Impact of Steel Fiber on the Mechanical Property of Concrete Containing Mineral Admixture

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Abstract. This article analyzes the mechanical behaviour of concrete containing fly ash, silica fume, and steel fibre, with 331 kg/m\textsuperscript{3} cement, 674 kg/m\textsuperscript{3} fine aggregate, and 1171 kg/m\textsuperscript{3} coarse aggregate. A concrete mixture with a water-binder ratio of 0.40 is prepared. Mineral admixtures such as silica fume and fly ash were also added to the cement in concentrations of 10% and 20%, respectively. The steel fibres are then incorporated in various proportion (0.5 percent, 1.0 percent, 1.5 percent, and 2.0 percent). The cube-shaped sample is used to test the compressive strength of hardened concrete with and without steel fibre, while the cylindrical sample and beam are utilised for indirect tensile and flexural strength testing. On the three replicas, all of the tests with various percentages of steel fibre were carried out, and the average value is reported in this article. The concrete without steel fibre had average compressive, flexural, and tensile properties of 60.05 MPa, 5.72 MPa, and 9.45 MPa, respectively and after adding 2 percent steel fibre, it increased to 74.25 MPa, 6.14 MPa, and 23.68 MPa, respectively, after 28 days. By performing a nonlinear analysis of the experimental data, a link between the percentages of steel fibre, curing days, compressive-tensile strength ratio, and compressive-flexural strength ratio has been established. The current study will help in lowering cement use, therefore minimising the negative environmental effect of cement manufacturing.

Keywords: Steel fiber; mineral admixture; mechanical property; statistical model

1. Introduction

Fibre in concrete has been used since the early twentieth century, when asbestos was widely utilised, but as a result of health concerns, it was gradually phased out. Due to the negative health impact of asbestos, several alternate fibers have been developed to use in concrete. Concrete is a building material having a high compressive strength relative to its tensile strength, which is about 8% of compressive strength. Further, the concrete is a brittle material showing low failure strain. Now a day, there is a trend of utilizing fiber reinforcement in the concrete to improve its mechanical behavior and durability. However, before using any fiber, its performance should be known to achieve the desired result [1–5]. To fully comprehend the performance, it is necessary to understand the many parameters like as length, diameter, and the technique utilised to create the fibre. Several academics have looked at the effects of geometry and fibre materials on concrete properties. The effectiveness of Polypropylene fiber has been proved to control the shrinkage crack of concrete by the previous researcher. However, with an
Improvement in mechanical behaviour of concrete glass fibre has been proven to be helpful in preventing shrinkage cracks. Several researches have also shown that Polypropylene fibre has a favourable influence on compressive strength, whereas, several reported no impact of the same on compressive strength. Similarly, several researchers reported no impact of Polypropylene fiber on flexural strength, whereas, several reported the positive impact and negative impact of the same. Steel fibre is widely utilised in the construction sector, for example, in pavement, precast concrete, and tunnel liner. The improved post crack performance of the concrete containing steel fibre has been reported by several researchers. But very few studies are available pointing the impact of fibre reinforcement on concrete containing mineral admixture and further development of a numerical model to find out the percentage of fiber reinforcement. As a result, the impact of fibre reinforcing on concrete with mineral additive has been investigated in this study, and a relationship between the percentage of fibre and strength and curing time has been established.

2. Materials and methodology

In this investigation, an arbitrary combination of cement, fine and coarse aggregate is made with a water-binder ratio of 0.40, and the quantity is shown in Table 1 [6–8]. In this investigation, fine aggregate with fineness modulus and specific gravity of 2.19 and 2.62 was employed. Whereas, the coarse aggregate was of 20mm, maximum size and specific gravity of 2.72 was used which was falling in Zone II. Mineral admixtures such as silica fume and fly ash were added in 10% and 20% of the cement, respectively, to analyze the impact of steel fibre on mechanical characteristics, and steel fibre was added in various percentages (0.5, 1.0, 1.5, and 2)%.

| Ingredient of concrete | Quantity kg/m³ |
|------------------------|----------------|
| Coarse aggregate       | 1171           |
| Fine aggregate         | 674            |
| Cement (OPC 43 grade)  | 331            |
| Silica fume            | 10% of cement  |
| Fly ash                | 20% of cement  |
| Water/Cement           | 0.4            |
| Steel fiber            | 0.0% 0.5% 1.0% 1.5% 2.0% |

Guru Corporation, Ahmedabad, Gujarat, provided the silica fume, which had a specific gravity of 2.3. The fly ash utilized in this investigation was collected from Onkar concrete blocks in Mohali, Punjab, and has a specific surface area and specific gravity of 5601 cm²/g and 2.24 [9–11], respectively. The steel fiber was obtained from Weldfab, Delhi, India and the property of the same is presented in Table 2.

| Properties       | Description              |
|------------------|--------------------------|
| Cross Section    | Straight, Hooked-End     |
| Diameter         | 0.3-0.77 mm              |
| Length           | 35-40 mm                 |
| Density          | 7900 kg/m³               |
| Specific Gravity | 7.9                      |
| Tensile Strength | 500-2000 N/mm²           |
For compressive strength testing, a 150mm cubical sample was employed, and the test was carried out according to IS 516. A split tensile strength test on a cylindrical sample with a length of 300 mm and a diameter of 150 mm was used to estimate the indirect tensile strength, as recommended by ASTM. The tensile strength of the cylindrical sample was evaluated using Equation 1 after a compressive force was applied along its length [12–14].

\[
T = 2PrDL
\]

Where \( T \), \( P \), \( L \), and \( D \) indicate for tensile strength, failure load, specimen length, and diameter, respectively.

The flexural strength was measured according to ASTM [15,16] on a beam with dimensions of 100 mm x 100 mm x 500 mm, and the flexural strength were calculated using Equation 2 or Equation 3. If the distance between the point of failure and the closest support “a” is more than 13.3 cm, Equation 2 is used otherwise Equation 3 is used.

\[
F_b = PLB \times d^2
\]
\[
F_b = 3PaB \times d^3
\]

Where \( P \), \( a \), \( B \), \( d \), and \( L \) are the failure load, the gap between the fracture line and a closest support, specimen width, failure point depth, and supported length respectively.

3. Result and Discussion

3.1 Mechanical Property

The compressive, tensile, and flexural strengths of concrete containing steel fibre were evaluated, and the average value is shown in Fig. 1, Fig. 2, and Fig. 3 respectively. The rate of change of strength is also investigated, and the curve is depicted in Fig. 4. The proportion of steel fibre enhances the concrete's strength (compressive, tensile, and flexural) for any curing duration.

![Fig. 1. Variation of compressive strength with the percentage of steel fiber.](image)

The average compressive strength of the controlled sample after 28 days was 60.05 MPa (Fig.1), which enhanced by 23.65% by the addition of 2% steel fibre. Prior literature studies show that the steel fibre can enhance the compressive strength by up to 10%, whereas, several reported in between 30%-125%.
However, the increase in concrete's compressive strength after 28 days curing (23.65%) is larger than the percentage increases after 7 days (13.40%) and 14 days curing (19.75%).

Figure 2 shows tensile strength of the controlled and steel fibres reinforced specimen. After a 28 day curing period, the controlled sample's tensile strength is observed to be 9.45 MPa. The addition of 2% steel fibre enhances the strength to 23.68 MPa. After 28 days, the sample containing 2% steel fibre has increased its tensile strength by 150.50%, which is quite comparable to the 14 day cured sample (152.01%). The percentage increase in tensile strength has been observed to increase by 72.28% after 7 day curing time.

Figure 2. Variation of tensile strength with the percentage of steel fiber.

Fig. 3. Variation of flexural strength with the percentage of steel fiber.
The controlled sample’s average flexural strength is 5.72 MPa, which increased by 7.3% (Fig. 3) after adding 2% steel fibre. The flexural strength has improved by 13.45% and 8.65% after 7 and 14 days of curing, respectively. However, increasing curing time with 2% steel fibre reduces the rate of increase in flexural strength of concrete.

Figure 4 shows a comparison of the rates of growth in strength with percentage of steel fibre during a 28 day curing time. Regardless of the proportion of steel fibre, the rate of increase of compressive and tensile strength was more than that of flexural strength. Further, the rate of change of compressive and tensile strength is observed maximum in between 1.5% and 2% steel fiber. However, further study is required in this direction to obtain the optimum quantity of steel fiber as a continuously increasing trend in strength (Fig. 1, 2, and 3) is observed upto 2% steel fiber in the present study.

3.2 Statistical analysis

The nonlinear analysis of the results obtained from the laboratory test has been performed and a correlation between the percentage of steel fibre, curing days, compressive-tensile strength ratio, and compressive-flexural strength ratio has been established. A model equation has been chosen as a correlation as shown in Equation 4 and the parameter $A1$, $A2$, $A3$, and $A4$ has been obtained from the nonlinear analysis.

$$S\%_f=A1-CpA2CFA3CTA4$$

Table 3 presents the values of the variables' minimum, maximum, mean, and standard deviation, whereas, the correlation matrix has been presented in Table 4. The $C/F$ and $C/T$ in the Table 3 presents the ratio of compressive strength (C) to flexural strength (F) and compressive strength (C) to tensile strength (T) respectively. Table 5 shows the calculated value of different parameters such as $A1$, $A2$, $A3$, and $A4$, whereas, the Table 6 shows the ANOVA results. Depending on the value of different parameters (Table 5), the final equation can be written as given in Equation 5.
Sf\%=3.64-Cp^{0.31}CF-0.63CT^{0.98} \quad (5)

Equation 5 shows that the proportion of steel fibre required is inversely proportional to the compressive strength to flexural strength ratio.

Table 3. Variables providing descriptive statistics.

| Variable | Minimum | Maximum | Mean  | Standard deviations |
|----------|---------|---------|-------|---------------------|
| $C_p$ (days) | 7       | 28      | 16.33 | 9.04                |
| $C/F$    | 10.16   | 12.09   | 10.88 | 0.46                |
| $C/T$    | 3.14    | 8.38    | 5.49  | 1.67                |
| $S_f$ (%)| 0       | 2       | 1     | 0.73                |

Table 4. Correlation matrix.

| Variable | $C_p$ (days) | $C/F$ | $C/T$ | $S_f$ (%) |
|----------|--------------|-------|-------|-----------|
| $C_p$ (days) | 1.0000       | 0.3596| -0.5678| 0.0000    |
| $C/F$     | 0.3596       | 1.0000| -0.7277| 0.6934    |
| $C/T$     | -0.5678      | -0.7277| 1.0000| -0.6965   |
| $S_f$ (%) | 0.0000       | 0.6934| -0.6965| 1.0000    |

Table 5. Parameter values calculated

| Parameter | Initial guess | Final estimate | Standard error | t     | Prob (t) |
|-----------|---------------|----------------|----------------|-------|----------|
| $A_1$     | 1             | 3.638632       | 2.444941       | 1.49  | 0.16479  |
| $A_2$     | 1             | 0.309197       | 0.26852        | 1.15  | 0.27395  |
| $A_3$     | 1             | -0.62915       | 1.29413        | -0.49 | 0.6364   |
| $A_4$     | 1             | 0.978743       | 0.851176       | 1.15  | 0.27458  |

Table 6. Variance analysis

| Source    | DF | Sum of a squares | Mean of Square | F value | Prob (F) |
|-----------|----|------------------|----------------|---------|----------|
| Regression| 3  | 6.273086         | 2.091029       | 18.75   | 0.00012  |
| Error     | 11 | 1.226914         | 0.1115376      |         |          |
| Total     | 14 | 7.5              |                |         |          |

4. Conclusion

Extensive laboratory test for compressive, flexural, and tensile strength has been performed and the data obtained has been analyzed to develop a model equation. With an increase in the proportion of steel fibre and the curing period, mechanical characteristics such as compressive, tensile, and flexural strength are seen to improve. Additionally, despite of curing duration, compressive and tensile strength increases at a faster pace than flexural strength. Between 1.5 and 2% percent steel fibre, the rate of growth in compressive and tensile strength was maximum. Further, from the developed correlation, it has been demonstrated that there is a negative correlation between ratio of compressive to flexural strength and percentage of steel fiber. The appropriate percentage of steel fibre, on the other hand, is seen as directly proportional to the ratio of compressive and tensile strength.
References

[1] Singh U and Rattan M 2014 Design of linear and circular antenna arrays using cuckoo optimization algorithm *Prog. Electromagn. Res. C* 46 1–11

[2] Abbas A T, Gupta M K, Soliman M S, Mia M, Hegab H, Luqman M and Pimenov D Y 2019 Sustainability assessment associated with surface roughness and power consumption characteristics in nanofluid MQL-assisted turning of AISI 1045 steel *Int. J. Adv. Manuf. Technol.* 105 1311–27

[3] Ramteke D D, Balakrishna A, Kumar V and Swart H C 2017 Luminescence dynamics and investigation of Judd-Ofelt intensity parameters of Sm³⁺ ion containing glasses *Opt. Mater. (Amst.)* 64 171–8

[4] Singh G, Pruncu C I, Gupta M K, Mia M, Khan A M, Jamil M, Pimenov D Y, Sen B and Sharma V S 2019 Investigations of machining characteristics in the upgraded MQL-assisted turning of pure titanium alloys using evolutionary algorithms *Materials (Basel).*

[5] Mittal M, Verma A, Kaur I, Kaur B, Sharma M, Goyal L M, Roy S and Kim T-H 2019 An efficient edge detection approach to provide better edge connectivity for image analysis *IEEE Access* 7 33240–55

[6] Kowalska J B, Kajdas B and Zaleski T 2020 Lithological indicators of discontinuities in mountain soils rich in calcium carbonate in the Polish Carpathians *J. Mt. Sci.* 17 1058–83

[7] Ayub T, Khan S U and Memon F A 2014 Mechanical characteristics of hardened concrete with different mineral admixtures: A review *Sci. World J.* 2014

[8] Tan K and Nichols J M 2018 Frost resistance of concrete with different strength grades and mineral admixtures *Comput. Sci. Eng.* 2 1–9

[9] Ganesh S L, Sabarish G, Krishnam Raju G L V and Harshan V P 2019 Metakaolin influence on concrete durability properties *Int. J. Innov. Technol. Explor. Eng.* 8 1109–11

[10] Qu D, Zhao Y and Zhou Z 2019 Experimental Investigation of the Material Performance of the Ultrahigh Early Strength Concrete *IOP Conference Series: Materials Science and Engineering* vol 471, ed D M M M D A-M R J Y I D M Coisson E. Segalini A. (Institute of Physics Publishing)

[11] Hu Y, Ma L and He T 2020 Effect of mineral admixtures on the sulfate resistance of high-strength piles mortar *Materials (Basel).*

[12] Lee H-S and Wang X-Y 2021 Hydration Model and Evaluation of the Properties of Calcined Hwangtoh Binary Blends *Int. J. Concr. Struct. Mater.*

[13] Sanjeev N and Manoj K 2019 An experimental programme on frc with opc, flyash, ggbs, and metakaolin *Int. J. Innov. Technol. Explor. Eng.* 8 3713–7

[14] Fomina E V, Lesovik V S, Fomin A E, Kozhukhova N I and Lebedev M S 2018 Quality evaluation of carbonaceous industrial by-products and its effect on properties of autoclave aerated concrete *IOP Conference Series: Materials Science and Engineering* vol 327 (Institute of Physics Publishing)

[15] Raggiotti B B, Positieri M J, Locati F, Murra J and Marfil S 2015 Zeolite, study of aptitude as a natural pozzolan applied to structural concrete *Rev. la Constr.* 14 14–20
[16] Sastry K V S G K, Ravitheja A and Reddy T C S 2018 Effect of foundry sand and mineral admixtures on mechanical properties of concrete *Arch. Civ. Eng.* 64 117–31