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REVIEW ARTICLE

# Fibers in Asphalt Mixture: A State-of-The-Art Review

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**ABSTRACT -** The use of fiber in asphalt mixture is gaining popularity as it can improve the mechanical properties of the asphalt pavement and enhance its durability and longevity. The main objective of this review is to discuss the recent research on the use of fiber in asphalt mixture and to provide an overview of its effects on the mechanical properties of asphalt. The article presents a review of the literature on the use of different types of fibers in asphalt mixture, including natural fibers, synthetic fibers, and glass fibers. The mechanical properties evaluated include stiffness, fatigue resistance, crack resistance, and rutting resistance. The review highlights the potential benefits of using fiber in asphalt mixture, including improved stiffness and crack resistance, reduced rutting, and increased fatigue resistance. However, the effectiveness of fiber in improving the mechanical properties of asphalt is influenced by various factors, such as fiber type, content, and distribution. In conclusion, the utilization of fibers in asphalt mixtures has demonstrated promising benefits in improving the properties and performance of the mix. However, further studies and investigations are necessary to optimize fiber selection, refine mix design procedures, develop accurate performance prediction models, monitor field performance, and assess the environmental and economic implications. By addressing these research gaps, we can advance the understanding and application of fiber-reinforced asphalt mixtures, leading to more sustainable and durable asphalt pavements in the future.

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## 1.0 INTRODUCTION

Due to the consistent rise in traffic volume and frequent exposure to harsh conditions, the majority of asphalt roads fail to meet their intended lifespan due to the presence of different types of damage, including but not limited to ruts, water-related issues, and cracks [1], [2]. Fiber reinforcement in asphalt mixtures refers to the incorporation of fibers into the asphalt matrix to enhance the mechanical properties and performance of the pavement [3], [4]. Fibers used in asphalt mixtures can be of various types, including natural fibers (such as cellulose or jute), synthetic fibers (such as polypropylene or polyester), glass fibers [5], [6]. These fibers are typically mixed into the asphalt binder-aggregate mixture during the production process. The use of fibers in asphalt mixtures dates back several decades. The first known use of fibers in asphalt can be traced back to the 1950s [7], when asbestos fibers were added to asphalt to improve its strength and durability. However, due to the health risks associated with asbestos, asbestos fibers in asphalt were discontinued in the 1970s and replaced with safer alternatives.

Since then, various types of fibers have been used in asphalt mixtures to improve their properties [8], [9], [10]. The use of synthetic fibers such as polypropylene and polyester became more popular in the 1980s, at the same time, natural fibers like cellulose and jute have also been used in recent years. Glass fibers and mineral fibers such as basalt have also been used in asphalt mixtures for their high tensile strength and durability [11]. Today, using fibers in asphalt mixtures is a well-established technique in the construction industry and is commonly used in new construction and maintenance applications [12]. The specific type and amount of fiber added to the asphalt mix depends on project requirements and desired performance characteristics. In general, adding fibers to asphalt mixtures is a well-established method for improving the mechanical properties of asphalt concrete [13]. Fibers are added to asphalt mixtures to enhance the strength, durability, and resistance to pavement cracking.

The use of fibers in asphalt mixtures can provide several benefits, including:

**Increased durability**: By adding fibers to the asphalt mixture, the pavement can better resist the effects of traffic, weather, and other environmental factors. This can extend the pavement's service life and reduce the need for repairs and maintenance [14], [15].

**Improved strength**: Fibers can help to increase the tensile strength of the asphalt, which can reduce the likelihood of cracking and other forms of deformation. This is especially important in high-stress areas such as intersections and bus stops [16], [17].

**Enhanced performance**: Pavements with added fibers can perform better under heavy loads and high traffic volumes. This can reduce the need for maintenance and improve the overall safety of the pavement [18]. Including fibers in asphalt

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mixtures can address many challenges, such as improving strength and reducing cracking and rutting. However, selecting fiber type, fiber content, and mixing method is critical for optimal performance. Overall, this review paper will provide insights into the state-of-the-art of fibers in asphalt mixtures and highlight the research gaps that must be addressed.

## 2.0 SYNTHETIC FIBERS

Polypropylene and polyester fibers are the most used synthetic fibers in asphalt mixtures. These fibers are typically added to the asphalt mix as tiny fibers or meshes to provide better crack resistance and improve the overall durability of the pavement. Synthetic fibers can help prevent the formation of cracks, reduce rutting and other forms of deformation, enhance the load-bearing capacity of the pavement, and resistant water and chemicals, making them useful in harsh environments [19]–[21].

So far, several studies have been conducted to examine the impact of various types and dimensions of fibers on the mechanical behavior, particularly in asphalt concrete (AC)[22]–[24][NO_PRINTED_FORM][NO_PRINTED_FORM]

Slebi-Acevedo et al. [25] investigated the effects of adding a combination of polyolefin/aramid fibers and homopolymer polyacrylonitrile fibers to porous asphalt (PA) mixtures, as well as changes in filler content, on the mechanical performance and functionality, the study conducted several tests to examine various factors such as air voids, permeability, moisture sensitivity, and particle loss. The testing was conducted under both dry and wet conditions. The mechanical performance of the mixture was observed in dry conditions, including fracture energy, post-cracking energy, and toughness. Results revealed that adding fibers increased the elasticity of the asphalt mixture, leading to better toughness without compromising functionality since the air void content remained above 20%.

After studying four types of synthetic fibers: polypropylene (PP) and polyester (Pe), nylon (Ny) and carbon (C) fibers, [26] concluded that the majority of asphalt concrete mixtures reinforced with fibers had demonstrated considerably better mechanical performance than the standard asphalt concrete specimen. The most effective fiber variety for all test criteria was Ny fiber, and the optimal quantity of Ny fiber was 1.0%, except for dynamic stability, where it was different.

Table 1: Physical and mechanical properties of fiber reinforcements [26]

| Fiber type | PP | Pe | Ny | C |
|---|---|---|---|---|
| Density (g/cm$^3$) | 0.91 ± 0.02 | 1.40 ± 0.02 | 1.14 ± 0.02 | 1.37 |
| Elastic modulus (GPa) | 3.5 | 11.6 | 3.5–7.0 | 230 |
| Melting point (°C) | 160 | 256 | 220 | Over 1000 |
| Tensile strength (MPa) | 500 | 1147 | 800 | 4900 |
| Length, $l_f$ (mm) | 6 | 6 | 12 | 12 |
| Diameter, $d_f$ (μm) | 40 | 41 | 23 | 7 |
| Aspect ratio ($l_f/d_f$) | 150 | 147 | 522 | 1714 |

The characteristics of fibers significantly impact the behavior and properties of fiber-reinforced asphalt mixtures. Longer fibers provide better reinforcement and load transfer capabilities, while thicker fibers offer increased tensile strength. The aspect ratio of fibers influences their ability to bridge cracks and distribute stress effectively. The proper surface treatment enhances the bonding between fibers and the asphalt matrix, improving the overall performance of the mixtures.

## 3.0 NATURAL FIBERS

Natural fibers like cellulose and jute are biodegradable and can be used in sustainable construction projects [27],[28] These fibers are typically used in asphalt mixtures to improve the stability and strength of the pavement and to reduce the occurrence of cracks and other types of damage [29]. Natural fibers can also help enhance the pavement’s flexibility and durability, making it more resistant to fatigue and deformation [30]. Natural fibers are derived from various plant sources and possess several properties that make the natural fibers are helpful for use in asphalt mixtures. Natural fibers are biodegradable and decompose naturally over time, making them environmentally friendly and sustainable [31]. Natural fibers are often less expensive than synthetic fibers, making them a cost-effective alternative for use in asphalt mixtures [27]. Many natural fibers have a high strength-to-weight ratio, making them suitable for high-performance applications. For example, fibers like coconut coir have a high tensile strength and modulus, which makes them an excellent reinforcement material for asphalt pavements [32]. Natural fibers are often absorbent and can help to mitigate moisture-related issues in asphalt pavements. For instance, cellulose fibers can absorb moisture and help to reduce the occurrence of reflective cracking in pavements [27], [33]

**Low thermal conductivity**: Some natural fibers have low thermal conductivity, making them suitable for high-temperature applications. For instance, jute fibers have low thermal conductivity and can help reduce rutting in asphalt pavements [32]. Natural fibers are often compatible with bitumen, the binding agent used in asphalt mixtures, which allows them to form a strong bond with the asphalt and improve its mechanical properties [34]. Several studies were conducted to test the possibility of using natural fibers in asphalt mixtures [35]–[39].

Kiran Kumar et al. [40]studied three types of natural fibers: coir, sisal, and banana. Among the fibers examined, coir fiber stands out as the most superior, whereas mixtures of sisal and banana fiber demonstrate similar properties on stabilization. Another study by Shanbara et al. [41] suggested using 0.35% of fiber to achieve the best performance in indirect tensile stiffness and recommended utilizing a fiber length of 14mm.


Figure 1: Natural Fibers [40]

A study by S. Singh et al. [42] explored using of natural fibers such as sisal, coir, and rice straw in stone matrix asphalt mixtures that incorporate waste marble as a filler. The research found that rice straw was the preferred, followed by coir and sisal. At a fiber content of 0.3%,. The maximum drain-down value was 0.335 based on ASTM-D 6390 and IRC-SP-79 at 0.3% natural fiber. Moreover, adding natural fibers significantly improved moisture susceptibility characteristics, with an over 80% improvement due to forming of a thin film around the aggregates. Glass fibers:

Glass fibers are made of fine glass strands that are woven together into a fabric-like material. These fibers have high tensile strength, resistance to weathering and aging, and are typically used in high-performance asphalt mixtures and can help to improve the overall durability and longevity of the pavement and can provide excellent resistance to cracking and other forms of damage [43]–[45]. Glass fiber is a versatile material that is widely used in both industrial and domestic applications, with a global market worth over US$7 billion [46]. Figure 2 shows the percentage of different glass-fiber composite applications in the market. In addition, the market for glass-fiber and carbon-fiber composites is rapidly expanding, leading to increasing interest from researchers in the field of glass-fiber composites, as illustrated in Figure 3. Glass fiber is also known for its durability under various environmental conditions.

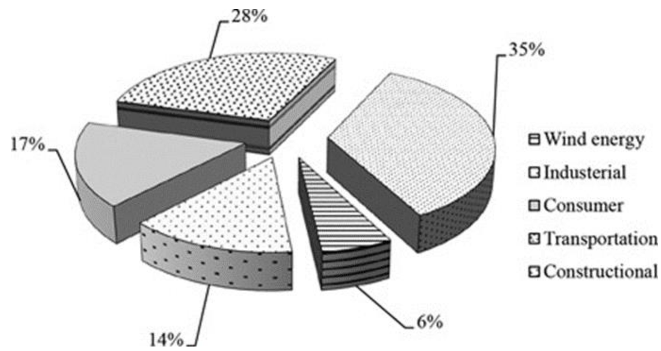


Figure 2: Market percentage of glass fiber in different applications [46]

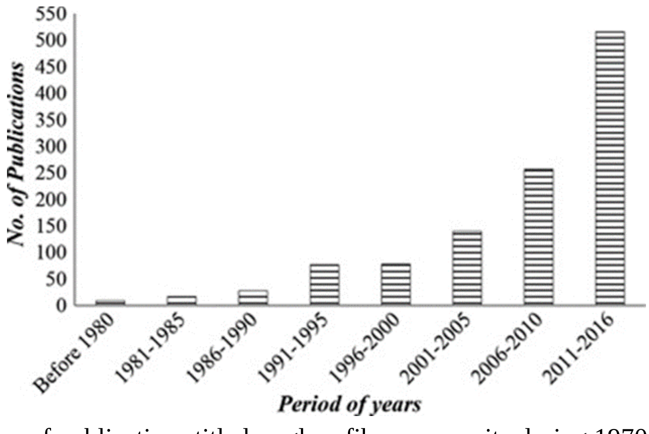


Figure 3: Number of publications titled as glass fiber composite during 1970–2016 [47], [48]

There are several types of glass fibers that can be used in asphalt mixtures, each with their own unique characteristics and properties. Here are some of the most common types of glass fibers used in asphalt mixtures:

**E-glass fibers:** E-glass fibers are the most commonly used type of glass fibers in asphalt mixtures. They are made from a type of borosilicate glass and have high tensile strength, good chemical resistance, and excellent resistance to alkali attack.

**C-glass fibers**: C-glass fibers are made from a type of calcium-aluminum-silicate glass and are less commonly used than E-glass fibers. They have good chemical resistance and are highly resistant to alkali attack, making them suitable for use in aggressive environments.

**S-glass fibers**: S-glass fibers are made from a type of magnesium-aluminum-silicate glass and have a higher tensile strength and modulus than E-glass fibers. They are used in applications where higher performance is required, such as in high-stress areas of pavement, but they are more expensive than E-glass fibers.

**AR-glass fibers:** AR-glass fibers (alkali-resistant glass fibers) are specially designed to resist the effects of alkali attack, which can cause fiber degradation and loss of strength over time. They are commonly used in areas where the pavement is exposed to aggressive environments, such as in bridges, tunnels, and other structures.

Zhang et al. [49]reported that using Glass Fiber (GF) into HMA mixtures can improve many of their properties. As a result, the study suggests a recommended mix with 0.25% GF based on the total mix weight. Another study by Taherkhani [50] tested the effectiveness of adding glass fibers and nanoclay to asphalt mixture at different weight percentages. Results showed that adding glass fibers was more effective than nanoclay in increasing the asphalt mixture's indirect tensile strength. In addition, Wu et al. [51] studied the effects of fibers on the dynamic properties of asphalt mixtures. The study indicated that the dynamic modulus of all the asphalt mixtures modified with fibers is higher than that of the control mixture.

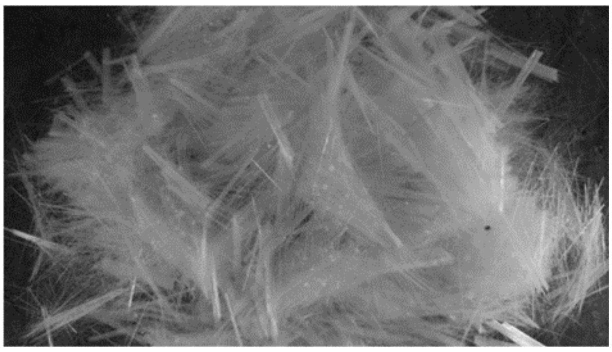

Figure 4: An example image of glass fiber [52]

## 4.0 CONCLUSION

The incorporation of fibers in asphalt mixtures offers significant potential for enhancing the properties and performance of the mix. Through the reinforcement of the asphalt matrix, fibers contribute to improved rutting resistance, crack resistance, fatigue resistance, and moisture damage resistance. The use of fibers in asphalt pavements has shown promising results in terms of extending pavement life, reducing maintenance needs, and achieving sustainable infrastructure. However, despite the extensive research conducted on fiber-reinforced asphalt mixtures, there are still several avenues for further study and exploration. Some key areas for future investigation include:

- Optimal Fiber Selection: More research is needed to identify the most suitable fiber types, lengths, diameters, aspect ratios, and surface treatments for different asphalt applications, considering factors such as climate, traffic conditions, and binder-aggregate combinations.
- Mix Design Optimization: Further studies are necessary to develop standardized mix design procedures and guidelines for fiber-reinforced asphalt mixtures. This includes determining the optimum fiber dosage levels and their impact on volumetric properties, workability, and long-term performance.
- Performance Prediction Models: More advanced models and tools are needed to accurately predict the performance of fiber-reinforced asphalt pavements. This involves developing predictive models that consider the interaction between fibers, binder, and aggregates, as well as the influence of external factors such as temperature, moisture, and aging.
- Field Performance Monitoring: Long-term field performance monitoring of fiber-reinforced asphalt pavements is crucial to validate laboratory findings and assess the real-world effectiveness of different fiber types and characteristics. This can provide valuable insights into the durability, maintenance needs, and cost-effectiveness of fiber-reinforced asphalt pavements.
- Environmental and Economic Analysis: Comprehensive life cycle assessments and economic analyses should be conducted to evaluate the environmental impact and economic feasibility of incorporating fibers in asphalt mixtures. This includes considering the potential energy savings, reduced material consumption, and long-term cost savings associated with fiber reinforcement.

In conclusion, the utilization of fibers in asphalt mixtures has demonstrated promising benefits in improving the properties and performance of the mix. However, further studies and investigations are necessary to optimize fiber selection, refine mix design procedures, develop accurate performance prediction models, monitor field performance, and assess the environmental and economic implications. By addressing these research gaps, we can advance the understanding and application of fiber-reinforced asphalt mixtures, leading to more sustainable and durable asphalt pavements in the future.

## 5.0 AUTHOR CONTRIBUTIONS

Abdullah Omar Abdullah Baqadeem: Data curation, Writing- Original draft preparation.

Khairil Azman Masri: Conceptualization, Methodology.

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## 7.0 DATA AVAILABILITY STATEMENT

The data used to support the findings of this study are included within the article.

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## 9.0 CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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