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Utilization of fibers in the modification of bitumen: A review

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Abstract
This article makes an effort to present, evaluate, and debate the literature related to earlier research findings on fiber-reinforced pavement engineering for road surface. The relevance of fiber-reinforced asphalt pavement and its function in providing effective and lasting surface for heavily travelled roads are also discussed in this paper, along with a discussion of the history and current state of road surfacing. To provide readers with the necessary background information so they can actively understand the experiments and discussions, the paper makes an effort to define a few terminology and concepts that are relevant to the talks. Results from numerous experiments show that fibre especially improves the appropriate bitumen content in the mixture's design and stops bitumen leaks because of its susceptibility to absorbing asphalt. The visco-elastic response, susceptibility to moisture, rutting resistance, and pavement fatigue cracking are all modified by fibre.

Keywords: Bitumen, Pavement, Fiber, Rutting, Reinforcement

Introduction

Typically, bituminous pavement surfaces are made up of a supporting course or courses, a bitumen binder, and a top layer of mineral aggregate. Above the prepared sub-grade, bitumen-bound layers and unbound layers of gravel or stone, make up the structure of bituminous pavement. The top or higher layers of the pavement are composed of a bituminous surface, which may be in the form of a chip seal or on HMA of high quality, depending upon types and requirement of pavement. It must be sturdy for a bituminous pavement surface to be able to resist deformation and provide a smooth but skid-resistant surface[1]. For the entire structure to remain stable and strong, it must also be impermeable and tightly bonded to the course or layer beneath[2]. The capacity of the pavement's structural stability is destroyed by moisture beneath the pavement that softens base materials and weakens subgrade soil[3-6]. Additionally, heavy traffic volume results in daily damages including pavement failures and fatigue cracks[6-8]. Scientists and engineers are permanently trying to improve properties of asphalt mixtures, such as their stability and durability, by incorporating new additives either in the bitumen or in the asphalt mixture[9]. Bitumen manufacturing in the majority of refineries is, in practice, a secondary operation that cannot compete with fuel and other refinery products in terms of income generation. Consequently, it is infrequent for petroleum refineries to employ the strategy of producing better-performing bitumen. Modification has been employed as one of the appealing options to enhance bitumen qualities when the generated bitumen binder does not fulfil the climatic, traffic, and pavement construction requirements[10]. Fibers and polymers are typically two significant examples employed in this approach[10, 11], while polymer modification is the most common bitumen modification strategy[12, 13]. However, it has been claimed that among the numerous asphalt modifiers, fibres have drawn a lot of interest because of their strengthening effects[14].

Fibers are added to the binder or bituminous mixtures to ensure their stability and mechanical strength. The qualities of the asphalt are altered by an adequate amount of fibres, which raises the softening point and decreases penetration. Additionally, it alters the bitumen's viscoelasticity[15]. Additionally, it has been demonstrated that incorporating fibres into asphalt concrete improves the material's ductility, strength, and fatigue behaviour as well as strengthening the mastic and reducing thermal susceptibility[16, 17]. Additionally, it has been noted that fibres in stone matrix asphalt (SMA) mixtures decrease binder drainage and increase moisture sensitivity and compressive strength[18-20]. Furthermore, a number of studies have shown that fibres in porous asphalt mixtures reduce drain-down problems[21, 22]. Asphalt concrete is widely used to build flexible pavements and is well-suited for supporting loads, therefore it has become a necessity for road engineers[23, 24]. In addition to the rapid expansion of building and traffic volumes, bituminous material usage has become essential. To achieve an asphalt mixture with high durability and performance, a variety of requirements in the mixture's ingredients are required.

As an alternative to traditional fibres, various types of fibres have been utilised in asphalt binders and Hot mix asphalt (HMA) to address primarily mechanical performance issues. The usage of these fibres in asphalt concrete has been studied since 1950, although they have already been considered as a component of Portland cement concrete[23]. This material now has increased modulus, resistance, durability, and deformation capacity thanks to fibres, which results in more ductile performance[24].

Numerous fiber-modified asphalt binders and combinations have been developed to address the major issues with flexible pavement, including rutting, fatigue cracking, thermal cracking, and rutting[25].

The viscoelastic qualities of asphalt binders are improved by fibres made of asbestos, lignite, polyester, polyacrylonitrile, carbon, and brucite[26-29]. The tensile strength and rutting resistance of asphalt concrete and porous asphalt mixtures are increased by the addition of cellulose and hybrid fibres. Additionally, a decrease in binder drain off is observed[30-32]. Investigations on the use of glass, aramid, steel, and waste fibres in SMA and asphalt concrete (AC) have also been performed[33-36]. Glass fibre reinforced SMA mixtures have greater resistant modulus and rutting resistance values[37], but employing carbon fibres increases the Marshall stability of asphalt concretes[23].

The use of fibres to alter the behaviour of materials, according to Hongou and Philips, is an old idea. A 4000-year-old Chinese bridge made of clay earth and fibres can be found in China, as can the Great Wall, which was constructed 2000 years ago[38]. But in the early 1960s, fibre reinforcement began to undergo modern advances[39]. The oldest known work on the strengthening of asphalt mixes was reported by Zube[40]. This study investigated different kinds of wire mesh positioned beneath an asphalt overlay in an effort to stop reflection cracking. The study came to the conclusion that longitudinal cracks were either prevented or significantly delayed by all types of wire reinforcement. Zube contends that the introduction of wire reinforcement would enable a reduction in overlay thickness while maintaining performance. The compatibility of steel/AC mixture was not found to be an issue. However, in South Carolina more than 60 years ago, layers of coarsely woven cotton were layered between applications of asphalt to reinforce the road surface and improve ride comfort[41, 42]. In order to prevent water from seeping through cracks and eroding the road base, the cotton served as both a waterproof blanket and a binder for the asphalt. The paving procedure was first introduced to Georgia, Louisiana, and Texas in 1976 after a test site in New Jersey produced positive results after a year[43].

Fibers have drawn a lot of interest as additives to asphalt mixtures due to their good reinforcing effects and simple processing method[44, 45].

The objectives of this review are to address the function of fibres in bituminous binders and asphalt mixtures; as a result, a physical and micro-structural characterization of fibres is provided. Based on the findings of the more common characterisation tests for this type of modified binders as well as the behaviour of the fibres at high, medium, and low temperatures, the use of several types of fibres in the bitumen is explored.

Deterioration and Deformation Asphalt Pavement

The pavement surface structure as depicted in Figure 1 is designed to withstand high traffic volumes and to offer resistance to water penetration during rainy weather, which can lead to the deterioration of the pavement surface and lower layers. Therefore, keeping water away from the pavement surface is crucial and can extend the pavement's service life. Since, heavy traffic loads can harm bituminous blends, especially in harsh weather and environmental conditions. In both hot and cold regions, asphalt pavement failure is a frequent issue. However, some types of failure, like permanent deforestation (rutting), are thought to be more severe and acute in warm climates than in colder temperatures because extreme temperature increases in the asphalt pavement can cause a reduction in pavement stiffness, which can lead to deformation, which is especially impacted by heavy traffic loading[46, 47].

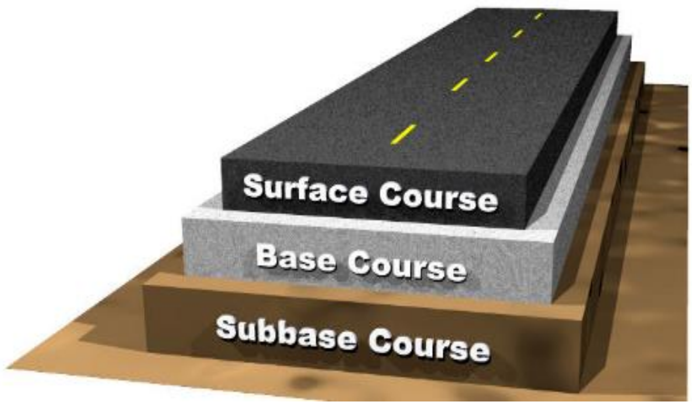

Figure 1. Pavement surface structure[48]

Common factors contributing to the deterioration of hot mix asphalt pavements include heavy traffic loads, as depicted in Figure 1, cold or hot weather, the use of inappropriate materials, and other factors like utility cuts exerted from the outside.

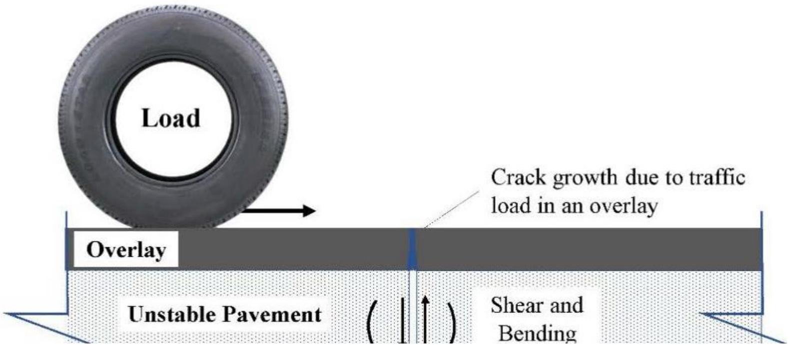

Figure 2. Loading and stresses in asphalt pavemernt.[1]

However, current research suggests a close cracking on the surface and the uneven distribution of 3D contact pressure measured between a vehicle's tyres and the pavement structure[49, 50]. The findings of the testing of free-rolling automobile and truck tyres show that, in addition to the conventional contact pressure affecting the contact area, there is a significant pressure produced by longitudinal and transverse contact[51]. Furthermore, in hot conditions longitudinal surface cracks are frequently anticipated because of extremely high transverse tensile stress concentrations close to the tyre edges. The horizontal tensile stress that repeated cycles of more unstable temperature swings placed on the asphalt layer, as is expected in some places with extreme and unstable climatic conditions, is another reason for surface cracking[52]. Cracking, rutting,

ravelling, and bleeding are some of the common types of pavement deterioration, and some of the most common varieties are discussed in the following section: cracking and rutting.
The different types of cracks that can appear in bituminous pavement are slippage, alligator, block, edge, and alligator cracking. Alligator cracking is the most popular type. Fatigue cracking, commonly referred to as "alligator cracking," is a pattern of interconnecting cracks that typically appears on asphalt pavement surfaces. It is known as "alligator cracking" because it is similar it seems to the cracks on an alligator's skin. Alligator cracks are frequently caused by strong traffic loads that continue in the tyre pressure area of asphalt pavement. Inadequate pavement thickness, excessive loading, weakness in the sub-grade or base coarse, or a combination of all or some of the aforementioned issues are the main causes of fatigue cracking[53].
One of the most prevalent issues asphalt pavements have encountered in recent decades is rutting and pavement deformation. Rutting is the term used to describe the continuous deformation that takes place on pavements in the vicinity of the wheel path caused by severe traffic loads[51]. Rutting occurs in regions with high traffic volumes due to the heavy loading that big vehicle tyres impose. The collapse of the asphalt layers and the sub-grade soil under intense strain from traffic loads causes rutting, which normally occurs within a few months after the road's opening. The applied asphlat needs to be sufficiently dense to resist this deformation, which can be accomplished by suitable compaction during construction. Rutting can also result from an improper ingredient combination, such as a high bitumen content, a lot of round aggregate, too much filler, or a thin enough asphalt layer. In a nutshell, inadequate HMA thickness, poor compaction, or weakened pavement layers brought on by moisture infiltration, as well as the use of low-quality materials while creating the asphalt mixture, are the causes of rutting[46, 52].

Applications and Types of Fiber

The incorporation of fibres in HMA enhances engineering qualities, fatigue resistance, rutting resistance, and stiffness, making it a useful substitute for the building of road pavements[54, 55].
Typically, fibres are divided into two categories: organic fibres and mineral fibres. The cellulose and lignite fibres that are used to make paper and textiles are examples of organic fibres. Asbestos, a collection of silicate minerals, is one example of a mineral fibre. Despite being soft and flexible, asbestos fibres are heat, electrical, and chemical corrosion resistant. To make them stronger, they can also be combined with cement, paper, fabrics, and other materials[56]. Since 1983, man-made fibres that are manufactured from raw materials and changed by chemical procedures (such as Rayon, which is regenerated from natural cellulose) have also been developed. These fibres are non-asbestos and semi-synthetic[57]. Synthetic fibres are produced using petrochemicals such as polymers. Nylon (polyamide), polyester, polyurethane, and aromatic polyamides (aramids) are the most popular synthetic fibres[58]. Additionally, some fibres, such as metal fibres, carbon fibre, and fibreglass, are manufactured from particular components (from, aluminium, nickel, iron or copper). Table 1 provides a brief summary of the various fibre types utilised in asphalt pavement as the primary raw material during production. The fibres alter the degree of mixture viscoelasticity by absorbing light bituminous components, which also helps to address the problem of bitumen drain down[73, 74].
Here, the author offers a critique of fibres that are either man-made or mineral. In the next article, a detailed discussion of how natural fibres are used to modify bitumen and asphalt will be provided.
Fibers can be incorporated in bitumen in two ways; wet and dry. While in the dry process, the fibre is blended with the aggregate before bitumen is added to the mixture, in the wet process, the fibre is combined with the asphalt cement before the binder is added. Thus, the dry process is typically preferred over the wet process for the following reasons: the dry process is the most practical to implement through which the fibre can be easily injected and dispersed in the mixture; the dry process does not cause the fibres to melt in the bitumen; and the dry process lessens the possibility of fibres clumping or balling in the asphalt mix. To ensure proper adhesion to the bitumen binder and eliminate any possibility of stripping brought on by moisture, fibre must be dried as much as possible before being added to the mixture[75, 76].
The use of fibres in structural engineering is dependent on three key characteristics: diameter, high flexibility, and high aspect ratio (length to diameter, L/d), which enables a sizeable portion of the load to be transferred from the matrix to the strong and stiff fibre in a composite reinforced with fibre.
The bias in a material's qualities with respect to length, however, is what makes fibrous material so significant. Because of the aforementioned factors, fibre is generally favoured, particularly continuous fibre. The high aspect ratio (length/diameter) of a particular material in a fibrous form makes it very flexible and enables the conversion of fibre into yarn, which may then be knitted, braided, or woven into complex textures with a variety of patterns and shapes. Some materials, like glass, alumina, silicon carbide, etc., are naturally brittle in their bulk. These fibres can be produced to be as flexible as any other organic textile fibre, such as nylon, which is frequently used in the production of women's stockings.

Table 1. Description of the basic materials used in the production of the HMA fibres

Fiber type	Remark
Mineral	The most widely used category of mineral fibres is thought to include asbestos, basalt, and brucite. They can be found in fractures in solid rock and are found deep within the Earth's crust. Silicates[59] are the most often utilised raw materials and can be produced via electrothermal processes[60, 61].
Polyester	One of the most popular synthetic fibres in the textile industry is polyester, which is produced by polymerizing ethylene[62]. Polyester is a thermoplastic polymer and is regarded as a material that can be recycled easily.
Polyacrylonitrile (PAN)	The polymerization of acrylonitrile with a peroxide catalyst results in polyacrylonitrile fibres, often known as PAN fibres[63, 64]. Its application is linked to composite structures for commercial and military aircraft.
Carbon Fiber	Compared to other types of reinforcement fibres, carbon fibres have the highest specific strength, fatigue resistance, and stiffness. They do, however, exhibit some other intriguing qualities, such as high thermal and electrical conductivity[65-67].
Glass	Glass fibre, commonly known as fibreglass, is regarded as a mineral fibre because it is produced using minerals such as fluorspar, dolomite, kaolin clay, limestone, and more[68].
Steel	Steel is produced into small, broken strips called fibres. As part of its manufacturing process, various arrangements and materials including carbon and phosphorous are used[69].
Aramid	High performance man-made fibres are referred to as aramid fibres. The primary use of aramid fibre is the reinforcing of composite materials, and its initial commercial applications date back to the early 1960s. Sporting goods, aircraft, ballistic protection, and structural applications, among others, utilise continuous fibre reinforcement polymers (CFRP) or aramid fibre reinforcement polymers (ARFP)[70, 71].
Coconut	The coconut fruit's outer shell was used to make this all-natural product. Lignin, a sophisticated wood chemical, makes up their walls[72].

Addition of Fiber in Bitumen Binder

In order to increase the rutting resistance, fatigue life, and drain-down of the asphalt pavement in gap-graded mixtures such stone mastic asphalt, stone mastic asphalt (SMA), and OGFC (open graded friction course), fibre is used in road construction. Bituminous pavements are sensitive to rutting and cracking due to temperature variations, such as low temperatures that can cause cracking, medium temperatures that can cause fatigue, and high temperatures that can result in rutting issues. In accordance with these facts, one of the common cures is to alter the composition phase and improve the engineering features of the bituminous mixture by injecting various additives. These additives are mostly made of organic polymers and several other fibre types that have been extensively researched in the literature. Typically, fibres are added to bituminous mixes to improve their engineering qualities by altering the bitumen binder in the mixture[77]. Bitumen is one of the primary components of pavement mixtures and is used to build bituminous pavements because it is very waterproof, resilient, and sticky and is comprised of strong cement. Bitumen is a plastic substance that gives mixes of mineral aggregates a manageable degree of flexibility and comprises asphaltenes, aromatic hydrocarbons, resins, and saturates[36]. Due to the physical absorption function on its surface, fibre easily absorbs the light molecular weighted saturate component. As a result, fibres have drawn a lot of attention among the various bitumen modifiers due to their effective improvement and impact on the rheological properties of bitumen binder and the ideal bitumen content needed for mix design, which considerably contributes to the development of interface bonding interlinking the bitumen and fibre. The optimum fibre content in a mixture is between 0.3% and 0.4%, depending on the type of fibre employed, as confirmed by numerous additional studies and researchers. Additionally, combining more fibres than the appropriate concentration is not cost-effective since too much reinforcement can produce brittle mastic, which could ultimately cause the pavement to degrade quickly. An even, homogeneous dispersion of fibres within a combination is the greatest answer to this issue[78].

Review on different types of Fibers

Asbestos or mineral Fiber

Asbestos is recommended as the one textile mineral fibre that can be found in serpentine rock reins. In the past, non-synthetic fibres like cotton and asbestos fibres were commonly utilised in pavements[46]. Cotton and asbestos fibres were employed in the early attempts to use non-synthetic fibres in pavements, but these materials degraded quickly and were unsuitable for use as long-term reinforcements[79]. Prior to its identification as a health risk, asbestos was also employed[80]. In 1990, Huet et al., presented the findings of a study in which they had examined changes in void contents and hydraulic properties of basic and modified asphalt mixtures deployed on the Nantes fatigue test track in France[81]. In two of the mixes, SBS, a polymer modifier, was employed to change the base mixture, while asbestos, a mineral fibre, was utilised in the third. After 1,100,000 load cycles, both unmodified and SBS-modified mixes showed comparable declines in void content and hydraulic characteristics. Huet came at the opposite conclusion, noting that after the same loading, the mixtures treated with fibres had undergone no reduction in void content; its drainage qualities were nearly unaffected; and rutting was minor.

Polyester Fiber

Polyester and bitumen, two materials, are both made from crude oil[82]. The bituminous mastic needed for hot areas can be made from polyester fibre since it is strong, long-lasting, and strengthened. According to Putman's study on the effects of fibre on SMA, adding polyester fibres to the mixture significantly increases the mixture's toughness beyond what cellulose fibre can accomplish. This shown that polyester fibre had a superior ability to patch up cracks created during the loading phase, increasing the mixture's toughness. Following cellulose fibre in order of stabilising ability to drain down was polyester fibre. Additionally, it showed that the asphalt and polyester fibres formed a stronger bond than cellulose fibres. The mixture including polyester fibre is anticipated to rut less than mixtures containing cellulose fibre, carpet, or tyres[34]. Rock wool, cellulose, and polyester fibres were employed by Chen and Lin in their research and were put into the bitumen mixture[82]. The findings demonstrated that the fibre reinforcement enhanced the bitumen's tensile strength while also fostering a solid bond between the fibres and bitumen. Strong bitumen and fibre adhesion enhances the mixture's capacity to carry loads. The mixture can withstand high temperatures because polyester has a melting point of about 280^0C. Polyester is easily entangled, raising its softening point. The penetration test supported these findings as well. Since polyester fibres form a localised network that increases the OPC in polyester fibre reinforced mixtures, Wu et al.'s investigation into the effects of polyester fibre on the rheological and fatigue characteristics of asphalt shows that increasing polyester fibre content increases the asphalt binder viscosity, particularly in colder conditions[83]. Their research proved that fibre can reduce asphalt fatigue, especially at lower stress levels. According to a study by Xu et al[84], fibres can significantly increase the resistance to flow of asphalt binder, rutting, and dynamic shear modulus. The study also examined the physical characteristics of fibres, their reinforcing effects, and their role in stabilising and reinforcing asphalt binder with polyesters, polyacrylonitrile, lignin, and asbestos. In contrast to asbestos and lignin fibres, polyacrylonitrile and polyester fibres appear to have a considerable network effect, with the resulting effect being amplified by the antenna features. In comparison to asbestos and lignin fibre, polymer fibres absorb and stabilise asphalt less. The fatigue characteristics and dynamic reactivity of fiber-reinforced asphalt mixes were also investigated in a study by Wu et al[83]. Their research suggested that fibre might enhance the property of fatigue. The findings of the fatigue test proved that the mixtures with fibre reinforcement are more fatigue-resistant than the control mixture. This may be due to the fiber's ability to deflect the tension placed on the asphalt mix, preventing cracks from developing later. Polyester fibre is said to be the most ideal fibre that can help increase the resistance of asphalt mixtures to fatigue[86]. In order to reduce rutting and bleeding at high temperatures during the hot season, glass fiber-reinforced asphalt concrete can increase the stability and deformability of the asphalt concrete without increasing the bitumen concentration of Hot Mix Asphalt.

Glass Fiber

Glass fibre has a high breaking strength, a low extension of about 3 to 4 %, and a 100% elastic recovery. Glass fibres do not burn, but at temperatures exceeding 315^0C, they start to lose strength and start to soften at 816^0C [85]. The addition of glass fibres to asphalt mixtures is believed to improve the material's strength and fatigue properties while boosting ductility. Glass fibres may offer an outstanding potential for modifying asphalt due to their high mechanical property. Reinforced bituminous mixtures can be more cost-competitive and cost-effective than modified binders thanks to recent advancements in the production of glass fibre. Glass fiber-reinforced asphalt mixtures can minimise maintenance costs while potentially raising building costs[88]. In order to reduce rutting and bleeding at high temperatures during the hot season, glass fiber-reinforced asphalt concrete can increase the stability and deformability of the asphalt concrete without increasing the bitumen concentration of Hot Mix Asphalt[87]. Among the industrial uses for asphalt are products for roofing and flooring, fillers, battery separators, radiant heat sources, and fire barriers. Glass fibre has a high resistance to deterioration and cracking, which are common in roofing shingles. According to a recent study by Tanzadeh et al., glass fibre treated asphalt of an open-graded friction course reduced permeability, decreased sensitivity to oxidation, and increased tensile strength. Additionally, the open-graded friction course (OGFC) combinations with glass fibre had better moisture sensitivity than those with basalt fibre[89].

Carbon Fiber

When it comes to changing the asphalt binder, carbon fibres are regarded to give more benefits than other fibre kinds. It is believed that because asphalt is a hydrocarbon and the fibres are carbon-based, they are naturally compatible. Due to the high mixing temperatures used during the production of carbon fibres (above 1000^0C), fibre melting is not a significant problem. The tensile strength and other attributes of AC mixes, such as resistance to heat cracking, should increase because to the high tensile strength of carbon fibres. The stiffening effect demonstrated by the addition of other fibres should also be present in carbon fibre modified mixtures, extending the pavements' fatigue life. Therefore, it was assumed that the most compatible and effective fibre type for modifying asphalt binder would be carbon fibres.Pitch or poly acrylonitrile precursors are used to make carbon fibres[90].

Investigations into the effects of carbon fibre on asphalt mixture performance parameters were conducted. In order to achieve this, asphalt mixes contained four different amounts of carbon fibre as an additive: 0%, 0.3%, 0.5%, and 0.7% by weight of bitumen. Indirect tensile stiffness modulus, creep stiffness, indirect tensile strength, and moisture resistance tests were used to examine the mechanical characteristics of created mixed specimens. Tests done on asphalt mixes revealed that the carbon fibre component increased shear stress resistance by 25%, fatigue life by 51% at 40 °C, and permanent deformation resistance by 2.25 times at 60 °C. By making asphalt mixes more resilient and cohesive, it also increased their resistance to being harmed by moisture. According to experimental findings, carbon fibre improved the performance characteristics of asphalt pavement[91].

Polypropylene Fiber

In asphalt concrete, polypropylene fibres were additionally used in the US. A standard for the incorporation of polypropylene fibres in high-performance asphalt concrete has been released by the Ohio State Department of Transportation (ODOT)[92]. In a 1993 study by Yi and Mc Daniel, polypropylene fibres were employed in an effort to lessen reflection cracking in an asphalt overlay. No reduction or delay in reflection cracking was found, despite the fact that crack intensities were lower on the fibre modified overlay areas. It was discovered that using fibres in either the base or binder layers reduced reflection cracking in areas where the pavement had already been cracked and seated prior to the overlay[93].

Researchers Huang and White[94] studied polypropylene fiber-modified asphalt overlays. These combinations were coring sampled, along with others that contained no fibre, and taken to the lab for additional examination. The results of the laboratory testing indicated that the fibre modified mixtures had a small increase in stiffness and had a better fatigue life. The major issue with polypropylene fibres was their inability to mix with hot asphalt binder because of the fiber's low melting point. Additionally, Huang and White noted that additional investigation was required to fully comprehend the viscoelastic characteristics of fiber-modified asphalt mixes.

Asphalt concrete specimens with polypropylene fibres were produced at the ideal bitumen content based on the comprehensive research conducted by Tapkin[95]. In fiber-reinforced specimens, it was found that the Marshall Stability values rose and the flow values fell noticeably. These specimens also had a longer fatigue life. The fiber-reinforced asphalt combination has a long fatigue life, strong rut resistance, and less reflection cracking. A comparative research conducted by Abtahi et al. revealed that Poly Propylene (PP) fibre performance at 0.125 percent by the total weight of mix and 12 mm length was statistically preferable to Styrene-Butadiene-Styrene (SBS). Marshall and Resilient Modulus were among the experiments[96].

According to a recent study by Tapkin et al.[97, 98], the best FRAC samples for Marshall Specifications and Static Creep Properties were found to be PP fibres that were 3 mm long and had a total dosage of 0.3 percent modifying bitumen when applied utilising the wet process.

Cellulose Fiber

Cellulose fibres are one of the important fibres used in concrete and bituminous mixes all over the world. The great tensile strength, rapid accessibility, and high elasticity modulus of wood fibre are some of its benefits. Asphalt can thicken more due to cellulose fibre, which also reduces binder leakage. After the injection of cellulose fibre, no appreciable changes in abrasion or void content were found. Drain-down tests revealed that all binder mixes with fibre reinforcement drained much less than controls or mixes with polymer reinforcement[1]. In another study on SMA, cellulose fibre was employed. The trials tested the static creep modulus, moisture susceptibility (tensile strength ratio), and binder drain-down in addition to recovery efficiency. Mixtures containing both conventional and polymer-modified binders were injected with fibre. Results pertaining to binder drain-down revealed appreciable advancements in all mixes reinforced with cellulose fibre. High indirect tensile strength was demonstrated by both unmodified and fiber-modified mixes. Damage was induced in all of the investigated mixes as a result of the tensile strength ratio. However, statistical and variable analyses suggest that efficiency and creep modulus are better fibre reinforced mixes and plain binders than those reinforced with fibre and polymer[99]. The mixture modified with fibre showed lower tensile strength and resistance to humidity than a polymer modified one. Researchers looked into the effects of fibre, especially cellulose fibre, and polymer modifiers in SMA[9, 89, 100]. According to their findings, fibre modified mixes significantly reduced permeability but exhibited no improvement in the manufactured samples' strength characteristics.

In conclusion, the use of fibre in asphalt modification is substantial and has a clear impact on creating a modifier binder in an eco-friendly manner. Waste fibre, cellulose, glass fibres, and synthetic polymer are examples of fibres that are encouraged for use in asphalt pavement mixtures[101, 102]. According to several studies[103-105], fiber-reinforced asphalt mixtures generally outperformed control mixtures in terms of resisting thermal cracking and preventing permanent deformation. They also occasionally outperformed control mixtures in terms of fatigue performance. The fibre blend would also be more resistant to thermal cracking, with strength 1.5 times larger than the control, according to the results of indirect tensile testing at low temperatures (0^0C, -10^0C, and -20^0C). The fibre combination also showed increased fracture energy, which is associated with less thermal cracking[106, 107].

Conclusions

The results show that adding fibres can effectively increase the resistance to flow and rutting and dynamic shear modulus of asphalt binder. The network impact of polyester and polyacrylonitrile appears to be stronger than that of asbestos, and the antenna property of lignin strengthens this effect even more. In contrast to asbestos and lignin fibres, polyacrylonitrile and polyester fibres appear to have a considerable network effect, with the resulting effect being amplified by the antenna features. On the other hand, glass fibre has great insulating qualities, a high tensile strength, and is very resistant to thermal and chemical changes. Glass fibre is remarkably resilient to deterioration and cracking, which are typical of roofing shingles. The results demonstrated the importance of the role of polymer in the beneficial modification of the mixture samples, as the mixture reinforced with cellulose did not significantly improve in the low temperature performance despite having a higher resistance to cracking than the polymer modified mixture. In order to determine the impacts of fibre content and type on SMA rutting performance, cellulose fibre and mineral were added to the specimen. The results showed that the fibre content and type can change how the SMA ruts. The combination supplemented with cellulose fibre has a higher maximum bitumen content and indirect tensile strength.

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