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STEEL FIBER REINFORCED CONCRETE

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ABSTRACT

Concrete is one of the world most widely used construction material. However, since early 1800's, it has been known that concrete is weak in tension, so it requires some form of tensile reinforcement to compensate its brittle behaviour and improve its tensile strength and strain capacity to be used in structural applications. Historically, , steel has been used as the material of choice for tensile reinforcement in concrete. Unlike conventional reinforcing bars, which are specifically designed and placed in the tensile zone of the concrete member, fibers are thin, short and distributed randomly throughout the concrete member. Fibers are commercially available and manufactured from steel, plastic, glass and other natural materials. Steel fibers can be defined as discrete, short length of steel having ratio of its length to diameter (i.e. aspect ratio) in the range of 20 to 100 with any of the several cross-section, and that are sufficiently small to be easily and randomly dispersed in fresh concrete mix using conventional mixing procedure. The random distribution results in a loss of efficiency as compared to conventional rebars, but the closely spaced fibers improve toughness and tensile properties of concrete and help to control cracking. In many situations it is prudent to combine fiber reinforcement with conventional steel reinforcement to improve performance. Realizing the improved properties of the fiber reinforced concrete products, further research and development on fiber reinforced concrete (FRC) has been initiated since the last three decades. This paper presents an overview of the mechanical properties of Steel Fiber Reinforced Concrete, its advantages, and its applications.

Keywords: Concrete, Fiber Reinforced Concrete (FRC), Mechanical properties, Steel Fiber Reinforced Concrete (SFRC), Tensile.

I. INTRODUCTION

One of the undesirable characteristics of the concrete as a brittle material is its low tensile strength, and strain capacity. Therefore it requires reinforcement in order to be used as the most widely construction material. Conventionally, this reinforcement is in the form of continuous steel bars placed in the concrete structure in the appropriate positions to withstand the imposed tensile and shear stresses. Fibers, on the other hand, are generally short, discontinuous, and randomly distributed throughout the concrete member to produce a composite construction material known as fiber reinforced concrete (FRC). Fibers used in cement-based composites are primarily made of steel, glass, and polymer or derived from natural materials. Fibers can control cracking more effectively due to their tendency to be more closely spaced than conventional reinforcing steel bars. It should be highlighted that fiber used as the concrete reinforcement is not a substitute for conventional steel bars. Fibers and steel bars have different roles to play in advanced concrete technology, and there are many applications in which both fibers and continuous reinforcing steel bars should be used.

Steel fiber (SF) is the most popular type of fiber used as concrete reinforcement. Initially, SFs are used to prevent/control plastic and drying shrinkage in concrete. Further research and development revealed that addition of SFs in concrete significantly increases its flexural toughness, the energy absorption capacity, ductile behaviour prior to the ultimate failure, reduced cracking, and improved durability (Altun et al., 2006). This paper reviews the effects of addition of SFs in concrete, and investigates the mechanical properties, and applications of SF reinforced concrete (SFRC).

II. STEEL FIBER REINFORCED CONCRETE (SFRC)

In 1910, Porter first suggested the use of SFs in concrete (Naaman, 1985). However, the first scientific research on fibre reinforced concrete (FRC) in the United States was done in 1963 (Romualdi and Baston, 1963). SFRC is produced using the conventional hydraulic cements, fine and coarse aggregates, water, and SFs. American concrete institution (ACI 544.IR, 1996) defines SFs as discrete, short lengths of steel having aspect ratio (ratio of length to diameter) in the range of 20 to 100 with any of the several cross-section which are sufficiently small to be easily and randomly dispersed in fresh concrete mix using conventional mixing procedures. To enhance the workability and stability of SFRC, super plasticizers (chemical admixtures) may also be added into the concrete mix. Figure 2 shows the engineering specifications of the SFs such as their shape, material, length, diameter, and type of cross-section (ACI 544.IR, 1996).

The behaviour of SFRC can be classified into three groups according to its application, fiber volume percentage and fiber effectiveness; for instance SFRC is classified based on its fiber volume percentage as follows: 1-Very low volume fraction of SF (less than 1% per volume of concrete), which has been used for many years to control plastic shrinkage and as pavement reinforcement. 2-Moderate volume fraction of SFs (l% to 2% per volume of concrete) which can improve modulus of rupture (MOR), flexural toughness, impact resistance and other desirable mechanical properties of concrete. 3-High volume fraction of SFs (more than 2% per volume of concrete) used for special applications such as impact and blast resistance structure; these include SIFCON (Slurry Infiltrated Fiber Concrete), SIMCON (Slurry Infiltrated Mat Concrete). In most cases, SFs may act as secondary reinforcement used along with conventional steel bars or prestressing strands as the main reinforcement. In the class of high volume fraction of SFs (more than 2% per volume of concrete), the SFs have excellent mechanical properties and can be used without other continuous reinforcement; however, these composite materials are often suited for highly specialized applications due to the limitations associated with processing and cost.

III. MECHANICAL PROPERTIES OF SFRC

The crack-arrest and crack-control mechanism of SFs has three major effects on the behaviour of SFRC structures (Ocean Heidelberg Cement Group, 1999). 1- The addition of SFs delays the onset of flexural cracking. The tensile strain at the first crack can be increased as much as 100 percent and the ultimate strain may be as large as 20 to 50 times that of plain concrete. 2-The addition of SFs imparts a well-defined post-cracking behaviour to the structure. 3- The crack-arrest property and the consequence increase in ductility

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impart a greater energy absorption capacity (higher toughness) to the structure prior to failure.

3.1 Compressive Strength

Johnston (1974), and Dixon and Mayfield (1971) found that an addition of up to 1.5% of SFs by volume increases the compressive strength from 0 to 15%. A gradual slope in the descending part of the stress-strain curves indicates the improved spalling resistance, ductility and toughness of SFRC as shown in Figure 4 (Padmarajaiah and Ramaswamy, 2002).

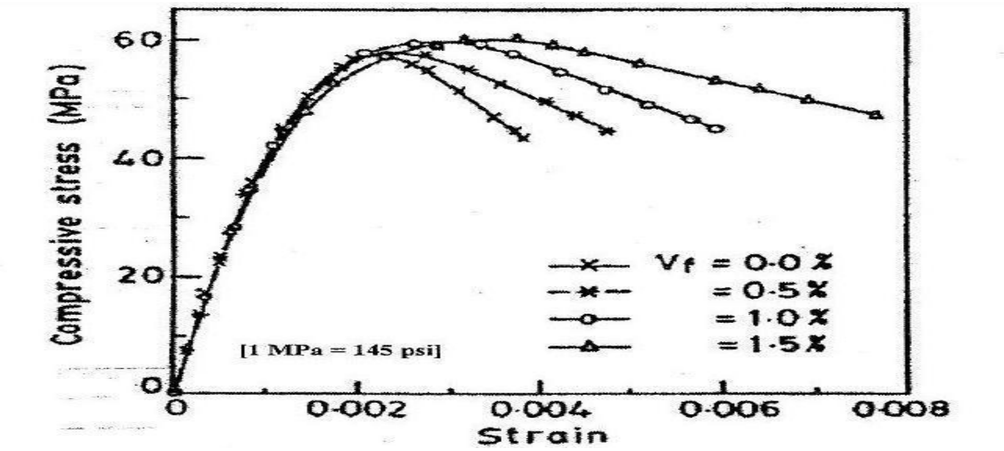

Fig. 1: Effects of SFs Content on Compressive Stress-Strain Curve of FRC [21]

3.2. Shear Strength

Previous research has shown that addition of SFs substantially increases the shear strength of concrete (Noghabai, 2000; Oh et al., 1999; Narayanan and Darwish, 1987; Barr, 1987). The ultimate shear strength of SFRC containing 1 % by volume of SFs increases up to 170% compared to RC without SFs (Narayanan and Darwish, 1987). Traditional transverse shear reinforcement can be completely replaced by addition of SFs as an effective alternative (Noghabai, 2000; Williamson, 1978). Rather than using a single type of SF, a combination of SFs with various aspect ratios is more effective in improving the mechanical performance of SFRC (Noghabai, 2000).

3.3. Tensile Strength

Addition of 1.5% by volume of SFs can improve the direct tensile strength of concrete up to 40% (Williamson, 1974). Those SFs aligned in the direction of the tensile stress contribute to an appreciable increase in the direct tensile strength of concrete as up to 133% for the addition of 6% by weight of smooth, straight SFs. However, for more or less randomly distributed fibers, the increase in strength is much smaller, ranging from as low as no increase in some instances to perhaps 60%, with many investigations indicating intermediate values, as shown

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in Figure 5. Splitting-tension test of SFRC show similar result. Thus, adding fibers merely to increase the direct tensile strength is probably not worthwhile. However, as in compression, steel fibers do lead to major increases in the post-cracking behaviour or toughness.

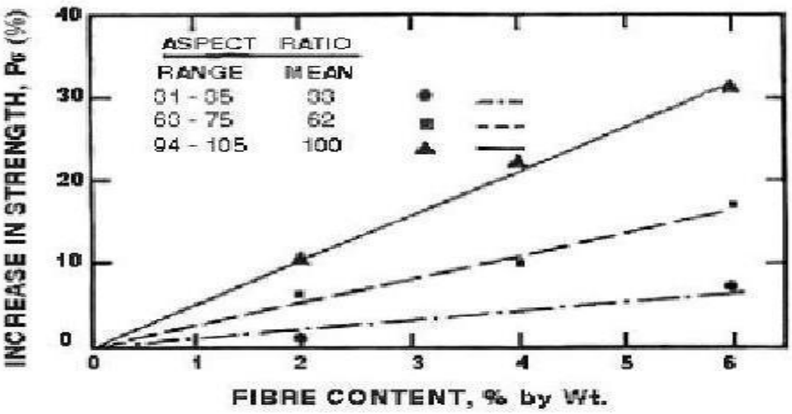

Fig. 2: Influence of Fibre Content on Tensile Strength [13]

3.4. Impact Resistance

The impact resistance of SFRC against dynamic loads due to the dropped weights or explosives is 8 to 10 times higher than that of the plain concrete. The test results of the specimens containing high tensile strength, crimped SFs with the diameter of 0.50mm indicate an improvement in the concrete toughness under impact loading more than 400 percent.

3.5. Durability

Corrosion in concrete structures due to the cracks is less severe in the SFRC structures compared to conventional RC ones (Mangat and Gurusamy, 1987; Williamson and Morse, 1977; Halvorsen et al., 1976; Aufmuth et al., 1974). Schupack (1985) found that a well-compacted SFRC has a limited corrosion of fibers close to the surface of the concrete even when concrete is highly saturated with chloride ions. Turatsinze et al. (2005) conducted a research to investigate the corrosion of SFRC due to the cracks. Prismatic SFRC specimens with the dimensions of 100*100*500mm containing hook-end SFs with the dimensions of 60 mm in length and 0.8 mm in diameter were prepared. Specimens with vertical cracks were exposed to a marine-like environment for 1 year. After 1 year, the prisms were tested in three-point bending setup with the span of 200 mm and load-deflection graphs were plotted and concluded that only those SFs crossing the crack within a 2 to 3mm rim from the external faces of the specimens exhibited extensive corrosion. Besides, no SFs corrosion was observed in narrower parts of the cracks (i.e. where crack mouth opening was about 0.1 mm) whilst in the wider parts of the cracks (i.e. where crack mouth opening was equal to 0.5mm) a light corrosion of the fibers with no reduction in their section was observed. Furthermore, no concrete bursting or sapling was recorded due to the corrosion of the fibers. The measurement of concrete electrical resistivity can give an indication of concrete durability (Chen and Hwang, 2001; Woodrow 1980). Figure 6 shows the relationship between the concrete electrical resistivity and curing ages, and it indicates the reduction of concrete electrical resistivity with the increase in the percentage of SFs due to the conductivity of the fibers (Tsai et al., 2009). However, the gel formation due to the

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cement hydration and pozzolanic reaction causing a dense microstructure and fills the conductive channel, thereby it decreases the effect of SFs conductivity. In the long run, with the addition of 1.0% of SFs the desired concrete electrical resistivity of over 20 kΩ-cm can be reached (Woodrow 1980).

3.6. Flexural Strength and Toughness

Hartman (1987) found that the influence of SF's on the flexural strength of concrete is much greater than its influence on direct tension or compression. Oh et al. (1999) reported that the flexural strength of SFRC is increased by about 55% with the addition of 2% of SFs. Hartman (1999) experimented with 12 different SFRC beams produced by SFs of Dramix RC-65/35-BN type with two different dosages of 60 kg/m^3 and 100 kg/m^3, and concluded that the ratio of the measured ultimate load to the theoretical ultimate load turned out to be greater for those SFRC beams having the dosage of 60 kg/m^3.

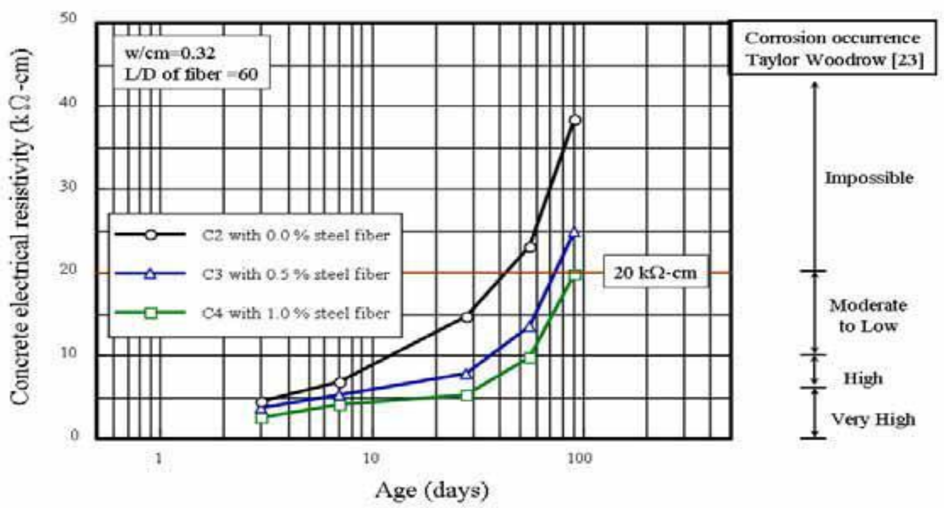

Fig. 3: Effects of Fibre Content on Concrete Electrical Resistivity [25]

IV. CONCLUSIONS

This paper presents an overview of the mechanical properties of Steel Fiber Reinforced Concrete (SFRC). During the last decade's incredible development have been made in concrete technology. One of the major progresses is Fibre Reinforced Concrete (FRC) which can be defined as a composite material consisting of conventional concrete reinforced by the random dispersal of short, discontinuous, and discrete fine fibres of specific geometry. Unlike conventional reinforcing steel bars, which are specifically designed and placed in the tensile zone of the concrete member, fibers are thin, short and distributed randomly throughout the concrete member. Among all kinds of fibers which can be used as concrete reinforcement, Steel Fibers are the most popular one. The performance of the Steel Fiber Reinforced Concrete (SFRC) has shown a significant improvement in flexural strength and overall toughness compared against Conventional Reinforced Concrete.

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