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Research Article

Predicting the mechanical characterization of polymer hybrid fiber-reinforced concrete using linear regression analysis and various codes

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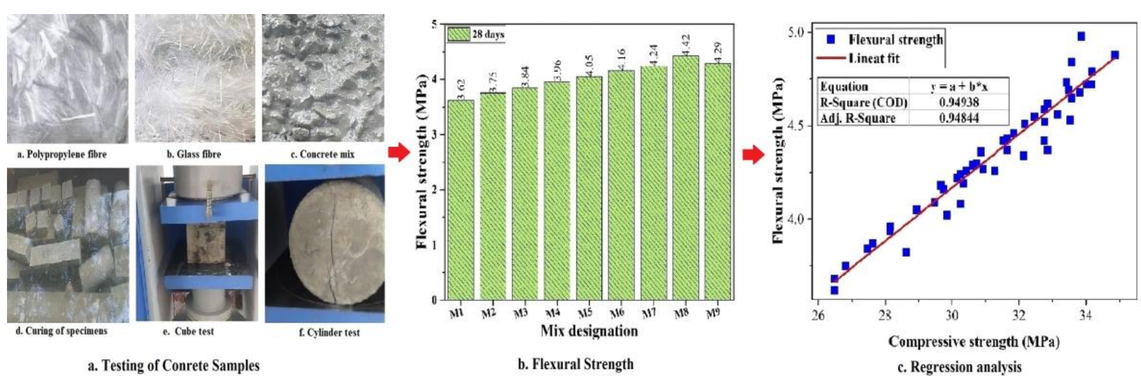
Graphical Abstract:



Highlights:

- To produce fiber-reinforced concrete with high performance.
- To increase the hardened concrete mechanical properties by adding the polymer.
- To compare the hardened concrete mechanical properties with regression analysis.

Abstract: The current study examined the Mechanical Properties (MP) of the concrete with the addition of the hybrid fibers and acrylic polymer in various proportions. Additionally, the MP of the concrete are compared using linear regression analysis and various design codes. A total of 56 mixes were examined the MP of the concrete, also the 56 mixes are divided in the 8 groups. The main objectives of the study, examine the mechanical properties of the concrete, find out the optimum mix proportions, and compare the experimental results to the proposed results. Based on the experimental results, the hybrid fiber RC carried out better than the remaining mixes. The Flexural Strength (FS) of the concrete improved by

16.99%, 26.66%, 12.43%, 8.26%, 20.37%, 24.63%, 13.96%, and 7.97%, respectively, which is compared to the control mix. Also, the proposed methods help to predict the results of experimental methods. Based on the analytical study, the ACI code and linear regression analysis results are highly correlated compared to the remaining codes.

Keywords: Hybrid fibers, polymer, polypropylene fiber, glass fiber, regression analysis.

List of abbreviations:

ACI - American concrete institute
CS - Compressive strength
CTM - Compression testing machine
E - Modulus of elasticity
FRC - Fiber reinforced concrete
FS - Flexural strength
IS - Indian standard
OPC - Ordinary Portland cement
PCC - Plain cement concrete
RC - Reinforced concrete
SP - Superplasticizer
STS - Split tensile strength
UTM - Universal testing machine

1. Introduction

In the current decade, significant advancements in concrete strength have been achieved through extensive research incorporating various cementitious materials. These substances include metakaolin, fly ash, ground granulated blast furnace slag, and silica fume. A variety of fibers, including glass, PF, SF, carbon and alkali-resistant glass fiber, has been used by many researchers. Furthermore, research has looked into the application of various polymers and chemical admixtures.

Polymer concrete (PC) is created by combining traditional concrete with polymers (Yooprasertchai et al., 2024). Cement characteristics containing HF and polymer latex has garnered research interest due to their important contributions to durability of the structure (Li et al., 2024; Sabu & Karthi, 2020). Recent studies have concentrated on the MP and durability of fiber-reinforced polymers (FRPs), especially those reinforced with glass and aramid fibers (Albuja-sánchez et al., 2024). The concrete industry is challenged to incorporate sustainable materials to enhance the properties of concrete (Hamed et al., 2024; Al-alusi et al., 2024). Research has examined the effects of hybrid fibers on the MP and shrinkage behavior of concrete, noting that steel fibers improved the strength properties of concrete (Hassan et al., 2024). Combining basalt and polypropylene fibers resulted in concrete with enhanced impact toughness (Yan et al., 2024; Liang et al., 2024; İsafça-kaya et al., 2024). Furthermore, a mixture of silica fume and polypropylene fibers demonstrated superior CS, STS and FS compared to control concrete mixes (Nabighod et al., 2024). Adding polypropylene fibers could improve impact resistance and damage and crack resistance (Lin et al., 2024). Additionally, integrating glass fibers into the concrete matrix improves the materials STS, toughness, and MP (El et al., 2024). The findings underscore the potential advantages of incorporating glass fiber-reinforced polymer (GFRP) waste into cement mortars, highlighting improvements in strength and toughness (Reddy et al., 2024). Incorporating hybrid fibers in concrete enhances its MP and impact resistance (Rajkohila et al., 2024). The ideal percentage of polypropylene fibers varies depending on the specific variable and property being analyzed (Ajwad et al., 2024).

Improved strength, durability, resistance to chemicals, and bonding properties are only a few advantages of polymer Portland cement concrete. Various amounts of polymer content were used to make and cure the specimens (El-Hawary et al., 2005). The effects of PF on the durability of concrete is investigated and noticed the improvements in resistance to chloride penetration and increased durability against sulfate attacks (Deeparaj & Ramachandran, 2019). It is also acknowledged that hybrid fibers have the potential to increase the MP and durability of geopolymer concrete. The main objectives of this research focus on enhancing concrete through the integration of polymer and hybrid fibers. Polymer concrete provides numerous advantages over traditional concrete, such as superior performance and strength. This specific concrete mix significantly boosts strength characteristics, including FS and ME. Many studies have used various materials, such as mineral admixtures and fibers. The present study examines polymer concrete by incorporating hybrid fibers at various percentages. The main objective of this study is to enhance the mechanical properties of concrete by integrating polymer and hybrid fibers.

2. Materials and methods

2.1. Properties of the materials

In this study, the mechanical properties of the concrete is examined with addition of the various materials such as OPC 53 grade cement (IS: 12269 – 2013), fine aggregate (IS: 383 – 1987), coarse aggregate (IS: 2386 Part III – 1963), glass fiber, polypropylene fiber, polymer, superplasticizer (IS: 9103 – 1999) and water respectively. The physical properties of all the materials are studied and the physical properties of all the materials are reported in Table 1.

Table 1. Physical properties of the materials.

Physical properties		CE	FA	CA	SP	PF	GF	P
Fineness modulus (%)		2.54	3.68	6.84	-	-	-	-
Consistency (min)	Initial	34	-	-	-	-	-	-
	Final	280	-	-	-	-	-	-
Density (g/cm^3)		-	-	-	-	0.90	2.40	-
Tensile strength (MPa)		-	-	-	-	3.60	6.40	-
Specific gravity (g/cm^3)		3.12	2.64	2.72	1.08	0.93	2.70	1.18
Water absorption (%)		-	1.54	0.47	-	-	-	-

2.2. Mix proportions of the concrete

A total of 56 mixes (M1 to M2) are evaluated in this present study; all groups of the materials are given in Table 2. The polymer concrete M25 was formulated with specific material proportions: CE at 320 kg/m³, FA at 720 kg/m³, CA at 1252 kg/m³, SP at 3.20 kg/m³, W at 144 kg/m³, and a W/C of 0.45. These proportions were established under the standards outlined in (IS: 10262 – 2019), with a comprehensive methodology illustrated in Figure 1.

Table 2. Mix proportions of the concrete in kg/m^3.

Mix groups	ID	CE	FA	CA	SP	W	W/C	PF (%)	GF (%)	P (%)
I	M1 - M9	320	720	1252	3.20	144	0.45	0 - 1.6	-	-
II	M10 - M17							-	0 - 1.6	-
III	M18 - M23							1.2	-	0 - 5
IV	M24 - M30							-	1.4	0 - 5
V	M31- M37							0 - 0.6	0 - 1.6	-
VI	M38 - M44							0 - 1.20	0 - 0.8	-
VII	M45 - M50							0.6	1.0	0 - 5
VIII	M51 - M56							1.0	0.8	0 - 5

Note: CE: cement, FA: fine aggregate, CA: coarse aggregate, SP: superplasticizer, W: water content, W/C: water cement ratio PF: polypropylene fiber, GF: glass fiber, P: polymer

By adding different percentages of PF specifically, 0.2%, 0.4%, 0.6%, 0.8%, 1.2%, 1.4%, and 1.6% in the first group the PC's strength is increased. The second group involves the addition of GF in the same percentages: 0.2%, 0.4%, 0.6%, 0.8%, 1.2%, 1.4%, and 1.6%. Furthermore, the third group determines that 1.2% is the ideal amount of polypropylene fiber, which is then mixed with various polymer amounts that range from 1% to 5%. The ideal glass fiber content of 1.4% is established for the fourth group, and it is identically mixed with polymer quantities in the same range (1% to 5%). With several percentages of glass fiber (0.2%, 0.4%, 0.6%, 0.8%, and 1.2%), the fifth group shows that the ideal polypropylene fiber concentration is 0.6%. The ideal GF content is 0.80%. at addition to the ideal GF content of 0.8%, PF is added at the following percentages in the sixth group: 0.2%, 0.4%, 0.6%, 0.8%, and 1.2%. The seventh group determines that the ideal ratio of glass fiber to polypropylene is 1.0% and 0.6%, respectively, with different polymer concentrations (1%, 2%, 3%, 4%, and 5%). Last but not least, the eighth group maintains the same range of polymer contents from 1% to 5% while establishing the ideal values for PF and GF at 1.0% and 0.8%, respectively.

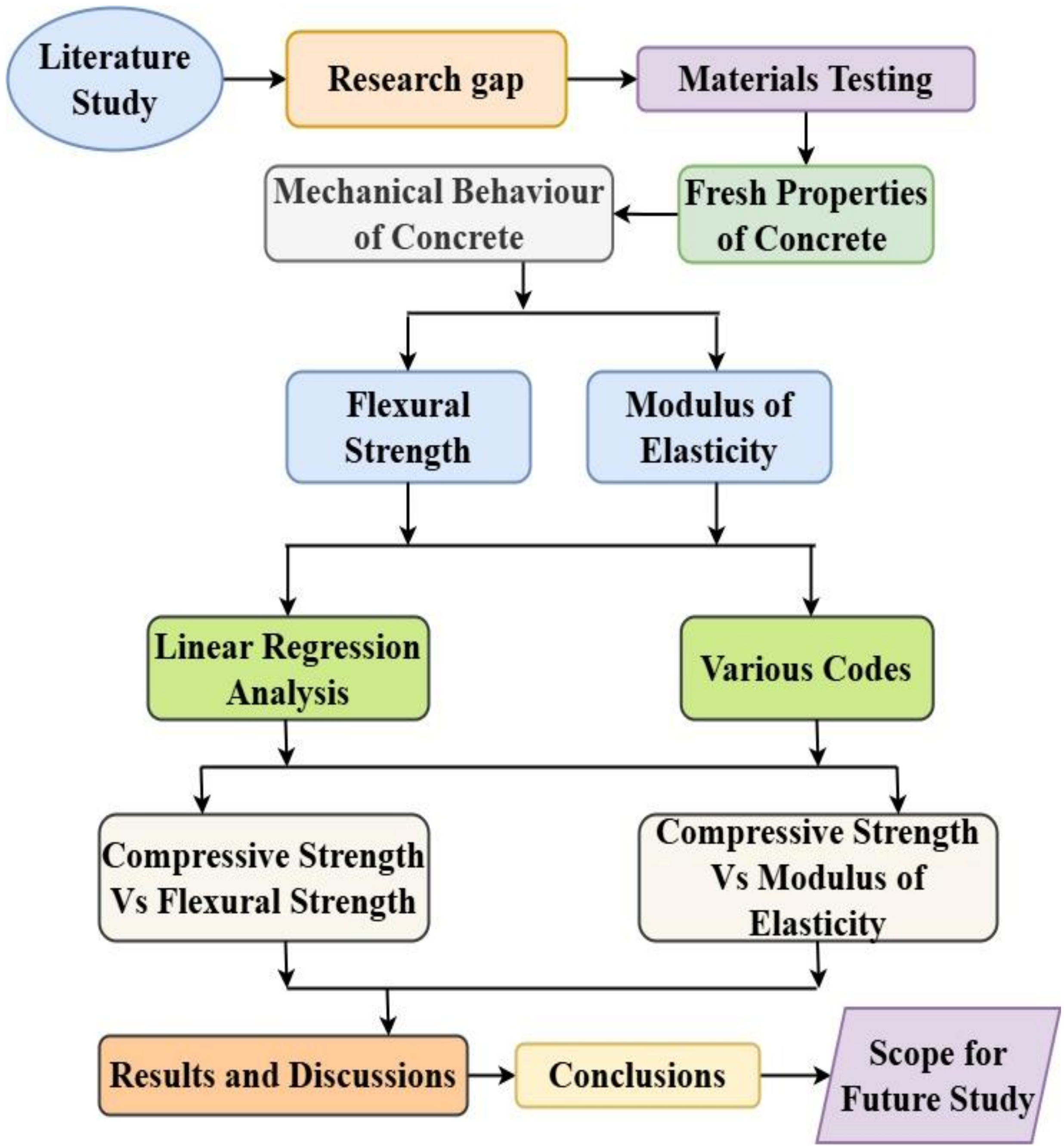


Figure 1. Research methodology.

2.3. Preparation of the concrete samples

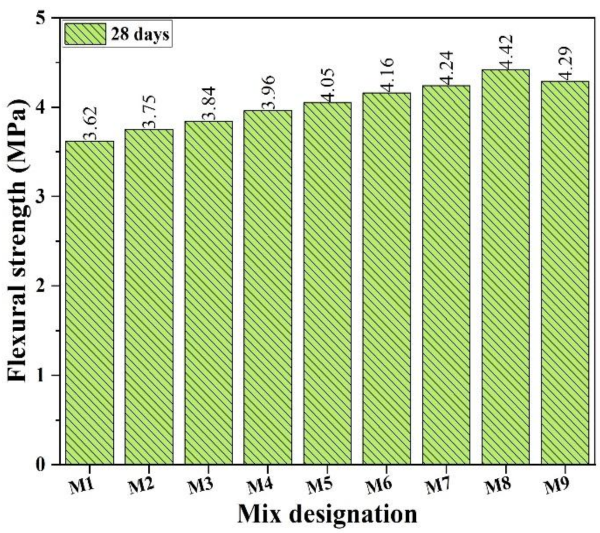
In this study, the mechanical characteristics of PC were investigated, with particular attention paid to FS and ME following seven and twenty-eight-day curing times. Concrete prism 150 x 150 x 750 mm were used to measure the FS, while cylindrical specimens 150 mm in diameter and 300 mm in length were used to measure the ME. Three samples were cast for each of the 56 distinct mixes that were created. In compliance with (IS: 516-1959), the specimens were examined using a CTM with a 3000kN capacity following the curing period, as seen in Figure 2. Table 3 shows the average strength of the PC, which was calculated after the trial load was recorded.

3. Experimental results and analysis

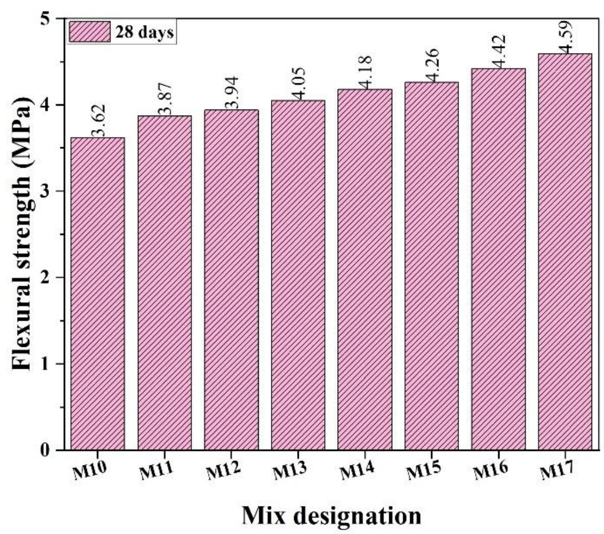
3.1. Flexural strength

The mechanical properties of the PC are examined at 28 days in all 56 mixes, the MP of the concrete is reported in Table 4. The mechanical properties of the concrete FS are improved by 3.72%, 6.20%, 9.39%, 12.00%, 15.02%, 16.99%, 22.09% and 18.42% respectively. This FS was enhanced by adding the PF 0.2%, 0.4%, 0.6%, 0.8%, 1.0%, 1.2%, 1.4%, and 1.6%. Similarly, the flexural strength is improved by 8.79%, 11.92%, 15.47%, 17.65%, 22.06%, 26.66%, 22.09% and 23.14% respectively, with the incorporation of the glass fiber 0.2%, 0.4%, 0.6%, 0.8%, 1.0%, 1.2%, 1.4%, and 1.6%. Furthermore, the MP of the FS is enhanced by 6.86%, 8.57%, 12.41%, 10.42% and 8.57%, respectively. This flexural strength was improved by incorporating polymer 1%, 2%, 3%, 4% and 5%. Beyond the optimum mix, the strength is reduced due to improper bond between cement paste and aggregates.

According to the experimental results of groups 1 to 3, the optimal mix proportions were used for further investigation of the concrete. Further investigation is examined with the addition of the hybrid fiber and polymer. For groups 4 to 8, the optimum mix (M28, M36, M43, M49, and M54) of flexural strength is improved by 8.26%, 20.37%, 24.63%, 13.96%, and 7.96%, respectively. A total of eight groups, comprising 56 different mix proportions with varying compositions of polymer, GF, and PF, were analyzed. The mechanical properties, specifically the FS of the PC, were assessed following a curing period of 28 days, as depicted in Figure 2.



(a) Group-I



(b) Group-II

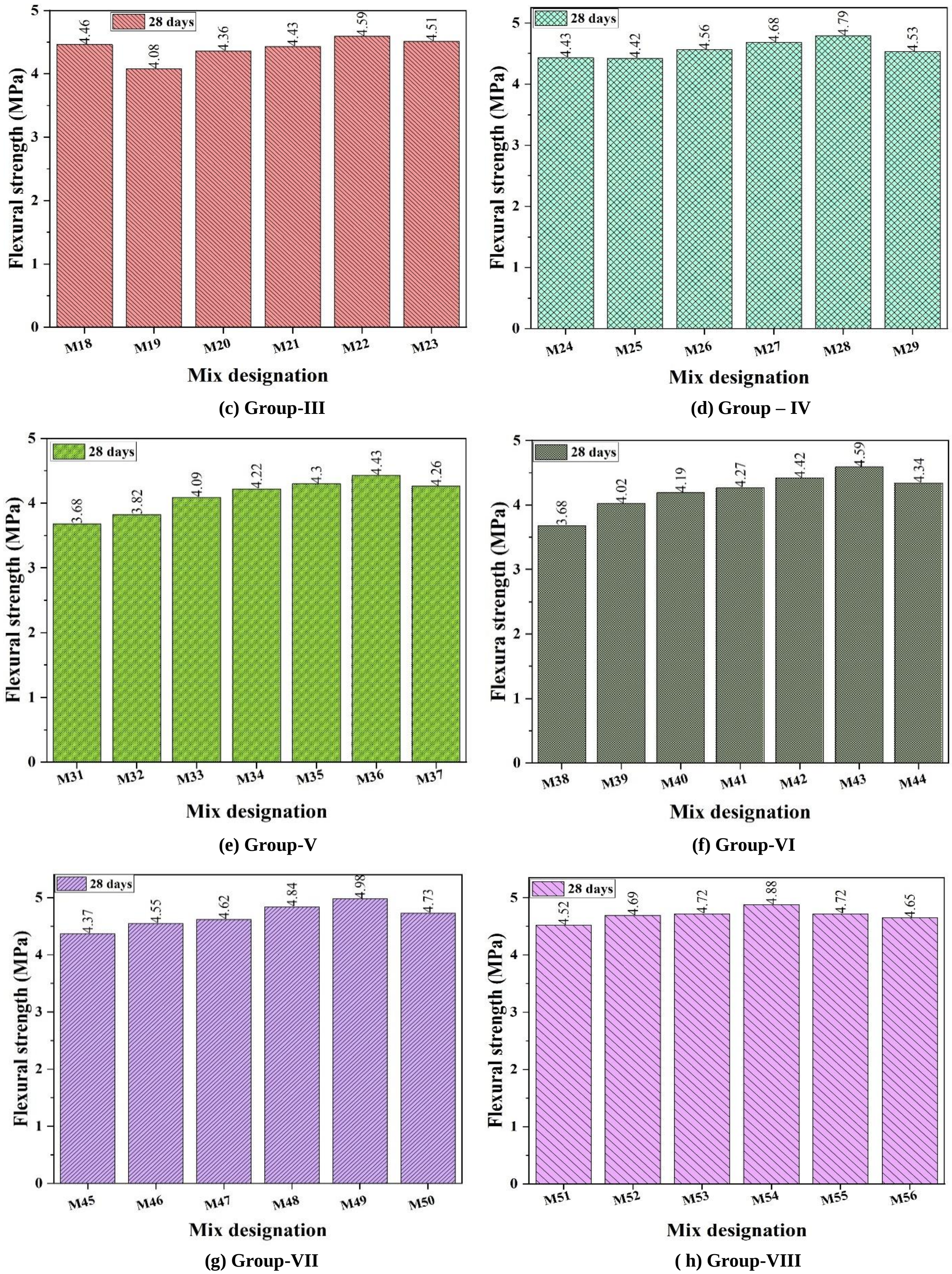
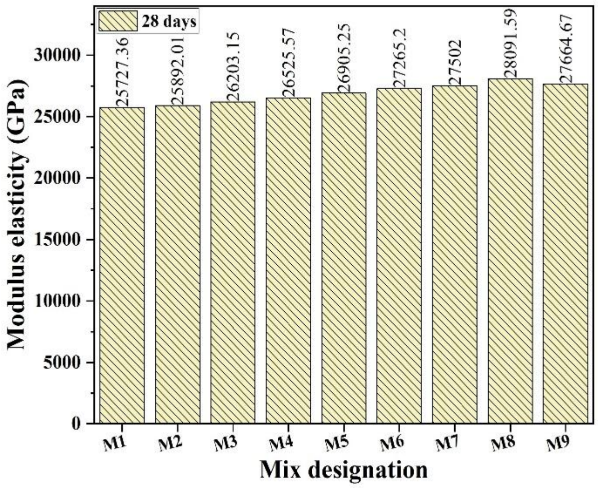


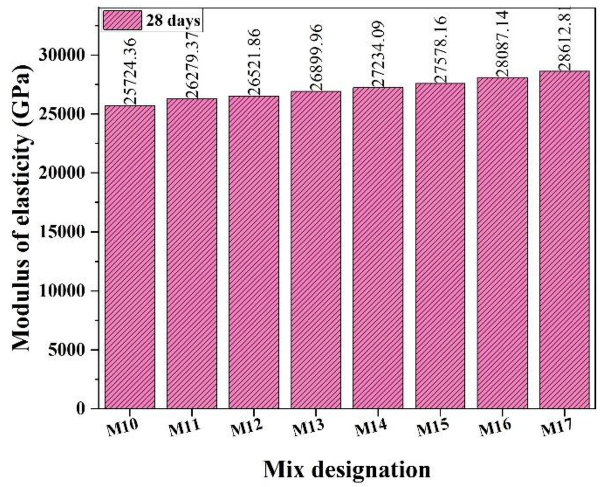
Figure 2. Flexural strength of the polymer concrete.

3.2. Modulus of elasticity

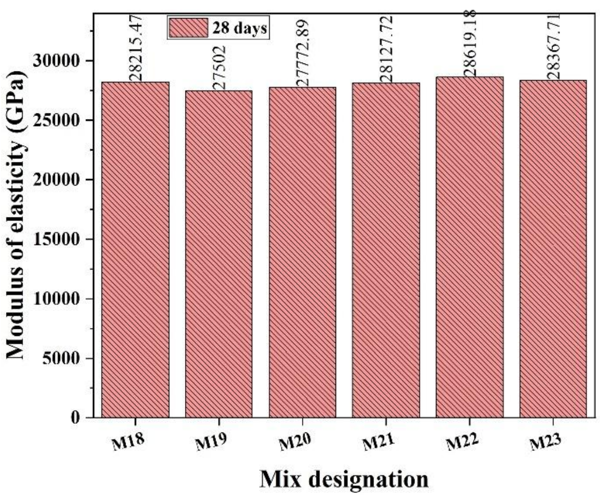
Furthermore, the ME of all concrete mixes is determined after a curing period of 28 days. The calculated modulus of elasticity is demonstrated in Figure 5. A total of eight groups of 56 concrete mixes were examined in this study. This study evaluated polypropylene fiber, glass fiber, polymer and hybrid fiber are incorporated and their modulus of elasticity were calculated.



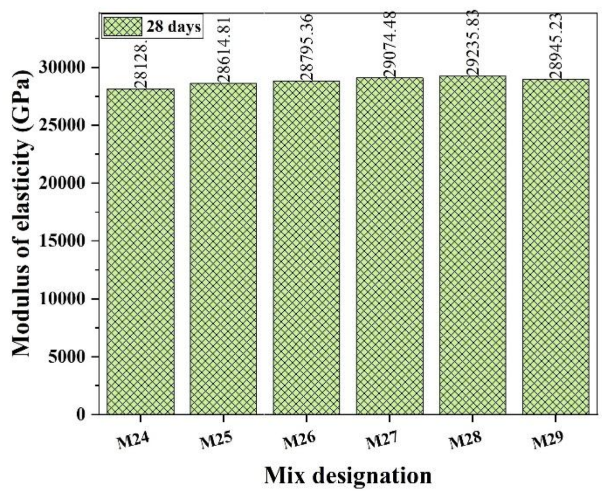
(a) Group - I



(b) Group – II



(c) Group - III



(d) - Group-IV

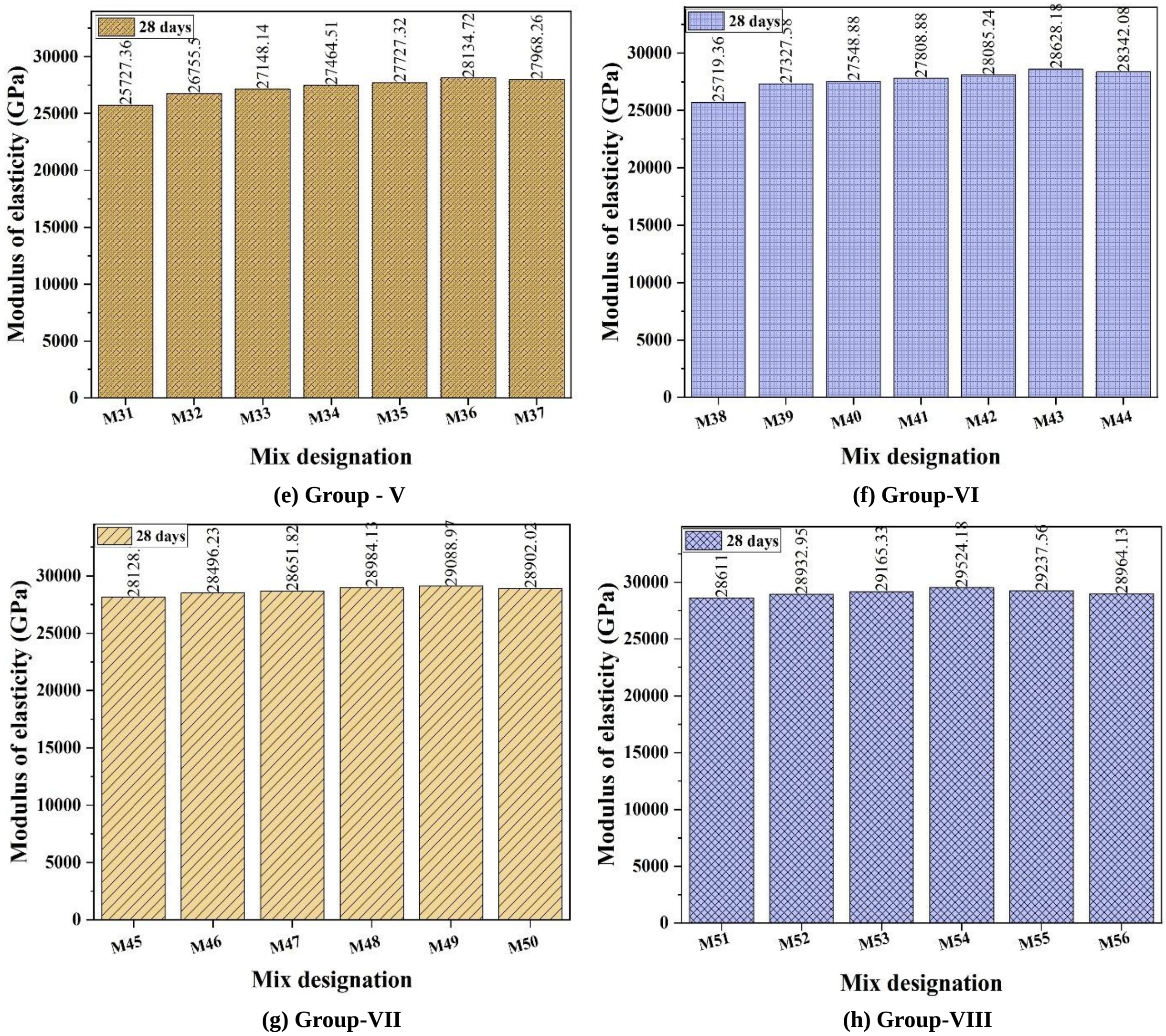


Figure 3. Modulus of elasticity of the concrete.

4. Statistical analysis

4.1. Regression analysis

The MP of the concrete are predicted using linear regression analysis. the linear regression analysis predicts the MP of the concrete in various factors such as strength, age, and W/C of concrete.

4.2. Comparative study between compressive and FS of concrete

The relationship between the CS and FS of 56 concrete mixes is evaluated and compared. The predicted FS of the concrete is reported in Table 3. Additionally, the flexural strength of the concrete is predicted using various codes (ACI: 318-08, Du Beton 2012, and IS: 456 - 2000), as preseneted in equations (2) – (4) The linear regression analysis predicted that flexural strength is highly correlated to the experimental results, and these regression coefficients (R^2) are 0.95. According to the analytical study, the linear regression analysis equation (1) and IS: 456 – 2000 code were given better results compared to other codes, which are given in Table 3. The experimental and predicted flexural strength is depicted in Figures 4 & 5.

$$f_b = -0.1241 + 0.1431 \times f_{ck} \quad \text{Eq. (1)}$$

$$f_b = 0.70x(fc)^{0.5} \text{ (IS: 456 - 2000)} \quad \text{Eq. (2)}$$

$$f_b = 0.81x(fc)^{0.5} \text{ (Du Beton 2012)} \quad \text{Eq. (3)}$$

$$f_b = 0.62x(fc)^{0.5} \text{ (ACI 318-08)} \quad \text{Eq. (4)}$$

Table 3. Comparative study between experimental and predicted FS of concrete.

Mix ID	Experimental values (MPa)		Predicted results (MPa)				Ratio = Pred / Expt			
	f_{ck}	fb	Eq.1	ACI	Du	IS	Eq.1	ACI	Du	IS
M1	26.48	3.62	3.67	3.19	4.17	3.60	1.01	0.88	1.15	1.00
M2	26.82	3.75	3.71	3.21	4.19	3.63	0.99	0.86	1.12	0.97
M3	27.46	3.84	3.81	3.25	4.24	3.67	0.99	0.85	1.11	0.96
M4	28.14	3.96	3.90	3.29	4.30	3.71	0.99	0.83	1.09	0.94
M5	28.96	4.05	4.02	3.34	4.36	3.77	0.99	0.82	1.08	0.93
M6	29.74	4.16	4.13	3.38	4.42	3.82	0.99	0.81	1.06	0.92
M7	30.25	4.24	4.20	3.41	4.46	3.85	0.99	0.80	1.05	0.91
M8	31.57	4.42	4.39	3.48	4.55	3.93	0.99	0.79	1.03	0.89
M9	30.62	4.29	4.26	3.43	4.48	3.87	0.99	0.80	1.04	0.90
M10	26.48	3.62	3.67	3.19	4.17	3.60	1.01	0.88	1.15	1.00
M11	27.62	3.87	3.83	3.26	4.26	3.68	0.99	0.84	1.10	0.95
M12	28.13	3.94	3.90	3.29	4.30	3.71	0.99	0.83	1.09	0.94
M13	28.94	4.05	4.02	3.34	4.36	3.77	0.99	0.82	1.08	0.93
M14	29.67	4.18	4.12	3.38	4.41	3.81	0.99	0.81	1.06	0.91
M15	30.42	4.26	4.23	3.42	4.47	3.86	0.99	0.80	1.05	0.91
M16	31.56	4.42	4.39	3.48	4.55	3.93	0.99	0.79	1.03	0.89
M17	32.75	4.59	4.56	3.55	4.64	4.01	0.99	0.77	1.01	0.87
M18	31.84	4.46	4.43	3.50	4.57	3.95	0.99	0.78	1.02	0.89
M19	30.25	4.08	4.20	3.41	4.46	3.85	1.03	0.84	1.09	0.94
M20	30.86	4.36	4.29	3.44	4.50	3.89	0.98	0.79	1.03	0.89
M21	31.64	4.43	4.40	3.49	4.56	3.94	0.99	0.79	1.03	0.89
M22	32.76	4.59	4.56	3.55	4.64	4.01	0.99	0.77	1.01	0.87
M23	32.18	4.51	4.48	3.52	4.59	3.97	0.99	0.78	1.02	0.88
M24	31.64	4.43	4.40	3.49	4.56	3.94	0.99	0.79	1.03	0.89
M25	32.75	4.42	4.56	3.55	4.64	4.01	1.03	0.80	1.05	0.91
M26	33.16	4.56	4.62	3.57	4.66	4.03	1.01	0.78	1.02	0.88
M27	33.82	4.68	4.72	3.61	4.71	4.07	1.01	0.77	1.01	0.87
M28	34.18	4.79	4.77	3.62	4.74	4.09	1.00	0.76	0.99	0.85
M29	33.52	4.53	4.67	3.59	4.69	4.05	1.03	0.79	1.04	0.89
M30	32.86	4.37	4.58	3.55	4.64	4.01	1.05	0.81	1.06	0.92
M31	26.48	3.68	3.67	3.19	4.17	3.60	1.00	0.87	1.13	0.98
M32	28.63	3.82	3.97	3.32	4.33	3.75	1.04	0.87	1.13	0.98
M33	29.47	4.09	4.09	3.37	4.40	3.80	1.00	0.82	1.08	0.93
M34	30.15	4.22	4.19	3.40	4.45	3.84	0.99	0.81	1.05	0.91
M35	30.73	4.3	4.27	3.44	4.49	3.88	0.99	0.80	1.04	0.90
M36	31.64	4.43	4.40	3.49	4.56	3.94	0.99	0.79	1.03	0.89
M37	31.28	4.26	4.35	3.47	4.53	3.91	1.02	0.81	1.06	0.92
M38	26.48	3.68	3.67	3.19	4.17	3.60	1.00	0.87	1.13	0.98
M39	29.85	4.02	4.15	3.39	4.43	3.82	1.03	0.84	1.10	0.95
M40	30.34	4.19	4.22	3.42	4.46	3.86	1.01	0.82	1.06	0.92
M41	30.92	4.27	4.30	3.45	4.50	3.89	1.01	0.81	1.05	0.91
M42	31.54	4.42	4.39	3.48	4.55	3.93	0.99	0.79	1.03	0.89
M43	32.76	4.59	4.56	3.55	4.64	4.01	0.99	0.77	1.01	0.87

M44	32.14	4.34	4.48	3.51	4.59	3.97	1.03	0.81	1.06	0.91
M45	31.64	4.37	4.40	3.49	4.56	3.94	1.01	0.80	1.04	0.90
M46	32.47	4.55	4.52	3.53	4.62	3.99	0.99	0.78	1.01	0.88
M47	32.86	4.62	4.58	3.55	4.64	4.01	0.99	0.77	1.01	0.87
M48	33.58	4.84	4.68	3.59	4.69	4.06	0.97	0.74	0.97	0.84
M49	33.87	4.98	4.72	3.61	4.71	4.07	0.95	0.72	0.95	0.82
M50	33.42	4.73	4.66	3.58	4.68	4.05	0.98	0.76	0.99	0.86
M51	32.76	4.52	4.56	3.55	4.64	4.01	1.01	0.79	1.03	0.89
M52	33.48	4.69	4.67	3.59	4.69	4.05	1.00	0.76	1.00	0.86
M53	34.02	4.72	4.74	3.62	4.72	4.08	1.01	0.77	1.00	0.87
M54	34.86	4.88	4.86	3.66	4.78	4.13	1.00	0.75	0.98	0.85
M55	34.17	4.72	4.77	3.62	4.73	4.09	1.01	0.77	1.00	0.87
M56	33.58	4.65	4.68	3.59	4.69	4.06	1.01	0.77	1.01	0.87
Mean							1.00	0.80	1.05	0.91
SD							0.02	0.04	0.05	0.04
COV (%)							1.72	4.38	4.38	4.38

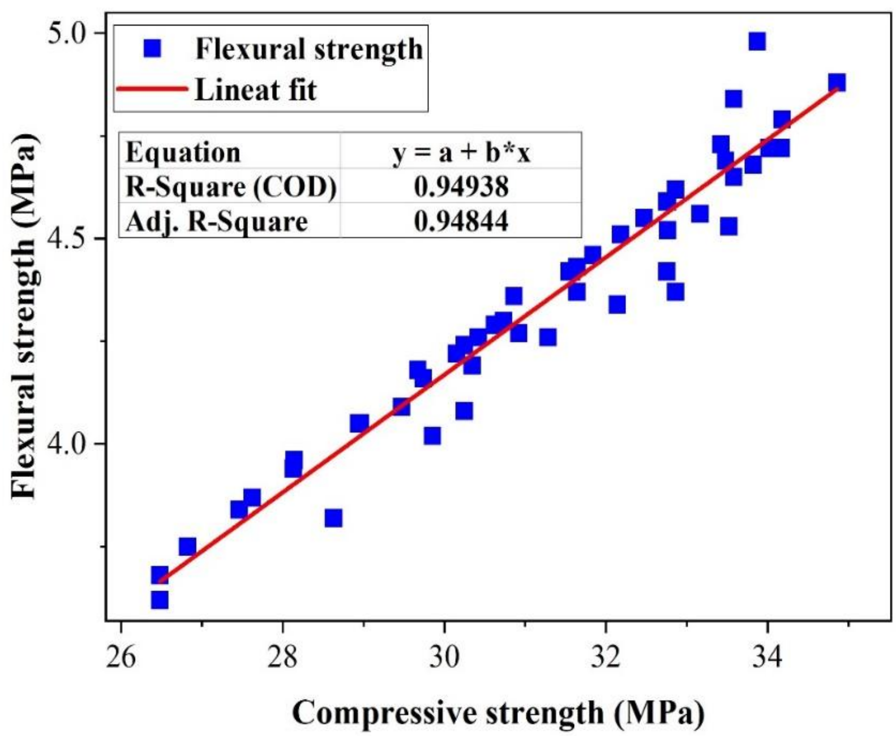


Figure 4. Linear regression analysis of CS and FS of the concrete.

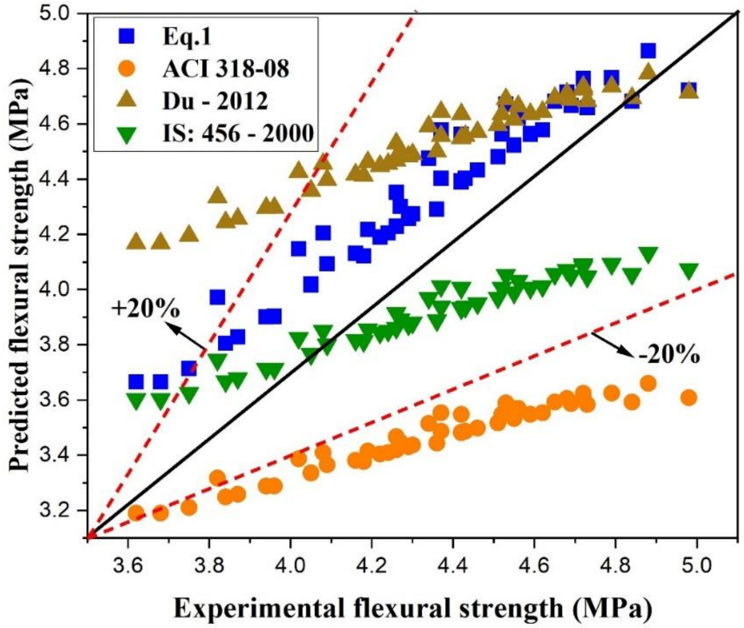


Figure 5. Comparison of the experimental and predicted flexural strength of concrete.

4.3. Comparative study between compressive and ME of concrete

Similarly, the relationship between the ME and CS examined in linear regression analysis and various codes (ACI 318-08 and IS: 456 - 2000) are reported in Table 5. The linear regression equation (2) and IS: 456 -2000, given the better correlations compared to the ACI 318-08, is presented in Table 6. Correlation coefficient (R^2) = 0.99 is determined for experimental CS and ME of concrete. The experimental and predicted ME is displayed in Figures 6 & 7.

$$E_c = 13754.7498 + 453.7361 \times f_{ck} \quad (5)$$

$$E_C = 4700 \times (f_c)^{0.5} \text{ (ACI 318-08)} \quad (6)$$

$$E_C = 5000 \times (f_c)^{0.5} \text{ (IS – 456: 2000)} \quad (7)$$

Table 6. Comparative study between experimental and predicted ME of concrete.

Mix ID	Experimental values (GPa)		Predicted results (GPa)			Ratio = Pred / Expt		
	f_{ck}	E_c	Eq.2	ACI	IS	Eq.2	ACI	IS
M1	26.48	25727.36	25769.68	24185.60	25729.36	1.00	0.94	1.00
M2	26.82	25892.01	25923.95	24340.37	25894.01	1.00	0.94	1.00
M3	27.46	26203.15	26214.34	24629.08	26201.15	1.00	0.94	1.00
M4	28.14	26525.57	26522.88	24932.16	26523.57	1.00	0.94	1.00
M5	28.96	26905.25	26894.95	25292.81	26907.25	1.00	0.94	1.00
M6	29.74	27265.2	27248.86	25631.16	27267.20	1.00	0.94	1.00
M7	30.25	27502	27480.27	25850.00	27500.00	1.00	0.94	1.00
M8	31.57	28091.59	28079.20	26407.98	28093.59	1.00	0.94	1.00
M9	30.62	27664.67	27648.15	26007.61	27667.67	1.00	0.94	1.00
M10	26.48	25724.36	25769.68	24185.60	25729.36	1.00	0.94	1.00
M11	27.62	26279.37	26286.94	24700.72	26277.37	1.00	0.94	1.00
M12	28.13	26521.86	26518.35	24927.73	26518.86	1.00	0.94	1.00
M13	28.94	26899.96	26885.87	25284.08	26897.96	1.00	0.94	1.00
M14	29.67	27234.09	27217.10	25600.98	27235.09	1.00	0.94	1.00
M15	30.42	27578.16	27557.40	25922.53	27577.16	1.00	0.94	1.00

M16	31.56	28087.14	28074.66	26403.80	28089.14	1.00	0.94	1.00
M17	32.75	28612.81	28614.61	26896.98	28613.81	1.00	0.94	1.00
M18	31.84	28215.47	28201.71	26520.66	28213.47	1.00	0.94	1.00
M19	30.25	27502	27480.27	25850.00	27500.00	1.00	0.94	1.00
M20	30.86	27772.89	27757.05	26109.34	27775.89	1.00	0.94	1.00
M21	31.64	28127.72	28110.96	26437.24	28124.72	1.00	0.94	1.00
M22	32.76	28619.18	28619.14	26901.09	28618.18	1.00	0.94	1.00
M23	32.18	28367.71	28355.98	26661.89	28363.71	1.00	0.94	1.00
M24	31.64	28128.72	28110.96	26437.24	28124.72	1.00	0.94	1.00
M25	32.75	28614.81	28614.61	26896.98	28613.81	1.00	0.94	1.00
M26	33.16	28795.36	28800.64	27064.82	28792.36	1.00	0.94	1.00
M27	33.82	29074.48	29100.10	27332.83	29077.48	1.00	0.94	1.00
M28	34.18	29235.83	29263.45	27477.92	29231.83	1.00	0.94	1.00
M29	33.52	28945.23	28963.98	27211.34	28948.23	1.00	0.94	1.00
M30	32.86	28665.82	28664.52	26942.11	28661.82	1.00	0.94	1.00
M31	26.48	25727.36	25769.68	24185.60	25729.36	1.00	0.94	1.00
M32	28.63	26755.5	26745.21	25148.29	26753.50	1.00	0.94	1.00
M33	29.47	27148.14	27126.35	25514.55	27143.14	1.00	0.94	1.00
M34	30.15	27464.51	27434.89	25807.24	27454.51	1.00	0.94	1.00
M35	30.73	27727.32	27698.06	26054.28	27717.32	1.00	0.94	1.00
M36	31.64	28134.72	28110.96	26437.24	28124.72	1.00	0.94	1.00
M37	31.28	27968.26	27947.62	26286.41	27964.26	1.00	0.94	1.00
M38	26.48	25719.36	25769.68	24185.60	25729.36	1.00	0.94	1.00
M39	29.85	27327.58	27298.77	25678.52	27317.58	1.00	0.94	1.00
M40	30.34	27548.88	27521.10	25888.43	27540.88	1.00	0.94	1.00
M41	30.92	27808.88	27784.27	26134.70	27802.88	1.00	0.94	1.00
M42	31.54	28085.24	28065.59	26395.43	28080.24	1.00	0.94	1.00
M43	32.76	28628.18	28619.14	26901.09	28618.18	1.00	0.94	1.00
M44	32.14	28342.08	28337.83	26645.31	28346.08	1.00	0.94	1.00
M45	31.64	28128.72	28110.96	26437.24	28124.72	1.00	0.94	1.00
M46	32.47	28496.23	28487.56	26781.75	28491.23	1.00	0.94	1.00
M47	32.86	28651.82	28664.52	26942.11	28661.82	1.00	0.94	1.00
M48	33.58	28984.13	28991.21	27235.68	28974.13	1.00	0.94	1.00
M49	33.87	29088.97	29122.79	27353.03	29098.97	1.00	0.94	1.00
M50	33.42	28902.02	28918.61	27170.72	28905.02	1.00	0.94	1.00
M51	32.76	28611.18	28619.14	26901.09	28618.18	1.00	0.94	1.00
M52	33.48	28932.95	28945.83	27195.10	28930.95	1.00	0.94	1.00
M53	34.02	29165.33	29190.85	27413.53	29163.33	1.00	0.94	1.00
M54	34.86	29524.18	29571.99	27749.91	29521.18	1.00	0.94	1.00
M55	34.17	29237.56	29258.91	27473.90	29227.56	1.00	0.94	1.00
M56	33.58	28964.13	28991.21	27235.68	28974.13	1.00	0.94	1.00
Mean						1.00	0.94	1.00
SD						0.0008	0.0002	0.0002
COV (%)						0.082	0.019	0.019

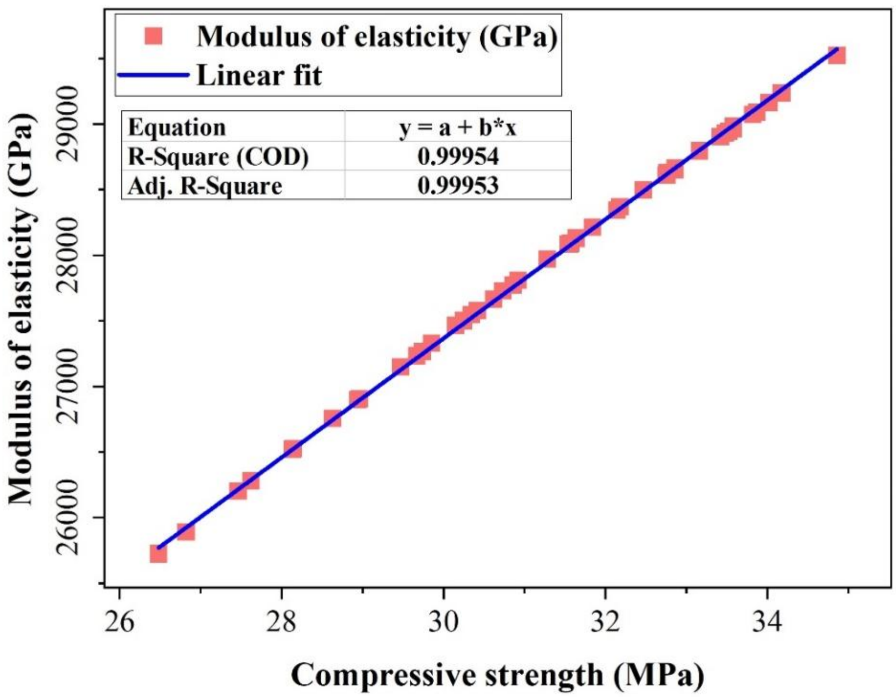


Figure 6. Linear regression analysis of CS and FS of the concrete.

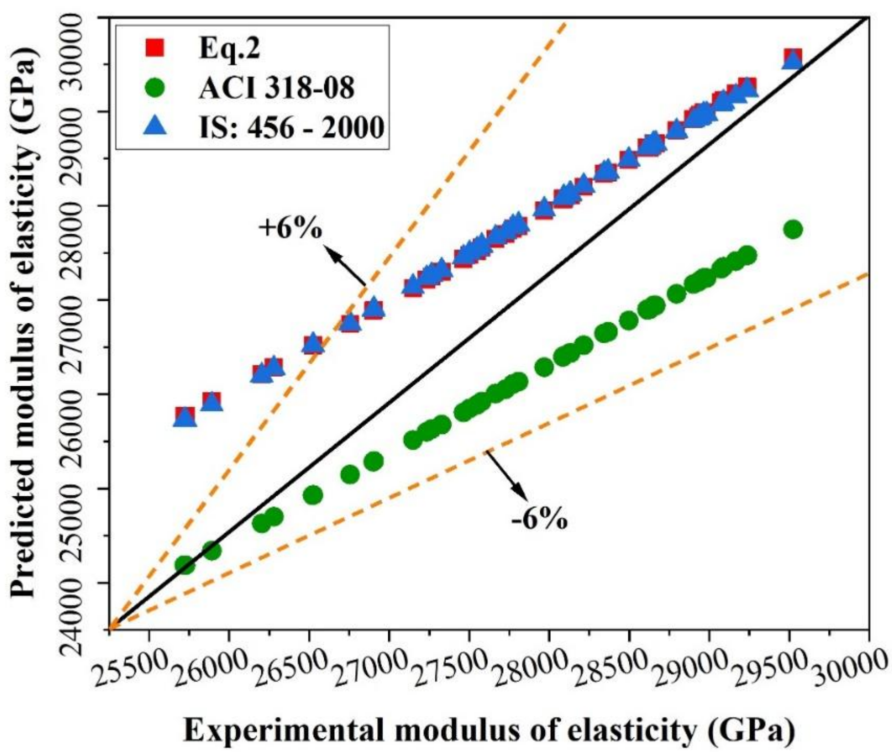


Figure 7. Comparison of the experimental and predicted modulus of elasticity of concrete.

5. Conclusions and recommendation for future research

The study has been completed to examine the MP of the concrete such as FS and ME of concrete. The accordance of the experimental study, the following conclusions are drawn:

1. Eight groups of 56 concrete mixes investigated the MP of the concrete. The MP of concrete were examined with the addition of PF, GF, and polymer.
2. Compared to the control sample, the flexural strength is increased by 16.99%, 26.66%, 12.41%, 8.26%, 20.37%, 24.63%, 13.96%, and 7.97%, respectively.
3. The optimum mix proportion of the concrete mix (M7, M17, M22, M28, M36, M43, M49, and M54) is identified in all eight concrete mixes.
4. Incorporating 1.20% polypropylene fiber, 1.40% glass fiber, and 3% polymer significantly improved the mechanical properties of the concrete.
5. Experimental observations indicate the flexural strength with the incorporation of glass fiber compared to polypropylene fiber.
6. The strength characteristics of polymer hybrid fiber-reinforced concrete were predicted with the help of linear regression analysis, and the expected strength characteristics quite matched the experimental results.
7. Furthermore, the present study can be extended to investigate reinforced concrete elements such as columns in axial loading conditions.

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