ESCUELA DE CONSTRUCCIÓN CIVIL
FACULTAD DE INGENIERÍA
Revista de la Construcción
Journal of Construction

*Research Article*

# Evaluation of mechanical characteristics of high strength steel fiber reinforced concrete with various concrete strengths

**Sasikumar P** [1]*

[1] Kumaraguru College of Technology, Anna University, Coimbatore (India), email: sasiserene@gmail.com
*Correspondence: sasiserene@gmail.com

**Received:** 20.11.23; **Accepted:** 23.03.24; **Published:** 31.08.24

**Citation:** Sasikumar, P. (2024). Evaluation of mechanical characteristics of high strength steel fibre reinforced concrete with various concrete strengths. Revista de la Construcción. Journal of Construction, 23(2), 374-387. https://doi.org/10.7764/RDLC.23.2.374

**Abstract:** The performance of concrete is robust in compression but lacks tensile strength, making it brittle. Steel fibres are added to enhance concrete properties. These fibres play a crucial role in construction by improving structural performance, preventing cracks, and increasing ductility. The study investigated high-strength steel fibre-reinforced concrete (HSSFRC) with varying concrete strengths. Three high-strength concrete grades (70 MPa, 80 MPa, and 90 MPa) and different water-cement ratios (WCR) (0.25, 0.30, and 0.35) were studied. Hooked-ended 50mm steel fibres were added at content levels of 0.25%, 0.50%, 0.75%, and 1.00%. As steel fibre content increased from 0.25% to 0.75%, the compressive strength (CS) improved by 3.37%, 7.29%, and 10.54%. At the same time, the split tensile strength (STS) increased by 20.86%, 24.07%, and 26.74%. Similarly, the flexural strength (FS) increased by 19.87%, 23.12%, and 25.82% for a WCR of 0.25 in 70 MPa grade of concrete. However, adding 1.0% steel fibre led to decreased mechanical properties. The optimal steel fibre content across all concrete mixes was 0.75%. Mechanical properties weakened with higher WCR (0.25, 0.30, and 0.35). Additionally, regression analysis explored the relationships between CS, STS, and FS in the concrete mixes. The comparison between the test results and the regression analysis was carried out alongside the previous empirical formulas. Remarkably, the empirical formulas exhibited strong alignment with the experimental findings.

**Keywords:** High-strength concrete, steel fiber, strength properties, regression analysis, empirical formulas.

## 1. Introduction

High-strength concrete (HSC) is crucial in construction, particularly for high-rise buildings, tunnels, marine structures, and road bridges. Adding steel fibres enhances reinforced concrete structures' strength, ductility, toughness, durability, and energy absorption capacity (Sasikumar & Manju 2023). Recent advancements in concrete technology have leveraged HSC (Vogel et al., 2015). Different steel fibres, including hooked and crimped varieties, are available, each with varying strength properties (Vairagade et al., 2013). Additionally, including steel fibres has led to a 30% increase in split tensile and flexural strength compared to control mixes (Srinivasa et al., 2016). Researchers have explored fibre shape, length, aspect ratio, modulus of elasticity, and the bond between steel fibres and cement paste (Yazici, 2007). The impact of steel fibres on HSC, including mechanical properties, peak load, optimal fibre content, and durability, has been well-documented (Topcu & Canbaz, 2007; Wang et al., 2010). High-performance fiber-reinforced concrete (HPFRC) has gained prominence in the construction industry. It is engineered to exhibit enhanced strength, toughness, and durability. Incorporating short discrete fibres into the concrete mix can mitigate and prevent cracks. A thorough literature review on HPFRC was conducted, aiming to outline its mechanical, physical, and durability-related characteristics comprehensively. The review confirmed that adding fibres to high-strength concrete significantly improves properties such as tensile strength, flexural strength, and ductility performance.

Incorporating fibres into concrete has several effects. While it reduces shrinkage and creep deformations, it can also negatively impact specific properties, such as workability, especially when adding steel fibres. Due to their conductivity, steel fibres significantly reduce concrete's electrical resistivity and its resistance to chloride penetration. Another study explored steel fibre percentages and aspect ratios in ultra-high-performance fiber-reinforced concrete (UHPFRC). Adding steel fibers improved mechanical properties like CS, FS, and toughness. However, it also decreased workability and increased setting time for UHPFRC (Biswas et al., 2021).

Based on the literature study, a limited investigation focused solely on (HSC). However, the present research has delved into various concrete and (WRC) grades. This study aimed to create high-strength concrete by incorporating different steel fibre percentages and varying WCR. The paper presents high-strength concrete properties, including CS, STS and FS at 28 days. Additionally, the study conducted regression analyses to explore the relationships between CS & STS, CS & FS and STS & FS. The experimental results aligned with previously published empirical formulas and regression analyses. The present has been displayed in the graphical representation for Figure 1.

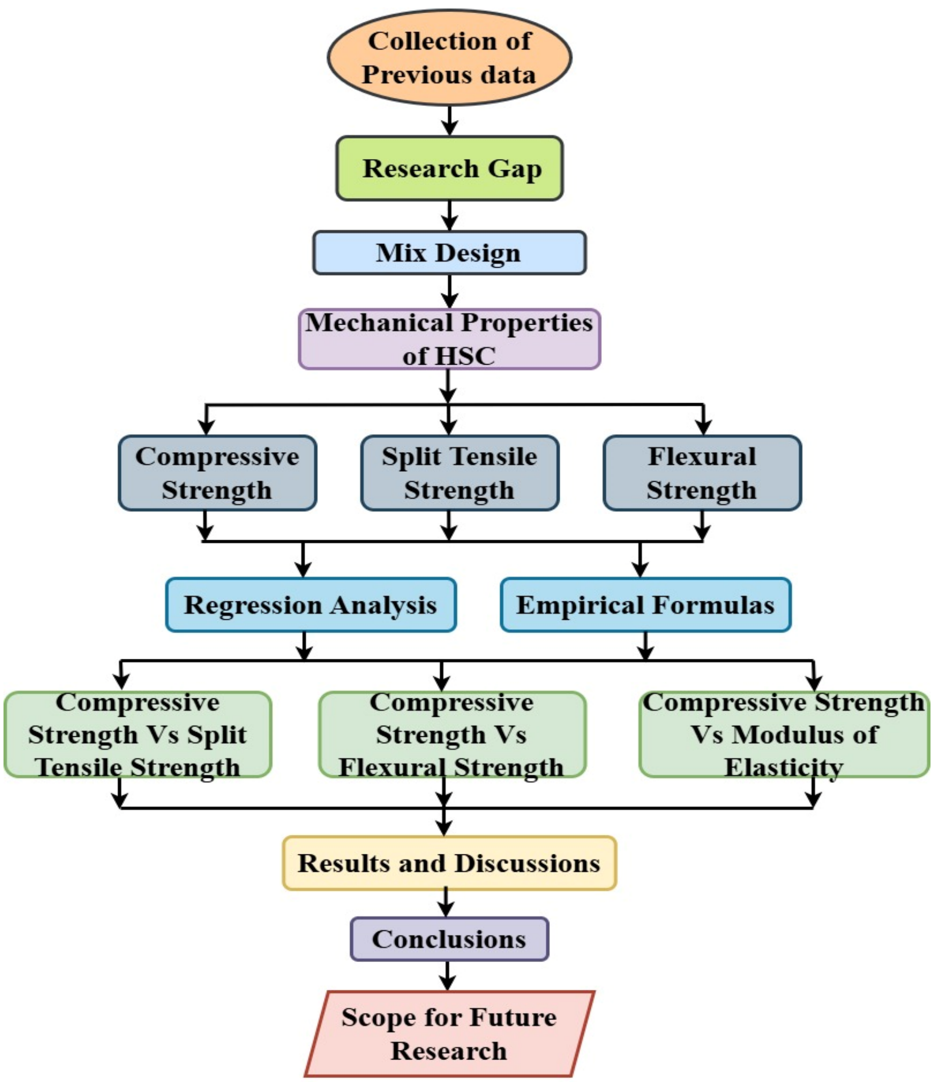



**Figure 1.** Flow chart of the research work.

## 2. Materials

### 2.1. *Cement*

The experimental study used ordinary Portland cement (OPC) 53 grade. The chemical composition was identified and is reported in Table 1. The mechanical properties of the OPC were studied as per (IS: 12269 - 1987), presented in Table 2.

**Table 1.** Chemical properties of cement and mineral admixtures.

| Components | Cement | Fly ash | Silica fume |
|---|---|---|---|
| $SiO_2$ | 21.52 | 58.38 | 93.45 |
| $Al_2O_3$ | 5.64 | 25.12 | 0.92 |
| $Fe_2O_3$ | 3.47 | 7.01 | 0.52 |
| CaO | 61.42 | 0.64 | 1.57 |
| MgO | 0.65 | 0.70 | 0.53 |
| $SO_3$ | 2.61 | 0.14 | 0.004 |
| $Na_2O$ | 0.26 | 0.30 | 0.58 |
| Loss on Ignition (%) | 1.38 | 3.89 | 4.20 |

### 2.2. *Mineral admixtures*

This project partially used fly ash, silica fume, and mineral admixtures to replace cement. These materials have specific chemical and physical properties, as Tables 1 and 2 outlines. Fly ash results from coal combustion, while silica fume is a by-product of silicon metal production. These finely divided admixtures enhance concrete's workability, durability, and strength when added to concrete in significant quantities (typically 20% to 70% by mass of the total cementitious material).

**Table 2.** Physical properties of cementitious materials.

| Test | Mineral admixtures | | |
|---|---|---|---|
| | Cement | Fly ash C | Silica fume |
| Specific gravity | 3.12 | 2.17 | 2.63 |
| Fineness modulus | 5.49 | 3.62 | 4.27 |
| Consistency | 4.12 | - | - |
| Initial setting time | 42 | - | - |
| Final setting time | 289 | - | - |

### 2.3. *Fine aggregate*

Fine aggregates that passed through a 4.76 mm sieve confirmed zone II per the (IS: 383 - 2016) standard. The particle size distribution of fine aggregates significantly affects concrete workability and strength. Physical properties of fine aggregate were determined: the specific gravity is 2.67, the modulus of elasticity is 3.57, and the fineness modulus is 1.52%, respectively. Understanding and controlling the particle size distribution of fine aggregates is crucial for achieving desired concrete properties. The fine aggregate particle size distribution is shown in Figure 2.

### 2.4. *Coarse aggregate*

Well-graded coarse aggregate was utilized in this study, adhering to the (IS: 383 - 2016) standard. The properties of the coarse aggregate were examined, including the specific gravity of 2.72, fineness modulus of 6.74, and water absorption capacity of 0.52%. The distribution of particle sizes in the coarse aggregate is depicted in Figure 3.

### 2.5. *Chemical admixture*

In this study, a high-range water-reducing agent superplasticizer called conplast-SP430 was employed. This superplasticizer adheres to the ASTM C494 Type F standard. To achieve significant water reductions or enhance workability without causing undue set retardation or air entrainment in cementitious mixtures. By using a superplasticizer, concrete workability and strength can be improved. Notably, this high-performance admixture can reduce water content by up to 30%.

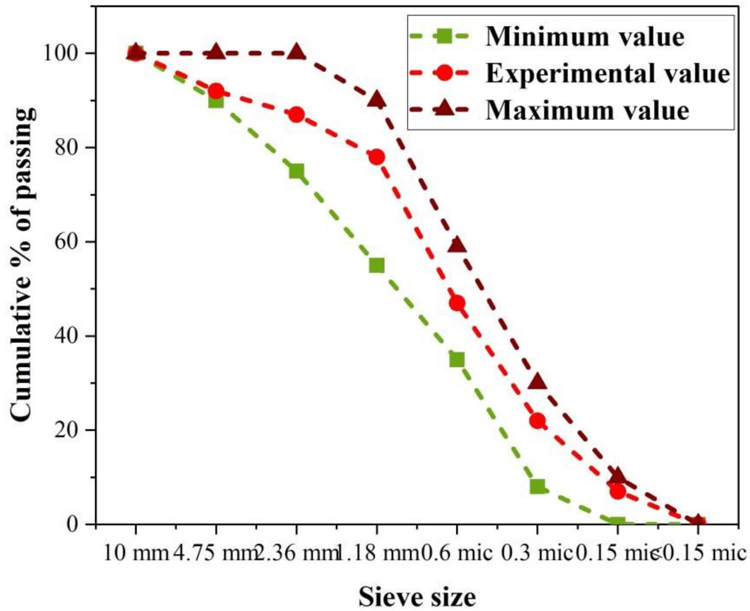



**Figure 2.** Cumulative % of passing fine aggregate versus sieve sizes.

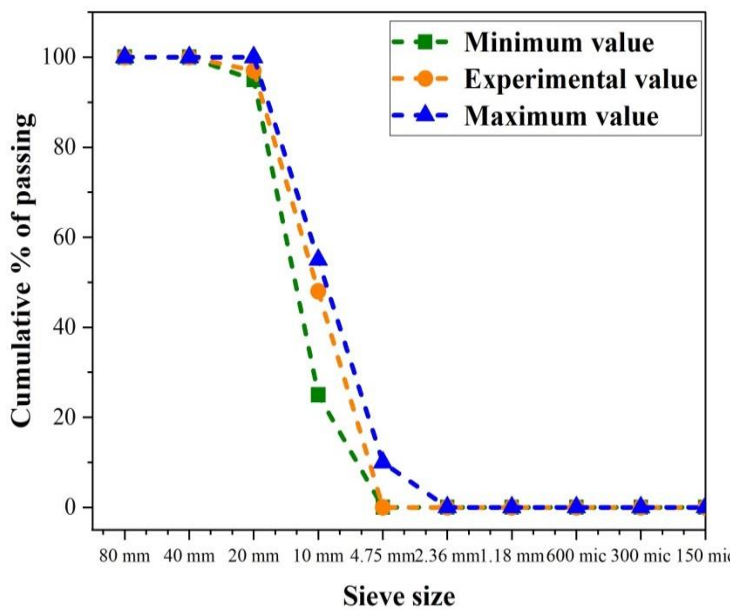



**Figure 3.** Cumulative % passing of coarse aggregate versus sieve sizes.

2.6. *Steel fibre*

The present study used the three high-strength concretes investigated, each incorporating steel fibres. The steel fibres used have a length, diameter and aspect ratio of 50 mm, 0.8 mm, and 62.50, respectively. The physical properties of the steel fibre were also examined, including specific gravity of 7.75 g/cm³, tensile strength of 1300 MPa. and modulus of elasticity of 206

GPa. These steel fibres play a significant role in enhancing the mechanical properties of high-strength concrete. The steel fibre is depicted in Figure 4.

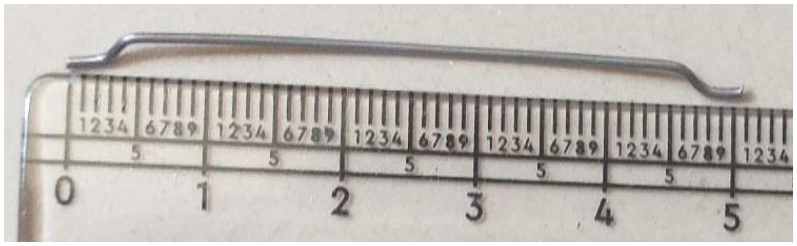



**Figure 4.** Hooked-ended steel fibre.

### *2.7. Mix proportion*

In this study, different mix proportions were examined as per the (IS: 10262 - 2019), while control mixes with WCR of 0.25, 0.30, and 0.35 were tested, along with high-strength concrete (HSC) strengths of 70 MPa, 80 MPa, and 90 MPa. Based on the materials and design available in the local market, the strength grade selected was constrained (IS: 10262 – 2019). Four different steel fibre percentages were employed in high-strength concrete: 0.25%, 0.50%, 0.75%, and 1.00%. Steel fibres were added per weight of cement. In all, 45 different mixes were made for this investigation. The 28-day cube CS was 73.48 MPa, 84.62 MPa, and 94.67 MPa for a WCR of 0.25%. Table 3 displays the mix proportions. The mix is identified as M70-SF0, where M70 and SF0 stand for the concrete's strength and fibre content, respectively. The strength properties of the HSSFRC mixtures are reported in Table 4.

**Table 3.** Mix proportion of HSC.

| Materials | Grade of concrete (MPa) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 70 | 80 | 90 | 70 | 80 | 90 | 70 | 80 | 90 |
| w/c ratio | 0.25 | 0.25 | 0.25 | 0.30 | 0.30 | 0.30 | 0.35 | 0.35 | 0.35 |
| Cement (kg/m$^3$) | 410 | 430 | 450 | 400 | 420 | 430 | 390 | 410 | 420 |
| Fine aggregate by a ratio | 1.24 | 1.15 | 1.06 | 1.35 | 1.29 | 1.14 | 1.42 | 1.35 | 1.25 |
| Coarse aggregate by a ratio | 1.92 | 1.85 | 1.76 | 2.04 | 1.94 | 1.86 | 2.25 | 2.03 | 1.96 |
| Steel fibre (%) | 0.25,0.50,0.75,1.0 | | | 0.25,0.50,0.75,1.0 | | | 0.25,0.50,0.75,1.0 | | |
| Fly ash | 10% by weight of cement | | | | | | | | |
| Silica fume | 10% by weight of cement | | | | | | | | |
| Chemical admixture | 0.5% by weight of cement | | | | | | | | |

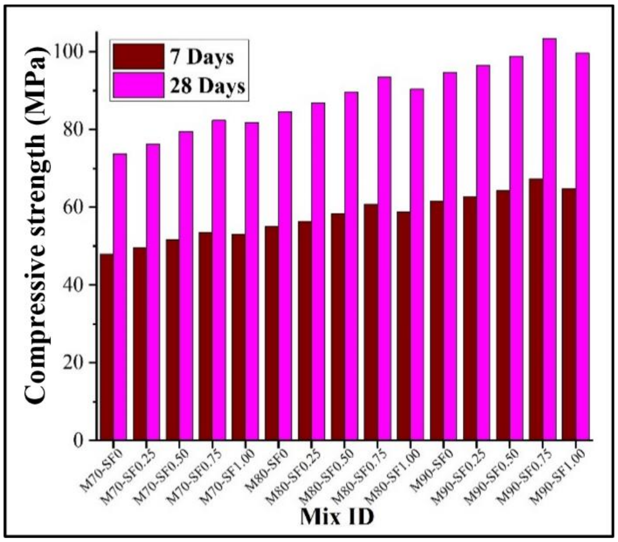
### *2.8. Preparation of samples and methods*

According to (IS: 516 – 1999), the study examined the mechanical properties of HSC, such as CS, STS, and FS. The CS and STS samples were made at ages 7 and 28 days. A steel mould was used to make the samples in cube shapes 150 mm x 150 mm x 150 mm and cylinder shapes 150 mm in diameter and 300 mm in height for CS and STS, respectively. The cubes and cylinders were examined at 7 and 28 days using a compression testing machine (CTM) with a capacity of 3000 kN. The prism for FS was made with dimensions of 150 mm x 150 mm x 750 mm and tested at 28 days using a Universal Testing Machine (UTM) with a capacity of 400 kN. Three samples were cast for each mix, and the average of the three sample results was computed and reported in the results.

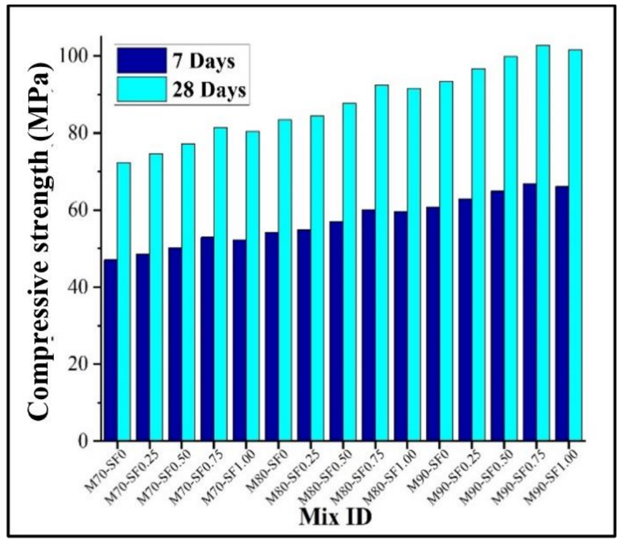
## 3. Experimental results and discussions

### *3.1. Effect of the steel fibre on the CS*

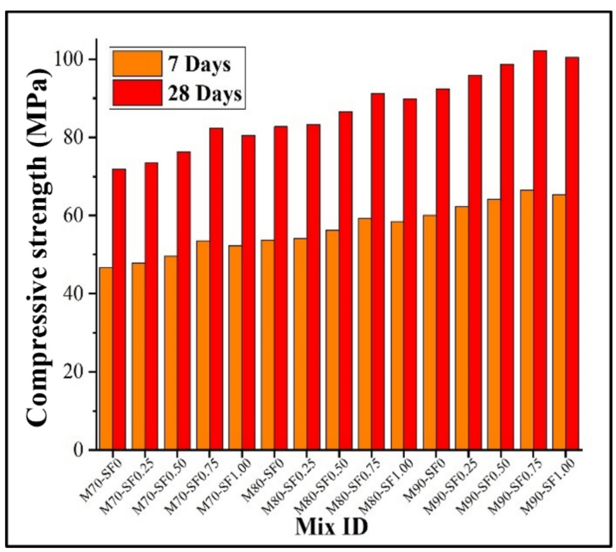
The average of the three samples was used to calculate the CS of HSSFRC. The HSSFRC's compressive strength was investigated with three different concrete strengths, and Table 4 shows the WCR at 7 and 28 days. The best steel fibre content was 0.75% for all WCR. The compressive strength rose by 10.77 %, 9.90 %, and 9.59 % for M70-SF0.75 with WCR of 0.25, 0.30, and 0.35, respectively, as Figure 4(a) illustrates, compared to the control specimen M70-SF0. Likewise, the compressive strength increased by 9.46 %, 9.29 %, and 8.72 % for M80-SF0.75 with WCR of 0.25, 0.30, and 0.35, respectively, as Figure 4(b) shows, compared to the control specimen M80-SF0. The compressive strength marginally rose by 8.47 %, 8.05 %, and 7.64 % for M90-SF0.75 with WCR of 0.25, 0.30, and 0.35, respectively, as Figure 4(c) demonstrates, compared to the control specimen M90-SF0. Adding steel fibres can enhance the compressive strength until the optimum fibre content is achieved. Steel fibres stop crack propagation and improve the bond between the cement paste, aggregates, and steel fibres. The concrete's workability is reduced by increased steel fibre content beyond the optimum mix (Candassamy et al., 2024; Sasikumar, 2024; Sasikumar & Manju, 2024; Sasikumar, 2023; Sasikumar et al., 2022). The compressive strength also slightly dropped when the WCR was raised from 0.25 to 0.35.




(a). HSSFRC – 0.25 w/c




(b). HSSFRC – 0.30 w/c




(c). HSSFRC – 0.35 w/c

**Figure 4.** CS of HSSFRC at 7 and 28 days.

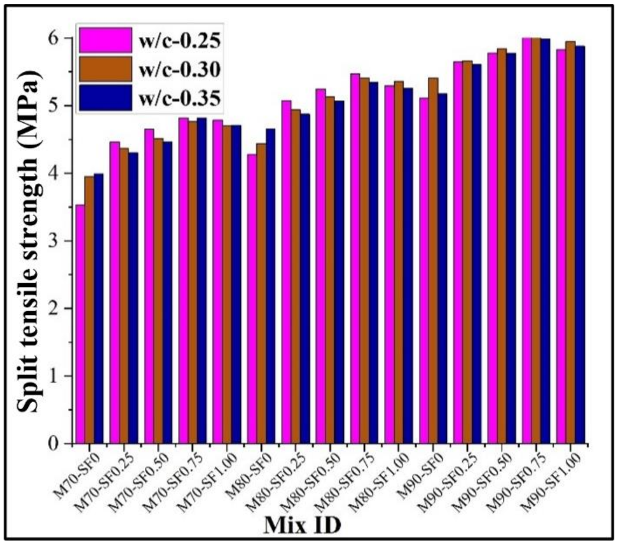
**Table 4.** Mechanical properties of the HSSFRC at 28 days.

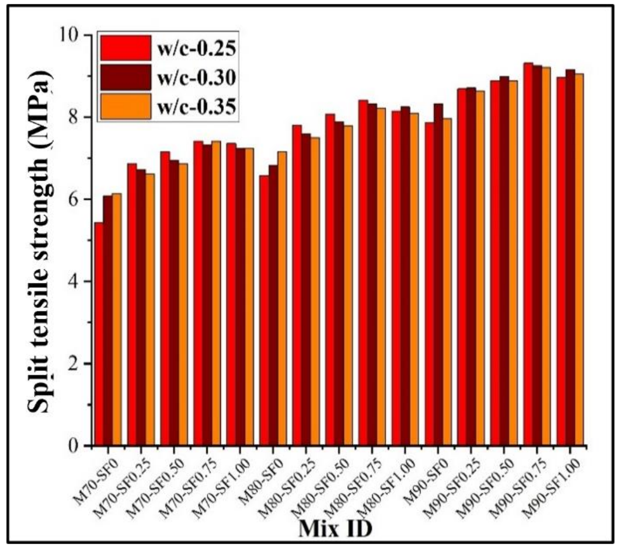
| W/c ratio | Mix ID | Compressive strength (MPa) | Increased the CS w.r.t. SF0 | Split tensile strength (MPa) | Increased the STS w.r.t. SF0 | Flexural strength (MPa) | Increased the FS w.r.t. SF0 |
|---|---|---|---|---|---|---|---|
| 0.25 | M70-SF0 | 73.48 | - | 5.43 | - | 6.72 | - |
| | M70-SF0.25 | 76.24 | 3.62 | 6.86 | 20.86 | 8.39 | 19.87 |
| | M70-SF0.50 | 79.46 | 7.53 | 7.15 | 24.07 | 8.74 | 23.12 |
| | M70-SF0.75 | 82.35 | 10.77 | 7.41 | 26.74 | 9.06 | 25.82 |
| | M70-SF1.00 | 81.74 | 10.11 | 7.36 | 26.19 | 8.99 | 25.26 |
| | M80-SF0 | 84.62 | - | 6.58 | - | 8.32 | - |
| | M80-SF0.25 | 86.73 | 2.43 | 7.81 | 15.70 | 9.54 | 12.79 |
| | M80-SF0.50 | 89.62 | 5.58 | 8.07 | 18.42 | 9.86 | 15.60 |
| | M80-SF0.75 | 93.46 | 9.46 | 8.41 | 21.77 | 10.28 | 19.07 |
| | M80-SF1.00 | 90.42 | 6.41 | 8.14 | 19.14 | 9.95 | 16.35 |
| | M90-SF0 | 94.67 | - | 7.86 | - | 8.74 | - |
| | M90-SF0.25 | 96.52 | 1.92 | 8.69 | 9.52 | 10.62 | 17.68 |
| | M90-SF0.50 | 98.76 | 4.14 | 8.89 | 11.57 | 10.86 | 19.55 |
| | M90-SF0.75 | 103.43 | 8.47 | 9.31 | 15.56 | 11.38 | 23.18 |
| | M90-SF1.00 | 99.62 | 4.97 | 8.97 | 12.33 | 10.96 | 20.24 |
| 0.30 | M70-SF0 | 73.37 | - | 6.08 | - | 6.98 | - |
| | M70-SF0.25 | 74.62 | 1.68 | 6.72 | 9.47 | 8.21 | 14.96 |
| | M70-SF0.50 | 77.16 | 4.91 | 6.94 | 12.45 | 8.49 | 17.76 |
| | M70-SF0.75 | 81.43 | 9.90 | 7.33 | 17.04 | 8.96 | 22.07 |
| | M70-SF1.00 | 80.37 | 8.71 | 7.23 | 15.94 | 8.84 | 21.05 |
| | M80-SF0 | 83.84 | - | 6.82 | - | 8.46 | - |
| | M80-SF0.25 | 84.36 | 0.62 | 7.59 | 10.17 | 9.28 | 8.83 |
| | M80-SF0.50 | 87.68 | 4.38 | 7.89 | 13.57 | 9.64 | 12.28 |
| | M80-SF0.75 | 92.43 | 9.29 | 8.32 | 18.02 | 10.17 | 16.79 |
| | M80-SF1.00 | 91.62 | 8.49 | 8.25 | 17.29 | 10.08 | 16.06 |
| | M90-SF0 | 94.46 | - | 7.92 | - | 8.94 | - |
| | M90-SF0.25 | 96.75 | 2.37 | 8.71 | 9.04 | 10.64 | 16.00 |
| | M90-SF0.50 | 99.82 | 5.37 | 8.98 | 11.84 | 10.98 | 18.58 |
| | M90-SF0.75 | 102.73 | 8.05 | 9.25 | 14.34 | 11.30 | 20.89 |
| | M90-SF1.00 | 101.64 | 7.06 | 9.15 | 13.42 | 11.18 | 20.04 |
| 0.35 | M70-SF0 | 72.82 | - | 6.14 | - | 7.26 | - |
| | M70-SF0.25 | 73.54 | 0.98 | 6.62 | 7.23 | 8.09 | 10.25 |
| | M70-SF0.50 | 76.28 | 4.54 | 6.87 | 10.56 | 8.39 | 13.48 |
| | M70-SF0.75 | 80.54 | 9.59 | 7.25 | 15.29 | 8.86 | 18.05 |
| | M70-SF1.00 | 80.47 | 9.51 | 7.24 | 15.22 | 8.85 | 17.98 |
| | M80-SF0 | 82.74 | - | 7.16 | - | 8.64 | - |
| | M80-SF0.25 | 83.29 | 0.66 | 7.50 | 4.48 | 9.16 | 5.70 |
| | M80-SF0.50 | 86.57 | 4.42 | 7.79 | 8.10 | 9.52 | 9.27 |
| | M80-SF0.75 | 90.64 | 8.72 | 8.16 | 12.23 | 9.97 | 13.34 |
| | M80-SF1.00 | 89.86 | 7.92 | 8.09 | 11.47 | 9.88 | 12.59 |
| | M90-SF0 | 93.45 | - | 7.96 | - | 9.13 | - |
| | M90-SF0.25 | 95.87 | 2.52 | 8.63 | 7.75 | 10.55 | 13.42 |
| | M90-SF0.50 | 98.69 | 5.31 | 8.88 | 10.38 | 10.86 | 15.90 |
| | M90-SF0.75 | 101.18 | 7.64 | 9.11 | 12.59 | 11.13 | 17.97 |
| | M90-SF1.00 | 100.47 | 6.99 | 9.04 | 11.97 | 11.05 | 17.39 |

### *3.2. Effect of the steel fibre on the STS*

Figures 5 (a) and (b) shows that the STS of the HSSFRC mixes was calculated after 7 and 28 days. The STS of HSSFRC rose to 0.75 % of steel fibre in all WCR (0.25, 0.30 and 0.35). The STS decreased beyond 0.75 % of the steel fibre. Compared to M70-SF0 for a WCR of 0.25, the STS of the M70-SF0.75 specimen rose by 26.67%, 17.04%, and 15.29%. Likewise, compared to M80-SF0 for a WRC of 0.30, the STS of the M80-SF0.75 specimen rose by 15.56 %, 14.34 %, and 12.59 %.

Similarly, compared to M70-SF0 for a WRC of 0.35, the STS of the M80-SF0.75 specimen rose by 15.56 %, 14.34 %, and 12.59 %. In this experimental study, the STS rose linearly with increased steel fibre content and decreased WCR. The STS also rose because of the crack prevention by adding steel fibre. Steel fibre improves the STS and stops cracks in the concrete.




(a). HSSFRC at 7 days (b). HSSFRC at 28 days

**Figure 5.** STS of HSSFRC at 7 and 28 days with various w/c ratio.

### *3.3. Effect of the steel fibre on the FS*

The FS of the HSSFRC was measured at 28 days and shown in Table 4. The concrete's FS was investigated with different concrete strengths (70 MPa, 80 MPa, and 90 MPa) and the quantity of steel fibre content (0.25%, 0.50%, 0.75%, and 1.00%), respectively, as Figure 6 displays. The flexural strength rises with a higher amount of steel fibre. Compared to M70-SF0 for a WCR of 0.25, the flexural strength of the M70-SF0.75 specimen rose by 25.82%, 22.07%, and 18.05%. Likewise, compared to M80-SF0 for a WCR of 0.30, the flexural strength of the M80-SF0.75 specimen rose by 19.07%, 16.79%, and 13.34%. Similarly, compared to M90-SF0 for a WCR of 0.35, the flexural strength of the M90-SF0.75 specimen rose by 23.18%, 20.89%, and 17.97%. The specimens without steel fibre developed cracks and failed with wide cracks compared to the steel fibre-reinforced concrete specimens.

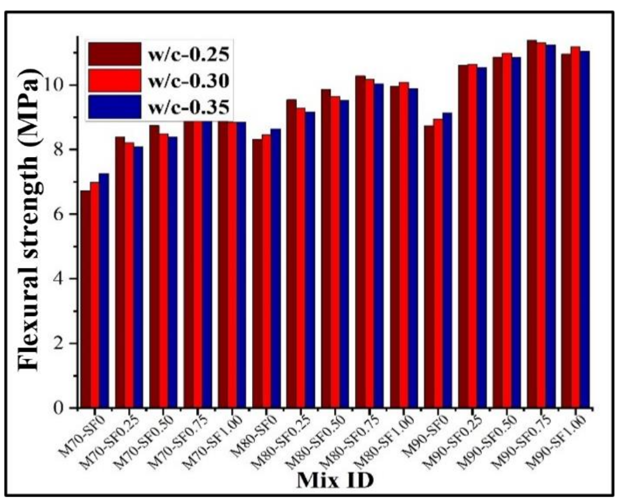
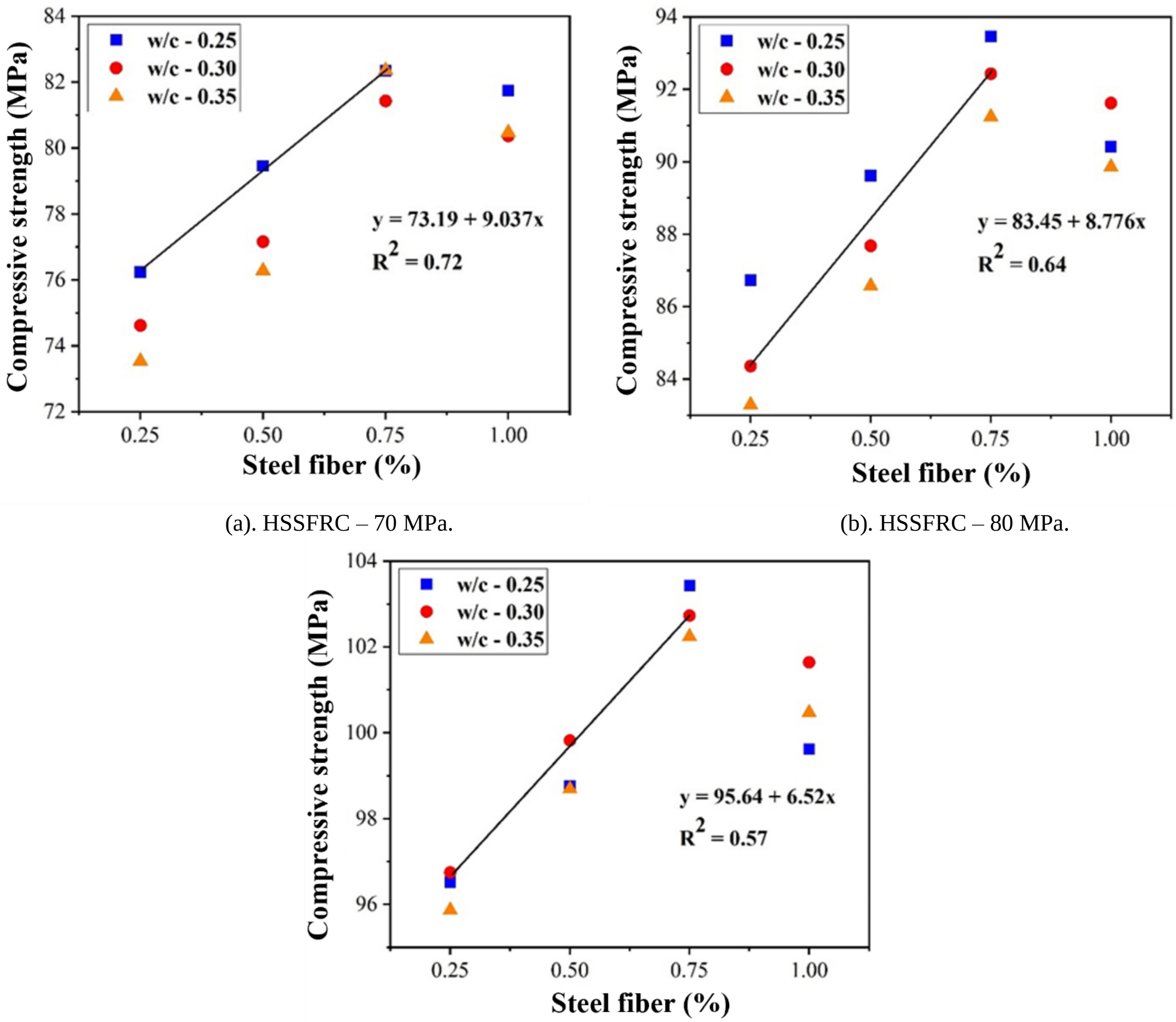



**Figure 6.** FS of HSSFRC at 28 days with various w/c ratio.

*3.4. Effect of the WCR on the HSSFRC*

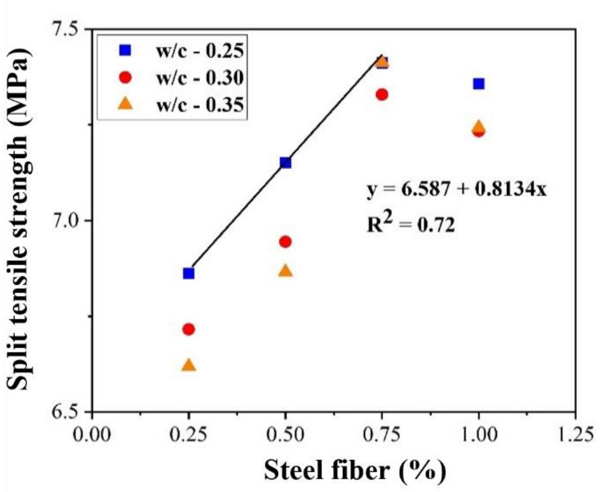
The concrete strength drops as the WCR rises from 0.25, 0.30, and 0.35. However, this experimental study found that the HSSFRC load-bearing capacity increases when the WCR falls to 0.25. The concrete compressive strength grows linearly by adding 0.25%, 0.50%, and 0.75% of steel fibre content. But the strength drops by adding 1.00% of steel fibre, as Figure 7 (a) – (c) shows. The split tensile strength test shows a similar pattern, as Figure 8 (a) – (c) displays. Also, the flexural strength of all concrete samples grows by adding steel fibre content up to the optimum fibre content. Then, the flexural strength drops, as Figure 9 (a) – (c) demonstrates. Likewise, when the WCR grows, the strength of the concrete drops after 0.75% of the steel fibre content.



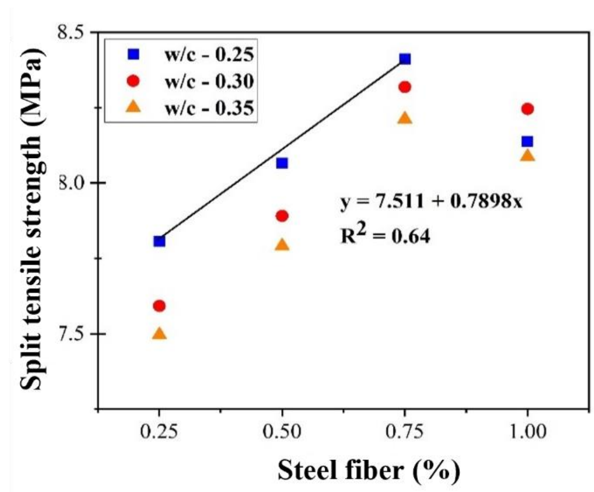

(a). HSSFRC – 70 MPa. (b). HSSFRC – 80 MPa.

(c). HSSFRC – 90 MPa.

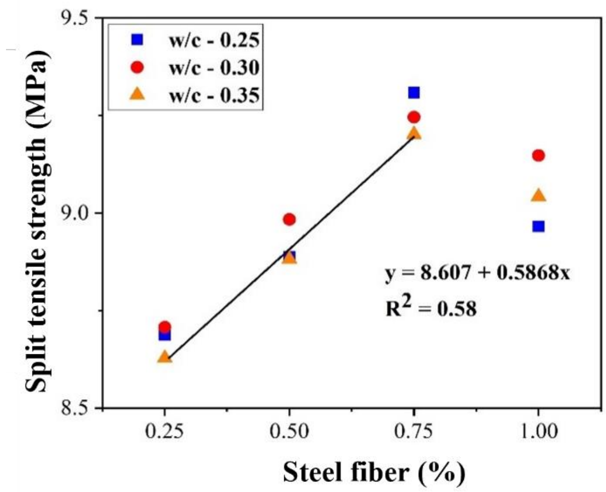
**Figure 7.** Relationship between CS and steel fibre at 28 days.




(a). HSSFRC – 70 MPa.

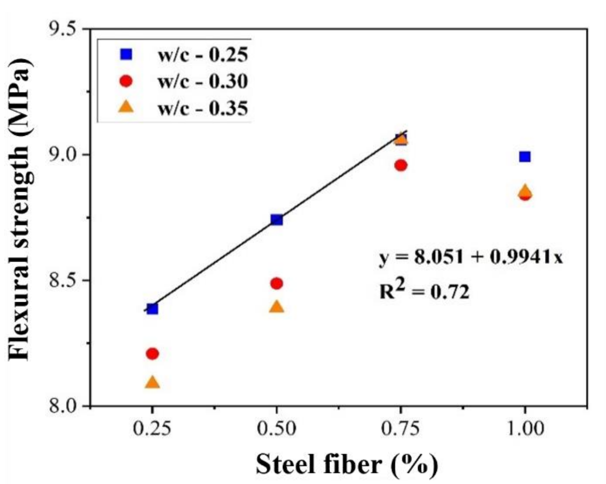



(b). HSSFRC – 80 MPa.

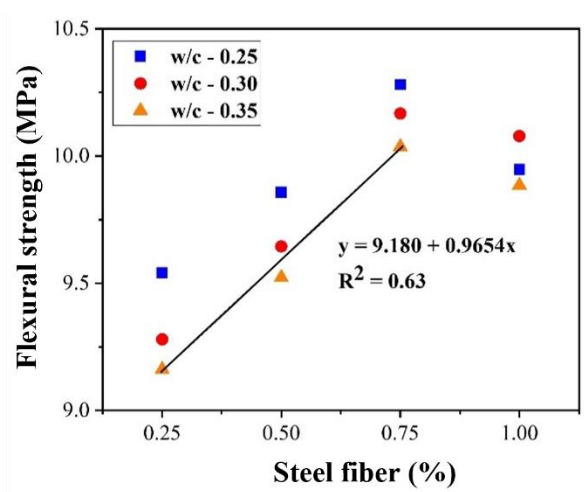



c. HSSFRC – 90 MPa.

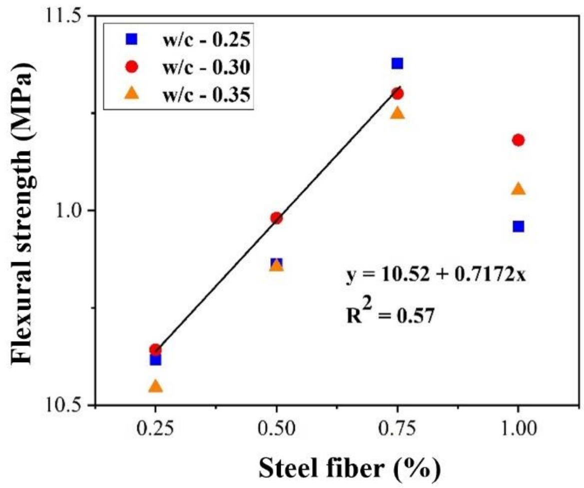
**Figure 8.** Relationship between STS and steel fibre at 28 days.




(a). HSSFRC – 70 MPa.



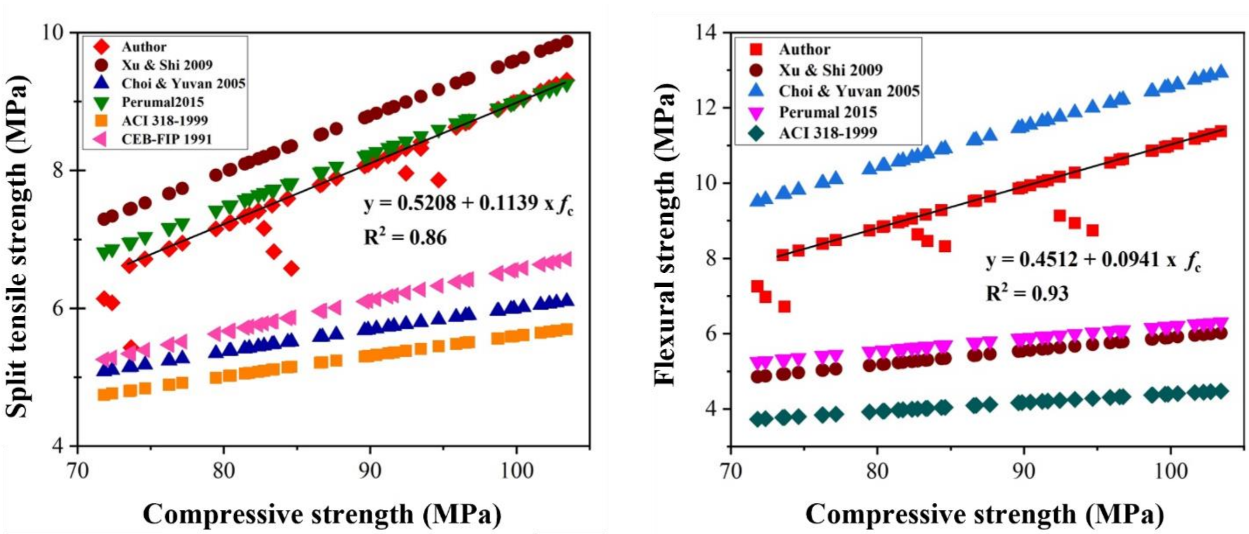

(b). HSSFRC – 80 MPa.




(c). HSSFRC – 90 MPa.
**Figure 9.** Relationship between FS and steel fibre at 28 days.

*3.5. Relationship between the strength properties of HSSFRC*

The various published empirical formulas in Tables 5 and 6, the current study examined the relationship between CS, STS and FS. The experimental results were compared to the analytical results. Previous studies (Xu & Shi 2009; Choi & Yuvan 2005; Perumal 2015; ACI 318; CEB-FIP 1991) were used to compare the CS and STS relationship. The regression analysis of the experimental results showed that the R2 values are 0.93, as Figure 10 (a) illustrates. Likewise, previous studies (Xu & Shi 2009; Perumal 2015; ACI 318; Ahmed & Shah 1985) were used to compare the CS and FS relationship. The regression analysis of the experimental results showed that the R2 values are 0.86, as Figure 10 (b) demonstrates. The relationship between the STS and FS results was also compared, and the regression analysis was done. The R2 value is 0.94, as Figure 11 shows. The experimental results were compared to the all-empirical formulas, and the experimental results were in close agreement with (Perumal 2015). The remaining previous studies formula (Xu & Shi 2009; Choi & Yuvan 2005; ACI 318-1999; CEB-FIP 1991; Ahmed & Shah 1985) significantly differed from the experimental results.




(a). CS versus STS. (b). CS versus FS.
**Figure 10.** Relationship between CS, STS and FS of HSSFRC at 28 days.

**Table 5.** Published empirical formulas for the relationship between CS and STS.

| Xu & Shi 2009 | Choi & Yuvan 2005 | Perumal 2015 | ACI 318-1999 | CEB-FIP 1991 |
|---|---|---|---|---|
| $f_t = 0.21f_c^{0.83}$ | $f_t = 0.6f_c^{0.5}$ | $f_t = 0.188f_c^{0.84}$ | $f_t = 0.56f_c^{0.5}$ | $f_t = 0.3f_c^{0.67}$ |

Note: $f_t$: Split tensile strength, $f_c$ Compressive strength

**Table 6.** Published empirical formulas for the relationship between CS and FS

| Xu & Shi 2009 | Perumal 2015 | ACI 318-1999 | Ahmed and Shah 1985 |
|---|---|---|---|
| $f_t = 0.39f_c^{0.59}$ | $f_t = 0.259f_c^{0.843}$ | $f_t = 0.62f_c^{0.5}$ | $f_t = 0.44f_c^{0.5}$ |

Note: $f_t$: Flexural strength, $f_c$ Compressive strength

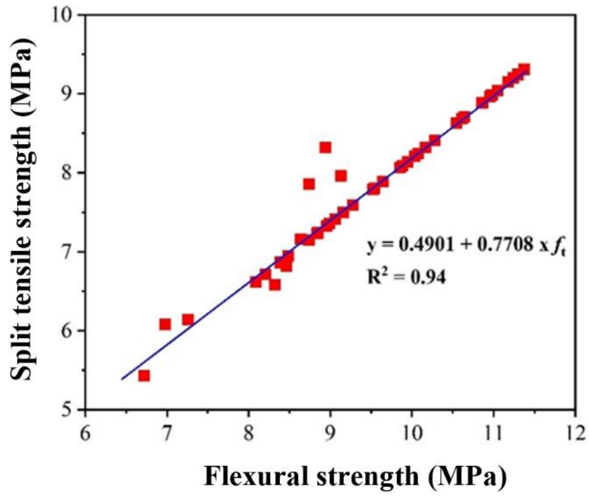



**Figure 11.** Relationship between STS and FS of HSSFRC at 28 days.

## 4. Conclusions and comments for future study

This study performed an experimental analysis of HSSFRC with different WCR, amounts of steel fibre content and concrete strengths. The experimental study results and regression analysis led to the following findings:

1. The study examined the mechanical properties of HSC with different quantities of steel fibre (0.25%, 0.50%, 0.75%, and 1.00%). The optimum fibre content has been found to be 0.75%. Also, three WCR (0.25, 0.30, and 0.35) were used in this study. The WCR of 0.25 performed better than the other two WCR. Compared to the control specimen M70-SF0, the CS rose by 10.77%, 9.90%, and 9.59% for M70-SF0.75 with WCR of 0.25, 0.30, and 0.35, respectively.

2. Likewise, compared to the control specimen M80-SF0, the CS grew by 9.46%, 9.29%, and 8.72% for M80-SF0.75 with WCR of 0.25, 0.30, and 0.35, respectively. The CS marginally rose by 8.47%, 8.05%, and 7.64% for M90-SF0.75 with WCR of 0.25, 0.30, and 0.35, respectively, compared to the control specimen M90-SF0.

3. Compared to M70-SF0 for a WCR of 0.25, the STS of the M70-SF0.75 specimen rose by 26.67%, 17.04%, and 15.29%. Likewise, compared to M80-SF0 for a WCR of 0.30, the STS of the M80-SF0.75 specimen rose by 15.56%, 14.34%, and 12.59%. Similarly, compared to M70-SF0 for a WCR of 0.35, the STS of the M80-SF0.75 specimen rose by 15.56%, 14.34%, and 12.59%.

4. The flexural strength grows with a higher amount of steel fibre. Compared to M70-SF0 for a WCR of 0.25, the flexural strength of the M70-SF0.75 specimen grew by 25.82%, 22.07%, and 18.05%. Likewise, compared to M80-SF0 for a WCR of 0.30, the flexural strength of the M80-SF0.75 specimen grew by 19.07%, 16.79%, and 13.34%. Similarly, compared to M90-SF0 for a WCR of 0.35, the flexural strength of the M90-SF0.75 specimen also grew by 23.18%, 20.89%, and 17.97%.

5. The previously published empirical formulas predicted the relationship between CS versus STS and CS versus FS. The experimental results were in close agreement and correlation with the proposed regression equation results.

The research has evaluated the strength properties of the high strength concrete with incorporated steel fibre. Furthermore, the study may extend to evaluate the behaviour of columns and beams with various loading conditions.

**Author contributions:** Sasikumar P: Participation in planning for the study, design, analytical, experimental parametric study, research methodology, implementation of the parametric study, and writing original manuscript preparation Review enhance the paper manuscript and supervising the experimental works.

**Funding:** This research received no external funding.

**Acknowledgements:** We gratefully thank Kumaraguru College of Technology for providing the necessary resources to accomplish the research work.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

Akcay, C., & Manisali, E. (2018). Fuzzy decision support model for the selection of contractor in construction works. Revista de la Construcción. Journal of Construction, 17(2), 258-266.

ACI Committee 318-1999. Building code requirements for structural concrete and commentary. Farmington Hills, MI: American Concrete Institute.

Afroughsabet, V., Biolzi, L., & Ozbakkaloglu, T. (2016). High-performance fibre-reinforced concrete: a review. Journal of materials science, 51, 6517-6551.

Ahmad, S.H., & Shah, S.P. (1985). Structural properties of high strength concrete and its implications for precast prestressed concrete. PCI journal, 30(6), 92-119.

ASTM - 2012. Standard Specification for Chemical Admixtures for Concrete. ASTM Standard C, 494.

Banthia, N., & Sappakittipakorn, M. (2007). Toughness enhancement in steel fibre reinforced concrete through fibre hybridisation. Cement and concrete research, 37(9), 1366-1372.

Bencardino, F., Rizzuti, L., Spadea, G., & Swamy, R.N. (2010). Experimental evaluation of fibre reinforced concrete fracture properties. Composites Part B: Engineering, 41(1), 17-24.

Bencardino, F., Rizzuti, L., Spadea, G., & Swamy, R.N. (2013). Implications of test methodology on post-cracking and fracture behaviour of steel fibre reinforced concrete. Composites Part B: Engineering, 46, 31-38.

Biswas, R.K., Bin Ahmed, F., Haque, M.E., Provasha, A.A., Hasan, Z., Hayat, F., & Sen, D. (2021). Effects of steel fibre percentage and aspect ratios on fresh and harden properties of ultra-high performance fibre reinforced concrete. Applied Mechanics, 2(3), 501-515.

Candassamy, K., Sreerambabu, J., & Sasikumar, P. (2024). A comparative study between linear regression analysis and various codes for predicting the mechanical characteristics of polymer concrete using R-sand and M-sand. Revista de la Construcción. Journal of Construction, 23(1), 129-150.

CEB-FIP 1991. Model code for concrete structures. Evaluation of the time dependent behavior of concrete. Bulletin information No. 199, Lausanne: Committee Europe du Beton/Federation International de Precontrainte.

Choi, Y., & Yuan, R.L. (2005). Experimental relationship between splitting tensile strength and compressive strength of GFRC and PFRC. Cement and Concrete Research, 35(8), 1587-1591.

IS 10262 – 2019. Guidelines for concrete mix design proportioning. Bureau of Indian standards, New Delhi.

IS 12269 – 1987. Specification for 53 grade ordinary Portland cement. Bureau of Indian standards, New Delhi

IS 383 – 2016. Specification for coarse and fine aggregate from natural sources for concrete. Bureau of Indian standards, New Delhi.

IS 516 – 1999. Methods of tests for strength of concrete. Bureau of Indian standards, New Delhi.

Kazemi, M.T., Golsorkhtabar, H., Beygi, M.H.A. & Gholamitabar, M. (2017). Fracture properties of steel fibre reinforced high strength concrete using work of fracture and size effect methods. Construction and Building Materials, 142, 482-489.

Lee, J.H. (2017). Influence of concrete strength combined with fibre content in the residual flexural strengths of fibre reinforced concrete. Composite Structures, 168, 216-225.

Perumal, R. (2015). Correlation of compressive strength and other engineering properties of high-performance steel fibre–reinforced concrete. Journal of Materials in Civil Engineering, 27(1), 04014114.

Sasikumar, P. (2023). A comparative study between buckling behaviour and statistical analysis of axially loaded fully encased composite columns made with high strength concrete. Revista de la construcción, 22(3), 694-706.

Sasikumar, P. (2024). Experimental study on the fully encased composite short columns made with high-strength fibre-reinforced concrete. Asian Journal of Civil Engineering, 25(2), 1-12.

Sasikumar, P., & Manju, R. (2023). Structural behaviour of axially loaded high strength concrete columns reinforced longitudinally with glass fibre reinforced polymer bars. Revista de la construcción, 22(2), 293-305.

Sasikumar, P., & Manju, R. (2024) Flexural behaviour of reinforced concrete beams reinforced with Glass Fibre Reinforced Polymer (GFRP) bars: experimental and analytical study. Asian Journal of Civil Engineering, 25(2), 1-14.

Sasikumar, P., Nandhakumar, P., & Manju, R. (2022). An experimental work on high strength concrete with addition of sisal fibre. In AIP Conference Proceedings, 2446(1).

Sirijaroonchai, K., El-Tawil, S., & Parra-Montesinos, G. (2010). Behavior of high performance fibre reinforced cement composites under multi-axial compressive loading. Cement and Concrete Composites, 32(1), 62-72.

Soutsos, M.N., Le, T.T., & Lampropoulos, A.P. (2012). Flexural performance of fibre reinforced concrete made with steel and synthetic fibres. Construction and building materials, 36, 704-710.

Srinivasa, R.N., Mohan, R.P., & Jagadeesh, P. (2016). Experimental evaluation of strength properties of steel fibre reinforced concrete. Asian Journal of Civil Engineering, 17(4), 487–494.

Topcu, I.B., & Canbaz, M. (2007). Effect of different fibres on the mechanical properties of concrete containing fly ash. Construction and Building Materials, 21(7), 486-1491.

Vairagade, V.S., & Kene, K.S. (2013). Strength of normal concrete using metallic and synthetic fibres. Procedia Engineering, 51, 132-140.

Vogel, F., Holčapek, O., Jogl, M., Kolář, K. & Konvalinka, P. (2015). Development of mechanical properties of steel fibres reinforced high strength concrete. Advanced Materials Research, 1077, 113-117.

Wang, Z.L., Wu, J. & Wang, J.G. (2010). Experimental and numerical analysis on effect of fibre aspect ratio on mechanical properties of SRFC. Construction and Building Materials, 24(4), 559-565.

Xu, B.W. & Shi, H.S. (2009). Correlations among mechanical properties of steel fibre reinforced concrete. Construction and building materials, 23(12), 3468-3474.

Yazıcı, Ş., İnan, G. & Tabak, V. (2007). Effect of aspect ratio and volume fraction of steel fibre on the mechanical properties of SFRC. Construction and Building Materials, 21(6), 1250-1253.