Reuse of improved recycled concrete aggregates (RCA) for sustainable and environmental-friendly construction materials.

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Reuse of improved recycled concrete aggregates (RCA) for sustainable and environmental-friendly construction materials.

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Abstract. Recycled aggregates have an essential role in constructing construction activities today to save natural aggregates because of industrial development. The research aims to assess the suitability of recycled aggregates for the construction of new roads, which will help achieve road construction efficiency and help prevent environmental deterioration in the extraction and reducing pollution. In contrast with natural aggregates, recycled aggregates are of lower quality, mainly due to the cement mortar's brittle nature attached to them. The point of the study is to increase the performance of RCAs in an environmentally friendly managing RCAs. In this process, RCAs are first soaked in acetic acid solution, in which acetic acid reacts with cement attached to the surface of the RCA. This reaction weakens the attached mortar and allows separating from the RCAs by using mechanical friction later. Treated RCAs have lower water absorption and more insufficient cement mortar adhesion. These RCAs used as aggregates in new the concrete increased the compressive strength, the tensile strength, and the concrete's flexural strength by 26%, 11%, and 26% at 28 days, respectively. It is clean, safe, efficient, and a new method to be applied, so no harmful products are used, and no dangerous substances are incorporated into the RCAs that are being treated. The waste treatment solution was used as a supplementary admixture construction, increasing the concrete's strength, and decreasing its environmental effects.

Keywords: Recycled Concrete Aggregate (RCA), Strength, Construction Materials, RCA treatment, Enhancement treatment, Mechanical properties.

1. Introduction

Globally, the concrete industry consumes massive quantities of natural resources, which can be turning into insufficient to meet the growing demands. Simultaneously, the previous infrastructures' efficiency is declining, and these structures are being demolished for new construction. The facilities are demolished for various purposes, i.e., Waste recycling is critical from multiple perspectives[1]. Reconstruction for better economic growth, natural hazards, and destruction from war, the rate of destruction increases each day[2][3]. The cost of disposal increases due to the anti-availability of suitable surrounding areas[2]. Another landfill alternative involves their silting, disposal costs, and public disapproval in addition to land shortages[2]. Recycled Aggregate's usage in concrete has been engaged because of society's knowledge of natural resources conservation. So, it is important to find a way to Mitigate this waste by reusing recycled concrete due to construction losses in many countries worldwide. Recycled aggregates (RA) may be a perfect substitute for natural aggregates for producing durable concrete of different forms[3]. The reused recycled concrete aggregate has been suggested to be used as a coarse aggregate in construction mixes to allow reasonable use of the waste materials[4][5][6]. The vast volumes of collapsed concrete are usable at various building sites, which pose a challenging recycling topic in urban environments. This can be placed for the concrete mixture quickly as addition and then applied. Research and development have indeed been performed worldwide to demonstrate its plausibility, effectiveness, financial viability, and cost-suitability[7]. Simultaneously removing, replacing, and reconstructing concrete buildings, concrete recycling, and reuse are becoming prevalent ways of utilizing the debris. Recycling and reuse have many benefits and numerous benefits[7]. This better environmental consciousness era has made it a more preferred option, more conservation rules, and construction costs. Study research is underway to decide if it can be used for heavy building operations, but detailed findings are still unclear[8]. Crushed concrete, recycled aggregates are commonly used in low building schemes such as solid pavements, etc. are currently utilized for low construction[9]. In all countries' overall economic and social development, the road transport system plays a key role[10]. Cement concrete pavement or solid pavement may provide a reliable and more effective traffic system with longer service life, less need for rehabilitation and replacement, and an improved surface for pavement assessment[10]. Certain benefits of solid or concrete pavement are 15-20 percent, even less fuel usage than asphalt road, saving 10 percent electrical energy in lane avenue illumination, saving 40 percent total stone pavement[4]. The lifestyle time expense of rigid or concrete paving is 10-15 percent lower than bituminous paving over a two-decade span[11]. Nevertheless, concrete pavement is typically less preferred in developed Asian countries because of its high initial building cost, which is around 15 percent more than bituminous paving. Since concrete is a porous substance prone to friction and tensile stress, it can be the source of unwanted micro cracks[12]. Many tiny cracks often exist on the pavement's bottom and top surface due to drying shrinkage and the early beginning of paving to traffic[10]. Over time, micro-cracks turn into the macro crack due to heating, temperature, and weathering effects, and at last, fracture[4]. Concrete exhibits specific and truly curious properties, and its recovery frequently slips between traditional interpretations and recycled and reuse concepts. Recycled broken concrete aggregate is never "reusable" in the context that it is reused in its initial component. Instead, concrete is separated and broken down into smaller aggregates for utilizing them in a new project[13]. The phrase "recycled and demolished concrete aggregate" This evaluation applies particularly to concrete removed from and reclaimed and used in a consumer product from waste concrete sources. For several countries, concrete mining is a well-stabilized sector where the most concrete can be broken reused as aggregates[14]. The current recycling technology is readily available via mechanical crushing and is inexpensive[15]. This can be achieved in both developing and emerging nations. Further work and development can be applied to the list of applications for recycled crushed concrete aggregates[16]. Nevertheless, even with the current technologies, substantial improvements in recovery levels may be accomplished in individual nations, with greater public tolerance of recycled crushed concrete aggregates and elimination of myths or misunderstanding regarding their use possibilities[17][18]19].

2. RCA (Recycled Concrete Aggregate)

2.1. The operation of recycling

1) Demolishing of old roads and buildings.
    - The removed concrete is often considered worthless.
    - Disposed of as demolition waste.
2) Collecting and quality-filtration.
    - The removed concrete is often considered worthless.
    - Disposed of as demolition waste.
3) Creating new resources.
    - Doing the proper treatment for enhancing the properties of concrete.

- Construct new infrastructures.

2.2. The need of recycling

Used RCA in Germany and other developing nations after the Second World War, when there was massive destruction of houses and highways and a tremendous need to help eliminate hazardous material and reconstruct the countries[9].

2.3. The impact of construction

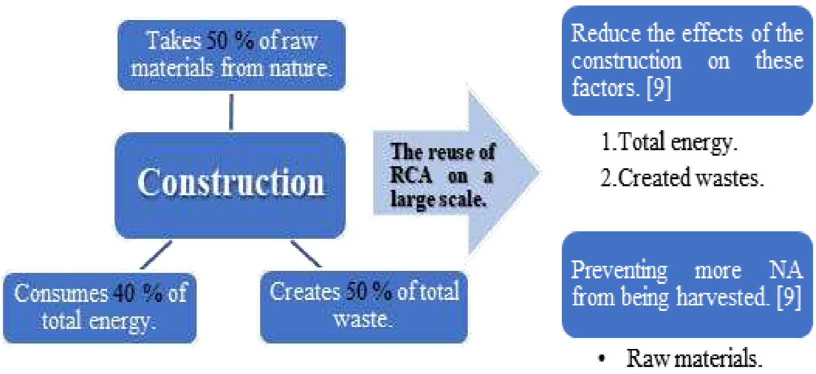


Fig. 1. The impact of construction.

- Natural aggregate has already hit unprecedented levels in countries India and other countries worldwide, leading to strong demand for building activities[9].
- This is one of the advanced topics in Western countries, but only a few Indian scholars have begun researching this subject[9].

2.4. Treatment Method for Enhancement of RCA Properties

Acid treatment. The removal of the attaching cement mortar from the RCA surface is a very complicated process. The hydration process is a long-term chemical reaction between the cement constituents with water, thereby imparting the concrete's durable and robust structure. However, the attached mortar is removed by various acids (high to medium concentration). In this acid solution, the cement hydration compounds are dissolved[20]. Several studies have demonstrated different acid solutions applications in the removal of the attached RCA mortar[5][21][1]. In this group, the most widely used acids were sulfuric acid (H2SO4), hydrochloride acid (HCl), phosphoric acid (H3PO4), and acetic acid (CH3COOH)[20][21]. Cementitious products are readily corroded due to cement's alkaline aspect, which may, therefore, be extracted using fatty acids. Acid corrosion is considered especially suited to India to remove RCA mortar since almost all the coarse concrete aggregates used are granite. Granite is highly resistant to chemicals and was used as corrosion resistance is needed in many applications as it is shown in (fig 2.)

2.5.1. Acetic Acid (CH_3COOH)

- Acetic acid, like (HCl and H_2SO_4), is less expensive than strong acids.
- Acetic acid treatment is much milder, causing fewer risks to workers' health.
- The treated aggregates do not have to be washed, which saves plenty of water and storage costs.
- More importantly, acetic acid can be partially regenerated.

$$Ca(OH)^2 + 2CH_3COOH \rightarrow Ca(CH_3COO)^2 + 2\,H_2O \quad (1)$$
$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O \quad (2)$$

$$CaCO_3 + 2CH_3COOH \rightarrow Ca(CH_3COO)_2 + H_2O + CO_2 \quad (3)$$
$$CaCO_3 + CH_3COOH \rightarrow Ca^{+2} + CH_3COO^- + CO_2 + H_2O \quad (4)$$
$$Ca^{+2} + 2CH3COO^- + CO_2 + H_2O \rightarrow CaCO_3 + 2CH_3COOH \quad (5)$$
Also:
$$CH + CH_3COOH \rightarrow Ca^{+2} + CH_3COO^- + H_2O \quad (6)$$
$$C\text{-}S\text{-}H + 2CH_3COOH \rightarrow Ca^{+2} + CH_3COO^- + SiO_2 + H_2O \quad (7)$$
The same result
$$Ca^{+2} + 2\,CH_3COO^- + CO_2 + H_2O \rightarrow CaCO_3 + 2CH_3COOH \quad (8)$$

Eq 1-8. The chemical reactions.

The treatment leads to produce:
1) $CaCO_3$ Precipitated Calcium Carbonate (PCC).
2) $Ca(CH_3COO)_2$ The Calcium Acetate.
3) CH_3COOH The Acetic Acid Back.
4) H_2O More water generating.

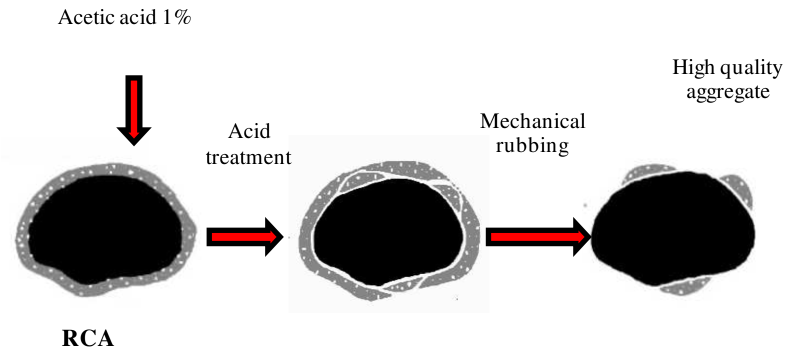


Fig 2. The Treatment Process.

- The RCAs are first immersed in Acetic Acid to remove other cement hydration materials.
- Any dismantled and damaged RCA mortar can be removed by this process, resulting in a reduction in RCAs' water absorption.
- There can be a major improvement in the mechanical properties of concrete produced with RCAs as an aggregate as per **Eq 2-8.**

3. Experimental program

3.1. Experimental design & work

M40 has been chosen because it is a viral material, it has a moderate strength demand of approximately 450 kg / mm2, and it has previously been made. Several mixture designs options have been selected simultaneously through the selection of concrete for M40. The M40 mix sets strict rules on the compound shape and amount, the cement ratio, and total air volume. The MU criteria in concrete M40 are based on several tests; the virgin ground aggregate was selected out of MU substantial laboratory waste. The sand from a MU concrete laboratory was selected as the fine aggregate, with a water-cement ratio of 0.36. The studied properties of virgin concrete and RCA were of interest, including slump, air content, aggregates, absorption, overall aggregate grading, compressive power growth over time, time split tensile strength gain, and flexicurity gain. Standard IS test methods have been chosen for each property to be tested.

Table 1. Physical properties of materials.

Physical properties		Natural	Recycled before	Recycled after	Sand
Specific gravity (SSD)		2.87	2.48	2.691	2.61
Absorption %		0.72	4.2	1.405	0.5
Bulk Density	Loose bulk density (kg/l).	1.465	1.277	1.366	-
	Rodded bulk density (kg/l).	1.586	1.385	1.482	-
	Percentage voids %.	48.95	48.48	48.73	-
Impact value%		13.77	31.08	20.86	-

3.2. Percentages of mix design:

$$D = \frac{m}{V}$$

Eq 9. The Density

Where D is the density, m is the mass, V is the void.

Table 2. Percentages of mix design.

Mix design	Percentage	weight
10mm	100%	2.79 kg
20mm	100%	2.71 kg
10mm	30%	2.89 kg
20mm	70%	
10mm	35%	2.74 kg
20mm	65%	
10mm	40%	2.84 kg
20mm	60%	
10mm	50%	2.85 kg
20mm	50%	

3.3. Concrete mix design

The designs are prepared according to (IS) to achieve the research objectives. The critical difference between these mixtures is the aggregate substitution levels of 0, 10, 20, 30, 40, 50 % (NCA and RCA). Furthermore, as per **Eq 9.**, and results are shown in **Table 2.** The aggregates contain 30% of 10mm aggregates and 70% of 20mm aggregates that achieve the best density. The samples are used as research specimens for comparison for NCA substitution percentages with RCA. (Table 3.) describes the mixtures used in the fundamental research and evaluated the various concrete forms of the research program. Mixture proportions of the concrete species tested were determined:

Table 3. Concrete Mix design.

Materials	Replacement Percentages					
	100% NCA	10% RCA	20% RCA	30% RCA	40% RCA	50% RCA
Water	158 kg	158 kg	158 kg	158 kg	158 kg	158 kg
Cement	439 kg	439 kg	439 kg	439 kg	439 kg	439 kg
Coarse Aggregates	1291 kg	1291 kg	1291 kg	1291 kg	1291 kg	1291 kg
Fine Aggregates	661 kg	661 kg	661 kg	661 kg	661 kg	661 kg
Recycled Aggregates	0 kg	129.1 kg	258.2 kg	387.3 kg	516.4 kg	645.5 kg

3.4. Materials

3.3.1. Concrete

A mixed design for the productivity of M40 has been developed and evaluated for this report; a pattern for the mix M40 was used for the study and as a basis for recycled crushed cement (RCA). It showed a Cement content of 439 kg / m^3, the air content of (1-3) %, and a water/cement relation of 0,36, a slump range of (75-100) mm. The total quantity defined as fine is 50%. Table 6 shows the results of tests for the CC concrete mixture's aggregates and the resulting RCA. As anticipated, the RCA has reduced specific weight and unit weight and significantly increased absorption. The abrasion test findings from Los Angeles were essentially the same.

3.3.2. Portland Cement.

On all research lots both in the laboratory and large-scale applications, cement type II was used. In the experimental research, the cement used was ordinary Portland, 53 grades developed according to IS 8112. Mortar cement will consist of 27N/mm2 and 47N/mm2, respectively, for 3 and 7 days. The cement's strength should not be less than 2.5N / mm2 and not less than 30 minutes and not greater than 10 hours, respectively, should be the initial setting and end times.

3.3.3. Coarse Aggregate.

The approximate amounts used in this section of the analysis consisted of virgin sums from the services MU offers. Broken, crushed stone was used, with a thickness of 20 mm and kept in 16 mm by a sieve of 12,5 mm, placed in a 10 mm sieve. The coarse aggregate was used. They are well graded, i.e., they give body to concrete in different size and cubic form, reducing the degradation and saving impact. 70-80% of the concrete volume is made of these aggregates. In present jobs, materials are taken from the storage yard.

3.3.4. Fine Aggregate.

For this part of the analysis, the fine aggregate used was virgin natural sand from resources supplied by MU. The natural sand from local sources, without silt and organic matter, is finely aggregated and is passed through a 4.75 mm seal in compliance with zone II, under IS 383-1970. The sand used was 2.61 gravity.

3.3.5. Water:

The water source that is usable in the laboratory is used to blend and cure the concrete. The pH value of the used water is 6 to 8 for concrete. There are also organic impurities excluded from the water.

3.3.6. Super plasticizer:

The Aster Super-Plasticizer ASP200 is used for this mission. This is a revolutionary polycarboxylic ether superplasticizer second generation. The rapid adsorption of the molecule on the cement particles exposed to increased surface areas of the cement grains with an effective dispersion effect to react with water. Hydration heat can be produced earlier and higher strengths at a very early age as a result.

3.3.7. Recycled coarse aggregates:

In this project, the recycled crushed concrete aggregation (RCA) used is extracted from the MU laboratory's demolished concrete members. Most waste concrete is made up of cylinders and waste cubes. These concrete wastes are shattered, and gross coagulates (RCA) recycled have been created. In the technical, environment, and economic respect. This is worthwhile to use recycled coarse crushed aggregates in concrete. The purpose of utilizing environmental and economic could be useful with recycled aggregate (RA). Future materials are recycled crushed concrete (RCA) aggregates. The recycled aggregate was used, with an overall 20mm scale and held on 4.75mm and a common weight of 2.48.

4. Results and discussion

4.1. Fresh Concrete Properties

They were all manufactured with a constant w/c of 0,36. In this phase, the total number of six replacements of aggregates was examined. Table 4. Shows that the slump was 40 and 50% lower because of the high amount of coarse aggregates and the decrease in this blend's fresh mortar content than other combinations.

Table 4. Fresh Concrete Properties.

Mixture type	0%R	10R	20R	30R	40R	50R
Slump(mm) B	75	65	55	40	30	25
Slump(mm) A	95	80	75	60	55	50

***R:** Replacement, **B:** Before treating RCAs, **A:** After treating RCAs.*

The RCA's specific gravity was 2.48, which means decreasing 14% of the natural aggregate. After using Acetic Acid for treating the RCA, the specific gravity became 2.691, which means 8% of increasing and only a 6% decrease from the NA. The impact value of the RCA was 31.2, which means decreasing 54% of the natural aggregate. After using Acetic Acid for treating the RCA, the impact value became 20.86, representing a 33% increase and only a 34% decrease from the NA. The density of the hardened concrete mixtures was increasing with the treatment of RCA materials. The fundamental explanation for this phenomenon is the less precise weight of recycled aggregates. The procedure improved the absorption of water. RCA's water absorption was approximately six times more than that of NCA can be observed in Table 1. However, it could be noted that the dry density is very close to NCA. Consequently, it can be concluded that there was no adverse effect on the density and water absorption capacity of hardened concrete following Acetic Acid therapy up to 50% substitution.

4.2. Hard concrete properties

4.2.1. Compressive strength:

The use of RCA as substitutes for coarse aggregates has shown a slight decrease. The decrease was, however, more pronounced for specimens with RCA substitutions of 40 and 50 percent. As per (Table

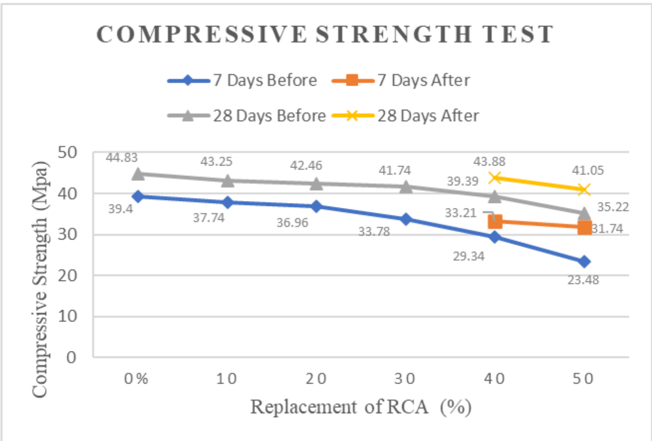
5.), the test results (Fig.3a.) of compressive strength at 7 and 28 days for M40 grade of mixtures, including RAC, achieve target strength by replacing (10 to 30) % RCA with NCA after many trials mix under controlled conditions. After 7 days the using of RCA increased the compressive strength about 16%, 18%, 25%, 35%, and 48% for replacement of 10, 20, 30, 40, 50%, respectively. However, by treating the aggregates using Acetic Acid, the lowest values, 40% and 50% of replacement increased the compressive strength by about 12% and 26%. After 28 days of treatment, the compressive strength increased by 11%, 14% for 40, and 50 percentage for replacement. In the first seven days, the aim strength of 33,75 MPa was met for all concrete mixtures with natural and recycled aggregates. The concrete's compressive strength was then increased at a shallow rate. 50% of the replacement (i.e., 43.88 MPa) has a maximum intensity of 28 days.

Table 5. Hard concrete properties (Compressive Strength).

Compressive strength (MPa)`	Replacement of Natural Aggregate					
	0%	10%	20%	30%	40%	50%
Weight– 28 Days (kg)	8.62	8.6	8.57	8.55	8.51	8.49
M40 – 7 Days (MPa) B	39.4	37.74	36.96	33.78	29.34	23.48
M40 – 7 Days (MPa) A	-	-	-	-	33.21	31.74
M40 – 28 Days (MPa) B	44.83	43.24	42.46	41.74	39.39	35.22
M40 – 28 Days (MPa) A	-	-	-	-	43.88	41.05

R: Replacement, B: Before treating RCAs, A: After treating RCAs.

a



b

Fig 3. **(a)** Compressive strength results; **(b)** Compressive strength test.

4.2.2. *Tensile strength:*

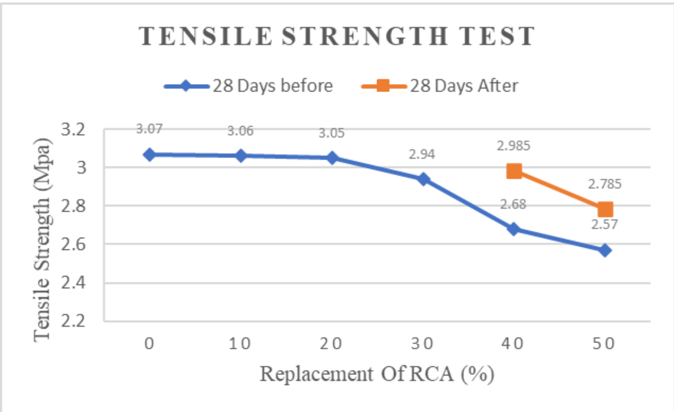
Based on the results in (Fig.4.) it can be observed that the strength for replacement of (10 to 20) % of aggregates is the highest at (3.05 MPa) and match the actual one (3.07 MPa), which means it can be used for producing new and workable concrete the second-highest tensile strength was achieved by using replacement of (30) % aggregates approximately value of 2.94 MPa. Meanwhile, the replacement of (40 to 50) % aggregates recorded tensile strength of 2.68 and 2.57 MPa, respectively, which is the lowest strength was recorded, for 10 and 20 % of the aggregates is the highest strength. In comparison, tensile strength for (30%) of the aggregates decreased. At (40% and 50) % of replacement, the lowest intensity was recorded. When replacement increases, the chances of failure are high. The sample was measured for 28 days after treatment of the aggregates, and the strength increased 11% and 8% for 40and 50 % of replacement, respectively as it is shown in (Table 6.).

Table 6. Hard concrete properties (Tensile Strength).

Splitting Tensile Strength (MPa)`	Replacement of Natural Aggregate					
	0%	10%	20%	30%	40%	50%
Weight– 28 Days (kg)	13.6	13.54	13.52	13.42	13.37	13.29
M40 – 28 Days (MPa) B	3.07	3.055	3.05	2.94	2.68	2.57
M40 – 28 Days (MPa) A	-	-	-	-	2.985	2.785

R: Replacement, B: Before treating RCAs, A: After treating RCAs.

a



b

Fig. 4. **(a)** Splitting Tensile Strength results; **(b)** Splitting Tensile Strength test.

4.2.3. Flexural Strength:

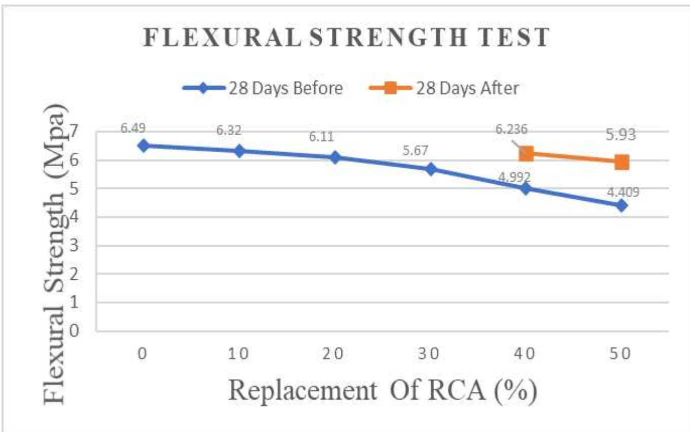
The flexural strength of the samples created with RCA was lower than the reference samples. With 40 % and 50% (Table 7.). This could be mainly due to increased air content, especially for 50 % of RCA samples. At 10 percent, 20 percent, and 30 percent RCA substitution, the specimens' bending strength was very close to the reference mix. Within the replacement of the aggregates, the strength was decreasing 3%, 6%, 13%, 23%, 32%, respectively. However, the strength increased by 20% and 26% for (40% and 50%) of replacement after the treatment. That means decreasing 4% and 9% for the last replacements, respectively. The use of soaking solutions as mixing water can improve mortars' flexural strength at 28 d, reaching up to 20% and 26%, respectively, for (40 and 50%) of replacement (Fig 5.).

Table 7. Hard concrete properties (Flexural Strength).

Flexural Strength (MPa)`	Replacement of Natural Aggregate					
	0%	10%	20%	30%	40%	50%
M40 – 28 Days (MPa) Before	6.49	6.32	6.11	5.67	4.992	4.409
M40 – 28 Days (MPa) After	-	-	-	-	6.236	5.93

R: Replacement, B: Before treating RCAs, A: After treating RCAs.

a



b

Fig. 5. (a) Flexural Strength results; **(b)** Flexural Strength test.

5. Conclusion

RCA has various characteristics than NA because of the attached RCA mortar. The RCA's specific gravity was low; however, the RCA absorption was increased. The new concrete properties that change with RCA use are also less workable than NC because of the increased RA water absorption. The air in the old mortar attached to the RA is even higher than the NC. RAC concrete properties have a lower strength (compressive, flexural, and tensile strength) than NC. The contrast's new properties were not substantially different from the concrete mixture made up with RCA replacements up to 30%. Due to the higher gross aggregate content and lower natural material, 40% and 50% blends were challenging with much lower workability than the other mixtures. Due to the increased air volume, compressive strength compared to the conventional mixtures produced by RCA substitution (40% and 50%) is lower. However, the total amount of acetic acid used in the mixture treated was 1%, with high compressive concrete strength in this process. Soaking aggregates in acetic acid did not help in improving compressive strength within 7-days. However, this mixture's 28-day compressive strength tends to be increased relative to the conventional RCA mixture. The RCA's splitting strength and flexural strength did not vary significantly. Compared to the conventional mixture, the treated RCA method's specimens had excellent tensile and flexural efficiencies. Moreover, the flexural strength has been increased for 28-days, efficiently.

6. Future Recommendations

Proper care should be taken when crushing concrete so that the mortar content can be minimized. As far as the concrete crushing is costly, a cost-benefit analysis should be carried out to assess RCA mortar's appropriate amount. Future field experiments should test the recycled concrete pavements after being subjected to even further traffic loading.

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Figures

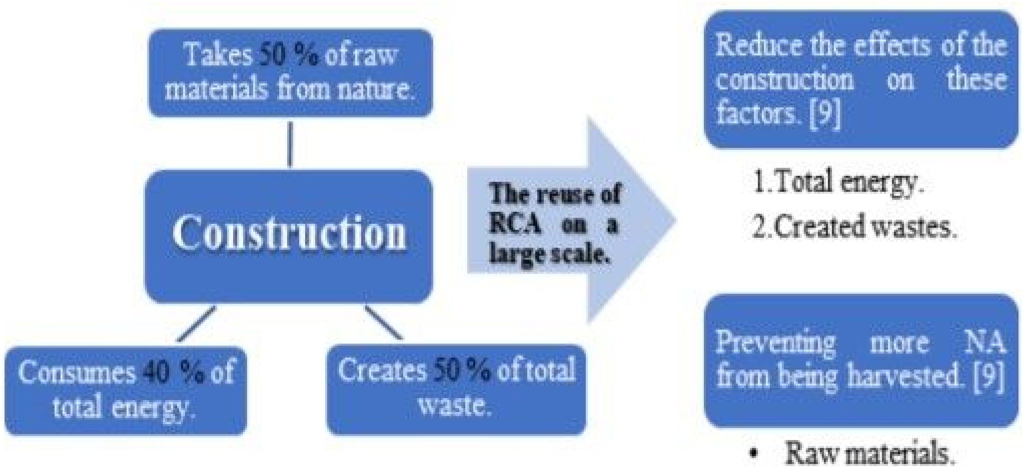

Figure 1

The impact of construction.

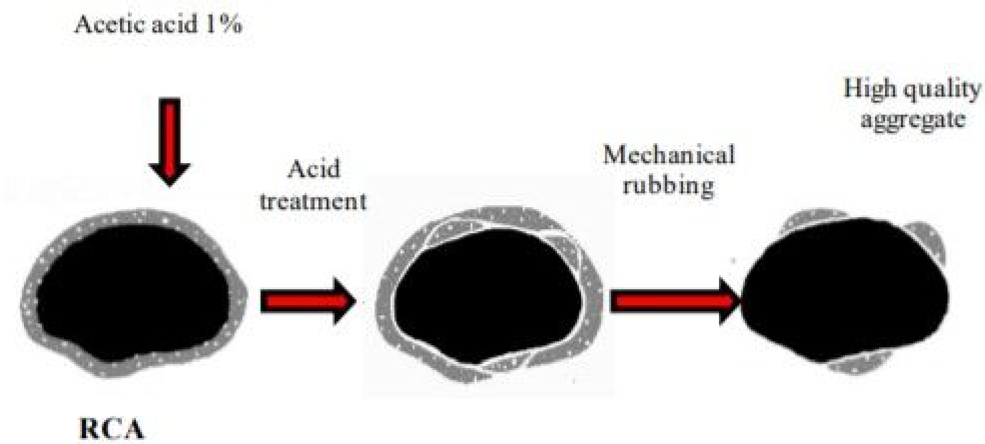

Figure 2

The Treatment Process.

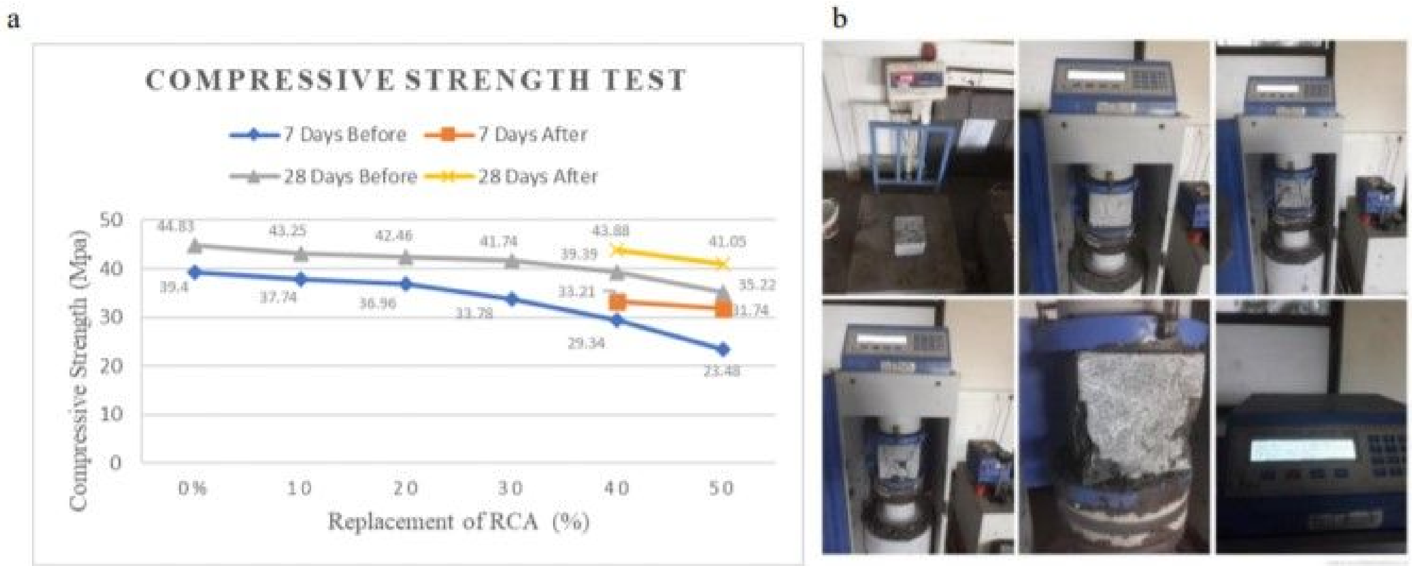

Figure 3

(a) Compressive strength results; (b) Compressive strength test.

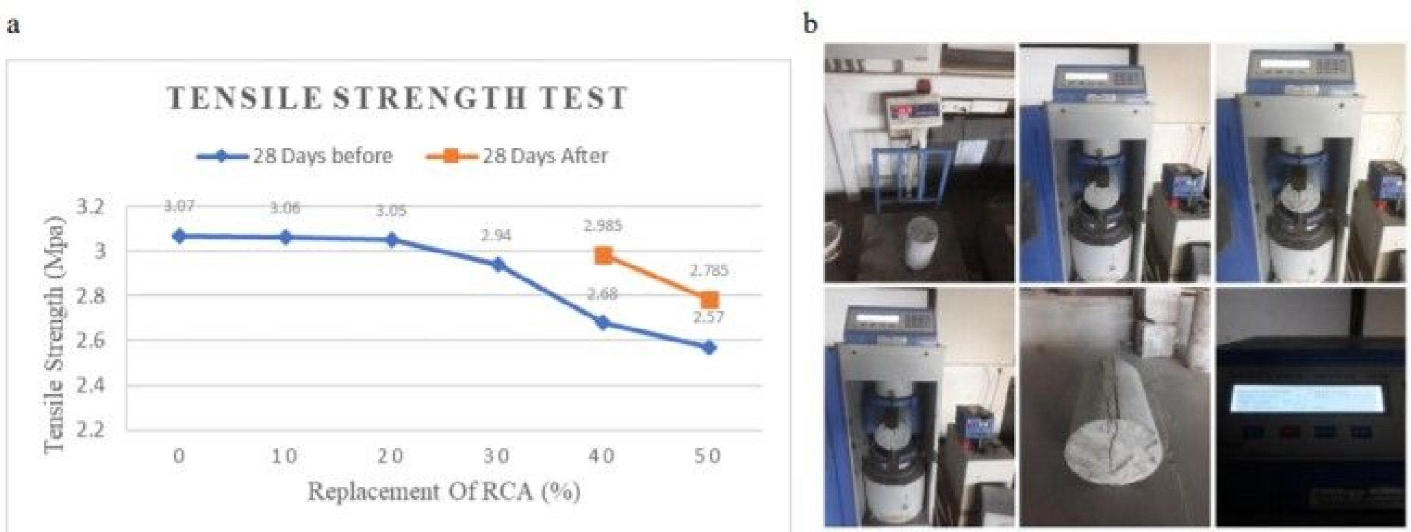

Figure 4

(a) Splitting Tensile Strength results; (b) Splitting Tensile Strength test.

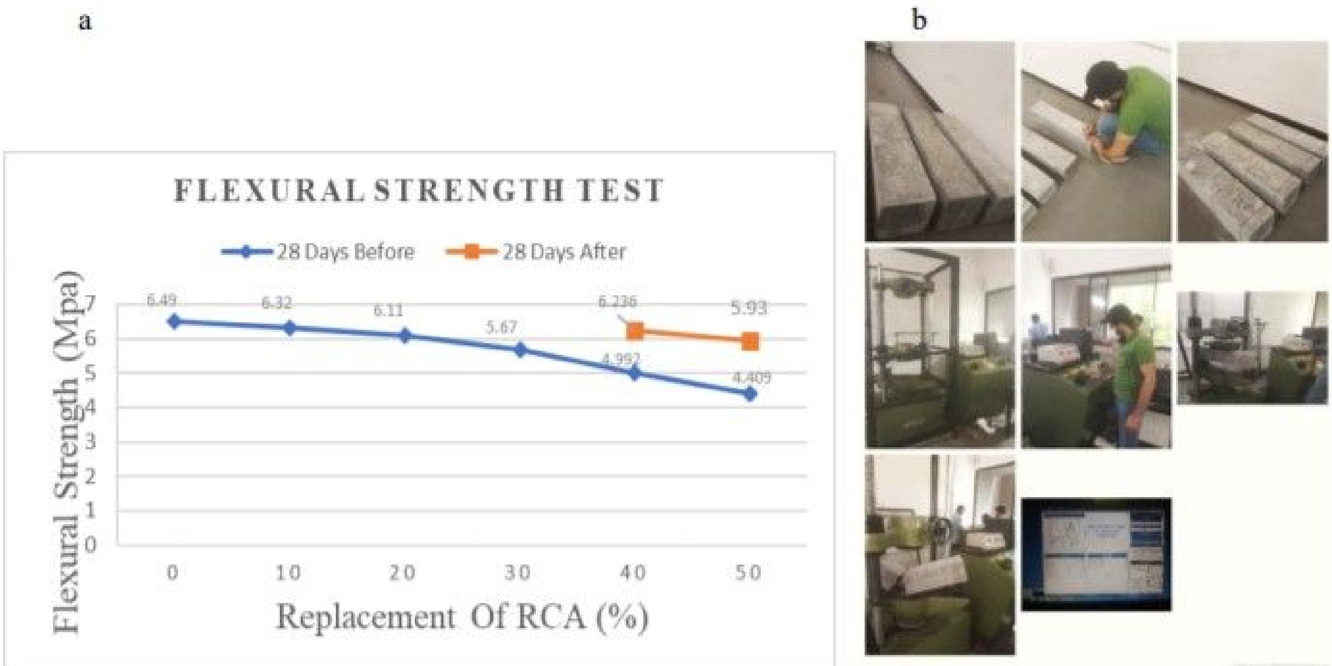

Figure 5

(a) Flexural Strength results; (b) Flexural Strength test