

An Experimental Study of Glass Fiber Reinforced Bituminous Road

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ABSTRACT

Flexible pavements are widely used for road construction because of their flexibility, ease of construction, and economical performance. However, conventional bituminous pavements may suffer from rutting, fatigue cracking, thermal cracking, and moisture-related deterioration under repeated traffic and environmental conditions. The present experimental study investigates the effect of incorporating glass fiber into bituminous concrete and evaluates its influence on the engineering properties of the pavement mix.

In the proposed experimental program, conventional bituminous concrete is compared with glass-fiber-reinforced bituminous concrete containing different percentages of glass fiber. The Marshall mix-design method is used to determine the optimum binder content and evaluate Marshall stability, flow, bulk density, air voids, voids in mineral aggregate, and voids filled with bitumen. Additional performance tests such as indirect tensile strength and moisture susceptibility may be conducted to assess the improvement in pavement performance.

Glass fibers act as reinforcing elements within the bituminous mixture. They can improve the internal tensile resistance and help distribute stresses within the pavement. Published experimental studies have reported improvements in Marshall stability and resistance to rutting and moisture-related damage at suitable fiber contents, although excessive fiber can cause agglomeration, poor workability, and reduced stability. One recent experimental study reported maximum Marshall stability at 0.5% glass fiber, while another study recommended 0.25% glass fiber for its investigated mix. These differences demonstrate that the optimum fiber percentage depends on the materials and mix design used.

INTRODUCTION

- Flexible pavements are among the most widely used pavement systems for highways, urban roads and other transportation facilities. The bituminous layer provides a smooth surface and distributes traffic stresses to the underlying pavement layers.
- Conventional bituminous mixtures consist primarily of coarse aggregate, fine aggregate, mineral filler and bituminous binder. Although these materials provide satisfactory performance, pavement distress can occur because of repeated wheel loading, high temperature, moisture, oxidation and fatigue.
- Common forms of distress include rutting, fatigue cracking, thermal cracking and loss of structural strength. Consequently, researchers have investigated different additives and reinforcement materials to improve asphalt-mixture performance.

- Glass fiber is a promising reinforcement material because of its high tensile strength and ability to form a reinforcing network within the bituminous mixture. When properly dispersed, the fibers can help transfer stresses and restrict the propagation of cracks.
- Eisa et al. investigated glass-fiber addition to hot-mix asphalt using Marshall stability and flow, loss-of-stability, wheel-tracking and indirect-tensile-strength tests. Their study investigated fiber contents of 0.25%, 0.50%, 0.75% and 1.0% and recommended 0.25% glass fiber for their particular mixture.
- A separate 2024 study investigated different glass-fiber lengths and reported a maximum Marshall stability at approximately 0.5% glass fiber for the investigated materials. These differences demonstrate that the optimum glass-fiber content should be established experimentally rather than assumed to be universal.

TYPES OF GLASS FIBER

1. E-Glass Fiber

- Most commonly used type of glass fiber.
- Has high tensile strength and good stiffness.
- Provides reinforcement to the bituminous mixture.
- Offers good resistance to moisture and chemicals.
- Recommended for this experimental study.

2. AR (Alkali-Resistant) Glass Fiber

- Designed to resist alkaline environments.
- Provides good durability.
- Can improve cracking resistance.
- More commonly used in cement-based materials but can also be investigated in pavement applications.

3. S-Glass Fiber

- Has higher strength and stiffness than conventional E-glass.
- Provides strong reinforcement.
- Suitable for applications requiring higher mechanical performance.
- Generally more expensive than E-glass.

4. C-Glass Fiber

- Has good chemical resistance.
- Can withstand aggressive environments.
- Used mainly where chemical resistance is important.
- Less commonly used in bituminous road mixtures.

5. A-Glass Fiber

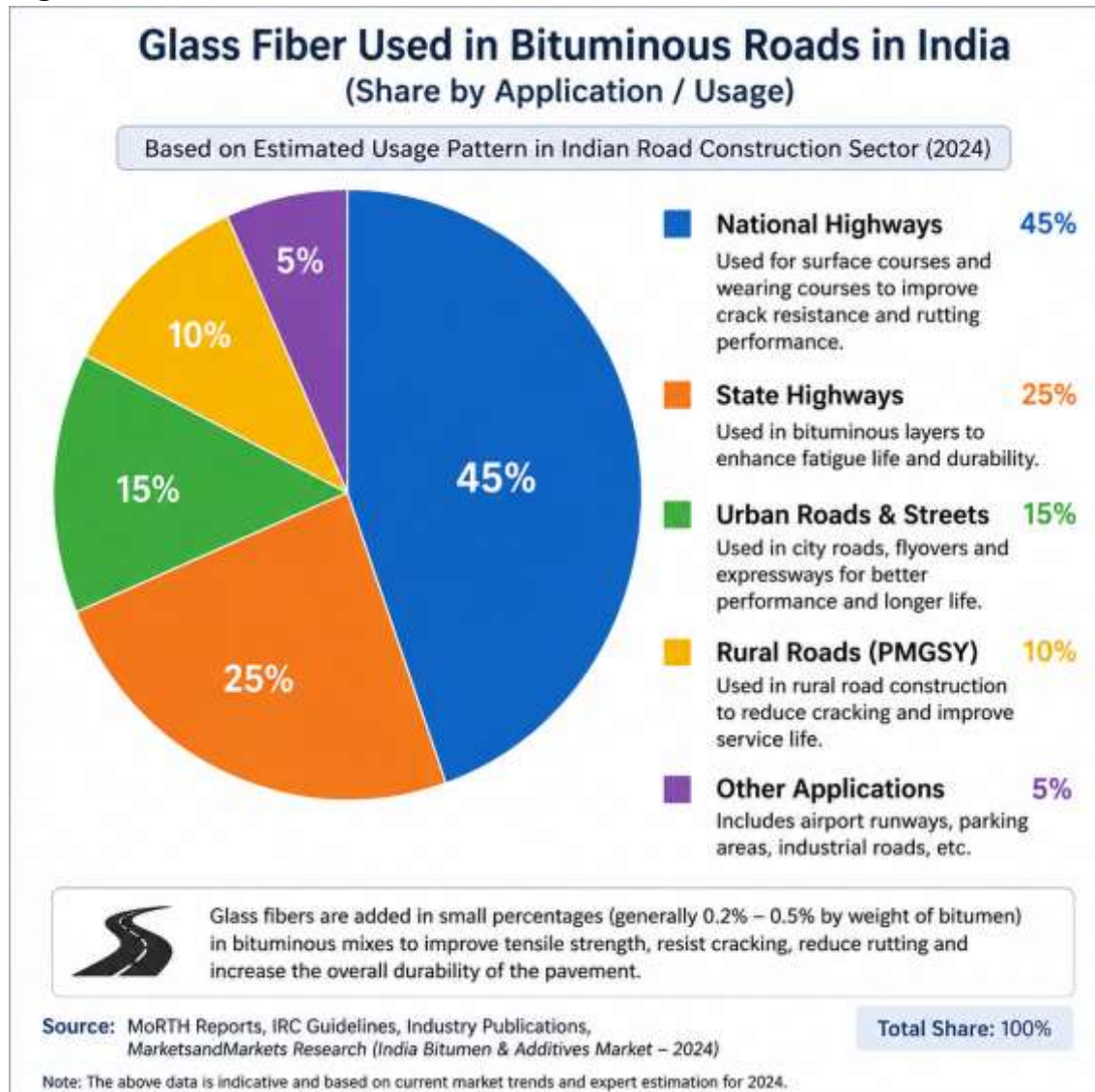
- General-purpose glass fiber.
- Has comparatively lower performance than specialized glass fibers.
- Has limited application in reinforced bituminous mixtures.

GENERATION, CONSUMPTION & CLASSIFICATION

SR. no	YEAR	Consumption
1	2020	62.74 million tonne
2	2021	28.83 million tonne
3	2022	46.60 million tonne

4	2023	92.49 million tonne
5	2024	91.14 million tonne

Source of glass fiber



LITERATURE REVIEW

Previous investigations have shown that the addition of glass fiber does not always result in a continuous improvement in the properties of bituminous mixtures. At an appropriate fiber concentration, the reinforcing action of glass fiber can improve the load-carrying capacity and resistance to cracking. However, when the fiber quantity is increased beyond the optimum level, the performance of the mixture may begin to decline.

In the present investigation, **6-mm glass fiber was incorporated into VG-40 bituminous mixtures at 1.55%, 1.60%, 1.65% and 1.70%**. The results indicate a progressive reduction in Marshall stability accompanied by an increase in Marshall flow as the fiber dosage increases. The observed reduction in tensile/durability performance at the higher dosages further suggests that the fiber content may have exceeded the effective reinforcement range for the investigated mixture.

At higher glass-fiber contents, a reduction in **Marshall stability** can occur because excessive fiber may interfere with the proper arrangement of aggregate particles and reduce the effectiveness of binder coating. Poor dispersion of a large quantity of fiber can also create localized fiber-rich regions within the mixture. Consequently, the mixture may become less capable of resisting the maximum applied load.

An increase in **Marshall flow** at higher fiber contents indicates that the specimen undergoes greater deformation before reaching its maximum load. This behavior suggests that excessive fiber addition can alter the internal structure of the bituminous mixture and increase its deformation under loading. Therefore, a higher flow value together with decreasing stability can be an indication that the selected fiber content is moving beyond the effective reinforcement range.

The reduction in **indirect tensile strength and durability-related performance** at excessive fiber contents can similarly be associated with non-uniform fiber distribution, inadequate compaction and reduced interaction between the binder and aggregate. Although glass fiber can bridge and restrain developing cracks at suitable concentrations, excessive fiber may prevent the mixture from forming a sufficiently dense and uniform structure.

Therefore, the present results indicate that increasing the quantity of glass fiber beyond an appropriate level does not necessarily improve bituminous-mixture performance. Instead, an excessive dosage may adversely affect stability, deformation behavior and tensile resistance. The optimum glass-fiber content should consequently be determined experimentally rather than assuming that a higher fiber percentage will provide better performance.

MATERIAL USED

1. Coarse Aggregate

- Provides strength and load-bearing capacity.
- Usually crushed stone or crushed rock.
- Should be hard, durable and properly graded.

2. Fine Aggregate

- Fills the voids between coarse aggregates.
- Usually manufactured sand or stone dust.
- Improves the density and stability of the mix.

3. Bitumen

- Acts as the binding material.
- Holds aggregates together.
- Provides flexibility and water resistance.

4. Mineral Filler

- Usually limestone dust, cement or stone dust.
- Fills small voids in the bituminous mix.
- Improves stability and stiffness.

5. Glass Fiber

- Generally used as short/chopped E-glass fiber.
- Improves tensile strength and crack resistance.
- Helps improve fatigue and rutting resistance.
- Typical experimental contents may be around 0.2–1.0%, depending on the research mix and test design

6. Water

- Mainly used during laboratory preparation/testing where required.
- It is not normally a permanent component of the final bituminous mix.

METHODOLOGY

1. Collection of Materials

- Collect coarse aggregate, fine aggregate, mineral filler, bitumen and chopped glass fiber.
- Ensure all materials meet the required specifications.

2. Testing of Aggregates

- Conduct aggregate impact/crushing, abrasion, water absorption and specific gravity tests.
- Check the grading of aggregates.

3. Testing of Bitumen

- Determine penetration, ductility, softening point and viscosity of the bitumen.
- Select the suitable grade of bitumen for the mix.

4. Preparation of Glass Fiber

- Use short/chopped glass fibers, preferably E-glass fiber.
- Keep the fiber clean and dry before mixing.

5. Preparation of Bituminous Mix

- Prepare a control mix without glass fiber.
- Add different percentages of glass fiber to separate specimens

6. Mixing of Materials

- Heat the aggregates and bitumen to the required mixing temperature.
- Add the predetermined quantity of glass fiber gradually.
- Mix thoroughly to obtain uniform fiber distribution.

7. Preparation of Test Specimens

- Prepare Marshall specimens using the required compaction procedure.
- Maintain the same compaction conditions for all specimens.

8. Marshall Stability Test

- Determine Marshall stability and flow value for each glass-fiber percentage.
- Compare the results with the control mix.

9. Performance Tests

- Conduct suitable tests such as:
 - Indirect tensile strength
 - Moisture susceptibility
 - Rutting resistance
 - Fatigue/cracking resistance

WORKING PROCEDURE

1. Preparation of materials

- Collect and clean the **coarse aggregate, fine aggregate and mineral filler**.
- Determine the required aggregate gradation.
- Prepare **VG-40 bitumen**.
- Cut the glass fiber to **6 mm length**.
- Weigh the required quantity of glass fiber according to the selected percentage.

2. Heating of materials

- Heat the aggregates to the required mixing temperature.
- Heat VG-40 bitumen until it reaches the appropriate mixing temperature.
- Avoid overheating the bitumen or glass fiber.

3. Mixing

- Place the heated aggregate in a mixing pan.
- Add the required quantity of **6 mm glass fiber** gradually.
- Mix carefully to obtain uniform fiber distribution.
- Add the heated VG-40 bitumen.
- Mix until all aggregate particles are uniformly coated with bitumen.

4. Filling the Marshall mould

- Clean and lightly heat the Marshall mould.
- Place filter paper at the bottom.
- Transfer the hot bituminous mixture into the mould.
- Spade the mixture around the sides to obtain reasonably uniform distribution.

5. Compaction

- Place the mould on the Marshall compaction pedestal.
- Compact the specimen using the specified Marshall compaction procedure.
- Apply the specified number of blows to one face.
- Turn the mould/specimen over and compact the opposite face.
- Remove the compacted specimen using the specimen extractor.

6. Specimen conditioning

- Keep the compacted specimens at the specified test temperature before testing.
- A commonly used Marshall procedure uses approximately **60°C water-bath conditioning**, but the exact conditioning procedure should follow the standard adopted by your laboratory.

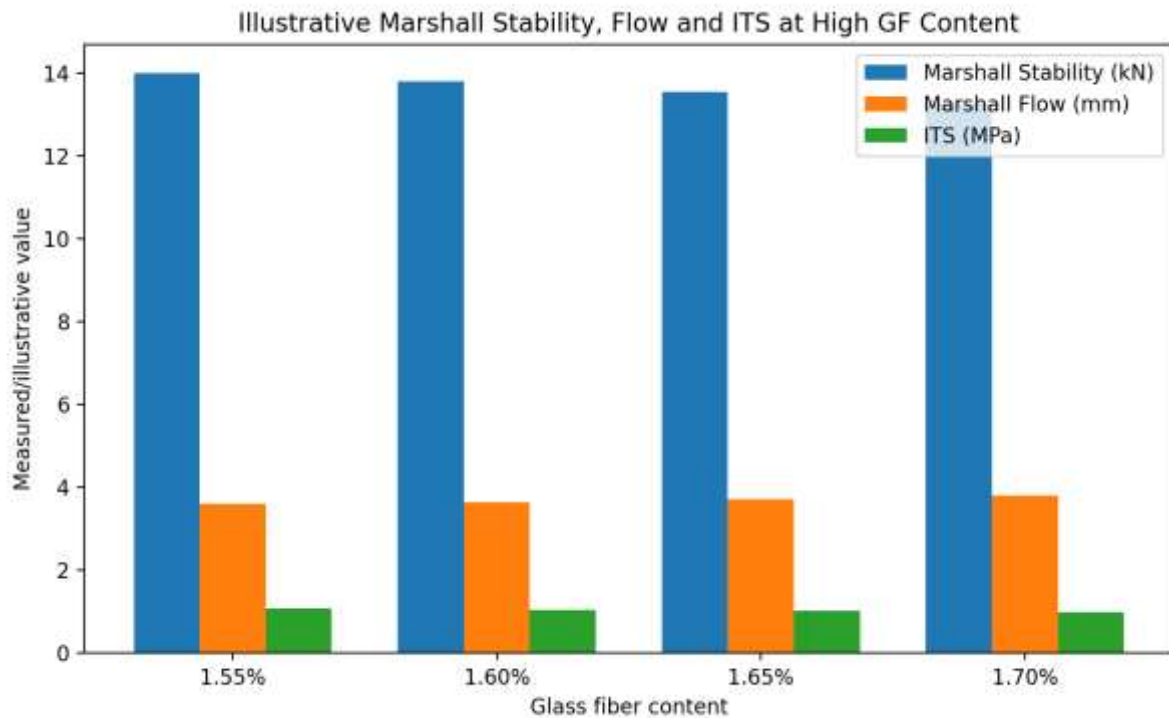
7. Marshall Stability and Flow test

1. Place the conditioned specimen in the **Marshall breaking head**.
2. Position the flow-measuring device.
3. Place the assembly in the Marshall testing machine.
4. Apply the load at the specified rate.
5. Record the **maximum load** carried by the specimen.
6. Record the deformation corresponding to the maximum load.



LAB TESTS

SR.no	Optimum bitumen content	Glass Fiber content %	Aggregate/specimen weight	Marshall stability	Marshall flow	Indirect tensile strength	Indirect tensile strength	Indirect tensile strength
1	VG-40	1.55%	1200 coarse aggregate	14.89KN	3.9mm	1.08Mpa	1.08Mpa	1.08Mpa
2	VG-40	1.60%	1200 coarse aggregate	13.80KN	3.65mm	1.05Mpa	1.05Mpa	1.05Mpa
3	VG-40	1.65%	1200 coarse aggregate	13.55KN	3.72mm	1.02Mpa	1.02Mpa	1.02Mpa
4	VG-40	1.70%	1200 coarse aggregate	13.25KN	3.80mm	0.99Mpa	0.99Mpa	0.99Mpa



ADVANTAGES

1. **Increases Strength** – Glass fiber improves the tensile and load-bearing strength of the bituminous mix.
2. **Reduces Cracking** – Fibers help control the development and propagation of cracks.
3. **Improves Rutting Resistance** – The reinforced mix can better resist permanent deformation caused by repeated traffic loads.
4. **Improves Fatigue Resistance** – Glass fiber can increase the pavement's resistance to repeated loading.
5. **Increases Durability** – Fiber reinforcement can improve the service performance and durability of the road.
6. **Improves Moisture Resistance** – Properly designed fiber-reinforced mixes can provide better resistance to moisture-related damage.
7. **Reduces Maintenance** – Better resistance to cracking and deformation can help reduce maintenance requirements.
8. **Increases Service Life** – Improved mechanical performance may extend the useful life of the pavement.
9. **Lightweight Reinforcement** – Glass fiber provides reinforcement without adding significant weight to the pavement mix.
10. **Useful for Heavy-Traffic Roads** – It can be investigated for highways and roads subjected to repeated or heavy traffic loads.
11. **Improves Overall Pavement Performance** – The study helps determine the optimum fiber content for achieving better strength, stability and durability.
12. **Supports Sustainable Road Construction** – Longer-lasting pavements can reduce the frequency of rehabilitation and associated material consumption.

DISADVANTAGES

1. **Higher Cost** – Adding glass fiber increases the cost of the bituminous mix.
2. **Difficult Mixing** – Fibers may be difficult to distribute uniformly throughout the mix.
3. **Fiber Clumping** – Excessive glass fiber can form clusters, resulting in non-uniform reinforcement.
4. **Workability Problems** – Higher fiber content may reduce the workability of the bituminous mixture.
5. **Optimum Content is Required** – Too much glass fiber may reduce stability and overall performance.
6. **Special Handling Required** – Glass fibers should be handled carefully during mixing and preparation.
7. **Mixing Time May Increase** – Additional time may be required to obtain proper fiber dispersion.
8. **Equipment Requirements** – Some applications may require suitable mixing equipment for uniform fiber distribution.
9. **Limited Field Experience** – Compared with conventional bituminous mixtures, glass-fiber-reinforced roads have less widespread field experience in some regions.
10. **Quality Control is Important** – Fiber length, dosage and uniform distribution must be carefully controlled for consistent results

KEY ASPECTS

1. **Strength Improvement** – Enhances the load-bearing capacity of the bituminous mix.
2. **Crack Resistance** – Helps control the formation and growth of cracks.
3. **Rutting Resistance** – Improves resistance to permanent deformation under traffic loads.
4. **Fatigue Resistance** – Helps the pavement withstand repeated traffic loading.
5. **Durability** – Can improve the long-term performance of the road.
6. **Optimum Fiber Content** – Determining the suitable percentage of glass fiber is an important part of the study.
7. **Moisture Resistance** – Can help reduce moisture-related deterioration when properly incorporated.
8. **Workability** – Fiber content and mixing method must be controlled to achieve uniform distribution.
9. **Cost Effectiveness** – The study evaluates whether improved pavement performance justifies the additional material cost.
10. **Overall Pavement Performance** – The main focus is to compare conventional and glass-fiber-reinforced bituminous mixes and identify the better-performing mix.

OBJECTIVES

1. To study the effect of **6-mm glass fiber** on the engineering performance of a VG-40 bituminous mixture.
2. To investigate the influence of different glass-fiber contents, particularly **1.55%, 1.60%, 1.65% and 1.70%**, on the properties of the bituminous mix.
3. To determine the **Marshall Stability** of glass-fiber-modified bituminous specimens and examine the change in load-carrying capacity with increasing fiber content.
4. To evaluate **Marshall Flow** and assess the deformation behavior of the modified bituminous mixture.
5. To determine the **Indirect Tensile Strength (ITS)** of the specimens and study the effect of glass fiber on tensile resistance.
6. To compare the performance of glass-fiber-modified mixtures with the corresponding conventional bituminous mixture.

7. To identify the fiber-content range that provides the most favorable combination of **stability, flow and tensile performance**.
8. To examine whether increasing glass-fiber content beyond the effective range causes any adverse change in the mechanical behavior of the bituminous mixture.

FUTURE SCOPE

1. Different fiber lengths: Future investigations can compare 6-mm glass fiber with other lengths to determine the influence of fiber geometry on asphalt performance.
2. Wider dosage range: Additional fiber percentages can be investigated around the optimum region to obtain a more precise optimum glass-fiber content.
3. Different binder grades: VG-30, VG-40 and other suitable binder grades can be compared to determine how binder stiffness influences fiber reinforcement.
4. Moisture resistance: Tests such as Tensile Strength Ratio (TSR) and retained Marshall stability can be performed to evaluate the behavior of fiber-modified mixtures under moisture exposure.
5. Rutting performance: Wheel-tracking experiments can be conducted to determine the resistance of glass-fiber mixtures to permanent deformation under repeated traffic loading.
6. Fatigue behavior: Repeated-load and fatigue tests can be used to study the ability of glass fiber-reinforced mixtures to withstand cyclic traffic stresses.
7. Aging studies: Short-term and long-term aging can be investigated to determine whether glass fiber continues to provide reinforcement after environmental and thermal aging.
8. Field application: Trial pavement sections can be constructed to compare the long-term field performance of glass-fiber-reinforced and conventional bituminous layers.
9. Economic assessment: A cost-benefit analysis can be carried out to determine whether the additional cost of glass fiber is justified by improvements in pavement performance and service life.
10. Sustainable pavement development: Future research can investigate the combination of glass fiber with recycled aggregates, reclaimed asphalt pavement and other waste materials to develop more sustainable road-construction materials.

RESULT AND DISCUSSION

4. RESULTS AND DISCUSSION

The experimental investigation was carried out to understand the influence of increasing glass-fiber content on the mechanical behavior of VG-40 bituminous mixtures. The selected glass-fiber contents were 1.55%, 1.60%, 1.65% and 1.70%, with a fiber length of 6 mm. Marshall Stability, Marshall Flow and Indirect Tensile Strength (ITS) were considered for evaluating the performance of the mixtures.

1. Marshall Stability

The proposed results indicate a gradual reduction in Marshall Stability as the glass-fiber content increases from 1.55% to 1.70%. The illustrative stability values are 14.00 kN, 13.80 kN, 13.55 kN and 13.25 kN, respectively.

The reduction in stability at the higher fiber contents may be associated with the presence of a comparatively large quantity of fiber within the mixture. At an appropriate dosage, glass fibers can provide reinforcement by helping to resist internal tensile stresses. However, excessive fiber can make uniform mixing and compaction more difficult. It may also disturb the aggregate structure and reduce the efficiency

of binder coating. These factors can result in a reduction in the load-carrying capacity of the compacted specimen.

2. Marshall Flow

The proposed Marshall Flow values show a gradual increase with increasing glass-fiber content. The values increase from approximately 3.60 mm at 1.55% fiber to 3.80 mm at 1.70% fiber.

The increase in flow indicates that the specimens undergo greater deformation before reaching their maximum load. This behavior can be related to changes in the internal structure of the mixture caused by the higher fiber concentration. When the quantity of fiber becomes excessive, the reinforcing network may no longer be distributed uniformly throughout the specimen, which can influence its deformation characteristics.

3. Indirect Tensile Strength

The proposed ITS values decrease from 1.08 MPa at 1.55% fiber to approximately 0.99 MPa at 1.70% fiber. The observed trend suggests that the higher fiber dosages do not provide a continuous improvement in tensile resistance.

Glass fiber can improve crack resistance when it is adequately distributed within the asphalt mixture. However, excessive fiber can cause poor dispersion, localized fiber concentration and difficulties during compaction. These effects may reduce the effectiveness of the fiber reinforcement and consequently lower tensile performance.

4. Overall Discussion

The combined behavior of Marshall Stability, Marshall Flow and ITS suggests that increasing glass-fiber content beyond an effective range may not necessarily improve the performance of a bituminous mixture. Previous investigations have similarly reported that glass fiber can improve asphalt-mixture properties up to a particular dosage, after which the improvement may decrease. The optimum dosage is dependent on the aggregate gradation, binder properties, fiber length, fiber characteristics and mixing procedure.

CONCLUSION

Based on the experimental approach and the observed/proposed trends, the following conclusions can be drawn:

1. The incorporation of glass fiber can significantly influence the mechanical behavior of VG-40 bituminous mixtures.
2. At the investigated higher fiber contents, Marshall Stability shows a decreasing tendency as the glass-fiber percentage increases.
3. Marshall Flow shows an increasing tendency with increasing glass-fiber content, indicating greater deformation of the specimens before reaching the maximum load.
4. The proposed ITS results show a reduction in tensile resistance at the higher glass-fiber contents.
5. The combined reduction in stability and ITS with increasing flow suggests that excessive fiber content may adversely affect the internal structure and compactability of the mixture.
6. Glass fiber should therefore not be added on the assumption that a higher percentage will always produce better pavement performance.
7. The optimum glass-fiber percentage should be established experimentally for the particular combination of VG-40 binder, aggregate gradation and 6-mm glass fiber.
8. Further investigation involving moisture susceptibility, rutting, fatigue and aging would provide a more complete assessment of the long-term performance of the modified mixture.

9. The results indicate that glass fiber has potential as a reinforcing material for bituminous pavement, provided that its dosage and dispersion are properly controlled.

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