

# Deformation Resistance of Stone Mastic Asphalt Mixtures with Fiber Mesh Added Materials

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## Abstract

Road pavement deformation is a major issue caused by excessive traffic loads, leading to reduced durability and decreased riding comfort. Stone Mastic Asphalt (SMA) is a hot mix asphalt designed to withstand heavy vehicle loads due to its gap-graded structure and high asphalt content. However, its performance can be further enhanced with stabilizing additives such as fibers. Among various synthetic fibers, fiber mesh is a cost-effective material that can improve the mechanical properties of SMA. This study aims to analyze the effect of fiber mesh as an additive on the deformation resistance of SMA mixtures. A laboratory experimental approach was conducted by preparing SMA samples incorporating fiber mesh at a content of 0.3% of the total mixture weight and a fiber length of 0.36 cm. The deformation resistance of the samples was evaluated using a wheel tracking test to assess deformation depth, dynamic stability, and deformation rate. The results show that the addition of fiber mesh significantly reduces deformation in SMA mixtures compared to those without fiber mesh. The fiber-reinforced SMA exhibited higher dynamic stability and a lower deformation rate, indicating improved resistance to rutting and long-term durability. These findings suggest that fiber mesh is an effective additive for enhancing SMA performance, making it a promising solution for improving pavement lifespan and reducing maintenance needs.

## Keywords:

Deformation; Fiber Mesh; Split Mastic Asphalt

## 1. INTRODUCTION

Stone Mastic Asphalt (SMA) mixture is designed with a gap-graded aggregate structure, predominantly composed of coarse aggregates, which play a crucial role in forming a stable and efficient framework for load distribution. This rigid frame structure allows SMA to effectively distribute loads from the surface down to the underlying layers, minimizing the potential for permanent deformation such as rutting and cracking (Bieliatynskiy et al., 2024; , Valdés et al., 2023). The effectiveness of SMA in load distribution can be attributed to its distinct compositional properties. SMA typically has a higher percentage of coarse aggregate compared to regular asphalt mixtures, creating a strong interlocking framework. This framework minimizes voids and improves the material's resistance to both permanent deformation and fatigue loading (Valdés et al., 2023; , Shaffie et al., 2023). Additionally, the presence of stabilizing additives, often in the form of fibers (natural and synthetic), further enhances the mechanical properties and moisture resistance of the mixture. Such additives play a crucial role in preventing the drain-down of asphalt mastic, which is particularly important in maintaining the integrity of the mix under varying environmental conditions (Alnadish et al., 2023; , Al-Saadi et al., 2023). This unique aggregate arrangement enhances the mixture's ability to resist deformation and rutting, making it highly suitable for high-traffic roads and heavy-load applications. The coarse aggregates in SMA are tightly interlocked, providing mechanical stability, while the voids between them are filled with a mastic-rich binder. This mastic consists of a combination of fine fillers, fibers, and polymers, which contribute to the durability and flexibility of the asphalt mixture. The relatively high asphalt content in SMA, as noted by Affandi (2010), results in a thick asphalt film that improves the mixture's resistance to fatigue and moisture damage. Additionally, the inclusion of fibers helps prevent asphalt binder drainage during mixing and placement, ensuring uniform distribution throughout the mixture. As a result, SMA

offers superior performance in terms of long-term durability, skid resistance, and reduced maintenance costs compared to conventional asphalt mixtures.

The correlation between increasing traffic volume and the resultant effects on asphalt pavement integrity, particularly through overload, is well-documented in road engineering literature. High traffic loads directly contribute to the deformation of asphalt surfaces, primarily manifesting as rutting, which is a critical failure mode resulting from repeated vehicle loading. This occurrence is emphasized by several studies that illustrate how excessive loads lead to deterioration in pavement quality (Aman et al., 2024; Albayati, 2023). As specified in the literature, heavy axle loads are a significant factor contributing to the fatigue life reduction of asphalt pavements, which are subjected to cyclical stress over time (Zhang et al., 2024). Moreover, Aman et al. discuss how permanent deformation, or rutting, is a prevalent issue in flexible pavements attributable to repetitive traffic loads, highlighting the necessity of using modified mixtures to mitigate these failures (Aman et al., 2024). This is complemented by studies indicating that inadequately designed asphalt mixtures and insufficient compaction during the construction phase exacerbate rutting, particularly in warm climates (Vámos & Szendefy, 2024; Taher et al., 2024). For instance, high temperatures coupled with increased traffic can soften the asphalt binder, thereby intensifying the risk of deformation under load (Vámos & Szendefy, 2024).

Deformation is a change in the shape, dimensions, and position of a material, whether part of nature or man-made, on a time and space scale (Sukmawaty, 2018). Deformation is an important deterioration of pavement conditions because it affects the quality of traffic comfort (roughness, puddles of water, which affect surface roughness) and can reflect damage to the pavement structure. One of the advantages of the SMA mixture (Błazejowski, 2016) is its high resistance to deformation as a result of the large coarse aggregate content and the formation of a strong aggregate framework. Past studies have demonstrated that the coarse aggregates in SMA typically comprise 70-80% of the mixture by weight and contribute significantly to the robust mechanical interlock essential for resisting permanent deformation and rutting under load (Jivitha et al., 2024; Sihombing et al., 2023; Kumar, 2023). The effectiveness of the stone-on-stone contact that occurs within the coarse aggregate skeleton prevents lateral displacement during stress application, which is critical for maintaining long-term pavement integrity (Shaffie et al., 2023; Raj & Ramesh, 2024). However, the SMA mixture contains a high asphalt content, so an additional material (additive) is needed that can stabilize and give strength. One additional material that can be used is fiber (Aminin, 2020). Fiber is an additional material that functions to absorb some of the asphalt. Fiber consists of pieces of components that form a complete elongated network. Fiber can be classified into two types, namely natural fibers and synthetic fibers (man-made fibers). Synthetic fibers can be produced cheaply in large quantities, one of which is fiber mesh.

## **1.1 Research Purposes**

This research aims to analyze the influence of Fiber Mesh as an additional material on the performance characteristics of Stone Mastic Asphalt (SMA) mixtures, particularly in terms of their resistance to deformation. The study focuses on evaluating how the incorporation of Fiber Mesh affects key parameters such as deformation resistance, dynamic stability, and the rate of deformation under varying conditions. By examining these aspects, the research seeks to determine the extent to which Fiber Mesh enhances the structural integrity and durability of SMA mixtures, potentially contributing to improved road pavement performance and longevity.

## **1.2 Study Literature**

Research on the use of cellulose fiber as an added material has been carried out, including research using Viatop66 (Abdillah et al., 2018), showing that the addition of Viatop66 cellulose fiber in SMA mixtures has an optimum limit of around 0.3%–0.4% of the total weight of the mixture. This is in accordance with what has been determined by SNI for the addition of additional ingredients in the form of cellulose fiber, namely 0.3% of the total weight of the mixture. The results of this research are a reference for determining the levels of added materials with different materials, namely fibermesh. Research Asbuton (LGA 50/25) (Suaryana, 2016) can behave as a stabilizer like cellulose fiber. LGA functions as a stabilizer, presumably because there is no

asphalt mobilization in LGA as a whole, and the relatively lower penetration rate of asphalt results in increased binder viscosity. In terms of resistance to fatigue, SMA with a cellulose stabilizer and SMA with an asphalt stabilizer have relatively the same performance. The fatigue performance of SMA blends and SMAB blends proves that SMAB is not only resistant to permanent deformation, as shown in the stability dynamic values, but also has sufficient flexibility, as shown in the relationship between strain and number of cycles. Researchers used the results of this study as a reference for SMA mixtures based on deformation testing with different materials. Research carried out (Alifuddin & Arifin, 2020) using asbestos fiber as an added material showed that the percentage value of the cellulose fiber (asbestos) added material used in the Split Mastic Asphalt (SMA) mixture met the optimum fiber content percentage, namely 2.81%. The percentage of cellulose fiber added to the Split Mastic Asphalt (SMA) mixture can increase the characteristic values of the asphalt concrete mixture. Researchers used the results of this research as a reference for SMA mixtures with different added materials. Research carried out in (Tahir .2011, n.d.) used rice bran as an added material. The results of the examination and analysis of the characteristics of the Split Mastic Asphalt (SMA) mixture using cellulose-added material (rice bran) show an increase in the performance of the asphalt concrete mixture. This research is a reference on SMA mixtures with different added ingredients and different testing methods.

## **2. METHODS**

### **2.1 Making Test Objects**

The materials used in this research were previously examined in the laboratory to obtain materials that meet the requirements for road work materials (Direktorat Jenderal Bina Marga, 2018). The asphalt content used is the optimum asphalt content, then mixed with fiber mesh as an additive to the asphalt. The fiber mesh used in this research is fiber mesh with a length of 0.36 cm and a content of 0.3% of the mixture weight; this is based on the best value from previous research (Bastari & Bulgis, 2023), (Bulgis & Salim, 2023).



Figure 1. Fibermesh after cutting

### **2.2 Deformation Testing**

Sample testing was carried out after all the ingredients were mixed and then stirred thoroughly until it reached a temperature of  $\pm 150^{\circ}\text{C}$ . Next, the mixture is put into a mold measuring  $30 \times 30 \times 5$  cm, and the mixture is compacted in 50 strokes. Next, the test object is cooled to room temperature, then removed from the mold and left at room temperature for 24 hours before being tested. Testing of test objects to obtain deformation values using the wheel tracking tool.



Figure 2. Whell Tracking Machine

### 3. RESULT AND DISCUSSION

#### 3.1 SMA Pavement Mixture Composition

Before mixing the ingredients, check the materials to be used. The types of materials examined were aggregate CS 2-3, CS 1-2, CS 0.5-1, and stone ash from Bili-Bili Makassar, while the asphalt used was Pertamina penetrasi 60/70 asphalt. Based on the inspection results, it shows that the above materials have met the required specifications. (Bina Marga). Next, determine the aggregate composition based on the results of the sieve analysis. The aggregate composition obtained from the results of combining the aggregates is shown in Table 1.

Table 1. Aggregate Composition

Sieve of Number	% Passing CS 2 - 3	% Passing CS 1 - 2	% Passing CS 0,5 - 1	% Passing Stone Ash	CS 2 - 3	CS 1 - 2	CS 0,5 - 1	Stone Ash	Total Aggregate	Specification		
					31%	26%	23%	20%			-	
25 (1")	100	100	100	100	31	26	23	20	100	100	-	100
19,1 (3/4")	83.93	100	100	100	26.02	26.00	23.00	20.00	95.02	90	-	100
12,7 (1/2")	27.47	67.38	100	100	8.51	17.52	23.00	20.00	69.03	50	-	88
9,52 (3/8")	0.30	36.25	56.34	100	0.09	9.43	12.96	20.00	42.48	25	-	60
No. 4	0	0.30	17.14	100	0	0.08	3.94	20.00	24.02	20	-	28
No. 8	0	0	0.27	99.60	0	0	0.06	19.92	19.98	16	-	24
No. 200	0	0	0	40.06	0	0	0.00	8.01	8.01	8	-	11

The results of the aggregate composition combining using the trial and error method determined that the aggregate composition was Crushed Stone (CS) (2–3) 31%, CS (1-2) 26%, CS (0.5–1) 23%, and Stone Ash 20%.

### 3.2 Determination of Optimum Asphalt Content

Next, the optimal asphalt content is determined from the plan asphalt content. The optimal asphalt content in a mixture influences the characteristics of the asphalt mixture, such as density, void in mix (VIM), void in material aggregates (VMA), VFA, stability, flow, and Marshall quotient.

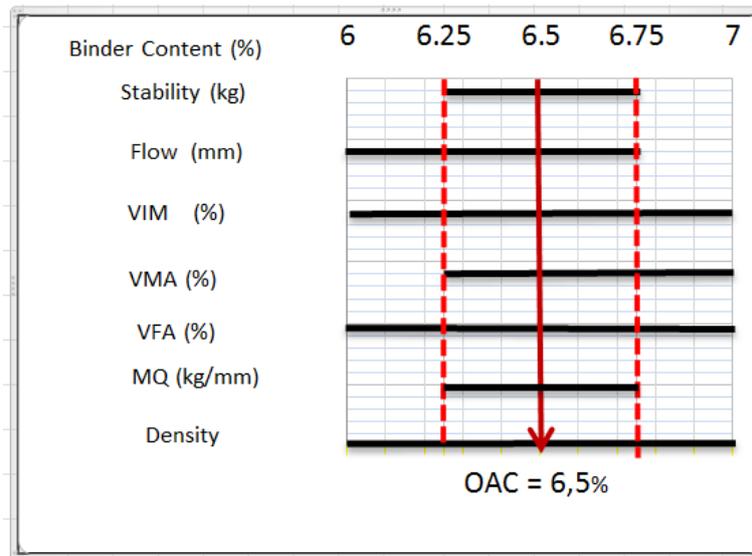


Figure 3. Optimum Asphalt Content (OAC)

Figure 3. regarding determining the OAC value using the barchart method, shows the relationship between asphalt content and mixture characteristics using the middle value on the graph that meets the characteristics of the Marshall Test. Starting from the minimum value obtained, namely 6%, and the maximum value obtained, namely 7%, Characteristics that meet specifications start at 6.25%, 6.5%, and 6.75%, so that the OAC determination is obtained at 6.5%.

The optimum asphalt content (OAC) value will be used in planning SMA mixtures with variations in the added material of Cellulose Fiber Mesh with variations in the added material content of 0%, 0.1%, 0.2%, 0.3%, and 0.4% of the total weight of the mixture with a length of 0.36 cm, 0.72 cm, 1.08 cm, 1.44 cm, and 1.80 cm. From the results of the analysis, determining the optimum fiber mesh content is also the same as determining the length, namely, by reference to the stability value, the highest marshall quotient of each grade with the minimum flow of all existing fiber mesh grades. The highest stability and marshall quotient values have a content of 0.3% and a length of 0.36 cm of 737.916 kg and 217.159 kg/mm, respectively, with a minimum flow value of 3.4 mm.

### 3.3 Deformation Test Results (Wheel Tracking)

Deformation Test Results (Wheel Tracking) This test was carried out to see the deformation resistance performance of the mixture based on the optimal asphalt content (KAO) with a content of 6.5%, a fiber mesh content of 0.3%, and a length of 0.36 cm. A review of three Wheel Tracking test parameters was carried out, namely groove depth (deformation), deformation rate (RD), and dynamic stability (DS). The following describes the wheel tracking test results shown in Table 2 and Table 3.

Table 3. Wheel Tracking Test Results for SMA Pavement without Fiber mesh

Time/Minutes	Number of cycles	30°C SMA Pavement Without Fiber mesh	Unit
0	0	0	mm
1	42	0.90	mm
5	210	1.10	mm
10	420	1.30	mm
15	630	1.70	mm
30	1260	3.10	mm
45	1890	3.40	mm
60	2520	3.90	mm
Total Deformation (D0)		2.200	mm
Dynamic Stability (DS)		2520	passes/mm
Deformation Rate (RD)		0.033	mm/minutes

Table 4. Wheel Tracking Test Results for SMA Pavement with Fiber mesh

Time/Minutes	Number of cycles	30°C SMA Pavement With Fiber mesh	Unit
0	0	0	mm
1	42	0.90	mm
5	210	0.98	mm
10	420	1.10	mm
15	630	1.30	mm
30	1260	1.40	mm
45	1890	1.50	mm
60	2520	1.70	mm
Total Deformation (D0)		1.269	mm
Dynamic Stability (DS)		6300	passes/mm
Deformation Rate (RD)		0.013	mm/minutes

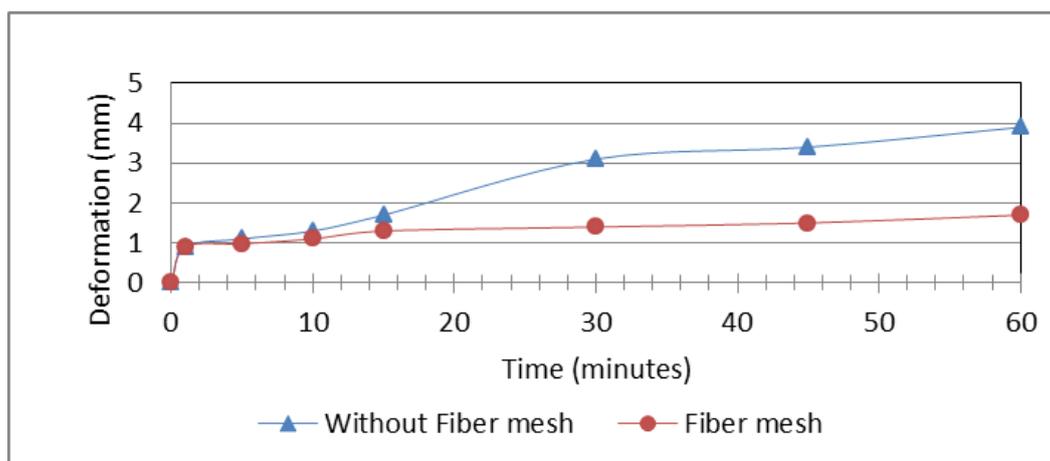


Figure 4. Comparison of Deformation of SMA Mixtures Without Fiber Mesh and Fiber Mesh

Based on Figure 4. and the comparison of the deformation of the SMA mixture without added fiber mesh and with fiber mesh, it is observed that changes in deformation tend to decrease as time increases. The mixture without fiber mesh has a high deformation change, namely 3.90 mm, up to 60 minutes, and the mixture using fiber mesh has a low change, with a value of 1.70 mm up to 60 minutes.

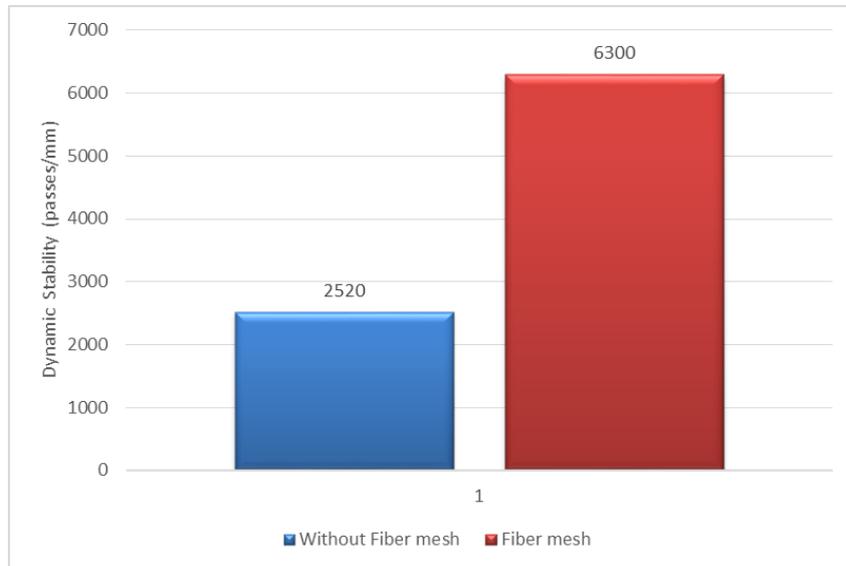


Figure 5. Dynamic Stability of SMA Mixtures without Fiber mesh and Fiber mesh

Figure 5 shows that the dynamic stability of the SMA mixture without fiber mesh and the fiber mesh observed in the mixture with fiber mesh obtained the highest dynamic stability of 6300 passes/mm. Meanwhile, the lowest dynamic stability was shown in the mixture without fiber mesh at 2520 passes/mm.

The dynamic stability value is inversely proportional to the amount of deformation that occurs; namely, the dynamic stability value is greater in the mixture using fiber mesh. The greater it indicates that the dynamic stability of the mixture decreases, so that the deformation resistance decreases.

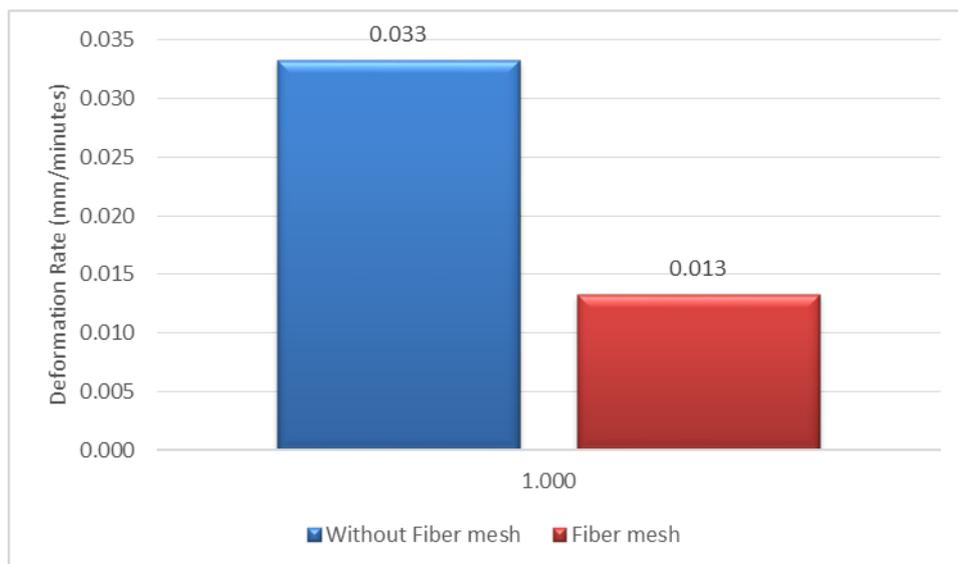


Figure 6. Deformation rate of SMA mixture without fiber mesh and fiber mesh

Figure 6 shows the amount of deformation that occurs in the SMA mixture each time. In the SMA mixture using cellulose fiber mesh, the lowest deformation rate was obtained with a value of 0.013 mm/minute, while the mixture without fiber mesh was 0.033 mm/minute.

The lower deformation rate obtained in mixtures that use fiber mesh indicates that the mixture has good stability and is resistant to deformation.

The results of this study indicate that the addition of fiber mesh significantly improves the deformation resistance of Stone Mastic Asphalt (SMA) mixtures. The comparison between SMA mixtures with and without fiber mesh shows a noticeable reduction in deformation, with the fiber mesh-enhanced mixture demonstrating superior resistance to rutting. This aligns with previous studies that highlight the effectiveness of synthetic fibers in enhancing the structural integrity of asphalt mixtures by improving their load distribution and reducing susceptibility to permanent deformation. The effectiveness of synthetic fibers in enhancing the structural integrity of asphalt mixtures is well-documented in the literature. Fibers, such as basalt, polyester, and polypropylene, have been shown to significantly improve the load distribution capabilities of asphalt mixtures, leading to reduced permanent deformation and enhanced durability (Guo et al., 2023; Jiu et al., 2023; Jia et al., 2023). Specific studies have demonstrated that the incorporation of various types of fibers contributes to increased dynamic stability and fatigue resistance, which are vital for the performance of asphalt roads under traffic loads and environmental stresses (Taher et al., 2023; Jiu et al., 2023). The reduction in deformation can be attributed to the ability of fiber mesh to reinforce the asphalt mastic, creating a more cohesive and stable matrix that resists the stresses imposed by traffic loads.

Furthermore, the dynamic stability results reinforce the role of fiber mesh in enhancing the long-term durability of SMA mixtures. The significantly higher dynamic stability values observed in fiber mesh-reinforced SMA indicate that these mixtures can withstand more load repetitions before experiencing substantial deformation. Research has shown that fibers act as reinforcements within asphalt mixtures, significantly improving resistance to permanent deformation. For instance, the study by Ji et al. reveals that basalt fibers, when incorporated into SMA mixtures, create a robust three-dimensional network that enhances the mechanical properties, thereby increasing overall durability and dynamic stability (Ji et al., 2024). Similarly, Alifuddin et al. highlight that the addition of fibers increases the stiffness, toughness, and fatigue resistance of asphalt mixtures, thereby reducing maintenance costs and extending service life (Alifuddin et al., 2024). Furthermore, studies involving synthetic fibers have documented improvements in rutting resistance, where mixtures enriched with these fibers could withstand higher loads before exhibiting permanent deformation (Aman et al., 2024; Jia et al., 2023). This is an important finding, as high dynamic stability is a critical parameter for road pavements subjected to heavy traffic. The increased dynamic stability observed in this study aligns with previous research on cellulose and synthetic fiber additives, which have been shown to enhance the structural performance of asphalt mixtures by preventing binder drain-down and improving cohesion.

The lower deformation rate recorded in fiber mesh-reinforced SMA mixtures also suggests improved resistance to environmental factors such as temperature fluctuations and moisture exposure. In regions with high temperatures, asphalt mixtures are prone to softening, which can lead to accelerated rutting. The softening of asphalt at elevated temperatures is primarily due to its viscoelastic properties, making it susceptible to deformation under repeated traffic loading conditions (Akkenzheyeva et al., 2024; Mahan et al., 2023). However, the addition of fiber mesh appears to mitigate this issue by enhancing the internal structure of the SMA mixture, making it more resistant to plastic deformation. This finding is consistent with prior studies that have demonstrated the role of fibers in improving the viscoelastic properties of asphalt binders, thereby increasing the mixture's ability to recover from deformation under repeated loading.

In addition to improving mechanical performance, the use of fiber mesh in SMA mixtures presents potential cost and sustainability benefits. The reduction in deformation and rutting implies longer pavement lifespan and reduced maintenance costs, which is particularly beneficial for heavily trafficked roads. Moreover, fiber mesh is a relatively affordable and widely available material, making it a practical solution for asphalt modification (Alnadish et al., 2023). Future research could explore the use of alternative fiber materials, including recycled or natural fibers, to further enhance the sustainability of SMA mixtures while maintaining their high-performance characteristics.

#### **4. CONCLUSIONS**

Split Mastic Asphalt (SMA) pavement mixture with an optimum asphalt content of 6.5% using synthetic cellulose fiber mesh with a content of 0.3% and a length of 0.36 cm, it can be concluded that the comparison of deformation without and using fiber mesh, namely the occurrence of deformation changes, has decreased with the presence of fiber mesh. This shows better deformation resistance than without using fiber mesh.

The results of this study demonstrate that the addition of fiber mesh significantly enhances the deformation resistance of Stone Mastic Asphalt (SMA) mixtures. The comparison between SMA mixtures with and without fiber mesh shows a notable reduction in deformation, a higher dynamic stability, and a lower deformation rate in mixtures containing fiber mesh. These findings indicate that fiber mesh effectively reinforces the asphalt matrix, improving load distribution and increasing the pavement's ability to withstand repeated traffic loads.

Furthermore, the increased dynamic stability and reduced deformation rate suggest that fiber mesh-reinforced SMA mixtures exhibit superior durability and resistance to environmental stressors such as high temperatures and heavy axle loads. The findings align with previous research on fiber additives in asphalt, confirming that fiber mesh enhances the structural integrity of SMA mixtures by reducing rutting and extending pavement lifespan. The economic and practical advantages of fiber mesh, including its cost-effectiveness and ease of application, further support its potential as a viable alternative to traditional stabilizing agents.

In conclusion, this study provides strong evidence that fiber mesh is a beneficial additive for SMA mixtures, offering improved performance in terms of deformation resistance, stability, and durability. Future research should focus on field applications and long-term performance evaluations to validate these laboratory findings in real-world road conditions. Additionally, exploring the use of alternative fiber materials, including recycled or natural fibers, could further enhance the sustainability and effectiveness of SMA mixtures in pavement construction.

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