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INFLUENCE OF STEEL FIBERS ON THE PROPERTIES OF CONCRETE: A REVIEW

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ABSTRACT

Fibers are effective in reducing plastic and shrinkage cracking. Steel in the form of short discrete fibers are added to concrete such that they are uniformly distributed and randomly oriented. Steel fibers do not significantly alter free shrinkage of concrete, but at high enough dosages they can increase the resistance to cracking and can reduce the crack widths. In this paper, the influences of steel fibers on the various properties of concrete are discussed based on the previous studies conducted.

KEYWORDS: Fiber Reinforced Concrete (FRC), High Strength Concrete, Steel Fibers

INTRODUCTION

Plain, unreinforced concrete is a brittle material; with a low tensile strength and a low strain capacity the roles of randomly distributed discontinuous fibres is to bridge across the cracks and provide some post-cracking “ductility”. If the fibres are sufficiently strong and sufficiently bonded to the material then it will permit the concrete to carry significant stresses over a relatively large strain capacity in the post-cracking stage. Plain concrete fails suddenly once the deflection corresponding to the ultimate flexural strength is exceeded; on the other hand, fiber-reinforced concrete continue to sustain considerable loads even at deflections considerably in excess of the fracture deflection of the plain concrete.

Fiber Reinforced Concrete (FRC)

According to ACI Committee 544 [1], the term Fiber Reinforced Concrete (FRC) is defined as a concrete made of hydraulic cements containing fine and coarse aggregates and discontinuous discrete fibers.Fibers include steel fibers, glass fibers, synthetic fibers and natural fibers each of which lend varying properties to the concrete. In addition, the character of fiber-reinforced concrete changes with varying concretes, fiber materials, geometries, distribution, orientation, and densities. The amount of fibers added to a concrete mix is expressed as a percentage of the total volume of the composite (concrete and fibers), termed "volume fraction" (V_f). V_f typically ranges from 0.1 to 3%. The aspect ratio (l/d) is calculated by dividing fiber length (l) by its diameter (d).Fibers are usually used in concrete to control cracking due to plastic shrinkage and drying shrinkage. They also reduce the permeability of concrete and thus reduce bleeding of water. Some types of fibers produce greater impact, abrasion, and shatter–resistance in concrete. Small microfibers stabilize the microcracks and increase the strength, reducing the porosity of the cement paste. According to American Concrete Institute (ACI) Committee 544 [1], there are four categories of Fiber Reinforced Concrete namely,

- SFRC (Steel Fiber Reinforced Concrete),

- GFRC (Glass Fiber Reinforced concrete),
- SNFRC (Synthetic Fiber Reinforced Concrete)
- NFRC (Natural Fiber Reinforced Concrete)

It is established that one of the important properties of steel fibre reinforced concrete (SFRC) is its superior resistance to cracking and crack propagation. As a result of this ability to arrest cracks, fibre composites possess increased extensibility and tensile strength, both at first crack and at ultimate, particularly under flexural loading; and the fibres are able to hold the matrix together even after extensive cracking. The net result of all these is to impart to the fibre composite pronounced post–cracking ductility which is unheard of in ordinary concrete. The transformation from a brittle to a ductile type of material would increase substantially the energy absorption characteristics of the fibre composite and its ability to withstand repeatedly applied, shock or impact loading.

Examination of fractured specimens of fiber-reinforced concrete shows that failure takes place primarily due to fiber pull-out or debonding. Thus unlike plain concrete, a fiber-reinforced concrete specimen does not break immediately after initiation of the first crack. This has the effect of increasing the work of fracture, which is referred to as toughness and is represented by the area under the load-deflection curve. In FRC crack density is increased, but the crack size is decreased.

Since, SFRC mixes contain higher cement contents and higher ratios of fine to coarse aggregate than do ordinary concretes, the mix design procedures that apply to conventional concrete may not be entirely applicable to SFRC. Commonly, to reduce the quantity of cement, a portion of the cement may be replaced with mineral admixtures. In addition, to improve the workability of higher fibre volume mixes, water reducing admixtures and, in particular, super plasticizers are often used.

Areas of Application of FRC Materials

The main areas of applications of FRC are thin sheets, roof tiles, pipes, prefabricated shapes, panels, curtain walls, precast elements, composite decks, vaults, impact resisting structures etc.

LITERATURE REVIEW

Definition of Fiber Types

Steel fibers used for reinforcing concrete are defined as short, discrete lengths of steel having an aspect ratio (ratio of length to diameter) from about 20 to 100, while length dimensions range from 0.25 to 3 in. (6.4 to 76 mm), that are sufficiently small to be randomly dispersed in an unhardened concrete mixture using usual mixing procedures. ASTM A820 [2] provides a classification of four general types of steel fibers based upon the product used in their manufacture:

Type I —Cold-drawn wire.

Type II —Cut sheet.

Type III—Melt-extracted.

Type IV—other fibers

ASTM A820 [2] establishes minimum tensile strength and bending requirements for steel fibers as well as tolerances for length, diameter (or equivalent diameter), and aspect ratio. The minimum tensile yield strength required by ASTM A820 [2] is 50,000 psi (345MPa).

Effect of Steel Fibers on the Mechanical Properties of Concrete

The grades of concrete used in the study were 35 MPa (normal strength), 65 MPa (moderately high strength) and 85 MPa (high strength) and the volume fractions of the fiber (V_f) considered for the study were 0.0, 0.5, 1.0, and 1.5%. The maximum increase in the compressive strength, modulus of elasticity, and Poisson's ratio due to the addition of steel fibers was found to be less than 10% for various grades of concrete, whereas the maximum increase in the strain corresponding to the peak compressive strength was found to be about 30% and the maximum increase in the tensile strength, namely, split tensile strength and modulus of rupture due to the addition of steel fibers, was found to be about 40% in various grades of concrete. The post-cracking response was found to be significantly enhanced with fiber dosages for the different concrete grades. Models were derived based on the regression analysis of the test data in order to predict the strength properties of steel fiber reinforced concrete [3].

Mechanical Properties of High Strength Steel Fiber Reinforced Concrete

The volume fractions of steel fibers considered were 0.5%, 1.0%, 1.5%, and 2.0%. The compressive strength of the fiber-reinforced concrete reached a maximum at 1.5% volume fraction. The splitting tensile strength and modulus of rupture of the fiber-reinforced concrete also improved with the increasing volume fraction and showed a maximum of 98.3% and 126.6% improvements, respectively, at 2.0% volume fraction. Strength models were developed for HSFRC and were found to predicts the compressive and splitting tensile strengths and modulus of rupture accurately [4].

Performances of Hybrid Fiber Reinforced Concrete

Hooked-end steel fibers with a length of 60 mm and polypropylene fibers with a length of 12 mm were used for the study. Volume fractions of hooked-end steel fibers were varied by 0.25%, 0.50%, 0.75%, and 1.0% and that of polypropylene fibers were varied by 0.15%, 0.30%, and 0.45%. All the fiber-reinforced concretes contained 10% silica fume as a cement replacement. It was observed that the addition of 1% steel fiber significantly enhanced the splitting tensile strength and flexural strength of concrete. The best performance was observed for a mixture that contained 0.85% steel and 0.15% polypropylene fiber. It was also found that adding fibers to concrete resulted in a decrease in water absorption and, electrical resistivity of concrete compared to that of the plain concrete [5]

In another study containing hybrid fibers as well, the steel fiber was found to improve the splitting tensile and bending strength of the concrete. The best ratio of hybrid fibers improved the concrete splitting strength about 44.34% and bending strength about 49.05% the hybrid fiber reinforced concrete has the best impact resistance ability which is 6.8 times more than that of plain concrete [6].

Influence of Hybrid Fibers on Flexural Behavior of RC Beams

Concrete beam specimens were tested under gradually increasing monotonic loading inorder to investigate its overall flexural response due to the addition of both metallic and non-metallic fibers to the concrete. Steel and polypropylene fibers of 0.5% and 1.0% volume fraction were used in the beam specimens. No much improvement is noticed in the compressive and splitting tensile strengths of concrete due to the addition of polypropylene fibers only. But, an improvement of 25–100% in the splitting tensile strength was noticed when steel and polypropylene fibers are added to the concrete. This study also showed that the addition of steel and polypropylene fibers (0.5% volume fraction) improved the ultimate resistance, displacement ductility, and residual strength of the flexural members as compared with other fiber combinations. While the additions of steel fibers to the concrete improve the load-resisting capacity, the addition of polypropylene fibers significantly enhances the displacement ductility response of flexural members [7].

Effect of Hybrid Fibers on Fracture Energy and Crack Propagation

The crack in cement matrix composites is allowed to fracture under mode-I loading with three-point bending beam specimens. The influence of fiber types and their combinations is quantified by using the toughness index and fracture energy. A proper hybrid combination of steel fibers and polyvinyl alcohol microfibers enhances the resistance to growth of the crack. The hybrid combination of 1.0% steel fiber and 1.0% PVA (12/6) microfibers showed good performance in flexural strength, deflection, and energy absorption capacities. The micromechanical model of the hybrid composites was proposed by using a fiber bridging law, and the numerical model was found to predict the behaviour with greater accuracy that it closely matches the behavior obtained from the experiment [8].

Flexural Behavior of FRC Containing Flat End Steel Fibers

This study tried to model the first-crack load as a function of steel-fiber fraction. For beams with steel-fiber volume fraction of 0.64%, 0.89%, and 1.28%, there was an increase in toughness by 4.8%, 12.4%, and 19.8%. Depending on the concrete mix used, a steel-fiber dosage ranging from 0.89% to 1.28% by volume of concrete is expected to be the best. Regression models were developed to predict the following: (1) first-net deflection; (2) net deflection at any applied load; and (3) first-crack load at different mix combinations of steel fibers. It was also observed that inclusion of steel fibers at 0.64% by volume of concrete did not cause a significant change in the first-crack strength [9].

Stress-Strain Behavior of Fiber-Reinforced Concrete

Three fiber volume fractions of 50 lb/cu yd, 75 lb/cu yd, and 100 lb/cu yd (30 kg/m3, 45 kg/m3, and 60 kg/m3) and three aspect ratios of 60, 75, and 100 are used in this study. A simple equation is proposed to predict the complete stress-strain curve. Addition of hooked-end steel fibers to concrete with or without silica fume was found to effectively increase the toughness of such concrete. A marginal increase in the compressive strength, the strain corresponding to peak stress, and the secant modulus of elasticity was also observed. The equation proposed to generate the complete stress-strain curve for non-silica-fume fiber-reinforced concrete was found to give good correlation between predicted and experimental results [10].

SFRC with a High Reinforcing Index

The reinforcing index is the product of the volume fraction and the aspect ratio of the fibers. The reinforcing index of steel fibers examined was as high as 1.7. Hooked-end steel fibers of various lengths and aspect ratios were considered. From the results it was observed that for a higher reinforcing index, higher is the strain at peak stress and a higher value was obtained for the toughness of SFRC, up to a reinforcing index approximately equal to that corresponding to a 2% fiber volume fraction. Steel fiber reinforced concrete with longer steel fibers and smaller aspect ratio was tougher and out of the tested fibers, the 10/60 fiber showed the best performance in toughness. But adding of fibers didn’t show much variation on the modulus of elasticity and the compressive strength of SFRC [11].

Abrasion Resistance of Hybrid FRC

This work studies the influence of using fly ash, polypropylene fibers, and steel fibers on the abrasion resistance of concrete. The different concrete mixtures considered contained 0, 10, 15, 20, 25, 30, and 45% fly ash as cement replacement in mass basis. The volume fractions of steel fibers were varied by 0.25, 0.5, 1, and 1.5% and that of polypropylene fiber were varied by 0.05, 0.1 and 0.2%. Water-binder ratio was kept constant at 0.35 for all concrete mixtures and the Bohme surface abrasions of the concrete mixtures were measured at 28 days. The experimental results showed that replacement of fly ash with cement reduced abrasion resistance of concrete, whereas, the inclusion of the steel fiber improved the abrasion resistance of concrete. In the case of compressive strength of concrete, addition of steel fibers did not show much effect but the flexural tensile strength was found to considerably increase with the increasing volume fraction of steel. The comparison between the relation of abrasion to compressive strength and abrasion to flexural tensile strength, made in terms of R^2 of the linear regression on log scale, showed that a stronger relation existed between abrasion and flexural tensile strength than between abrasion and compressive strength of the concrete. Polypropylene fiber was not found to improve the abrasion resistance of concrete made with or without fly ash [12].

Fiber Efficiency in SFRC Members Subjected to Uniaxial Tension

The test variables considered were the compressive strength, fiber volume fraction, and fiber aspect ratio. The test results showed that more ductile behavior could generally be achieved with a higher fiber volume fraction and a higher fiber aspect ratio; however, fiber efficiency generally decreased with an increasing fiber index, particularly when the fiber volume was increased beyond 1.0%. A model was derived through the comparison of the test results and the prediction of the DEM. Diverse Embedment Model (DEM) is a rigorous model for predicting the tensile behavior of SFRC. A coefficient was introduced to the DEM to reflect the fiber efficiency. The proposed fiber efficiency factor was found to predict the tensile behavior of SFRC members more accurately particularly for members with a high fiber volumetric ratio [13].

Combined Effect of Silica Fume and Steel Fibers on the Impact Resistance and Mechanical Properties of FRC

This study investigated the impact resistance and mechanical properties of steel fiber-reinforced concrete with water-cement ratios of 0.46 and 0.36, with and without the addition of silica fume. Hooked end steel fibers with 60-mm length and an aspect ratio of 80, with three volume fractions of 0%, 0.5%, and 1% were used as the reinforcing material and silica fume is used as a cement replacement material at 8% weight of cement. The experimental results show that incorporation of steel fibers improve the strength performance of concrete, particularly the splitting tensile and the flexural strengths. The results also demonstrate that when steel fiber is introduced into the specimens containing silica fume, the impact resistance and the ductility of the resulting concrete are considerably increase [14]

In another study on the combined effect of silica fume and steel fibers on the mechanical properties of high strength concretes, two types of steel fibers with aspect ratios of 65 and 80 were used in the experiments and volume fractions of steel fibers considered were 0.5% and 1%. Additions of silica fume into the concrete were 0%, 5%, 10% and 15% by weight of cement content. Water/cement ratio was 0.38 and the reference slump was 120 mm. Compressive strength, splitting tensile strength and flexural strength tests were made on hardened concrete specimens. The use of silica fume was found to increase both the mechanical strength and the modulus of elasticity of concrete. The addition of steel fibers into concrete also improves toughness of high strength concrete significantly. As the steel fiber volume fraction increases, the toughness increases, and high values of aspect ratios give higher toughness. The toughness of high strength steel fiber reinforced concrete depends on silica fume content, the fiber volume fraction and the fiber aspect ratio [15]

Correlations among the Mechanical Properties of High-Performance SFRC

This study analysed the correlations among the compressive, flexural, and splitting tensile strengths of high-performance steel fiber reinforced concrete (HPSFRC). For the study the data was collected from the previously published papers with water/binder ratio in the range of 0.25–0.48, steel fiber volume fraction of 0.5–2.0% with aspect ratio of 40–80, and specimens of 150 mm Ø cylinders and 100 × 100 × 500 mm size prisms. Through the statistical analysis of the collected data, power relations for flexural and splitting tensile strengths as a function of compressive strength was obtained along with the relation between flexural and splitting tensile strengths of HPSFRC with r = 0.94. It was observed that the performances of the proposed models are quite accurate in estimating 28-day flexural and split tensile strengths of HPSFRC, where 90% of the estimated values were within 5% of the actual values. Incorporation of steel fibers up to a volume fraction of 1.5% in HPC was found to show a significant improvement in the indirect tensile strengths [16].

CONCLUSIONS

- The most important property of steel fibre reinforced concrete (SFRC) is its superior resistance to cracking and crack propagation.
- The volume fraction of steel fiber for optimum strength and durability properties were found to be between 0.5% and 2% and the aspect ratios mainly considered are between 50 and 100.
- Among the different types of fibers available hooked end steel fibers were found to be superior in their performance and are mostly used in the previous studies.
- Fibre composites possess increased extensibility and tensile strength, both at first crack and at ultimate, particularly under flexural loading; and the fibres are able to hold the matrix together even after extensive cracking.
- Both the mechanical and durability properties were found to be enhanced when fiber is added to concrete.
- The increase in the compressive strength, modulus of elasticity, and Poisson's ratio due to the addition of steel fibers was found to be less.
- The results of previous studies show that incorporation of steel fibers improves considerably the strength performance of concrete, particularly the splitting tensile and flexural strengths.
- No much improvement is noticed in the compressive and splitting tensile strengths of concrete due to the addition of polypropylene fibers alone. But, an improvement of 25–100% in the splitting tensile strength was noticed when they are supplemented with steel fibers.
- When steel fiber is introduced into the specimens containing silica fume, the impact resistance and the ductility of the resulting concrete are considerably increased.

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