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ORIGINAL ARTICLE

The investigation of using waste plastic fiber in economic concrete production

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Abstract: Much research has been done on concrete using new materials, especially when reinforced with fibers, but researchers did not know how to include the plastic fibers in concrete. However, this study has investigated the effect of replacing natural aggregate with recycled coarse aggregate (RCA) at 25%, 50% or 75%, and adding plastic fiber (PF) at 0.5%, 1%, or 2% in concrete. Compressive strength, flexural strength, tensile strength, and elastic modulus were tested to gain knowledge of concrete behavior, and the study comprehensively covers hardened properties of concrete. The most important results were reached from the analysis of concrete properties, such as substituting a low amount of RCA by 25% and adding a small proportion of fiber by 1% can enhance the strength of a concrete; on the other hand, substituting larger amounts of RCA by higher than 50% and adding greater proportions of fiber up 2% can decrease of strength. The highest increase in compressive strength was recorded when a mixture of 25% of RCA with 1%PF by 10.92% compared to the control mixture.

Keywords: recycled coarse aggregate (RCA), economical concrete (EC) and sustainable high-performance concrete (SHPC), waste plastic fiber (WPF), compressive strength (CS), flexural strength (FS), splitting strength (SS), modulus of elasticity (ME)

1 Introduction

Fibre-reinforced concrete is a construction material comprising a cement-based matrix and an array of fibres that may be orderly or disordered. These fibers could be made from steel, nylon, or polythene [1, 2]. Including steel fibres in the concrete enhances its characteristics, such as flexural and impact strength properties. Several inert and non-decomposable materials are contained in the construction and demolition waste (C&DW) [3, 4]. Examples include concrete, cement, wood, metal, plastic, scrap glass, and bricks. Concrete constitutes a significant percentage of the total weight of all these wastes produced by building activities. However, it should be noted that concrete is a substantial constituent of C&DW [5-7].

Concrete makes up a considerable proportion of C&DW waste material by weight because it is widely applied in many construction projects. Its ability to last long without breaking, coupled with its being a mainly used material, makes it responsible for large amounts of concrete debris arising from demolitions or renovations [7-9]. It is essential to find sustainable ways of managing and recycling concrete waste to minimize the effects it has on the environment. In any case, demolition is inevitable as soon as a concrete construction ends [10, 11]. Old structures are often demolished to pave the way

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for new developments or infrastructure projects such as roads, highways, and power lines [12-14]. Although debris from demolished buildings is usually referred to as waste, it is crucial to practice efficient environmental management by organizing proper disposal systems. Environmental concerns could arise from some components of construction waste, mainly because some non-biodegradable components could remain in the ecosystem for hundreds or even thousands of years [14-16]. Recycling is an effective option for managing this type of concrete waste. Debris from demolished concrete structures can be reused as aggregates for new concrete production [17, 18].

This refers to creating recycled coarse aggregate concrete from crushed concrete. As shown [19-21], Recycling wastes considerably lessens the ecological impact of concrete waste while minimizing reliance on natural aggregate. In addition, recycled aggregate concrete remedies the disposal problem associated with concrete waste, the detrimental consequences concrete waste has on disposal sites, and the limitations placed on these sites. This practice also aids resource conservation by minimizing the impact associated with the extraction of raw materials and the new concrete creation process. Furthermore, it is resource recovery, which is recycling. Waste management provides economical practices in promoting recycled aggregate concrete. Sustainable construction practices and environmental conservation emphasize effective waste management and promoting recycled aggregate concrete. [22-24]. Some recent experimental investigations have concentrated on the mechanical characteristics of RCA [25, 26]. While there may be differences in findings among different researchers, they generally support the idea that RAC could replace NCA (natural coarse aggregate) in concrete [24-26]. Most studies recommend that replacement ratios not exceed 75% of the natural aggregate, as this results in a loss of more than half of the strength compared to the control sample [27-30].

Fiber-reinforced concrete is advantageous because it can change brittle concrete to a material that looks like ductile [29, 30]. Fibers in concrete assist in managing the formation and recapturing sustained damage of micro-cracks, avoiding slow failure propagation [9, 31, 32]. There is a chance of developing bio-fibers from low-cost or waste materials for cement mortar composites made for structural members. This method shifts the economic balance favorably by lessening the use of conventional reinforcing materials [33-35]. Especially in resource-poor environments, the concrete's constructability and durability may benefit from integrating waste or low-cost resource fibers. Employing low-cost and fibers would improve construction processes, modern construction methods, and provide a means for recycling construction waste. Construction waste includes materials that would otherwise go to a landfill [36, 37]. This approach supports green construction principles, enhancing efficient and responsible exploitation of building industry resources [38, 39].

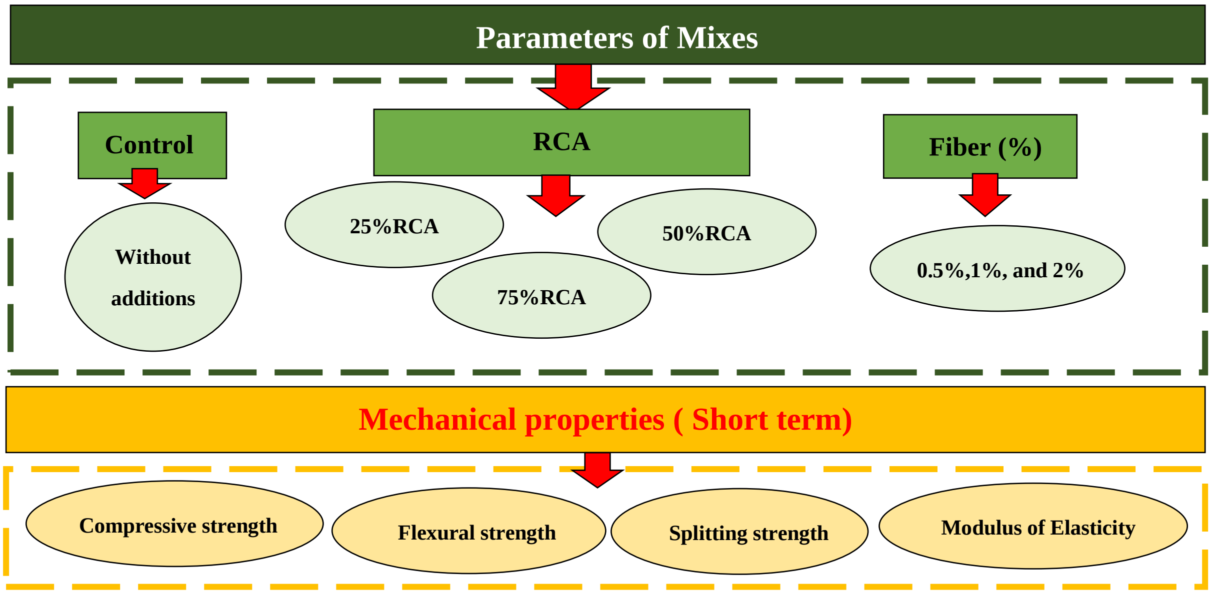


Fig. 1. Experimental program

2 The Research Methodology

This research investigates the effects of incorporating RCA as a partial replacement for natural coarse aggregate (NCA) and of including waste plastic fibers in the formulation of structural concrete. This paper presents a preliminary analysis of experimental measurements on concrete specimens containing 0%, 25%, 50%, and 75% RCA by weight of NCA (see **Fig. 1**), and incorporating fiber plastic at fiber-to-concrete volume ratios of 0.5%, 1.0%, and 2.0%. The importance of mechanical properties such as CS, FS, SS, and ME was elaborated, as they are properties of hardened concrete that influence numerous other mechanical properties. CS is readily measured and is an important indicator of concrete quality and durability.

Therefore, this study primarily assesses the compressive, flexural, splitting, and elastic moduli for all possible combinations of the studied mixtures. Insights into the effectiveness of partially replacing natural coarse aggregates with recycled aggregate and adding fiber in concrete for structural applications will be obtained from strength comparisons between RAC and plastic fiber (PF) concrete.

3 Objectives

The study focuses on the feasibility of using demolished waste as a substitute for natural coarse aggregate (NCA) in structural concrete, combined with plastic fiber (PF), at the proportions of 0.5%, 1.0%, and 2.0%. It also aims to assess the benefits of incorporating waste plastic fibers and recycled concrete aggregate (RCA) into the mixtures (See **Fig. 2**). The objectives of the study were summarized in the following points:

- Incorporating plastic waste as fiber in concrete is necessary for developing novel fiber types.
- The inclusion of fibers strengthens durability, and this has a positive effect on the fracture pattern in the concrete samples observed.
- Finding the best ratio of recycled concrete replacement that achieves the highest resistance, with the best ratio of fibers that achieves the same goal, to reach an optimum mixture that achieves the best resistance.
- Recycling waste while reducing its risk to the environment and turning it into a positive impact.

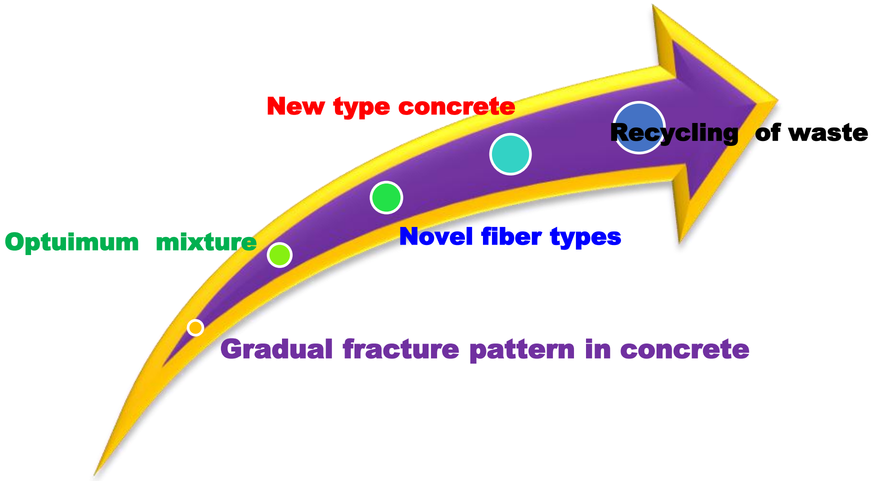


Fig. 2. Summary of study objectives

4 Materials investigation

4.1 Materials

The cement used in this study was Helwan cement, specifically CEM I 42.5 N, which was manufactured following the BS EN 197-1 (EN 2000) standard. The ordinary Portland cement (OPC) used was of an Egyptian brand. It was sourced from a company to ensure its stability and prevent the use of expired or damp cement, which could affect the quality of the concrete. Natural gravel that passed through a sieve with an aperture size of 4.76 mm (Sieve no. 4) was utilized for the fine aggregates, carried out according to the (ESS 1109/ 2008). The fine sand used in the study underwent a screening examination to ensure it fell within the specified range. On the other hand, Dolomite crushed stone was used as course aggregate in this study, and Testing of course aggregate was carried out according to the (ESS 1109/ 2008). The water used in the experiments adhered to the British standard BS EN 1008 (EN 2002). To enhance the properties of economical concrete, recycled coarse aggregate was added to the concrete in ratios of 25%, 50%, and 75%. On the other hand, plastic fiber (PF) was added in ratios of 0.5%,1%, and 2%. The RCA was acquired by pulverizing aged laboratory concrete samples. The waste concrete was crushed using a hammer, and the resulting reclaimed aggregates were washed and sifted by hand. The RCA used in the study underwent a screening examination to ensure it fell within the specified range, See **Table1**.

Table 1: Mechanical and Physical Properties of NCG and RCA used, [1,3,102]

Sample	Water absorption (%)	Crushing value (%)	Specific unit weight	Volume unit weight (kN/m3)	Los Anglis Coefficient (%)
NCG	2.25	21.5	2.45	15.7	27.1
RCA	4.73	27.6	2.27	12.2	32.8

4.2 Waste Plastic Fiber

The study utilized a variety of trash bottles, such as those used for carbonated beverages, water, tea, and fruit juices, as the waste material. The bottles were obtained from domestic refuse and subjected to a water-based cleansing procedure. The recycled fibers, shown in **Fig. 3**, were acquired through the cutting of bottles in a spiral configuration along the sides of the bottles. This cutting technique guaranteed consistency in the width of the fibers, See **Table 2.**

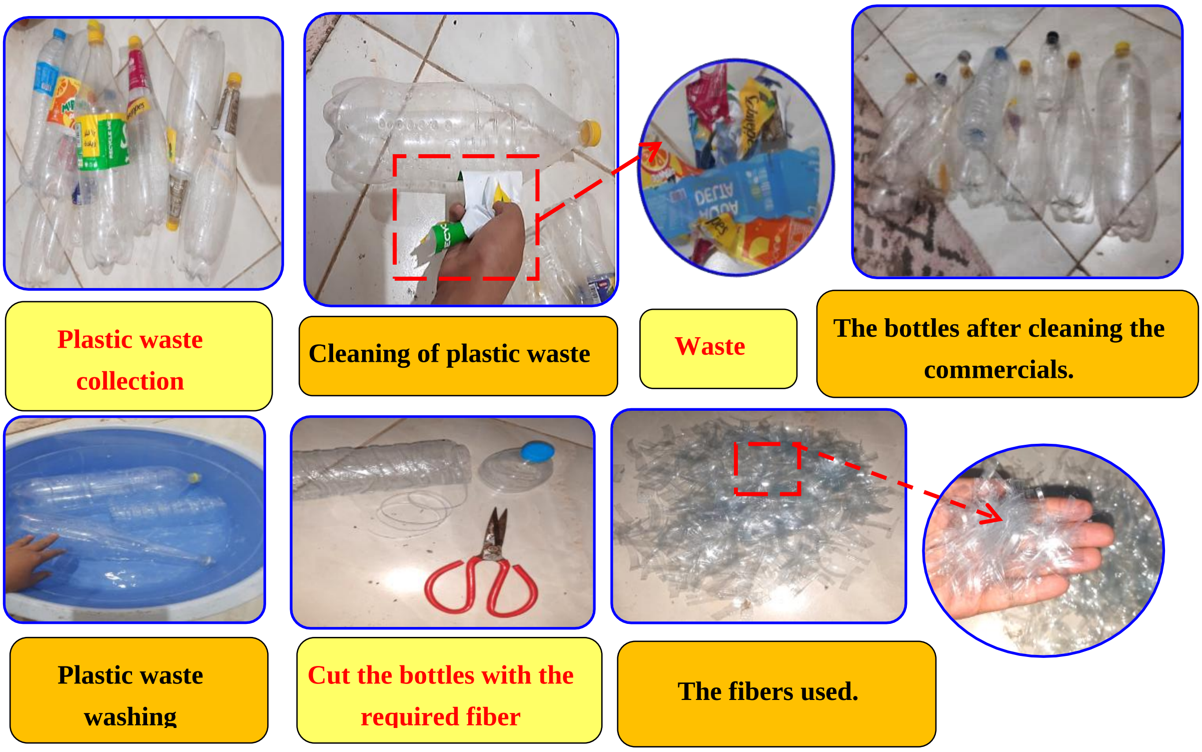


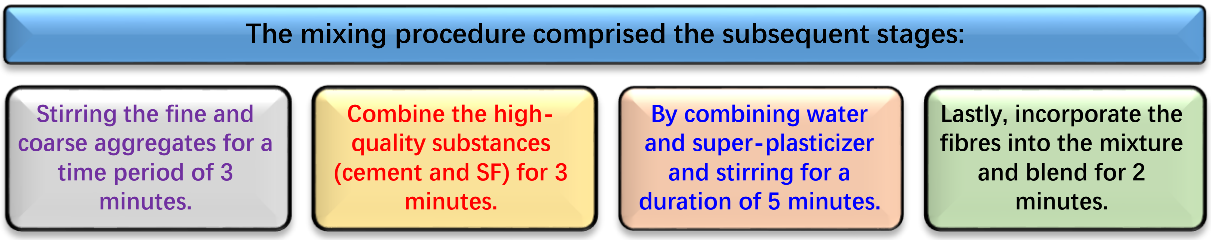
Fig. 3. The fiber manufacturing process

Table 2. Properties of plastic fiber (PF)[89, 90]

Fiber type	Width (mm)	Thickness (mm)	Length (mm)	Aspect-ratio (Length /Thickness)	Surface	Color
PF	3.0	0.40	10.0	10/0.40=25	Soft	White Transparent

4.3 Mixing procedure

The study's mixed designs are detailed in **Table 3**. The control mixture and nine supplementary blends were developed using plastic Fiber (PF) at 0.5%, 1%, and 2% volume ratios. RCAs were added with ratios 25%, 50%, and 75% of local dolomite crushed stone size 10 mm (kg) to assess the impact of PF and RCA hardened concrete characteristics. The mix design adhered to the absolute volume technique. The cement content remained consistent at 450 kg/m^3. 20% of the cement content was supplemented with Silica Fume (SF). At the same time, the ratio of fine-to-coarse aggregate was kept at 1:1.5. The mixture's water/binder materials ratio is 0.265, as illustrated in **Table 3**. The dosage of the super-plasticizer was 3.6% of the weight of the cement. **Fig. 4** shows the mixing procedure, which comprises the following stages.


The mixing procedure comprised the subsequent stages:

Stirring the fine and coarse aggregates for a time period of 3 minutes.

Combine the high-quality substances (cement and SF) for 3 minutes.

By combining water and super-plasticizer and stirring for a duration of 5 minutes.

Lastly, incorporate the fibres into the mixture and blend for 2 minutes.

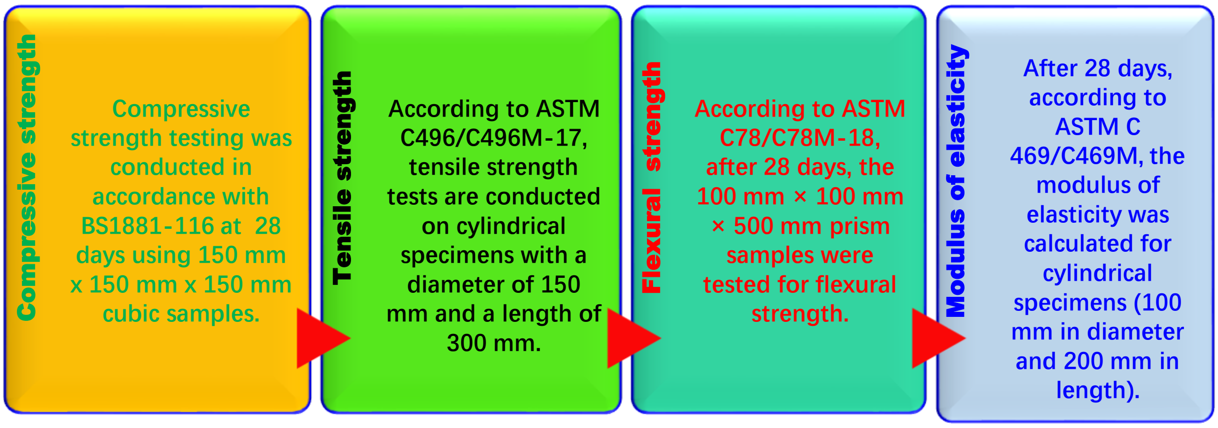
Fig. 4. The stages of mixing procedure

Table 3. Description of quantities of mixtures (Kg/m^3)

No.	Description		Cement	SF	Coarse aggregate	Fine aggregate	Water	SP	RCA(%)	Fibber (%)
1	Control		450	90	1038	692	143	16.2	0.0	0
2	25% RCA+0.5%F	25%RCA +F	450	90	778.5	692	143	16.2	259.5	0.5
3	25% RCA+1.0%F		450	90	778.5	692	143	16.2	259.5	1.0
4	25 %RCA+2.0%F		450	90	778.5	692	143	16.2	259.5	2.0
5	50%RCA+0.5%F	50%RCA +F	450	90	519.0	692	143	16.2	519.0	0.5
6	50%RCA+1.0%F		450	90	519.0	692	143	16.2	519.0	1.0
7	50%RCA+2.0%F		450	90	519.0	692	143	16.2	519.0	2.0
8	75%RCA+0.5%F	75%RCA +F	450	90	259.5	692	143	16.2	778.5	0.5
9	75%RCA+1.0%F		450	90	259.5	692	143	16.2	778.5	1.0
10	75%RCA+2.0%F		450	90	259.5	692	143	16.2	778.5	2.0

4.4 Testing procedure

The study assessed the mechanical properties of high-strength concrete (HSC). From **Fig.5**, the subsequent testing methodologies and measures were executed as follows:


Compressive strength

Compressive strength testing was conducted in accordance with BS1881-116 at 28 days using 150 mm x 150 mm x 150 mm cubic samples.

Tensile strength

According to ASTM C496/C496M-17, tensile strength tests are conducted on cylindrical specimens with a diameter of 150 mm and a length of 300 mm.

Flexural strength

According to ASTM C78/C78M-18, after 28 days, the 100 mm × 100 mm × 500 mm prism samples were tested for flexural strength.

Modulus of elasticity

After 28 days, according to ASTM C 469/C469M, the modulus of elasticity was calculated for cylindrical specimens (100 mm in diameter and 200 mm in length).

Fig. 5. Methodologies and measures for tests

5 Results and discussion

In **Table 4**, results for all mixtures are presented, including CS, SS, and FS, as well as ME.

Table 4. Results of mixtures at 28 days (MPa)

No.	Description		Compressive strength	Splitting strength	Flexural strength	Modulus of elasticity
1	Control		76.19	7.85	9.32	43777.9
2	25% RCA+0.5%F		83.07	8.71	10.35	47858.1
3	25% RCA+1.0%F	25%RCA	84.50	8.88	10.56	48728. 2
4	25 %RCA+2.0%F	+F	81.25	8.51	10.11	45789.1
5	50%RCA+0.5%F		74.01	7.65	9.07	41673.4
6	50%RCA+1.0%F	50%RCA	75.18	7.71	9.13	42755.9
7	50%RCA+2.0%F	+F	72.21	7.25	8.71	40343.7
8	75%RCA+0.5%F		63.86	6.38	7.65	37868.4
9	75%RCA+1.0%F	75%RCA	68.35	6.85	8.23	38748.8
10	75%RCA+2.0%F	+F	58.76	5.86	7.02	35576.3

5.1 Properties of Hardened concrete

5.1.1 RCA and PF's relationship to Compressive strength (CS)

Fig. 6 illustrates that the developed sustainable high-performance concrete (SHPC) attained a CS at 28 days, which satisfies the necessary criteria for structural purposes, And this phenomenon was discovered when varying the proportions of gravel replaced with recycled coarse aggregates (RCA) and the addition of plastic fiber (PF) [40, 41]. When the high amount of natural gravel was replaced with RCA in the SHPC, ranging from 50% to 75% replacement, the CS of the SHPC decreased by 1.32% to 22.87%. It indicates that as the replacement ratio of natural sand with CWA increased, the CS of the SHPC declined [41-43]. on the other hand, Low ratio addition of plastic fiber, ranging from 0.5% to 1% by volume of concrete, with replacement 25% recycled concrete aggregate (RCA), led to a high enhancement in CS, approximately 9.04% and 10.92%, respectively. [44, 45], See **Fig.7**.

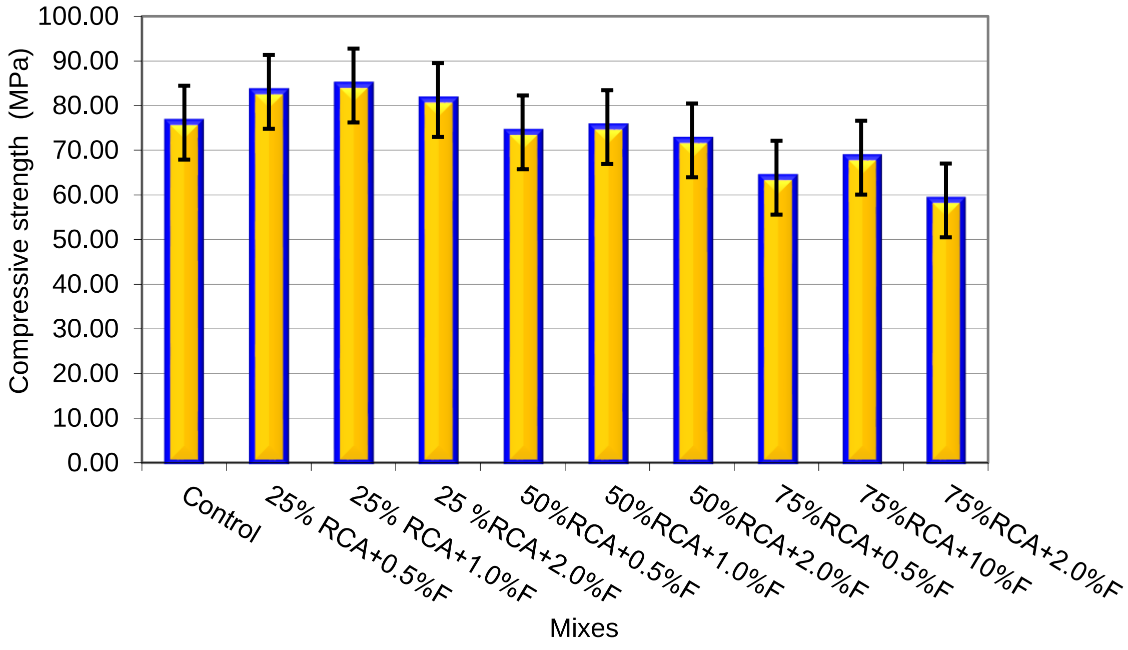


Fig. 6. CS for all mixtures at 28 days

More precisely, when 75% of NCA by the RCA (Recycled Concrete Aggregate) was replaced, and an additional 1.0% Fiber, the CS decreased by 10.29% (high decrease ratio). However, when the replacement was 75%RCA+2.0%F, the fall in CS was even worse, amounting to 22.87%, See **Fig. 7**. However, adding plastic fiber (PF) at a concentration of 1% significantly improved CS. Nevertheless, when the replacement ratio of PF surpassed 2%, a more pronounced decline in strength was noted [46-48]. It indicates that the utilization of PF in SHPC can improve CS, potentially due to disparities in its characteristics. Surprisingly, the combination of RCA (recycled concrete aggregate) and PF effectively reduced the rate at which the strength of the SHPC deteriorated. The CS reduced 1.32% and 10.29% when 1.0% PF with 50%RCA and 75% RCA were utilized as substitutes, respectively [49, 50]. The standard deviations for RCA and PF CS are acceptable, indicating the low variability in the results obtained for RCA and PF [51-53], See **Fig. 8**.

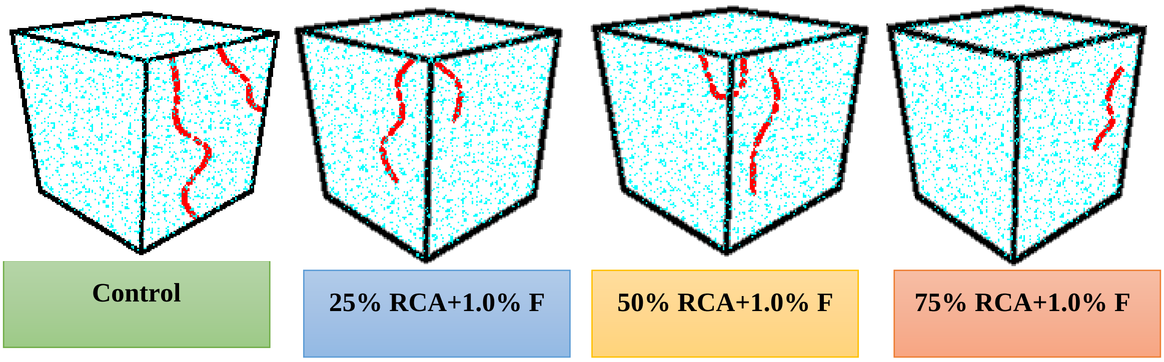
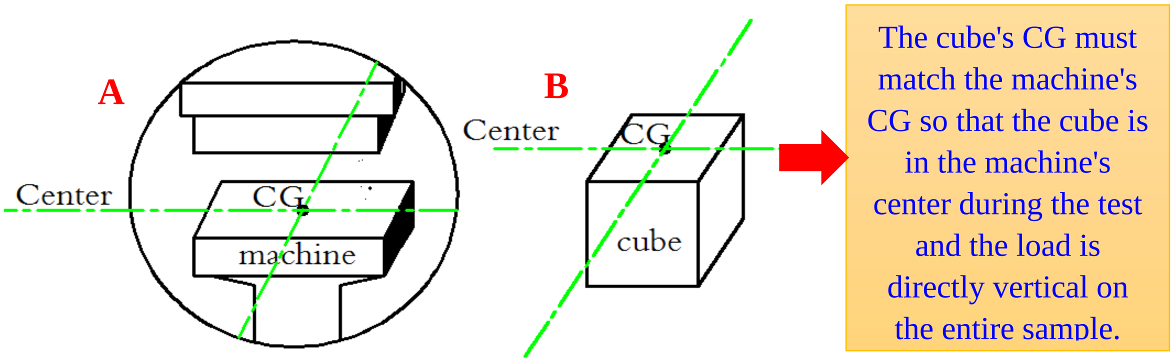
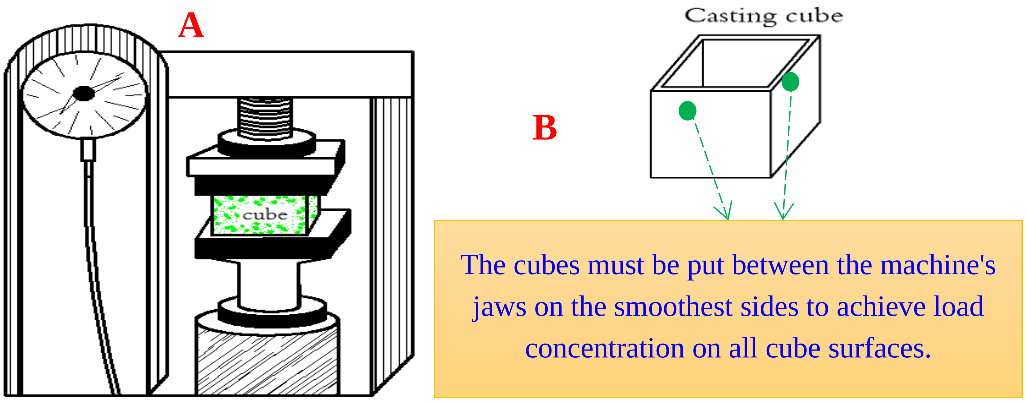


Fig. 7. Shape of failure for cubes



The cube's CG must match the machine's CG so that the cube is in the machine's center during the test and the load is directly vertical on the entire sample.

Fig. 8. A, B, CG for machine and cube



The cubes must be put between the machine's jaws on the smoothest sides to achieve load concentration on all cube surfaces.

Fig.9. A, The machine during the test, and B, casting cube (sides of cube used in machine test)

The results suggest that replacing NCA with RCA and adding PF to the concrete mixture improves the concrete's density, strength, and interfacial zone. It can be attributed to a decrease in pores or empty spaces and the enhancement of a clearly defined interfacial zone in the fabricated samples at a low replacement ratio of RCA and an addition of a low ratio of PF (25%RCA+1.0%F) [54-56]. Nevertheless, when RCA substitution rates and the addition of PF escalate, there is a proportional rise in voids, which might hurt the integrity of the concrete structure [57, 58]. **Fig. 9** shows the machine during the test, and the casting cube. Adding silica fume (SF) to the mixture prevents resistance deterioration and increases its workability. This can be observed by comparing the CS of mixtures at different replacement ratios of RCA.

From **Fig. 10 and 11**, it is vital to strike the appropriate equilibrium between utilizing these aggregates and fiber for sustainable objectives and preserving the concrete's requisite strength and structural integrity [58, 59]. Thoroughly evaluating the replacement ratios is crucial to guarantee that the intended characteristics of the concrete are attained without sacrificing its overall performance. The exceptional performance of the concrete at 28 days is in line with the performance observed in samples evaluated for the rest of the concrete properties. These findings indicate that the positive impacts of including RCA and PF persist over time and stay stable during concrete solidification [47, 60].

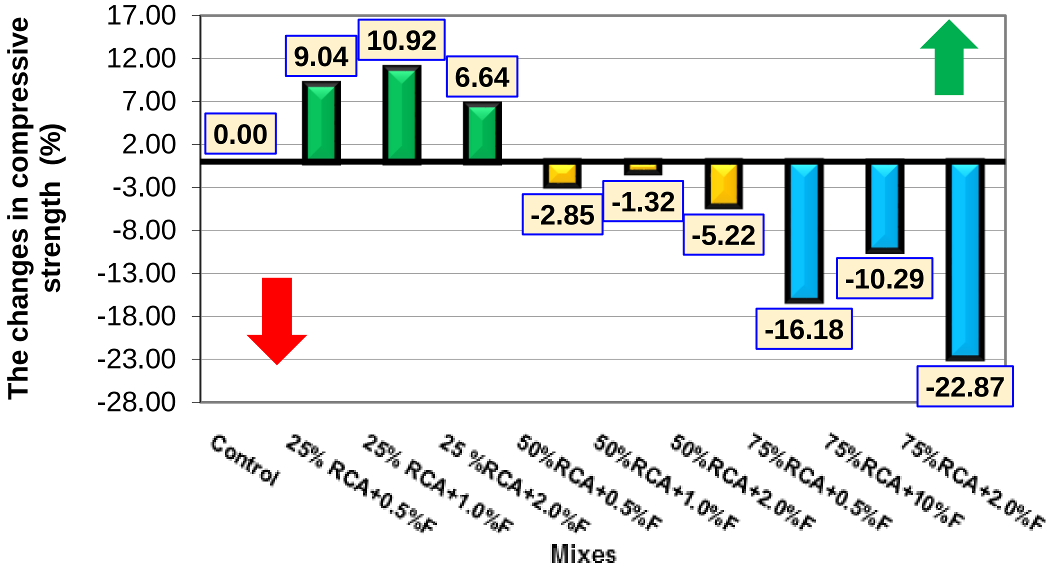
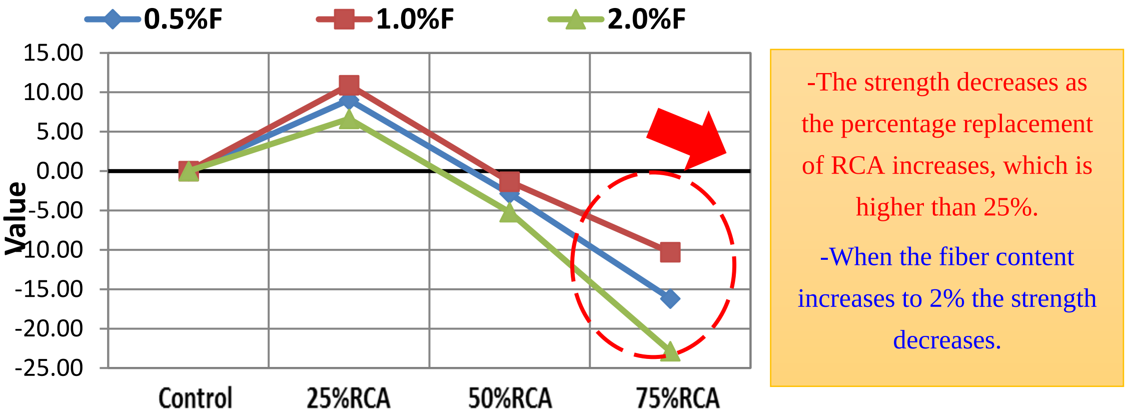


Fig. 10. The changes in CS for mixtures at 28 days (%)



-The strength decreases as the percentage replacement of RCA increases, which is higher than 25%.

-When the fiber content increases to 2% the strength decreases.

Fig. 11. The effect of the PF addition ratio and the RCA replacement ratio on CS

5.1.2 RCA and PF's relationship to Flexural Strength (FS)

Fig. 12 demonstrates that replacing recycled concrete aggregate (RCA) and adding plastic fiber (PF) in sustainable high-performance concrete (SHPC) at replacement rates of 25% for RCA and additions of 0.5% and 1% for PF augments FS after 28 days to 11.05% and 13.30%, respectively [52, 61]. When RCA is substituted with 50% RCA and 1.0% plastic fiber, the FS decreases by 2.04%. It is worth noting that even with a replacement ratio of 2% of fiber, there is still a significant decline in FS, amounting to a 6.55% reduction with RCA 50% [55, 62]. Furthermore, when replacing more than 75% of the gravel with RCA and adding 0.5%, 1%, or 2% of fiber, the FS decreases by 17.92%, 11.70%, and 24.68% respectively, compared to the control FS [52, 63].

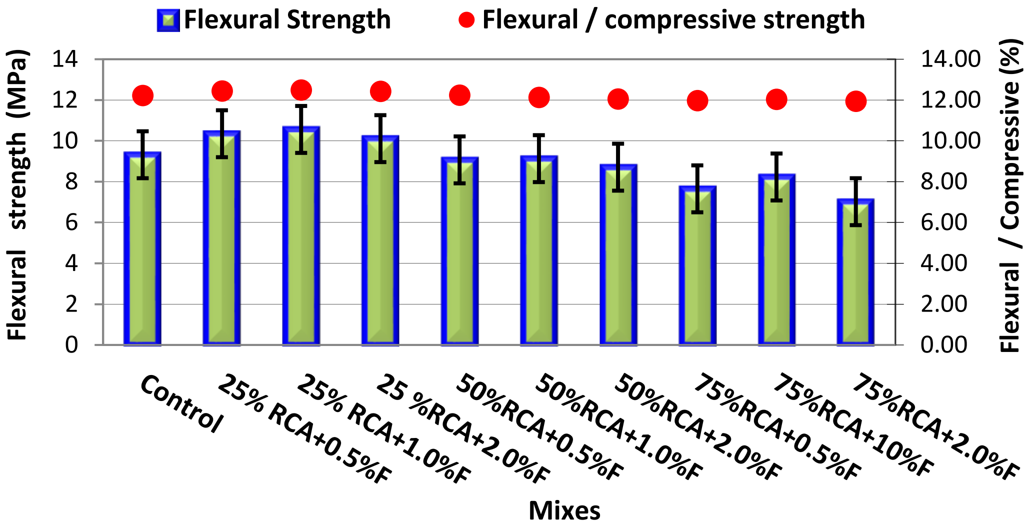


Fig. 12. FS for mixtures at 28 days

From **Fig. 13**, The results of this investigation are consistent with previous research. It show that the increase in FS percentage while substituting natural gravel aggregates with RCA and including plastic fiber aligns with earlier studies. Furthermore, the amount of high RCA and plastic fibers affects the flexural to compressive (F/C) ratio [58, 64].

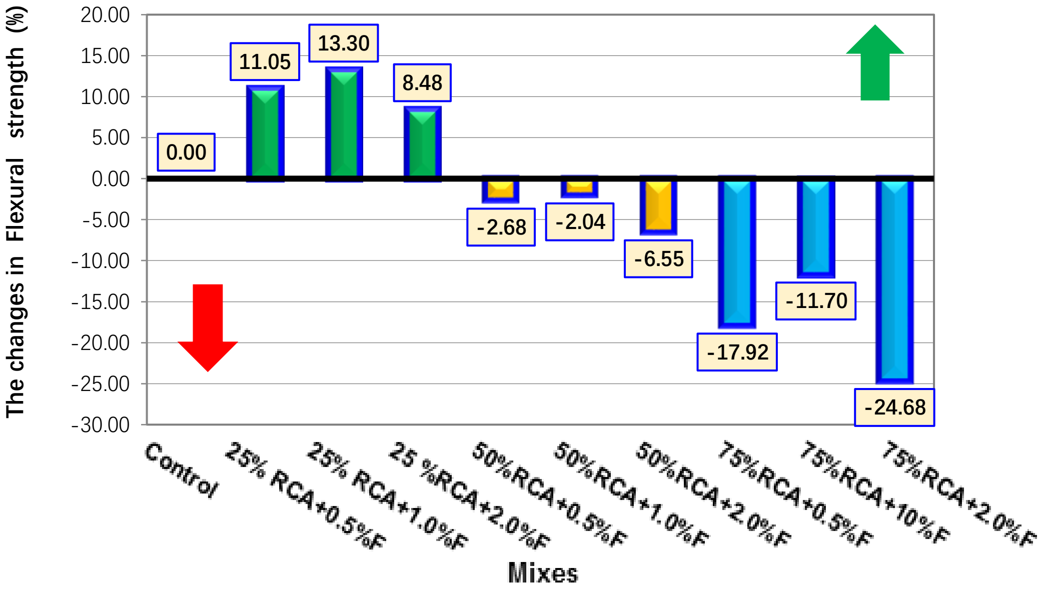


Fig. 13. The changes in FS for mixtures at 28 days (%)

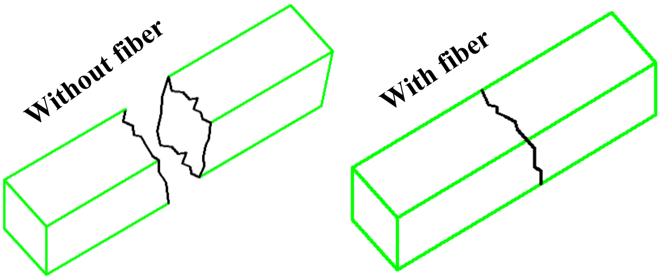


Fig. 14. Shape of failure for brims

However, the flexural test results for sustainable high-performance concrete (SHPC) showed that using RCA or PF in the concrete mixture increases the SHPC's FS, see **Figs. 13 and 14** [65, 66]. **Fig. 12** also displays the standard deviations for the FS of RCA and PF, which signify the low variability in the obtained results [67, 68].

5.1.3 RCA and PF's relationship to Splitting Strength(SS)

Fig. 15 depicts the impacts of substituting RCA and PF in sustainable high-performance concrete (SHPC) at different rates of replacement. The RCA replacement rates are 25%, 50%, and 75%, whereas the PF addition rates are 0.5%, 1%, and 2% [68, 69]. Based on the data presented in **Fig. 16**, substituting 25% of RCA and adding 1% fiber results in a notable enhancement in SS after 28 days, leading to a 13.12% increase. Nevertheless, when RCA is replaced with a mixture of 50% RCA and 1% plastic fiber, there is a marginal reduction in SS up to 1.78% [70, 71]. It should be emphasized that the SS is substantially decreased despite a replacement ratio of only 50% RCA and the addition of 2% fiber by 7.64% in the SS [72, 73].

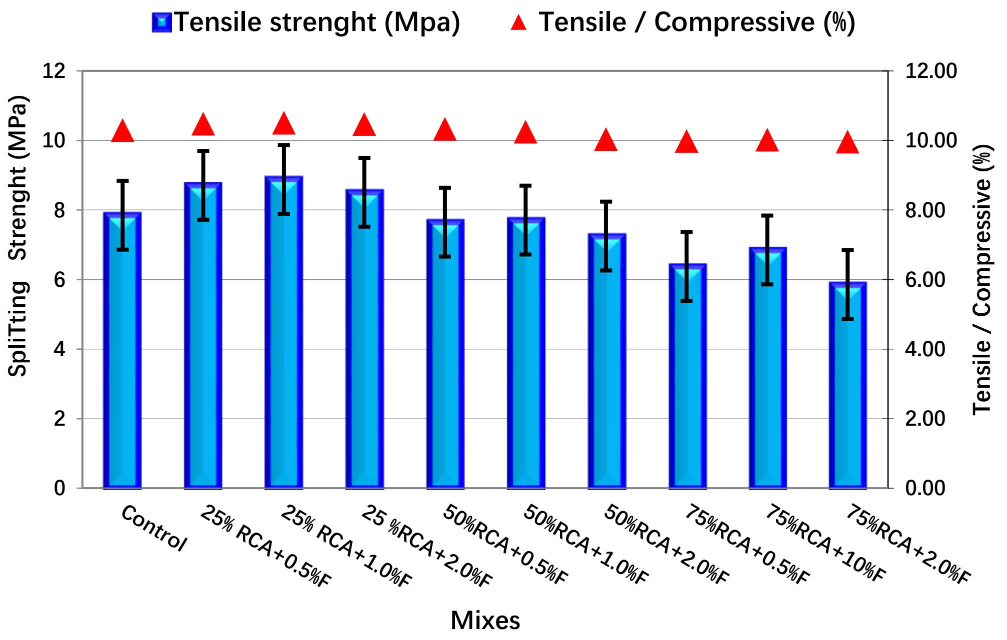


Fig. 15. SS for mixtures at 28 days

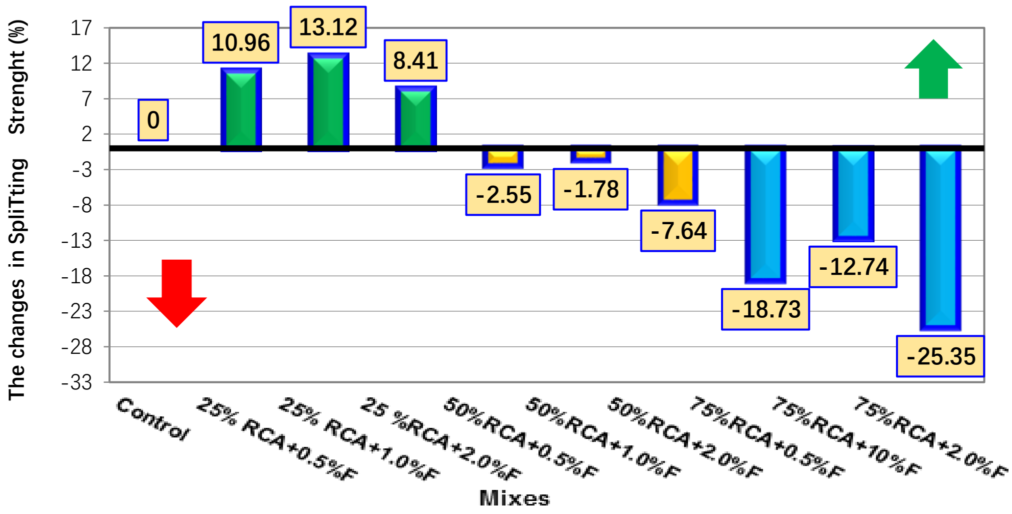
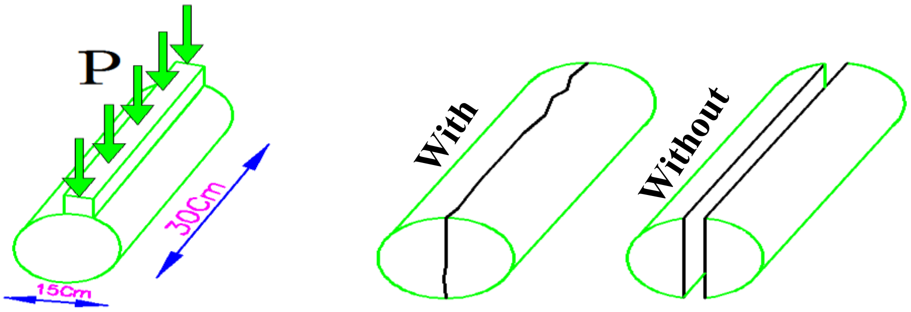


Fig. 16. The changes in SS for mixtures at 28 days (%)

Furthermore, when the proportion of recycled concrete aggregate (RCA) exceeds 75% and fiber is added at ratios of 0.5%, 1%, or 2%, the SS is significantly reduced compared to the control SS by 18.73%, 12.74%, and 25.35%, respectively [73, 74]. The quantity of recycled concrete aggregate (RCA) and the addition of fibers (PF) do impact the splitting to compressive ratio (F/C) [75, 76].

The results suggest that adding plastic fiber to SHPC can have varying impacts on SS, depending on the replacement ratios RCA [75, 76]. Substituting a moderate amount of recycled concrete aggregate (RCA) and a small proportion of fiber can enhance the ability of a material to resist splitting, but using larger amounts of RCA and greater proportions of fiber can decrease its ability to resist splitting [75, 77]. The results of this analysis agree with previous studies, suggesting that replacing natural gravel aggregates with recycled concrete aggregate (RCA) and adding plastic fiber (PF) raises the SS percentage at replacement at a low ratio of RCA and addition of a low ratio of PF; see **Fig. 17** [78-80].



A) **Shape of Loading**

B) Concrete Cylindrical Sample

Fig. 17. Shape of loading on the concrete cylinder of the splitting test

5.1.4 RCA and PF's relationship to Modules of Elasticity (ME)

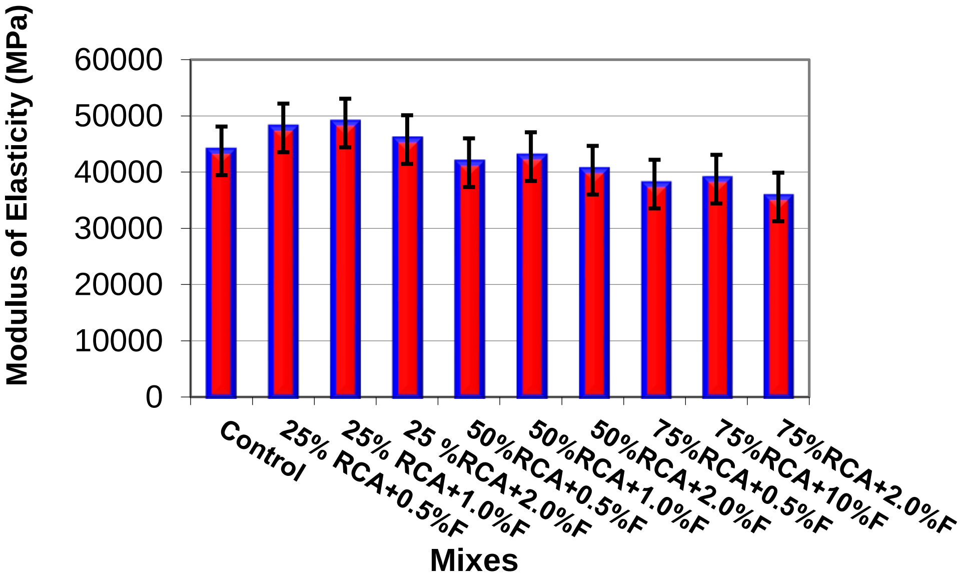


Fig. 18. ME for mixtures at 28 days

Fig. 18 displays the evaluation of the ME in SHPC that includes RCA and PF, compared to the control mix. The results show that when the replacement and addition ratio is 25% RCA+1.0%F, the ME increases by 11.31% of the control [80, 81]. However, when the replacement and addition ratio is above 50%RCA+0.5%F, the ME starts to decline. See **Figs. 18 and 20** demonstrate that the most significant decrease in the ME is observed when the mixture is replaced by 75%RCA+2.0%F, reducing roughly by 18.73% compared to the control mix [82-84]. The reduction in the ME can be ascribed to discrepancies in the coefficient of flatness and stickiness among the RCA and regular aggregates utilized in the mixture. The variations in the structure and surface characteristics of these alternative aggregates can impact the connection between the aggregates and the concrete matrix, reducing the ME [85-87].

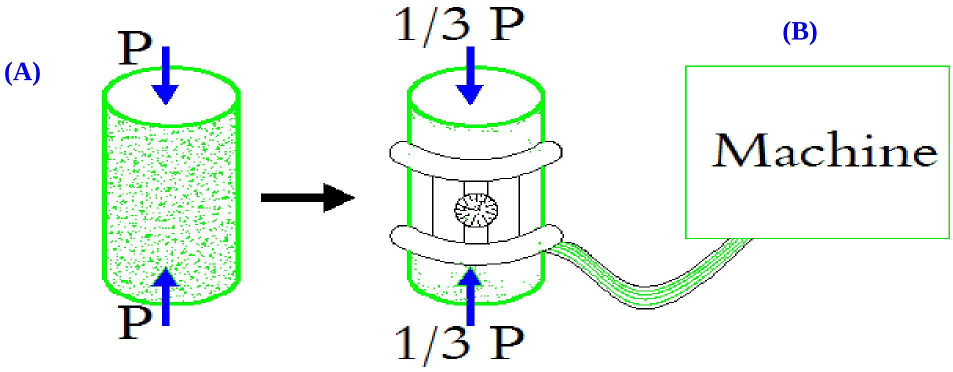


Fig. 19. A) CS of cylinder, B) and Modules of elasticity during loading

From **Fig. 20**, the low ME reported in SHPC combinations with RCA can be attributed to the structural features of these alternative aggregates [87, 88]. The limited impact on the ME is attributed to the difference in the composition of RCA and PF. Furthermore, the CS of Group I mixes, which incorporate a 25%RCA substitution of RCA, is documented to be greater than that of Group II mixes containing 50%RCA and 75%RCA. Therefore, Group I blends exhibit a higher ME [32, 88, 89].

Fig. 18 presents the standard deviations for SHPC modulus of elasticity. The standard deviations offer valuable data on the consistency of the ME values obtained for SHPC, See **Fig. 19**. Through the analysis of the standard deviations, one can assess the dependability and uniformity of the experimental findings [91, 93].

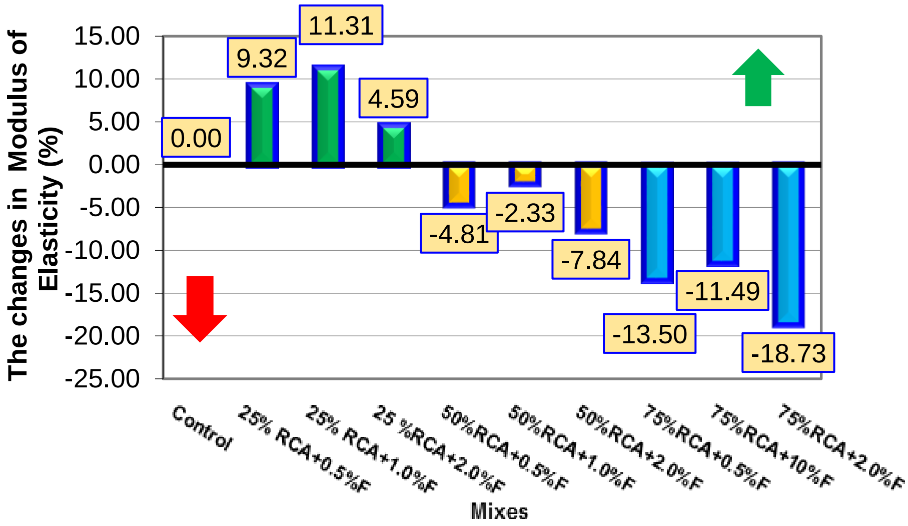


Fig. 20. The changes in ME for mixtures at 28 days (%)

6 Economic Feasibility

Recycling can create new products and can provide a lot of benefits for the economy and the environment recycling helps dispose of trash that can be harmful to everyone and to the environment. For instance, a million sea animals die every year due to plastic waste that is thrown into the sea. Recycling helps to conserve the environment, helps avoid the overuse of new natural resources to create new products, and helps lower costs for producers, because recycled materials are cheaper than natural materials [94, 95].

Economic feasibility encompasses two main elements. The first is reducing environmental pollution and the carbon footprint. It is achieved by minimizing the depletion of natural resources, such as utilizing waste materials, such as recycling plastic bottles as fibers in concrete and reusing construction waste as aggregate instead of natural aggregate. The second element involves cost reduction. A cost comparison between different mixes revealed up to 4.56% cost reductions [96.97].

From **Table 5**, Group I experienced a 1.52% cost reduction when 25% RCA was replaced compared to the control mixture. Group II experienced a 3.04% cost reduction when 50% RCA was replaced compared to the control mixture. Finally, Group III experienced a 4.56% cost reduction when 75% RCA was replaced compared to the control mixture. Thus, two main objectives were achieved in recycling. The first objective was to reduction the negative environmental impact by utilizing waste and minimizing the depletion of natural aggregates. The second objective was to reduce costs significantly compared to the control mix [98. 99].

Table 5. Cost of raw materials used per mixture ($)

No		Description	Cement	SF	NCA	NFA	Water	SP	RCA	Fiber	Total cost ($)
1		Control	38.7	39.6	10.38	0.415	1.89	79.70	0.00	0.00	170.69
2		25% RCA+0.5%F	38.7	39.6	7.785	0.415	1.89	79.70	0.00	0.00	168.09
3	G	25% RCA+1.0%F	38.7	39.6	7.785	0.415	1.89	79.70	0.00	0.00	168.09
4	I	25 %RCA+2.0%F	38.7	39.6	7.785	0.415	1.89	79.70	0.00	0.00	168.09
5		50%RCA+0.5%F	38.7	39.6	5.19	0.415	1.89	79.70	0.00	0.00	165.49
6	G	50%RCA+1.0%F	38.7	39.6	5.19	0.415	1.89	79.70	0.00	0.00	165.49
7	II	50%RCA+2.0%F	38.7	39.6	5.19	0.415	1.89	79.70	0.00	0.00	165.49
8		75%RCA+0.5%F	38.7	39.6	2.595	0.415	1.89	79.70	0.00	0.00	162.9
9	G	75%RCA+1.0%F	38.7	39.6	2.595	0.415	1.89	79.70	0.00	0.00	162.9
10	III	75%RCA+2.0%F	38.7	39.6	2.595	0.415	1.89	79.70	0.00	0.00	162.9

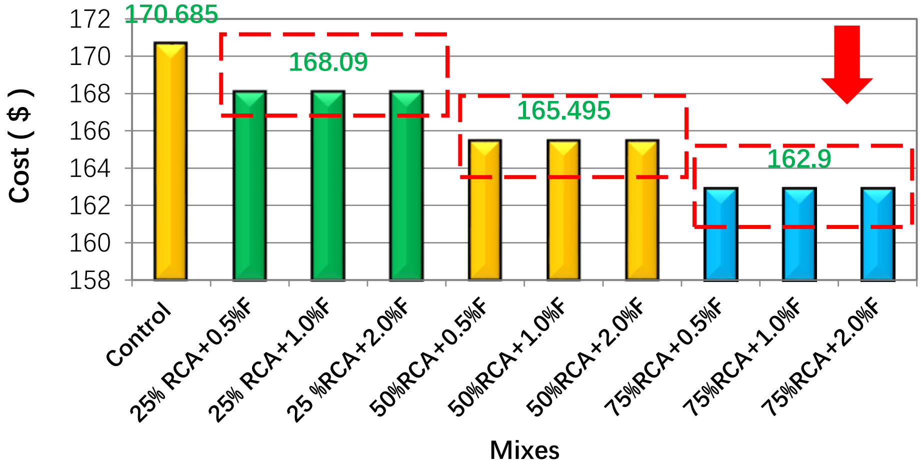


Fig.21. Cost of mixtures

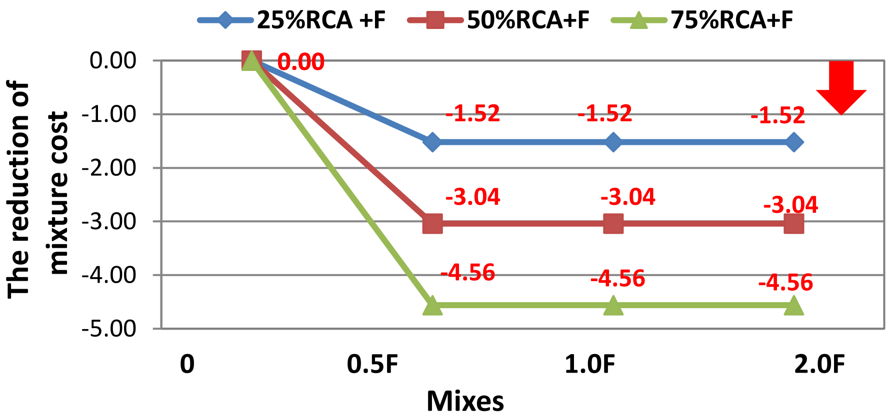


Fig.22. The reduction in mixture cost

The first group achieved increased strength and decreased cost, while the second group achieved slightly lower strength than the control mix and a greater price reduction. The first and second groups are suitable for construction applications [100-102]. However, the third group achieved a much smaller cost reduction than the first two groups, and the strength reduction was greater than the previous two, See **Figs 21, and 22**. Ultimately, the negative environmental impact was reduced, and resource depletion was prevented. The environment is an integrated system, and resource depletion must be avoided [103-105].

7 Conclusion

The key conclusions were reached after studying the properties and behavior of concrete as follows:

The combination of RCA and PF effectively reduced the rate at which the SHPC's strength deteriorated.

A low-ratio addition of plastic fiber, ranging from 0.5% to 1% by volume of concrete, with replacement 25% RCA, led to a high enhancement in CS, approximately 9.04% and 10.92%, respectively.

When the high amount of natural gravel was replaced with RCA in the SHPC, ranging from 50% to 75% replacement, the CS of the SHPC decreased by 1.32% to 22.87%.

It demonstrates that replacing RCA and adding PF in SHPC at replacement rates of 25% for RCA and additions of 0.5% and 1% for PF augments FS after 28 days to 11.05% and 13.30%, respectively.

When the proportion of RCA exceeds 75% and fiber is added at ratios of 0.5%, 1%, or 2%, the SS is significantly reduced compared to the control SS by 18.73%, 12.74%, and 25.35%, respectively.

The results show that when the replacement and addition ratio is 25% RCA+1.0%F, the ME increases by 11.31% of the control. However, when the replacement and addition ratio is above 50%RCA+0.5%F, the ME starts to decline.

The most significant decrease in the ME is observed when the mixture is replaced by 75%RCA+2.0%F, reducing roughly by 18.73% compared to the control mixture. The reduction in the ME can be ascribed to discrepancies in the coefficient of flatness and stickiness among the RCA and regular aggregates utilized in the mixture.

Two main objectives were achieved in recycling. The first objective was to reduction the negative environmental impact by utilizing waste and minimizing the depletion of natural aggregates. The second objective was to reduce costs significantly compared to the control mix.

Group I experienced a 1.52% cost reduction when 25% RCA was replaced compared to the control mixture. Group II experienced a 3.04% cost reduction when 50% RCA was replaced compared to the control mixture. Finally, Group III experienced a 4.56% cost reduction when 75% RCA was replaced compared to the control mixture.

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Interest Conflicts

The authors declare no conflicts of interest.

Data Availability Statement

The data, models, or codes used to support the findings of this study can be requested from the corresponding author.

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