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Production of Steel Fiber Reinforced Concrete with Different Mix Design Ratios

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Abstract

Concrete is a brittle material and in order to make it ductile steel is used. In the current project, steel fibers were used as an additive material by weight of sand. Tests were performed on three different design mix ratios, i.e., M1, M2 and M3 at 0%, 5%, 10% and 15%. Numerous physical tests were performed on the materials used. The slump test was performed in fresh state and compressive test was performed in the hardened state of concrete mixes. From the result of the slump test, it was concluded that workability decreased due to two reasons. The first reason was an increase in the percentage of steel fiber and the second reason was the difference in mix design ratio. The compressive strength increased at 5% in M1 and M2. On the contrary, the strength decreased in M3 at 5%. In all M3 mixes, the strength significantly decreased. Conclusively, the strength increases due to the crack bridging effect and it decreases due to weak bonding.

Keywords: steel fiber reinforced concrete, compressive strength test, workability, mix design ratio, additive

Introduction

Concrete is a fragile material which has a high compressive quality. However, it also has a low tensile strength which is around one tenth of its compressive quality. To defeat this confinement of solid concrete, it is strengthened with steel. Plain cement has been considered for this purpose for quite a while, yet another range of potential outcomes is unguarded with the utilization of steel fibers. This project looks at the use of steel fibers in concrete from the stand point of the effects of steel fibers in terms of optimum quantity, impact of their shape and size on key concrete characteristics. The steel fibers used in this project are the tiny pieces (typically 1mm to 3mm in length) of reinforcing material possessing specific characteristics. An important characteristic of tiny steel fibers is their "aspect ratio" (ratio of length to its diameter). This aspect has been reported to be of paramount importance by earlier researchers and it was also proved to be of similar significance in this work. Steel fiber has been used in concrete since the early 1900s.

SFRC (Steel fiber reinforced concrete) is a composite material which can be made with ordinary Portland cement, coarse aggregate, fine aggregate and incorporating them with steel fibers. The main uses of steel fibers are to improve the mechanical resistance, improve resistance to abrasion, capacity to carry impact load and to improve the fire resistance of concrete [1]. The effect of steel fiber is significant when it comes to crack control and energy absorption which increases the capacity of load transfer of concrete [2]. Addition of fibers in concrete, however, generally result in decrease of workability of fresh concrete. The factors which contribute in decreasing the workability are the length of fibers and the roughness of the surface area of the fibers.

Besides increasing the energy absorption characteristics of concrete, steel fibers also increase its toughness.

The increase in flexural and tensile strength of concrete as a result of the inclusion of steel fibers has been known for some time [3]. In this project, the purpose of adding steel fibers is to improve the mechanical properties of concrete with varying percentages of fibers. The variation in their shape and size has been investigated also while keeping other parameters constant. Earlier researchers have reported an increase in strength of concrete under almost all types of loading [4]. Steel fibers significantly reduce the growth of cracks although they cannot totally eliminate the concrete cracking [5]. Randomly distributed steel fibers in a concrete matrix are extremely effective in enhancing the compressive as well as the tensile strength of concrete and thus enhancing its application in a number of fields [6]. The aim of the current research is to study the potential use of steel fibers by weight of sand which includes the evaluation of the effect of steel fibers on the compressive strength of concrete with different mix design ratio, ascertaining the performance of different mix design ratio on steel fiber reinforced concrete and to find out the characteristics of fresh concrete and hardened concrete incorporating steel fibers.

Considerable amount of research has been done on concrete incorporating steel fibers in recent years. Khaloo did a research on the use of steel fibers in self-compacting concrete and concluded that the workability of medium and high strength self-compacting concrete classes is reduced by increasing the steel fiber volume fraction [7]. Tiberti studied cracking behavior in reinforced concrete members with steel fibers and concluded that steel fibers may significantly improve the tension stiffening into the undamaged portions of concrete among cracks. Additionally, they may provide noticeable residual stresses at a crack due to the bridging effect caused by its enhanced toughness [8]. Karahan used milled cut steel fibers in concrete and found out that milled cut steel fibers significantly improve the tensile strength and decrease the drying shrinkage. Although no significant increase was observed in absorption, porosity and sorptivity, chloride ion permeability increased drastically with the increase of milled cut steel fiber content [9]. Pajak studied flexural behavior of self-compacting concrete reinforced with different types of steel fibers and concluded that self-compacting concrete achieves the maximum crack mouth displacement for lower deflections as compared to normal vibrated concrete [10]. Aggelis monitored the mechanical behavior of concrete with chemically treated steel fibers by acoustic emission and found out that coating effectively contributes to the deflection of the cracks from the fiber–matrix interphase into the concrete matrix [11].

2. Experimental Program

To see the effect of steel fiber on the properties of concrete, tests were performed on concrete samples. For the preparation of these samples, different physical tests needed to be performed on crush and sand.

The first step was to collect the coarse aggregate, fine aggregate and cement. Then, different tests were performed to find out different physical properties.

2.1.Materials Used

i. Cement

Askari Portland cement was used in this research for casting cylinders of all concrete mixes.

ii. Fine Aggregate

The fine aggregate used in this research was Lawrencepur sand which was collected from the region of Taxila. The fineness modulus of fine aggregate was 2.66. The water absorption of coarse aggregate was 1.12% and the moisture content was 2.29%. The compacted bulk density came out to be 1600 kg/m^3.

iii. Coarse Aggregate

The coarse aggregate were also collected from Taxila region and are also known as Margalla crush. The coarse aggregate used in this experimental investigation were of 12.5mm and 10mm sizes, crushed angular in shape and added in equal percentages. The water absorption of coarse aggregate came out to be 1.01% whereas moisture content was 0.53%. The compacted bulk density was also determined to be 1911 kg/m^3.

iv. Water

Tap water was used with a pH value of 7.2.

v. Steel Fibers

The steel fibers used in this project were obtained from local resources. The length of steel fibers was 3mm and the steel fibers used were straight round fibers.

2.2. Materials Used

The mix design ratio and W/C ratio adopted for concrete during this research is shown in table 1. Three different types of mixes were made using same W/C ratio but with varying mix ratio. W/C ratio was selected to be 0.55 because it is the ideal mix ratio for normal and low strength concrete as described in the current standards and past researches.

Table 1. Mix Design Ratio for Concrete Mixes

Concrete Mixes	Mix Design Ratio	W/c Ratio
M1	1:2:4	0.55
M2	1:3:6	0.55
M3	1:4:8	0.55

Four unique sorts of blends were set up in which the first one was control blend. Likewise, the other three blends were set up by the expansion of the various rates of steel fiber. Cement, sand and crush were blended in a mixer; first in dry condition for one minute and afterwards the required quantity of water was added and blending was achieved within two minutes in any event. Temperature was also noted at the time of mixing. Slump test was performed after the proper mixing of the specimens.

For casting the cylinder, standard cast iron metal moulds of size 150mm x 300mm cylinders were used. The cylinders were oiled on all sides before the concrete was poured into the moulds. The mixed concrete was filled in three layers and temped in the concrete mould. Excessive concrete was removed with trowel and the top surface was refined to achieve a smooth level. Fresh concrete was levelled and allowed to set in.

After casting, the moulded specimens were stored at a room temperature for 24 hours in the laboratory. The specimens were then removed from the moulds and immediately submerged in a curing tank filled with fresh water for 28 days.

3. Scope of Testing

A total of 108 cylinders were casted and tested in this project as shown in table 2.3. 6 cylinders were casted and tested for each mix on 7, 28 and 90 days at different percentages.

Table2. Total Number of Cylinders for 7, 28, and 90 Days

S.F percentage	M1 (Cylinders)	M2 (Cylinders)	M3 (Cylinders)
0	9	9	9
5	9	9	9
10	9	9	9
15	9	9	9

4. Results and Discussion

4.1. Slump Test

The steel fiber reinforced concrete specimens showed that increasing the percentage of steel fiber reduced the workability of the concrete which was reduced due to higher friction and rough surface texture of steel fibers. Another reason for the reduction of workability was the increase in coarse and fine aggregate of the design mix ratio. The results are shown in Table 3.

Table 3. Slump Test Values for All Mixes

S.F percentage	M1 (in)	M2 (in)	M3(in)
0	2.63	1.42	1
5	2.07	0.9	0.3
10	1.28	0.1	0
15	0.15	0	0

4.2. Compressive Strength Test

The cylinders of size 150mm x 300mm were used for compressive strength test. The load was applied in accordance with the ASTMCA39/C39M-12a test method. The test results are presented in Figs. 1-3 given below.

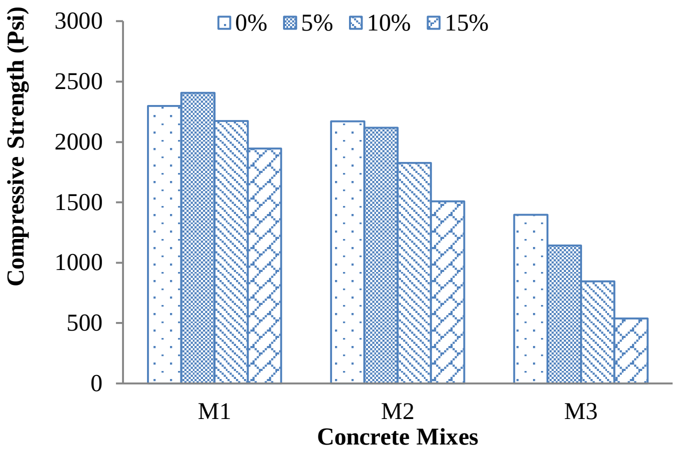

Figure 1. Test results for 7 days for all mixes

It can be observed that the addition of steel fibers resulted in increasing concrete compressive strength at 5% and significantly decreasing it at 10% and 15% as compared to the normal concrete at 7 days strength.

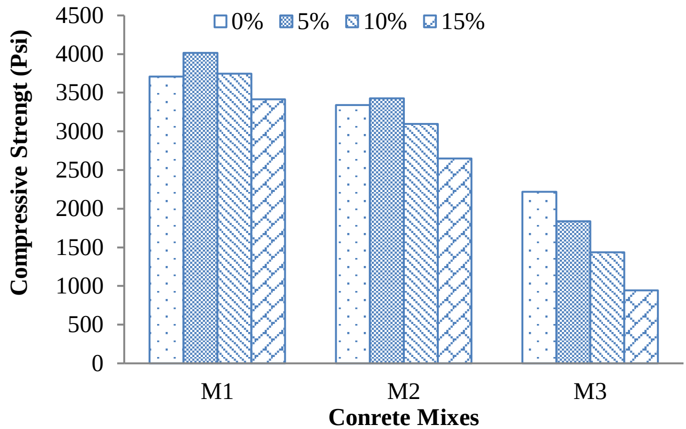

Figure 2. Test results for 28 days for all mixes

This increase in compressive strength was more prominent at 28 days as compared to the initial strength of 7 days. In case of M2 mix, when steel fibers were added at 5%, compressive strength decreased initially but at 28 days, it came out to be more than control blend. This might be due to reduction in initial hydration because of steel fibers. Although at 28 days, when concrete had gained most of its strength, steel fibers acted as a barrier against crack propagation which led to an increase in the overall compressive strength. Whereas in case of M3 mixes, the strength of concrete was significantly reduced when steel fibers were added. This reduction was because of weak bonding between concrete and steel fibers. Bonding got even worse when mixes were prepared with low cement and increased fiber content.

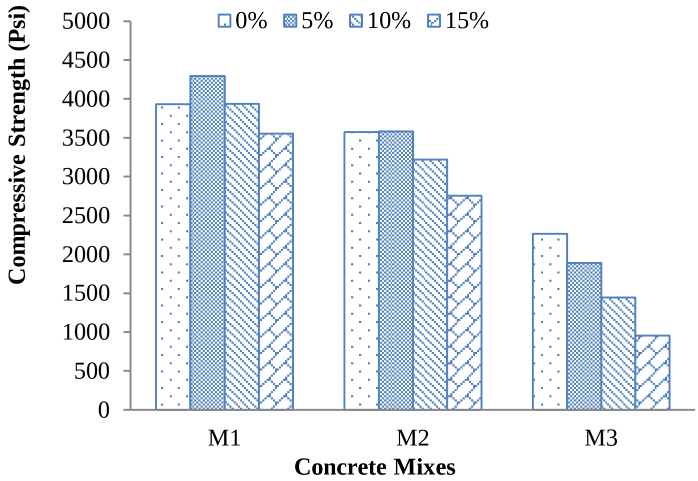

Figure 3. Test result for 90 days for all mixes

The results obtained for 90 days testing were very similar to that of 28 days strength. When steel fibers were added at 5%, the compressive strength for 90 days came out to be more than the control blend. This was because most of the hydration process was complete by 28 days and no significant changes occurred afterwards. Whereas in case of M3 mixes, the strength was significantly reduced when steel fibers were added.

5. Conclusions

Following conclusions were drawn from the work carried out in this research.

1) It was observed that the workability of steel fiber reinforced concrete was reduced as the percentage of steel fibers increased.
2) The steel fibers used in this project showed a considerable effect in increasing the compressive strength of concrete as compared to conventional concrete in M1 and M2 (up to 5%), whereas SFRC showed unsatisfactory performance in M3.
3) The strength increased due to the crack bridging effect of steel fibers and decreased due to the weak bonding between concrete and steel fibers, especially with reduced cement and an increased steel fiber content.

4) The ultimate strength at 90 days of M1, M2 at 5% was 4293 psi and 3583 psi, respectively.

6. Recommendation

It is recommended that a 5% addition of steel fibers is optimum in case of concrete mixes with mix ratios of 1:2:4 and 1:3:6, since it increases its compressive strength over time. On the contrary, addition of steel fibers is not recommended in case of lean concrete, that is mix ratio of 1:4:8 as its strength decreases considerably over time.

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