Study of Improving the Mechanical Characteristics of HMA by Using Carbon Fiber

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Asphalt concrete is commonly utilized to build parking lots, runways, and roads and it is the most popular option in the pavement industry. At the same time, numerous issues can arise with asphalt pavements, such as cracks because of their long-lasting, water-resistant, and comfortable riding mechanics and rutting. These defects in pavements might be an outcome of inadequate blending characteristics and/or increase in traffic volumes. The use of fibers in (HMA) for the building of road pavements has become a far more desirable alternative. This paper's goal is to evaluate the mechanical impacts of adding carbon fibers to HMA through an analysis of their reinforcement effects. This was accomplished by adding five different amounts of carbon fiber to asphalt mixes: 0%, 0.5%, 1%, 1.5%, 2%, and 2.5% by volume of mix were examined. Utilizing Marshall and Indirect Tensile Strength Tests, the resulting features are evaluated. According to the research results on asphalt mixes, the use of carbon fiber enhanced resistance to shear stress, and additionally, it made them more resistant to being damaged by moisture, strengthening, and cohesiveness of asphalt mixtures. According to experiment results, carbon fiber improved the performance characteristics of asphalt pavements. Its main characteristics were enhanced by the addition of 1.5% carbon fiber and it could be utilized in hot weather. Marshall stability is raised by 45.45%, the flow is decreased by 13%. The ITS likewise increased by 5.86% and TSR increased by 12.874%. Improved Mechanical Properties Addition of carbon fibers typically leads to improvements in mechanical properties such as tensile strength, and cracking. Carbon fibers act as reinforcement within the asphalt matrix, enhancing its overall structural performance. Carbon fibers can improve the resistance of asphalt mixtures to permanent deformation (rutting) caused by repeated traffic loading and helps to maintain the stability and integrity of the pavement surface, reducing rutting over time. The enhanced mechanical properties provided by carbon reinforcement contribute to the overall performance and service life of the pavement.

Keywords: carbon fiber, Marshall stability, moisture resistance, physical performance.

1. Introduction

Since pavement on roads is regarded as the nation's capital, a portion of the construction budget is set aside each year for its upkeep, renovation, and repair [1, 2]. Researchers have been utilizing several additives to enhance the performance of asphalt mixtures in recent times.

These sorts of additives include fibers like carbon or glass fibers, polymers like SBS, ashes like fly ash, and date seed ash [3-5]. It is believed that adding fibers like glass, polyester, and carbon to asphalt mixtures will boost their tensile strength because these materials have higher tensile strengths than asphalt mixtures [6]. Fiber addition can reduce the asphalt mixture's susceptibility to moisture and the harm that moisture can do [7]. Advances in the automotive industry and the manufacture of vehicles with heavier axles, including buses and trucks with multiple axles, and the failure to consider these loads in the design of procedures, especially asphalt procedures, cause various breakdowns in the paved surface and the attention of pavement researchers has been diverted to strengthen and improve the pavement performance of roads [8, 9]. Materials used to improve the characteristics of HMA can be divided into three general kindes: bitumen modifiers, asphalt mixers, and stone material substitutes. Asphalt reinforcement using a variety of fibers is another way to improve the performance of asphalt mixtures. Fu investigated the effect of fibers on the performance properties of asphalt mixtures. The results of this study showed that the use of 0.3% glass fibers significantly improves the cohesion between materials and has a positive effect on the performance properties of mixtures [10]. Ameri et al. also examined fibers like glass and basalt fibers and concluded that these Fibers may improve indirect tension, dynamic creep, modulus of resistance, and Marshall strength [11]. Combinations of asphalt are evaluated by employing a range of techniques and tests. Performance tests of HMA, such as modulus of resistance, dynamic wear, indirect tension, and the like, have been utilized more frequently in earlier studies [12]. Because of the fibers, this material is more durable and exhibits less deformation, making it more ductile. [13]. These strands give increased stiffness and strength to the composites allowing the grid to transfer loss between the strands. Similarly, adding fibers enhances the characteristics of the mixes, adds to durability by increasing the life of service, as well as minimizes the need for frequent route maintenance. Several asphalts treated with fiber mixes and binders have been created to solve the primary issues of flexible rutting, fatigue cracking, heat cracking, and raveling are examples of flexible pavement. [14]. The incorporation of carbon fiber presents a beneficial addition to the act homes of asphalt pavements., CF has applications in real-global settings for creating improved performance and greater pavement protection [15]. The primary objective of research involving asphalt combos and carbon reinforcement usually revolves around improving the performance and durability of asphalt pavements. Carbon reinforcement, which includes carbon fibers or carbon nanotubes, can be brought to asphalt combinations to improve properties like strength, stiffness, fatigue resistance, and resistance to cracking and rutting. These studies purpose to investigate the outcomes of incorporating carbon reinforcement at the mechanical and rheological properties of asphalt combos, in addition to their lengthy-term overall performance beneath diverse loading and environmental situations. Ultimately, the purpose is to expand asphalt combinations with more suitable homes that may cause greater durable and sustainable pavement substances.

This study aimed to evaluate the effects of using carbon fiber (CFS) as a modifier for high-strength pavements by modifying asphalt mix performance characteristics combined with resistance to water damage and permanent deformation. Adding 0%, 0.5%, 1%, 1.5%, 2%, and 2.5% of CF by volume of mix were tested, and the mechanical effects of carbon fiber incorporation on HMA were evaluated through a combination of laboratory tests and numerical simulations.Here are some

Marshall Stability Test: This test examines the resistance of the asphalt mixture to plastic deformation at elevated temperatures and heavy loads. Samples with different percentages of carbon fibers have been prepared and are being tested with Marshall stability apparatus to determine stability and flow values

Indirect Tensile Strength (ITS) Test: The ITS test measures the tensile strength of asphalt mixtures by applying tensile loads on cylindrical specimens Samples of various quantities of carbon fiber are prepared and tested to evaluate their resistance to cracking under tensile stress.

2. MATERIALS AND METHODS

Asphalt Binder: Bitumen grade of 40–50, from the Al Durrah refinery, was used to prepare the asphalt mixes. The physical properties are listed in Table 1.

Table 1. Asphalt binder's physical properties

Examine	**Conditions of Testing**	**Standards**	**Outcomes**	**Limitations of Specifications according to (SCRB/R9 (2003)**
Penetration	100gm- 25°C, 5 sec.- (0.1mm)	(ASTM- D5 2018)	48	40-50
Ductility	25°C- 5cm/min	(ASTM- D113 2018)	>100	>100
Flash & Fire Point		(ASTM- D92 2018)	Flash point 308 °C	> 232 °C
			Fire point 315°C	---
Rotational Viscosity*	Pa. sec	(ASTM- D4402-2018)	@ 135℃ 0.612 @ 165℃ 0.155	---
Softening Point	…..	(ASTM- D36 2018)	50	---

Aggregates: Bitumen mix samples were arranged utilizing both fine and coarse particles. Limestone is the filler material utilized Table 2. shows the characteristics of the in this study aggregates that were employed in this study

Carbon fiber: Carbon fiber (CF) has a tube-like form and a consistent distribution. The integral The asphalt matrix's strength is boosted by aggregate swaying at the interface, which also disperses and reduces emphasize focus. Table 3 displays the elements of the CF.

Specifications of Fibers	Sample length (mm)	Fiber diameter (µm)	Tensile strength (GPA)	Modulus of elasticity (GPA)	Special Weight (g/cm3)
Carbon	**7**	**10**	**4.1**	**242**	**2.77**

Table 2. Physical characteristics for course & fine aggregate

Property	**Standard**	**Results**	**Specification**
Coarse Aggregates> 4.75			
Bulk Specific Gravity	ASTM-C127	2.615	-
Apparent Specific Gravity	ASTM-C128	2.656	-
Water Absorption %	ASTM-C127	0.91	-
Angularity	ASTM-C128	97%	90%min
Toughness, by	ASTM-D5821	20.8%	30%max
(loss Angles Abrasion)	ASTM-C535	4.1%	
Soundness	ASTMC88		12%max
Fine Aggregates properties (Crushed Sand < 4.75)			
Bulk Specific Gravity	ASTM-C 128	2.567	
Apparent Specific Gravity	ASTM-C 128	2.629	
Water Absorption %	ASTM-C 128	0.49	
Angularity	-		90%min
Toughness, by	-		30%max
(loss Angles Abrasion)	-		12%max
Soundness	-		
	-		

PREPARATION OF SPECIMENS

CF contents were selected. to be: 0%, 0.5%, 1%, 1.5%, 2%, and 2.5% by volume of based mix volume. Using Marshall

three triplicate asphalt sample samples and a device to compress generated mixture samples were used. Prepare the asphalt mixes according to standard procedures. This typically involves heating asphalt binder and mixing it with aggregatesIntroduce the carbon fiber into the asphalt mixture during the mixing process. The fibers should be dispersed evenly throughout the mixture to ensure uniform reinforcement.. Mix the asphalt and carbon fiber thoroughly to ensure proper dispersion and bonding. This may require specialized equipment capable of handling the addition of fibers. Monitor and control various parameters such as temperature, mixing time, and fiber distribution to optimize the performance of the modified asphalt.

CHARACTERIZATION OF THE MODIFIED ASPHALT MIXTURES

Marshall test determines HMA properties for the changed and control mixes. Three sets of HMA samples that have been prepared at 4.0%, 4.5%, 5.0%,5.5% & 6% of asphalt were used. Specimens are compacted by 75 blows from a standard hammer. The purpose of the first sample group is to assess the control mix's parameters. , more sets of specimens are created by using a modified mix & different CF % to get the required mixture characteristics.

PREPARATION OF INDIRECT TENSILE STRENGTH SAMPLES

Purpose of the test is to determine resistance to fracture or tensile strength of the asphalt mixture samples. The same steps used to prepare speicemens like Marshall method. They were immersed for 30 minutes in a water bath 25℃ before undergoing tensile strength testing. Next, the specimen was placed between two parallel loading bands at a vertical diametrical level (12.7 mm wide). For this test, samples are subjected to a load 50.8 mm/min until broken; maximum When the fracture happens, the load value is recorded.

THE MOISTURE SUSCEPTIBILITY EVALUATION ON MOISTURE DAMAGE

The degree of moisture damage is referred to as moisture sensitivity. S dry (ITS for unconditioned specimens) showed an average (ITS) value over three samples following they were placed for 30 minutes at 25℃ in a water bath. The last three examples were created by putting in a (4000 ml) volumetric container filled with water at room temperature and applying a vacuum of 3.74 KPa for 5-10 minutes to attain a saturation level (55 to 80%). The six specimens for each kind of asphalt were then prepared in Marshall mold with air gaps from (6-8)%. Specimens were placed at 60 ℃ for 24 hr , and after that, they were transferred to a 25 ℃ water bath for 1-2 hr. After that, the strength of their indirect tensile was assessed. The combination should contain a minimum of 80% tensile strength ratio.

3. RESULTS AND DISCUSSION

Impact of CF on Marshall Stability:

The addition of CF to asphalt mixtures alters the properties of the mixtures. Figure 1 shows that an increase in CF% to 2.5% at the optimum binder content increased Marshall Stability; adding 1.5% of CF to the HMA can be considered as the optimal percent for CF to attain the higher stability of the mixes. Adding 1.5% CF boosts the stability by 45.45%, by increasing from 11 KN to 16 KN. Carbon fibers enhance the tensile strength of the asphalt mixture, making it more resistant to tearing and cracking.

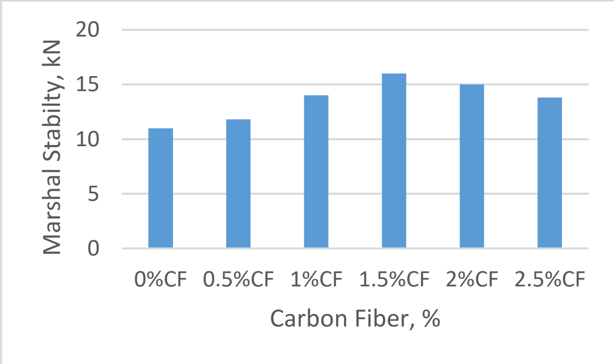

Figure 1. Impact of CF % on Stability

This improvement in stability demonstrates that the mixture's resistance to rutting and plastic deformation under traffic loads has risen, the combination of 0.5% CF showed a light reduction in stability.

Impact of CF on Marshall Flow:

The evidenense based on Figure 2 the Marshall Flow drops by a substantial 13%. The decline in flow levels illustrates how well Settlements and subgrade variations can be tolerated by asphalt mixtures without causing breaking. Furthermore, the flow value also represents the parameter for rutting. Additionally, it can be inferred that these mixes maintain pavement for longer periods without bending due to the volume of traffic. CF can enhance the stability of the asphalt mixture, leading to a more rigid and resistant material. This increased stability can result in reduced flow or deformation under load during the Marshall flow test.

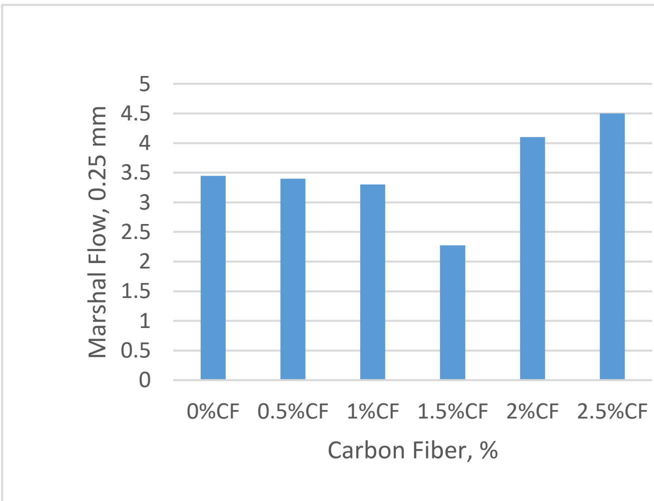

Figure 2. Impact of CF % on flow

Impact of CF on the Unit Weight of HMA:

Figure 3 indicates a reduction in the unit weight with increasing CF content up to about 2.5%, by wt. of asphalt. It steadily declined until it reached its lowest value of 2.1 This is explained by the decreasing sites of contact between the aggregates when the mixture is heavily supplemented with CF. This can be attributed to the decreasing of places of contact between the aggregates when the mixture is heavily supplemented with CF.

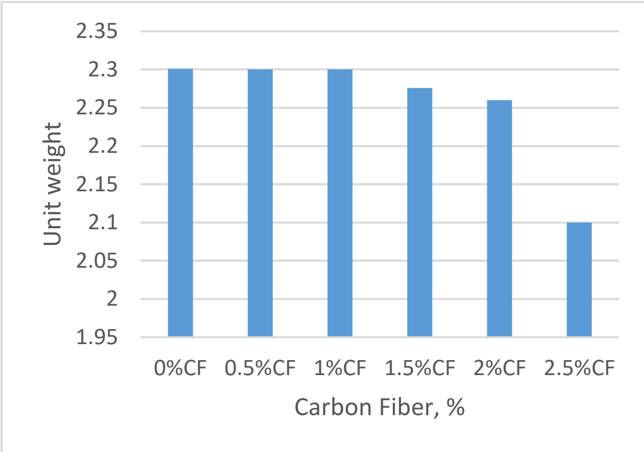

Figure 3. Impact of CF% on Unit weight

Impact of CF on Air Voids :

Figure 4 demonstrates an increase in CF % results in a notable rise in AV%. reaching to 6.75% at 2.5 CF. The rise in the air voids can be discussed because the asphalt binder becomes more viscous at higher temperatures, making it unable to fill in spaces and compact the asphalt mixture's particles. However, the AV% discovered for different Levels of CF content are all inside the range that asphalt mixtures are allowed to use.

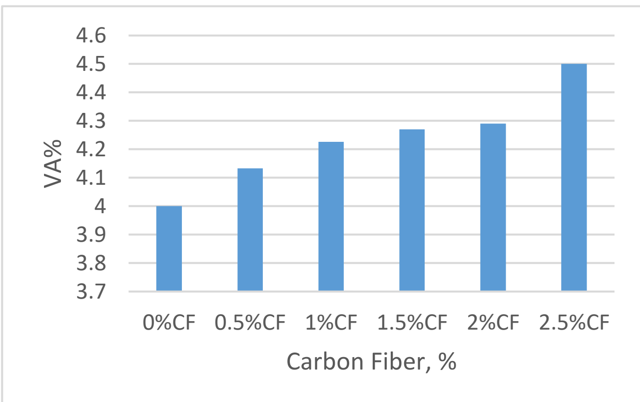

Figure 4. Impact of CF % on Air Void %

Impact of CF on ITS:

Its findings in Tables 4 & Figure 5 exhibit that ITS value increases from 988.89 to 1011.2 KPA, signifying a 98% improvement... This means that adding 1.5% CF added to a mixture of asphalt will increase the mixture's ability to withstand tensile strains. Thus, it is possible to greatly enhance the characteristics of the bond between bitumen and aggregate . by the inclusion of CF as a support system. Put another way, mixes made with CF have a higher cohesive strength than combinations prepared without CF. Figure 6 showes the relation between various mixture types and TSR. The increased of TSR ratios due to the increase in CF content. TSR% for the 1.5% CF mix is 95.5. This maximum result suggests that CF provides the asphalt mixtures' sensitivity to moisture. The improvement will increase the damage resistance such as fatigue cracking which can be a result of environmental changes. CF's high tensile strength can improve everything in the general tensile strength of the asphalt mixture. This reinforcement can help resist cracking and improve the ITS value.CF can enhance the cohesion and bonding properties of the combination of asphalt. This was better. bonding between the asphalt binder and aggregate particles can result in a stronger and more cohesive mixture, leading to an increase in ITS.

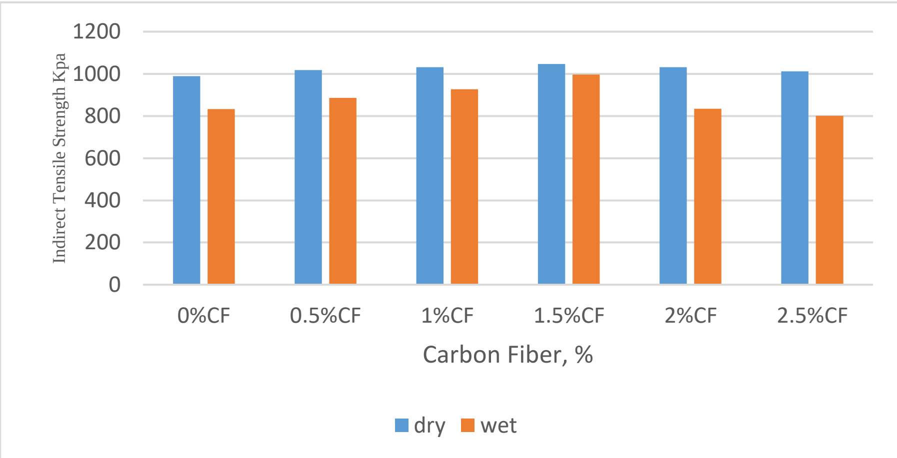

Figure 5. ITS values for conditioned and un- conditioned

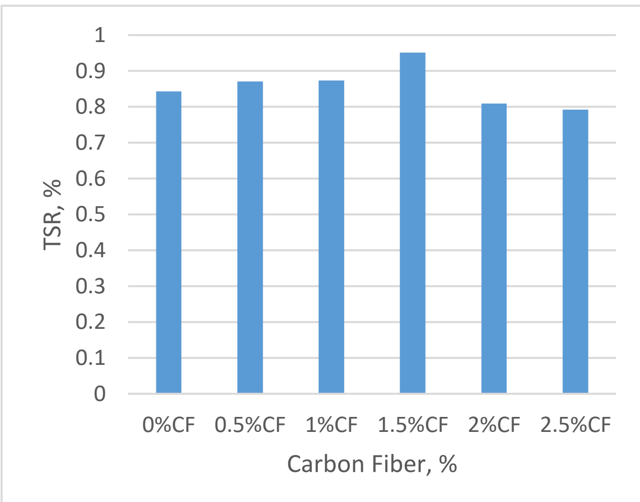

Figure 6. Effect of CF Addition on Moisture Damage

Table 4. The improvement obtained with modifications in the ITS test

Modifications	ITS Dry, kPa	ITS Wet, kPa	TSR, %
Conventional	988.89	833.25	0.843
0.5% CF	1017.336	886.09	0.870912
1% CF	1031.5	927.4555	0.87369
1.5% CF	1046.9	996.1655	0.95153
2% CF	1031.7	834.8183	0.80916
2.5% CF	1011.2	800.8	0.792

While the study may highlight the benefits of using carbon fiber in asphalt mixtures, it's also important to consider potential limitations and challenges associated with this approach. Here are some that might have been highlighted: Carbon fiber is typically more expensive than traditional asphalt reinforcement materials, such as polymer modifiers or fibers. The increased cost of carbon fiber could pose a significant barrier to widespread adoption, particularly for large-scale pavement projects with budget constraints. And Incorporating carbon fiber into asphalt mixtures may require specialized equipment and procedures for mixing and handling. Ensuring proper dispersion and alignment of the fibers within the mixture without causing fiber breakage or clumping can be challenging and may require adjustments to existing asphalt production processes.

4. CONCLUSIONS

This article examined how carbon fiber additions impacted additions performance characteristics of HMA and the following points are concluded:

1. The results of the Marshall stability and flow studies indicate, that the addition of carbon fiber to asphalt mixes lowers their flow values from 3.5 to2.5 while increasing their stability from11 to 16. Consequently, Combined with carbon fiber added had high Marshall Quotient values. These high values show that the addition of carbon fiber has improved mixtures' resilience to persistent deformations and shear stresses. 1.5% of CF asphalt mixture produced the best results, with an increase of 45.45%.

2. The use of carbon fiber addition significantly enhanced the durability and cohesiveness ability of HMA, according to findings of ITS tests .Increase TSR% from0.843 to 0.95153 by adding 1.5% CF . A further indication mix had a high water resistance to water damage came from the specimens' indirect tensile strength ratios. As a reinforcement addition, carbon fiber has enhanced the mixture's adherence to the relationship between the asphalt and the aggregate, as seen by the excellent moisture resistance.

3. Adding carbon fiber can improve The asphalt pavement's performance attributes, therefore, adding CF can be used in consequences in practice to create a higher performance and more pavement safety by :

Enhanced Cohesiveness: Carbon fiber reinforcement contributes to the cohesiveness of HMA by increasing the bonding between asphalt binder and aggregate particles. This improved bonding helps to maintain the integrity of the asphalt mixture, reducing the potential for aggregate loss, stripping, and raveling.

Reduced Moisture Sensitivity: Carbon fiber reinforcement can help mitigate moisture-induced damage in HMA by enhancing its resistance to moisture infiltration and stripping. The presence of carbon fibers improves the adhesion between asphalt binder and aggregate, reducing the susceptibility of the mixture to moisture-related distresses.

The findings suggest that incorporating carbon fiber reinforcement into asphalt pavements can lead to significant improvements in performance characteristics such as mechanical strength, durability, and resistance to distresses like cracking, rutting and surface irregularities contribute to smoother and more stable road surfaces, minimizing the risk of accidents and enhancing overall road safety for motorists.. This can result in pavements that withstand heavy traffic loads better and require less frequent maintenance, ultimately leading to cost savings and extended service life.

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