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Performance Evaluation of Natural Fiber-Reinforced Bituminous Mixes Using Marshall Method

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***Abstract* - Bituminous mixes are made up of coarse aggregate, fine aggregate, filler, and binder. In Hot Mix Asphalt (HMA), all these materials are heated before mixing, laying, and compaction. HMA can be of two types: Dense Graded Mixes (DGM) like Bituminous Concrete (BC), and Gap Graded Mixes like Stone Matrix Asphalt (SMA). SMA requires stabilizing materials like fibres to stop binder drain down.**

This study focuses on evaluating the performance of BC and SMA when natural sisal fibre, which is easily available locally, is added. The aim was to see how sisal fibre affects the strength and durability of these mixes. The aggregates used followed MORTH grading, and the binder content was varied from 4% to 7%. Sisal fibre was added in different amounts, from 0% to 0.5% of the total mix. Fly ash, which gave good strength results, was used as filler.

The Marshall Method was used to find the best binder and fibre content. The Optimum Fibre Content (OFC) was found to be 0.3%, while the Optimum Binder Content (OBC) was 5% for BC and 5.2% for SMA.

Performance tests such as drain down test, indirect tensile strength test, and static creep test were carried out on the mixes prepared at their OBC and OFC. The results showed that adding sisal fibre improved the stability, reduced binder drain down, and increased tensile strength of the mixes. SMA mixes performed better than BC in terms of strength and resistance to deformation.

Keywords: Bituminous Concrete (BC), Stone Matrix Asphalt (SMA), Sisal Fibre, Marshall Properties, Indirect Tensile Strength, Static Creep.

I. INTRODUCTION

Highway construction requires precise engineering and substantial investment, where effective bituminous mix design plays a critical role in ensuring pavement performance and longevity. A well-designed bituminous mix should be strong, durable, fatigue-resistant, and economical while maintaining environmental compatibility. This study emphasizes the mix design aspect of flexible pavement, aiming to optimize the proportion of coarse aggregates, fine aggregates, filler, and binder. Traditional binders like 60/70 penetration grade bitumen and advanced binders such as Polymer Modified Bitumen (PMB) and Crumb Rubber Modified Bitumen (CRMB) are commonly used. Stone Matrix Asphalt (SMA) and Bituminous Concrete (BC) are preferred mixtures due to their mechanical stability and durability. To enhance performance and minimize binder drain down in SMA, stabilizing additives like natural and synthetic fibers are used. This research investigates the effect of Sisal Fibre, a naturally available and eco-friendly material, as a stabilizing additive in both BC and SMA mixes, aiming for a sustainable and high-performing pavement solution.

II. OBJECTIVE OF PRESENT INVESTIGATION

This study compares Bituminous Concrete (BC) and Stone Matrix Asphalt (SMA) mixes with varying binder contents (4%-7%) and fiber contents (0.3%-0.5%), using 60/70 penetration grade bitumen as the binder and sisal fiber as the stabilizing additive. The investigation is carried out in four stages:

1. Study Marshall Properties of BC Mixes: Analyze BC mixes with three fillers (fly ash, cement, stone dust) without fiber.
2. BC Mixes with Fly Ash and Sisal Fiber: Evaluate BC mixes using fly ash as filler and sisal fiber as a stabilizer.
3. SMA Mixes with Fly Ash and Sisal Fiber: Assess SMA mixes with fly ash as filler and sisal fiber as a stabilizer.
4. Performance Evaluation: Conduct tests on BC and SMA mixes, including the drain down test, static indirect tensile strength test, and static creep test.

III. EXPERIMENTAL INVESTIGATIONS

3.1 Tests on Materials Used

3.1.1 Aggregates

For preparation of Bituminous mixes (BC, SMA) aggregates as per MORTH grading as given in Table 3.1 and

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Table 3.2 respectively, a particular type of binder and fibre in required quantities were mixes as per Marshall Procedure

Table 3.1: Adopted Aggregate Gradations for BC (MORTH)

Sieve Size (Mm)	Percentage Passing
26.5	100
19	95
9.5	70
4.75	50
2.36	35
0.30	12
0.075	5

Table 3.2: Adopted Aggregate Gradations for SMA (MORTH)

Sieve Size (Mm)	Percentage Passing
16	100
13.2	94
9.5	62
4.75	34
2.36	24
1.18	21
0.6	18
0.3	16
0.15	12
0.075	10

3.1.1.1 Coarse Aggregates

Coarse aggregates were stone chips sourced locally; with a maximum size of 4.75 mm (IS sieve). The specific gravity of the coarse aggregates was 2.75. Standard tests were conducted to determine their physical properties, as detailed in Table 3.3.

3.1.1.2 Fine Aggregates

Fine aggregates were stone crusher dust collected from a local crusher, with particles passing through a 4.75 mm sieve and retained on a 0.075 mm sieve. The specific gravity of the fine aggregates was 2.6.

3.1.2 Filler

Aggregates passing through a 0.075 mm IS sieve are classified as fillers. In this study, cement, fly ash, and stone dust were used as fillers, with specific gravities of 3.0, 2.2, and 2.7, respectively. Initially, a comparative study was conducted on Bituminous Concrete (BC) using all three fillers. Subsequently, fly ash was selected as the sole filler for further comparative studies on BC and Stone Matrix Asphalt (SMA), both with and without the addition of fiber.

Table 3.3: Physical Properties of Course Aggregate

Property	Test Method	Test Result
Aggregate Impact Value (%)	IS: 2386 (P IV)	14.3
Aggregate Crushing Value (%)	IS: 2386 (P IV)	13.02
Los Angeles Abrasion Value (%)	IS: 2386 (P IV)	18
Flakiness Index (%)	IS: 2386 (P I)	18.83
Elongation Index (%)	IS: 2386 (P I)	21.5
Water Absorption (%)	IS: 2386 (P III)	0.1

Here 60/70 penetration grade bitumen is used as binder for preparation of Mix, whose specific gravity was 1.01. Its important property is given in table 3.4.

Table 3.4: Properties of Binder

Property	Test Method	Value
Penetration at 25°C (mm)	IS : 1203-1978	67.7
Softening Point (°C)	IS : 1203-1978	48.5
Specific gravity	IS : 1203-1978	1.03

3.1.3 Fibre

Here sisal fibre is used as additive whose length is about 900 mm. and diameter varied from 0.2 to 0.6 mm. The sisal fibres were cleaned and cut in to small pieces of 15-25 mm in length to ensure proper mixing with the aggregates and binder during the process of mixing.

3.2 Preparation of Mixes

The mixes were prepared following the Marshall procedure (ASTM D1559). For both BC and SMA, coarse aggregates, fine aggregates, and fillers were mixed according to the gradations in Tables 3.1 and 3.2.Initially, a comparative study on BC used three different fillers: cement, fly ash, and stone dust. The Optimum Binder Content (OBC) was determined using the Marshall Test, with binder content varying from 0% to 7%.

Next, both BC and SMA were analyzed to determine the OBC and Optimum Fibre Content (OFC) using the Marshall Method, with binder content ranging from 0% to 7% and fiber content from 0.3% to 0.5%. Sisal fibers, cut into 15-20 mm pieces, were added directly to the aggregate sample in different proportions. Aggregates and fibers were heated to 10°C higher than the binder's mixing temperature. The binder was then added to the pre-heated aggregate-fiber mixture and mixed manually for 2-5 minutes until uniform in color and consistency. The mixture was poured into pre-heated Marshall Moulds, and specimens were compacted with 75 blows on each side. After cooling overnight to room temperature,

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samples were extracted and tested at 60°C according to standard procedures.

3.3 Tests on Mixes

Presented below are the different tests conducted on the bituminous mixes with variations of binder type and quantity, and fibre concentration in the mix.

3.3.1 Marshall Test

The Marshall Mix design is a standard laboratory method widely used to determine the strength and flow characteristics of bituminous paving mixes. In India, this method is popular for characterizing bituminous mixes due to its simplicity and cost-effectiveness. Many researchers have employed the Marshall method to test bituminous mixes. Given its advantages, this method was chosen to determine the Optimum Binder Content (OBC) and study various Marshall characteristics such as stability, flow value, unit weight, and air voids.

Figures 3.1 and 3.2 show the Marshall sample and apparatus with a loaded specimen. The Marshall properties, including stability, flow value, unit weight, and air voids, were studied to obtain the OBC and Optimum Fibre Content (OFC). The mix volumetrics of the Marshall samples, such as unit weight and air voids, were calculated using the procedure by Das and Chakroborty (2003). Due to time constraints, not all tests could be completed on all types of mixes. Therefore, further experiments, including drain down test, static indirect tensile test, and moisture susceptibility tests, were performed on the mixes prepared at their OBC and OFC.

Figure 3.1: Marshall Sample

Figure 3.2: Marshall Test in Progress

3.3.2 Drain Down Test

There are several methods to evaluate the drain-down characteristics of bituminous mixtures. The drain down method suggested by MORTH (2001) was adopted in this study. The drainage baskets fabricated locally according to the specifications given by MORTH (2001) is shown in Figure 3.3. The loose un-compacted mixes were then transferred to the drainage baskets and kept in a pre-heated oven maintained at 150°C for three hours. Pre- weighed plates were kept below the drainage baskets to collect the drained out binder drippings. From the drain down test the binder drainage has been calculated from the equation:

Drain down equation is $d=\frac{W_2-W_1}{1200+\times}$

Where

W_1 = Initial mass of the plate
W_2 = Final mass of the plate and drained binder
X = Initial mass of fibres in the mix

For a particular binder three mixes were prepared at its optimum binder content and the drain down was reported as an average of the three. Figure 3.3 shows the drainage of 60/70 bitumen.

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Figure 3.3: Drainage of 60/70 Bitumen Sample (SMA without Fibre)

IV. ANALYSIS OF TESTS RESULTS AND DISCUSSIONS

4.1 Drain Down of Mixes with Fibre

It is observed that addition of the sisal fibre the drain down characteristics of mixtures decreases, Drin down value of SMA is reduced to 0.02% and there is no drain down of binder of BC.

4.2 Static Indirect Tensile Test

Static indirect tensile test of bituminous mixes measures the indirect tensile strength (ITS) of the mix which helps in assessing the resistance to thermal cracking of a given mix. The static indirect tensile tests were carried out on SMA and BC mixes prepared at their OBC and OFC as described in chapter 3. The effect of temperature on the ITS of mixes with and without fibre is also studied. The results of static indirect tensile test are presented and discussed in this section.

4.2.1 Effect of Fibre on Static Indirect Tensile Strength

A Figure shows the variations of indirect tensile strength with temperature for mixes. It is seen that the ITS value decreases with increase in temperature and for a particular binder, when fibre is added to the mix it increases.

4.2.2 Effect of Temperature on Static Indirect Tensile Strength

A figure shows the variations of ITS value with temperature for mixes with and without fibre and with different binder content. It is observed that for a particular binder, the ITS value decreases with increase in temperature. At lower temperature, the SMA mixes has the highest indirect tensile strength than BC.

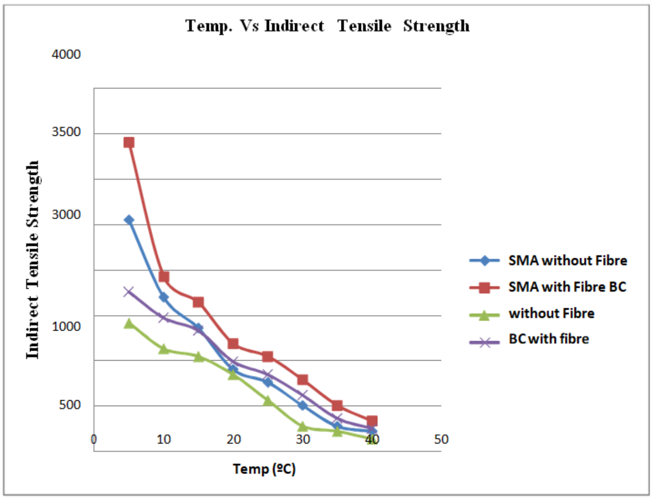

Figure 4.1: Variation of ITS Value of SMA and BC with Different Temperatures

4.3 Static Creep Test

Static creep test is done to measure permanent deformation of bituminous mixes when static load is applied. It is observed from fig-20 that deformation of mix decreases by addition of fibre. If mix is prepared at their OBC and OFC and load is applied it has less deformation then mix without fibre. Another conclusion drawn is that deformation of BC is more than SMA.

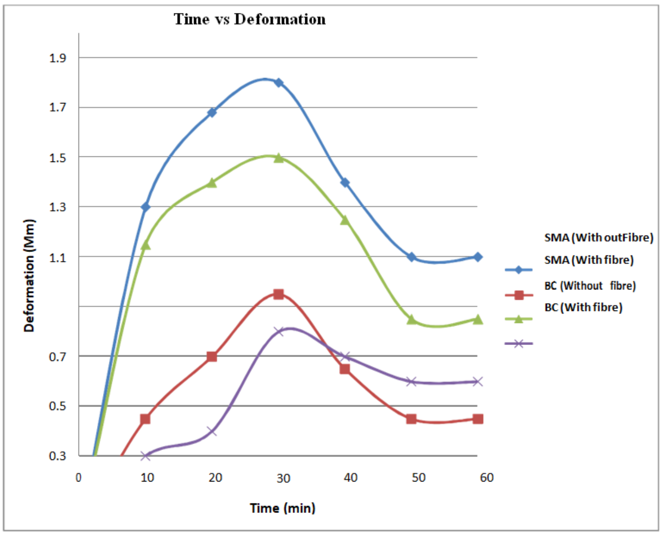

Figure 4.2: Deformation of SMA and BC (With and Without Fibre)

V. CONCLUSION

5.1 Conclusion

This study focused on evaluating the performance of Bituminous Concrete (BC) and Stone Matrix Asphalt (SMA) mixes using 60/70 penetration grade bitumen and incorporating sisal fibre as a natural additive. The Marshall Method of mix design was employed to determine the

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Optimum Binder Content (OBC) and Optimum Fibre Content (OFC).

- As per MoRTH and IRC SP-79:2008 specifications, all designed mixes satisfied the required parameters for stability, flow, air voids, VFB, and VMA.
- Among the fillers used in BC mixes, cement provided the highest stability, but fly ash and stone dust were also found suitable. The use of fly ash is environmentally beneficial as it helps utilize industrial waste.
- The addition of sisal fibre up to 0.3% improved Marshall Stability in both BC and SMA mixes. Beyond 0.3%, stability decreased.
- Flow values initially decreased with fibre addition, indicating increased stiffness, but slightly increased again at 0.5% fibre content.
- For SMA, the binder drain down reduced with fibre addition; 0.3% sisal fibre addition lowered the binder content requirement and minimized binder drain down.
- The inclusion of fibre in SMA and BC helped reduce air voids and permanent deformation under load, as shown by the Static Creep Test.
- SMA showed higher Indirect Tensile Strength (ITS) than BC, confirming its superior structural performance.
- SMA mixes with fibre had a permanent deformation value of about 0.45 mm, well within MoRTH's permissible limit of 0.5 mm.

Overall, incorporating 0.3% sisal fibre in both BC and SMA mixes enhances their mechanical properties and durability, making it a promising solution for sustainable and high-performance flexible pavements.

5.2 Future Scope

While this investigation provided valuable insights into the performance of natural fibre-reinforced bituminous mixes, the following areas can be explored in future studies:

- Fatigue Performance: Assess the long-term fatigue life of the mixes under repeated loading.
- Moisture Susceptibility: Evaluate resistance to moisture damage to ensure durability in varied climatic conditions.
- Rutting Resistance: Study the behavior of mixes under high traffic loads to assess deformation resistance.
- Dynamic Creep Testing: Investigate the long-term deformation behavior using dynamic creep tests.
- Alternative Fibres and Binders: Explore the use of other natural and synthetic fibres as well as modified binders for performance enhancement.
- Cost-Benefit Analysis: Analyze the economic advantages of using sisal fibre in large-scale pavement applications.
- Field Performance Monitoring: Construct experimental road stretches using the optimized mixes and monitor their performance over time under actual traffic and environmental conditions.

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