

# **Effect of Synergistic Incorporation of Fiber Reinforced Polymers and Rice Husk Ash on Behavior of Recycled Concrete**

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**Abstract:** The adoption of sustainability in buildings is increasingly important as natural concrete aggregate supplies diminish. The disposal and remediation of construction and demolition (C&D) waste are costly and environmentally harmful. Recycling C&D waste offers a more sustainable option, potentially reducing natural aggregate usage and benefiting the environment. However, recycled concrete often has substandard hardening properties compared to natural concrete aggregate (NCA). The weakest bond in recycled concrete typically occurs between the recycled concrete aggregate (RCA) and other components, including low-density mortar. To address these shortcomings, enhancing recycled aggregate (RA) with appropriate treatment methods is essential. Reinforcing recycled concrete (RC) with steel fibers, polypropylene fibers, and polyester polymers has shown promise in improving its mechanical performance. These materials contribute to higher tensile strength, improved stiffness, and better tensile strain capacity, all of which are crucial for recycled concrete's durability. An experimental study was conducted to evaluate the combined effects of rice husk ash (RHA), steel fibers, polypropylene fibers, and polyester polymers on the hardening properties of RC. The study focused on key mechanical properties, including compressive strength (CS), splitting tensile strength (STS), and flexural strength (FS). A slump test assessed the workability of fresh concrete, while water absorption (WA) tests examined the permeability resistance of RC compared to NCA. Using the ACI Method of Mix Design 211-1-91, the concrete mix included 10%, 12.5%, and 15% RHA as cement Replacement, along with 0.75%, 1%, and 1.25% steel fibers. Additionally, 0.80%, 1%, and 1.20% polypropylene fibers with polyester polymer were used as supplementary materials

with 100% RCA. The study found that replacing 10% cement with RHA and adding 0.75% steel fibers or 0.80% polypropylene fibers with polyester polymer enhanced the hardened properties of RCA. However, exceeding these replacement levels led to reduced strength and durability, highlighting the need for optimized material proportions to balance sustainability and structural performance.

**Keywords:** Construction & Demolition Waste, Recycled Concrete, Polypropylene Fiber, Rice Husk Ash

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## 1. Introduction

### 1.1 General

Construction of new buildings and the maintenance or dismantling of existing ones generate Construction & Demolition Waste (C&DW), a byproduct that often requires environmentally sensitive and costly disposal methods. Utilizing C&DW to produce recycled aggregates is a logical solution for developing more sustainable concrete production methods in Lima [1]. Despite the environmental and economic benefits, recycled concrete (RC) is generally considered to have poorer consolidation properties compared to natural concrete (NC) aggregates Khoso, Ansari, & Bangwar, [2]. To mitigate these deficiencies, appropriate treatment strategies are necessary, such as reinforcing or removing attached mortar in RC Ali, [3].

Incorporating fibers into RC enhances its tensile and stiffness properties, improving both the hardened and durability characteristics of the material. Fibers help control degradation during acid attacks and freeze-thaw cycles, and they also increase flexural strength Altun & Aktaş, [4] fatigue resistance, and splitting tensile strength Abbasi, Qureshi, [5]. Various fibers, including basalt fiber (BF), glass fiber (GF), polypropylene fiber (PF), nylon fiber (NF), asbestos fiber (AF), carbon fiber (CF), and steel fiber (SF) Chen, He, Yang, Chen, & Guo, [6] are used in concrete reinforcement. Steel fiber is particularly popular due to its availability, affordability, and ability to enhance concrete's mechanical performance and resistance to corrosive environments Xiong, Lan, Li, Li, & Long, [7] Carbon fiber, composed of amorphous and graphitic carbon, provides high tensile strength, while glass fiber improves durability, fatigue lifespan, and resistance to corrosive environments. Polypropylene fibers, made from polyolefin chemicals, do not absorb water and resist most chemicals. They also bridge cracks, limiting their length, width, and number Abbasi, Raza, Hussain, & Iqbal, [8]. PF and CF improve acid attack resistance more effectively than SF and

GF. Additionally, Rice Husk Ash (RHA) can partially replace Portland cement in concrete production, creating a microstructure that resists degradation agents like chloride infiltration and sulfate attacks Tayeh, Al Saffar, Aadi, & Almeshal, [9]. This results in durable concrete with good shrinkage properties Fapohunda, Akinbile, & Shittu, [10], Rumman, Bari, Manzur, Kamal, & Noor, [11].

## 2. Materials

This portion explains the materials used in the preparation of mixes. Figure 1. shows the materials used. The primary binding material was Portland cement Maple leaf Pakistan which According to ASTM C150 ASTM, [12] cement, is classed as Type I. Sand (Sakhi Sarwar sand, Pakistan) that is the most commonly used fine aggregate. It contains a silt level of less than 4%. It has a minimal level of small stones and mud-balls. The size of particles of this sand varies from 1/16mm to 2mm. Crushed stone from the Sakhi Sarwar from DG Khan is used to make NA. Its stone is usually identified by its extreme red color. The maximum aggregate size that is used in this work is 16mm. Concrete Crushed and graded specimens have a compressive strength of 26 MPa in cubic form were used to produce recycled aggregates (RA). RA has maximum particle sizes of 16 mm. The recycled concrete aggregate is made from Sakhi Sarwar aggregates. Rice husks are the material that remains after the rice grains have been separated. The ash is collected from rice husks (Lodhran, Punjab, Pakistan) and burned in the open air until it turns into ash. This raw rice husk ash is passed through a no. 30 to remove undesirable materials and used as a partial replacement for cement in proportions of 10%, 12.5%, and 15% respectively. The steel fibers utilized in this project came from binding wire used in RCC projects to hold steel reinforcement in place. The wire was spliced into little fibers or fragments. Steel fiber is used 0.75%, 1%, and 1.25% as additional material. Polypropylene fiber, also called polypropylene or PP. It is a synthetic fiber made from propylene and is used in various applications, such as construction. Polyester polymers are in the form of monofilaments and belong to the group of thermoplastic polymers. They are temperature-sensitive and hydrophobic. They are produced as by-products of the textile industry and are not biodegradable.



**Figure 1: Materials for mix design (Sand, NCA, RCA, RHA, S.F, PPF, PP)**

### ***2.1 Mix Portioning and mixing of concrete.***

ACI method of Mix Design 211-1-91 ACI, [13] was followed to proportionate the ingredients of the concrete mix as 10 %, 12.5% & 15% RHA (Rice Husk Ash) was used as cement replacement with 0.75%, 1% & 1.25 % SF (Steel Fiber) and 0.80%, 1.0% and 1.20 % PPF/PE as shown in Table 1. as additional material. Contains all of the information about the mix's composition. The concrete mixtures were mixed in a mixer with a capacity of 0.15 m<sup>3</sup> and adjustable speed (rpm). First, the aggregates were mixed with half this amount of water for 4 minutes at 40 rpm. Then the binder, steel fibers, rice husk ash, and half of the water were added to the mixer and mixed at 60 rpm for 6 minutes. All mixtures were then subjected to a slump test to check the desired workability. After checking the desired workability; the mixer was set to a lower speed of 20 rpm until the sample was ready. The Samples Preparation for Strength and Permeability Tests are shown in Figure 2.

To measure the workability of fresh concrete, a slump test was carried out. The size of the descent device was 100 mm x 200 mm x 300 mm. The effects of rice husk ash and steel fibers on increasing the overall strength of NC and RC were investigated using three major mechanical properties: CS, STS, and FS. To evaluate the CS-Cube samples Figure 3. with dimensions 100×100×100 mm and STS, cylindrical samples Figure 4. with a diameter of 150 mm and a length of 300 mm were used. ASTM (C109) was used to calculate the CS. STS was measured according to ASTM C496. A test was performed on a 100 mm (width), 100 mm (horizontal), and 500 mm (long) cube in two-point orientation according to ASTM. C1609 ASTM, [14] to examine redirection-based load information. The maximum load during the bending test was used to determine FS Figure 5. In this study, the normal

value of three repeated examples was used to determine the strength. WA tests were conducted to better understand the interactions of rice husk ash and steel fibers on RC and NC permeability resistance. The cubic concrete samples were subjected to the WA test with dimensions of 100 × 100 × 100 mm according to ASTM standards.

**Table 1: ACI Mix Design Method 211-1-91 for Concrete Mixes**

ACI Mix Design Method 211-1-91 for Concrete Mixes (kg/m <sup>3</sup> )								
Mix	Cement	Sand	Coarse Aggregate	Recycled Aggregate	Water	Rice Husk Ash	Steel Fiber	Polypropylene Fiber
Mix-01	386	820	945		193	-	-	-
Mix-02	347.4	820		945	193	38.6	2.895	-
Mix-03	337.75	820		945	193	48.25	3.86	-
Mix-04	331.5	820		945	193	57.9	4.825	-
Mix-05	347.4	820		945	193	38.6	-	3.088
Mix-06	337.75	820		945	193	48.25	-	3.86
Mix-07	331.5	820		945	193	57.9	-	4.632



**Figure 2: Sample preparation for Strength and Permeability**



**Figure 3: Cube 100×100×100mm for Compressive Strength**



**Figure 4: Cylinder 150×300 mm for S.T.S**



**Figure 5: Prism 100×100×500 mm for F.S**

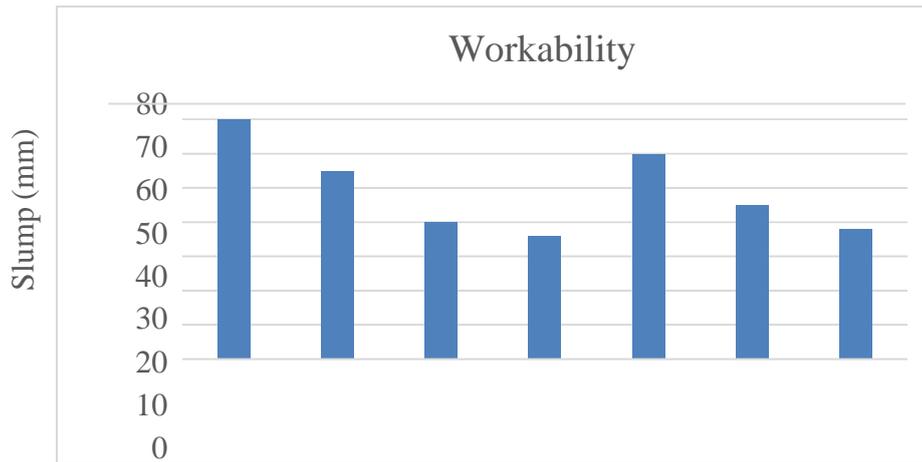
### 3. Results and Discussion

#### 3.1 Slump Test

A slump test was carried out to assess the suitability of the new concrete. Slump tests ASTM, [15] were carried out on continuous smooth concrete with 10%, 12.5%, and 15% RHA as a concrete replacement and 0.75%, 1%, and 1.25% steel fibers as additional material. The results of the slump test using (Steel Fiber) are shown in Table 2. and Figure 6. It is clear from the results that the workability of concrete decreases as we use Recycled concrete aggregates and increase the replacement of RHA and Steel fiber. This reduction is due to the greater porosity of RCA and the fineness of RHA compared to cement. The porous aggregates trap water and grinding the RHA powder increases the surface area. Therefore, usable water has been absorbed by the aggregate and covers the surface of the RHA, resulting in a lower slump. The results of the slump test using (Polypropylene Fiber and Polyester polymer) are shown in Table 2. and Figure 6. It is observed that concrete without RHA or PPF and PEP showed good sag. However, replacing RHA and adding PPF and PEP reduced the sag of the concrete mix, which could be due to water absorption by RHA. Furthermore, mixes to which PPF and PE were added showed reduced slump, which could be due to the increase in fiber number with increasing percentage, resulting in difficulty in moving the other concrete constituent and thus reduced workability.

**Table 2: Slump values of concrete for different mixes using Steel Fiber**

SLUMP OF CONCRETE							
Mix Proportions							
Mix	NA (%)	RA (%)	RHA (%)	S.F (%)	W/C Ratio	PPE (%)	Slump (mm)
Mix-01	100	0	0	0	0.5	-	70
Mix-02	0	100	10	0.75	0.5	-	55
Mix-03	0	100	12.5	1	0.5	-	40
Mix-04	0	100	15	1.25	0.5	-	36
Mix-05	0	100	10	-	0.5	0.8	60
Mix-06	0	100	12.5	-	0.5	1	45
Mix-07	0	100	15	-	0.5	1.2	38



**Figure 6: Variations of Slump of NCA & RCA with different mix proportions**

### 3.2 Compressive Strength (CS)

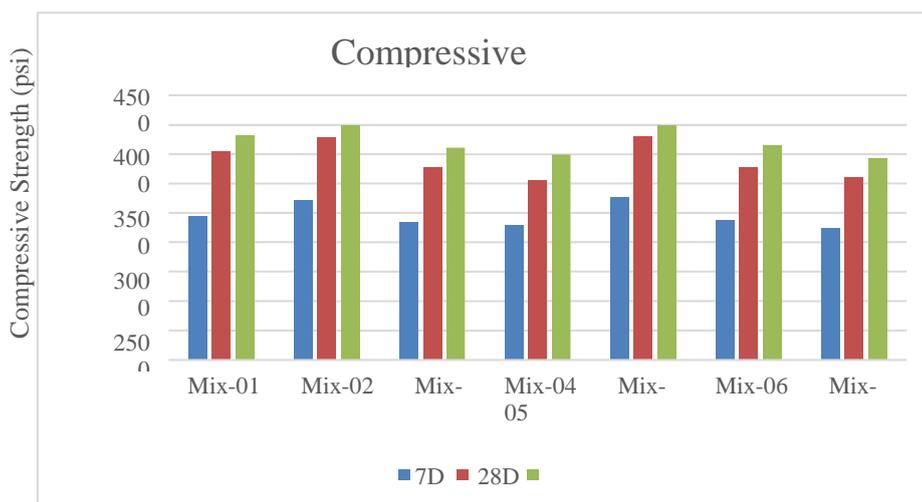
Compressive strength was performed on a cube sample of size 100\*100\*100mm. In compressive strength, the behavior of NA cube samples was compared with RCA with different replacement levels of RHA and Steel Fibers. The results of the CS using (Steel Fiber) are shown in Table 3. and Figure 7. The CS of RC was increased by using 10% rice husk ash and 0.75 percent steel fiber by 10.92 times that of NA, according to the data. The inclusion of RHA raised the CS of RC considerably. This is because RC and NC have distinct pozzolanic potentials due to the presence of CH in the adhering mortar in RC. As a result, RC has a higher potential for pozzolancity than NC. The pozzolanic collaboration between RHA and CH contributed to a further net increase in RC strength by strengthening the ITZ between old and new mortar with a further addition of RHA of 10% each, resulting in a reduction in compressive strength of 4.68 and 6.25 led times compared to normal concrete. The presence of several decreased densities of recycled concrete aggregates and the interfacial transition zones (ITZs) in RC than normal coarse aggregate can also be blamed for RC's lower strength than NC. Under compressive loads, the existence of many ITZs in RC Both aggregates and the binder matrix may experience premature bonding breakdown. Furthermore, when subjected to a compressive load RC has minimal stiffness & maximum lateral deformation than NC.

Similarly, the results of the CS using (Polypropylene Fiber and Polyester polymer) are shown in Table 3. and Figure 7. The compressive strength of concrete with RHA, PPF, and PE is shown in the table above. From the table, it can be seen that after replacing 10% RHA and

Adding 0.80% PPF and PE, the compressive strength increases for 7, 28, and 56 days, respectively. This is due to the ability of PPF and PE to strengthen the bond and act as a reinforcing bond that can limit crack propagation. However, further increasing the RHA, PPF, and PE contents resulted in a substantial loss of strength as compared to the control sample. This reduction could be due to the greater fiber content and lead to compaction of the fibers, causing a spherical effect and poor adhesion to the concrete.

**Table 3: Compressive Strength at 7, 28 & 56-Day Steel Fibers and Propylene Fiber**

COMPRESSIVE STRENGTH OF CONCRETE (PSI)									
Mix Proportions									
Mix	NA (%)	RA (%)	RHA (%)	S.F (%)	W/C Ratio	POPE (%)	7D	28D	56D
Mix-01	100	0	0	0	0.5	-	2450.5	3544	3817
Mix-02	0	100	10	0.75	0.5	-	2717	3782	3998
Mix-03	0	100	12.5	1	0.5	-	2335	3278	3605
Mix-04	0	100	15	1.25	0.5	-	2297	3059	3492
Mix-05	0	100	10	-	0.5	0.8	2765	3795	3989
Mix-06	0	100	12.5	-	0.5	1	2375	3285	3650
Mix-07	0	100	15	-	0.5	1.2	2245	3105	3429



**Figure 7: C.S at 7, 28 & 56 Day using Steel Fibers and Polypropylene Fiber**

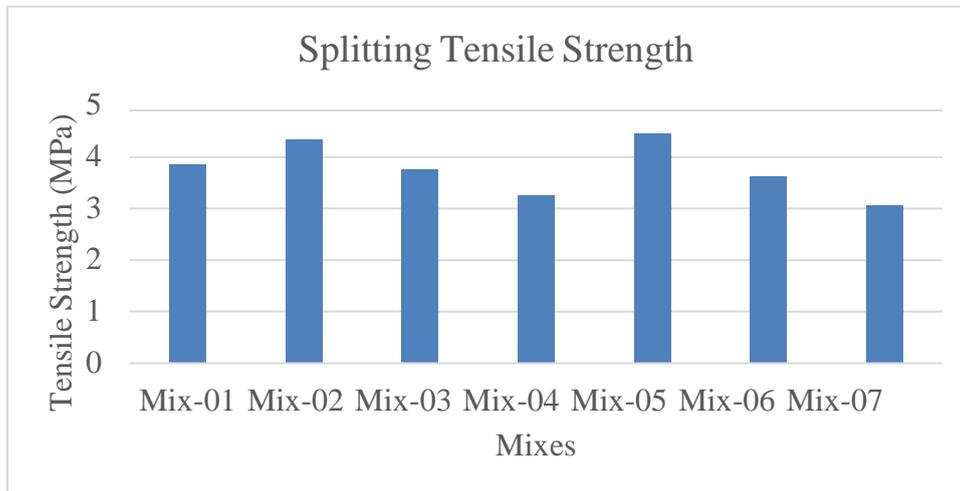
### *3.3 Splitting Tensile Strength*

The results of the STS ASTM, [16] using (Steel Fiber) are shown in Table 4. and Figure 8. which shows the change in STS of NC and RC with the addition of RHA and steel fibers. The results show that steel fiber and RHA have a positive synergistic effect on the STS of the RC. The addition of RHA up to 10% and steel fiber by 0.75% as additional material improves the STS of recycled concrete aggregates by 8.9%. Specifically, RHA enhancing the binder matrix as a result of potential pozzolanic activity between RHA molecules & CH aided in the development of the tensile capacity of RC. Because of its high CH content, RC has a higher potential for STS improvement with RHA and Steel fiber than NC. The invasion of high tensile strength fiber material overcomes the concrete matrix in tension has a deficit or brittleness. The combination of fiber and silica fume improved RC's tensile strength even more. The tensile strength of RC was improved by 8.9 percent, when 10 percent RHA, and 0.75 percent fiber were combined incorporating steel fiber It not only provides mineral additive and reinforcing benefits, but it also aids in the improvement of fiber efficiency to improve concrete strength features. Moreover, there was no substantial improvement when we increased the RHA amount by 12.5 and 15% and Steel by 1% and 1.25% respectively.

The results of the STS using (Polypropylene Fiber and Polyester polymer) are shown in Table 4. and Figure 8. The splitting tensile strength (STS) of concrete using RHA, PPF, and PE is shown in the table above. It was observed that the addition of PPF and PE up to about 0.80% in concrete containing 10% RHA gave good results as it increased the splitting tensile strength of the recycled concrete. This increase is due to the fiber-bridging mechanism that transforms brittle concrete into ductile concrete. However, as the fiber and polymer content gradually increase, it becomes unable to resist crack formation, propagation, and expansion. In addition, increasing RHA content somewhat decreased the splitting tensile strength. The loss in splitting tensile strength may be due to the decrease in available  $\text{Ca}(\text{OH})_2$ .  $\text{Ca}(\text{OH})_2$  resists the pozzolan reaction and eventually the formation of C-S-H gels that contribute to the strength enhancement.

**Table 4: S.T.S of different mix proportions of the SF and PPE**

SPLITTING TENSILE STRENGTH OF CONCRETE (MPa)							
Mix Proportions							
Mix	NA (%)	RA (%)	RHA (%)	S.F (%)	W/C Ratio	PPE (%)	28D
Mix-01	100	0	0	0	0.5	-	3.86
Mix-02	0	100	10	0.75	0.5	-	4.34
Mix-03	0	100	12.5	1	0.5	-	3.76
Mix-04	0	100	15	1.25	0.5	-	3.27
Mix-05	0	100	10	-	0.5	0.8	4.45
Mix-06	0	100	12.5	-	0.5	1	3.63
Mix-07	0	100	15	-	0.5	1.2	3.06



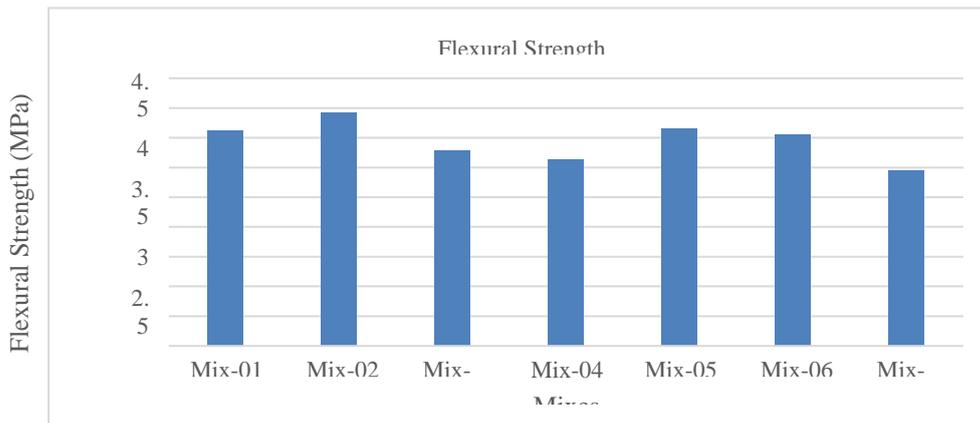
**Figure 8: (S.T.S) Split Tensile Strength of NCA & RCA in 28 Days using Steel Fiber**

### 3.4 Flexural Strength (FS)

Table 5. and Figure 9. show the flexural strength ASTM, [17] with different mix proportions using steel fiber. It depicts the change in FS of RC as a function of RHA content & steel fiber. The results show that FS of RC was improved by more than 9% when 10% RHA and 0.75% were combined. Because the binder matrix was strengthened, the binder had a better grip on the fibers which aided in the productive pliable pressure transmission from substantial lattice to high elasticity fiber. As a result; RHA addition had a significant impact on FS. Furthermore, there was no substantial improvement when we increased the RHA amount by 12.5 and 15% and Steel by 1% and 1.25% respectively.

**Table 5: Flexural Strength with different mix proportions of Steel Fiber**

FLEXURAL STRENGTH OF CONCRETE (MPa)								
Mix Proportions								
Mix	NA (%)	RA (%)	RHA (%)	S.F (%)	W/C Ratio	PPE (%)	Load (kN)	28D
Mix-01	100	0	0	0	0.5	-	2450.5	3.62
Mix-02	0	100	10	0.75	0.5	-	2717	3.92
Mix-03	0	100	12.5	1	0.5	-	2335	3.28
Mix-04	0	100	15	1.25	0.5	-	2297	3.13
Mix-05	0	100	10	-	0.5	0.8	2765	3.66
Mix-06	0	100	12.5	-	0.5	1	2375	3.55
Mix-07	0	100	15	-	0.5	1.2	2245	2.95



**Figure 9: Flexural Strength for NCA & RCA**

#### 4. Conclusions

Experiments were conducted to study the synergistic effects of RHA and steel fibers, polypropylene fibers, and polyester polymers on the hardened properties of NCA & RCA. Below are the main results of this study:

1. The incorporation of RHA & Steel fiber at the same time has synergistic effects for RC strength and porousness obstruction is fantastic. RHA's bond with the concrete aggregates is reinforced by the expansion of Steel fiber. Furthermore, it can be observed that Concrete without RHA and PPF & PE exhibited good slump, however, the replacement of RHA and addition of PPF & PE reduced the slump of the concrete mix.
2. Distinctive incorporation of 10% RHA & 0.75 % steel fiber advanced the CS of RC by 10%, and the cumulative impact of 10% RHA & 0.75 % Steel fiber improved the

CS by

10.93 %. The CS of RC with 10 percent RHA and 0.75 percent Steel fiber was higher than that of the reference "NC." It can be observed that with the replacement of RHA up to 10% and the addition of 0.80 % of both PPF & PE compressive strength increases for all 7,28 and 56 days respectively. This is due to the ability of PPF and PE to act as reinforcing bonds that improve bonding and prevent further propagation of cracks. However, further increasing the content of RHA, PPF, and PE resulted in a substantial reduction in strengths as compared to the control sample. This decrease is probably due to an increase in fiber content, which can lead to fiber accumulation, leading to balling effects, and poor bonding with concrete.

3. The synergistic effect using RHA & Steel Fiber was noticeable in the STS and FS results. The addition of 10% RHA and 0.75 percent Steel fiber increased the STS of RC by 9%, but the combined effect of RHA & steel addition increased the STS of RC by 10% percent. The results of FS testing followed a similar pattern. It was observed that the addition of PPF & PE to about 0.80 % to concrete incorporating 10% RHA exhibited positive results as it increases the splitting tensile strength of recycled concrete. This increase can be attributed to the bridging mechanism of the fibers which convert the brittle concrete into ductile. However, with the gradual increase in fiber and polymer content, they cannot resist the formation, propagation, and widening of cracks. Furthermore increase in RHA content slightly decreased the splitting tensile strength. The loss in splitting tensile strength can be attributed to a reduction in available Ca (OH)<sub>2</sub> which resists the pozzolanic reaction and ultimately the development of C-S-H gels which contribute to the strength gain.
4. Taking into account the impact of supplemental material (RHA or Steel fiber), When compared to plain NC, the inclusion of 0.75 percent steel flexural strength of RC is expanded by more than 8-9 times when the fiber is added.

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