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Sustainable Fiber Reinforced Lightweight Concrete Using Waste Materials: Mechanical and Durability Properties

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Abstract:
This study investigates the use of discarded lightweight aggregates and fibers in fiber reinforced lightweight concrete (FRLWC) as a sustainable substitute. Fibers were added between 0.5% and 1.0%, while waste aggregates were added at different rates (25% to 100%). The findings showed that increasing use of waste aggregate reduced density and compressive strength while fibers improved tensile and flexural strength. Concrete's density was lowered by roughly 33% when sintered fly ash aggregate was used, making it suitable for lightweight applications. However, because of its increased porosity, lightweight concrete without fibers showed lower mechanical strengths. Performance was greatly enhanced by the use of recycled polypropylene fibers: flexural strength rose by 30-57%, split tensile strength by 45-52%, and compressive strength by 28-35%. Improved water absorption and sorptivity (30-40% reduction) and negligible strength decline under sulfate were seen in durability assessments.

Keywords:
Fiber Reinforced Lightweight Concrete, Sintered Fly Ash Aggregate, Recycled Polypropylene Fibers, Waste Materials Utilization.

1. Introduction:

Achieving zero carbon dioxide emissions from human activity is crucial to combating global warming since delays make climate change worse. Technologies like Light Weight Concrete (LWC), which uses lightweight aggregates to lower building emissions while enhancing acoustic and fire resistance, have drawn more attention as a result of this urgency. Additives can improve the performance of LWC despite its disadvantages, such as a higher chance of shattering. Sustainability is enhanced by the incorporation of waste materials such as industrial wastes and coconut shells. In order to mitigate the environmental effects of concrete in building, current research places a strong emphasis on recycling and resource reuse.

LWC, which has a density of less than 2000 kg/m^3 and a compressive strength of more than 20 N/mm^2, has advantages such as less dead weight, increased fire resistance, and improved seismic performance. These elements lessen the damage caused by earthquakes. Expanded clay and pumice are examples of lightweight materials that reduce structural dimensions, increasing productivity and cutting expenses. However, because to problems with brittleness and durability, particularly with regard to permeability, LWC is less frequently utilized for load-bearing applications than normal-weight concrete (NWC). Its qualities have been used for more than 2000 years in both contemporary high-rises and structures like the Coliseum. The goal of ongoing study is to improve it even further in the building sector. According to ACI and IS classifications, lightweight aggregates produce concrete densities between 1400 and 2000 kg/m^3, which are substantially lighter than conventional aggregates.

Yasin et al.'s 2023 study investigated the use of sisal (SF) and coconut (CF) fibers as distributed reinforcement to create lightweight expanded-clay fiber concrete (ECFC) with improved characteristics. The study found that adding natural fibers greatly increases the mechanical strength of lightweight expanded clay concrete employing test procedures and scanning electron microscopy (SEM) for structural analysis. Significantly, the ideal density-to-strength ratio for lightweight concrete was determined, emphasizing that the 2% fiber content by mass significantly increases flexural and compressive strength. SF performed better than fiber-free composites, increasing compressive strength by 18.3% and bending strength by 16.1%, whereas CF increased compressive strength by 8.9%. When compared to the fiber-free composite, both types of fibers increased the coefficient of constructive quality by up to 18% and 16%, respectively, and prediction models for compressive strength were developed.

The goal of a different study by Patrycja et al. (2024) was to create a lightweight, fiber-reinforced concrete mix that was almost self-compacting and appropriate for precast applications. A final blend that met certain requirements, such as a strength class of at least LC 25/28, was the result of several design iterations and experimental experiments. Steel fiber additives improved the potential concrete types during testing, leading to the ultimate choice of a mix with a density of 1640 kg/m^3 and a strength class of LC 30/33.

In order to increase the ductility and crack resistance of concrete, Fawad and colleagues (2024) investigated hybrid glass and steel fiber combinations due to difficulties in recovering discarded steel fibers with sharp edges from industrial operations. Their results showed that 2.5% lathe waste steel and 0.75% glass fibers produced the best strength, and that larger fiber concentrations significantly reduced performance.

Elzoriky and colleagues (2025) looked into replacing natural coarse aggregate (NCA) in concrete mixtures with popcorn coarse aggregate (PCA), a byproduct of recycled polyester fiber manufacture. Their research showed that when PCA was substituted for NCA in a variety of compositions, density and compressive strength were drastically reduced. The best improvement was obtained with 0.25% glass fibers, which increased flexural and breaking tensile strength [24].

The effects of several steel fiber kinds and their volume fractions on the mechanical performance of High-strength Lightweight Aggregate Concrete (HLAC) were investigated by Yanxia Ye et al. (2020). Micro steel fibers were shown to be the most effective reinforcement, leading to notable increases in toughness. Their research revealed a relationship between fiber type and mechanical strength.

In their investigation of the effects of glass and polypropylene fibers at high temperatures, Zanjad et al. (2024) discovered that whereas polypropylene fibers resulted in increased porosity and decreased strength at high temperatures, glass fibers improved compressive and flexural strengths.

The benefits of employing lightweight aggregates for structural applications were covered by Shah et al. (2024), who emphasized striking a compromise between obtaining a reduced density and preserving sufficient strength. Expanded polystyrene (EPS) was used in their work to replace fine aggregates, and steel fiber reinforcements were added to improve structural qualities.

In general, the literature highlights the substantial research on lightweight aggregates, which can improve the thermal and acoustic qualities of concrete while reducing its density by 30 to 40%. The sustainable strategy of utilizing recycled resources, such as fly ash and polymer fibers, to improve the mechanical qualities of concrete while resolving environmental issues related to traditional building materials is supported by this body of work.

Because of its less weight and better thermal qualities, lightweight concrete has gained popularity as a sustainable building material. According to studies, employing lightweight aggregates including waste materials improves sustainability without sacrificing mechanical performance. Lightweight concrete, however, typically has poorer crack resistance and tensile strength. The use of fibers metallic, synthetic, natural, and mineral—has been investigated as a way to lessen this, with steel fibers showing the best mechanical advantages. There is a noticeable lack of studies integrating waste-based lightweight aggregates with waste fibers, despite substantial research on fiber-reinforced and lightweight aggregate concrete independently. The goal of this project is to use waste resources to improve the durability performance, mix optimization, and material selection of fiber-reinforced lightweight concrete.

2. Materials and methods

The investigation's ingredients are described in depth in this chapter, including natural river sand for fine aggregate, regular Portland cement as a binder, sintered fly ash aggregate and recycled PP fibers for coarse aggregate, and crushed granite for coarse aggregate. Potable water was used for mixing and curing, and each material is explained in detail in the sections that follow.

The use of grade 53 ordinary Portland cement (OPC), which satisfies IS 12269 (2013) requirements and has a specific gravity of 3.15 and a surface area of 3510 cm^2/g, is investigated in this study. 10%

of the cement weight is replaced with Class F fly ash, which has a density of 2130 kg/m³ and a specific surface area of 7290 cm²/g. The fine aggregates, which had a specific gravity of 2.58 and a fineness modulus of 2.25, were made from river sand, passed through a 4.75 mm filter, then cleaned to remove silt.

Angular stones from a nearby quarry were used for coarse aggregates in accordance with IS 383:2016 guidelines, guaranteeing sufficient strength and stability. With a maximum size of 20 mm, a specific gravity of 2.67, a water absorption of 0.5%, and a bulk density of 1500 kg/m³, these aggregates demonstrated appropriate grading, which improved packing density and decreased voids.

Conplast SP430, a superplasticizing ingredient added at 1.2% of the cement weight, was added to the mixture together with water from the college campus that had a pH of 6.3. Furthermore, coal combustion wastes were pelletized and sintered at 1000–1200 °C to create SFAA, a lightweight, long-lasting aggregate with a typical particle size range of 10–20 mm, bulk density of 790 kg/m³, and specific gravity of 1.5.

The qualities of the concrete were improved by the addition of recycled PP fibers, which are derived from discarded plastics. These fibers serve as crack arresters because of their 6–12 mm length, 0.91 g/cm³ density, and superior chemical resistance. Without appreciably increasing the total weight of the concrete, their addition to lightweight concrete solves problems with plastic shrinkage and microcrack propagation.

The compatibility of SFAA with recycled PP fibers was emphasized, pointing out that while PP fibers increase ductility and crack resistance in lightweight concrete, SFAA decreases concrete density while improving sustainability. The study finds a void in the literature about the combined usage of these materials, which improves structural performance while also promoting environmental sustainability. The results highlight the advantages of incorporating these environmentally friendly ingredients into lightweight concrete, demonstrating potential for improving mechanical and durability qualities.

Figure 1 Sintered Fly Ash Aggregate

Table 1 Properties of SFAA

Property	Value (Typical Range)	Test Standard
Particle size	10–20 mm	IS 2386 (Part 1)
Bulk density	790 kg/m³	IS 2386 (Part 3)
Specific gravity	1.5	IS 2386 (Part 3)
Water absorption	20 %	IS 2386 (Part 3)
Crushing value	26 %	IS 2386 (Part 4)
Aggregate impact value	23 %	IS 2386 (Part 4)
Shape	Nearly spherical	Visual

Table 2 Properties of Recycled PP fibers

Property	Value
Fiber type	Recycled Polypropylene
Fiber length	6–12 mm
Diameter	18–40 microns
Aspect ratio	400
Density	0.91 g/cm³
Tensile strength	400 MPa
Elastic modulus	3.5 GPa
Melting point	~165 °C
Water absorption	Nil
Chemical resistance	Excellent

Figure 2 Recycled PP fibers

To evaluate the mechanical characteristics of fiber-reinforced lightweight concrete, concrete specimens were created utilizing sintered fly ash aggregate and recycled polypropylene fibers. Along with control and fiber-free mixes, thirteen M30 grade mixes had different fiber dosages and aggregate replacement amounts. A tilting drum mixer and precise material weighing were necessary to create a workable mixture, and water was added gradually after dry mixing. To ensure consistency for compressive, split tensile, and flexural strength tests, specimens were cured in drinkable water at room temperature for seven or twenty-eight days.

The paper describes three basic tests to evaluate the mechanical characteristics of concrete: the flexural strength test, the split tensile test, and the compressive strength test.

2.1 Test of Compressive Strength

The test assesses the concrete's resistance to axial loads. Before testing, 150 mm³ cube specimens were cast, cured in drinkable water, and cleaned. According to IS 516, a calibrated Compression Testing Machine (CTM) with a 2000 kN capacity was used to apply a load at a rate of 140 kg/cm²/min until failure occurred. The formula is given below was used to get the compressive strength. The average of three specimens is the final reported compressive strength.

$$fc = P/A$$

, where "fc" is the compressive strength in MPa,
"P" is the maximum load at failure in N, and "A" is the cross-sectional area in mm.

2.

Figure 3 Compressive strength test

2.2 The Split Tensile Test

This test uses cylindrical specimens that are 150 mm in diameter and 300 mm in height to evaluate the indirect tensile strength of concrete. The specimens were tagged for correct alignment and put in the CTM for testing after a 28-day curing period. To guarantee uniform load distribution, a piece of plywood was utilized. The split tensile strength was determined using below formula. The average of three specimens is the ultimate outcome.

Where:

$$ft = 2P/\pi DL$$

ft= Split tensile strength (MPa)
P = Maximum applied load (N)
D = Diameter of cylinder (mm)
L = Length of cylinder (mm)

Figure 4 Split tensile test

2.3 Test of Flexural Strength

This test uses 100 mm x 100 mm × 500 mm beam specimens that were cured for 28 days to measure the bending strength of concrete. The test was carried out using a flexural testing machine under a two-point loading system in accordance with IS 516. Two rollers with a span length of 400 mm supported the beam, and the stress was applied gradually until it failed. The stated value is the mean of the tests that were performed.

The following formula was used to get the flexural strength (modulus of rupture):

Where:

$$Fr= PL/bd^2$$

fr = Flexural strength (MPa)
P = Maximum applied load (N)
L = Span length (mm)
b = Width of specimen (mm)
d = Depth of specimen (mm)

The tests used to assess the permeability and durability of hardened concrete are described in this section.

Figure 5 Flexural test

2.4 Water Absorption Test

This test gauges the porosity and permeability of concrete; a lower water absorption indicates a denser microstructure and improved durability. After cubic specimens are oven-dried, weighed, and saturated in water, the absorption percentage which represents the compactness of the concrete—is determined by comparing the weights of the specimens.

Figure 6 Water absorption test

2.5 Sorptivity Test

This test measures the rate at which water penetrates unsaturated concrete, which is crucial during initial exposure, in contrast to the water absorption test. In order to measure sorptivity—lower values signify more durability cylindrical specimens that have been wet at one end are weighed over time.

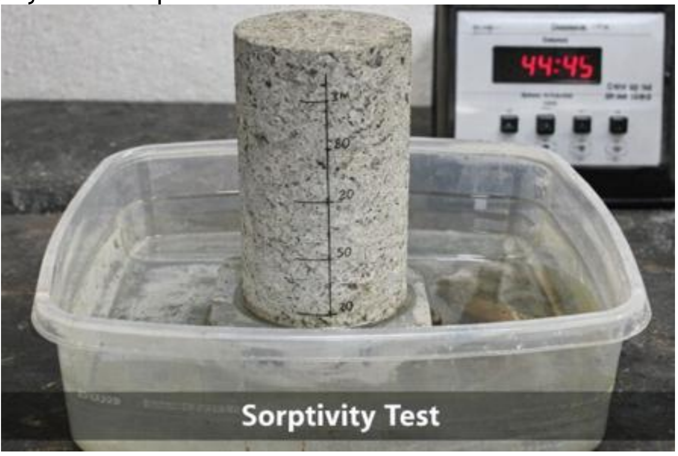

Figure 7 Sorptivity test

2.6 Rapid Chloride Penetration Test (RCPT)

This test, which is carried out in accordance with ASTM C1202, measures the charge that passes through the specimen when it is subjected to solutions of sodium hydroxide and sodium chloride in order to evaluate chloride ion resistance. Reduced permeability and increased resistance to chloride penetration are indicated by a lower charge.

Figure 8 RCPT test

2.7 Acid Attack Test

Specimens are immersed in 5% sulfuric acid for 28 days to imitate exposure to acidic conditions. To assess resistance to acid assault, weight loss and compressive strength are assessed; higher durability is indicated by smaller losses.

Figure 9 Acid Attack

2.8 Sulfate Attack Test

This test aspects at how sulfate intrusion affects concrete, where expansion from hydration chemicals causes cracking and a loss of strength. To measure sulphate resistance, specimens are immersed in a 5% sodium sulphate solution, and weight changes and strength decreases are tracked; lesser losses indicate greater durability.

Figure 10 Sulphate attack test

2.9 Carbonation Test

This chemical interaction between carbon dioxide and calcium hydroxide in concrete puts embedded steel at danger of corrosion when pH levels fall. To evaluate the depth of carbonation, specimens are exposed to air and treated with phenolphthalein; a shallower penetration indicates greater resistance to CO_2 infiltration.

3 Results and discussion

In order to create fiber-reinforced lightweight concrete, the study assesses the use of SFAA as a lightweight aggregate and PP fibers as reinforcement. Thirteen concrete mixes with different fiber dosages and SFAA replacement percentages were tested, with an emphasis on mechanical strength and durability properties.

3.1 Density

The results show that replacing natural coarse aggregate with SFAA significantly lowers the density of concrete. Concrete containing 100% SFAA has a density of about 1644 kg/m³, which is 33% less than the control mix's density of 2457 kg/m³. Density reductions of roughly 13%, 19%, and 27% were obtained with partial replacements of 25%, 50%, and 75% SFAA, respectively. The use of recycled PP fibers resulted in only slight density increases of less than 2–8%, and all changed combinations continued to be categorized as lightweight concrete.

Table 4.1 Density test results of LWAC specimens

S.No	Mix ID	Waste LWA (%)	Fiber Content (%)	Density (kg/m3)
1	CM	0	0	2457
2	LWC25	25	0	2136
3	LWC50	50	0	1987
4	LWC75	75	0	1790
5	LWC100	100	0	1644
6	FRLWC25-0.5	25	0.5	2200
7	FRLWC50-0.5	50	0.5	1988
8	FRLWC75-0.5	75	0.5	1770
9	FRLWC100-0.5	100	0.5	1654
10	FRLWC25-1.0	25	1	2300
11	FRLWC50-1.0	50	1	2240
12	FRLWC75-1.0	75	1	1870
13	FRLWC100-1.0	100	1	1630

3.2 Compressive strength

Compressive strength dropped as the amount of SFAA in lightweight concrete rose; results for 25%, 50%, 75%, and 100% SFAA mixes were 34.0 MPa, 31.0 MPa, 29.6 MPa, and 27.6 MPa, respectively, while a control mix reached 36.2 MPa. Strength was greatly increased by the addition of recycled PP fibers; blends containing 1% PP fibers outperformed non-fiber mixes by 28% to 35%. Remarkably, the mix containing 1% PP fibers and 25% SFAA showed a compressive strength of about 40.1 MPa, which was 11% higher than the control.

Table 4.2 28 days compressive strength results

S.No	Mix ID	Waste LWA (%)	Fiber Content (%)	Compressive Strength 28d (MPa)
1	CM	0	0	36.19
2	LWC25	25	0	34
3	LWC50	50	0	31.01
4	LWC75	75	0	29.63
5	LWC100	100	0	27.64
6	FRLWC25-0.5	25	0.5	36.78
7	FRLWC50-0.5	50	0.5	35
8	FRLWC75-0.5	75	0.5	32.68
9	FRLWC100-0.5	100	0.5	30.44
10	FRLWC25-1.0	25	1	40.15
11	FRLWC50-1.0	50	1	39.23
12	FRLWC75-1.0	75	1	37.33
13	FRLWC100-1.0	100	1	35.4

3.3 Split tensile strength

The results on split tensile strength demonstrated the usefulness of fiber reinforcement in lightweight materials. Concrete with 100% SFAA has a split tensile strength of about 2.1 MPa, which is more than 32% less than the control concrete's 3.1 MPa. Tensile performance was greatly improved by the addition of PP fibers; fiber-reinforced blends were 45% to 52% stronger than non-fiber mixes. The blend containing 1% PP fibers and 25% SFAA had the highest split tensile strength, at about 3.6 MPa.

Table 4.3 Split Tensile Strength test results

S.No	Mix ID	Split Tensile Strength 28d (MPa)
1	CM	3.1
2	LWC25	2.8
3	LWC50	2.7
4	LWC75	2.4
5	LWC100	2.1
6	FRLWC25-0.5	3.5
7	FRLWC50-0.5	3.2
8	FRLWC75-0.5	3.0
9	FRLWC100-0.5	2.8
10	FRLWC25-1.0	3.6
11	FRLWC50-1.0	3.4
12	FRLWC75-1.0	3.5
13	FRLWC100-1.0	3.2

3.4 Water absorption

Water absorption values increased with LWA replacement, with LWC100 exhibiting a notable improvement at 8.20% as opposed to CM's 6.10%. The porous nature of the lightweight aggregate is the cause of this rise. Fiber-reinforced mixes, on the other hand, had lower absorption; the FRLWC100-0.5 mix had 4.75% absorption, which was 22.1% less than CM and 42.1% less than LWC100, suggesting improved matrix densification. Due to reduced workability, the FRLWC100-1.0 mix reported a 5.30% absorption, which was 35.4% lower than LWC100 but higher than the 0.5% mix. As a result, the porosity increase caused by LWA substitution was successfully reduced by a 0.5% fiber dosage.

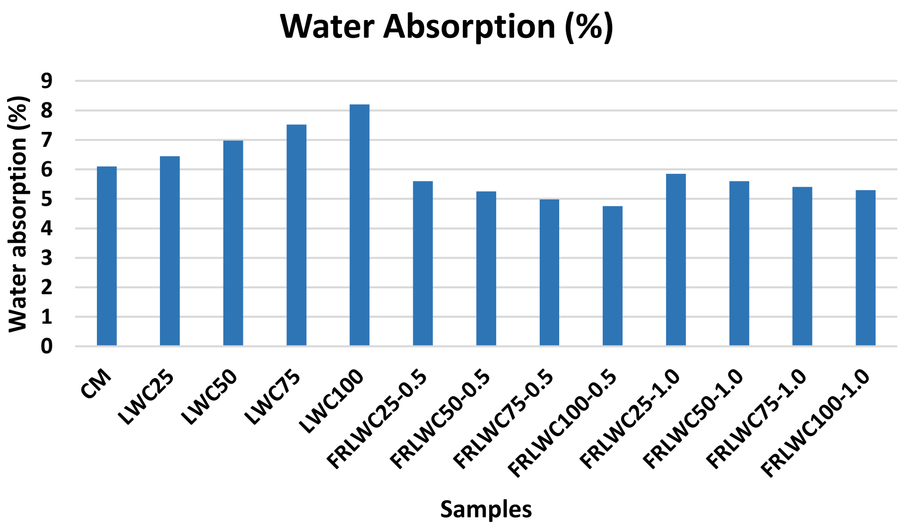

Figure 11 Water absorption (%) outcomes

3.5 Sorptivity test

Improved capillary suction behavior is indicated by higher sorptivity values; LWC100 increased by 43.8% to 0.128 mm/√min as opposed to CM's 0.089 mm/√min. Moisture transport is greatly impacted by the addition of fiber; FRLWC is 0.058 mm/min, which represents a 54.7% decrease from LWC100 and a 34.8% decrease from CM. This implies improved pore structure and fewer moisture routes. While FRLWC100-1.0 attained 0.066 mm/√min, FRLWC75-0.5 approximated high-performance concrete at 0.062 mm/min. The findings show that whereas fibers enhance crack-bridging and lessen capillary suction, a high fiber concentration may marginally diminish material compactness.

Table 4.6 Sorpitivity test results

Mix ID	Sorptivity (mm/√min)
CM	0.089
LWC25	0.095
LWC50	0.104
LWC75	0.115
LWC100	0.128
FRLWC25-0.5	0.074
FRLWC50-0.5	0.068
FRLWC75-0.5	0.062
FRLWC100-0.5	0.058
FRLWC25-1.0	0.078
FRLWC50-1.0	0.072
FRLWC75-1.0	0.069
FRLWC100-1.0	0.066

3.6 Acid attack test

According to the study on acid assaults, adding fibers and using lighter materials greatly increases the durability of concrete. The CM lost 7.5% of its weight and 18.2% of its strength after being exposed to a 5% H2SO4 solution for 28 days. Due to its increased porosity, which permits deeper acid penetration, the lightweight concrete mix (LWC100) showed a 28.3% strength loss and a 70.7% increase in weight loss when compared to CM. Additionally, acidic environments damaged calcium compounds' microstructure, hastening their breakdown. Nevertheless, adding fibers increased acid resistance; in comparison to both LWC100 and CM, the FRLWC100-0.5 combination showed only a 3.8% weight loss and an 8.2% strength fall. The best resistance was achieved with a fiber dosage of 0.5%, whereas a dosage of 1.0% resulted in somewhat greater weight loss because of decreased workability.

Table 4.7 Acid Attack Test

Mix ID	Weight Loss (%)	Strength Loss (%)
CM	7.5	18.2
LWC25	8.1	19.5
LWC50	9.2	21.4
LWC75	10.5	24.6
LWC100	12.8	28.3
FRLWC25-0.5	5.2	12.5
FRLWC50-0.5	4.6	10.8
FRLWC75-0.5	4.1	9.5
FRLWC100-0.5	3.8	8.2
FRLWC25-1.0	5.8	14
FRLWC50-1.0	5	12.2
FRLWC75-1.0	4.6	11
FRLWC100-1.0	4.3	10.4

3.7 RCPT test

RCPT results show that a higher percentage of SFAA increases concrete permeability. The CM demonstrated moderate permeability with a charge passing value of 3250 coulombs, while LWC100 demonstrated significant permeability at 4100 coulombs because the porosity of lightweight aggregates improved pore connection and ion transport. On the other hand, PP fibers greatly decreased the penetration of chloride ions; the fiber-reinforced combination FRLWC100-0.5 achieved 1750 coulombs, which is roughly 57% less than LWC100. Because of the fibers' capacity to prevent continuous pore channel creation and bridge cracks, this reduction causes the categorization to change from high to low permeability. Mixtures with 0.5% fiber content outperformed those with 1.0% because the higher fiber dose may make workability worse even while it helps manage cracks. However, when compared to lightweight concrete without fibers, all fiber-reinforced mixtures showed better durability. Overall, the durability of fiber-reinforced lightweight concrete is greatly increased by the addition of PP fibers, even though lightweight particles may increase permeability.

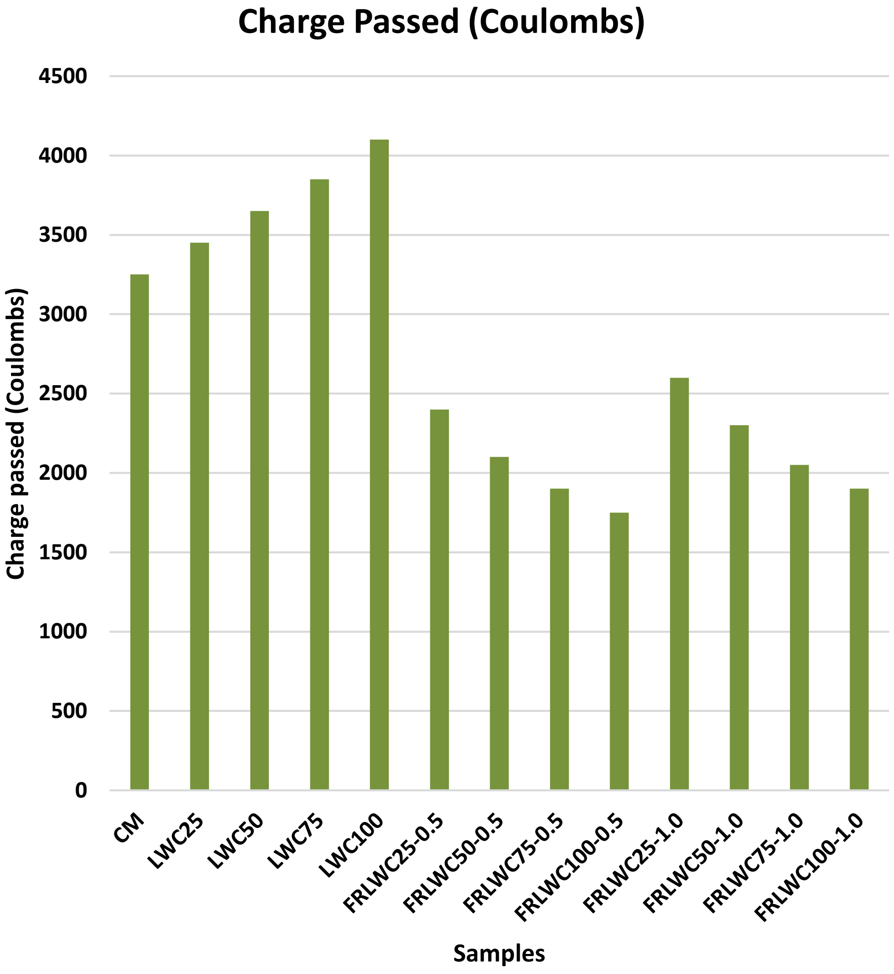

Figure 12 RCPT test outcomes

3.8 Sulphate Attack

Due to sulfate exposure, all mixes showed expansion and strength loss. In a 5% Na_2SO_4 solution, the control mix expanded by 0.40 mm and lost 15% of its strength. Greater expansions resulted from replacing more lightweight aggregate; the LWC100 mix exhibited a 26.1% strength loss and a 0.72 mm expansion. Sulphate ions can react with tricalcium aluminate in LWC mixes with higher permeability, resulting in expansion and degradation of strength. Significant improvements were shown by fiber-reinforced mixtures; FRLWC100-0.5 showed just 0.15 mm expansion, a 79.2% reduction compared to LWC100 and 62.5% compared to CM, combined with a strength drop of only 6.4%. Despite a minor increase in expansion with higher fiber concentration due to decreased matrix homogeneity, moderate fiber addition significantly improves sulphate resistance.

Table 4.9 Sulphate Attack test results

Mix ID	Expansion (mm)	Strength Reduction (%)
CM	0.4	15
LWC25	0.45	17.2
LWC50	0.52	19.8
LWC75	0.6	22.5
LWC100	0.72	26.1
FRLWC25-0.5	0.28	9.5
FRLWC50-0.5	0.22	8.2
FRLWC75-0.5	0.18	7
FRLWC100-0.5	0.15	6.4
FRLWC25-1.0	0.3	11.2
FRLWC50-1.0	0.26	10.5
FRLWC75-1.0	0.22	9.8
FRLWC100-1.0	0.19	9

3.9 Carbonation test

Concrete's carbonation depth increased when more lightweight aggregate was substituted; LWC100 measured 10.5 mm, a 61.5% increase over the control mix's 6.5 mm. This rise implies that the associated pore networks are responsible for increased CO2 diffusion. Concrete's pH is lowered by carbonation, which turns calcium hydroxide into calcium carbonate. When the pH falls below 9, it indicates decreased long-term durability and increases the danger of corrosion. Carbonation depth was greatly decreased by fiber inclusion; the FRLWC100-0.5 recorded just 2.8 mm, a 73.3% decrease from LWC100. Due to enhanced pore refinement, even FRLWC75-0.5 displayed a low 3.3 mm, indicating improved CO_2 penetration resistance. The depth increased somewhat to 3.4 mm when the fiber content was increased to 1.0%, although it was still below non-fiber blends. These results highlight the significance of the correct amount of fiber.

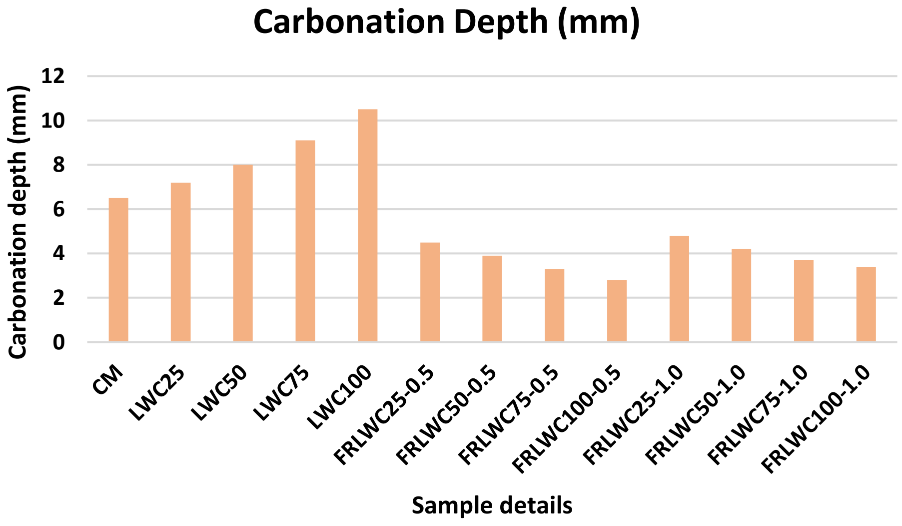

Figure 13 Carbonation test results

3.10 Flexural strength test

According to a comparison of flexural strength, control concrete recorded about 4.7 MPa, while fiber-free lightweight concrete recorded about 3.4 MPa due to decreased aggregate interlock. However, compared to non-fiber versions, fiber-reinforced lightweight concrete showed notable strength increases of 30% to 57%. A mixture of 25% SFAA and 1% PP fibers had the maximum flexural strength at about 5.4 MPa, indicating improved ductility and post-cracking performance.

Table 4.4 Flexural Strength test results

S.No	Mix ID	Waste LWA (%)	Fiber Content (%)	Flexural Strength (MPa)
1	CM	0	0	4.7
2	LWC25	25	0	4.44
3	LWC50	50	0	4.14
4	LWC75	75	0	3.74
5	LWC100	100	0	3.44
6	FRLWC25-0.5	25	0.5	5.01
7	FRLWC50-0.5	50	0.5	4.7
8	FRLWC75-0.5	75	0.5	4.3
9	FRLWC100-0.5	100	0.5	4
10	FRLWC25-1.0	25	1	5.4
11	FRLWC50-1.0	50	1	5.1
12	FRLWC75-1.0	75	1	4.7
13	FRLWC100-1.0	100	1	4.4

4. Conclusions

Using PP fibers and SFAA as a waste lightweight aggregate, the study examined fiber-reinforced lightweight concrete. After testing thirteen different concrete mixes, it was found that while PP fibers slightly increased density by 2–8%, larger SFAA concentration considerably decreased concrete density from 2457 kg/m³ to 1644 kg/m³ at 100% SFAA. Higher SFAA percentages, however, had a detrimental effect on compressive strength; the 100% SFAA mix achieved 27.6 MPa as opposed to the control's 36.2 MPa. The best combination of 1% PP and 25% SFAA produced a compressive strength of 40.1 MPa, which was 11% higher than the control. The inclusion of 1% PP fibers boosted strength by 28–35%.

Tensile strength showed similar tendencies, with the 100% SFAA mix at 2.1 MPa; however, fiber addition resulted in increases of 45–52%. The blend of 25% SFAA and 1% PP had a peak tensile strength of 3.6 MPa. Similar gains were seen in flexural strength, with the best mixes reaching 5.4 MPa. By reusing waste materials, the ideal blend (25% SFAA and 1% PP) showed reduced density (2290 kg/m³), excellent compressive strength, and improved tensile and flexural strengths, indicating its potential for sustainable construction.

With a 30–35% decrease in water absorption and a notable 35–40% drop in the sorptivity coefficient, the amended concrete mix demonstrated increased durability. A 40–50% decrease in weight and strength loss when exposed to acid demonstrated resistance to chemical attack. Additionally, the adjusted mix's sulfate attack strength loss dropped from 12–15% in the control to 6–8%. Performance shifted to lower permeability regions with a drop of more than 50–55% when chloride ion permeability improved. Strength loss decreased by about 50% during cycle exposure, suggesting improved internal matrix integrity and crack resistance.

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