Effects of Mineral Filler to Polymer Modified Bitumen Ratio on the Design Properties of Hot Mix Asphalt and its Performance

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ABSTRACT

Current development in the design of asphalt concrete especially in the upper layers of flexible pavements contains about acceptable proportion of mineral fillers passing 75µm (# 200) sieve, which contributes towards the mix cohesion, resistant to rutting and improves serviceability. Three filler to PMA (Polymer Modified Asphalt) ratios (i.e. 2.4, 3.4. and 4.4%) in Marshall Method of mix design were used in order to determine the optimum filler content at relatively low design asphalt contents (3.83%), for asphalt concrete having PMA and 100% lime stone dust. Designed mix was laid on Southbound Turnol Taxila National Highway Section (N-5), Pakistan as a trial in year 2003.

The study reveals that filler to asphalt ratio affects the mix properties to a greater extent and mix laid at site have shown relatively better performance during its service life of initial four critical years. For coarse graded mixes with low asphalt contents, designed especially for heavy loading and high temperatures regions like Pakistan, filler to asphalt ratio less than equal to 1.0 yields better results.

Key Words: **Pavement, Hot Mix Asphalt, PMA, Mineral Filler.**

1. INTRODUCTION

According to previous studies, it is believed that mineral fillers are the part of mineral aggregates, they fill interstices and provide contact points between larger aggregates particles and thereby strengthen the mixture.

The size and the size distribution of filler affected the void contents and void diameter of packed powders [1]. Size of filler and interactions between asphalt cement and filler greatly influenced the reinforcement of asphalt mastic [2].

The properties of asphalt such as ductility, penetration and viscosity changed drastically with the increase in percentage mineral filler even at concentration levels considerably lower than commonly used in paving mixtures. In fact, the addition of filler transforms the original asphalt into a binder which closely resembles higher consistency grade AC (Asphalt Cement) [3].

According to Asphalt Institute mix durability is related with the amount of fine "dust or dirt" particles in the

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asphalt mixture. Excessive fine lowered the quality of the asphalt film on the aggregate. Depending on the size of these particles, the mix may be stiffer or tender [4].

Mohammad, I.N., et. al. [5] investigated the effect of filler such as hydrated lime on pavement deformation and moisture damage and suggested that mineral filler had mostly increased the mixture stiffness [5].

Alijassar, A.H., et. al. [6] studied the effect of filler type especially Portland cement and lime stone on the strength properties of asphalt mixes. They concluded that cement filler resulted higher values of retained strength [6].

When asphalt binder is mixed with aggregate, the fines mix with the asphalt binder to form a fines-asphalt mortar. The additions of fines to the asphalt binder can have three main effects; extend the asphalt binder, or stiffness the asphalt binder, or both [7].

Huang, B., et. al. [8] investigated the effects of three filler types and four filler contents on stiffening effect in asphalt mastics and HMA mixtures and concluded that filler content for mix design should be determined based on the overall performance of HMA mixture [9].

Hugo, B., et. al. [9] evaluated the potential benefits of using calcareous fillers to improve aging resistance of bitumen. They concluded that calcareous fillers greatly influenced the properties of bitumen provided that filler content does not exceeds a critical concentration determined by the type of filler and binder to be used [9].

Wojciech, G., and Jaroslaw, W., [10] studied the structure of lime stone mineral filler and evaluated their stiffening properties in fill-bitumen mastic. They concluded that specific surface area, average grain diameter, grain diameter and grain morphology greatly influenced the stiffening properties in filler-bitumen materials [10].

Villiers, C., et. al. [11] reported that a 2% increase in dust can be at least as or more detrimental than 0.7% reduction in the asphalt content [11].

The influence of filler to modified asphalt in its performance is however, a potential research work that requires detailed investigation. The main objective of this study was to determine the optimum filler content, design properties of mix. Volumetric analysis, stability, flow and stiffness index are mainly involved in this experimental study. The performance of mix with PMA (with higher percentage of Elvaloy Terploymer) designed at low asphalt contents have also been evaluated in the field. Traffic passed over the laid asphalt and cores extracted after every three-month period were analyzed to observe seasonal variation so that change in the density of laid asphalt, designed at low contents could best be evaluated. The observed single axle load and tyre pressure of heavily loaded trucks, passed on the specific section were about 14 tons and 150psi, respectively.

2. EXPERIMENTAL PROGRAM

2.1 Aggregates

Sieve analysis of mineral filler was performed as recommended by AASHTO-T 11[12].

Utmost effort was made that material passing Sieve No. 200 (75μm) should have less organic impurities and Plasticity index of less than 4. Material retained on sieve no. 4 was crushed rock or crushed gravel having two faces mechanically crushed. The type of source was uniform throughout the quarry location in Margalla, Pakistan from where such a material was obtained and physical properties determined in the laboratory has reported in Table 1 [13]. NHA (National Highway Authority) aggregate combined grading for wearing course (Class-A) has been used in this research work [14].

2.2 Formulation of PMA

Asphalt cement penetration grade "60/70" modified with 1.6% Elvaloy® 4170 and 0.7% superphsophoric acid at

Attock Laboratory, Pakistan produced a binder that met a performance grade PG 78-23 grade. This grading was developed using Attock Refinery "60/70" grade and Elvaloy at Mathy Technology & Engineering Services where in different trials were made to prepare a final blend that would be more suitable for climatic conditions for the specific project [15].

Results of those trial blends have reported in Table 2. When tested at 76°C, the final blend meeting the requirement of the project produced DSR (Dynamic Shear Rheometer) value of 1.66 Kpa at 16 hrs and 1.3 Kpa at 184 hrs after blending.

2.3 Asphaltic Concrete

Adopted aggregate gradation reported in Table 3 and shown in Fig. 1 has been used with three different percentages of fillers i.e. 2.4, 3.4 and 4.4% and Asphalt Institute Marshall Mix Design Criteria was adopted with 75 numbers of blows.

TABLE 1: PHYSICAL AND MECHANICAL PROPERTIES OF AGGREGATES

Test	Specification Description	Results Reference	Specification Limits Asphalt Institute (Superpave) [13]
Sodium Sulphate Soundness value	AASHTO T104	3.32%	10-20% (Maximum)
ACV (Aggregate Crushing Value)	BS 812, Part-1	22.5	
AIV (Aggregate Impact Value)	BS 812, Part-3	13.5	
LAA (Loss Angles Abrasion Value)	ASTM C 131	23%	35-45% (Maximum)
EI (Elongation Index)	BS 812, Part-1	11%	10% (Maximum)
FI (Flakiness Index)	BS 812, Part-1	4.75%	10% (Maximum)
Sand Equivalent	AASHTO T 176	72%	40-50% (Minimum)
Polished Stone Value	BS 812-114	70%	

TABLE 2. MODIFICATION RESULTS OF AC 60/70 PENETRATION WITH ELVALOY TERPOLYMER

Asphalt	Control	C1	D	D1	E
Penetration grade "60/70"		500g	500g	500g	500g
Elvaloy 4170		1%	1.5%	1.75%	2%
SPA (super phosphoric acid)		0.2%	0.2%	0.2%	0.2%
Mix Temperature		190C	190C	190C	190C
Mix Time		3hrs	3hrs	3hrs	3hrs
Penetration (dmm) at 25°C		39	36	42	42
DSR					
G*/s in (delta)	1.9567	1.3896	1.3443	1.103	1.7680
Phase Angle	86.2	72.50	62.90	57.80	57
Pass/fail	63.1	73.20	79.30	83.20	82.70
PG Grade	58C	70C	76C	82C	82C
Ring & Ball Softening point		141/60C	160f/71C	162f/72C	169f/76C
Elastic Recovery 25°C (20cm)		50%	72.5%	75%	78%
Ductility @25°C		37cm	20cm	23cm	22cm
Absolute Viscosity 60C (poise)		9107	56946	112060	183474
Brookfield viscosity 165C (centipoises)		2590	4200	5040	8400
Torsional Recovery %		18	25	32	32

3. RESULTS AND DISCUSSION

3.1 Mix Design Properties

Mix properties i.e. densities, volumetric parameters, stability and flow was calculated at 2.4, 3.4 and 4.4% filler contents and results have summarized in Tables 4-6.

3.2 Design Properties of HMA

Results of mix design parameters at filler to asphalt content ration have been reported in Tables 4-7 and graphically plotted in Figs. 2-7. As shown in Fig. 2, the improvement tendency of density (G_{mb}) reduces with

TABLE 3. SUMMARY OF GRADING

Passing Sieve Size		Adopted Gradation	Specifications NHA (Class-A)
Inch	mm		
1	25	100	100
¾	19	90-100	90-100
½	12.50	-	-
3/8	9.50	56-69	56-70
#4	4.75	38-46	35-50
#8	2.36	25-33	23-35
#50	0.300	5-12	5-12
#200	0.075	3.4-5.4	2-8

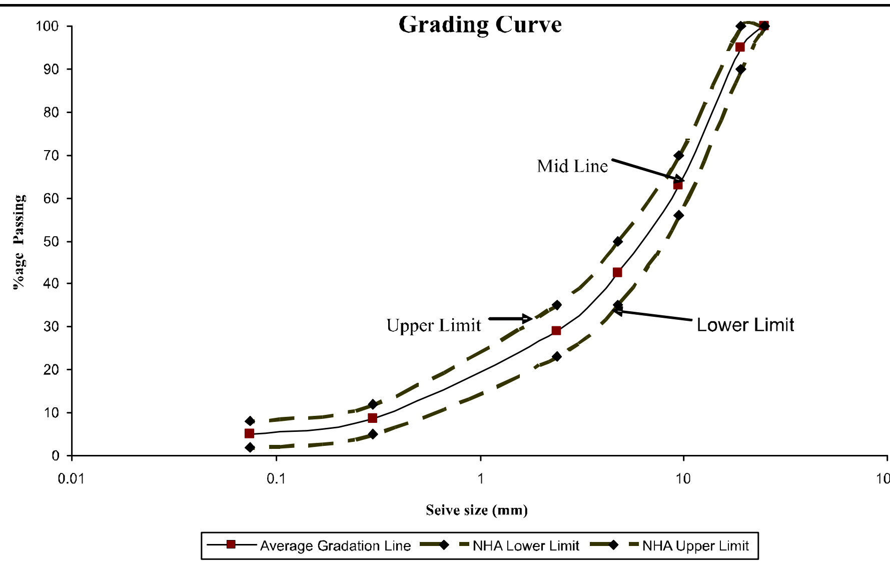

FIG. 1. GRADATION ENVELOPE AND LIMITS

TABLE 4. PROPERTIES OF MIX AT 2.4% FILLER

AC (%)	G_{mb}	G_{mm}	Stability (Kg)	Flow (%)	Stiffness Index	VA (%)	VMA (%)	VFA (%)
3	2.326	2.551	1362	2.5	545	8.82	15.62	43.53
3.5	2.356	2.53	1450	2.4	604	6.88	14.53	52.67
4	2.369	2.515	1393	2.4	580	5.81	14.06	58.71
4.5	2.351	2.494	1295	2.5	518	5.73	14.71	61.03
5	2.325	2.477	1204	2.8	430	6.14	15.66	60.81

the increase in filler to asphalt F/A ratio. Stability test performed at 60°C as shown in Fig. 3 indicates that mix with F/A ratio of 0.9 achieved maximum value at OAC. Flow trends shown in the Fig. 4 indicates that increase in F/A ratio increases flow values. A higher value of stiffness index (stability to flow ratio) indicates a stiffer mixture. Results shown in Fig. 5 revealed that air voids (VA) increases with increase in F/A ratio. At all F/A

TABLE 5. PROPERTIES OF MIX AT 3.4% FILLER

AC (%)	G_{mb}	G_{mm}	Stability (Kg)	Flow (%)	Stiffness Index	VA (%)	VMA (%)	VFA (%)
3	2.34	2.552	1464	2.5	585	8.31	15.11	45.03
3.5	2.362	2.535	1550	2.4	646	6.82	14.31	52.32
4	2.378	2.52	1488	2.5	595	5.63	13.73	58.97
4.5	2.367	2.5	1381	2.6	531	5.32	14.13	62.36
5	2.351	2.48	1343	3	448	5.20	14.71	64.65

TABLE 6. PROPERTIES OF MIX AT 4.4% FILLER

AC (%)	G_{mb}	G_{mm}	Stability (Kg)	Flow (%)	Stiffness Index	VA (%)	VMA (%)	VFA (%)
3	2.305	2.544	1301	2.6	500	9.39	16.38	42.65
3.5	2.345	2.525	1373	2.5	549	7.13	14.93	52.25
4	2.368	2.505	1331	2.7	493	5.47	14.10	61.20
4.5	2.357	2.485	1214	3	405	5.15	14.50	64.47
5	2.342	2.467	1106	3.5	316	5.07	15.04	66.31

TABLE 7. SUMMARY OF MIX DESIGN PARAMETERS

Mix Type	Filler (%)	Stability (Kg)	Loss of Stability (%)	Flow (0.25mm)	Stiffness Index	G_{sb} (g/cc)	G_{mm} (g/cc)	G_{mb} (g/cc)	VA (%)	VMA (%)	VFA (%)
Mix-1	2.40	1415	11.00	2.40	566	2.651	2.521	2.363	6.0	14.10	57.10
Mix-2	3.40	1510	11.50	2.45	579	2.67	2.525	2.374	5.97	13.89	57.00
Mix-3	4.40	1360	13.80	2.60	500	2.640	2.520	2.359	6.51	14.50	55.21

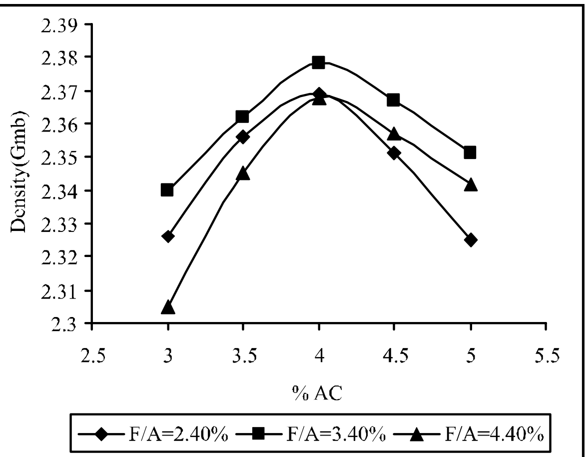

FIG. 2. INFLUENCE OF FILLER TO ASPHALT CONTENT ON DENSITY (G_{MB}) VALUE OF HMA

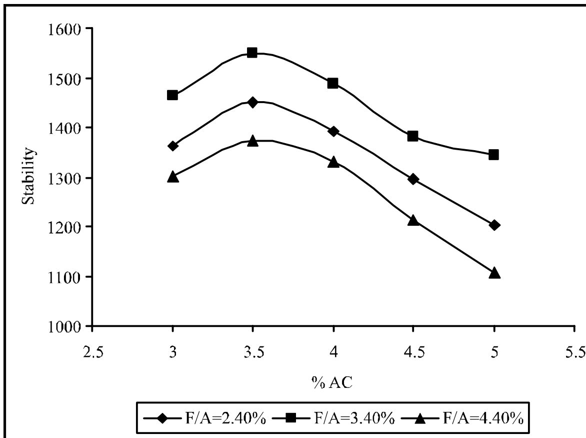

FIG. 3. INFLUENCE OF FILLER TO ASPHALT CONTENT ON STABILITY VALUE OF HMA

ratios, as shown in Fig. 6, trends of VMA similar to VA have been observed. Results in Fig. 6, shows that there is a significant increase in the value of VFA from 3-4% asphalt contents, but once the mix achieved its optimum F/A ratio, trend lines become flatter.

One can draw a conclusion that mixes designed at lower asphalt content has optimum range of filler to asphalt content from 0.9-1.0. At lower F/A ratios, loss of stability (difference of stability at 60°C, taken for 30 minutes and 24 hours values) is minimum. More stiffness beyond F/A ratio "1.0" at optimum asphalt contents may lead to cracking.

Change in softening point of PMA with the addition of mineral filler was also conducted at optimum asphalt content in quality control laboratory, Rawalpindi, Pakistan and reported in Table 8 to study the effect of filler on the consistency of asphalt cement.

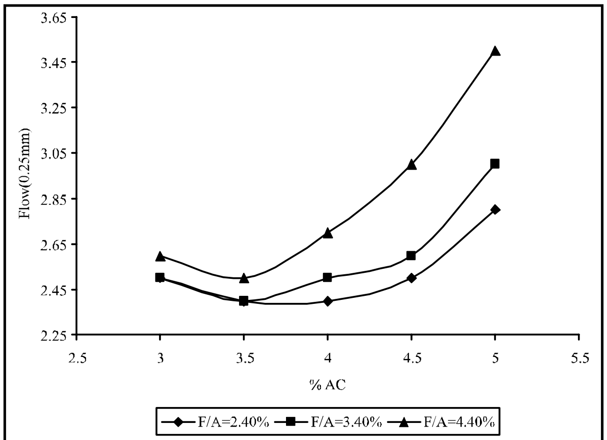

FIG. 4. INFLUENCE OF FILLER TO ASPHALT CONTENT ON FLOW VALUE OF HMA

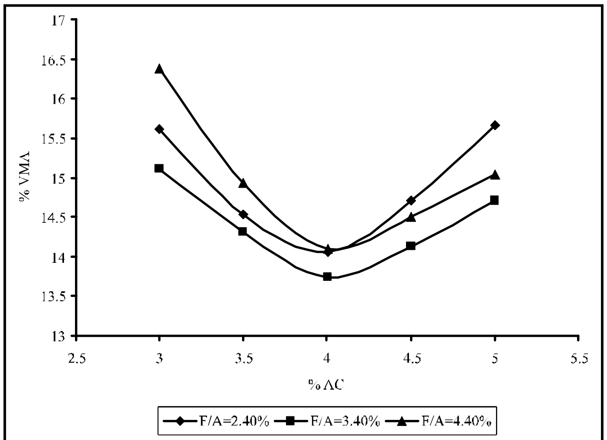

FIG. 6. INFLUENCE OF FILLER TO ASPHALT CONTENT ON % VMA OF HMA

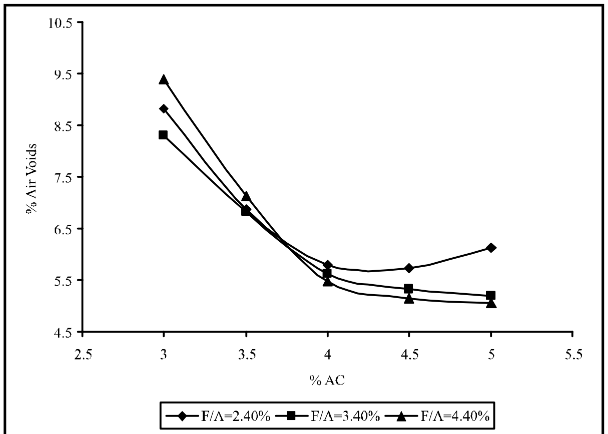

FIG. 5. INFLUENCE OF FILLER TO ASPHALT CONTENT ON % AIR VOIDS OF HMA

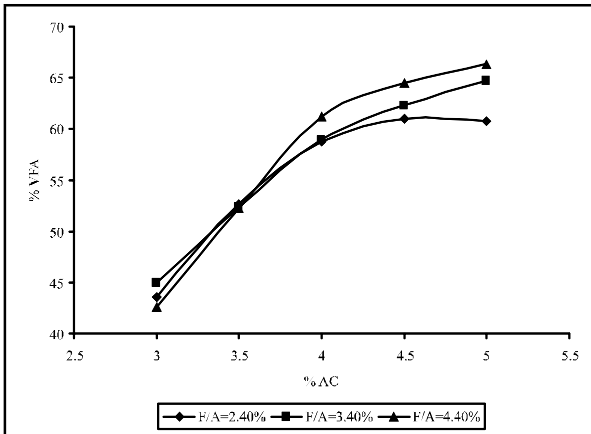

FIG. 7. INFLUENCE OF FILLER TO ASPHALT CONTENT ON % VFA OF HMA

TABLE 8. SOFTENING POINT OF AC AT DIFFERENT FILLER RATIOS

No.	Filler Percentage	Percentage Aasphalt at (OAC)	Filler/PMA Ratio	Softening Points (°C)
1.	Zero	-	Without filler	66
2.	2.40	3.83	0.63	73
3.	3.40	3.83	0.98	77
4.	4.40	3.83	1.15	84

3.3 Field Compaction and Coring

Asphalt concrete with PMA (with 1.6% Elavloy Terploymer) and adopted gradation as given in Table 5 was prepared using Parker (160 Ton/Hr. Capacity), fully automated asphalt plant capable of producing 100% controlled mix. Mixing and paving temperatures of asphalt concrete were controlled at 165-150°C respectively, followed by the standard compaction procedures. Cores were extracted 24 hours after finished rolling, ensuring that the pavement surface and ambient temperatures were the same. The specific gravities and hence the volumetric parameters were calculated as per AASHTO, ASTM recommendations. Core from the same sections were extracted at each three months period after opening of traffic. Field density and air void results have been reported in Table 9 and plotted graphically in Figs. 8-9 [16].

TABLE 9. SUMMARY OF CORE RESULTS TAKEN FROM THE PAVEMENT

Quarter No.	Month	Accumulative ESAL'S (millions)	G_{mb}	Va (%)
1.	September, 2003	0.399	2.318	8.02
2.	December, 2003		2.335	7.34
3.	March, 2004	3.03	2.345	6.94
4.	June, 2004		2.359	6.39
5.	September, 2004	6.14	2.368	6.03
6.	December, 2004		2.373	5.83
7.	March, 2005	9.50	2.380	5.56
8.	June, 2005		2.386	5.32
9.	September, 2005	13.01	2.392	5.08
10.	December, 2005		2.396	4.92
11.	March, 2006	16.76	2.400	4.76
12.	June, 2006		2.405	4.56
13.	September, 2006	20.50	2.409	4.40
14.	December, 2006		2.412	4.29
15.	March, 2007	24.14	2.415	4.17
16.	June, 2007		2.418	4.05
17.	September, 2007	28.00	2.420	3.97

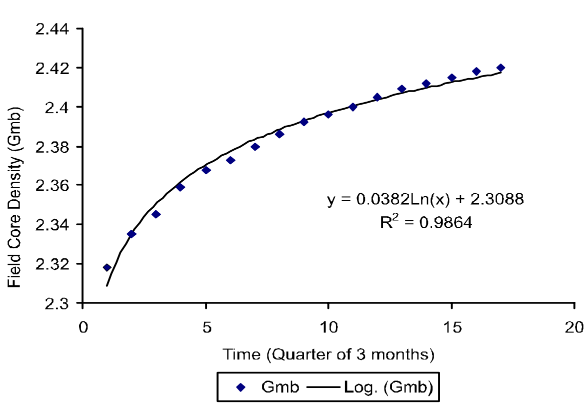

FIG. 8. PERIODIC VARIATION IN THE PAVEMENT DENSITY

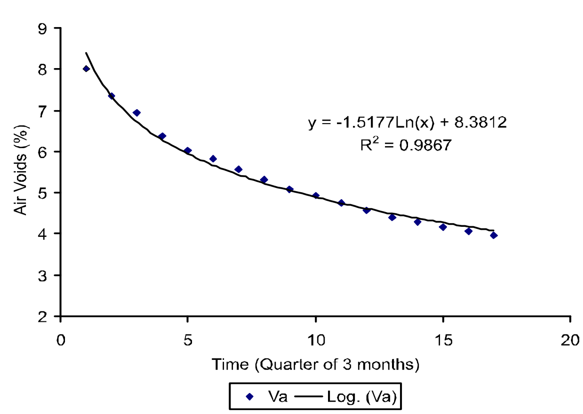

FIG. 9. PERIODIC VARIATION IN THE PAVEMENT AIR VOIDS

3.4 Traffic History

Accumulative axle load as reported in Table 9 were revealed in year 2001, 2004 and 2005 at the same section and extrapolated to estimate the applied load on pavement. The damaging factors for loaded trucks traveling at an average speed of 25 Km/hr were taken from axle load study conducted by National Transportation Research Center [17].

4. CONCLUSIONS

The objectives of the study were to evaluate the effects of mineral filler to bitumen ratio on the design properties and performance of hot mix asphalt. Conclusions drawn from the above mentioned work has been given as under.

(i) Presence of high or low percentage of fillers affects design properties of HMA.

(ii) Coarse graded mixes, designed at low asphalt contents for heavy loading and high temperatures achieved optimum results at filler to polymer modified asphalt ratio from 0.9-1.0.

(iii) Increase in filler to asphalt (PMA) ratio increases the softening point.

(iv) Density improvement tendency of a mix reduces with the increase in the filler to asphalt ratio.

5. RECOMMENDATIONS

A pavement that showed rutting in the early stage of its service life may have imbalance amount of mineral fillers in the mix, which should be systematically calculated using optimum filler content criteria. Mixes designed upto an asphalt content of 4% should have filler to asphalt ratio (F/A) of 1.0. For higher asphalt content mixes, this ratio may exceed 1.0.

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