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CIVIL AND ENVIRONMENTAL ENGINEERING REPORTS

E-ISSN 2450-8594

CEER 2020; 30 (3): 0186-0199
DOI: 10.2478/ceer-2020-0039

Original Research Article

EFFECTS OF STEEL FIBRES ON FRESH AND HARDENED PROPERTIES OF CEMENT CONCRETE

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Abstract

Concrete possesses distinct features that make it widely acceptable for use across the globe; however, along with its obvious benefits, it has numerous drawbacks i.e., it is brittle in nature and its production causes an adverse impact on the environment. To counter such problems, researchers around the world have introduced sustainable measures. Fibre addition is foremost among these solutions in that it prevents crack propagation and increases the overall strength of concrete. In the present age, civil engineering structures have their own structural and durability requirements and so, modification in traditional concrete has become a necessity. This research is targeted at steel fibre reinforced concrete (SFRC), which is a superior quality concrete because of its enhanced strength. The steel fibres are obtained from binding wire that is used to tie the steel reinforcement. By referring to past research, steel fibres with an aspect ratio (length to diameter ratio) of 30 were considered favourable. The controlled, mixed design of the concrete was prepared with a targeted strength of 4000 psi and, while mixing the concrete ingredients, fibres were added to allow uniform dispersion. The fresh and hardened properties of workability, compressive, and tensile strength were tested and the results of fibres at 0%, 1%, 2% and 3% concrete mass were compared and analysed. The results indicated that highest compressive and tensile strength values were achieved with

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3% fibre addition. However, with further addition, it was observed that concrete loses its workability. Therefore, it is suggested that 1% addition of steel fibres produces good strength with sufficient workability.

Keywords: concrete, steel fibres, compressive strength, workability, tensile strength

1. INTRODUCTION

Concrete is a blend of different materials such as cement, fine aggregates, coarse aggregates, and a suitable amount of water. It is currently the most used building material [1,2]. This material, today, is employed in the construction of gravity defying skyscrapers and other marvellous structures. In essence, the fresh and hardened properties of concrete rely on the mix design proportions; starting as a liquid material, when it dries, it becomes as hard as stone. This property has earned it its name: "liquid rock". Intrinsically, concrete is classified as a quasi-brittle material [1]. Under increased load, concrete loses its loading capacity when failure begins, resulting in developing cracks under stress. Moreover, the cement industry is regarded as one of the major contributors of hazardous greenhouse gases, particularly CO_2 [3,4], and the cement industry is considered to be responsible for 10% of global CO_2 emissions [5]. Hence, cement usage must be minimized in order to meet the goals of a sustainable environment and so, in order to acquire the necessary strength or to maintain the targeted strength, it is preferable to employ other more sustainable methods than to use cement in excessive quantities. This practice is both feasible as well as environmentally friendly. Of all the techniques employed to cater to this need, the addition of cementitious materials and fibres is both prominent and distinct [6–9]. Fibres are introduced in order to increase the ductile behaviour of concrete, supplement its strength, and make it more eco-friendly. These fibres are randomly distributed in the concrete mix and prevent and control propagation of cracks. Fibre reinforced concrete (FRC) can also be considered a better alternative as steel bars are costly and non-renewable [10]. FRC not only achieves higher tensile and flexural strength but also improves its modulus of elasticity, ductility, and fatigue resistance [11]. Many studies have been conducted to evaluate the strength and fresh-state behaviour of fibre reinforced concrete. Various fibres i.e., sisal, hemp, plastic, carbon, hybrid, glass, human scalp hair, polypropylene etc. are currently in use for preparation of FRC [12–17].

Sisal plant fibres have been used in concrete reinforcement and the results obtained were highly acceptable with improvement to both tensile strength and elastic modulus [12]. Similarly, domestic plastic waste fibres were introduced in M20 concrete and at 0.5% reinforcement level, the compression strength of the concrete increased by up to 5.12% at the 28th day of curing [13]. In another study, the compressive strength of concrete containing glass fibres and aramid fibres was compared, wherein the results revealed that aramid fibres increased the strength of M20 concrete by up to 66%. It can, therefore, be said that by using aramid fibres in M20 concrete, one can enjoy the benefits of M35 concrete [18]. Recently, another study demonstrated that nylon fibres of 20mm length supplement the compressive and tensile strength of concrete by up to 31% and 66%, respectively. Such an increase in the tensile strength of concrete in particular, is no doubt a huge development in the field of concrete technology [9]. Among all the available fibres, steel fibres are more prominently used in concrete. Although the workability of steel fibre reinforced concrete (SFRC) is observed to be less than conventional concrete, the SFRC exhibits greater ductility and strength values [1,11,19]. In G30 concrete, steel fibres at 0.86% concentration increased the tensile and compressive strength of concrete when tested at 28 days of curing [20]. Moreover, crack formation is also observed as very small in steel fibre reinforced specimens when compared to non-fibre specimens [15,16].

Reviewing all of the above led to the idea of determining the optimum level of steel fibre reinforcement in normal strength, conventional concrete. The present research is based on an analysis of the fresh and hardened properties i.e., workability, compressive strength, and tensile strength, of Steel Fibre Reinforced Concrete (SFRC). Generally, fibre is characterised by its aspect ratio, being the ratio of length to cross sectional dimension (diameter in the case of a circular cross section). The quantity of steel fibre and the aspect ratio are factors that impact the hardened properties of concrete [20]. The flexural and tensile strength of SFRC can be increased by increasing the aspect ratio from 40 to 70 [21]. The decreased workability and plasticity of SFRC can be maintained by adding newly developed, high-range super plasticizers [22]. Because of its enhanced strength and reduced threat to the green environment, SFRC is used in the construction of hydraulic structures, highway pavements, rock slope stabilisation, tunnel lining, manhole covers. etc. [22].

This study represents a novel investigation because it employs fibres obtained from cheap and economic binding wire, locally available in abundance from markets, for the purpose of inducing tensile strength in the concrete. This can all very easily be done with manual labour on-site or in the laboratory. Hence, this study is novel from both an economic and eco-friendly perspective. For fibre reinforcement in concrete, the aspect ratio (ratio of length to diameter) is of extreme importance [23,24]; short and straight fibres allow easy dispersion in fresh concrete [15,16] and, so, straight steel fibres of 30mm length were used in this study, as adopted from previous studies of prevailing literature [23,25,26].

2. MATERIALS, MIX DESIGN, AND METHODOLOGY

2.1. Materials

The materials used in this study were steel fibres together with the basic ingredients of a concrete matrix i.e., coarse aggregates, fine aggregates, Ordinary Portland Cement (OPC), and water in a suitable quantity as illustrated in the standard mix design.

2.1.1. Steel Fibres

The steel fibres used in this research were obtained from binding wire, employed for binding steel reinforcements in RCC works. The wire was cut into small pieces or fibres as depicted in Figure 1. The properties of the fibres are summarized in Table 1 hereunder:

Fig. 1. Steel Fibres

Table 1. Properties of Steel Fibres

Properties	Values
Fibre Length	30mm
Fibre Diameter	1.05mm
Aspect Ratio	28.6

2.1.2 Cement

Grade 43 OPC was used in this study. The chemical composition of OPC included Al_2O_3 (6.03%), Fe_2O_3 (3.2%), SiO_2 (20.67%), CaO (59.63%), MgO (3.66%), K_2O (0.67%), SO_3 (2.49%), Free Lime (1.36%), and Loss on Ignition

(8.44%). The physical properties of the cement are detailed in Table. 2 hereunder.

Table 2. Properties of Ordinary Portland Cement

Properties	**Values**	**Standards** [27]
Consistency	29%	-
Fineness	2.88%	
Initial Setting Time	85 minutes	≥45 minutes
Final Setting Time	310 minutes	≤375 minutes
Compressive Strength (MPa)		
3 days	15.74	
7 days	23.88	
28 days	31.92	≥19 MPa

2.1.3 Water

Ordinary drinkable water, meeting the standards of [28], obtained from a water cooler was used in this research work for the mixing and curing of concrete mixes. The temperature of the water used for mixing concrete is of extreme importance; it is recommended that mixing of concrete should be conducted at room temperature (20-35 degree centigrade) [29]. Hence, the concrete in this study was mixed as suggested in [29] and the specimens were prepared to comply with the standards set in [30].

2.1.4 Fine Aggregates

Fine aggregates are another essential constituent of mortar and concrete. The sand particles which, when sieved, pass through a #4 sieve and are retained on a #200 sieve are known as fine aggregates. The properties are given in Table 3 hereunder.

Table 3. Properties of Fine Aggregates

Properties	**Values**
Fineness Modulus	2.72
Specific Gravity	2.78
Water Absorption	0.48%

2.1.5 Coarse Aggregates

The aggregates which are retained on a #4 sieve are known as Coarse aggregates. In this study, aggregates in the size range between 19.5 mm to 4.75mm were utilized. The aggregates were weighed and sieved prior to mixing to ensure adequate bonding and filling in the concrete matrix. The properties are given in Table 4 hereunder.

Table 4. Properties of Coarse Aggregates

Properties	Values
Specific Gravity	2.65
Water Absorption	1.32%
Shape	Angular

2.2. Mix Proportions

Controlled concrete mix consists of 615 kg/m^3 sand, 1080 kg/m^3 coarse aggregate, 410 kg/m^3 cement, and a water–cement ratio of 0.55, for a targeted mean strength of 4000 psi. The mix design ratio adopted was 1: 1.5: 2.61 as calculated from the traditional DoE mix design method. The control mixes had 0% steel fibre (SF0) and were cured for 3,7, and 28 days, respectively. Other mixes were SF1, SF2, and SF3, corresponding to 1%, 2%, and 3% addition of steel fibres by weight of cement, respectively.

2.3. Specimen

Six concrete cubes of 100 mm × 100 mm × 100 mm, and six concrete cylinders of 100 mm diameter and 200 mm height were prepared, each with a varying quantity of steel fibres: 0%, 1%, 2%, and 3%. The cubes were moulded for a compressive strength test and the cylinders were cast for a split tensile test.

2.3.1 Specimen Preparation

The controlled concrete mix was cast into lubricated cube moulds and cylinders and then compacted using a table vibrator, after which they were kept undisturbed for 24 hours before being demoulded and put in curing tanks for 3, 7, and 28 days of curing.

2.3.2 Specimen Testing

The concrete mixes were subjected to a slump test in order to evaluate their flow and workability. The concrete specimens i.e., cubes and cylinders, were tested for compressive and tensile strength with the help of a universal testing machine in a concrete laboratory. The strength values are the average of three trials on each of the specimens.

2.4 Research Methodology

The basic ingredients of concrete: ordinary Portland cement, fine aggregates, coarse aggregates, and water were collected. Fine aggregates were then tested for their zones, the coarse aggregates were well graded, and a specific range of aggregate sizes were selected from 4.75 mm to 20 mm. Steel fibres of 3 cm in length and with a diameter of 0.105 cm each were also prepared by cutting the bending wire manually. Controlled concrete mix designs were made to an appropriate target mean strength. Five concrete mixes were thus prepared with varying quantities of steel fibres: 0%, 1%, 2%, and 3%. For checking the freshly prepared property, a slump test was conducted to test the workability of the concrete. Six cubes, each with dimensions of 100mm x 100mm x 100mm, and six cylinders of 100 mm diameter and 200 mm height were prepared with each of the aforementioned proportions of steel fibre. The cubical compressive strength and split tensile strength of the cylinders was then determined.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

3.1 Workability of SFRC Mixes

If concrete is transported, placed, compacted, and finished properly, without segregation or bleeding, then it is said to be workable. Compacting equipment, reinforcement, grading of aggregates, method and duration of transportation, quantity and characteristics of cementing materials and chemical admixtures, shape and surface texture, amount of water and entrained air, section size, and temperature all affect the workability. In this research, the workability of concrete mixes was recorded using a slump cone as per the specifications set in ASTM C143 [31]. The results depicted that the workability of concrete is highest with the conventional mix i.e., when no fibres are added. The data evidently shows that the increasing percentage of steel fibres negatively affects the workability of concrete. The reduction in the flow-ability of the concrete is caused by the rough ends of the steel fibres and it is observed that the steel fibres tend to introduce resistance to the mobility of concrete [11]. The reduction in slump of fibre reinforced concrete was also observed in the results of [12,15,19,32].

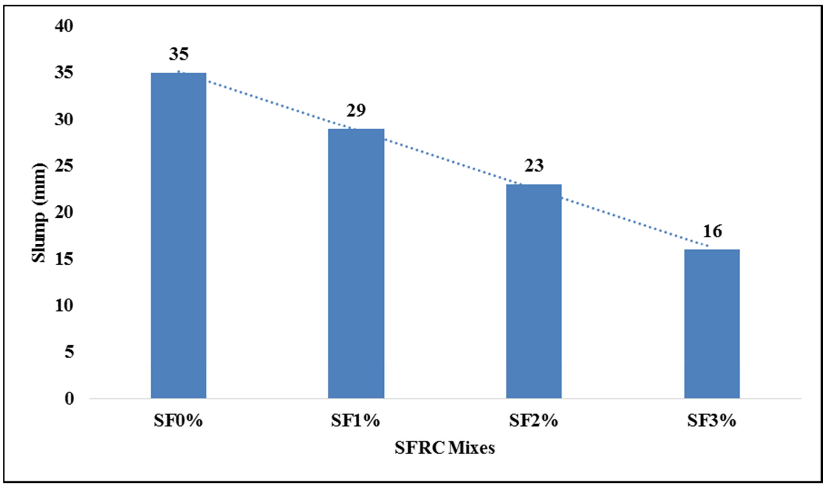

Fig. 2. Workability of SFRC Mixes

3.2 Compressive Strength of SFRC

Compressive strength is the ability of a material or structure to carry loads on its surface without any cracking or deflection. A material under compression tends to reduce in size, while when in tension, its size elongates. This provides an idea about the properties of concrete and this test helps in observing whether the concreting has been done properly or not. For general construction, the value of compressive strength ranges from 15 MPa to 30 MPa and is higher for commercial and industrial structures. The factors which affect the compressive strength of concrete are water-cement ratio, cement strength, quality of concrete material, and quality control during production of concrete, etc. Concrete cubes are recommended as the standard specimen for carrying out compressive strength testing. The compressive strength of concrete cubes in this research was tested at 0%, 1%, 2%, and 3% steel fibre addition to the mass of concrete. The compressive strength test was conducted as prescribed in [33]. All the samples were tested at curing periods of 3 days, 7 days, and 28 days and the full results are shown in Figure 3 hereunder.

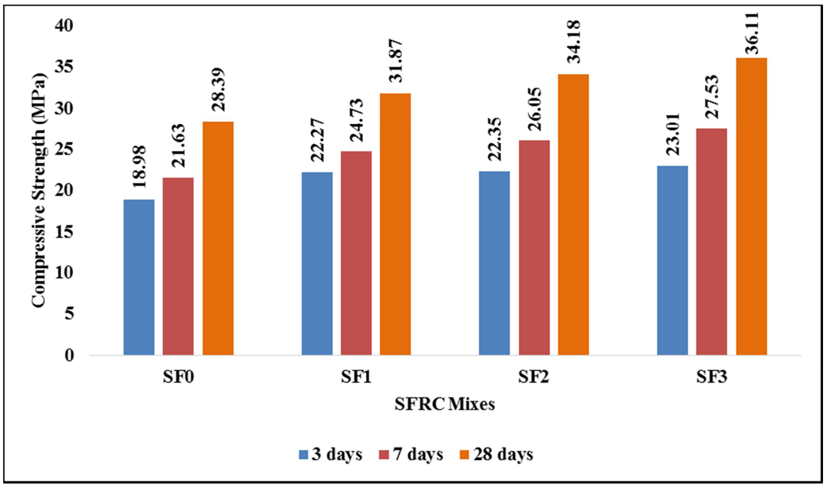

Fig. 3. Compressive Strength of SFRC Cubes

3.3 Tensile Strength of SFRC Cylinders

Tensile testing is also known as tension testing. In this test, a sample was subjected to a controlled tension until failure. Ultimate tensile strength, breaking strength, maximum elongation, and reduction in area are the properties which are directly measured through a tensile test. Concrete cylinders are recommended as the standard specimen for carrying out the tensile strength test. The tensile strength affects the extent and size of cracking in a structure. As concrete does not perform well under tension, so cracks could developed when the tensile forces exceed its tensile strength. Therefore, by determining the tensile strength, we can know the load at which particular concrete members may begin to crack. Testing the splitting tensile strength of concrete cylinders is a method used to determine the tensile strength of concrete as recommended in the standards of ASTM C496 [34]. This research procedure likewise included the preparation of concrete cylinders for testing the tensile strength of concrete. The cylinder dimensions were 200mm in length and 100mm in diameter. For each steel fibre ratio, two cylinders were prepared. The specimens were cured for a period of 3 days, 7 days, and 28 days, respectively, in a curing tank. The test was carried out in a Universal Testing Machine (UTM) by placing the concrete cylinders laterally. The load is increased to a limit where the cylinder develops lateral cracks and splits into two halves. It is quite clear from the results that there is a high increase in splitting tensile strength of concrete when mixed with 1% steel fibres. Comparatively, the splitting tensile strength increases at a lower rate with 2% and 3% steel fibre addition, respectively. The results are illustrated in Figure 4 hereunder.

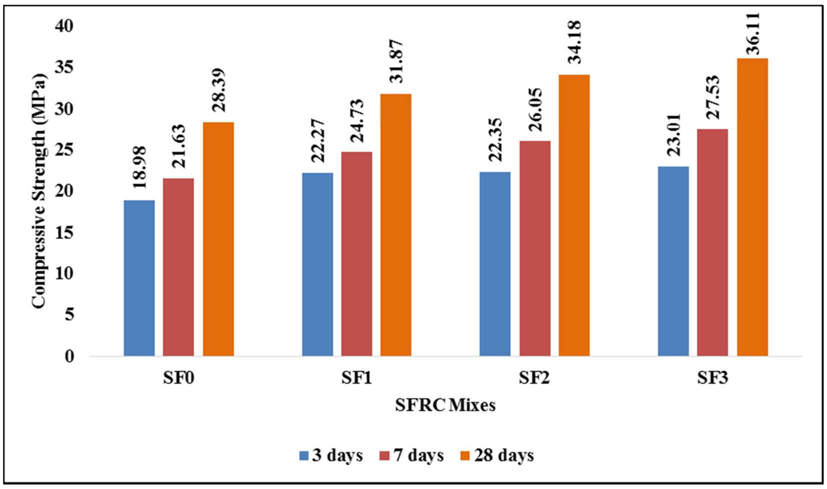

Fig. 4. Tensile Strength of SFRC Cylinders

It is evident from Figure 5 that there is a strong relationship between compressive strength and tensile strength of steel fibre reinforced concretes. With increasing quantity of fibres, both the tensile and compressive strengths increased. Nevertheless, this relationship justified the theory that tensile strength is a function of compressive strength and both are directly proportionate i.e., an increase in compressive strength gives a similar increase in tensile strength and vice versa.

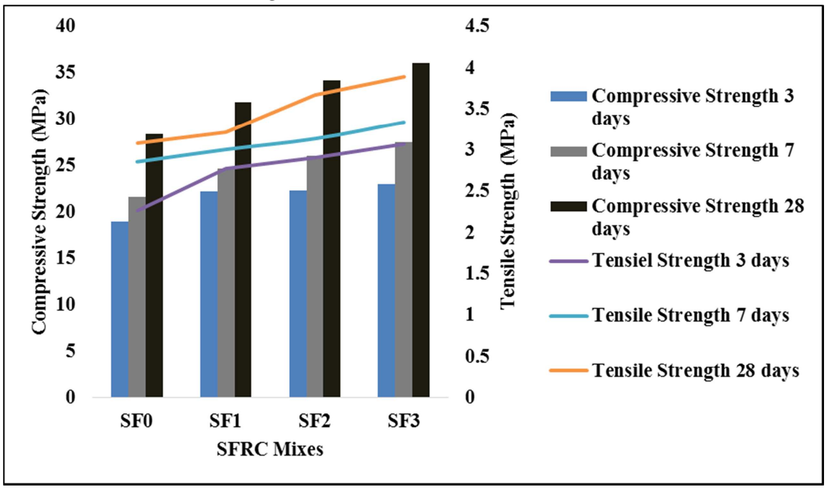

Fig. 5. Comparison of Compressive and Tensile Strength Values

4. CONCLUSIONS

It is evident from the results that, with the addition of steel fibres, the concrete workability reduces, which can be compensated by using admixtures and plasticizers. Moreover, the results of compressive and tensile strength tests and the comparison of strength values suggest that the addition of steel fibres is beneficial for strength as the strength values were found to increase with the addition of fibres, and the trend of strength development continued with increase in days of curing. However, the highest strength values were obtained for SF3% mix, but there was a serious adverse impact on workability with 3% fibre reinforcement.

It is, therefore, concluded that with increasing percentage of steel fibres, the workability reduces greatly. The percentage of steel fibres employed for the SFRC should be 1%, because, in comparison to other ratios, the workability is satisfactory and compressive strength and tensile strength are also adequate.

5. RECOMMENDATIONS

Although sufficient strength is obtained while retaining good workability at 1% steel fibre addition, it is suggested that the strength must be tested at a steel fibre ratio less than 1%, greater than 1%, and less than 2% in decimals. Only a certain kind of straight steel fibres of approximate aspect ratio 33 are added to the mix. Hence, further research is needed whereby changes are made to the dimensions and shape of the fibres. Steel fibres are obtained from bending wire, hence, the material can easily be altered to observe the varying results.

Acknowledgements

This research work would not have the spirit and excellence it possessed without the invaluable academic, psychological, and supervisory help provided by our worthy teachers and parents. Furthermore, the authors are also grateful to the staff and workers of the Concrete Laboratory of Civil Engineering Department, MUET Jamshoro, for providing the required facilities for this research.

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Editor received the manuscript: 02.06.2020