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Fiber Reinforced Concrete: A Review †

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Abstract: Concrete is the most widely used constituent in the construction industry as a construction material due to its wide range of applications to civil infrastructure works. However, the use of concrete has been limited due to its certain deficiencies such as brittleness, low tensile strength, proneness to crack opening and propagation and low durability. To subdue these drawbacks, researchers have modified concrete by adding various synthetic and natural fibers to upgrade the nature of concrete. The demand for high strength and cracks resistant concrete led to the development of fiber-reinforced concrete. This paper reviews the effects of fibers inclusion on the performance of concrete. Generally, the addition of fibers improves tensile strength, flexural strength, and durability performance. Moreover, incorporating fibers reduces the shrinkage cracks of concrete. However, incorporating fibers in concrete has some negative effects like low workability.

Keywords: fiber-reinforced concrete; tensile strength; crack opening; brittleness

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1. Introduction

Fiber Reinforced Concrete (FRC) is a composite material made up of fibrous material that adds structural strength and integrity. The term FRC is defined by ACI as concrete, incorporated with dispersed randomly oriented fibers. Since concrete is a significantly brittle material and exhibits a very poor tensile strength, it cracks easily and results in freeze and thaw damage, scaling, discoloration, and also steel corrosion. Therefore, to sort out these issues, fibers are added to concrete to control the cracks and crack growth [1]. Commonly, various synthetic and natural fibers are used in concrete to control cracking and its propagation caused by plastic and drying shrinkage. The papers published by Romualdi and Batson in the early 1960s brought FRC to the notice of academic and industry research scientists all around the world [2]. At that time there was a significant sense of discovery and enthusiasm that FRC can promise a great future development for Portland cement-based composite material. Since then multiple investigations have been made by the researchers into the development of FRC by incorporating various fibers like glass, polypropylene, plastic, bamboo, carbon, sisal, and jute fibers. This paper intended to present the effects of adding various types of fibers in concrete.

2. Fibers Used in Concrete

Various synthetic and natural fibers are added to improve concrete properties:

2.1. Synthetic Fibers

The common synthetic fibers used in the previous studies are steel, glass, polypropylene, carbon, and plastic fibers as shown in Figure 1a–e respectively.

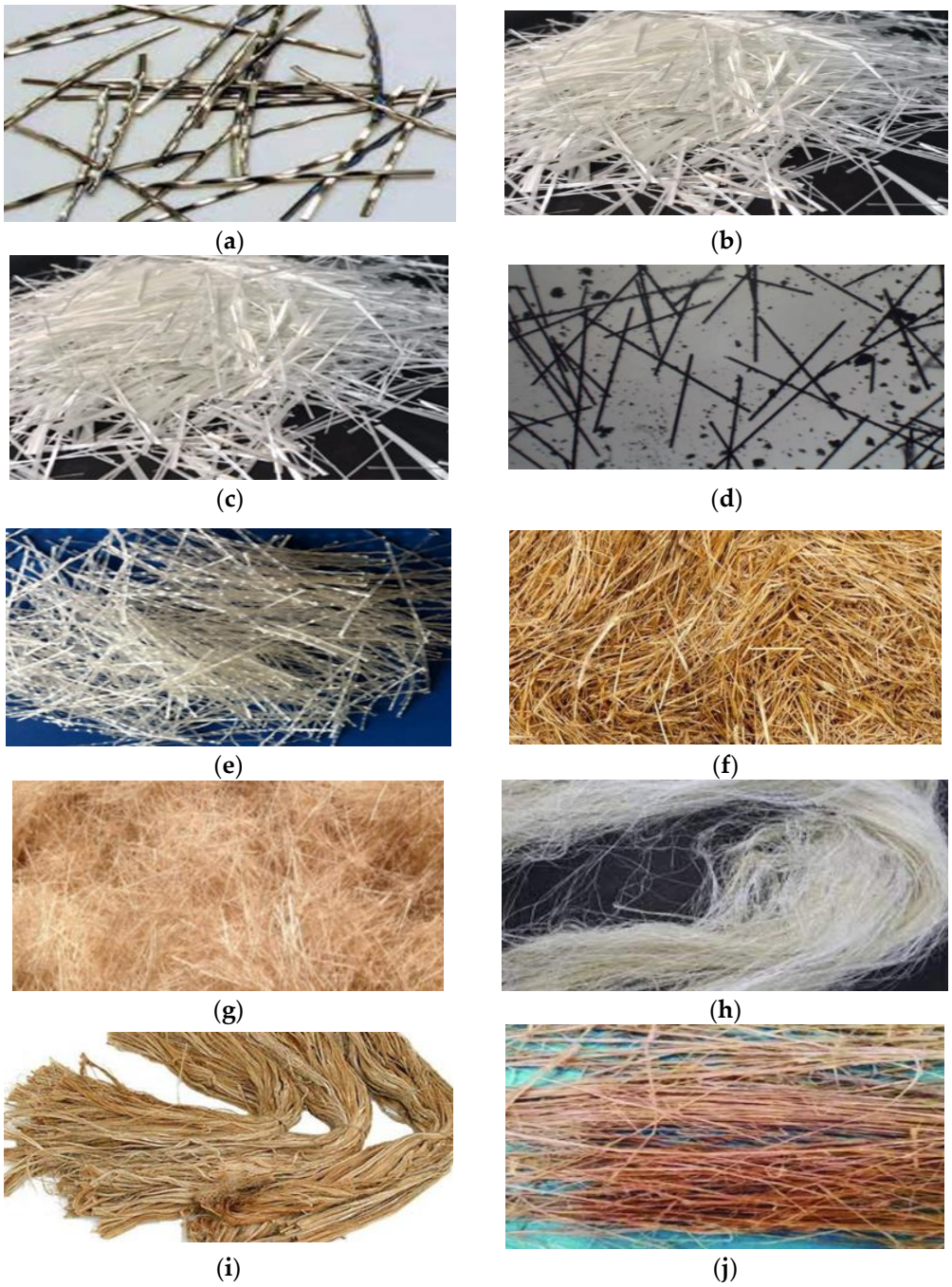

Figure 1. Appearance of some fibers used in concrete. (**a**). Steel fibers. (**b**). Glass fibers (**c**). Polypropylene Fibers (**d**). Carbon fibers. (**e**). Plastic fibers. (**f**). wheat straw. (**g**). Sugarcane fibers. (**h**). Sisal fibers (**i**). Jute fiber. (**j**). Bamboo fibers.

2.1.1. Steel Fiber

Steel fibers significantly increase the compressive strength of concrete. A viable increase in the compressive strength along with flexure strength of concrete is achieved by the use of 3% steel fiber by volume of cement [3]. The shear strength of the concrete also increases as the volume fraction of steel fibers increases but the workability of concrete decreases up to a greater extent, so super plasticizers are needed to be used in FRC [4]. The steel fibers increase the toughness of concrete, crack pattern changes as SFRC has a ductile mode of failure as compared to the crack pattern in the normal concrete [5].

Studies have addressed the flexure behavior of SFRC (Steel fiber reinforced concrete) beams, focusing greatly on the improvement in crack resistance, stiffness, ductility, impact

resistance, resistance to abrasion and energy absorption, the result shows significant improvement [6]. It was investigated that the propagation and severity of the localized cracks in the steel fiber reinforced concrete were strongly affected by the steel fiber content and the SFRC slabs performed better under impact loading as compared to non-fibrous slabs [7]. The efficiency of the bond between the steel fibers and the matrix in the tensile zone of fiber reinforced concrete beams can be varied from 1.0 to 2.2 [8].

2.1.2. Glass Fiber

The addition of glass fiber to concrete increases the tensile strength and reduces steel reinforcement requirement, thus minimizing the deterioration of steel reinforcement in the marine environment and hydraulic structures [9]. Glass fibers improve fatigue resistance, enhance flexure strength, and disturb the crack pattern by reducing the crack width [10]. Glass fiber reinforced concrete (GFRC) was noted to perform well in the impact strength and absorbed more energy [11]. The usage of glass fiber in concrete has no significant effect on the compressive strength of concrete [12]. The ANSYS analysis showed that, with the increase in volume fraction of glass fiber, a decrease in the rate of temperature evolution under high temperatures occurred. Thus, the addition of glass fiber provides better safety of the rebars by lowering the temperature in the cross-section under high temperatures [13]. The study revealed that the use of industrial waste of glass not only increases the flexure and tensile strength but also gives an efficient means of disposal of this industrial waste [14].

2.1.3. Polypropylene Fiber

Damages in concrete due to fire or high temperatures can extend from simple discoloration to destruction of the member or structure by loss of its mechanical strength. Due to the addition of polypropylene fiber content, there is no significant reduction in compressive strength when exposed to temperature up to 600 °C [15]. The weakness of concrete in tension and flexure decreases its durability, the addition of polypropylene fiber increases the flexure strength of the concrete mix and also enhances with the increase in percentage of fiber [16]. The polypropylene fibers have low density and are highly crystalline, with high stiffness and also offer better resistance to chemical and bacterial attacks [17]. By increasing the content of fiber, the increase in fracture toughness is not observed; rather it has a large increase in unstable toughness. The fracture process of concrete reinforced with polypropylene basalt fiber can be explained by the "bilinear softening constitutive curve" improved by Xu and Reinhardt [18]. The intrusion of polypropylene fiber into concrete showed negative impacts on mixing and handling while increasing the compressive strength of concrete [19]. Since the public spaces, parks roads and beaches are subjected to unfavorable environmental conditions, such as impact damages and surface abrasion, etc. so the concrete of enhanced properties with polypropylene fiber is very beneficial to use in such spaces [20].

2.1.4. Carbon Fiber

Dispersed reinforcement of concrete is obtained by fibers of minerals, when introducing carbon fiber into the concrete it forms spatial micro-fiber reinforced concrete [21]. The Carbon Fiber Reinforced Polymer Concrete (CFRP) used for the strengthening of the existing bridge was used which prevented the premature debonding of CFRP composites from the surface of concrete and the composite did not degrade under fatigue loads [22]. The crack bridging effect of carbon polymer fiber improves the post-cracking ductility [23]. The stiffness, ductility and bearing capacity of reinforced concrete columns were increased when strengthened with carbon fiber-reinforced polymer [24].

The inclusion of carbon fiber does not affect the compressive strength of concrete, but the flexure capacity was doubled as compared to normal concrete [25]. Since deep RC beams are generally prone to decay due to weathering action and chemical (Sulphur) attacks, rehabilitation, and strengthening of these structures using carbon fiber become

cost-effective alternatives [26]. The use of synthetic fiber in columns reduces the quantity required for transverse reinforcement and improved its cyclic behavior [27]. The bonded CFRP to pre-cracked beams holds the beam and prevents the shear crack at both span end [28]. The density of CFRP is low, providing high resistance to segregation, however, decreases the slump flow [29]. The use of industrial waste such as marble dust and bottom ash in non-structural components has significant potential for achieving sustainable construction and reducing CO_2 emissions [30]. Under varying impact energy compared with normal carbon fiber the impact performance of recycled fiber was significant along with the mechanical behavior of recycled carbon fiber being superior to normal carbon fiber [31]. The formulation of CFRC worked well for increasing the flexure strength and was more efficient when an air-entrainer was not used. The increase of flexure toughness was due to an increased flexure strength and ductility [32].

2.1.5. Plastic Fiber

To prevent our environment from degradation due to improper waste management, it is necessary to dispose of or recycle plastic bottles or plastic wastes. Hence use of plastic fiber as a reinforcing material makes the construction eco-friendly [33]. The cost of construction reduces by the replacement of cement content by waste plastic fibers, it is investigated that the optimum percentage of replacement of cement with fiber is 1.5% [34]. Further investigation showed that the novel arrangement (continuous plastic fiber reinforcement arrangement) in concrete has high adherence (bond) between PET and the concrete mix [35]. The plastic waste fibers reduce the compressive strength of the mix. Therefore, to counter this effect some additives like silica fume and metakaolin are to be used [36]. The PET fibers hold the ingredients of concrete together, increase the tensile strength of concrete, make the failure mode ductile [34] and enhance the flexure behavior of concrete [37]. The inclusion of PET fiber affects the flow properties of concrete, causing spalling in the mix [38].

2.2. Natural Fibers

Due to their light weight, economical cost, greater specific strength and modulus, and no health risk natural fibers are promising reinforcements for the use in concrete and are easily procured in many countries [6]. The common types of natural fibers include wheat straw, sugarcane fibers, sisal fiber, jute fiber, and bamboo fiber are shown in Figure 1f–j respectively.

2.2.1. Wheat Straw

The study revealed that the early age effect of wheat Straw Reinforced Concrete (WSRC) on pavements was significant. The severity and quantity of shrinkage cracks were reduced to a greater extent [6]. The slump of the mix was reduced due to the addition of WS while the flexure, tensile and compressive strengths were improved [39]. The ductility of the mix increased, which led to a ductile failure and limited the crack width. The application of the concrete in which wheat straw was added can be used in pavements because of its good post-cracking behavior. The sewing effect in the concrete due to the wheat straw could resist the cracks and ultimately increase the absorption capacity. The rigid pavements with at least 1% wheat straws behave better in compression as compared to the pavements with plain concrete [6]. Wheat straw is a type of green material. The environmental hazard of crop burning is reduced by using these in concrete and the construction cost is also reduced [40].

2.2.2. Sugarcane Fiber

The study provided that sugarcane fibers reduce the thermal conductivity of the concrete matrix and lightweight concrete is produced. The replacement of ordinary Portland cement with sugarcane bagasse ash SCBA (sugarcane bagasse ash) enhances the flexure, compression, and tensile strength of the concrete composite [41], along with the increase

in setting time and reduction in hydration temperature of the setting. The composite becomes thermally stable up to a temperature of 450 °C [42]. The addition of sugarcane bagasse to cement composite concrete with 6% showed the highest stiffness. The electron beam radiation technique performed on the sample revealed that the elastic modulus was remarkably increased. Scanning electron microscopy showed that the voids in the matrix were greatly reduced and therefore increase in the mechanical behavior of the concrete was observed [43].

2.2.3. Sisal Fiber

The investigation on fiber reinforced concrete showed that the concrete reinforced with sisal fibers was reliable to use in the production of structural components and it could be a replacement for steel reinforcement whose mass production is a serious risk to human and animal health [44]. The compression, tensile and flexure tests on concrete composite with sisal fiber showed that the matrix can be used in drainage plates and is 1.85 times more affordable than the ordinary steel reinforcement. The optimum percentage of cement replacement with ground granulated blast furnace slag is 20% [45]. Although the workability of the mix decreased by the addition of sisal fiber, the initial crack value is increased which indicates that the strength is increased as compared to conventional concrete [46].

2.2.4. Jute Fiber

The research on jute fiber reinforced concrete concludes that the toughness, ultimate flexure strength, and load-carrying capacity of RC beams strengthened with jute fiber was increased with the increase of strip width and thickness, but the stiffness and ductility were decreased with the increase of strip width [47]. The initial cracking load was enhanced by 12.92% and the ultimate load by 6.94% for the RC beams cast with natural jute fibers throughout the beam [48]. The significant change in the JFRC properties increases the resilience of the concrete which enhances its application in slab for structural purposes. The jute fibers increase flexure strength, initial crack energy, toughness, and bridging patterns show better bonding between concrete fibers and the matrix [49]. Natural jute fibers make the construction economical and durable [50].

2.2.5. Bamboo Fiber

The study divulges that intrusion of the bamboo fiber in concrete increases the compressive strength and split tensile strength by 22% and 17%, respectively. This enhancement is due to the bridging action of the fiber which hinders the crack propagation in the hardened mix. The results of the investigation revealed that the strength achieved by using bamboo as a reinforcing material was 82% while the ductility was 93% in contrast to steel reinforced slabs, thus bamboo can prove as a substitute for steel reinforcement in concrete, although further research is required to investigate or increase the mechanical properties [51].

3. Conclusions

The study reveals that the incorporation of fibers enhances the mechanical characteristics of concrete such as tensile strength, flexural strength, and ductility performance. Furthermore, the addition of fibers reduces the shrinkage and creep deformation of concrete. Fibers like steel have some negative effects on concrete because it significantly reduces the workability. In addition, it has been observed that other parameters of fibers such as aspect ratio, length of fiber, shape of fiber, have a significant effect on the creep behavior of fiber-reinforced concrete. It has been shown that a high aspect ratio provides excellent performance regardless of the fiber content. The addition of synthetic fibers such as polypropylene has more influence on energy absorption and crack control than enhancing load-bearing capacity. Similarly, longer fibers show better performance as compared to shorter ones.

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