	
OBC, %	5.69	5.66	5.706	5.4 minimum
Stability, Kg	1820.4	1905.1	1967.08	900
Flow, mm	3.37	3.5	3.35	**2-4**
Air voids %	3.920	3.277	3.622	**3-5**
Gt, gm/cc	2.462	2.404	2.412	-------
Gb, gm/cc	2.331	2.341	2.325	-------
VMA, %	17.05	16.466	16.71	**14 minimum**
VFB, %	77.01	80.095	78.335	**65-75**
Film thickness	7.891	7.218	6.735	-------

Table 4: Marshall Properties at Optimum Binder Content – Cement Filler

Filler type/ Properties	Cement			Requirement as per MORTH
	2%	4%	6%	
OBC, %	5.82	5.76	5.703	5.4 minimum
Stability, Kg	1808.1	1630	1730.9	900

Flow, mm	3.5	3.95	4.1	**2-4**
Air voids %	4.05	3.09	3.67	**3-5**
Gt, gm/cc	2.434	2.423	2.447	-------
Gb, gm/cc	2.361	2.367	2.35	-------
VMA, %	17.504	16.719	17.256	**14 minimum**
VFB, %	76.85	81.51	78.68	**65-75**
Film thickness	8.071	7.343	6.721	-------

Table 5: Marshall Properties at Optimum Binder Content – Fly Ash Filler

Filler type/ Properties	**Fly ash**			**Requirement as per MORTH**
	2%	**4%**	**6%**	
OBC, %	5.75	5.603	5.636	5.4 minimum
Stability, Kg	1306.7	1905.1	1502.9	900
Flow, mm	3.97	3.6	3.8	**2-4**
Air voids %	3.918	3.118	2.353	**3-5**
Gt, gm/cc	2.419	2.412	2.399	-------
Gb, gm/cc	2.324	2.337	2.343	-------
VMA, %	17.152	16.425	15.695	**14 minimum**
VFB, %	77.162	81.014	85.013	**65-75**
Film thickness	7.981	7.137	6.660	-------

4.3 Asphalt film thickness calculation

The technique used in calculating for asphalt film thickness is by Hveem Method of Mix design. The film thickness is the function of surface area of aggregate and the percent of binder used in the mixture. Table 4.6 below shows the surface area factors and total surface area calculation.

Table 6: Surface area factors and obtained surface area ‘SA’ in m^2/Kg

Hveem method of Surface area determination			
Sieve Size (mm)	**% Passing**	**Surface area Factor**	**Surface Area ‘SA’, m^2/kg (Surface factor x Passing %)**
26.5	100	0.41	0.41 x 1 = 0.41
19	100		
13.2	86.59		
9.5	83.43		
4.75	65.49	0.41	0.27
2.36	51.75	0.82	0.42
1.18	39.46	1.64	0.65
0.6	34.36	2.87	0.99
0.3	19.81	6.14	1.22
0.15	11.7	12.29	1.44
0.075	5.3	32.77	1.74
Cement	2	32.77	0.6554
Total Surface area SA'm^2/kg'			**7.37**

** Total surface area for 4% and 6% fillers are 8.03 and 8.68 in m^2/Kg and these values are same for other two fillers at 2%, 4% and 6%

$$TF = \left(\frac{Vasp}{SA * W}\right) * 1000 \qquad (8)$$

Where,
TF= Average film thickness in µ
Vasp= Effective volume of binder (lt)
SA= Surface area of the aggregate in m^2/Kg
W= Weight of aggregate

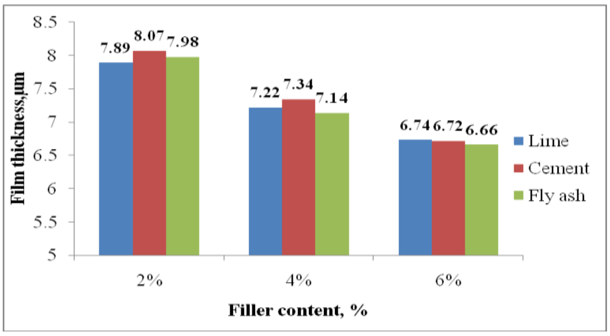

Figure 4.1 Variation of Film thickness with Filler content

4.4 Indirect Tensile Strength test

It is a design tool for evaluating moisture susceptibility of HMA mixes. In this test Marshall Specimens are subjected to compressive loads, which act along the vertical diametrical plane, which were tested unconditioned and conditioned as per standard procedure AASHTO 283

The load at failure was recorded and ITS values were calculated using the expression below.

$$\sigma x = \frac{2000 * P}{\pi * d * t} \qquad (10)$$

Where,

σ_x= Horizontal tensile stress, KPa

P= Applied load in N

d= Dia of specimen, mm

t= Thickness of specimen

The result thus obtained is represented in the bar chart shown in Fig 4.2

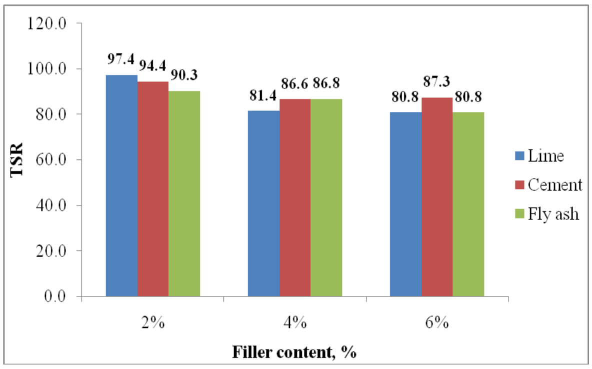

Figure 4.2 Variation of TSR with Filler content

3.5 Fatigue Test for Bituminous mixes

The test is carried out on the bituminous mixes for evaluating the fatigue life of BC mixes by subjecting the specimen to repeated loading at 250C test temperature. In this present investigation the fatigue life is tested for the specimens prepared for different types of fillers at different percentages. The input load for the test will be the failure load of ITS value of conditioned specimens prepared at OBC. And 30% of this ITS value is taken as stress level.

The result thus obtained is represented in the bar chart shown in Fig 4.3

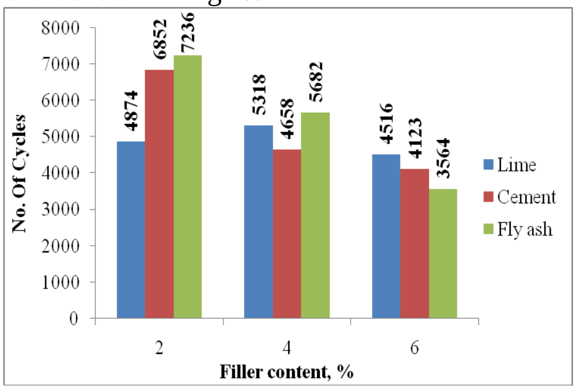

Figure 4.3 Variation of Fatigue life with Filler content

5. Conclusions

1. Mixes with cement filler requires higher bitumen content that makes them to be costly from practical point of view.This is probably due to the fact that there is higher bitumen absorption when mixes prepared with Cement. Hence higher optimum bitumen content values were required to fulfil the Marshal requirements. Whereas, mixtures prepared with lime or Fly ash filler, optimum asphalt content are relatively the same. The optimum bitumen content requirement in case of fly ash is less. Considering the free and abundant availability of fly ash particularly at places near thermal power plants and where coarse aggregates are scarce, use of fly ash shall be cheaper compared to other two types of fillers.
2. Stability values of mixes prepared with fly ash is found to be increasing up to maximum and then decreasing with the increase in the amount of filler content starting from 2% this is due to the fact that voids at lower filler content is too high and aggregates tend to be finer as filler content increases, hence both effect tend to reduce the stability values. Whereas, the stability values of mixes containing lime keeps increasing with the filler content. Higher stability values were obtained for mixtures containing lime for all filler contents. Mixes prepared with fly ash provide higher stability values for filler content 4%.
3. From the figure 4.1 it is observed that as filler content increases the film thickness coating over the aggregate is decreased. On comparing all fillers, at filler content 6% film thickness is lowest for Fly ash and at 2% film thickness is highest.
4. The method of calculation of film thickness is empirical, as it assumes aggregate particles to be spherical and cubical. The weight of aggregates and the effective volume of bitumen are determined from the bulk density of the mix at OBC. It is generally observed that Film thickness is above 6µm, for the various trials with different fillers.
5. Higher TSR values were obtained from mixtures prepared with lime as compared to crushed stone.
6. It is observed that the value of Tensile Strength Ratio (TSR) for mixes prepared with lime as filler offers highest Tensile Strength Ratio

value followed by cement and fly ash filler. However, the variations are so small to be considered significant and all the mixes satisfy the minimum TSR value requirement i.e. 80%. It means all the mixes including that with fly ash as filler have very good resistance to moisture induced damages.

7. When lime is used as a filler fatigue resistance increases from 2% to 4%. But at higher percentage of lime content as filler reduces the fatigue resistance and this can be attributed to stiffening of mix to a greater extent at 6% and mix becomes too stiff to compact which has resulted in the reduced fatigue resistance. Cement as filler should be limited to 2%. Because too much cement as filler reduces the interaction between aggregate and binder as coating of aggregate by fillers will increase the OBC hence weakening the mix and seen as reduced fatigue resistance. Fly ash as filler in BC mixes shows decreasing fatigue resistance as filler content increases. On comparing with other fillers fly ash has the better fatigue resistance for all filler contents except at 6% filler content it is lowest this can attributed to that too much cement as filler reduces the interaction between aggregate and binder as coating of aggregate by fillers and hence reducing the fatigue resistance.

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