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Research Article

Prediction of mechanical properties of high strength steel fibre reinforced concrete using linear regression techniques

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Abstract: In this study, researchers investigated the mechanical properties of high-strength steel fiber-reinforced concrete (HSFRC). The experimental study involved evaluating high strength concrete (HSC) using various steel fibre contents (ranging from 0.25% to 2.00%) and different water-cement ratios (WCR) (0.25, 0.30, 0.35, and 0.40). Adding 1.50% steel fibre to HSC led to an increase in compressive strength (CS). Specifically, the CS improved by 13.42% to 15.19% for WCR of 0.25, 0.30, 0.35, and 0.40. Including 1.50% steel fibre enhances split tensile strength (STS). The STS increased by 25.89% to 32.62% for the same WCR. High-strength concrete with 1.50% steel fiber exhibited improved flexural strength (FS). The FS rose 29.00% to 35.07% for the specified water-cement ratios. The study also considered the modulus of elasticity (ME) at 28 days. Interestingly, the strength of HSC decreased as the WCR increased. Lower WCR generally contributed to better mechanical properties. The experimental results were compared with linear regression analysis and existing empirical formulas. The regression analysis demonstrated good agreement with the experimental findings. Overall, the optimal steel fibre content was 1.50% across all WCR, significantly improving mechanical properties. The study provides valuable insights for designing HSC with enhanced performance.

Keywords: Steel fibre, steel fibre-reinforced concrete, linear regression analysis, high-strength concrete.

1. Introduction

The HSSFRC is a composite material based on cement, comprising fine and coarse aggregates along with discrete steel fibres. When these fibres are added to the concrete mix, they enhance its toughness, tensile strength, and resistance to cracking. The steel fibres are randomly distributed within the concrete during the mixing process, leading to overall property improvements (Kene et al., 2012). SFRC finds applications in various contexts, including industrial floors, pavements, bridge decks, and precast products (Gornale et al., 2012). Some notable advantages of SFRC include increased durability, reduced maintenance costs, and enhanced resistance to impact, abrasion, and shattering (Afroughsabet et al., 2016). The incorporation of fibres into concrete has been scientifically proven to enhance its mechanical properties, particularly in terms of STS, FS, and ductility. Additionally, the presence of fibres leads to reductions in shrinkage and creep deformations of the concrete (Debasree et al., 2023). Another related material is fiber-reinforced cementitious composites (FRCC), which involves adding randomly distributed fibres to a cementitious matrix. These fibres contribute to improved material toughness through their crack-bridging behavior (Bentur, A. & Mindess, 2006).

Adding steel fibres to concrete enhances its mechanical properties, making it more resilient against fractures. Research indicates that incorporating fibre ropes alongside steel bars in coir concrete results in a 6% increase in FS and a 7% increase in CS. This improvement improves concrete structures' overall durability and longevity (Yusuf et al., 2023). Adding concrete fibres can also change the cracking pattern of reinforced concrete beams (Williamson, 1974). Steel fibre-reinforced self-consolidating concrete offers several advantages over ordinary steel fibre-reinforced concrete. It enhances performance in various ways and is a valuable consideration for extending the lifespan of concrete structures (Tsai et al., 2009). When it comes to enhancing concrete properties, both silica fume and steel fibres play crucial roles. Adding silica fume to concrete leads to several benefits. It increases mechanical strength and ME. Silica fume contributes to overall concrete performance by reinforcing its structural integrity. Incorporating steel fibres further improves concrete toughness, especially in high-strength variants. The study observed a significant enhancement in toughness when steel fibres were added to HSC. Combining silica fume and steel fibres yielded remarkable results, contributing to strength and durability. These innovative approaches contribute to more substantial, resilient concrete structures (Köksal et al., 2009).

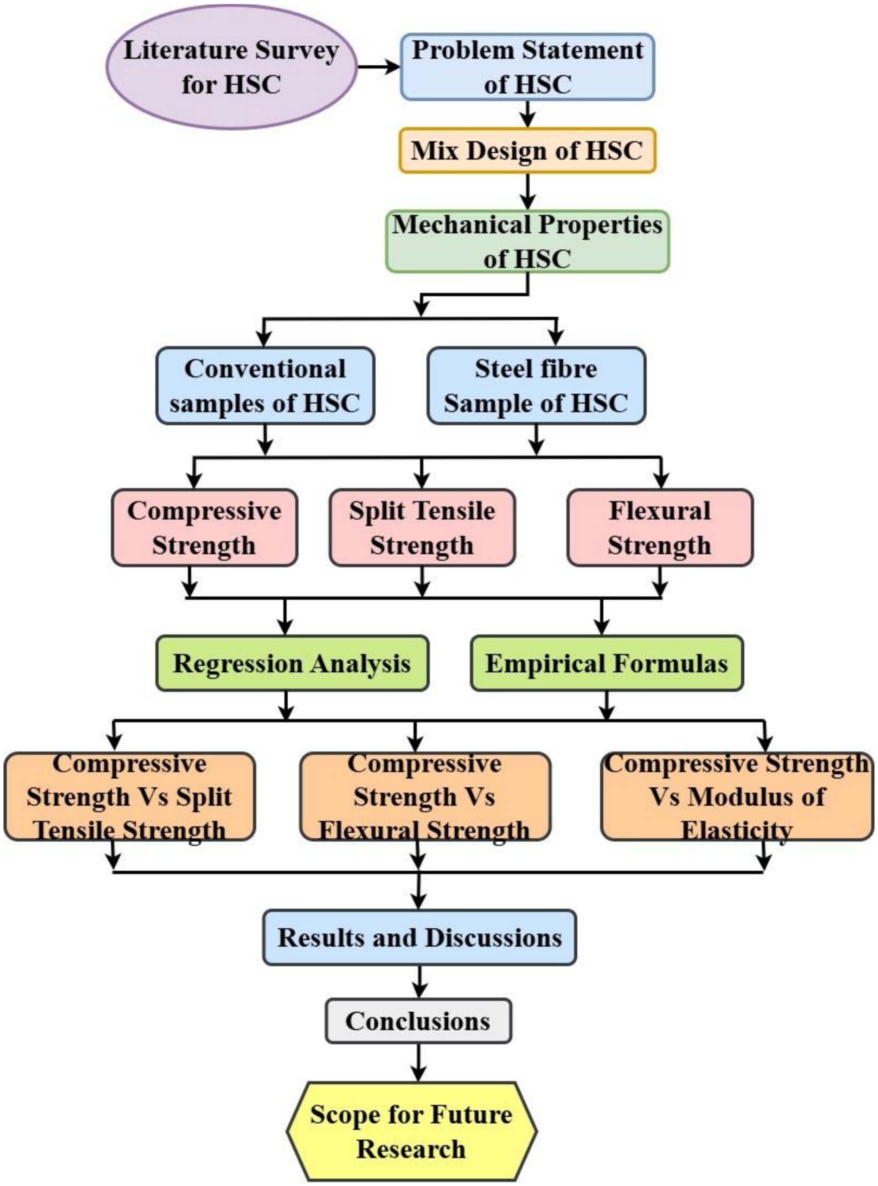


Figure 1. Flow chart for this study.

Adding fly ash to fibre-reinforced concrete composites can indeed enhance their mechanical properties. A study investigated the strength characteristics of steel fibre-reinforced concrete when fly ash was incorporated. The results revealed that the addition of fly ash, along with silica fume, led to improvements in both the workability and CS of the concrete. This finding underscores the potential benefits of using fly ash in concrete mixtures, contributing to sustainability efforts by reducing the carbon footprint (Abbass et al., 2018). Another research study delved into the impact of high-volume fly ash on the mechanical properties of fibre-reinforced concrete. The results revealed that fibre-reinforced concrete incorporating a substantial volume of fly ash exhibited remarkable CS and STS improvements. These strength values were more than twice those observed in concrete without fly ash 1. This finding underscores the significant role that fly ash can play in enhancing the performance of fibre-reinforced concrete, contributing to its overall durability and structural integrity (Saravana et al., 2017). The study conducted extensive experiments to investigate the impact of silica fume and styrene-butadiene latex (SBR) on the FS of concrete. Various WCR and different percentages of silica fume and SBR were examined. The researchers employed Abrams' Law, formulated initially for conventional concrete, to predict the flexural strength of these silica fume-SBR concretes. Their goal was to construct an empirical model that considers concrete ingredients and curing time in water to estimate FS. Furthermore, they compared the results from experimental FS tests with the predicted outcomes1. This work contributes valuable insights for designing concrete with improved flexural performance (Shafieyzadeh, 2015).

The primary aim of this research was to investigate the mechanical properties of HSSFRC. The study examined parameters such as CS, STS, FS, and ME. These properties were evaluated across various WCR and different percentages of steel fibres. To assess the effectiveness of HSSFRC, the obtained results from the SFRC samples were compared to those from the control samples. Additionally, the study employed linear regression analysis to explore the relationship between the mechanical properties of the hardened concrete. Notably, the predicted results demonstrated a stronger correlation with the experimental findings. This research contributes valuable insights into optimizing SFRC mixtures for enhanced durability and structural performance. The current research is illustrated in Figure 1.

2. Materials and methods

2.1. *Cement*

This research used ordinary Portland cement (OPC) 53 grade to examine HSSFRC. The chemical and physical properties of the cement are detailed in Table 1 and Table 2.

2.2. *Mineral admixtures*

Mineral admixtures play a significant role in enhancing the quality of concrete. Silica fume is utilized in varying percentages to improve the strength of the concrete (Köksal et al., 2008; Abbass et al., 2008). Fly ash is employed in high-strength concrete to enhance the workability of fresh concrete and increase the strength properties of the hardened concrete Saravana & Sumathi 2017). Adding fly ash to high-strength concrete enhances its durability characteristics (Nath & Sarker, 2011). When combined, silica fume and fly ash further enhance the strength properties of steel fiber-reinforced concrete (Saha, 2018; Shmlls et al., 2022). For detailed information on the chemical components and physical properties, please refer to Table 1 and Table 2.

Table 1. Chemical properties of cementitious materials.

Components	Cement	Silica fume	Fly ash
SiO_2	23.68	56.78	91.42
Al_2O_3	4.85	24.62	0.87
Fe_2O_3	3.42	6.01	0.48
CaO	62.38	0.54	1.52
MgO	0.45	0.60	0.48
SO_3	2.41	0.18	0.002
Na_2O	0.23	0.32	0.48
LOI (%)	1.34	2.87	2.20

2.3. *Aggregates*

The fine aggregate, which passes through a size of 4.75 mm, and the crushed coarse aggregate of 10 mm were sourced from the local market for manufacturing high-strength concrete in this study. The physical properties of the fine and coarse aggregate are provided in Table 2. Based on the experimental study, the 10mm coarse aggregate improved the physical properties of the concrete compared to the 20mm coarse aggregate.

2.4. *Chemical admixtures*

The chemical admixtures (conplast SP 430) were used to increase the strength of high-strength SFRC. Superplasticizer reduces the high-range water content in high-strength concrete during manufacturing. The superplasticizer 0.5% dosage enhances the concrete slump and strength properties (Khan & Ali, 2008; Aruntaş et al., 2018). The specific gravity of superplasticizer 1.08 and its dark brown color was observed from the physical test.

2.5. *Steel fibre*

In this research, hooked-end steel fibres were employed with a length of 50 mm and a diameter of 0.62 mm. These fibres were incorporated in varying percentages: 0.25%, 0.50%, 0.75%, 1.00%, 1.25%, 1.50%, 1.75%, and 2.00%. Adding these steel fibres significantly enhanced the mechanical properties and durability of the hardened concrete (Köksal et al., 2008; Yazıcı et al., 2007; Jhatial et al., 2018). For detailed information on the physical properties of the hooked-end steel fibres, please refer to Table 2.

Table 2. Physical properties of all ingredients.

Properties / Materials	Cement	Silica fume	Fly ash	Fine aggregate	Coarse aggregate	Steel fibre
Specific gravity (g/cc)	3.14	2.34	2.52	2.64	2.68	7.15
Consistency (%)	4.52	-	-	-	-	-
Initial setting time (Min)	48	-	-	-	-	-
Final setting time (Min)	356	-	-	-	-	-
Fineness modulus	4.62	3.42	2.96	3.82	6.54	-
Water absorption (%)	-	-	-	1.27	0.42	-
Tensile strength (MPa)	-	-	-	-	-	1200
Diameter (mm)	-	-	-	-	-	0.62
Length (mm)	-	-	-	-	-	50
Aspect ratio (L/D)	-	-	-	-	-	80.64
Modulus of elasticity (GPa)	-	-	-	-	-	201

2.6. *Mix proportions*

The mix proportion of HSSFRC of M70 grade, designed as per IS: 10262 – 2019 [20], is reported in Table 3. A total of thirty-six HSSFRC mix proportions were prepared with various WCR (0.25, 0.30, 0.35, and 0.40) and percentages of steel fibres (0.25%, 0.50%, 0.75%, 1.00%, 1.25%, 1.50%, 1.75%, and 2.00%), respectively. The sample was designated W0.25-70-SF0, where W denotes water-cement ratio, 70 denotes characteristic compressive strength, and SF denotes steel fibre.

2.7. *Methods*

The mechanical properties of HSSFRC studied include CS, STS, FS and ME as per the (IS 516 – 1959). The mold size for the CS test was 150 mm x 150 mm x 150 mm; for the FS test, it was 150 mm x 150 mm x 750 mm; and for the STS and ME test, it was 150 mm in diameter and 300 mm in length. The sample was prepared with various ages, and the CS and STS were tested at 7 and 28 days under a 3000 kN capacity compression testing machine (CTM). Similarly, FS was tested at 28 days under the 400 kN capacity of the universal testing machine (UTM). The ME test was conducted in CTM with an attachment of the digital deflection meter in cylinder specimens. The reading was observed, and the ME was calculated from the load versus deflection curve. The sample preparation is illustrated in Figure 2. Each mix was cast with three samples, and the average results are reported in Table 4.

Table 3. Mix proportioning high-strength concrete per kg/m^3.

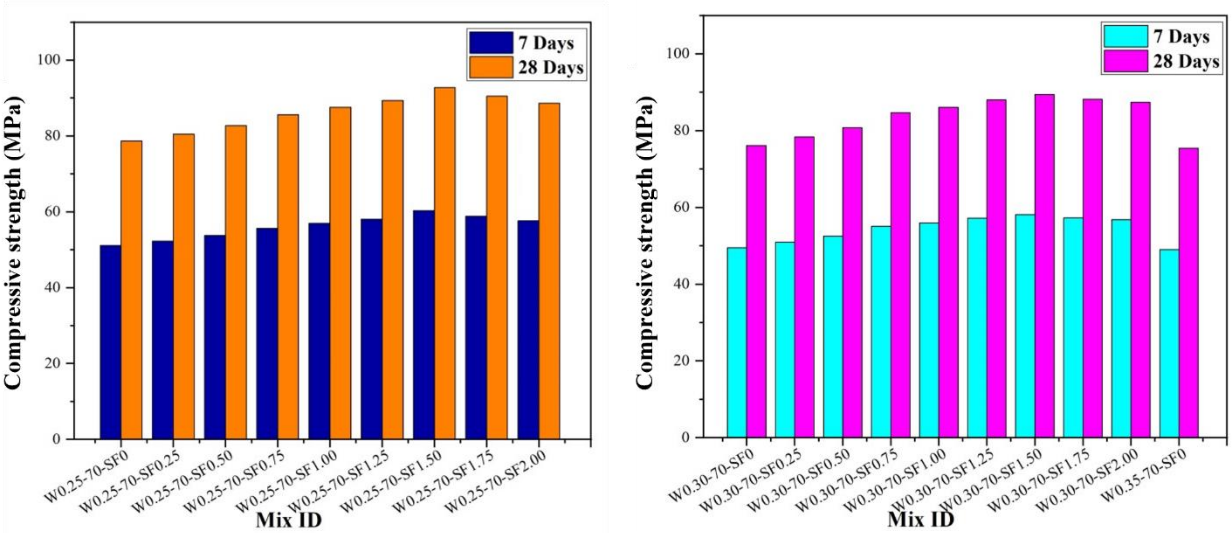
Materials	Water cement ratio			
	0.25	0.30	0.35	0.40
Cement	560	540	510	480
Fine aggregate	630	658	682	690
Coarse aggregate	1068	1120	1152	1186
Fly ash	56	54	51	48
Silica Fume	56	54	51	48
Water	108	115	127	136
Superplasticizer	2.80	2.70	2.55	2.40
Steel fibre (%)	0.25, 0.50, 0.75, 1.00, 1.25, 1.50, 1.75, 2.00			

Figure 2. Compressive strength of high strength SFRC at 7 and 28 days.

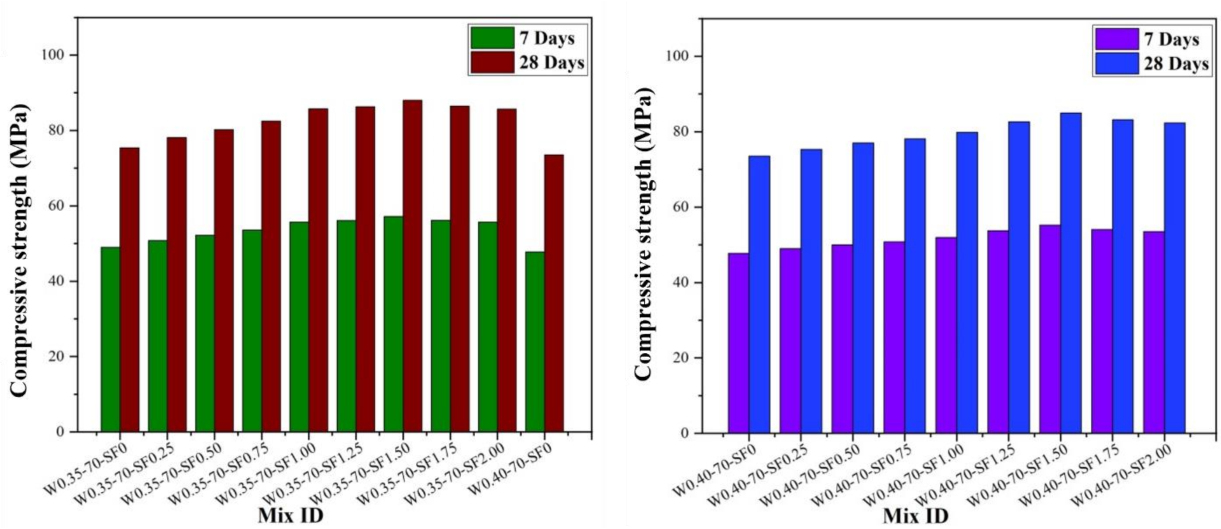
3. Results and discussion

3.1. Effect of the steel fibres on compressive strength

The samples were cast with HSC to examine the CS at 7 and 28 days, as shown in Figure 3. The samples were also cast with various steel fibres (0.25%, 0.50%, 0.75%, 1.00%, 1.25%, 1.50%, 1.75%, and 2.00%) and WCR (0.25, 0.30, 0.35, and 0.40) is listed in Table 4. Increasing the steel fibre content improved the CS by 2.27%, 4.89%, 8.15%, 10.21%, 11.96%, 15.19%, 13.06%, and 11.28% at 28 days for a WCR of 0.25, respectively. Based on the experimental study, the compressive strength was increased by 15.19% at 1.50% of steel fibre. Furthermore, CS is reduced by 13.06% at 1.75% of steel fibre. This observation shows that the optimum fibre content is 1.50% of the steel fibre, which gives better results than the remaining mix. Similar behaviour was observed from the remaining WCR mixes. The optimum steel fibre content compressive strength increased by 15.19%, 14.87%, 14.28%, and 13.47% for WCR 0.25, 0.30, 0.35, and 0.40, respectively. Compared to the remaining mixes, the CS enhanced for WCR 0.25 is a better improvement. Beyond the optimum blend, the strength is reduced due to the lack of bond between the cement paste, aggregates, and steel fibres.



(a). 0.25 (b). 0.30



(c). 0.35 (d). 0.40

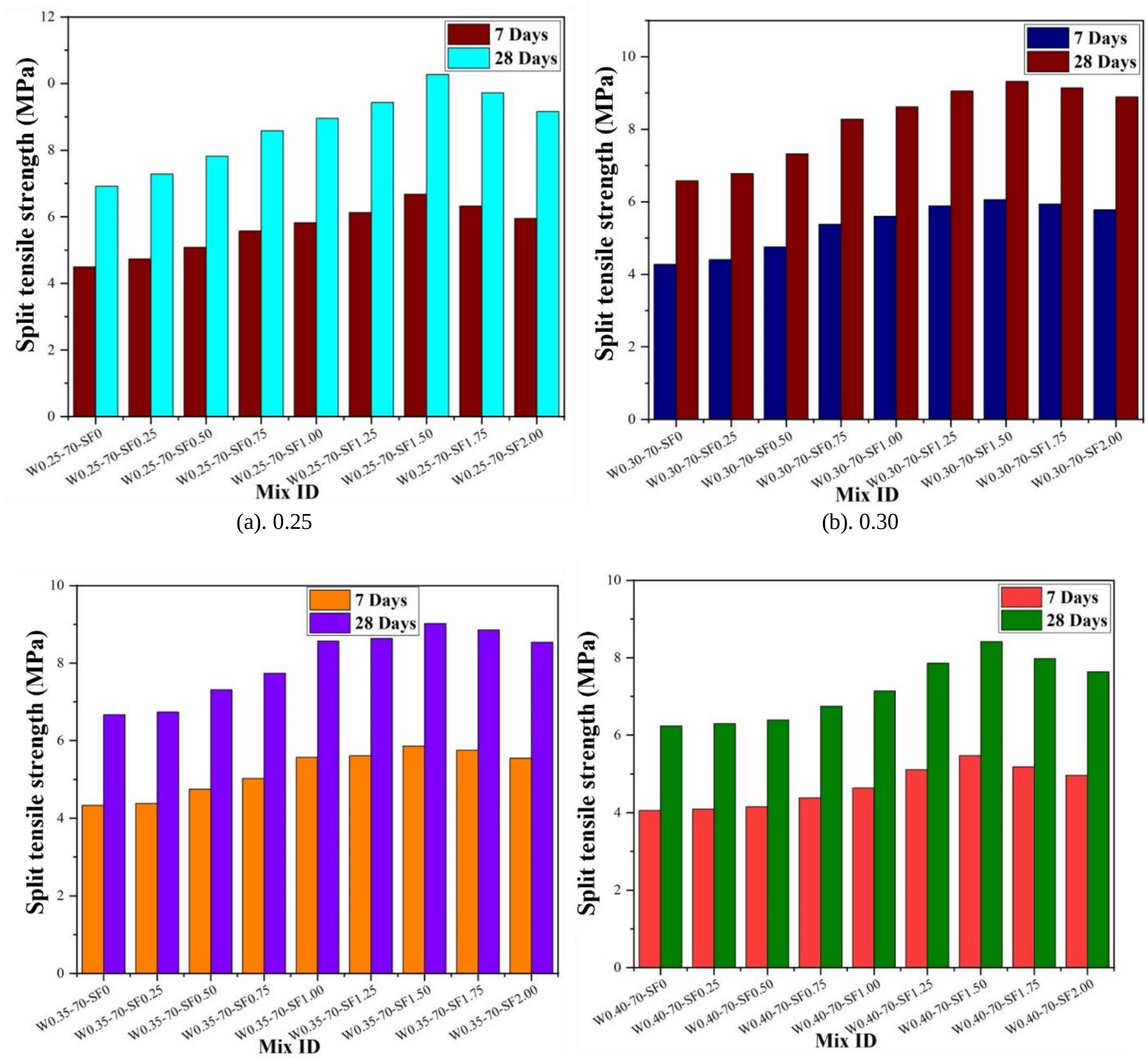
Figure 3. CS of high strength SFRC at 7 and 28 days.

Table 4. Mechanical properties of high-strength SFRC.

Mix ID	Compressive strength (MPa)	Increased CS compared to SF0 (%)	Split tensile strength (MPa)	Increased STS compared to SF0 (%)	Flexural strength (MPa)	Increased FS compared to SF0 (%)
W0.25-70-SF0	78.64	-	6.92	-	9.24	-
W0.25-70-SF0.25	80.47	2.27	7.28	4.95	9.78	5.52
W0.25-70-SF0.50	82.68	4.89	7.82	11.51	10.52	12.17
W0.25-70-SF0.75	85.62	8.15	8.58	19.35	11.63	20.55
W0.25-70-SF1.00	87.58	10.21	8.96	22.77	12.47	25.90
W0.25-70-SF1.25	89.32	11.96	9.43	26.62	12.76	27.59
W0.25-70-SF1.50	92.73	15.19	10.27	32.62	14.23	35.07
W0.25-70-SF1.75	90.45	13.06	9.72	28.81	13.42	31.15
W0.25-70-SF2.00	88.64	11.28	9.16	24.45	12.67	27.07
W0.30-70-SF0	76.12	-	6.58	-	8.62	-
W0.30-70-SF0.25	78.36	2.86	6.78	2.95	9.14	5.69
W0.30-70-SF0.50	80.72	5.70	7.32	10.11	9.96	13.45
W0.30-70-SF0.75	84.69	10.12	8.28	20.53	11.38	24.25
W0.30-70-SF1.00	86.04	11.53	8.62	23.67	11.84	27.20
W0.30-70-SF1.25	87.96	13.46	9.06	27.37	12.47	30.87
W0.30-70-SF1.50	89.42	14.87	9.32	29.40	12.93	33.33
W0.30-70-SF1.75	88.12	13.62	9.14	28.01	12.57	31.42
W0.30-70-SF2.00	87.36	12.87	8.89	25.98	12.36	30.26
W0.35-70-SF0	75.42	-	6.67	-	8.62	-
W0.35-70-SF0.25	78.12	3.46	6.74	1.04	9.14	5.69
W0.35-70-SF0.50	80.24	6.01	7.31	8.76	9.87	12.66
W0.35-70-SF0.75	82.47	8.55	7.74	13.82	10.64	18.98
W0.35-70-SF1.00	85.74	12.04	8.57	22.17	11.52	25.17
W0.35-70-SF1.25	86.27	12.58	8.64	22.80	11.97	27.99
W0.35-70-SF1.50	87.98	14.28	9.02	26.05	12.48	30.93
W0.35-70-SF1.75	86.42	12.73	8.86	24.72	11.69	26.26
W0.35-70-SF2.00	85.67	11.96	8.54	21.90	11.72	26.45
W0.40-70-SF0	73.52	-	6.24	-	7.98	-
W0.40-70-SF0.25	75.34	2.42	6.30	0.95	8.23	3.04
W0.40-70-SF0.50	76.98	4.49	6.39	2.35	8.72	8.49
W0.40-70-SF0.75	78.12	5.89	6.75	7.56	9.26	13.82
W0.40-70-SF1.00	79.86	7.94	7.14	12.61	9.64	17.22
W0.40-70-SF1.25	82.65	11.05	7.86	20.61	8.36	4.55
W0.40-70-SF1.50	84.96	13.47	8.42	25.89	11.24	29.00
W0.40-70-SF1.75	83.14	11.57	7.98	21.80	10.68	25.28
W0.40-70-SF2.00	82.36	10.73	7.64	18.32	10.57	24.50

3.2. Effect of the steel fibres on STS

The STS of HSSFRC was tested at 7 and 28 days and is presented in Table 4. The STS of the HSSFRC mixes was compared to the control mix in all WCR, as shown in Figure 4. The experimental results showed that 1.50% steel fibre is the optimum fibre content in all WRC mixes. The optimum 1.50% steel fibre increased STS by 32.62%, 29.40%, 26.05% and 25.89% for WCR 0.25, 0.30, 0.35 and 0.40, respectively. The STS decreases to increase the WCR, and the STS improve to reduce the WCR. The STS increases linearly with the addition of steel fibre to all WCRs. The advantage of adding steel fibre to HSC is that it enhances the STS and arrests the crack (Abbass et al., 2018).



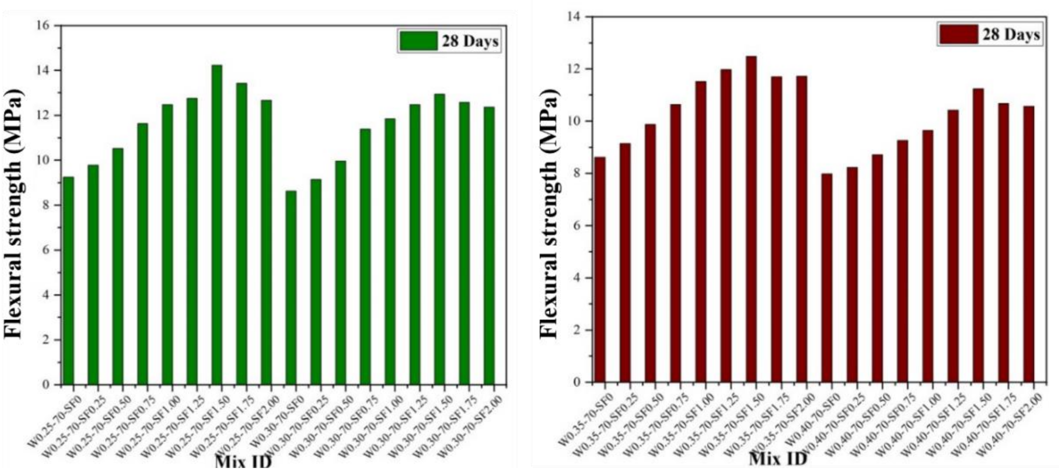
(a). 0.25 (b). 0.30

c). 0.35 (d). 0.40

Figure 4. STS of high strength SFRC at 7 and 28 days.

3.3. Effect of the steel fibres on FS

The FS of HSSFRC is linearly improved by increasing the steel fibre content to the optimum dosage, as shown in Figure 5. Increasing the steel fibre content improves the FS by 2.52%, 12.17%, 20.55%, 25.90%, 27.596%, 35.07%, 31.15%, and 27.07% at 28 days for a WCR of 0.25, respectively. Similar behaviour was observed for the remaining WCR mixes. The FS increases by 35.07%, 33.33%, 30.93%, and 29.00% for WCR of 0.25, 0.30, 0.35, and 0.4, respectively. However, increasing the WCR decreases the FS due to the lack of bonds. The FS can be increased by arresting the cracks and enhancing the bond between steel fibre, aggregates, and cement paste (Sasikumar, 2024; Sasikumar & Manju, 2024; Sasikumar, 2023; Sasikumar et al., 2022).

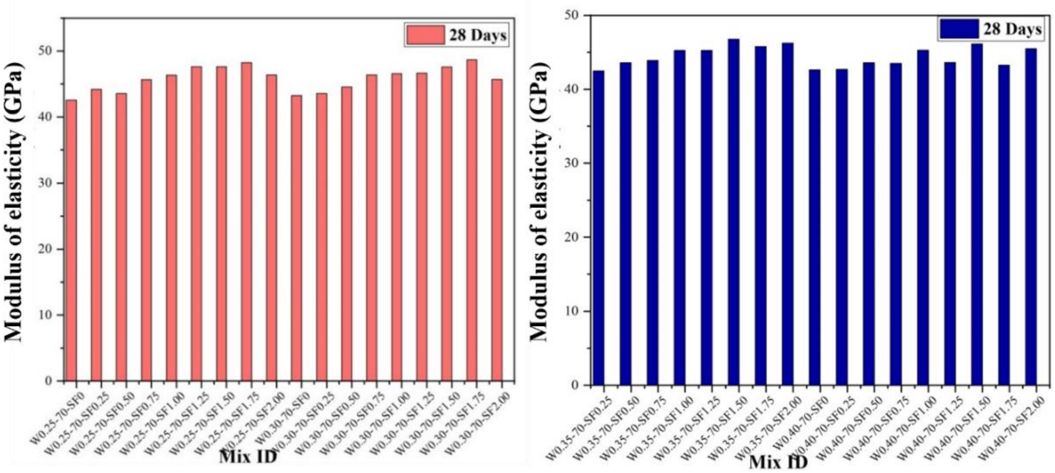


(a). 0.25 & 0.30 (b). 0.35 & 0.40

Figure 5. Flexural strength of high strength SFRC at 28 days.

3.4. Effect of the steel fibres on ME

The ME of HSSFRC is calculated from the stress-strain curve at 28 days, as shown in Figure 6. The ME gradually improves with an increase in steel fibre content up to 1.50%. However, for all mixes, the modulus of elasticity reduces after this optimum mix. Meanwhile, the ME increases with a decrease in the WCR of the HSSFRC.

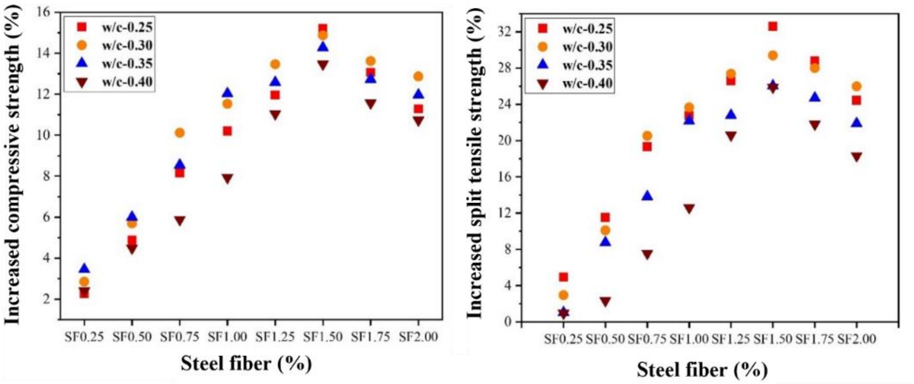


(a). 0.25 & 0.30 (b). 0.35 & 0.40

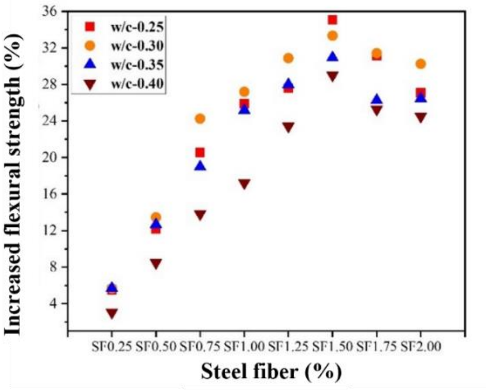
Figure 6. ME of high strength SFRC at 28 days.

3.5. Effect of the steel fibres and WCR on HSC

The steel fibre and WCR influence the improvement of the strength of the concrete. The CS, STS & FS and the relationship between steel fibre and these properties are shown in Figure 7. However, increasing the WRC leads to a decrease in the mechanical properties (Abbass et al., 2018). Reddy et al. report that the water-cement ratio enhances the CS and FS of SFRC (Nili & Afroughsabet, 2010; Li et al., 2021). SRFC investigated the relationship between STS and FS with various WCR. The strength of the concrete decreased as the WCR increased (Shah et al., 2020; Lee et al., 2013). The FS was experimentally studied with various WCR (Lee et al., 2013). They have investigated the strength properties of different WCR and steel fibre content. Increased steel fibre enhances the strength properties of the concrete, and the low WCR provides better improvement compared to the remaining mixes (Zeynal, 2008; Nili & Afroughsabet, 2012; Candassamy et al., 2024).



(a). CS (b). STS



(c). FS

Figure 7. Increased strength properties of high-strength SFRC at 28 days.

3.6. Relationship for strength properties of the HSSFRC

The regression analysis was performed on HSSFRC to study the relationship between CS and STS, with an R^2 value of 0.99, as shown in Figure 8. The regression equation (1) was derived to predict the STS. The predicted STS value is closely correlated with the experimental values. Additionally, various codes listed in Table 5 were used to predict the split tensile strength. The regression equation (1) and multiple codes (ACI 318-08; Iravani 2010; GB 2010) better protected split tensile strength values, as presented in Table 6.

$f_{sp} = -10.3932 + 0.221 f_c$……………………………………………. (1)

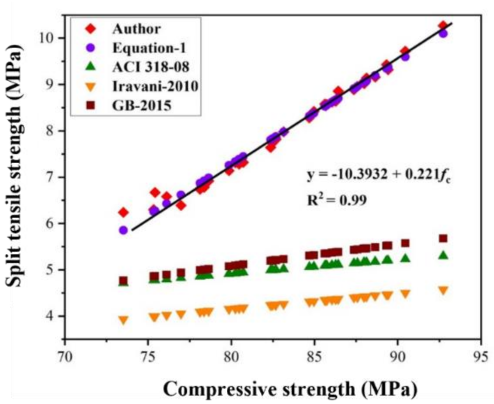


Figure 8. Relationship between the CS and STS of high strength SFRC at 28 days.

Table 5. Prediction of the strength properties of the HSSFRC using existing empirical formulas.

Type of concrete	Split tensile strength (f_{sp})	Flexural strength (f_b)	Modulus of elasticity (Ec)
Plain cement concrete	$f_{sp} = 0.55x(f_c)^{0.5}$ (ACI 318-08)	$f_b = 0.62x(fc)^{0.5}$ (ACI 318-08)	$E_c = 4700x(f_c)^{0.5}$ (ACI 318-08)
	$f_{sp} = 0.301x(0.8xf_c)^{0.65}$ (Iravani 2010)	$f_b = 0.81x(fc)^{0.5}$ (GB 2010)	$E_c = 5000x(f_c)^{0.5}$ (IS 456 - 2000)
	$f_{sp} = 0.19x(f_c)^{0.75}$ (GB 2010)	$f_b = 0.70x(fc)^{0.5}$ (IS 456 - 2000)	

Table 6. Comparison of the experimental results of high-strength SFRC with regression equations and existing empirical formulas.

Mix ID	Experimental results (MPa)				Predicted STS (MPa)				Predicted FS (MPa)				Predicted E (GPa)		
	CS	STS	FS	E (GPa)	Eq. (1)	ACI	Iravani	GB	Eq. (2)	ACI	GB	IS	Eq. (3)	ACI	IS
W0.25-70-SF0	78.64	6.92	9.24	42.56	6.99	4.88	4.11	5.02	9.22	5.50	7.18	6.21	46.94	41.68	44.34
W0.25-70-SF0.25	80.47	7.28	9.78	44.21	7.39	4.93	4.17	5.10	9.85	5.56	7.27	6.28	47.61	42.16	44.85
W0.25-70-SF0.50	82.68	7.82	10.52	43.57	7.88	5.00	4.25	5.21	10.60	5.64	7.37	6.36	48.43	42.74	45.46
W0.25-70-SF0.75	85.62	8.58	11.63	45.67	8.53	5.09	4.34	5.35	11.59	5.74	7.50	6.48	49.52	43.49	46.27
W0.25-70-SF1.00	87.58	8.96	12.47	46.34	8.96	5.15	4.41	5.44	12.26	5.80	7.58	6.55	50.24	43.98	46.79
W0.25-70-SF1.25	89.32	9.43	12.76	47.64	9.35	5.20	4.46	5.52	12.85	5.86	7.66	6.62	50.89	44.42	47.25
W0.25-70-SF1.50	92.73	10.27	14.23	47.62	10.10	5.30	4.57	5.68	14.00	5.97	7.80	6.74	52.15	45.26	48.15
W0.25-70-SF1.75	90.45	9.72	13.42	48.25	9.60	5.23	4.50	5.57	13.23	5.90	7.70	6.66	51.31	44.70	47.55
W0.25-70-SF2.00	88.64	9.16	12.67	46.36	9.20	5.18	4.44	5.49	12.62	5.84	7.63	6.59	50.64	44.25	47.07
W0.30-70-SF0	76.12	6.58	8.62	43.27	6.43	4.80	4.02	4.90	8.37	5.41	7.07	6.11	46.00	41.01	43.62
W0.30-70-SF0.25	78.36	6.78	9.14	43.58	6.92	4.87	4.10	5.00	9.13	5.49	7.17	6.20	46.83	41.60	44.26
W0.30-70-SF0.50	80.72	7.32	9.96	44.57	7.45	4.94	4.18	5.12	9.93	5.57	7.28	6.29	47.71	42.23	44.92
W0.30-70-SF0.75	84.69	8.28	11.38	46.36	8.32	5.06	4.31	5.30	11.28	5.71	7.45	6.44	49.17	43.25	46.01
W0.30-70-SF1.00	86.04	8.62	11.84	46.58	8.62	5.10	4.36	5.37	11.73	5.75	7.51	6.49	49.67	43.60	46.38
W0.30-70-SF1.25	87.96	9.06	12.47	46.67	9.05	5.16	4.42	5.46	12.39	5.81	7.60	6.57	50.38	44.08	46.89
W0.30-70-SF1.50	89.42	9.32	12.93	47.59	9.37	5.20	4.47	5.52	12.88	5.86	7.66	6.62	50.92	44.44	47.28
W0.30-70-SF1.75	88.12	9.14	12.57	48.69	9.08	5.16	4.43	5.46	12.44	5.82	7.60	6.57	50.44	44.12	46.94
W0.30-70-SF2.00	87.36	8.89	12.36	45.72	8.91	5.14	4.40	5.43	12.18	5.79	7.57	6.54	50.16	43.93	46.73
W0.35-70-SF0	75.42	6.67	8.62	42.75	6.27	4.78	4.00	4.86	8.13	5.38	7.03	6.08	45.74	40.82	43.42
W0.35-70-SF0.25	78.12	6.74	9.14	42.48	6.87	4.86	4.09	4.99	9.05	5.48	7.16	6.19	46.74	41.54	44.19
W0.35-70-SF0.50	80.24	7.31	9.87	43.57	7.34	4.93	4.16	5.09	9.77	5.55	7.26	6.27	47.53	42.10	44.79
W0.35-70-SF0.75	82.47	7.74	10.64	43.89	7.83	4.99	4.24	5.20	10.52	5.63	7.36	6.36	48.35	42.68	45.41
W0.35-70-SF1.00	85.74	8.57	11.52	45.23	8.56	5.09	4.35	5.35	11.63	5.74	7.50	6.48	49.56	43.52	46.30
W0.35-70-SF1.25	86.27	8.64	11.97	45.24	8.67	5.11	4.36	5.38	11.81	5.76	7.52	6.50	49.76	43.65	46.44
W0.35-70-SF1.50	87.98	9.02	12.48	46.78	9.05	5.16	4.42	5.46	12.39	5.82	7.60	6.57	50.39	44.08	46.90
W0.35-70-SF1.75	86.42	8.86	11.69	45.78	8.71	5.11	4.37	5.39	11.86	5.76	7.53	6.51	49.81	43.69	46.48
W0.35-70-SF2.00	85.67	8.54	11.72	46.24	8.54	5.09	4.35	5.35	11.61	5.74	7.50	6.48	49.54	43.50	46.28
W0.40-70-SF0	73.52	6.24	7.98	42.60	5.85	4.72	3.93	4.77	7.49	5.32	6.95	6.00	45.04	40.30	42.87
W0.40-70-SF0.25	75.34	6.30	8.23	42.67	6.26	4.77	4.00	4.86	8.11	5.38	7.03	6.08	45.72	40.80	43.40
W0.40-70-SF0.50	76.98	6.39	8.72	43.58	6.62	4.83	4.05	4.94	8.66	5.44	7.11	6.14	46.32	41.24	43.87
W0.40-70-SF0.75	78.12	6.75	9.26	43.49	6.87	4.86	4.09	4.99	9.05	5.48	7.16	6.19	46.74	41.54	44.19
W0.40-70-SF1.00	79.86	7.14	9.64	45.27	7.26	4.92	4.15	5.08	9.64	5.54	7.24	6.26	47.39	42.00	44.68
W0.40-70-SF1.25	82.65	7.86	10.49	43.62	7.87	5.00	4.24	5.21	10.59	5.64	7.36	6.36	48.42	42.73	45.46
W0.40-70-SF1.50	84.96	8.42	11.24	46.12	8.38	5.07	4.32	5.32	11.37	5.71	7.47	6.45	49.27	43.32	46.09
W0.40-70-SF1.75	83.14	7.98	10.68	43.24	7.98	5.01	4.26	5.23	10.75	5.65	7.39	6.38	48.60	42.86	45.59
W0.40-70-SF2.00	82.36	7.64	10.57	45.47	7.81	4.99	4.24	5.19	10.49	5.63	7.35	5.63	48.31	42.65	45.38

Note: f_{ck} - compressive strength; f_{sp} – Split tensile strength f_b - flexural strength Ec – Modulus of elasticity

The relationship between CS and FS experimental results was compared, and the regression equations were formed with an R^2 value of 0.98, as displayed in Figure 8. The predicted plain cement concrete flexural strength was calculated using various codes in Table 5. The experimental flexural strength values were compared to regression equation (2), and different codes (ACI 318-08; IS: 456 - 2000; GB 2010) were reported in Table 6. Compared to the codes, the experimental FS values correlate closely with the regression equation (2).

$$f_b = -17.4498 + 0.3392\, f_c \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

The regression analysis studied the experimental values of ME and CS of HSSFRC. The regression equation (3) derived a high-strength SFRC, and the R^2 value is 0.80, as depicted in Figure 10. Table 5 reports that the (ACI 318-08) and (IS 456 - 2000) codes were used to predict the modulus of elasticity. The regression equation (3) predicted the ME. The predicted ME values closely correlate with the experimental values reported in Table 6.

$$E_c = 17.8392 + 0.37f_c \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (3)$$

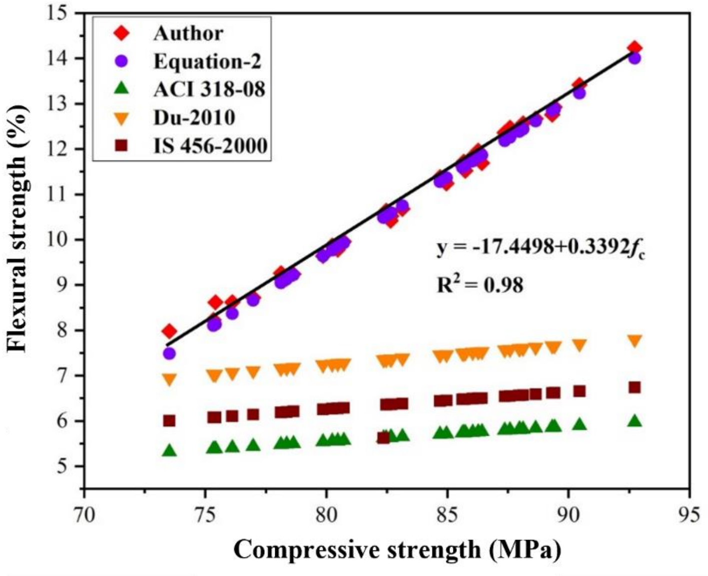


Figure 9. Relationship between the CS and FS of HSSFRC at 28 days.

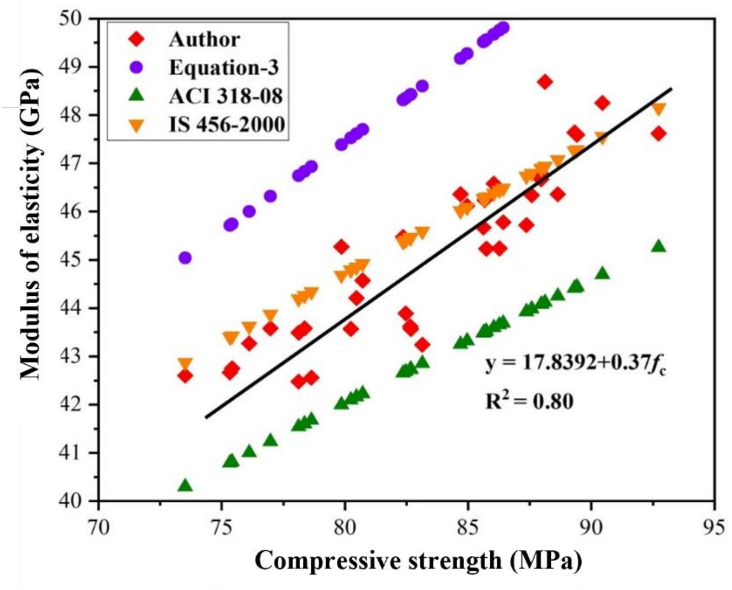


Figure 10. Relationship between the CS and ME of HSSFRC at 28 days.

4. Conclusions and comments for future study

This paper presents an experimental investigation of HSSFRC made with different proportions of steel fibre and various WCR. The WCR helps to increase the workability of HSSFRC in a fresh state. The experiment investigates hardened concrete, including CS, STS, FS, and ME. The results reveal that 1.50% of steel fibre enhances the strength properties of HSSFRC. Based on the experimental and regression results, the following conclusions were drawn:

1. The optimum steel fibre content of 1.50% tends to increase the CS by 15.19%, 14.87%, 14.28%, and 13.47%; STS increased by 32.62%, 29.40%, 26.05%, and 25.89%; and FS increases by 35.07%, 33.33%, 30.93%, and 29.00% for WCR of 0.25, 0.30, 0.35, and 0.40, respectively.
2. The modulus of elasticity of HSSFRC is enhanced using steel fibre to reduce the WCR. The strength properties of HSSFRC were improved up to the optimum steel fibre content.
3. The optimum steel fibre content shows better bond behaviour with the 0.25 WCR than the remaining WCR. The strength properties decrease beyond the optimum steel fibre content due to the lack of bond between the steel fibre, cement paste, and aggregates.
4. The linear regression analysis studied the strength properties of all blends of HSSFRC. The mechanical properties were predicted with existing empirical formulas, and the predicted results were compared to the experimental results.
5. The regression equations prediction values agreed with experimental results compared to the existing empirical formulas.

The present study completed the HSC with various steel fibre and water-cement ratio percentages. The mechanical properties were improved by adding steel fibre and mineral admixtures. Furthermore, the research was extended to multiple grades of concrete and mineral admixtures. The optimum mixes were used to develop structural elements that improve the performance of columns and beams.

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