International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Study of Bituminous Mix Using Glass Fiber of Different Aspect Ratios

Sumit Chandrol[1], Prof. Balram Nargawe[2]

[1]MTech Scholar, Civil Engineering Department, Rewa Engineering College Rewa Madhya Pradesh 486001
[2]Assistant Professor, Civil Engineering Department, Rewa Engineering College Rewa Madhya Pradesh 486001

Abstract
The use of glass fibers in bituminous concrete has gained attention as an effective method for improving the performance and durability of flexible pavements. This study examines the impact of glass fibers with different aspect ratios (lengths: 8 mm, 16 mm, and 24 mm) on the mechanical behavior of asphalt mixtures. Key parameters evaluated include Marshall Stability, flow value, air voids, voids in mineral aggregate (VMA), and voids filled with bitumen (VFB). The bituminous mixes were prepared using a dry mixing technique, with glass fibers incorporated at varying proportions (2.5%, 5%, 7.5%, and 10%)
As a partial replacement for bitumen by weight Marshall Stability testing was carried out to evaluate the influence of fiber inclusion on structural integrity, resistance to deformation (rutting), fatigue life, and moisture sensitivity. The results demonstrate that the addition of glass fibers enhances both the strength and durability of the bituminous mix, with the most favorable performance observed at a fiber content of 7.5%. Beyond this level, the improvements were marginal or declined slightly. The study also highlights the role of fiber aspect ratio in improving compaction and crack resistance, emphasizing its importance in mix optimization. Overall, the findings support the use of glass fibers as a sustainable modifier for extending the service life of asphalt pavements.
Each sample undergoes a Marshall Stability test to assess stability, flow, and void characteristics. Additionally, the study evaluates the impact of fiber addition on rutting resistance, fatigue life, and moisture susceptibility of the asphalt mix. The results indicate that the optimal fiber content significantly improves the stability and durability of the mix, reducing susceptibility to deformation and enhancing load-bearing capacity. The study also explores the effects of fiber size and dosage on cracking resistance, demonstrating that properly optimized fiber incorporation enhances the overall performance of asphalt pavements. This research provides valuable insights into sustainable pavement design, advocating for the effective utilization of glass fibers in bituminous mixtures for improved road performance and longevity.

Keywords: Ductility, Flow value, Glass fiber, Marshall test, Stability

1. INTRODUCTION

A reliable and long-lasting road network is vital for economic development and connectivity. Bituminous Concrete (BC), a common material used in flexible pavement construction, consists of a mixture of aggregates and bitumen. However, with the increasing load from modern traffic and climatic stresses, conventional BC often suffers from issues like fatigue cracking, rutting, and ravelling. To address these challenges, researchers have explored various modification techniques, including the use of fibers and polymers to enhance pavement performance.

Fibers, both natural and synthetic, have been incorporated into bitumen mixtures to improve tensile strength, flexibility, and resistance to cracking and deformation. While materials like cotton and asbestos were previously considered, their long-term durability and health impacts have limited their usage. In contrast, synthetic fibers, particularly glass fibers, have emerged as a promising solution due to their high tensile strength, durability, and resistance to environmental degradation.

Glass fiber-reinforced bituminous mixes aim to improve structural performance by increasing strain energy absorption and reducing binder drainage. These fibers also contribute to better load distribution, crack resistance, and moisture stability. Their inclusion is especially beneficial in high-traffic areas and extreme weather conditions, where conventional mixes may fail prematurely.

This study focuses on evaluating the effect of glass fibers with different aspect ratios (lengths) on the performance of bituminous mixes. By examining key parameters such as Marshall Stability, flow value, air voids, and voids filled with bitumen, the research aims to determine the optimal fiber length and dosage for achieving improved mechanical properties. The findings are intended to contribute to more sustainable, durable, and cost-effective pavement solutions for modern infrastructure demands.

Bituminous concrete pavements are flexible compared to rigid Portland cement pavements, consisting of several layers designed to distribute loads and provide a durable surface. These pavements are made by combining aggregates and bitumen, along with optional additives that improve the mix's performance and longevity. The aggregates provide structural strength and load-bearing capacity, with coarse aggregates providing the main support and fine aggregates filling voids for better compactness. Filler materials such as lime or cement help improve cohesion and fill micro-voids. The bitumen binder acts as an adhesive, binding the aggregates together while offering flexibility and resistance to water and environmental variations.

In bituminous mix design, several factors influence the desired properties of the final mix. These include bitumen content, aggregate characteristics (such as gradation and surface profile), compaction, and the type of binder used. Key properties include stiffness, stability, durability, and fatigue resistance, each crucial for the pavement's performance and longevity. Proper aggregate gradation is essential, as it affects the strength, stability, and workability of the mix. Well-graded aggregates minimize void spaces, improve compaction, and enhance the stability and durability of the mix, contributing to better resistance to rutting, cracking, and water infiltration.

To improve the performance of Bituminous Concrete (BC), various fibers are added to bitumen mixes as additives. These fibers, which include both natural and synthetic types, enhance the strength and stiffness of bituminous mixes, particularly those with high tensile strength [8]. The addition of fibers increases the energy absorption and stiffness of bitumen, leading to harder mixes with reduced binder drainage and improved stability [3]. Fiber reinforcement has been a common practice in construction since the 1950s, showing benefits like reduced aggregate runoff and improved properties in the bitumen mastic [6, 9].

Literature reviews

Early research, such as **Zube's** 1956 study, demonstrated that wire mesh reinforcement in bitumen overlays delayed cracking and enabled thinner overlays without compromising performance [10].

Simpson et al. (1994) found that polypropylene fibers enhanced tensile strength and cracking resistance in modified bituminous mixtures, although moisture resistance was not affected [11]. Recent studies, such as **Qunshan et al.** (2009), highlighted improvements in fatigue resistance with fibers like polyester and cellulose [12], **while Park et al.** (2015) found that steel fibers significantly improved low-temperature cracking resistance, tensile strength, and fracture energy, with fiber performance being dependent on length, diameter, and deformation characteristics [13].

Nursuhana Borhanuddin et al. (2024) [14] explored the use of waste glass fibers as modifiers in stone mastic asphalt (SMA). Glass fibers were added to bitumen 60/70 PEN at 0.5%, 1.0%, 1.5%, and 2.0% by weight, and to SMA14 at 0.3% by weight. The study found that glass fiber modification improved penetration, softening point, viscosity, and rutting resistance, with the dry method enhancing abrasion resistance, rutting resistance, and tensile strength.

Hassan Ziari et al. (2020) [15] assessed the cracking behavior of asphalt mixtures with reclaimed asphalt pavement (RAP) and glass fibers. The study showed that adding 0.12% glass fiber significantly improved crack resistance, mitigating the negative impact of RAP, allowing for 100% RAP mixtures without reducing crack resistance.

M. S. Eisa et al. (2020) [16] evaluated the impact of incorporating glass fiber (GF) into hot mix asphalt (HMA) mixtures. The study found that adding GF significantly enhanced most HMA properties, with 0.25% GF by total mix weight being recommended as the optimal mix.

Dong Luo et al. (2019) [17] reviewed the impact of lignin and glass fibers as modifiers in bituminous mixtures. The findings indicated that incorporating lignin or glass fibers significantly enhanced the overall quality of bitumen mixes. The study highlighted that glass fibers improved high-temperature resistance, though a single modifier remains insufficient for comprehensive performance improvements.

Mahmoud Enieb et al. (2019) [18] examined bitumen mixtures with fibers and developed a model to assess the impact of fiber dosage on mechanical properties. The study found that while 12-mm fibers showed minimal improvement over 6-mm fibers, glass fibers enhanced strength, rutting resistance, moisture damage resistance, and fatigue crack retardation, offering long-term benefits despite higher initial costs.

Reza Tanzadeh et al. (2019) [16] explored the performance of mixtures enhanced with nano-silica, polymer, basalt fiber, and glass fiber. The study concluded that the optimal mixture included basalt fiber, nano-silica, and SBS polymer for improved performance, with glass fiber being more effective than basalt fiber in reducing permeability.

Shukla et al. (2013) [19] investigated the feasibility of modifying asphalt/bitumen concrete using glass fibers. They found that glass fiber modified asphalt mixes exhibited increased stiffness, better resistance, and enhanced characteristics compared to conventional mixes.

S.M. Abtahi et al. (2013) [2] demonstrated that combining polypropylene (PP) and glass fibers improved asphalt concrete mixtures, with a hybrid approach of 0.1% glass fiber and 6% PP fiber showing superior results in terms of stability, flow reduction, and improved consistency, making it suitable for hot regions.

Mahrez et al. (2005) [3] studied bitumen reinforced with glass fibers and found that the inclusion of glass fibers led to improved performance, enhancing several critical properties of flexible pavements.

2. MATERIALS AND METHODOLOGY

Primary aim of this research was to assess properties of bituminous concrete with glass fiber. The laboratory testing involved several stages, starting with the evaluation of material properties, including aggregates, bitumen, and glass fiber. Sieve analysis was conducted on the aggregates to determine their particle size distribution, and they were blended to create a suitable gradation curve for the bituminous concrete mix. Bituminous mixes were then prepared with varying bitumen contents, and the Marshall Stability test was used to determine the Optimum Bitumen Content (OBC). Using the OBC, bitumen mixes were modified by incorporating glass fibers at varying percentages (2.5%, 5%, 7.5%, and 10%) and different sizes (8 mm, 16 mm, and 24 mm). The properties of the modified mixes were assessed through the Marshall test to examine the impact of fiber content and size on the mix. Finally, the results were compiled and analyzed to evaluate the effectiveness of glass fiber modification in improving bituminous concrete.

The experimental work was carried out in three main stages:

1. **Determination of Optimum Bitumen content (OBC)**

Bituminous mixes were first prepared using varying bitumen contents (4%, 5%, 6%, and 7% by weight of total mix). For each percentage, three Marshall specimens were cast and tested to evaluate parameters such as stability, flow, air voids, and voids filled with bitumen. Based on these results, the OBC was determined to be 5%, offering an optimal balance between strength and workability.

2. **Preparation of Modified Mixes with Glass fibers**

Using the OBC of 5%, glass fibers were added to the mix in four different proportions (2.5%, 5%, 7.5%, and 10%) for each fiber length (8 mm, 16 mm, and 24 mm). The fibers were used as a replacement for part of the bitumen, ensuring the combined weight of fiber and bitumen remained constant at 60 grams. A total of 39 specimens were prepared across all combinations, in addition to 12 specimens used for OBC determination and 3 control specimens (0% fiber), resulting in a total of 51 samples.

3. **The testing and evaluation**

The modified mixes were subjected to Marshall Stability tests to determine key performance parameters including stability, flow, air voids, bulk specific gravity, voids in mineral aggregate (VMA), and voids filled with bitumen (VFB). All tests were conducted in accordance with standard specifications. This systematic methodology allowed for a comprehensive evaluation of how different fiber lengths and dosages affect the structural performance and durability of bituminous concrete.

The material testing for this study was conducted in two stages. In the first stage, four different percentages of bitumen (4%, 5%, 6%, and 7%) were tested to determine the optimum bitumen content (OBC) for the selected aggregates. Three specimens were cast for each bitumen percentage, resulting in a total of 12 samples, which were subjected to Marshall Stability testing. In the second stage, based on the OBC calculated earlier, three samples were prepared for each glass fiber percentage (0%, 2.5%, 5%, 7.5%, and 10%) by total bitumen weight, with varying fiber sizes (8 mm, 16 mm, and 24 mm), resulting in a total of 39 samples. In total, 51 samples were required for testing.

Table 1. Bitumen testing results

S. No	Test	Result	limits	References
1.	Penetration test (mm)	67	60-80	IS: 1203 – 1978
2.	Specific gravity (gm/ml)	1.033	0.97-1.06	IS: 1202 – 1978
3.	Ductility (cm)	44	<50	IS 1208 – 1978

4.	Softening point (°c)	49	48-56	IS 1205 - 1978

These results confirmed that the bitumen was suitable for the study.

Glass fibers of varying lengths (8 mm, 16 mm, and 24 mm) with a specific gravity of 2.5 were prepared and added to the mix to improve its properties. The aggregates used ranged from 13.2 mm to 75 microns, with a well-graded mix. Tests such as Sieve Analysis, Specific Gravity, Water Absorption, Los-Angeles Abrasion and aggregate impact value test were performed on the aggregates.

Table 2. Aggregates testing results

S.No	Test	Result	Specified limits	References
1.	Specific gravity Coarse aggregate Fine aggregate	 2.67 2.31	 2.5 - 3.2 2.3 – 2.9	 IS : 2363(III) - 1963
2.	Aggregate impact value (%)	15.73 (strong)	10 - 20	
3.	Los angeles abration test (%)	22.48	<40	IS : 2386(IV) - 1963
4.	Water absorption test (%)	1.12	0.1 – 2.0	

The specific gravity of the coarse aggregates was found to be 2.67, the apparent specific gravity was 2.761, and water absorption was 1.12%. The Los-Angeles Abrasion Value was 22.48%, which is within the acceptable range for road construction. The Aggregate Impact Value (AIV) was 15.73%, indicating that the aggregate is tough and suitable for construction applications. The aggregates were blended according to a specified sieve distribution, with 3% filler material (36 g) and 5% bitumen (60 g), bringing the total sample weight to 1200 g. Overall, the material properties were suitable for the study's experimental objectives, ensuring that both the bitumen and aggregate met the necessary specifications.

Figure 1. Sample testing

Figure 2.cutting Glass Fiber

The laboratory experiments conducted in this study aimed to evaluate the effect of varying percentages of glass fiber (GF) on the properties of bitumen mixtures, with a focus on determining the optimal GF percentage for incorporation into hot mix bitumen. This chapter presents the laboratory results in three stages.

Figure 3. Prepairing the mix

Figure 4. Rammering of mix

In the first stage, the results of aggregate blending were analyzed to develop the gradation curve for the bitumen wearing course. The aggregate proportions were chosen to comply with ASTM specifications, ensuring that the final mix met the required gradation limits. The aggregate blend consisted of 40% coarse aggregate, 57% fine aggregate, and 3% filler, totalling 100%. The sieve analysis data for the aggregates are shown in Table 3, which provides details on the sieve sizes, percentage passing, and the specified ASTM D5315 limits. The aggregate gradation was critical in ensuring a well-graded mix for the bitumen wearing course.

Sieve Size (in mm)	% Passing (Range)	% Retain	Weight Passing (in gm)	Weight Retained (in gm)
19	100	0	1200	0
13.2	79-100	5	1140	60
9.5	70-88	20	960	180
4.75	53-71	40	720	240
2.36	42-58	52	576	144
1.18	34-48	64	432	144
0.6	26-38	73	324	108
0.3	18-28	82	216	108
0.15	12-20	88	144	72
0.075	4-10	92	96	48

Table 3 Blending of aggregate

In the second stage, the Marshall Test was conducted using varying percentages of bitumen, ranging from 4.0% to 7.0%, to determine the optimum binder content (OBC). A total of 12 specimens, each weighing approximately 1200 grams, were prepared using different bitumen content levels. The Marshall test results for different bitumen percentages (4%, 5%, 6%, and 7%). The key parameters measured included the weight in air, weight in water, specific gravity, stability, plastic flow, stiffness, air voids, voids in mineral aggregate, and voids filled with bitumen. From the results, the optimum bitumen content (OBC) was determined to be 5%, which provided a good balance between stability, flow, and air voids.

Once the OBC was established, the third stage involved the incorporation of varying percentages of glass fiber 2.5%, 5%, 7.5%, and 10% of bitumen content (60 grams) with sizes of 8 mm, 16 mm, and 24 mm. with the addition of glass fiber into the mix we also use the glass fiber as a replacement of bitumen, which means the weight of both (glass fiber and bitumen) will remain the 60 grams. The impact of these fibers on the properties of the bitumen mixture was evaluated through additional Marshall test, The results of the tests for mixes with 0% glass fiber (pure bitumen mix)

3. RESULT AND DISCUSSION

Description	Stability (kg)	Flow (mm)	Stiffness (kg/mm)	Air Voids (%)
0% GF	1646.33	3.06	538	3.56
8mm GF, 2.5%	1705	3.17	537.9	3.39
8mm GF, 5%	1807	3.22	561.2	3.08
8mm GF, 7.5%	1906.7	3.64	523.3	3.18
8mm GF, 10%	1788	3.3	541.3	3.35

Table 4A - 8mm Glass fiber

Description	Stability (kg)	Flow (mm)	Stiffness (kg/mm)	Air Voids (%)
0% GF	1646.33	3.06	538	3.56
16mm GF, 2.5%	1730.33	3.21	539	3.36
16mm GF, 5%	1833	3.22	568.7	3.43
16mm GF, 7.5%	1917.33	3.73	519.2	3.66
16mm GF, 10%	1790.67	3.32	538.2	3.22

table 4B - 16mm Glass fiber

Description	Stability (kg)	Flow (mm)	Stiffness (kg/mm)	Air Voids (%)
0% GF	1646.33	3.06	538	3.56
24mm GF, 2.5%	1759	3.19	554.8	3.05
24mm GF, 5%	1849	3.23	573.6	3.3
24mm GF, 7.5%	1946	3.77	516.7	3.26
24mm GF, 10%	1787.33	3.31	539.9	3.18

table 4C - 24mm Glass fiber

The results of the study illustrate the influence of glass fibers on the properties of bituminous mix. From the table no. 4A, 4B & 4C

This section presents the performance analysis of bituminous mixes reinforced with glass fibers of three lengths—8 mm, 16 mm, and 24 mm—added at various dosages (2.5%, 5%, 7.5%, and 10% by weight of bitumen). The influence on Marshall Stability, flow, stiffness, and air voids was evaluated to assess structural integrity and mix workability.

1. Performance with 8 mm Glass Fiber

The inclusion of 8 mm glass fibers showed a consistent improvement in stability and stiffness up to a dosage of 7.5%. The peak stability was observed at 7.5% fiber content, reaching 1906.7 kg, significantly higher than the control mix (1646.33 kg). Flow increased moderately, indicating better flexibility. Air voids decreased initially, suggesting improved compaction, but rose slightly at 10%.

- **Stability - increased up to 7.5%, then declined at 10%.**
- **Flow - rose from 3.06 mm to 3.64 mm at 7.5%, indicating improved deformation resistance.**
- **Stiffness - peaked at 5% (561.2 kg/mm) and dropped slightly at higher dosages.**
- **Air Voids were lowest at 5% (3.08%) and rose again at 10% (3.35%).**

Conclusion: 7.5% 8 mm GF provided the best balance of strength and flexibility, while 5% offered better compaction.

2. Performance with 16 mm Glass Fiber

For the 16 mm fibers, the highest stability (1917.33 kg) occurred at 7.5%, with performance trends closely mirroring those of the 8 mm length. Flow and air voids increased beyond this dosage, potentially indicating over-saturation and poor fiber dispersion.

- Stability - peaked at 7.5% GF, improving over the control.
- Flow - rose steadily from 3.06 mm to 3.73 mm.
- Stiffness - was highest at 5% (568.7 kg/mm), followed by a drop at 7.5%.
- Air Voids - increased to 3.66% at 7.5%, which may reduce durability.

Conclusion: 5% 16 mm GF offered the best stiffness, while 7.5% gave the highest strength but at the cost of increased voids.

3. Performance with 24 mm Glass Fiber

The 24 mm fibers delivered the highest stability overall (1946 kg at 7.5%), highlighting their superior reinforcement potential. Flow and stiffness showed favorable results at lower dosages, but performance slightly declined beyond 7.5%.

- Stability - Improved significantly from 1646.33 kg to 1946 kg.
- Flow - Reached 3.77 mm at 7.5%, the highest among all.
- Stiffness - Peaked at 5% (573.6 kg/mm), then declined slightly.
- Air Voids - Lowest at 2.5% (3.05%), increasing moderately at higher dosages.

Conclusion: 7.5% 24 mm GF provided the strongest structure, while 5% maintained optimal stiffness and compaction.

Summary of Optimal Performance

- All fiber lengths demonstrated best performance at 7.5% content.
- 24 mm GF at 7.5% delivered the highest Marshall Stability.
- 5% dosage offered the best balance of strength, stiffness, and compaction for all fiber lengths.
- Excessive fiber content (>7.5%) slightly hindered performance due to poor dispersion and higher air voids.

In summary, increasing fiber percentages up to 7.5% enhances stability, with smaller fiber sizes (8 mm and 16 mm) generally offering better performance in terms of compaction, stability, and stiffness compared to larger fibers (24 mm). Further investigations could refine these findings and explore long-term durability. Figure 5 shows the graphical representation of results.

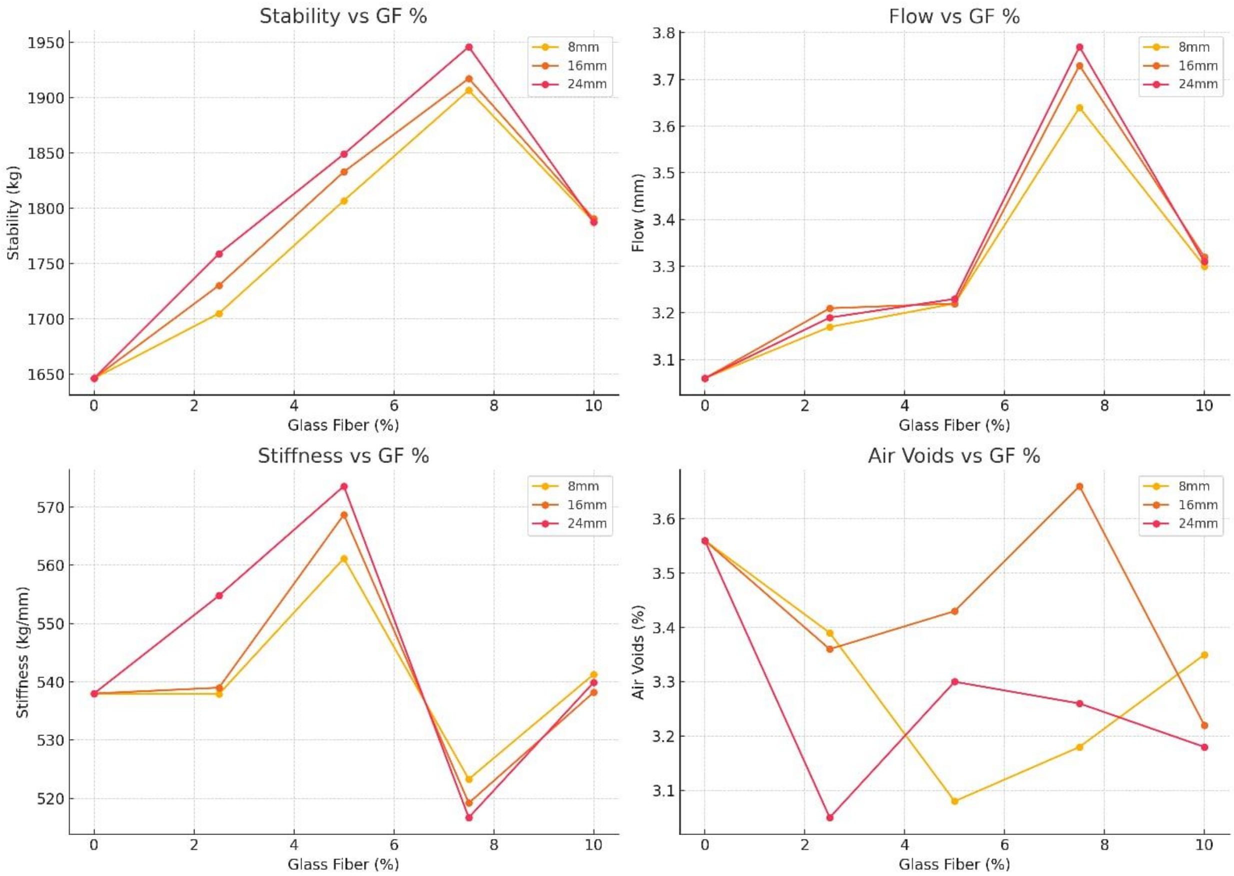

Figure 5 Graphical representation of results

4. Conclusion

Brief Conclusion Based on Fiber Length

The study clearly demonstrates that the length of glass fiber plays a crucial role in enhancing the performance of bituminous mixes:

- **8mm** fibers improved workability and compaction, making them ideal where mix density and smooth handling are priorities.
- **16mm** fibers offered a balance between strength and compaction, with the best stiffness observed at moderate dosages.
- **24mm** fibers delivered the highest stability, making them most suitable for strength-critical

applications, though care must be taken to avoid excessive dosage which may impact mix homogeneity.

Overall, a fiber content of 7.5% across all lengths yielded optimal performance, with 24 mm fibers at 7.5% standing out for maximum Marshall Stability.

Based on the results obtained these recommendations are suggested.

1. **Optimal Fiber Content**

A dosage of 7.5% by weight of bitumen is recommended for achieving maximum Marshall Stability across all fiber lengths.

2. **Fiber Length Selection**

Use 24 mm fibers where high strength and load-bearing capacity are required, such as in highways or industrial pavements.

Use 8 mm or 16 mm fibers in urban roads or areas needing better compaction and flexibility.

3. **Avoid Over-Dosage**

Fiber content beyond 7.5% may lead to reduced performance due to poor dispersion and increased air voids. Maintain proper dosage control.

4. **Mixing and Dispersion**

Ensure uniform mixing of fibers during the hot mix process to avoid clumping, which can negatively affect homogeneity and mechanical properties.

5. **Field Trials before Adoption**

Conduct pilot pavement trials to assess performance under actual loading and environmental conditions before large-scale implementation.

6. **Explore Sustainability Options**

Investigate the use of recycled or waste glass fibers as an eco-friendly and cost-effective alternative to commercial fibers.

7. **Further Research**

Future studies can explore combinations of fiber types or hybrid reinforcements, their effect on fatigue life, and long-term durability

References

1. M. Remadevi, A. G. Pillai, E. B. George, P. Narayanan and S. Sunny, "Study of Fibre Reinforced Bituminous Concrete," International Journal of Engineering Research and Development, vol. 10, no. 4, pp. 49-56, 2014.
2. "Abtahi, S. M., Sheikhzadeh, M., & Hejazi, S. M. (2010). Fiber-reinforced asphalt- concrete – A review. Construction and Building Materials, 24(6), 871-877".
3. "Mahrez, A., Karim, M. & Katman, H. (2005). Fatigue and Deformation Properties of Glass Fiber Reinforced Bituminous Mixes. Journal of the Eastern Asia Society for Transportation Studies, 6, 997 - 1007.".
4. "Sadd, M. H., Dai, Q., Parameswaran, V., & Shukla, A. (2004). Microstructural Simulation of Asphalt Materials: Modeling and Experimental Studies. Journal of Materials in Civil Engineering, 16(2), 107-115".
5. "Siriwardane, H., Gondle, R., & Kutuk, B. (2008). Analysis of Flexible Pavements Reinforced with

Geogrids. Geotechnical and Geological Engineering, 28(3), 287- 297.".
6. "Jahromi, s., & Khodaii, A. (2008). Carbon Fiber Reinforced Asphalt Concrete. The Arabian Journal for Science and Engineering. 33(2B), 355-364".
7. "A manual for design of hot mix asphalt with commentary. (2011). Washington, D.C.: Transportation Research Board.".
8. "Serfass, J. P., & Samanos, J. (1996). Fiber-Modified Asphalt Concrete Characteristics, Applications and Behavior. Journal of the Association of Asphalt Paving Technologists, 65, 193-230.".
9. "Brown, S. F., Rowlett, R. D., & Boucher, J. L. (1990). Asphalt modification. In Proceedings of the conference on the United States strategic highway research program: Sharing the benefits, ICE, 181–203".
10. "Zube, Ernest. (1956). Wire Mesh Reinforcement in Bituminous Resurfacing. Highway Research Record, Bulletin, 131, 1-18".
11. "Simpson, Amy L. & Mahboub C. (1994). Case study of modified bituminous mixtures: somerset, Kentucky. In: Proceedings of the third materials engineering conference, ASCE, 88–96".
12. "Ye, Qunshan & Wu, Shaopeng & Li, Ning. (2009). Investigation of the dynamic and fatigue properties of fiber-modified asphalt mixtures. International Journal of Fatigue. 31. 1598-1602. 10.1016/j.ijfatigue.2009.04.008".
13. "Park, P., El-Tawil, S., Park, S., & Naaman, A. E. (2015). Cracking resistance of fiber reinforced asphalt concrete at −20°C. Construction and Building Materials, 81, 47-57".
14. N. Borhanuddin, M. K. I. Mohd Satar and H. Yaacob, "Glass fber waste as a potential bitumen modifer and stabilizing agent in asphalt mixture," Environmental Science and Pollution Research, p. online, 2024.
15. M. Enieb, A. Diab and X. Yang, "Short- and long-term properties of glass fiber reinforced asphalt mixtures," International Journal of Pavement Engineering, 2019.
16. R. Tanzadeh, J. Tanzadeh, M. honarmand and S. A. Tahami, "Experimental study on the effect of basalt and glass fibers on behavior of open-graded friction course asphalt modified with nano-silica," Construction and Building Materials, vol. 212, pp. 467-475, 2019.
17. M. Eisa, M. E. Basiouny and M. I. Daloob, "Effect of adding glass fiber on the properties of asphalt mix," International Journal of Pavement Research and Technology, 2020.
18. D. LUo, A. Khater, Y. Yue, M. Abdelsalam, Z. Zhang, Y. Li, J. Li and D. T. Iseley, "The performance of asphalt mixtures modified with lignin fiber and glass fiber : A review," Construction and Building Materials, vol. 209, pp. 377-387, 2019.
19. "Shukla, M., Tiwari, D., & Sitaramanjaneyulu, K. (2014). Performance Characteristics of Fiber Modified Asphalt Concrete Mixes. International Journal on Pavement Engineering & Asphalt Technology, 15(1), 38-50".
20. M. Abdelaziz, M. R. Karim and H. Y. Katman, "Fatigue and deformation properties of glass fiber reinforced bituminous mixes," Journal of the Eastern Asia Society for Transportation Studies, vol. 6, pp. 997-1007, 2005.
21. H. Ziari, M. Aliha, A. Moniri and Y. Saghafi, "Crack resistance of hot mix asphalt containing different percentages of reclaimed asphalt pavement and glass fiber," Construction and Building Materials, vol. 230, 2020.