MANTECH Publications

Journal of Transportation Engineering and Its Applications
Volume 7, Issue 2, May-August, 2022

The Impact of Fiber Additives on the Physical Properties of Pavements

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Abstract

The transportation network is a significant aspect in determining a country's success. Pavement is a fundamental component of transportation. Pavements are in poor condition in most nations, particularly in India. This is mostly due to inadequate road maintenance, the use of low-quality materials, and other factors. Potholes form on a pavement when it loses its capacity to convey traffic weight to the subgrade. The transportation industry is constantly expanding. This results in a significant rise in the number of cars, which increases traffic congestion. Existing pavements are incapable of bearing this increased strain. The traditional materials utilised in pavement construction are unable to withstand the heavy traffic load. It signifies that there is a need to increase the strength, quality, and other characteristics of the pavement mix. The inclusion of fibres is one of the simplest and most efficient ways to accomplish this. The fibres enhance the mechanical, rheological, and volumetric qualities of the mixtures. Some obvious benefits are increased fracture resistance, durability, adhesion, and flexibility. This research examines how the characteristics of pavement mixes change when they are amended with synthetic fibres, natural fibres, and mineral fibres. Changes in pavement mix parameters such as Marshall stability, flow value, indirect tensile strength, Marshall quotient, VMA (voids in mineral aggregate), VFA (voids filled with asphalt), drain down values, and so on have been investigated. Mixtures containing fibres provide improved impact resistance, a

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reduction in traffic abrasiveness, and a delay in the initiation and propagation of fractures.

Keywords: *Mineral fiber, Physical Properties, Pavements, Synthetic fibers, Natural fibers*

INTRODUCTION

The majority of the roads in our towns and cities are uneven and in poor condition. There are ups and downs on roadways, especially in village areas, which cause accidents at night. The government is not concerned with constructing or repairing decent roads. The state of the city's roadways is similarly deplorable. The roads are not adequately tarred, and the prevalence of alligator cracking, rutting, delamination shear failures, bleeding, and other defects indicate a lack of mobility.

There is widespread concern that streets and roads in many towns and cities are not properly maintained. Both the citizens and the government share responsibilities for keeping the roads in excellent shape. Pavement defects arise when it loses its capacity to convey traffic loads to the subgrade. Pavement's durability will deteriorate over time. We all know that the number of automobiles on the road is rapidly rising. Pavements built prior to a few years ago may be unable to withstand the increased weight. As a result of the inability to sustain axle stress, cracks will begin to emerge on the road surfaces.

There may be potholes in the centre of the road where water may be stagnant, and a car travelling straight may abruptly shift its direction to escape the pothole. The car in front may crash with the back end of the vehicle in front, resulting in an accident. Good roads must be created to provide the safe and enjoyable movement of vehicles on the road. Roads that are damaged or badly maintained jeopardise the lives of vehicle users.

These sorts of roads also diminish the degree of service, causing motorist discomfort. However, if the time between maintenance periods is particularly short, it indicates that cracks are growing on the road at a rapid pace. Consider the following two road segments. After one year of building, cracks occur on the first road. After one year, maintenance should be performed. However, fissures occur on the second road portion within a year after its construction.

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It signifies that distresses are forming at a quicker pace on the second road stretch. As a result, the time between maintenance intervals is shorter. It is possible that this is related to the low quality of materials employed in the building of the second road portion. So, if we can build the pavements with high-quality materials, we can eliminate most of the faults and postpone the creation of cracks. This will assist to boost pavement durability.

Basic raw materials used for the preparation of bituminous mix are bitumen, aggregate, filler. The selection of materials and the proportion of each material greatly affect the pavement properties. The pavement mix properties like Marshall stability, flow value, moisture resistance, indirect tensile strength, durability ,etc are influenced by the proportion of raw materials added to the mix. But, the conventional type of pavement mix made using aggregate, binder and filler are ineffective to resist the increasing traffic load. It indicates, the need to introduce some materials which help to increase the properties of conventional pavement materials. One of the widely accepted materials to improve the characteristics of pavement raw materials is fibers.

The main components in the fiber-modified mixtures are matrix and fibers. The content and length of fibers, physical properties of fibers and adhesion between fibers and matrix are some of the factors affecting performance of the mixtures. The flexibility and tensile strength of pavement mixes have improved due to introduction of fibers in pavement mixes. The Fiber mixture is harder than the original bitumen mixes. Adding fiber to bitumen reduces softening point, crack propagation and moisture absorption. Fiber addition reduces bitumen drainage that reduces the bitumen content and increases the slippery resistance of mix.

The fibers increase the bitumen cover on aggregate which causes hardening of bitumen and improving the bitumen properties. The Use of fiber in concrete mixes required for rigid pavements reduce cost of construction, as they can be used as reinforcement, replacing the traditional and energy-consuming methods of wire mesh and steel reinforcement. Labor cost, build cost, maintenance cost, and time of construction can be lowered by incorporating fibers. Energy can be saved since the quantity of fiber used is significantly less than the volume of raw material required for traditional reinforcement of roads.

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Fibers can be mainly divided into three categories: Mineral fibers, Natural fibers and Synthetic fibers. These fibers have advantages and disadvantages. This paper deals with the changes in pavement strength which is caused by each type of fiber. Type of fiber should be chosen carefully by considering both merits and demerits causing by the fiber in the pavement mix.

MINERAL FIBERS

These are naturally occurring fibers such as carbon or manufactured mineral fiber. Mineral fibers can be manufactured by melting minerals then forming fibers by spinning or extruding. Slag or mixture of slag and rock, basalt, brucite, steel, carbon etc. can be used to create mineral fibers. Electrically conductive asphalt which can be used to heal micro-cracks can be produced by carbon and steel fibers. The First type of mineral fibers used in asphalt mix was asbestos fiber. Negative environmental impacts evolved by this fiber created restrictions to use the fiber.

An experimental study is carried out by K.Karthik et al.,[13] on the conventional bituminous mix and carbon fiber modified bituminous mix. Optimum fiber content, optimum binder content were found out by the Marshall method. Carbon fiber content was 0.5% to2.5% by weight of the binder. Lime of specific gravity 2.3 was used as filler. The Bitumen grade used was 60/70. Samples of different contents of binder without fiber and samples of different contents of fiber were prepared and tests were conducted on the samples. It was observed that the addition of fiber affects the characteristics of bituminous mixtures by increasing their stability, stiffness and voids and decreasing the flow value. Compared to mix without fiber, carbon fiber modified samples gave better results in terms of stability.

The effect of carbon fiber on the performance of asphalt mix was investigated by Tacettin Geckilet al.,(2018). Different percentages of carbon fiber were sadded in asphalt mixtures. Marshall stability values increased with an increase in carbon content and flow values decreased with an increase in carbon content. Carbon fiber improved the resistance of mixtures against shear stresses and permanent deformations. The indirect tensile strength ratio increased with an increase in carbon content. It implies that moisture resistance can be increased by adding carbon fiber. Cohesion ability of mixture was also increased, so that durability of the mixture will be high. The cold service temperature

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behavior of carbon fiber modified bitumen was studied by Cleven,(2000). The high tensile strength of the carbon fiber is the main reason behind this property.

The effect of glass fiber on asphalt mix was analyzed by M.S.Eisa et al.,(2020). Five hot mix asphalt specimens with different percentage (0.25%, 0.5%, 0.755 and 1%) were prepared. The addition process resulted in the reduction of flow value and the increase in stability of the mix samples. They determined that high angularity glass particles have higher internal friction and better interlocking between particles. This reduces final tensile stress in asphalt mixes due to applied loads and prevents initial cracking and crack propagation in the mixes. Erhan Burak Pancaretal [7] found that the addition of glass in concrete pavement reduces temperature gradient.

Rigid pavements constructed with concrete mixes containing glass particles show low-temperature differences between top and bottom surfaces. The outcomes of research conducted by Nejad et al,(2014); help to evaluate the mechanical property of carbon fiber in improving the strength of the mix. Steel fiber shows better results for composite pavement. Abdul Ahadetal., (2015); have described the benefits of using steel fiber in the composite pavement. Steel fibers prevent micro cracks. Fibers bridge across cracks where it develops and prevents widening into majorcracks.

So, steel fibers impart post-cracking ductility. Toughness, shear resistance, tensile strength can be increased by introducing steel fibers in pavement mix.

The fibers hold the matrix together even after cracking. Toughness imparting by steel fibers depends upon aspect ratio of the fibers used. Based on the type of corrugations and end hooks of fiber, these can be classified into straight, hooked, crimped, double duo form, ordinary duo form, paddled, enlarged end forms, irregular, and intended fiber. At cracks, hooked end of steel fiber remains solidly anchored on each side of cracks. Traffic loads acting on the road distributes to the entire length of the road section which will be absorbed by the steel fibers.

SYNTHETIC FIBERS

Mainly the process adopted to produce synthetic fibers is polymerization. It is a process of combining monomers to make a long chain or polymer. The main motive to use synthetic fibers in pavement mix is to reduce plastic wastes which have become

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one of the major environmental pollutions all over the world.

The studies conducted by Hasan Taherkani et al.,(2016); using nylon fiber in asphalt concrete indicates the suitability of synthetic fibers to be used as an additive in pavement mix. Indirect tensile strength of mix increases with increase in nylon fiber content, which implies high moisture resistance of mix. But this increased moisture resistance decreases when fiber length increases.

Even if nylon fibers increase the stability, moisture resistance etc increased fiber content may increase the flow value of the mix. Air voids in the mix increase due to the addition of nylon fibers. These increased air voids give easy passage for the moisture through the pavement and also increase softening behavior of the mix.

Manoj Shukla et al [14]; have examined the properties of polyester fiber-modified asphalt mixtures. According to the test results analyzed by them, polyester fibers give rise to the production of mixtures having high crack resistance. These fibers form three-dimensional networks in the mix. Polyester fibers show lipophilicity, which is the reason for the absorption of hydrocarbons, aromatic hydrocarbons by the fibers present in the asphalt mix. The three-dimensional structure holds aggregate particles together.

Polyester fibers present around the aggregate will absorb the bitumen. This causes the thickening of bitumen film forming around each aggregate particle. The importance of optimum polyester fiber content can be recognized by the studies conducted by Jin rong Wu et al [10]. These fibers impart good qualities in pavement mixtures up to a particular fiber content. If the fiber content increases beyond this particular amount, it causes negative effects on pavement properties. One of the reasons behind this is high sticking effect of polyester fiber compared to other fibers. The sticking effect of polyester fibers is high. Because of the sticking effects the fibersstick to each other and enlarge in size to form fiber balls.

These agglomerations of fibers reduce contact between particles in the mixture which leads to increased air voids, decrease in tensile strength, flexural stiffness modulus. But, Tons et al., (1960) stated that metal wires would rust easily if water penetration occurs in the pavement. Serkan Tapkin[19] states that asphalt mixtures modified with polypropylene

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fibers exhibit good resistance to rutting, crack resistance and durability.

According to the results concluded by Serkan Tapkin [19] polypropylene fiber provides a positive contribution to the asphalt mix properties. Disha Rajyaguru et al.,(2016); examined changes in mix properties due to polypropylene fiber. The increase in the fiber content resulted in increased stability, and air voids. At the same time, the polypropylene fiber content caused a reduction in flow values. Polypropylene fibers are useful for hot regions where bleeding and flushing are critical distresses due to the property that, the fibers increase the air voids in mix. Extensive analysis carried out by Spanish center of research CEDEX (2003), on bituminous mixtures prepared with acrylic fibers, concluded that these fibers in bituminous mixtures reduce the thermal susceptibility, increase the resistance to permanent deformations and to fatigue cracking. Rowlett et al., (1985); evaluated the behavior of bituminous mixtures in road overlays using glass fibers together with polymer-modified bitumen to minimize the propagation of cracks.

It is found that, the combination of glass and polymer fibers can be used to reduce the scaling of deteriorated cracks before the construction of a new overlay due to the property that polymer fiber protects the strengthening material (glass fiber).

NATURAL FIBERS

Coconut, sisal, palm, jute, straw, bamboo, cane etc. are some of the natural fibers. Natural fibers are readily available and abundant. The energy required to produce these fibers is very less. The fibers can be extracted from waste material. So, these fibers are economical and low in cost. There is no environmental impact. The main disadvantage of natural fibersis, they may degrade by natural means over time, so durability is less.

Sigit Pranowo Hadiwardoyo [20] investigated the effect of coir fiber in pavement mixtures. Coir fiber reduced ductility and penetration grade of bitumen but increased the softening point. The length of coir fiber is a factor that affects the mixing process of ingredients of the mixture. Shorter coir fibers are suitable to facilitate the mixing process. These fibers

do not burn in the asphalt mixing process. The evaluation is done by Ahmed Aljubory [2] by using palm fibers on asphalt mixtures indicates the influence of natural fibers on tensile and volumetric properties of asphalt mixture. Density and

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voids filled with asphalt (VFA) increase while voids in mineral aggregate (VMA) decrease with the increase in palm fiber content. The cracking resistance of mixtures will be high when reinforced with palm fiber, due to the increased indirect tensile strength.

Sisal fibers are naturally and locally available fiber which is obtained from leaf skin after removal of the pulp. Amit Kundal et al [3] observed that after adding sisal fiber to the bituminous mixture the stability of mix increased, but when sisal fiber content was added more the stability decreased. The addition of these fibers more than optimum fiber content, reduces stability and increase the flow and air voids. Modification of asphalt mixture with jute fibers and synthetic fibers was studied by Kumar et al [16]. Mixtures prepared with jute fiber showed a higher creep modulus than synthetic fibers mixtures. Yang et al.,[22] investigated the resistance to deformation of cellulose and polyester fibers modified bitumen. Polyester fibers showed better results than cellulose fibers to resist rutting. Muniandy et al [17] used cellulose fiber extracted from oil palm bunch to study the influence of natural fibers on the rheological performance of asphalt binders. The tests have shown the base binder (PG64-22) could be upgraded to PG70-22 grade and also the fatigue performance of the asphalt mixture had increased.

Saswat Biswapriya Dash et al., (2015); tried to use sisal fiber and coal ash to improve the properties of dense graded bituminous mixes. They used coal ash as fine aggregate and sisal fiber as additive. Samples with varying content and length of sisal fibers were tested. Samples with higher fiber content and length showed high Marshall quotient and air void and flow values. The samples also had better thermal cracking resistance.

Another research conducted by Muniandy et al [17]; dealt withthe advantage of date empty fruit bunch and oil palm trees to generate cellulose fiber to be used as additives in bitumen. The outcomes showed that the used fibers bettered the rheological properties of asphalt mastic by increasing the PG grading two steps from PG58 to be PG70 at 0.3% oil palm cellulose fiber concentration. The use of cellulose fiber in asphalt mix increases viscosity and softening point values and reduce penetration value.

Brown et al.,(1990) concluded from their researches that, the tensile strength of some fibers is more thanthat of bituminous

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mixtures. This feature can be utilized to improve the tensile strength and cohesive property of mixes. Their search of Bushing et al.,(1968) proved that cotton fibers could not act as long-term reinforcement due to the faster degradation of these fibers. Most of the studies recommend the use of natural fibers as an additive in mixes, since they are eco- friendly and cost-effective.

According to Fitzgerald (2000); the excellent mechanical properties of fibers enhance fatigue life and material strength of mixes, but ductility may be increased. Maurer et al., (1989) recommended fibers as the best crack barrier. The main function of reinforcing elements used in conventional rigid pavements is to resist crack propagation and distribute tensile loads. The laying processes and transportation of reinforcement bars make labor costs higher. Fibers can also resist crack propagation and impart post-cracking features to the pavement. Unlike reinforcing bars, fibers need not be placed.

The fibers can be added easily to the mix during the mixing process. So, the introduction of fibers helps to reduce the cost and efforts of labors.

The results found by Goel et al [3] support the concept that, fibers are good to increase the life of pavements by lowering reflection cracking, bleeding ,and aging. Many studies reveal that the fibers can form three-dimensional networks in the mix and hold the constituents together. These networks form thick coats on the surface of aggregates and reduce drain down and bleeding. Optimum fiber content and length of fibers have a great influence on the strength properties of the mixes.

CONCLUSION

- Including fibre in the pavement mix is an excellent technique to eliminate low durability and distresses that arise in typical bituminous pavements. Fibers in the pavement mix can enhance both flexible and stiff pavements. Each type of fibre has advantages and disadvantages.

- A significant benefit of natural fibres is that they are both environmentally benign and plentiful. Natural fibres need less energy to create and extract. In any case, these fibres do not pollute the environment. The biggest disadvantage is the incompatibility between the fibre with the matrix.

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- Ligno-cellulosic fibres absorb a lot of moisture, which causes dimensional changes in the fibre modified mix. This reduces the adhesive qualities. Natural fibres have the potential to deteriorate over time.

- Using synthetic fibres in asphalt blends produced superior pavement mixes. The primary motivation for using synthetic fibres in mix preparation is to reduce plastic waste.

- Some major drawbacks include high initial costs, negative environmental repercussions, and the need for a considerable amount of energy to make synthetic fibres. Mineral fibres are also commonly employed in mix design.

- Mineral fibres, such as steel fibres, produce abrasive mixtures, making mixing difficult. Some mineral fibres' manufacturing processes have an environmental impact.

- The overall impact of fibre addition is good. The presence of fibres in the pavement allows it to withstand increased stresses, fracture propagation, and moisture absorption.

- The stability, indirect tensile strength, fatigue life, Marshall quotient and rheological properties can be improved by the use of fibers. As a result, fibre modified pavement mixes aid in the development of very durable, efficient, and cost-effective pavements.

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