Mechanical Properties of Steel Fiber Reinforced Self-Compacting Concrete: A Review

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Abstract - *Self-compacting concrete (SCC) is relatively a recent development in the construction world. SCC is defined basically by two properties: Deformability and segregation resistance. It flows under its own weight while remaining homogeneous in composition. Similarly, use of steel fiber is being encouraged to increase the mechanical characteristics of self-compacting concrete. This paper present literature review on examining the feasibility of using steel fiber Self-Compacting Concrete.*

***Key Words*: Self compacting concrete, steel fiber, Mechanical properties**

1. INTRODUCTION

Self-compacting concrete (SCC) is a fluid mixture, which is appropriate for placing in difficult surroundings and also in congested reinforcement, without vibration. The advancement of self- compacting concrete (SCC) is an advantageous accomplishment in the construction industry in order to beat problems associated with cast-in-place concrete. In principle, a self-compacting or self-consolidating concrete must:

- Have a fluidity that allows self - compaction without external energy
- Remain uniform in a form during and after the placing technique and
- Flow effortlessly through reinforcement. Self compacting concrete is not exaggerated by the skills of workers, the shape and amount of reinforcing bars or the understanding of a structure and, due to its high fluidity and resistance to segregation it can be pumped longer distances [1].

The addition of fiber into SCC may make improvement of extending the prospect of field application of SCC [2]. The substitute of conventional concrete totally or to some extent with fiber will improve the construction development. Using the reinforcement bars in the construction of concrete structures has a substantial economic impact on the cost of construction [3]. It is likely to lessen the energy consumption, better working environment, with concentrated noise and health hazard [4], however, fiber are known to significantly affect the workability of concrete [2]. Designing a appropriate fiber reinforced (FR)-SCC is not an easy job. Several investigations were approved out in order to get the proportions of fiber reinforced (FR)-SCC [5]. In order to improve and expand the ability of SCC and FR-SCC to flow and to be able to keep its workability within the addition of steel fiber, superplasticizer was used.

Okamura and Ouchi [6] have reported that the coarse and fine aggregate contents can be kept constant to obtain the self-compatibility easier by adjusting the water/cement ratio and the superplasticizer quantity only [5,6].

The present review article presents the current state of art present worldwide for self compacting concrete containing different types of steel fiber.

1.1 Steel Fiber

This study focuses on steel fiber. They operate as crack arrestor in concrete. Steel fiber length ranges from 1/4 to 3 inches (1.5 to 75 mm) and aspect ratio ranges from 30 to 100.
Types of steel fiber

Fiber are in a range of sizes and shapes. Round steel fiber prepared up of low-carbon steel or stainless steel, having diameters in the range of 0.25 to 1 mm. Flat steel fiber, formed by shearing sheet or flattening round wire and are accessible in thicknesses ranging from 0.15 to

0.41 mm. Crimped and deformed steel fiber are obtainable both in full length or crimped at the ends simply. A typical volume fraction of steel fiber is 0.25 to 1.5% (of the volume of concrete) [7].

Properties of fiber

A good fiber is the one which own the following qualities:

- Good adhesion surrounded by the matrix.
- Adaptable elasticity modulus (sometimes higher than that of the matrix).
- Compatibility with the binder, which should not be attacked or damaged in the long term.
- A reachable price, taking into account the proportion contained by the mix.
- Being satisfactorily short, fine and flexible to allow mixing, transporting and placing.
- Being sufficiently strong, yet sufficiently strong to withstand the mixing process.

Aspect ratio

Aspect ratio is defined as the ratio of length to width of the fiber. The value of aspect ratio varies from 30 to 150. Usually, the increase in aspect ratio increases the strength and stiffness till the aspect ratio of 100. Beyond that the strength of concrete decreases, in sight of decreased workability and concentrated compaction. On or after investigations, it can be found out that good results are obtained at an aspect ratio around 80 for steel fiber.

Fiber quantity

Commonly, quantity of fiber is calculated as percentage of cement content by weight. As the volume of fiber increase, as a result augment in strength and toughness of concrete occurs.

Orientation of fiber

The orientations of fiber play a key function in formative the capacity of concrete. In RCC, the reinforcements are positioned in desired direction. But in FRC, the fiber will be oriented in random direction. The FRC will have maximum resistance whilst fiber are oriented parallel to the load applied.

1.2 Fiber Mechanism with Concrete

Fiber employ with concrete utilizing two mechanisms: the spacing mechanism and the crack bridging mechanism. The spacing mechanism requires a large quantity of fiber well distributed contained by the concrete matrix to arrest any existing micro crack that could potentially enlarge create a sound crack. For typical volume of fractions of fiber utilizing small diameter of fiber or micro fiber can make sure the required number of fiber for micro crack arrest. The second mechanism termed crack bridging requires larger straight fiber with adequate bond to concrete. Steel fiber are considered a prime instance of this fiber type that is usually referred as large diameter fiber or micro fiber.

1.3 Fiber- matrix interaction

The tensile cracking strain of cement matrix is to a great extent lower than the yield or ultimate strain of fiber. As a consequence, when a fiber reinforced composite is loaded the matrix will crack long before the fiber can be fractured. Once the matrix is cracked composite continues to hold increasing tensile stress. The peak stress and strain of the concrete composite are better than those of the matrix alone during the inelastic range between first cracking and the peak.

1.4 Bridging Action

Pullout resistance of fiber (dowel action) is vital for effectiveness. Pullout strength of fiber considerably improves the post-cracking tensile strength of concrete. As an FRC beam or other structural element is loaded, fiber bridge the cracks. Such bridging action provides the FRC specimen with larger ultimate tensile strength and, more significantly, larger toughness and improved energy absorption.

1.5 Fiber Reinforced Self-Compacting Concrete (FR-SCC)

The removal of vibration for the compaction of fresh concrete makes the utilization of self- compacting concrete (SCC) advantageous in stipulations of cost reduction and development of the work environment. In addition, due to its intrinsic low porosity, SCC usually has high performance properties also in requisites of mechanical behavior and durability. These properties could even be elevated improved if steel fiber is integrated, thus obtaining FR-SCC [8].

The adding of fiber into self-compacting concrete may take benefit of its high performance in the fresh state for homogeneously dispersal within the matrix as well as many advantages like the development in the economic efficiency of the construction procedure, increased speed of construction, decrease or suitably focused rearrangement of labor resources, costs and energy consumption, better working environment, with condensed noise and health hazards, also the role toward the automation and reliability of quality control [4].

The use of fiber might expand the possible fields of application of SCC. Fiber is formed in a wide range of materials, at different shapes, with divergent prop or stiff, cylindrically, rectangular or irregular shaped. They are recognized to affect the workability and the flow characteristics of plain concrete basically. A high content of fiber is not easy to distribute uniformly; a good distribution, however, is required to achieve most favorable benefits of the fiber. Manufactures try to look up the pull-out resistance of the fiber by deforming or crimping them, giving them a surface texture that increases the roughness, in addition to bend or increase the ends to improve the anchorage capacity [2].

Steel fiber and micro-filler materials are extensively used in the construction industry. These materials augment the performance of self-compacting concrete, consisting of very fine powder. Studies proved that these materials advance the quality of the concrete both in fresh and hardened states. As the volume of the micro-filler materials increases, the distance between the large sizes aggregates also increases, dropping the internal friction of the concrete. Since the blockage of the large aggregates is not permitted, the flow and workability properties of the fresh concrete are improved. The developed volumetric water-to-powder ratio method enables the use of binding materials successfully and provides a tool for optimization, as well as new areas for study on the interaction between the microstructure and mechanical properties of the concrete [10].

2. CONCRETE PROPERTIES

2.1 Fresh State Concrete

Kamal et al. [9] prepared five mixes with 10 mm maximum size of aggregate and four mixes with 14 mm maximum size of aggregate. For the experiment, he took 400 kg/m^3 cement and fly ash content each for all ten mixes with different proportions of coarse aggregate and sand with w/p ratio 0.35 for 8 mixes and 0.4 for ninth mix along with various percentages of HRWR admixture ranging from 2 to 3.5%.

Rambo et al. [11] studied the rheological properties of SCC with the addition of two types of steel fiber. One straight (SF1) and one with hooked ends (SF2). With the addition of steel fiber, all concrete mixes had adequate viscosity and deformability under their own weight. The slum flow is observed in range of 620-720 mm which is as per limits given by EFNARC (2005). The unreinforced mix and concrete mix prepared with 1% fiber i.e. C1.0% and C1.0%H also meet the EFNARC specification for viscosity (V-funnel) and passing ability (L-box).The concrete with 1.5% hooked steel fiber was found blocked in V- funnel and L-box Test with two bars.

Anastasiou et al. [12] prepared three series of test mixtures A, B, C with the incorporation of hooked steel fiber of length 30 mm and aspect ratio 60. The self-compacting ability of concrete fresh mixtures was assessed by measuring slum flow, T_{500} sec, L-box for passing ability segregation resistance. It was observed that the slump flow is adequate in all mixes i.e. in range 500-600 mm but clearly decreases with increase of fiber content. Despite higher dosage of chemical admixtures, all mixes showed values higher than 4 sec for T500 sec test which correspond to higher viscosity in SCC. Regarding the passing ability, L-box ratios are also low in all cases which means that all mixes are marginally considered Self compacting concrete mixes, since EFNARC (2005) suggests L2/L1 ratio greater than 0.8. Segregation resistance values of all mixes are found below 1.5% which is the limit as per EFNARC (2005). From rheological properties of mixes it is concluded that higher amount of ladle furnace slag as powder can compensate for the increased segregation due to the use of fiber.

Sahmaran and Yaman [13] prepared five mixes for the study. Fly ash is replaced with 50% of cement content. SF1 (Hooked, l-30mm, l/d-60), SF2 (Straight, l-6mm, l/d-37.5) indicates types of steel fiber. It is concluded from the test results that the slump flow diameter of all mixes were in range 560- 700 mm .The V-funnel flow time were in range of 2.4-2.7 sec. Therefore, all concrete mixes were considered as SCC. In all mixes there was not segregation of aggregates near the edge of spread out concrete as observed from slump flow.

Steel fiber also affected the fresh properties of concrete mixtures.SF1 did not affect the water requirement of mix for same workability. However SF2 type fiber having small diameter reduced the amount of water required for workable SCC mix.

Akcay and Tasdemir [14] studied five concrete SCC mixtures containing cement, silica fume, aggregate and water which were kept same. The nominal content of cement was 700 kg/m^3.The range of high range water reducer admixture was 3.8% by weight of cement for all concrete mixtures. The mixture proportion was Cement: Silica Fume: Water: Natural Sand: Crushed Stone: Coarse Aggregate in ratio 1:0.15:0.22:0.61:0.52:0.93. Three different steel fiber were added with and without hooked ends. Concrete mixtures were designated as REF (Plain SCC), C0.75N (concrete with 0.5%HSS + 0.25%NSH), C0.75H (concrete with 0.5%HSS + 0.25%HSH), C1.5N (concrete with 1% HSS + 0.5%NSH), C1.5H (concrete with 1%HSS + 0.5%HSH)

where, HSS denotes High strength straight steel fiber having length- 6mm, d-0.15mm and l/d-40 NSH denotes Normal strength hooked end steel fiber having length-30mm, d-0.55, l/d-55 HSH denotes High strength hooked end steel fiber having length-30mm, d-0.55, l/d-55. It is observed that with the addition of steel fiber in SCC flow time has increased. The main influencing factor on flow ability is geometry of fiber. Flow rate is decreased with increasing fiber content. Flow test results are found in limits set by EFNARC (2005) specifications.

Khaloo et al. [15] studied the SCC with various volume fractions of 0.5, 1, 1.5 and 2%.Ten mix designs were prepared ,two of which were plain and without any fiber while others had fiber. The abbreviation MS-SCC-PX stands for medium strength self compacting concrete and X is steel fiber volume fraction in percentage and HS-SCC-PX stands for the high strength self compacting concrete with steel fiber volume fraction in percentage. Hooked steel fiber of length 20.6, diameter 0.5 mm and aspect ratio 20 are incorporated in the SCC mixes. The obtained results of fresh concrete revealed that slum flow time were less than 3.4 sec. According to EFNARC (2005), this time must be 2-5 sec. The time for two mixes was found less than 2 sec. The slump flow diameter was in range of 640-800, satisfactory as per EFNARC (2005) specifications. The blocking ratios of all mixes in L-box test were in range of 0.65-0.96. The lowest ratio was 0.65 from MS-SCCF2 and the highest value is 0.96 for HS-SCC. The Blocking ratio of all mixes of MS-SCC was found less than 0.5. Also V- Funnel time observed was in range of 3 sec for HSC-SCC mix and 19.1 sec for SCC-F2. The rheological tests indicated that medium strength SCC reinforced with high vol. fraction especially 2% cannot be considered an acceptable mixture for heavenly reinforced sections due to difficulty of passing.

Gencel et al. [16] studied the fresh concrete properties. *Slump flow time* - All five mixes exhibited satisfactory results in ENFARC range of SCC i.e. 550-800 mm which is an indication of good deformability. Slump flow decreases with the addition and increase in percentage of fiber content. *V-funnel test* - All five mixes of SCCs show flow time value in range of EFNARC i.e. 14- 20 sec. V- funnel flow time and T_{500} measurement of slump flow values are increasing with the addition and percentage of fiber content in the mixtures. *J-*

Ring test - All SCC mixes exhibit differences in heights of concrete inside and outside of ring, approximately 115 mm on an average. The steel fiber with hooked ends cause blocking of particles during flow.

2.1 Hardened State Concrete

2.2.1 Compressive strength

Khaloo et al. [15] studied the compressive strength of medium strength and high strength SCC mixes with steel fiber of different volume fractions. The cylindrical specimens of sizes 150 x 300 mm were casted, cured in water and tested at ages 7, 28 and 91 days. It was observed from test results that compressive strength decreases by increasing the percentage of steel fiber. Strength reduction might be due to decrease of workability of concrete which in turn causes reduction in compaction levels of vibrated concrete.

For Medium strength SCCs, at different ages, addition of fiber volume fractions from 0.5 to 2.0% causes compressive strength to decrease 4.3, 11.6, 14.6 and 18.6% respectively for 28 days specimens with respect to plain concrete (MS-SCC).

For High Strength SCCs, compressive strength decreases by adding more fiber volume fractions from 0.5 to 2.0%. The decrease in compressive strength of 28 days specimens is 0.7, 2.2, 4.2 and 7.5% respectively with respect to plain SCC specimens (HS-SCC).

The decrease in compressive strength for HS-SCC specimens are less than MS-SCC specimens and it may be due to HS-SCC specimens are workable than MS-SCC specimens.

The compressive strength increases with age yet the rate of this increase descends when age of specimen ascends.

Oliveira et al. [17] studied compressive strength of 6 cubic specimens at age of 28 days. The results confirm that the steel fiber volume does not influence significantly the SFRSCC compressive strength. This fact is observed in mixture A to D where total aggregate and w/b was kept constant. For normal steel reinforced concrete it is known that increasing volume and size of fiber did not offer a substantial improvement in compressive strength due to the fact that a fiber addition may lead to increased porosity.

Aydin [18] studied the compressive strength by preparing ten SCC mixes with the incorporation of steel fiber in ratio of 0.25 to 2.0% with the increment of 0.25% and compared the compressive strength test results achieved by plain SCC mixes and all other steel fiber reinforced SCC mixes. It is observed that an increase in compressive strength was registered as the steel fiber content was increased. The highest compressive strength is achieved by Mix, having 2% fiber content by volume.

Kamal et al. [9] studied the compressive strength of SCC mixes containing steel fiber Different percentages of fiber were used in SCC mixes. It is observed that compressive strength was found in range between 30.3 and 42.3 MPa at 28 days. An increase in compressive strength was observed in range between 33 to 40% for steel fiber SCC mixes compared with plain SCC.

Gencel et al. [16] studied the compressive strength of five SCC mixes with steel fiber. The addition of steel fiber at 15, 30, 45 and 60 kg/m^3 and observed an increased the compressive strength by 3.2% and decreased by 3.4, 2.0 and 1.0% respectively. Addition of steel fiber converts the properties of brittle concrete to a ductile material, generally improving the compressive strength. It is concluded that two factors are at play here. Thus, the addition of steel fiber provides reinforcement. Higher fiber concentration disrupts the homogeneity of concrete and causes decrease of strength.

Sahmaran and Yaman [13] studied the compressive strength of hybrid steel fiber reinforced concrete and compared with control concrete mix design. It was observed that reduction in compressive strength was 43% at 28 days and 31% at 56 days. This reduction could be attributed to pozzolanic activity of coarse fly ash. Fiber inclusion does not significantly affect the compressive strength. However, the volumetric ratio of SF2 type fiber of small dimensions increased the compressive strength.

2.2.2 Split Tensile strength

Khaloo et al. [15] studied the splitting tensile strength by casting the cylindrical specimens of sizes 150 x 300 mm, cured and tested at ages of 7, 28 and 91 days. Splitting tensile strength increases by the addition of steel fiber. Adding more fiber vol. fractions causes more increase in splitting tensile strength. It was observed from the results that for medium strength class SCCs, with the addition of fiber vol. fractions 0.5, 1, 1.5 and 2.0% causes split tensile strength to increase 0.9, 10.1, 17.8 and 28.5% respectively with respect to plain specimens (MS-SCC) after 28 days of curing. For High Strength class SCCs, increasing the fiber vol. fractions from 0.5 to 2.0% causes splitting tensile strength to increase 1.2, 3.8, 7.8 and 17.1% respectively with respect to plain concrete (HS-SCC) after curing at 28 days.

Gencel et al. [16] studied the compressive strength of five SCC mixes. It was concluded that when compared with plain concrete, splitting tensile strength of fiber- reinforced concrete increases by 18.6, 23.3, 14, and 21% for mixes 2, 3, 4 and 5 respectively. The increases are significant and the highest value is seen in Mix 3. The splitting tensile strength varies between 8.4 and 10% for 28 days compressive strength of concrete. There are numerous fiber bridging the micro cracks and preventing the expansion. When the tensile stress is transferred to fiber, the transfer can arrest the propagation of macro cracks and substantially improves the splitting tensile strength of concrete.

Sahamaran and Yaman [13] studied the compressive strength of specimens prepared by SCC concrete mixes with the inclusion of steel fiber along with fly ash. The most significant changes are seen in splitting tensile strength results. When coarse fly ash is substituted with Portland cement resulted in lower compressive and tensile strength at 28 and 56 days even though the w/p of mix was reduced. It is observed that there is reduction in splitting tensile strength as volume of Fiber was increased. This reduction of splitting tensile strength is explained by loss of presence of longer fiber that also had hooked ends. Therefore, fiber were mainly responsible for increase in tensile strengths.

2.2.3 Flexural strength

Khaloo et al. [15] prepared SCC with the addition of steel fiber in vol. fractions 0.5, 1.0and 1.5%.For the determination of flexural strength, beams of sizes 100 x 140 x 1200 mm were casted of each mixes and tested at 28 days. It was observed that by increasing the fiber volume fractions, the maximum bending load and flexural strength is increased. For medium strength SCC class, the addition of fiber vol. fractions from 0.5 to 2.0% causes the flexural strength increase by 4.1, 10.6, 13.4 and 46% respectively with respect to plain SCC specimens (MS-SCC) at 28 days.

Moreover, on addition of fiber volume fractions from 0.5 to 2.0% for high strength SCC class causes the flexural strength increase by 5.7, 9.2, 15.2 and 37.5% respectively with respect to plain SCC specimens (HS-SCC) at age of 28 days.

Gencel et al. [16] compared the flexural strength of fiber reinforced SCC with Plain SCC. It was observed that when compared with plain concrete, the flexural strength of fiber reinforced concrete is higher by 13.1, 24.2, 40.6 and 51.7% for mixes 2, 3, 4 and 5 respectively. The highest flexural strength is seen in Mix 5 which has the highest fiber content. Randomly distributed steel fiber control the cracks and stitch them. Therefore, the presence of fiber increases the load needed to fail the beam specimens.

3. CONCLUSIONS

A review of experimental studies and normative documents on steel fiber self-compacting concrete was carried out. Addition of fiber to self-compacting concrete improves its mechanical properties and makes the material very attractive for applications in construction. One of the important roles of steel fiber in SCC structures and elements is providing ductile behavior required for proper structural response to dynamic loadings. Fiber also limit - cracks' development and propagation in structural concrete elements. Experimental studies show that SCC is tough and has high residual strengths after the first crack appeared. Effective fiber contents, appropriate fiber types and most efficient combination of fiber and regular rebars can be selected based on available experimental data.

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