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A Survey on Steel Fibre as a Reinforcement in Concrete: A General Review

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Abstract- Commercially available fibres are made from steel, plastic, glass, etc. Steel fibres, characterised by their discrete, short lengths, are small enough to be easily and randomly dispersed in the fresh concrete mix using conventional mixing procedures. They typically possess an aspect ratio (length to diameter) ranging between 20 and 100, with various cross-sectional shapes. While the random distribution of steel fibres may result in some loss of efficiency compared to traditional rebars, their close spacing enhances the concrete's hardness, tensile properties, and crack resistance. Combining fibre reinforcement with traditional steel reinforcement often enhances overall performance. Fibre Reinforced Concrete (FRC) is a composite material comprising regular concrete or mortar randomly reinforced with discrete, short, and fine fibres of specific geometry. Fibres, including horse hair and straw, have historically reinforced brittle building materials like clay sun-baked bricks, dating back to around 3500 years ago. Although the concept of fibre reinforcement in fragile materials is ancient, using fibres in concrete gained traction in the early 1960s. Over the past three decades, extensive research and development in fibre-reinforced concrete have significantly improved product characteristics. This study provides an overview of steel fibre-reinforced concrete's mechanical properties, advantages, and applications.

Keywords- Fibre Reinforced Concrete (FRC), Steel Fibre Reinforced Concrete (SFRC), Mechanical properties

1. INTRODUCTION

The investigation of normal concrete (NC) beams, and steel fibre reinforced concrete beams (SFRC) has revealed notable enhancements in flexural strength, bearing capacity, yield load, ultimate load, and ductility of SFRC beams compared to normal concrete [1]. The distribution and orientation of fibres in SFRC are crucial, with proper orientation contributing significantly to flexural strengthening and increased load-carrying capacity. However, the direct shear force exerted by the fibre limits the extent of this increase [2]. Studies indicate that employing a double-hook steel strategy marginally affects the crack-bridging degradation rate and flexural cyclic modulus of SFRC beams compared to a single-hook strategy [3]. The alignment of steel fibres in concrete using a magnetic field facilitated by a magnetic pulse has been explored, with fibre orientation exceeding 80% during SFRC casting. Characterisation of fibre orientation can be achieved through parameters like fibre orientation factor and fibre orientation coefficient, with methods such as image analysis or CT scan aiding visualisation. Subsequent mechanical property evaluations, including compression, flexural, tension, torsion, and shear strength, are imperative for post-fibre orientation.

Additionally, fibre alignment significantly enhances concrete strength, although mechanical properties decline with increasing temperature (200-800 °C) in Ultra High-Performance Concrete (UHPC) with steel fibres [6]. Investigations into the effect of fibre alignment on flexural strength using steel fibres of varying lengths have demonstrated several-fold increases in flexural strength and toughness with longer fibres compared to shorter ones [7]. In direct shear strength tests, single-hooked steel fibre samples in concrete exhibited higher strength than oriented samples, with fibres enhancing concrete ductility and promoting stretching rather than brittle failure in shear conditions [8]. Fibre-reinforced concrete (FRC) has exhibited superior mechanical properties compared to normal concrete, with spalling resistance enhanced by altering temperature-dependent mechanical properties through various fibre types, thereby mitigating micro-crack formation and growth through the bridging effect during thermal cycling [9]. Furthermore, the inclusion of steel fibres (twisted, hooked, and half-hooked) in Ultra-High-Performance Fibre fibre-reinforced concrete (UHPFRC) has led to improved pullout resistance and tensile strength, with optimal bond strength achieved at fibre orientations ranging from 30 to 45 degrees [10].

1.1 Steel Fibres

Since the early 1900s, steel fibres have been used in concrete. The wire was chopped or sliced into the necessary lengths, and the early fibres were smooth and spherical. The use of smooth, straight fibres has disappeared, and contemporary fibres are either crimped or have rough surfaces, hooked ends, or undulating throughout their length. Contemporary steel fibres sold commercially are made from drawn steel wire or cut sheet steel, or they are used in a method called melt-extraction that yields fibres with a crescent cross-section. Steel fibres typically have lengths of 7 to 75 mm and comparable diameters (depending on cross-sectional area) of 0.15 to 2 mm. The typical range of aspect ratios is 20 to 100. (The definition of aspect ratio is the ratio between fibre length and its equivalent diameter, which is the diameter of a circle with an area equal to the cross-sectional area of fibre.) ASTM A 820 divides them into four categories based on their manufacturing process. The most widely accessible type of wire fibre made from drawn steel wire is Type I-Cold-drawn wire fibre. As the name suggests, Type II-Cut sheet fibres are made by laterally shearing steel sheets into steel fibres. Type III-Melt-extracted fibres are produced using a somewhat intricate process involving a revolving wheel to lift liquid metal by capillary action from a molten metal surface. Centrifugal force causes the extracted molten metal to freeze into fibres and quickly launch itself off the wheel. The cross-section of the resultant fibres is crescent-shaped. Type IV: Additional fibres. Refer to ASTM A 820 for minimum tensile strength, bending requirements, and length, diameter, and aspect ratio tolerances.

1.2 Different Types of Fibres

Fibres can be categorised using two approaches based on their origin or modulus of elasticity. Fibres can be divided into two main groups based on their modulus of elasticity: those with a modulus of elasticity greater than the concrete mix (referred to as hard intrusion) and those with a modulus of elasticity lower than the concrete mix (referred to as soft intrusion). Fibres with low elastic modulus include vegetal and polypropylene, while materials with greater elastic modules include steel, carbon, and glass. While low elastic modulus fibres can enhance concrete's impact resistance but not much of its flexural strength, high elastic modulus fibres can concurrently improve flexural and impact resistance.

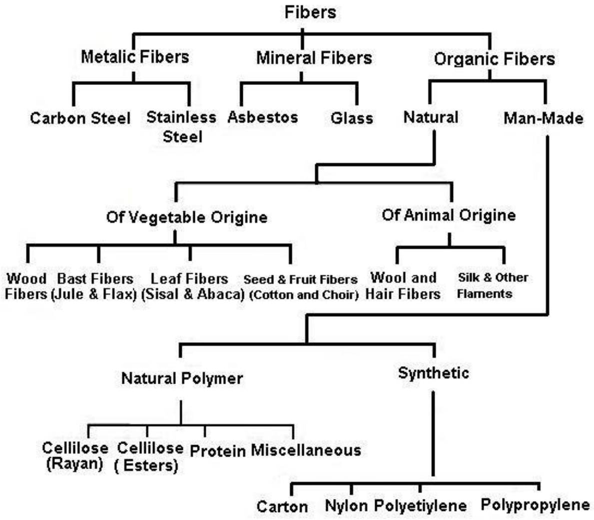

Figure 1. Fibres Classification

2. .4 Steel Fibre Reinforced Concrete (SFRC)

Fibres are divided into three groups based on their origin: metallic fibres, which include steel, carbon steel, and stainless steel; mineral fibres, which include asbestos and glass fibres; and organic fibres. Natural and synthetic fibres are additional categories for organic fibres. Natural fibres can be divided into two categories: animals (like silk and hair fibres) and plants (like wood and leaf fibres). Another way to categorise manufactured fibres is as natural polymers (like cellulose and protein) and synthetic polymers (like nylon and polypropylene). Depending on its application, fibre volume %, and fibre efficacy, SFRC's behaviour may be divided into three groups. For example, SFRC is categorised as follows depending on its fibre volume percentage: For many years, a very low fraction of SF (less than 1% per volume of concrete) has been utilised as pavement reinforcement to limit plastic shrinkage. 2. A moderate volume percentage of SFs (between 1% and 2% per volume of concrete) might enhance the concrete's impact resistance, flexural toughness, modulus of rupture (MOR), and other desired mechanical properties. 3. Special applications, such as impact and blast resistance structures, need a high volume percentage of SFs (greater than 2% per volume of concrete); examples of these include SIFCON (Slurry Infiltrated Fibre Concrete) and SIMCON (Slurry Infiltrated Mat Concrete).

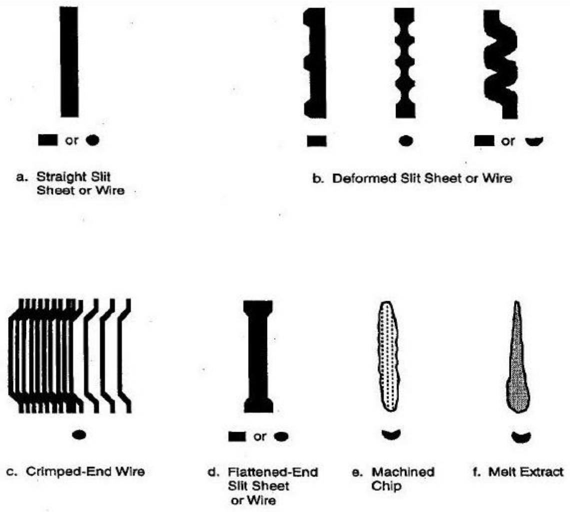

Figure 2. Different Shapes of Steel Fibres

Wei Zhang et al. (2024) present the findings of a comprehensive investigation into the behaviour and performance characteristics of fibre-reinforced concrete (FRC), focusing on its potential applications in airfield pavements and overlays. Compared to those without fibres, the study includes a comparative analysis of the static flexural strength of concrete samples containing four distinct types of fibres—polypropylene, corrugated steel, hooked-end steel, and straight steel. Various percentages of fibre content (0.5%, 1.0%, 1.5%, and 2.0% by volume) were evaluated using the same mix proportions for concrete. Additionally, Sustersic, Mali, and Urbancic (1991) discussed the results of an investigation into the abrasion resistance and erosion-abrasion resistance of steel fiber-reinforced concrete specimens. Nine different mix proportions were tested, ranging from water-to-cement ratios of 0.30 to 0.65, with varying volumetric percentages of hooked steel fibres. The study concluded that the inclusion of steel fibres improves the resistance of concrete to erosion and abrasion.

Furthermore, Ghugal et al. (2003) conducted experimental examinations on different strengths of steel fibre-reinforced concrete (SFRC), considering various fibre volume fractions and strengths. Mathematical equations for different strengths were established and found to agree with experimental data, indicating superior strength performance with the addition of steel fibres. Moreover, Murthy Dakshina et al. (2005) investigated the enhancement of tensile strength in concrete by combining fly ash and random steel fibres across different concrete grades, noting improved flexibility with the addition of steel fibres. Additionally, Ganeshan et al. (2007) researched the structural elements of steel fibre-reinforced high-performance concrete (SERHPC) and explored the use of crimped steel fibres along with partial cement replacement with fly ash and silica fume. Ghugal et al. (2010) examined the impact of varying aggregate sizes on steel fibre-reinforced concrete, highlighting the role of short, randomly dispersed fibres in slowing microcrack propagation and increasing material strength. Finally, Marciukaitis, Salna, and Jonaitis (2011) proposed a strength and strain analysis model of steel fibre-reinforced concrete based on reinforced concrete codes and design guidelines, demonstrating negligible variations between theoretical and experimental values. This model is useful for analysing reinforced concrete members reinforced with steel fibres.

3. CONCLUSIONS

A thorough literature study spanning conference proceedings and journal articles was conducted; most publications were based on fibre-reinforced concrete. According to the literature research, few papers on fibre-reinforced concrete use hook-tain steel fibres. Aspect ratio, concrete grades, and steel fibre percentages are examples of variables not concurrently covered in the examined articles—the benefits and uses of Steel Fibre Reinforced Concrete (SFRC). Amazing advancements in concrete technology have been made over the past few decades. Fibre Reinforced Concrete (FRC) is a significant advancement in concrete technology. It is a composite material made of ordinary concrete reinforced with discrete, short, and short fine fibres with a specified shape that is randomly distributed.

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