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ADVANCING BITUMINOUS PAVMENT PROPERTIES VIA JOB MIX FORMULATION AND POLYMER MODIFICATION

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Abstract: The enhancement of properties of bituminous pavement is critical for improving road performance and longevity. This study explores the advancements in bituminous pavement by optimizing job mix formulations and polymer modifications. Asphalt mixes can have their mechanical qualities, durability, and resistance to deformation increased by adjusting the mix amounts and adding thermosetting polymers. Various polymers, including phenol formaldehyde resin (PhR) and epoxy resin (ER) were evaluated for their effectiveness in modifying the bitumen. Numerous scholars have devised methods for calculating Job Mix Formulations (JMF) in order to determine the proper aggregate mix in the field. In this study, the effects of nominal maximum aggregate size and aggregate gradation were examined. The outcomes showed that aggregate gradation does affect how mixes behave. The trial and error approach were used in the study's grading and job mix design processes. The findings demonstrate that appropriate mix design grading and the strategic use of polymer enhances pavement performance.

Index Terms - Job mix formula (JMF), Trial and error method, Aggregate gradation, Thermosetting polymers.

I. INTRODUCTION

Bitumen plays a crucial role in job mix formulation (JMF) for asphalt concrete, influencing the performance and durability of flexible pavements (Penki et al., 2022). When designing a work mix using conventional methods, it is important to take certain factors into account. These include the mix design's need to be precise, affordable, and time-efficient. Gradation aims to increase the performance of the mix by decreasing empty space. The preparation of overall gradation of aggregates for mix design is considered as an essential step in the design of asphalt concrete mixture (Sarsam et al., 2015). The objective gradation must be thick, consistent, and must not travel along a border or from one extreme boundary to the other. On the other hand, the maximum size of aggregate and the percent fill are fixed for each type of asphalt concrete mix. The first stage in the production of hot mix asphalt is to proportion the components of the mix design. The mix designer must develop the "recipe" for mixing aggregates, asphalt and air to produce a mixture that will meet the performance demands of the pavement (Decker et al., 2004). One keeps in mind that the laboratory mix design is only the beginning of the mix production process. During production, it is necessary to adjust the Job Mix Formula in order to meet volumetric properties of the in-place pavement. Even though these modifications are usually small, they are crucial to make sure the mix created has the volumetric qualities needed in the field. The trial and error method are one of the techniques proposed for aggregate blending in the job mix formulation process, aiming to optimize costs and meet graduation requirements for flexible pavements (Ramayya et al., 2019). This method involves iteratively adjusting the aggregate proportions until the desired mix properties are achieved, often through manual adjustments based on experience and judgment (Iwan et al., 2018). However, it is crucial to note that the laboratory mix design is just a starting point, and adjustments to the job mix formula are often necessary during production to ensure the mix meets the required volumetric properties in the field (Decker et al., 2004). By incorporating trial and error alongside other optimization techniques, such as graphical methods and Bailey's method, practitioners can develop effective job mix formulations that balance cost efficiency with performance requirements (Yuki et al., 2019). The portion of each of these ranges of values below and above similar values for the corresponding job-mix formula has been determined. It is demonstrated that bands, the width of which mostly relies on the tolerances being applied, should take the place of the single curves now used to display design data for various paving mixture parameters, such as air voids, VMA, etc., vs asphalt content. The qualities of paving mixtures that are impacted by filler/bitumen ratios are significantly impacted by ASTM and AASHTO tolerances.

II. METHODOLOGY

A. Bitumen

The bitumen with 60/70 penetration grade, extensively used in the production of asphalt paving materials, was supplied from Bharat Petroleum refinery via Raviraj construction and used throughout the study. Characterization of bitumen used in all experiments in given in table 1.

Table 1. Chemical and physical properties of bitumen with 50/70 penetration

Property	Value
Penetration, 25C, 5 sec, 0.1 mm	68
Softening point,	51
Ductility in cm	75+
Flash point,	260+
Viscosity in sec	34

B. Aggregates

In accordance with standard, the course and fine aggregates were sourced from Akashganga constructional machines PVT. LTD, Satara, Maharashtra were tested. Table 4 present the indices for course aggregates.

C. Tests on materials

Tests were conducted on bitumen and aggregates to determine their engineering qualities and establish whether they are appropriate as the material to be used in BC mixes.

Test on bitumen

Basic tests were conducted on bitumen and polymer modified bitumen where penetration test (ASTM D-5), Softening point test (ASTM D-36), Ductility test (ASTM D-113) and Specific gravity test (). The test result shown in table no 1 and 2

Tests on aggregates

Common tests of aggregates include sieve analysis, crushing tests, impact tests, abrasion tests, shape tests, and soundness and specific gravity test. The test results are shown in table 6. Design of aggregate Gradation was carried out for the preparation of one of the top layers in flexible pavement that is bituminous concrete (BC). In this wearing and profile courses single layer of bituminous concrete is construct which has 50 mm thickness. (as per MORTH)

Fine aggregates and coarse aggregates

The coarse aggregates consist of crushed rocks, crushed gravels or other hard material retained on 2.36 mm sieve. In experiment aggregates satisfied the physical requirements which is specified in Table 4. Where crushed gravel used as aggregate which was not less than 90 percent by weight of crushed material retained on 4.75 mm sieve and Fine aggregates consist of crushed or naturally occurring mineral material, passing 2.36mm sieve and retained on 75-micron sieve.

Table 2 Aggregate technical index

Technical index	Unit	Specifications requirements	Reference
Crushing value test	%	30% max	
Impact value test	%	24% max	
Specific gravity	-	2-3	
Water absorption	%	2% max	
Flakiness	%	30% max	
Elongation	%	30% max	
Stripping value test	%	Min. 95%	

D. Method used for aggregate gradation

The trial and error method are applied in this experiment to determine the aggregate gradation. Additionally, aggregate grading is done using the analytical and graphical methods. The adopted aggregate gradation for BC given in table 3.

Table 3. Adopted aggregate Gradation for Bituminous concrete (BC) for grade 1 as per the MORTH

Sieve size (mm)	**Percent passing (grading 1)**
26.5	100
19	95
13.2	69
9.5	62
4.75	45
2.36	36
1.18	27
0.6	21
0.3	15
0.15	9
0.075	5
Bitumen Content % by mass of total mix	Min. 5.2

Trial and error method

Trial and error method include the proportion of materials until the required aggregates gradation is achieved.

Formula:

$$P= A_a + B_b + C_c$$

Where, P= % materials passing a given sieve for the blended aggregate A, B, C

A, B, C = % Material passing a given sieve for each aggregate A, B, C

A,b,c = Proportions of aggregates A,B,C to be used in blend a+b+c+….+ =100

Sieve analysis

Sieve analyses determine the gradation or distribution of aggregate particles within a given sample in order to determine compliance with design and production standards.

Table 4. Sieve analysis

Sr. no	Sieve size (mm)	Aggregate percentage				
		20 mm	12.5 mm	10 mm	6 mm	Grit
1	26.5	100	100	100	100	100
2	19	98.8	100	100	100	100
3	13.5	1.2	100	100	100	100
4	9.5	-	72.3	74.6	100	100
5	4.75	-	5.6	7.3	70.5	98.6
6	2.36	-	1.1	0.4	7.3	70.1
7	1.18	-	-	-	1.2	47.9
8	600 microns	-	-	-	0.3	38.4
9	300 microns	-	-	-	0.1	22.1
10	150 microns	-	-	-	-	14.2
11	75 microns	-	-	-	-	10.4

Job mix formula

The end result of a successful mix design is a recommended mixture of aggregate and asphalt binder. This recommended mixture, which also includes aggregate gradation and asphalt binder type is often referred to as the job mix formula (JMF)

III. EXPERIMENTAL RESULTS

A. Bitumen test results

From the result shown in table 1 and 5. For virgin bitumen and polymer modified bitumen, there is sharp decrease in penetration value of 77 to 47 for phenol formaldehyde resin and 26.3 for hybrid polymer that is combination of phenol formaldehyde resin and epoxy resin. As we decrease the percentage of polymers it decreases the penetration value of bitumen in other words increase in the hardness of bitumen. The results obtained from the ring ball shown in Table 1 and 5 shows that there is no great difference in the softening temperature for virgin bitumen and thermosetting polymer modified bitumen. Homogeneity which was achieved during compared with blending of lower concentration of polymer with base bitumen would be good in terms of storage stability and it may offer better rutting resistance at higher temperature. 2% phenol formaldehyde resin, 4% phenol formaldehyde resin, and 2% epoxy resin have performed better than other percentages. From the results shown in the table 1 and 5. For virgin bitumen and polymer modified bitumen, there is not much great difference in results. The bitumen forms a thin ductile film around aggregates so that physical interlocking of the aggregates is improved.

Figure 1 Ductility test filled with bitumen

Figure 2 Softening point test

Figure 3 Moulds

Table 5. Tests results for modified bitumen

Polymer content%	Penetration at 25°C	Softening point °C	Ductility in cm
Phenol formaldehyde resin			
8%	77	44.6	81.3
6%	70	50.1	89.85
4%	67	49	96.5
2%	47	53.3	100
Hybrid polymer (Phenol formaldehyde resin and epoxy resin)			
8% + 2%	49.6	46.1	86
6% + 2%	47	48.5	87
4% + 2%	34.6	53.3	94.2
2% + 2%	26.3	52	93.5

B. Aggregates test results

Aggregates are most important material used in the pavement construction due to its strength and durability. This material forming the main skeleton of pavement and should be tested with reference to MORTH 2001 and IS codes. Number of tests were carried out on the aggregates like crushing test, impact value test, specific gravity test, water absorption test, flakiness and elongation test and stripping value test. The results obtained are shown in table no. 6

Table 6. Tests results for aggregates

Property	Name of the test	Actual Results	As per MORTH 2001	Reference
For strength	Crushing strength	**19.9%**	30% max	IS 2386 part 4
	Impact value	**15.5%**	24% max	IS 2386 part 4
Average specific gravity	Specific Gravity	**2.6%**	2-3 %	IS 2386 part 5
Water absorption	water absorption	**1.8%**	2% max	IS 2386 part 3
Particle shape	Flakiness	**18%**	35% max	IS 2386 part 1
	Elongation	**17%**	35% max	IS 2386 part 1
Stripping	Coating and stripping of bitumen aggregate mixture	**99%**	Minimum retained 95%	IS:6241

C. Job mix formula for BC results

From the table 7 the blending percentages are given as 22%, 12%,12%,12% and 42% for 20mm, 12.5mm, 10mm, 6.3mm and git respectively. The job-mix formula for each mixture shall establish a single percentage of aggregate passing each required sieve size and a single percentage of bituminous material to be added to the aggregate. The job mix formula was introduced for Bituminous concrete with integrating polymers in bituminous mixture.

Table 7. Job mix formulation

Sieve size (mm)	Cumulative percentage passing					Blending percentage					Actual Results	As per MORTH 2001 (Grading 1)
	20 mm	12.5 mm	10 mm	6.3 mm	Grit	20 mm	12.5 mm	10 mm	6.3 mm	Grit		
						22%	**12%**	**12%**	**12%**	**42%**	**100**	100
26.3	100	100	100	100	100	22	12	12	12	42	**100**	100
19	91.6	100	100	100	100	21.73	12	12	12	42	**99.73**	90-100
13.2	9.0	100	100	100	100	0.264	12	12	12	42	**78.23**	59-79
9.5	1.7	70.1	78.2	100	100	0.374	8.18	9.38	12	42	**71.93**	52-72
4.75	0.2	5.6	7.3	70.5	100	0.044	0.67	0.876	8.46	42	**52.05**	35-55
2.36	-	1.1	0.4	7.3	98.6	-	0.132	0.048	0.87	41.41	**42.46**	28-44
1.18	-	-	-	1.2	70.1	-	-	-	0.144	29.44	**29.58**	20-34
0.6	-	-	-	0.3	47.9	-	-	-	0.036	16.12	**16.18**	15-27
0.3	-	-	-	0.1	34.4	-	-	-	1.2	14.44	**15.64**	10-20
0.15	-	-	-	-	22.1	-	-	-	-	9.28	**9.28**	5-13
0.075	-	-	-	-	11.6	-	-	-	-	4.87	**4.87**	4-10

Figure 4. Aggregate gradation

IV. CONCLUSION

- This research has presented the development of the assessment of JMF for BC grade 1. Job mix formula had to fulfil MoRTH requirements. It is capable of generating blends fulfilling MoRTH parameters. The results of a study were also discussed wherein the gradation of aggregates obtained from a local quarry and was observed to fulfil MoRTH requirements with various combinations of aggregate. The gradation of aggregates plays a vital role in designing the JMF.
- From the study, it can also be concluded that the MoRTH requirements are more stringent for gradation. Further, this mix design was used in the current study for Marshall stability and flow test.
- The key findings indicate that polymer-modified asphalts outperform traditional mixtures in critical performance metrics, making them highly suitable for modern road construction demands. The strategic design of mix formulations, to incorporate thermosetting polymers, has proven to be a main factor in achieving superior pavement properties.
- Future research should focus on exploring additional polymer types and their hybridisation, optimizing their concentrations, and evaluating their environmental and economic impacts. The implementation of studies in the field and monitoring of polymer-modified pavements will be crucial in validating laboratory findings and refining mix design strategies.

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