Improving Mechanical Properties of Polymer Modified Steel Fiber Reinforced Concrete Made with Concrete Waste by usingPC-600-Super-Plasticizer

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Abstract: This study investigates the enhancement of mechanical properties in polymer-modified steel fiber-reinforced concrete (PMSFRC) incorporating demolition waste as a sustainable coarse aggregate replacement. The work addresses the dual objectives of resource recycling and performance optimization within environmentally responsible construction practices. Results show that replacing natural coarse aggregates with demolition waste slightly reduces compressive strength from 44.1 MPa to 41.6 MPa. However, the incorporation of PC-600 Flocrete superplasticizer effectively compensates for this reduction, increasing compressive strength to 49.4 MPa. Significant improvements were also observed in tensile strength, which increased from 5.7 MPa to 6.1 MPa, and in flexural strength, which increased from 12.1 MPa to 15.5 MPa for mixes with 100% waste replacement. Additionally, the modulus of elasticity improved from 26.5 GPa to 30.5 GPa, demonstrating enhanced stiffness and structural viability. These findings confirm that polymer modification enables effective utilization of concrete waste without compromising structural integrity, promoting cleaner production, circular material use, and sustainable innovation in civil infrastructure.

Keywords: Polymer-modified concrete, Steel fiber, Demolition waste, PC-600 Superplasticizer, Sustainable materials, Mechanical properties, Environmental management.

INTRODUCTION

Polymer-modified steel fiber concrete (PMSFRC) is widely used in construction due to its higher durability, ductility, and toughness. It is characterized by its high resistance in terms of tensile, compression, and flexural strength compared to conventional concrete. These properties for SFPMC are achieved by incorporating polymers and steel fibers. Polymers play a significant role in developing next-generation construction composites, offering tunable mechanical and durability properties through molecular and interfacial modification. The integration of polymers such as SBR into cementitious matrices enhances cohesion, toughness, and resistance to environmental degradation, aligning with recent advances in functional and specialty polymer applications. Additionally, the use of this type of concrete helps prevent sudden structural failures due to the good ductility achieved by steel fibers and the effect of polymer films, which also exhibit good tensile strength and ductility [1-5]. Polymers such as styrene butadiene rubber latex (SBR) is the most wide spread and common type of liquid polymers and also widely used polymer in concrete and cement mortars applications, it can be added to concrete mixes to improve toughness, ductility and also other properties both physical and mechanical properties such as compressive strength, decreasing water absorption, increase impact stength and also increase duability of concrete [6-9]. In recent decades, substantial quantities of demolition waste can cause several problems such as environmental pollution and unclean environment, demolition waste such as concrete, bricks, tiles can be used in concrete production to reduce total cost of concrete and achieving less environmental pollution, a lot of studies show that using demolition waste can reduce workability and also reduce some mechanical properties values such as flexure, tensile strength and static modulus of elasticity. Some researchers attribute the reason for the decrement in strength due to the use of concrete demolition as aggregate to the nature of the waste aggregate, which has a lower strength and modulus of elasticity than natural gravel [7-8]. However, in this study, the use of admixtures can solve these problems.

Some researchers have investigated the impact of using concrete waste from damaged buildings on the mechanical properties of steel fiber-reinforced concrete [9-12], concluding that incorporating waste leads to a decrease in the strength and workability of concrete containing waste as a coarse aggregate. Some other researchers [13,14] have studied the use of waste aggregates in polymer concrete and polymer reactive powder concrete, concluding that using waste aggregates leads to a decrease in concrete strength but achieves a lower cost of new concrete and a cleaner environment with reduced environmental pollution.

Recent mechanistic studies show that styrene-butadiene rubber (SBR) latex modifies cementitious matrices through film-forming and surface adsorption phenomena. During curing, SBR particles coalesce

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into a continuous polymer film that coats hydration products and aggregate surfaces, which improves inter-particle bonding and bridges microcracks, thereby increasing toughness, post-crack ductility and impermeability. However, this coating effect can retard early hydration rates by limiting ion transport to cement grains and can alter the morphology and composition of C–S–H and portlandite, producing a combined effect of improved durability and modified early-age strength development [15-18]. These mechanistic behaviors explain SBR's pronounced enhancement of tensile and flexural performance even when conventional compressive gains are modest. Polycarboxylate ether (PCE) superplasticizers such as PC-600 primarily act by adsorbing onto cement particles through carboxylate anchoring groups while long, grafted polyethylene-oxide side chains generate steric repulsion that disperses particle agglomerates [19-21]. The resulting electro-steric stabilization decreases yield stress and plastic viscosity, enabling a lower water/cement ratio, improved packing of solid phases, and reduced porosity. In addition to rheological benefits, PCEs can subtly influence hydration kinetics and the nano-structure of the C–S–H gel, which underpins observed increases in compressive strength and modulus when PCEs are used in combination with polymers and fibers. Modern PCE formulations also show structure–property tunability (anchoring groups, side-chain length, topology) that affects adsorption behaviour and performance in blended or recycled-aggregate systems. This study aims to enhance and develop the mechanical properties of PMSFRC containing waste by using PC-Super-Plasticizer.

Experimental Program

Cement type V (sulfate resisting cement)used in all mixes, the mix proprtions used in this study is shown in Table **1** and contains constant ratios of steel fibers (1% by volume of concrete), the steel fibers is from hooked-end type with aspect ratio equal to and its properties given in Table **2**, styrene butadiene rubber (SBR) with specific gravity of 0.95 and white color is added also with constant ratio of 5% by weight of cement, the 5% ratio was chosen to decrease the cost of concrete because the optimum value of SBR dosage mostly ranged between 10-15%. The coarse aggregate has a maximum size of 20 mm and conforms to the Indian Standard IS 383 [22]; the coarse aggregate is of the natural gravel type, obtained from Najaf city in Iraq. The fine aggregate used in this study is from Zone 2 and is of the type red natural sand from Najaf city as well. The sieve analysis and grading of coarse and fine aggregate are shown in Tables **3** and **4**.

Table 1: Details of SFPMC Mix, Ingredients for One Cubic Meter of Concrete (in Kilograms)

cement	sand	gravel	water	Silica fume	SBR	Steel fibers
450	650	1050	180	50	22.5	78.5

Table 2: Hooked Steel Fibers Details

Steel fiber type	length	Diameter	Aspect ratio	Tensile strength
Bent(Hooked-End steel fiber) type SD60/30	30 mm	0.5 mm	60	1150 MPa

Table 3: Sieve Analysis of Coarse Aggregate and Limitations

Sieve dimension	% pass by weight	IS-393 LIMITS
40 mm	100	100
20 mm	95.9	95- 100
10 mm	47.2	25- 55
4.75 mm	1.1	0- 10

Table 4: Sieve Analysis of Fine Aggregate

Sieve dimension	% pass by weight	Zone 2 limits
10 mm	100	100
4.75 mm	100	90- 100
2.36 mm	85.3	75- 100
1.18 mm	87.4	55- 90
600 mic	51.8	35 -59
300 mic	23.1	8- 30
150 mic	3.7	0 -10

Testing procedure: The compressive strength test was conducted using cubes with dimensions of 1100 mm x 100 mm x 100 mm. Three specimens were tested in 28 days (after curing in water) for each mix, and the average compressive strength was found. Tensile strength was determined using 150 × 300 mm cylinder specimens, which were tested at 28 days using the splitting tensile test (indirect method), as per BS EN 12390 Part 6 [23]. The flexural strength test was conducted using prisms with dimensions of 100 mm x 100 mm x 400 mm and tested according to British Standards (BS EN 12390-Part 5) [24]. The stress-strain and static modulus of elasticity (chord modulus) tests were conducted using steel cylinder molds with a diameter of 150 mm and a height of 300 mm. Mechanical strain gauges (as shown in Figure **1**) were fixed on the concrete specimen before testing it. The modulus of elasticity was determined according to ASTM C-469 [25], which includes estimating the chord modulus of elasticity using Equation 1. Figure **2** shows a cylinder specimen after a splitting tensile test.

$$Ec = \sigma_2 - \sigma_1 / \epsilon_2 - \epsilon_1 \qquad \{1\}$$

Where/: σ_2: is the applied stress that corresponds to 0.4 *(maximum stress applied),σ_1 : stress that corresponding to a strain value equal to 0.00005 ,$\epsilon_2$is the strain corresponding to σ_2, and ϵ_1 : is the strain equal to 0.00005 .

RESULTS AND DISCUSSION

Table **5** presents the mechanical properties of SFPMC with varying percentages of concrete waste, excluding the use of Superplasticizer. The table shows that using concrete waste reduces compressive strength. The ordinary gravel concrete yields a

Figure 1: SFPMC specimens during and after stress-strain test.

Figure 2: PMSFRC specimens after the splitting tensile test.

Table 5: The Mechanical Properties of SFPMC and Waste Aggregate SFPMC

Mix type	Compressive Strength (MPa)	Tensile Strength (MPa)	Flexural Strength (MPa)	Modulus of Elasticity (MPa)
Ordinary SFPMC	44.1	6.5	13.4	28.0
25%, Replacement	43.7	6.2	13.1	27.6
50 % replacement	42.9	6.0	12.8	27.3
75% replacement	42.2	5.9	12.4	26.7
100% replacement	41.6	5.7	12.1	26.5

compressive strength of 44.1 MPa. Still, when using 100% replacement with garbage, the new concrete compressive strength became 41.6 MPa, tensile strength also decreased from 6.5 MPa to 5.7 MPa, flexural strength decreased from 13.4 MPa to 12.1 MPa, and the chord modulus of elasticity decreased from 28 GPa to 26.5 GPa when using total replacement of coarse aggregate with waste aggregate. Figures **3-6** illustrate the decrease in compressive, tensile, flexural strength, and static modulus of elasticity, respectively, resulting from the use of concrete waste as coarse aggregate. Using PC-600 superplasticizer in mixes with waste can significantly improve the mechanical properties, as

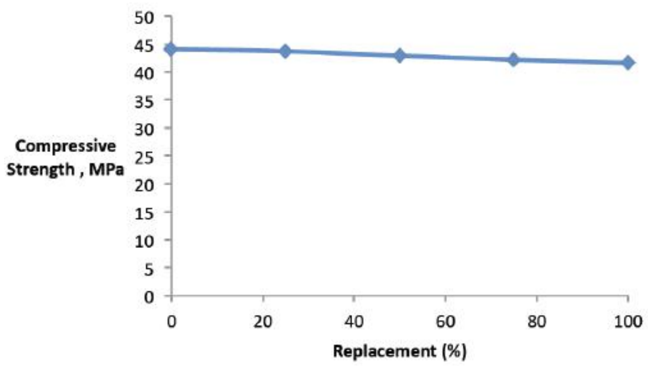

Figure 3: Slight decrement in strength of PMSFRC due to concrete waste replacing.

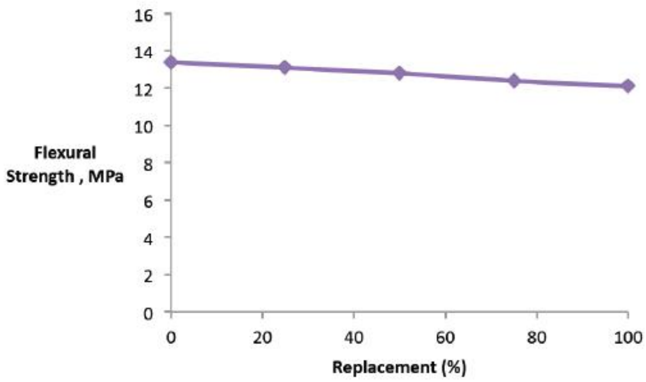

Figure 4: Tensile strength of PMSFRC with different concrete waste replacement.

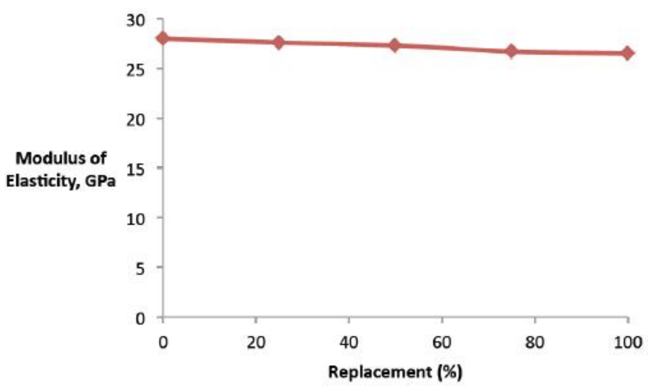

Figure 5: Flexural strength of PMSFRC with different Concrete waste.

shown in Table **6**. The compressive strength increased from 41.6 MPa for mixes with total replacement to 49.4 MPa when using Superplasticizer.

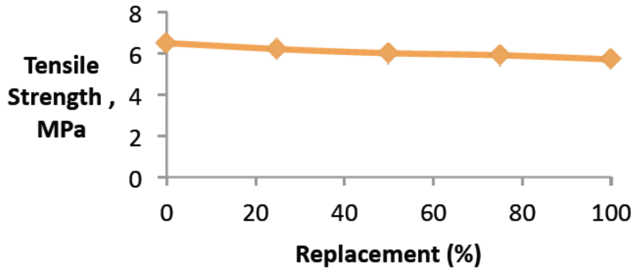

Figure 6: Modulus of Elasticity of PMSFRC with different Concrete waste.

Additionally, other mechanical properties are also improved. Figure **7** shows the decrease in toughness due to the total replacement of coarse aggregate with waste concrete, and Figure **8** shows the improvement in toughness for mixes with waste due to the use of PC-600 superplasticizer. Table **6** shows the mechanical properties of mixes containing concrete waste as coarse aggregate with different replacement levels modified with PC-600 Superplasticizer. The compressive strength increased from 41.6 to 49.4 MPa for a 100% replacement, and the flexural strength increased from 12.1 to 15.5 MPa for a 100% replacement. Additionally, other mechanical properties have been significantly improved. These improvements may be attributed to the action of PC-600 superplasticizer, which can reduce the water/cement ratio. Its carboxylate particles can fill pores inside the cement gel, and also play a role in rearranging fine particles within concrete, thereby improving the mechanical properties of SFPMC. Figures **9-12** illustrate the improvements in compressive strength, tensile strength, flexural strength, and modulus of elasticity, respectively, resulting from the use of Superplasticizer in the mixes. The reuse of demolition waste in concrete production not only reduces the environmental footprint of construction activities but also contributes to circular economy goals. Combining polymer modification with recycled aggregates offers a promising route toward sustainable infrastructure materials that meet performance and ecological standards simultaneously. This research, therefore, contributes to global efforts in sustainable material development by combining polymer technology with waste valorization strategies, presenting a practical example of polymer application in the construction sector that bridges material science and environmental engineering.

The improvements observed here — a recovery of compressive strength from 41.6 MPa (100% recycled coarse aggregate) to 49.4 MPa after PC-600 addition,

Table 6: The Mechanical Properties of Waste SFPMC Modified with PC-600 Superplasticizer

Mix type	Compressive Strength(MPa)	Tensile Strength(MPa)	Flexural Strength(MPa)	Static Modulus of Elasticity(MPa)
25%, Replacement	54.4	6.8	17.8	36.6
50 % replacement	52.8	6.5	17.1	35.1
75% replacement	50.6	6.3	16.9	33.7
100% replacement	49.4	6.1	15.5	30.5

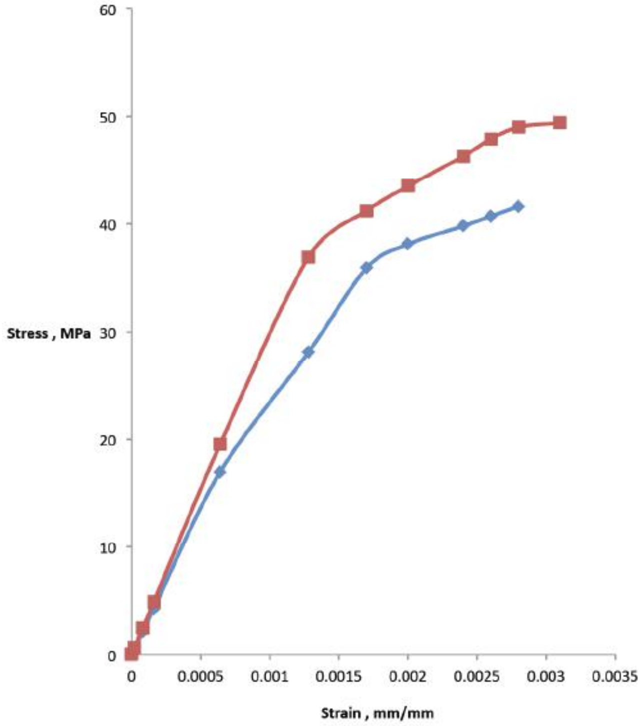

Figure 7: Decrease in toughness of PMSFRC due to the use of concrete waste with total replacement.

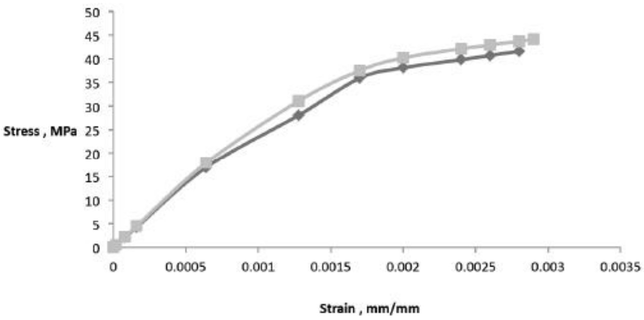

Figure 8: Improvement in toughness for 100% replacement mixes by using PC-600.

tensile strength increase from 5.7 MPa to 6.1 MPa, and flexural strength increase from 12.1 MPa to 15.5 MPa — are consistent with the established role of polymer modifiers and modern polycarboxylate superplasticizers in improving mechanical performance of blended and modified concretes (see reviews and experimental studies in the literature). Compared to earlier investigations that examined either polymer modification or recycled aggregate replacement alone, our data show that the synergistic combination of SBR, a PCE-type superplasticizer (PC-600), and hooked steel fibers can both mitigate strength losses due to recycled aggregate and produce net gains in certain properties. For example, prior reports have documented reductions in compressive strength when using high proportions of recycled aggregate unless compensated by admixtures or additional binders; our results demonstrate that a PCE-based superplasticizer together with polymer modification and fiber reinforcement can restore compressive strength to values comparable with conventional SFPMC mixes while improving flexural and tensile behavior. The novelty of the present work lies in the integrated system-level approach: we combine (i) 100% replacement of natural coarse aggregate with demolition waste, (ii) polymer modification with SBR to improve toughness and post-crack behaviour, (iii) a modern PCE-type superplasticizer (PC-600) to lower effective w/c and refine microstructure, and (iv)

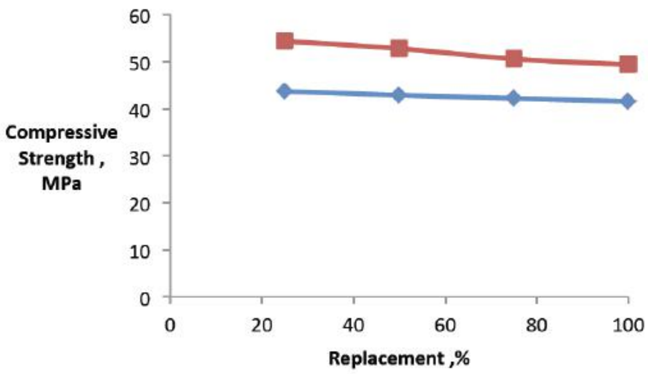

Figure 9: Improvement of compressive strength for PMSFRC containing waste.

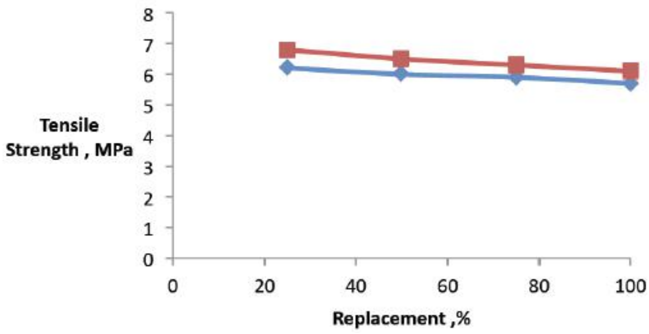

Figure 10: Improvement of tensile strength for PMSFRC containing waste.

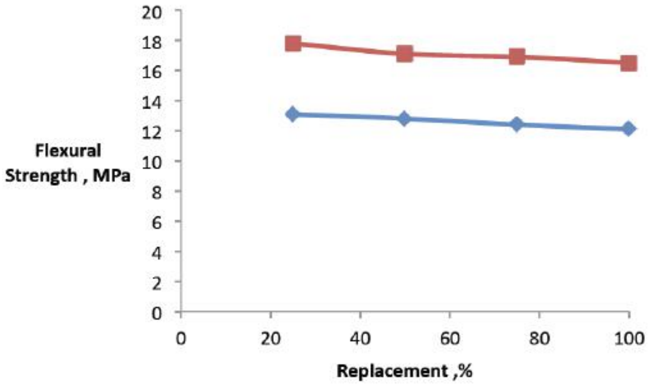

Figure 11: Improvement of flexural strength for PMSFRC containing waste.

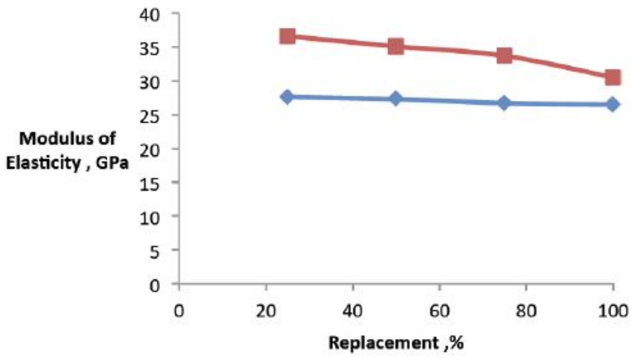

Figure 12: Improvement of modulus of elasticity for PMSFRC containing waste.

hooked-end steel fibers for crack-bridging. While individual elements of this strategy have been explored separately in the literature, reports that demonstrate restoration — and measurable improvement — of compressive, tensile and flexural properties for fully recycled coarse aggregate mixes using this precise combination remain limited. Thus, this study contributes by showing a practical formulation that achieves both circular-economy benefits and structural performance targets, expanding the evidence base for using demolition waste in structural-grade polymer-modified fiber-reinforced concretes. From a practical standpoint, the results indicate that adoption of a PCE (PC-600) in combination with SBR and steel fibers enables the reuse of demolition waste at high replacement levels without sacrificing key mechanical properties, which supports sustainable materials practice and potential cost savings in large-scale construction. Practitioners should note, however, that variability in recycled aggregate quality can increase result dispersion (as observed in our standard deviations) and that mix optimization (dosage of SBR, PC-600 and fiber content) will be necessary to suit local waste characteristics. Future work should therefore focus on (a) long-term durability under field conditions, (b) lifecycle environmental and economic assessment of the proposed mixes, and (c) exploring process controls to reduce variability when using heterogeneous recycled aggregates. The improvement in mechanical performance achieved through polymer modification in PMSFRC is consistent with broader findings reported in related polymer-composite and materials optimization studies. Olaiya *et al*. [26] demonstrated that amphiphilic polymer systems enhance viscoelasticity and refine microstructure through improved interfacial bonding, a mechanism that parallels the densification and pore reduction observed in SBR- and PC-600-modified mixes in the present study. Similar trends of microstructural enhancement through controlled process–material interactions have been reported in advanced additive manufacturing research, where optimized thermal energy input and parameter tuning significantly improved strength and surface quality [27-32]. Optimization-driven studies using FDM, including fuzzy TOPSIS and AHP-based decision frameworks [33-37], further support the importance of systematic parameter control in achieving superior mechanical outcomes. Additionally, recent work on graphene-reinforced PETG and polymer nanocomposites confirms that polymer incorporation enhances load transfer, matrix cohesion, and toughness through refined microstructure [38-44] These collective insights reinforce the present findings by demonstrating that polymer modification—whether in cementitious systems or polymer-based composites—consistently leads to improved mechanical performance and microstructural stability, validating the effectiveness of SBR and PC-600 in restoring and enhancing the properties of demolition-waste concrete.

CONCLUSIONS

The study demonstrates that polymer modification through PC-600 superplasticizer significantly improves the mechanical properties of steel fiber-reinforced concrete made with demolition waste. Although the use of waste aggregates slightly reduces strength, the incorporation of PC-600 restores and even enhances compressive, tensile, and flexural strength, along with the modulus of elasticity. These improvements confirm that high-performance, sustainable concrete composites can be achieved using polymer-based admixtures. The results highlight the practical potential of functional polymers in enabling waste utilization, reducing environmental pollution, and advancing sustainable construction practices. Future work may explore other polymer systems and hybrid additives to further optimize mechanical behavior and environmental benefits.

From the data obtained in this research, the points below are concluded

1- Using waste aggregate from demolished concrete can reduce the strength of PMSFRC.

But the use of Superplasticizer can solve the problem.

2- Compressive strength decreases from 44.1 to 41.6 MPa by using total replacement; other mechanical properties are also lowered when using waste.

3- The problem of the decrement in strength can be solved by using the superplasticizer type PC-600. The study reveals that the use of superplasticizer results in an increase in compressive strength from 41.6 to 49.4 MPa, along with improvements in other properties, such as tensile strength, flexure, and static modulus of elasticity.

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