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Fiber Reinforced Concrete (FRC) as Composite Material in Pavement

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Abstract

Conventional bituminous pavements are extensively utilized across India, yet they face challenges such as limited impact resistance, low tensile strength, and brittleness compared to concrete alternatives. Despite concrete's superior strength and durability, it exhibits deficiencies in ductility, fatigue resistance, and ability to withstand substantial deformations. This research delves into the feasibility of fiber-reinforced concrete as a composite material for pavements, with a primary goal of extending the service life of concrete infrastructure. FRC integrates fibers into the concrete matrix to bolster its tensile strength, crack resistance, and overall performance under varying loads. The study examines the performance of FRC pavements, highlighting critical obstacles and the behavior of this composite material across different loading conditions. Experimental results evaluate the viability of employing FRC in a novel pavement restoration method. Furthermore, the research investigates the relationship between the ability of concrete specimens to retain frozen solutions within their pores and the resultant damage levels. The importance of extended durability testing under real-world conditions is underscored as pivotal for enhancing infrastructure robustness and achieving reliable service life predictions. By addressing the limitations of conventional materials through innovative use of FRC, this study aims to contribute valuable insights towards sustainable and resilient pavement solutions in India's infrastructure landscape.

Keywords: Composite Material, Fiber Reinforced, Concrete, Infrastructure, Pavement.

INTRODUCTION

Portland cement concrete makes up concrete pavements, also referred to as stiff pavements. The layered surface that cars drive on is called a pavement. It has two functions: it relieves pressure on the underlying soils and gives cars a sturdy and comfortable surface. The classic bituminous pavement technology is extensively utilized in India. Because concrete had some shortcomings, such as poor impact strength, low workable strength, brittleness, and low ductility, as well as a limited fatigue life and the inability to accommodate massive deformations. When failure is started, cement concrete exhibits brittle failure, which is the almost total loss of loading capability. The bituminous pavement would be a thing of the past in two to three decades and would need routine upkeep. It is now imperative to consider an alternative material that meets the necessary specifications. In order to strengthen the concrete mixture's toughness—that its capacity to withstand the formation of cracked micro-fibers, similar to those found in conventional composite materials, have been added more recently. FRC is concrete made of Portland cement and reinforced by fibers that are arranged somewhat randomly. When concrete is mixed with FRC, hundreds of tiny fiber is randomly incorporated into the mixtures,

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improving the concrete's qualities in every direction. When the structure experiences a peak tensile load and is unable to sustain more stress or deformation, the simple concrete structure fractures into two parts. The fiber-reinforced concrete structure can withstand loads up to very big deformations and cracks at the same peak tensile load without separating. FRC meets two of the most important pavement material criteria in India: lower pollution and economy. It also offers a number of other benefits, including a longer lifespan, less maintenance costs, fuel efficiency, and improved ride quality, a higher load bearing capacity, and water resistance over flexible pavements. Polymeric fibers are becoming more and more well-liked due to their cost-effectiveness and corrosion-free nature. Three types of polymeric fibers are frequently utilized: polyester, polypropylene, and Recron. As fiber reinforcements, a variety of recycled fibers can be employed, including plastic, tires that have been disposed of, carpet trash, textile industry waste, etc. Somewhat stable layer built above the natural dirt that distributes wheel weight appropriately and supports the wearing surface is known as pavement. Depending on how weights are transferred to the foundation earth, pavements have historically been classified as either flexible or stiff. Because the load is dispersed over a relatively short area, flexible pavements have a gradual stiffness rise from the foundation soil to the wearing route. This causes considerable soil stress. Conversely, because the road base is more rigid than the soil, there are less strains on the soil in rigid pavements. The primary benefits of Portland Cement Concrete pavement is strong and can maintain the necessary shape. The rate of pavement deterioration determines the serviceability and durability of concrete pavement constructions. One way to think of cracks in concrete pavements is as a tensile failure. When the pavement experiences higher tensile pressures than the concrete's bending strength, cracks start to appear at various places in the pavement. The PCC is a brittle material with a lower induced strain at failure as well as a lower tensile or bending strength. Steel reinforcement, or bars, are added to the concrete constructions to address this issue. Fiber reinforced concrete's primary effect is to delay and regulate tensile cracking. Because it has less thickness, requires less work and money to maintain, and has a longer service life, fiber-reinforced concrete has a substantial impact on pavement construction costs. An Asphalt pavement has a similar life cycle. Modifying the cracking process is the primary goal of adding steel fiber to concrete floors. After revision, the static and dynamic qualities of the cracking system are improved, along with its performance under different load scenarios. The usage of discontinuous, randomly oriented, discrete fibers have advanced during earlier studies to address these shortcomings. This is referred to as fiber-reinforced concrete. Due to severe shear and tensile stresses caused by constant, heavy traffic loading, asphalt concrete (AC) pavement resilience is frequently destroyed. Because of these bad road conditions, road authorities and practitioners in Thailand are looking for better and alternative pavement materials as a remedy. In order to prevent the premature deterioration of AC pavements, Hot Mix Asphalt (HMA) pavements can be improved by adding modifiers, such fibers, polymers, and synthetic/crumb rubber, as well as by using higher asphalt concentrations. It was discovered that fiber reinforcements improved the performance of AC pavements. In order to enhance AC pavement, the author added natural asbestos fibers to asphalt mixtures. It was shown that the fibers enhanced the breaking capabilities at low temperatures. Fiber-modified portion was said to have good resistance to both transverse and longitudinal cracking. After roughly 4 years of use, rutting/cracking was found to be less common in all sections. Because of this, rigid pavement was created as an alternative to flexible pavement for use on roads with high traffic volumes and harsh exposure conditions. The components of a rigid pavement are a cement concrete slab, also known as concrete pavement. Therefore, the capacity of a concrete structure to tolerate these exposure circumstances without requiring significant maintenance or rehabilitation determines how durable it is. It had long been accepted, concrete is an innately strong materials that requires little to no maintenance over many decades or even centuries.

FRC is a unique kind of concrete in which fiber is mixed into the mixtures to increase the concrete resistance to tensile loads. There have been uses for fibers having a variety of cross sections, including flat, round, rectangular, etc. Good tensile strength, ductility, and fatigue resistance are just a few of the many benefits that have made fiber reinforced composites (FRCs) popular for usage in a variety of

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applications, such as impact-resistant buildings, industrial floors, tunnel linings, slope stabilization, and pavements. When FRC is used properly, it can make a structural element more resilient and long-lasting, which lowers the part's environmental effect over the course of its lifetime. FRC's great toughness and impact resistance make it less prone to damage during handling and transportation, which makes it a potentially useful material for the precast sector.

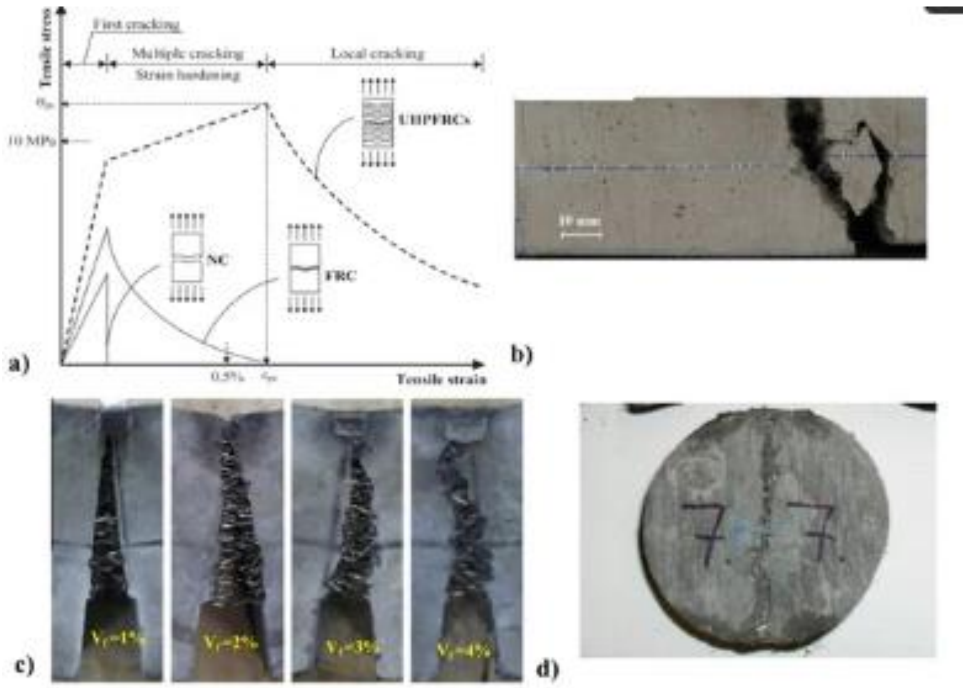

Figure 1. Depicts the advantages of fiber-based concrete (a) A comparison of the tensile stress and strain of various concrete types (b) SHCC cracks (c) the opening of the crack mouth in notched beams for varying volumes of steel fibers and (d) FRC damaged in a splitting tests [1]

LITERATURE REVIEW

Suvash Chandra Paul et al. [1] said that the performance of FRC in relation to the longevity of concrete infrastructures is reviewed in this article's literature study. Concrete infrastructure is considered durable if it can maintain consistent levels of serviceability and structural integrity for the course of its design service life, even under extreme environmental conditions, without requiring significant maintenance intervention. Because of its comparatively low tensile strength and ductility, conventional concrete is prone to cracking. It is thought that paths for gasses, liquids, and harmful solutes to enter the concrete through cracks cause the concrete or reinforcing steel to deteriorate more quickly. It has been demonstrated that adding steel or non-metallic fibers appropriately can improve the tensile strength and ductility of FRC. Numerous researchers have looked into using FRC to increase durability. The proof is based on documented controlled laboratory experiments as well as the observed functionality of real FRC-built infrastructure. The goal of the paper is to assist design engineers in more confidently and effectively contemplating the usage of FRC in actual concrete infrastructures.

Milind Mohod [2] proposed that without question, road transport is the backbone of the country; hence its improvement is vitally important. Due to their longer service lives, lower maintenance needs, and smoother riding surfaces, cement concrete pavements have been increasingly popular in India in recent years. This document provides an extensive overview of research on FRC pavement with steel, glass, hybrid, and polypropylene fibers. Concrete pavements reinforced with polymer fibers are more effective than regular cement concrete pavements. There is also discussion of a number of problems and the behavior of fiber-reinforced concrete in pavements.

Majid Khan et al. [3] proposed that Concrete is the material used in building projects the most commonly in the civil infrastructure industry. Concrete's use has been limited because of a number of drawbacks, including as brittleness, low durability, inadequate tensile strength, and sensitivity at crack openings and propagations. In order to improve the qualities of concrete, researchers have added a range of artificial and natural fibers to the material. The necessity for concrete exhibiting high strength and fracture resistance led to the development of FRC. This study examines how the presence of fibers affects concrete's functionality. Additionally, adding fibers lessens the likelihood of concrete shrinkage cracks. Nevertheless, adding fibers to a concrete has several drawbacks, such as poor workability.

Hadeel et al. [4] said that the behavior of various components or materials under applied loading is a factor in soil-structure interaction problems. Both the concrete and the soil will distort when a concrete pavement is lying on soil that is subject to traffic loads. Portland cement concrete is used to make rigid pavements (PCC). It accomplishes two goals: it keeps the pavement sturdy and makes driving comfortable for cars. Reducing the loads on the subbase and subgrade pavement layers beneath the surface is the second goal. It is believed that concrete cannot withstand tensile strains well. Therefore, a rigid pavement easily cracks when low tensile forces are applied. Using various types of fiber reinforcement in concrete pavement could be a useful way to enhance these qualities. The concrete pavement has a variety of fiber types that function in place of traditional reinforcing. Fibers are added when the concrete is still fresh, during mixing. This study presents a thorough examination of the types of distresses that can occur in concrete (stiff) pavement and discusses the effects of adding various fiber types to the concrete to improve its capacity to stop or even slow down the failure process.

Mishutin A. et al. [5] said that using experimental planning and statistical modeling, the complicated effects of cement content, polypropylene fiber, and polycarboxylate superplasticizer on the characteristics of concrete for rigid pavement were ascertained. S1 was the fluidity of every mixture. Concrete with a reasonable amount of fiber and superplasticizer had a minimum cement content of 350 kg/m3, but it still had a minimum compressive strength of 65 MPa, a minimum flexural strength of 6 MPa. These kinds of qualities allow concrete to be utilized for any kind of highway. Concrete's great resistance to frost and low abrasion capability give it the longevity required for stiff pavement.

Fady M. A. et al. [6] proposed that because of its longevity, low maintenance requirements, and durability, rigid pavement—also known as concrete pavement or rigid pavement—has gained popularity as an alternative to flexible pavement, or asphalt pavement, on freeways and highways where heavy vehicles are frequently driven. Creating a novel reducing the necessary thickness of concrete pavement and improving the performance of the concrete mixture were crucial concerns in the design of rigid pavements to lower the high cost of construction. Using precise proportions of steel fibers and steel slag, a new concrete mixture was created in this study.

Thaworn et al. [7] said that the laboratory and field performance as well as the cost analysis of “Fiber-Reinforced Asphalt Concrete (FR-AC)” pavement employing “Polymer Modified Asphalt (PMA)” and AC60/70 as binders are included in this paper. Field tests of PMA and AC60/70 combinations were conducted with and without fibers, and the mixtures' rutting, texture depth, and the International Roughness Index were tracked over time. The PMA + Fiber combination performed the best out of all the materials evaluated. Due to the identical FR-AC performance for both the plant mixed samples and the testing specimens, the field performance may be evaluated using the laboratory mix design data. The fiber-reinforced AC60/70 combination was found to be the most economical. The results of the study may be used as a guide to create FR-AC pavement requirements in Thailand as well as other countries that have similar mix patterns.

Ashish [8] said that in light of traffic and environmental loadings, this study proposes a new technology that allows advanced fiber-reinforced concrete to be used in streets, roads, highways, bridges, and airfields. This material can postpone or avoid the deterioration of transportation

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infrastructure. The main issue with plain concrete is that loading and weather can significantly shorten its service life. It eventually needs to be replaced and needs regular repairs, which uses additional natural resources. Because of its damage tolerance and dense microstructure, ultra-high-performance FRC (UHP-FRC) significantly improves the sustainability of concrete structures. The goal of this research is to provide UHP-FRC material for pavements repairing that are simply cast on-site without the need for specific treatment, in a timely and sustainable manner. This expedites the usage of UHP-FRC materials and prevents significant modifications to the way concrete is currently produced. The new pavement restoration procedure is feasible, as demonstrated by the experimental findings.

DISCUSSION

One of the building materials that is used extensively worldwide is concrete. Rigid pavement is an essential use of concrete in the transportation sector because it is more resilient than asphalt pavement, needing less upkeep during its longer lifespan. One of the main components in the design of a concrete pavement is its flexural strength, which is reduced in conventional concrete due to the breakdown of the paste-aggregate bond. As a result, improvements in flexural strength can be utilized to decrease the necessary pavement thickness and improve performance sections.[9,10] It has shown to be a dependable building material with better performance effects when added to concrete. The development of a more firm pavement depends heavily on all of these acquired benefits. +e type, size, aspect ratio, and volume percentage of fibers are among the factors that determine how effective it is to improve these parameters. Steel slag, a waste product from steel manufacturing facilities, is another substance that is utilized to improve some aspects of concrete. [11,12]

Significant progress has been made in the area of steel fiber reinforced concrete pavement. Additionally, it has been reported that some researchers have reinforced concrete fibers using recycled steel tire-cord wire. Additionally, steel fiber reinforced concrete was used to address pavement fatigue issues. The use of "glass fiber-reinforced polymers (GFRP)" as load transfer devices has been the subject of certain research presentations. Flexural tests were performed on all mixture samples at 7 and 28 days, and the results were noted. According to the findings of the slump tests, the reference concrete mixture which had no slag or fibers—obtained the maximum slump value, measuring 190 mm. The mixture with 2.0% fibers had a minimum slump value of 2 mm, as seen in figure 2. Every concrete mixture showed a reduction in slump values when 20% steel slag was added. ACI 211.1-91 states that the least allowable slump value for concrete pavement is 24 mm [13,14]. Figure 3 illustrates that the maximum flexural strength of 1.5% steel fiber with a value of 9.7 MPa was attained.

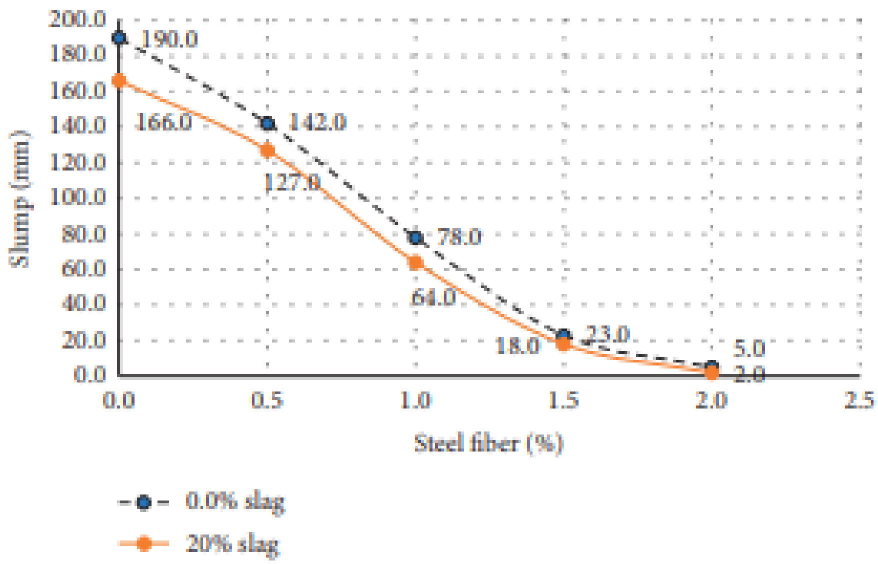

Figure 2. Slump findings with 0% and 20% slag at various fiber concentrations [6].

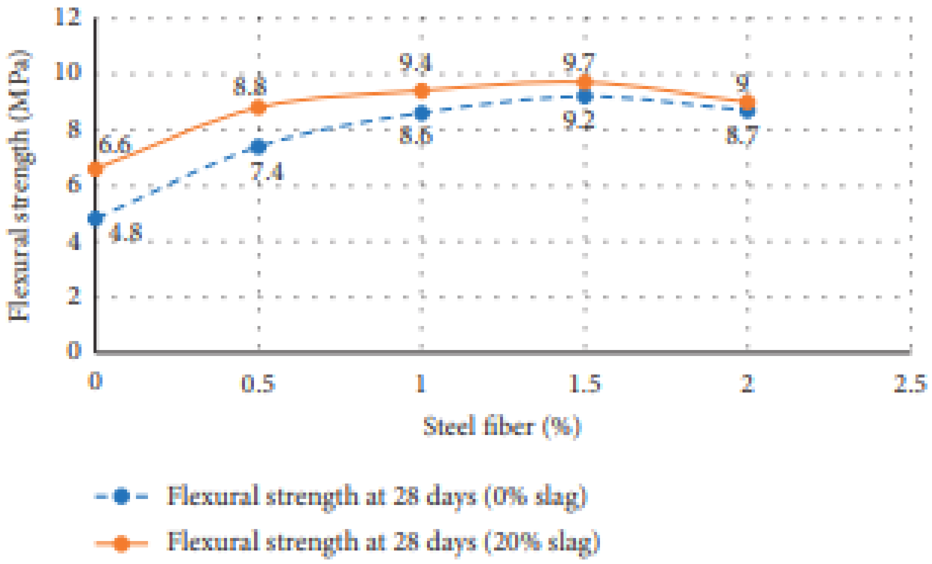

Figure 3. Flexural test results at varying fiber concentration using 0% and 20% slag [6].

As the amount of steel fiber in the FRC sample rose, the weight loss decreased. It was also discovered that the w/c affected the specimens' weight loss. It was discovered that the FRC specimens with lower w/c (0.26) had an ultimate freeze-thaw cycle of 1900, whereas the specimens with w/c of 0.32 and 0.44 only sustained 780 and 260 cycles, respectively, before being removed from the testing chamber. In contrast to greater w/c, even the mass loss was much smaller at low w/c. Compared to the control specimen, the FRC specimens showed a slower drop in dynamic modulus of elasticity. The capacity of the concrete specimens to hold the larger amount of frozen solution in the pores determines the extent of damage. [15,16] Further recent approaches on drying of natural rubber materials[17]incorporation of waste into asphalt pavements[18], mechanical behavior of concrete with partial replacement of the fiber[19] is discussed in the recent researches.

CONCLUSION

The study shows that adding fibers improves concrete's mechanical properties, including its tensile strength, flexural strength, and ductility. Additionally, adding fibers lessens the concrete's creep and shrinkage deformation. Steel and other fibers drastically decrease the workability of concrete, which might have detrimental impacts. In a similar vein, longer fibers function better than shorter ones. just as a result of modest tensile stresses. Fibers come in a range of sizes, forms, lengths, and depths and can be utilized singly or in combination (hybrid) in concrete pavements. The primary findings from earlier research indicate that fiber hybridization enhances concrete's characteristics more than mono fibers, as demonstrated by previous data. The cost of the construction increased when fibers were added to the mixture in comparison to regular concrete, but this cost rise is not a major issue because the addition of fibers to a mixture enhances the qualities of both fresh and hardened concrete. Nonetheless, a number of research examined the impact of incorporating steel fibers into concrete; nonetheless, workability issues limited the usage of steel fiber in concrete. In order to improve infrastructure durability and predictability for dependable service life design, long-term durability testing are essential in the field.

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