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# Impact of Steel Fibers on the Hardened Properties of High Strength Concrete

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**Abstract -** *Fragility due to low tensile strength of high strength concrete (HSC) can be overcome by adding steel fibers.In this paper, the mechanical properties (compressive and tensile strength along with modulus of rupture) of high strength steel fiber reinforced concrete are investigated. The steel fibers were added at 1% volume fractions comprising three aspect ratio i.e. 50, 62.5 and 75. The compressive strength of strength steel fiber reinforced concrete (HSFRC) reached upto 13.4%, split tensile strength reached upto 41%, and flexural strength reached upto 6.5%.*

**Key Words –***Steel Fibers, High Strength Concrete, Workability, Hardened Properties, Regression Equation.*

## 1. INTRODUCTION

For many decades fibers have been added to conventional concrete to improve its mechanical properties. As the properties of high strength concrete are superior to normal concrete, so the research to increase its application in construction industry has no end. Therefore, trend of adding steel fibers to high strength concrete (HSC) began 40 years ago. These steel fibers influence inherent properties of HSC as they have different mechanical properties and capacity for stress distribution and absorption. Research and design for high strength steel fiber reinforced concrete (HSFRC) has no end as steel fiber of various shape, size and structure have been developed [1,2,3].

When HSFRC hardens, shrinks, or develop cracks under service load, the evenly distributed steel fibers in HSFRC resist the propagation of cracks. Thereby the load carrying capacity increases [4].

Eren and Celik[5] reported volume and aspect ratio of fiber govern the compressive strength of HSC while studying effect of steel fibers and silica fume in HSC . Similarly, Marar et al [6] confirmed increment in compressive strength of HSFRC with fiber volume of particular fiber aspect ratio.

Khaloo and Kim {7} reported 1% increment in compressive and split tensile strength and 1.5 % increment in modulus of rupture with addition 0.5%, 1% and 1.5% steel fibers by volume to HSC while

Chunxiang and Patnaikuni{4} reported 24% increase in compressive strength of HSFRC after 76 days.

From above literature it can be concluded that mechanical properties got improved with different fiber aspect ratio and volume fraction, but the thorough study is under way to design and develop HSFRC.

The current research aims to investigate the dependence of fresh properties of HSCs with fibers. The framework of this research will examine the dependence of hardened concrete properties such as compressive strength, tensile strength and modulus of rupture. The study will focus on the effect of fiber aspect ratio on the hardened properties of concrete. The results obtained from this study are expected to form the basis for proper fiber type selection and their effective combination with steel reinforcement of structural members.

## 2. EXPERIMENTAL PROGRAMS

### 2.1Materials

Type I cement, river sand with a fineness modulus of 2.9, and coarse aggregate of 20 mm nominal size were used. Table 1 presents quantity of material used for production of concrete. The water-to-cement ratio of 0.43 is used for production of HSFRC. Three different round crimped steel fibers of varying aspect ratio were used. Table2 presents the details of different types of fiber used. The maximum and minimum dosage of fiber was obtained using expression given by Banthia N et al [8] with an objective of strength and ductility in mind but in no case the dosage of 1% was used. Fiber used has ultimate strength of 940Mpa while density of fiber was 7850kg/m$^3$. Table 3 gives details of constituent chemical composition of fiber certified by manufacturer.

**Table - 1** Quantity of materials

| Material | Quantity |
|---|---|
| Water | 194.4 lts |
| Cement | 450 kg/m$^3$ |
| Sand | 395.5 kg/m$^3$ |
| Aggregate | 1295.7 kg/m$^3$ |

**Table - 2** Details of different types of fiber

| S.No. | Fiber type | Length ($l_f$) mm | Diameter ($d_f$) mm | Aspect Ratio $l_f/d_f$ |
|---|---|---|---|---|
| 1 | Crimped round | 40 | 0.80 | 50 |
| 2 | Crimped round | 50 | 0.80 | 62.5 |
| 3 | Crimped round | 60 | 0.80 | 75 |

**Table - 3** Details of chemical composition

| Chemical | Percentage (%) |
|---|---|
| Carbon | 10 |
| Manganese | 60-90 |
| Sulphur | 16-20 |
| Chromium | 6 |

### 2.2 PREPARATION OF SAMPLES

For preparing concrete matrix, material without fiber was initially mixed. Concrete without fiber was represented as a 'ref con'. Fibers were then added in small quantities to avoid agglomeration of fibers and to produce concrete with uniform stability and good workability. For concrete mixture with 1.0% volume of fiber, additional time was required for mixing. Freshly mixed steel fiber-reinforced concrete was placed in two equal layers in a cylinder mold of size 150 × 300 mm, 150 × 150 × 150 mm cube mold compressive strength test and beam mold of size 100 × 100 × 500 mm for flexure strength test. Compaction was conducted on vibratory table . At the end of 24 h the specimen were demoulded and kept in water at $27\pm2^0$c for 28 days. After curing strength tests were conducted. Table 4 gives details of mixes.

**Table - 4** Mix details

| Mix | Fiber volume % | Aspect ratio ($F_{AR}$) |
|---|---|---|
| Ref | 0 | |
| Mix 1 | 1% | 50 |
| Mix 2 | 1% | 62.5 |
| Mix 3 | 1% | 75 |

## 3. TEST METHODS

For workability slump cone test was performed in accordance IS1199:1959 {Reaffirmed 2004}.

The compressive strength test was performed on 21 standard cubes as per ASTM C39/C36 standard. The rate of loading was kept 0.3 MPa/s until failure.

The splitting tensile test was conducted on 21 of the test cylinders in accordance with the ASTM C496 standard, at a constant rate of loading 900 kPa/min until failure.

The flexural strength (modulus of rupture, MOR) test was conducted on 21 test beams under three- point loading in accordance with ASTM C78.

## 4. RESULT AND DISCUSSION

### 4.1 WORKABILITY

Table 5 gives details of slump. Decrease in workability can be attributed to improper dispersion of fibers. Due to improper dispersion of fibers agglomerates are formed. These agglomerates entrap fillers which result in decrease in workability.

Table - 5

| Mix | slump (mm) |
|---|---|
| Ref | 47.55 |
| M1 | 14 |
| M2 | 11 |
| M3 | 13 |

### 4.2 HARDENED PROPERTIES

Table 6 presents the strength test results on HSFRC and HSC. The compressive strength, splitting tensile strength, and modulus of rupture of HSFRC improved to different extents in response to the fiber aspect ratio.

**COMPRESSIVE STRENGTH**

Fig. 1 shows comparison between compressive strength of HSFRC and HSC, it is observed that the compressive strength $f_{ck}$ of HSC i.e reference mix was 52 MPa while HSFRC showed an enhancement at each aspect ratio. The enhancement of strength-effectiveness is shown in Table 6. The compressive strength of HSFRC enhanced from 10% to 14% with increment of aspect ratio of fiber.

Following from the compressive strength test results, the compressive strength $f_{ck}$ of HSFR was predicted using the compressive strength $f_{ck}$ of HSC and aspect ratio, and was expressed as

$$f_{ck}(MPa)= f_{ck}+A\ F_{AR}+B\ F_{AR}^2 \quad (1)$$

Substituting $f_{ck}$ =52 MPa in Eq. (1) and applying the regression analysis gave

$$f_{ck}(MPa)= 58.78-0.080\ F_{AR}+0.001\ F_{AR}^2 \quad (2)$$

The compressive strength predictions using Eq. (2) agreed favorably with the test result

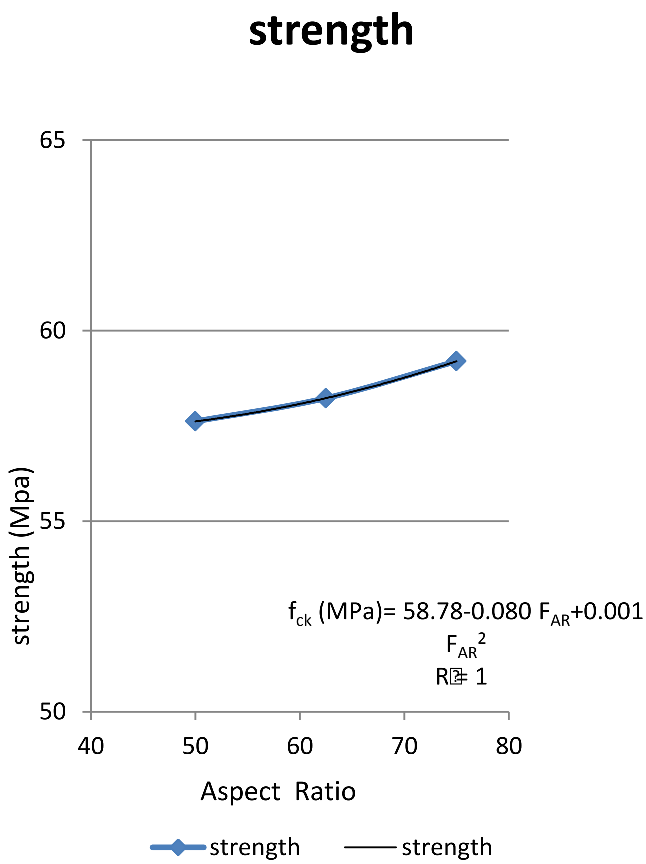


**Fig. 1-** Effect of aspect ratio on Compressive Strength

**Table - 6** Strength test results and Strength Effectiveness

| Mix | Compressive strength | | Split tensile strength | | Flexural strength | |
|---|---|---|---|---|---|---|
| | Measured (Mpa) | Increment% | Measured (Mpa) | Increment % | Measured (Mpa) | Increment % |
| Ref | 52 | | 5 | | 4.9 | |
| M1 | 57.62 | 10.8 | 6.7 | 34 | 5.15 | 5.1 |
| M2 | 58.23 | 11.98 | 6.88 | 37.6 | 5.19 | 5.9 |
| M3 | 59.2 | 13.84 | 7.05 | 41 | 5.22 | 6.5 |

**SPLITTING TENSILE STRENGTH**

Fig.2 depicts development of splitting tensile strength of HSFRC at various fiber aspect ratios. It's observed that the strength of HSFRC improved with increasing the fiber aspect ratio. The Strength increment is shown in Table 6, theenhancement started from 34% for M1, 37.6 for M2 and 41% for M3.

The splitting tensile strength $f_{tf}$ of HSFRC was pre dicted by using the compressive strength $\sqrt{f_{ck}}$ of HSC and the aspect ratio $F_{AR}$ , and was given as follows:

$F_{tf}(MPa)=A\sqrt{f_{ck}}+ B F_{AR}+C F_{AR}^2$ (3)

Substituting $f_{ck}$= 52 MPa in Eq. (3) and applying the regression analysis gave

$F_{tf}(MPa)=5.88+0.018 F_{AR}-3?0^{-5} F_{AR}^2$ (4)

At $F_{AR}$=0%, Eq. (4) gives HSC a value of $F_{tf}$= 5.88MPa equall to that given by $0.81\sqrt{f_{ck}}$(= $0.81\sqrt{52}$). Coefficient 0.63 was obtained by Song et. al [9] for different volume of fiber content used.

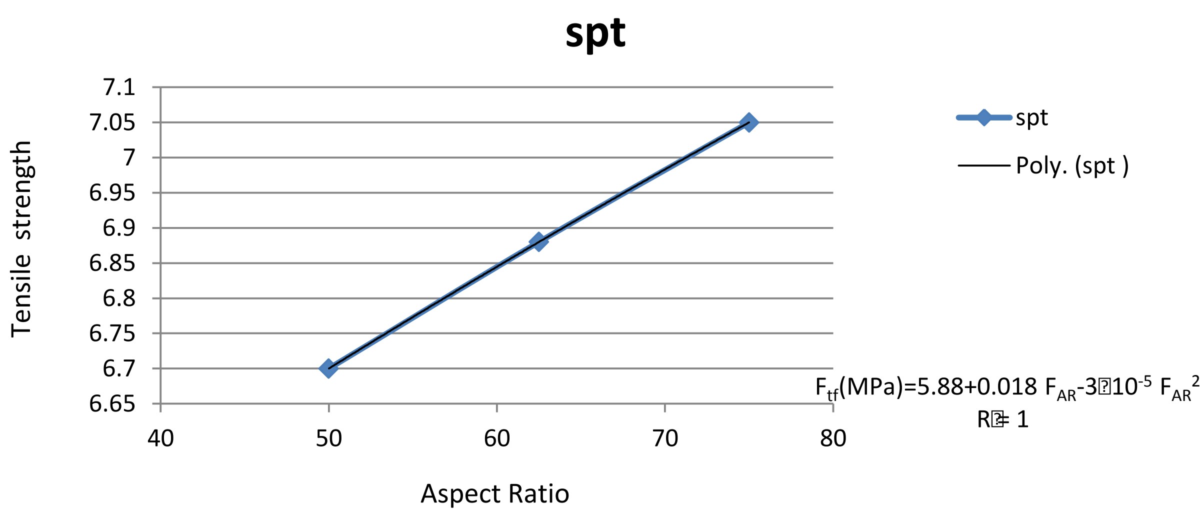


**Fig. 2 -** Effect of fiber volume on splitting tensile strength.

**MODULUS OF RUPTURE**

Fig. 3 compares the MOR of HSC and HSFRC for various aspect ratio. And the strength-increment in Table 6 indicates that the MOR values are higher by 5.1% for M1, 5.9% for M2 and 6.5% for M3 compared to HSC.

The Modulus of rupture $f_{rf}$ of HSFRC was related to compressive strength $\sqrt{f_{ck}}$ of HSC and the aspect ratio $F_{AR}$ , and was given as follows:

$F_{rf}(MPa)=A\sqrt{f_{ck}}+ B F_{AR}+C F_{AR}^2$ (5)

Substituting $f_{ck}$= 52 MPa in Eq. (5) and applying the regression analysis gave

$F_{rf}(MPa)=4.89+0.006 F_{AR}-3?0^{-5} F_{AR}^2$ (6)

At $F_{AR}$=0%, Eq. (6) gives HSC a value of $F_{rf}$= 4.89MPa equall to that given by $0.67\sqrt{f_{ck}}$(= $0.67\sqrt{52}$).

Coefficient 0.69 was obtained by Song et. al [9] for different volume of fiber content used.

Over all increment in strength can be attributed tensile strength of steel fibers which got added to over all concrete matrixes. Also as fiber aspect ratio increased strength increased. It's because fiber of longer length resisted the propagation of cracks

## 5. CONCLUSIONS

1. Workability decreased with increment of aspect ratio.
2. The compressive strength of HSC improved with additions of steel fibers at various aspect ratio. The strength showed a maximum at 14%
3. The splitting tensile strength and modulus of rupture of HSFRC both improved with increasing fiber aspect ratio. The splitting tensile strength ranged from 34% to 41%. And the modulus of rupture ranged from 5.1% to 6.5%

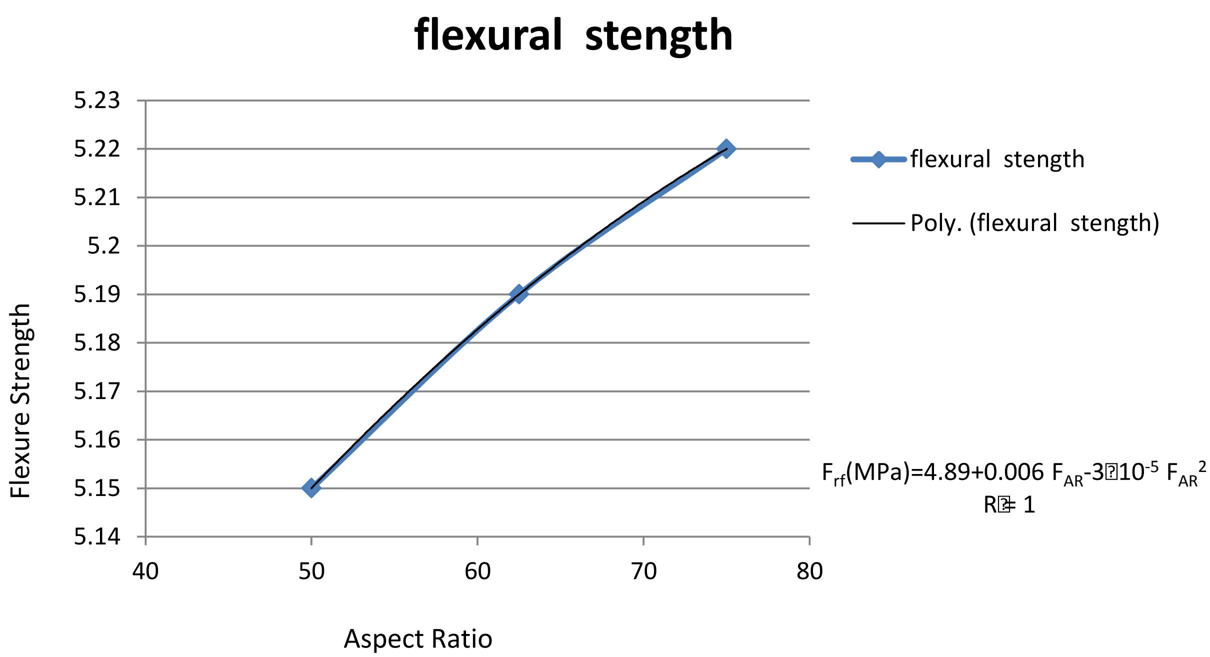


**Fig. 3-** Effect of fiber aspect ratio on modulus of rupture.

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