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Effect of fiber on mechanical properties of concrete asphalt

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Abstract:

Fibers have been used in asphalt paving mixtures and binder to alter their performance. They have been used since the mid-1960s to improve the mechanical properties of traditional asphalt products. Studies have shown that fibers can enhance the mechanical qualities of asphalt mixtures, such as stiffness modulus, fracture toughness, resistance to moisture damage, and tensile strength. Fibers also create a spatial networking in asphalt binder, which can be reinforced by polymer fibers. Fibers have been found to increase the resistance to flow, rutting, and dynamic shear modulus of asphalt binder. Fibers also increase the fatigue resistance of asphalt mixtures, with polyester fibers showing the most benefits for enhancing the asphalt mixture's fatigue. A study using a blend of aramid and polypropylene fibers assessed the performance attributes of an altered asphalt mixture, comparing the performance of fiber-reinforced and control HMA with a control HMA without fibers. The results showed that fibers enhanced the mechanical qualities of the HMA, potentially improving the performance of asphalt pavements against typical distresses.

The study combines mineral fibers (asbestos) and synthetic fibers (polyester and nylon) to create a densely graded aggregate. The presence of fibers enhances the mixed rheological characteristics and stiffening effect of the fiber properties. The addition of fibers weakens the Marshall and slightly raises the proportion of optimal bitumen content and air spaces in the asphalt compared to normal fiber. The inclusion of fibers, depending on the percentage of fibers, considerably increases the mixture's endurance.

Bitumen content was optimized for creating asphalt concrete specimens with polypropylene fibers, resulting in a decrease in flow values and an increase in Marshall Stability values. These examples also had an extended fatigue life. The beneficial impact of polypropylene fibers is the enhanced characteristics of asphalt concrete, such as good resistance to rutting, longer fatigue life, and reduced reflection cracking.

Carbon fiber (CF) is a fibrous substance with low specific gravity, remarkable performances, and exceptional mechanical qualities. It has great potential for modifying asphalt or mixtures due to their exceptional mechanical qualities and compatibility with asphalt. Glass fiber is suitable for corrosion and moisture resistance, hardness and strength, mechanical qualities maintained at high temperatures, and relatively low cost.

1.Introduction:

Fibers are utilized in asphalt paving mixtures and asphalt binders to change their performance. It's not new to use fibers to change the way asphalt materials behave. Although there is considerable debate over their utility and efficacy, it dates back to the mid-1960s. Most flexible pavement and airfield applications can be effectively served by conventional asphalt mixtures.

But in the last few years, there has been an increase in traffic, harsh weather, and larger loads. This, combined with concerns about affordability and durability, has increased the need for

Alteration to enhance the mechanical characteristics of traditional asphalt products. Fibers might be able to modify this way, improving the mechanical qualities of asphalt mixtures in the process(Mohammed, Parry et al. 2019)**.** Several studies have found that fiber improves the technical qualities of asphalt matrix.

1.2 Literature review:

A study compares the main types of distress encountered by flexible pavements with the relative performance of asphalt mixtures modified with various fiber types and contents. At a test temperature of 20 degrees Celsius, the results indicate that fibers significantly affect the stiffness modulus and fracture toughness of asphalt mixes. Furthermore, primarily at low strain values, fibers offer a somewhat longer fatigue life for asphalt mixtures supplemented with fibers. Additionally, the results show that fibers have no negative effect on the combinations' resistance to moisture damage or tensile strength(Mohammed, Parry et al. 2019). Another study conducted that Fibers have greatly increased the resistance to flow, rutting, and dynamic shear modulus of asphalt binder, In asphalt binder, fibers create a spatial networking that can

Be further reinforced for the polymer fibers examined in this work by the antenna features at the fiber ends,

Through their roles in spatial networking, asphalt absorption, and adhesion, fibers can reinforce asphalt binder; the reinforcing effects are also influenced by the structure and characteristics of the fibers, such as their size, shape, and tensile strengths.

The lignin and asbestos fibers exhibit a higher capacity to absorb asphalt compared to the polymer fibers because of their bigger specific surface areas.

The fibers made of polyester and polyacrylonitrile exhibit a higher degree of networking function in comparison to those made of lignin and asbestos(Chen and Xu 2009)

Another search concludes that The findings of fatigue tests also show that fiber modifiers increase the asphalt mixtures' fatigue resistance. Additionally, there is a good correlation between the fatigue test findings and the fatigue parameter derived from dynamic response data. Of these three fiber kinds, polyester fiber exhibits the most benefits for enhancing the asphalt mixture's fatigue(Ye, Wu et al. 2009).

Another study In this work, a blend of aramid and polypropylene fibers was utilized to assess the performance attributes of an altered asphalt mixture. The material utilized was the traditional dense-graded hot mix asphalt (HMA) found in São Paulo, Brazil. Compacted hot mix asphalt's (HMA) resistance to moisture-induced damage, resilient modulus, dynamic modulus, flow number test, fatigue by flexural bending, and fracture energy using the semi-circular test were all evaluated as part of the laboratory experimental program. In the lab program, two asphalt mixtures were used: one that was fiber-reinforced and contained fibers, and the other that was a control HMA without any fibers. The performance of the fiber-modified mixture was compared to the control using the data, The outcomes demonstrated that the fibers enhanced the hot mix asphalt control's mechanical qualities. The performance of asphalt pavements against typical distresses such as rutting, raveling, fatigue, and reflective cracking may be improved by the inclusion of polypropylene and aramid fibers in HMA(Klinsky, Kaloush, et al. 2017).

In the last reviewed study Mineral fibers (asbestos) and synthetic fibers (polyester and nylon) were combined to create a densely graded aggregate. Comparing the various rheological characteristics, mechanical characteristics, and moisture susceptibility of fiber blends was done in laboratory tests. The penetration and softening point results on bitumen-fiber mixtures demonstrate that the presence of fibers enhances the mixed rheological characteristics and stiffening effect of the fiber properties. According to the results of the Marshall Tests, the addition of fibers weakens the Marshall and slightly raises the proportion of optimal bitumen content and air spaces in the asphalt as compared to normal fiber. The inclusion of fibers, depending on the percentage of fibers, considerably increases the mixture's endurance, according to the findings of the indirect tensile tests(Motlagh and Mirzaei 2016).

In the last reviewed paper Bitumen content was optimized for creating asphalt concrete specimens with polypropylene fibers. The results showed a discernible decrease in flow values and an increase in Marshall Stability values for the fiber-reinforced specimens.

These examples also had an extended fatigue life. An indication of the beneficial impact of polypropylene fibers is the enhanced characteristics of asphalt concrete. Good resistance to rutting, a longer fatigue life, and reduced reflection cracking are characteristics of the fiber-reinforced asphalt mix. In light of this, it can be said that adding polypropylene fibers to asphalt mixtures significantly improves their properties(Tapkın 2006).

2. Objective:

The aim of this review is to know furthermore about the mechanical properties of concrete asphalt reinforced with various types of fiber to overcome some unacceptable behavior of asphalt which cause a reduction in in service live and costly maintenance.

Also this research aims to perform a thorough analysis of the impact of fibers on the mechanical characteristics of asphalt concrete. This research delves into a range of fiber kinds, including as glass, carbon, polyester, cellulose, nylon, and polypropylene, and examines how they affect asphalt mixtures. The goal of the study is to shed light on the evolution of fiber use since the mid-1960s, with a focus on how fibers improve tensile strength, stiffness modulus, fracture toughness, and resistance to moisture damage.

The literature study explores particular data about various fiber kinds and how they affect asphalt mixtures, taking into account things like high traffic loads and temperature sensitivity. The effects of spatial networking in asphalt binder and the enhanced fatigue resistance linked to particular fiber types, such as polyester and polypropylene, are highlighted in the research.

The report summarizes previous research as well as suggesting topics for future investigation. The recommended goals include investigating the impact of fiber geometry, evaluating the environmental impact, analyzing the performance of fiber-reinforced asphalt at different temperatures, incorporating cutting-edge testing methods, analyzing performance under heavy traffic loads, and performing cost-benefit analyses. The need for more research is emphasized in the paper's conclusion, especially in the areas of advanced microscopy to evaluate fiber distribution and mechanical property modeling.

3. Types of fiber

Carbon fiber:

Carbon fiber (CF) is a fibrous substance with a micrographite crystal structure that is created by heat-treating acrylic resin that has been fibrillated from oil/coal pitch. The carbon fibers have

Low specific gravity, remarkable performances (high heat conductivity, chemical stability, low thermal expansion coefficient, electric conductivity, heat resistance), and exceptional mechanical qualities (high tensile strength, high tensile modulus).

Owing to their genetic

CFs have great potential for modifying asphalt or mixtures due to their exceptional mechanical qualities and compatibility with asphalt(GECKIL1 and AHMEDZADE 2019). Three contents, namely 0.02%, 0.025%, and 0.03% by weight of mixture, and three lengths, including 1, 2, and 3 cm for carbon fibers, were taken into consideration to assess the impact of fiber content with properties in Table 1. and length. According to the Marshall design, the ideal binder content for mixes without fiber was 5.5%; combinations with 0.02%, 0.025%, and 0.03% of fiber were deemed to have an optimal binder concentration of 5.7%, 5.75%, and 5.8%, respectively(Nejada, Vadoodb, et al. 2014).

Table 1: carbon fiber properties.

Elongation (%)	**1.32**	**Specific gravity (gr/cm3) 1.75**	**1.75**
Tensile modulus (GPa) 2	**230 Diameter (μm) 8**	**Diameter (μm)**	**8**
Tensile strength	**3.3**	**Source**	**Polyacrylonitrile**

(GPa)			

After testing The following graphs effect of carbon fiber on some mechanical properties :

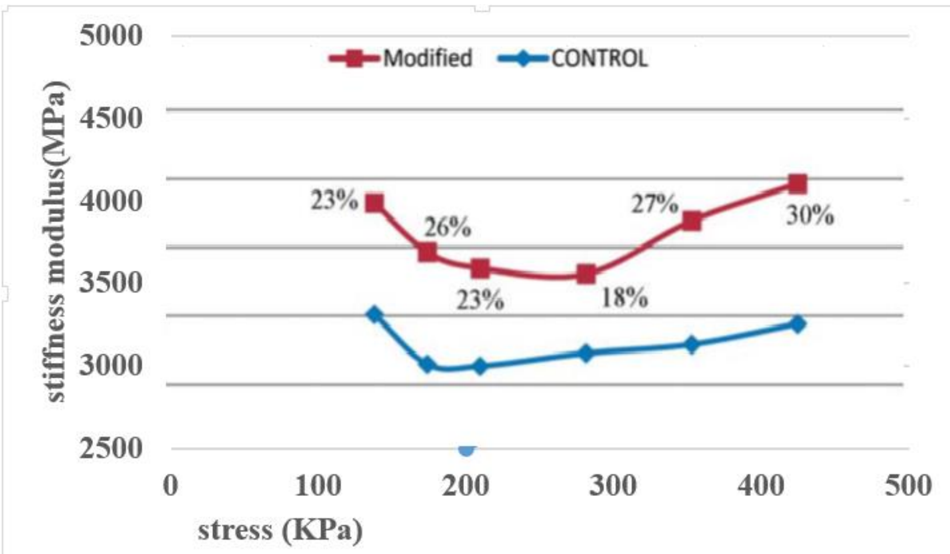

Figure 1;The modified samples and CONTROLs had an average stiffness modulus of 0.025% by weight of mixture and a fiber length of 3 cm(Nejada, Vadoodb et al. 2014).

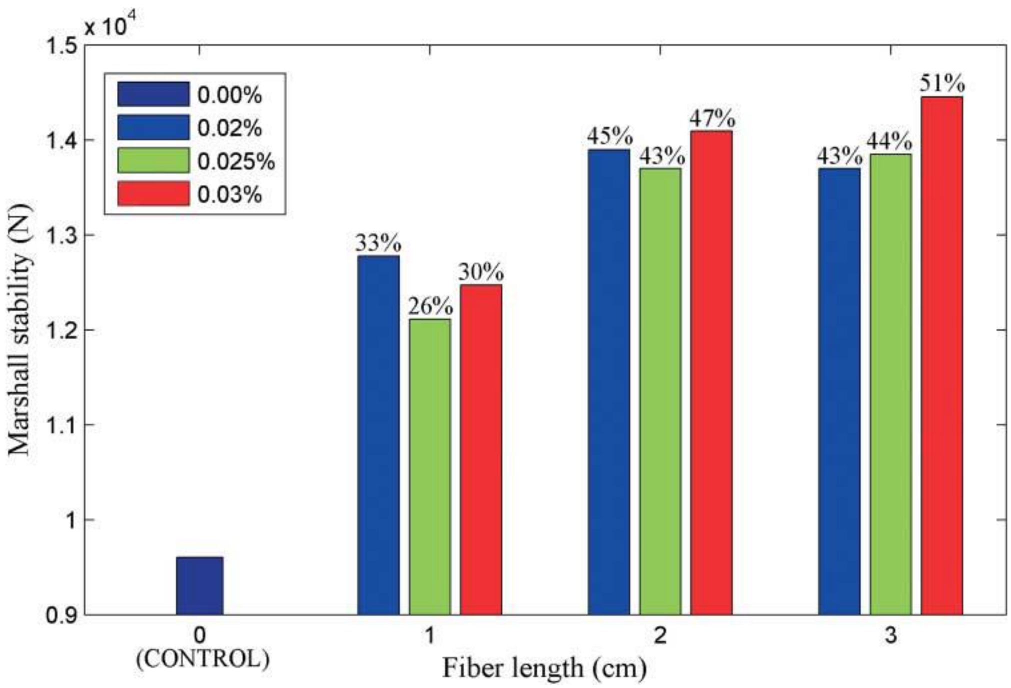

Figure 2: The values above each column show the percentages of increasing Marshall stability about CONTROL for adjusted samples(Nejada, Vadoodb, et al. 2014).

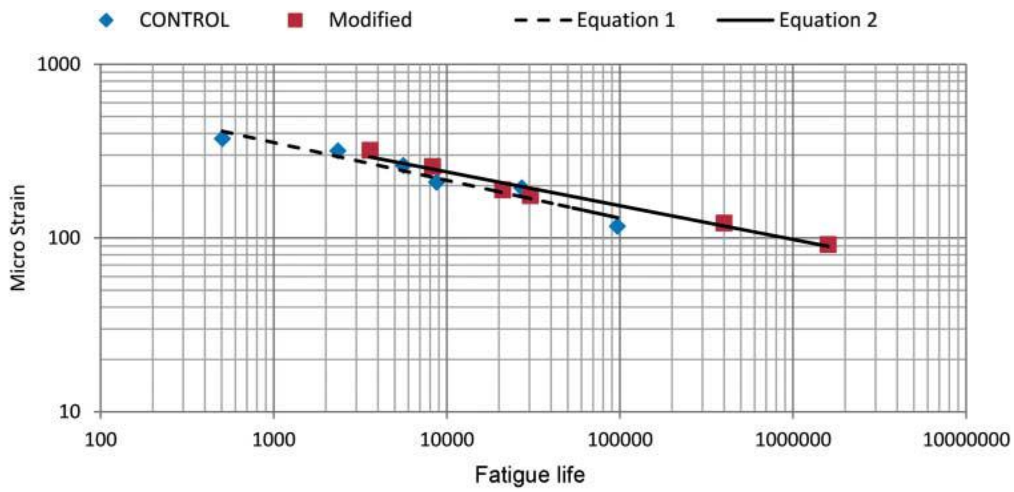

Figure 3: Fatigue life as a function of strain for altered samples and controls(Nejada, Vadoodb, et al. 2014) Conclude that using carbon fiber has significant role in improving mechanical properties of asphalt mix.

2. Glass fiber:

Suitable corrosion and moisture resistance, suitable hardness and strength, mechanical qualities maintained at high temperatures, and relatively low cost are all attributes of glass fiber.

Reasonably priced. Bulk commercially available fiber that has been industrially cut in the aforementioned sector(Zarei, Zarei, et al. 2017), an example study of using glass fiber which uses glass fiber with following properties

Table 2:properties of glass fiber(Eisa, Basiouny et al. 2020)

Properties of glass fiber.	**Properties of glass fiber.**
Fiber type	**Glass fiber**
Color	**White**
Shape	**Rectangular**
Length	**(mm) 10**
Width	**(mm) 1**
Density	**(g/cm3) 2.53**
Melting point	**(ºC) > 300**
Moisture	**< 0.2**
Loss on ignition (%) < 0.25	**(%) < 0.25**
Non-Fibrous materials (%) < 1.0	**(%) < 1.0**

The mechanical properties of the mix after testing the fiber as follows:

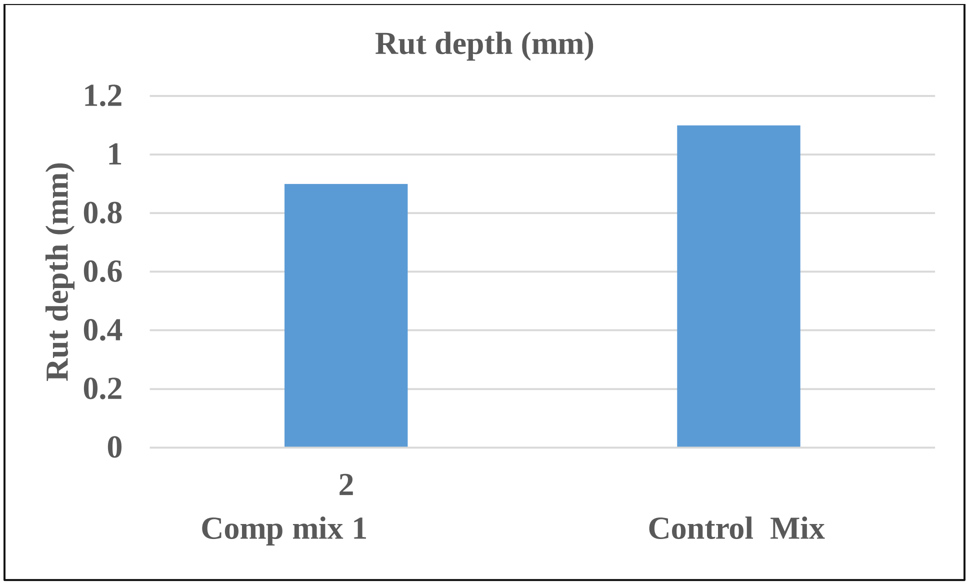

figure 4:depth of rutting of mix with and without modification(Eisa, Basiouny et al. 2020).

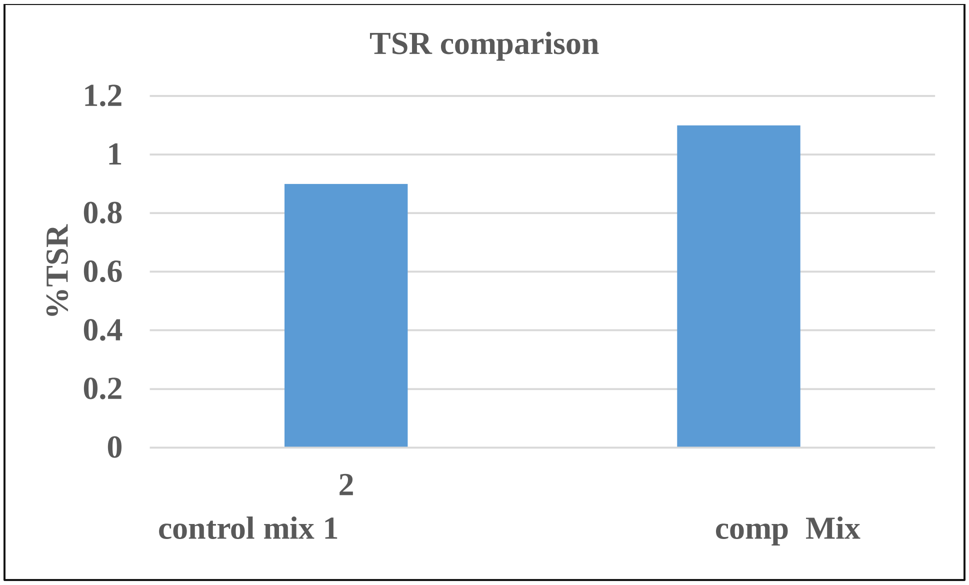

Fig. 5. Tensile Strength Ratio (TSR) for the two main mixtures(Eisa, Basiouny et al. 2020)

The ideal amount of GF in a hot asphalt mixture is 0.25% of the total mix weight. This results in hot asphalt mixes with increased stability values (by 10%) and adjusted flow values.

higher rutting resistance by lowering the rutting value by 19.7% in comparison to the control asphalt mixture, and by reducing it by 13%, In comparison to control asphalt mixtures, the mixture with GF at a proportion of 0.25% exhibits a good resistance to moisture damage (indirect tensile strength).

When utilizing GF at its optimal content as opposed to the control mix, the loss of stability value rose. Still, it was within the allowable limit (< 25%)(Eisa, Basiouny et al. 2020).

3- Polyester fiber:

Polyester is composed of polypropylene and has an average diameter of 20 lm and length of 6 mm.

Polyester fibers have a specific gravity of 1.35 g

The stress strength is 520 MPa and the volume is cm^3. Polyester fiber has a melting point of 248 degrees Celsius, which means it won't melt when mixed at high temperatures when preparing asphalt. A study conducted using percentages of polyester fiber in the asphalt that are 0.1, 0.3, and 0.5 percent by weight

And stirred for two hours. Subsequently, the viscosity and rheological characteristics of the fiber-modified asphalt binder and the control sample were examined using the viscosity test and the dynamic shear test. Frequency sweep dynamic shear measurements were performed at 15°C after the binders were aged in the RTFO. Follow the property of sample shown (Shaopeng Wu, Ye et al. 2008).

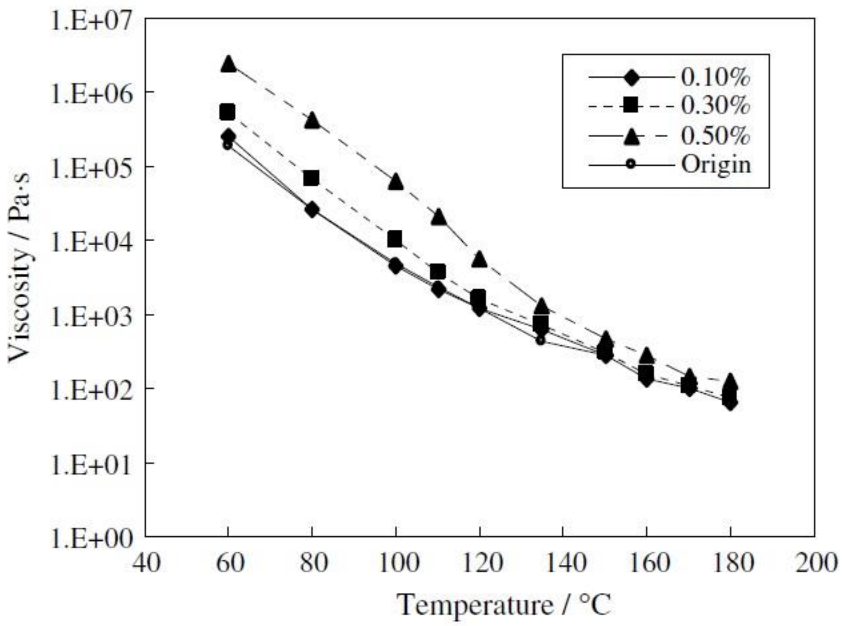

Figure6: Temperature-dependent viscosity of asphalt mixed with polyester fibers(Hadidy.A and Yi-qiu.T 2009).

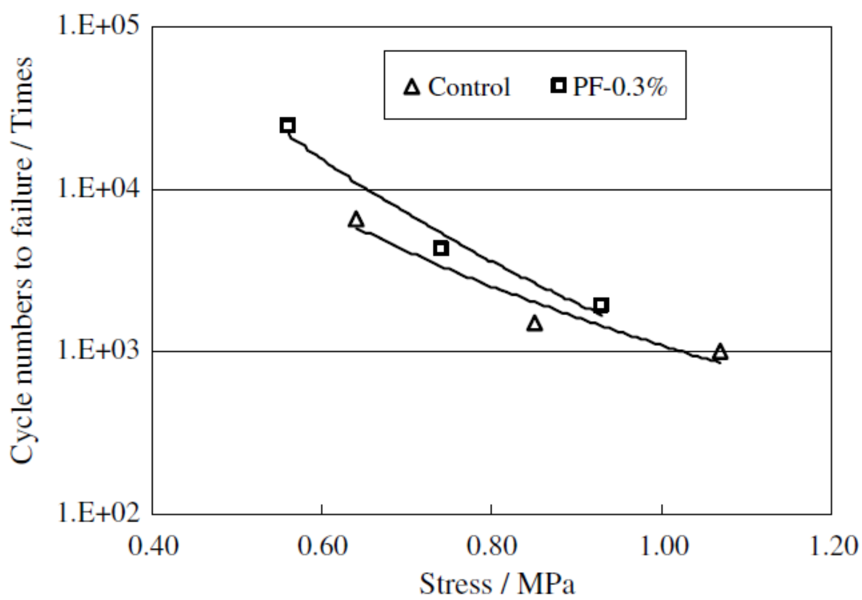

Figure7: Cycle counts to failure in comparison to the stress lever in asphalt mixtures(Shaopeng Wu, Ye et al. 2008)

4- Cellulose fiber:

A study using cellulose fiber the Semi-Circular Bending (SCB) test and loading rates ranging from 0.25 to 1 mm/min, the study intends to investigate the impact of cellulose fiber at doses of 0.3% to 0.5% w/t on the mechanical properties of asphaltic mixtures.

Boosted the tensile strength by 8.8%–13.7% and 20%–45% at low loading rates, with the addition of 0.3% w/t fiber achieving the highest value. Furthermore, a higher dose of fiber did not improve the mixtures' qualities as the critical strain energy (Jc) increased by 5.88% - 24.5% at the low rate and 3.4% - 38.2% at the high-speed rate. Because of the altered behavior of the fiber-matrix interfacial, the amount of improvement in the mechanical characteristics of bituminous mixes is inversely related to the dosage of fiber; in this investigation, the optimal result is obtained when 0.3% w/t of fiber is included(Daniel and Felix1 2023).

5. Nylon fibers:

As another fibers nylon fiber used to modify asphalt properties, No-run is the origin of the word "Nylon." The moniker was initially intended by its inventors to highlight the sturdiness of women's undergarments made of it(Gohl and Vilensky 1983) . One common facing yarn used in carpets is nylon.

is the term for the real recycled carpet strands found in asphalt pavement. By utilizing fracture energy, (S, Rust et al. 2005) examined the impact of nylon fibers on the fatigue cracking resistance of asphalt concrete. The indirect tension strength test and the single fiber pull-out test were the two phases that made up the experimental program. 9.2 mm was shown to be the key fiber embedding length using pull-out experiments on 15-denier single nylon fibers. To conduct indirect tension strength testing, samples of asphalt concrete were made and mixed with nylon fibers of six and twelve millimeters in length. And evaluated using three volume fractions of 0.25%, 0.5%, and 1% as well as the outcomes of the pull-out tests (critical embedded length). 1% volume fibers with a 12 mm length were used to create asphalt concrete samples. produces an 85% increase in fracture energy compared to specimens without reinforcement, indicating enhanced resistance to fatigue cracking(S, Rust, et al. 2005).

6. Polypropylene fiber:

Fibers made of polypropylene are frequently utilized to reinforce concrete(Parameswaran. 1991). The concrete is reinforced in three dimensions by the polypropylene fibers. Concrete gets stronger and more resilient in this way(Noumowe 2005). High-performance concrete requires polypropylene fibers as a necessary ingredient(Einsfeld and Velasco 2006). In the US, polypropylene fibers were also utilized as modifiers in asphalt concrete. A standard for the use of polypropylene fibers in high-performance asphalt concrete has been released by the Ohio State Department of Transportation (ODOT) (TransportationOhio: 1998)

To lessen reflection cracking in an asphalt overlay, (McDaniel.S. 1993)employed polypropylene fibers in their 1993 investigation. There was no decrease or delay in reflection cracking on the fiber-modified overlay areas, even though the crack intensities were lower there. Portions where the pavement Fibers in the base or binder layers were found to reduce reflection cracking in sections of the pavement where cracking and seating occurred before the overlay. (McDaniel.S. 1993).

(Huang.H and WhiteTD. 1996)study focused on polypropylene fiber-modified asphalt overlays. These mixes, along with others devoid of fiber, were sampled by coring and sent to the

Lab for additional examination. The results of the lab tests indicated that the fiber-modified mixtures had better fatigue life and were marginally stiffer. The main issue with polypropylene fibers was their low melting point, which made them inherently incompatible with hot asphalt binders.

In addition, Huang and White said that more investigation was required to comprehend the viscoelastic characteristics of asphalt mixes enhanced with fiber.

Polypropylene-fiber-infused asphalt concrete specimens were produced at the ideal bitumen concentration, drawing from research (Tapkın.S. 2008). That was noted in

Specimens reinforced with fiber, where there was a discernible rise in Marshall Stability values and a drop in flow values. These specimens also had an increase in fatigue life. The fiber-reinforced asphalt mixture has less reflection cracking, a longer fatigue life, and superior resistance to rutting.

According to a comparison study by (Abtahi. SM, Ameri.M et al. 2009), Polypropylene (PP) fibers with a length of 12 mm and a weight percentage of 0.125% of the total weight of the mix performed better statistically than Styrene–Butadiene–Styrene (SBS). Marshall and Resilient Modulus were among the experiments.

Due to their low melting point of 162 degrees Celsius, PP fibers function better, as demonstrated by another research program. Thus, a characteristic is known as "tackiness"

Complements the fiber by adhering it to the matrix. This accomplishment has been observed through experiments and validated by an Artificial Neural Network (ANN)(Hejazi. S.M, Abtahi. S.M et al.).

According to recent findings by(Tapkin.S, A et al.), the optimal FRAC samples in Marshall Specifications and Static Creep Properties are represented by a PP fiber that is 3 mm long and has a total dosage of 0.3% modified bitumen. This was determined utilizing the wet technique. The temperature was 163 °C, the mixing rate was 500 rpm, and the duration was 2 hours. Hence, compared to control specimens, the FRAC specimens under repeated creep loading at various loading patterns improved by 5–12 times, while the Marshall stability increased by 20% in this optimized condition. A different exploratory study recommends preparing FRAC samples using a wet method with PP fibers (Hadidy. A. and Yi-qiu. T. 2009)

7. Asbestos fiber:-

The only mineral utilized to make textile fibers is asbestos.

The material is present in the fibrous reins of amphibole or serpentine rock (Majoryl. L 1986). The use of non-synthetic fibers in pavements was initially attempted;

As a result, fibers made of cotton and asbestos were employed, but they were biodegradable and unsuitable for use as long-term reinforcements (Bushing. H, Assoc, et al. 1968). Before its recognition as a health threat, asbestos was also used (Marais.C. 1979).

The findings of a study conducted comparing the void contents and hydraulic properties of modified and plain asphalt mixtures placed on the French Nantes fatigue test track were published. To alter the base combination, a mineral fiber (asbestos) was added in the third mixture, and a polymer modifier (SBS) in the first two. Simple and SBS versions(Huet.M, A et al. 1990)

After 1,100,000 load cycles, the mixtures' void content and hydraulic characteristics decreased similarly, on the other hand, found that under the same loading, the mixtures treated with fibers "had undergone no reduction in void content; its drainage properties were practically unchanged and rutting was minimal."

4. Recommendation:

1-Effect of Fiber Geometry: Examine how the mechanical characteristics of asphalt mixtures are affected by the length, diameter, and aspect ratio of the fibers. Find the fibers with the best geometric properties to attain the required performance gains.

2-Temperature Sensitivity: Examine how fiber-reinforced asphalt performs in different temperatures. Examine how temperature variations affect the mechanical characteristics of asphalt mixtures with varying fiber types and concentrations.

3-Environmental Impact: Investigate whether adding different kinds of fibers to asphalt mixtures is environmentally sustainable. To ascertain the overall sustainability of fiber-reinforced asphalt, evaluate the environmental impact of the material's life cycle, taking into account factors related to production, installation, and end of life.

4-Integration of sophisticated Testing Techniques: To obtain a deeper understanding of the microstructure and failure mechanisms within fiber-reinforced asphalt, utilize sophisticated testing techniques, such as non-destructive testing and imaging technology. This might offer insightful information on how the fibers are arranged and distributed inside the asphalt matrix.

5-Performance under High Traffic Loads: Examine how fiber-reinforced asphalt performs in situations with exceptionally high traffic volumes, such as those found on busy highways or in industrial districts. Examine whether fiber-reinforced asphalt can reduce permanent deformation and lengthen the lifespan of the pavement as a whole.

6-Cost-Benefit Analysis: To determine whether employing fiber-reinforced asphalt is economically feasible, perform thorough cost-benefit assessments. Take into account elements including the original cost of construction, ongoing maintenance needs, and the possibility of extending pavement service life.

5. Conclusion:

The benefits of employing random-inclusion fibers as fiber-reinforced asphalt-concrete, or FRAC, materials in flexible pavements were examined in this review. Consequently, it was suggested that using fibers.

Three distinct goals have been addressed in AC mixes: the creation of electrically conductive mixtures, the improvement of mechanical properties, and the development of a new market for the disposal of waste textile fibers. In general, fibers alter the mixture's viscoelasticity and decrease reflective cracking in asphalt mixtures and pavements. They also enhance the mixture's dynamic modulus, moisture susceptibility, creep compliance, rutting resistance, and freeze-thaw resistance.

These characteristics were covered in detail for several types of fibers, such as nylon, polypropylene, polyester, asbestos, cellulose, carbon, and glass. Additionally, sample preparation techniques and executive issues were discussed. Consequently, it was discovered that the wet process and the dry process are the two possible ways in which the fibers could be introduced. For

several reasons covered in the paper, the dry one is typically chosen over the other. Research reviewed in this paper repeatedly shows that adding fibers to asphalt mixtures improves their mechanical properties. Stiffness modulus, fracture toughness, moisture damage resistance, tensile strength, and fatigue resistance are all improved by fibers. Further reinforcing the material is the spatial networking effect that polymer fibers, in particular, induce in asphalt binder. The study highlights the distinct advantages linked to various fiber kinds, including the remarkable mechanical properties of carbon fibers, the resistance to corrosion of glass fibers, and the efficiency of polyester fibers in augmenting fatigue resistance.

On the contrary, a new area of study may be the modeling of the mechanical properties of FRAC mixes utilizing the concepts of composite sciences. Lastly, it is advised that optical and/or scanning electron microscopy be used to assess the direction of fibers within a FRAC specimen. It appears that this is an unexplored study topic.

Also following points can be concluded:

1-Using X-ray CT, the distribution and orientation of steel fibers have been successfully studied. When applied to glass or cellulose fibers, which have densities comparable to other ingredients in the mixture.

2-Although there is considerable variation in their distribution across the sample, steel fibers were discovered to be present throughout the combination. Images demonstrated how the steel fibers are positioned throughout the sample at different angles to form a three-dimensional network.

3-Through load distribution through the fiber networks in the mixture and bitumen mastic modification (as shown by other experiments), the fibers made the asphalt mixes more rigid.

3-For fiber amounts of 0.5% and 1.0%, the fatigue life of the modified asphalt mixtures was greater at low strain values than the control mixtures. How long the control did sample tire? Was greater at values of high strain.

4-In comparison to other fiber contents and the control combination, adding 2.0% glass and steel fiber to the asphalt mixture reduces fatigue life.

The addition of fibers increases the asphalt mixture's indirect tensile strength. All fiber kinds exhibited improvement, however, steel fibers showed the greatest amount.

5-After being subjected to the moisture damage procedure, the control and fiber-reinforced asphalt mixtures showed excellent resistance to moisture damage and an improvement in their ITS.

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