

Enhancing Mechanical Properties of Recycled Aggregate Concrete Through Advanced Treatment Techniques

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ENHANCING MECHANICAL PROPERTIES OF RECYCLED AGGREGATE CONCRETE THROUGH ADVANCED TREATMENT TECHNIQUES

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ABSTRACT

Construction and demolition waste production has significantly increased in recent years, which has negative consequences on both the economy and the environment. In an effort to counteract this, recycled coarse aggregate (RCA) from concrete that had been demolished was brought out and utilized to make fresh concrete. Consuming untreated RCA diminishes the overall performance of concrete. The recycled coarse aggregate was manually scrubbed in a Los Angeles abrasion mill employing two acids, sulfuric acid, and hydrochloric acid, to eliminate whatever residue mortar that had become attached to the aggregate layer. Ultimately, it was determined that the mechanical and durability parameters of concrete are significantly compromised when untreated recycled coarse aggregate is substituted. However, compared to recycled aggregate concrete that hasn't been acid or mechanically treated, the aggregate's surface characteristics are more effective, and the concrete's mechanical characteristics and durability are enhanced.

Keywords: Manufactured sand, Raw Recycled Aggregate, Treated Recycled Aggregate, Recycled concrete, Optical and SEM Image

1. Introduction

Construction and demolition (C&D) waste were created in massive amounts due to the growth of urbanization [1]. The discarding of (C&D) waste was not only difficult but also generated substantial economic problems and contamination [2]. On the other

hand, the use of massive amounts of natural resources, such as coarse aggregate, in concrete manufacturing has produced serious issues for the environment. As a result, there is a widespread disagreement about how to stop the depletion of natural resources & promote the reprocessing and reclaim of C&D waste [3]. The issues can be resolved by recovering RCA from C&D trash and using it to make new concrete. The RCA may be substituted whole or partially with natural coarse aggregate to create recycled aggregate concrete [4&5] The production of RAC was found to be more cost-effective & eco-friendlier, which can lessen the need for landfill space and the scarcity of natural resources [6-10] Ceramic is one of the most often used building and construction materials, and it contributes around 8% of the world's carbon dioxide emissions [11,12,3]. Over the last 20 years, cement production has expanded globally, roughly tripling from 1.10 to 3.27 billion tons. It was predicted that increasing construction activity will lead to cement production to influence almost 4.83 billion tons in 2030. [14-22]. since fine and coarse aggregate contribute 60–75% of the concrete's overall volume, this might effectively accommodate the increasing demand for natural resources. (American Cement Manufacturers 2019). Figure 1 symbolizes the method used to produce recycled aggregate.

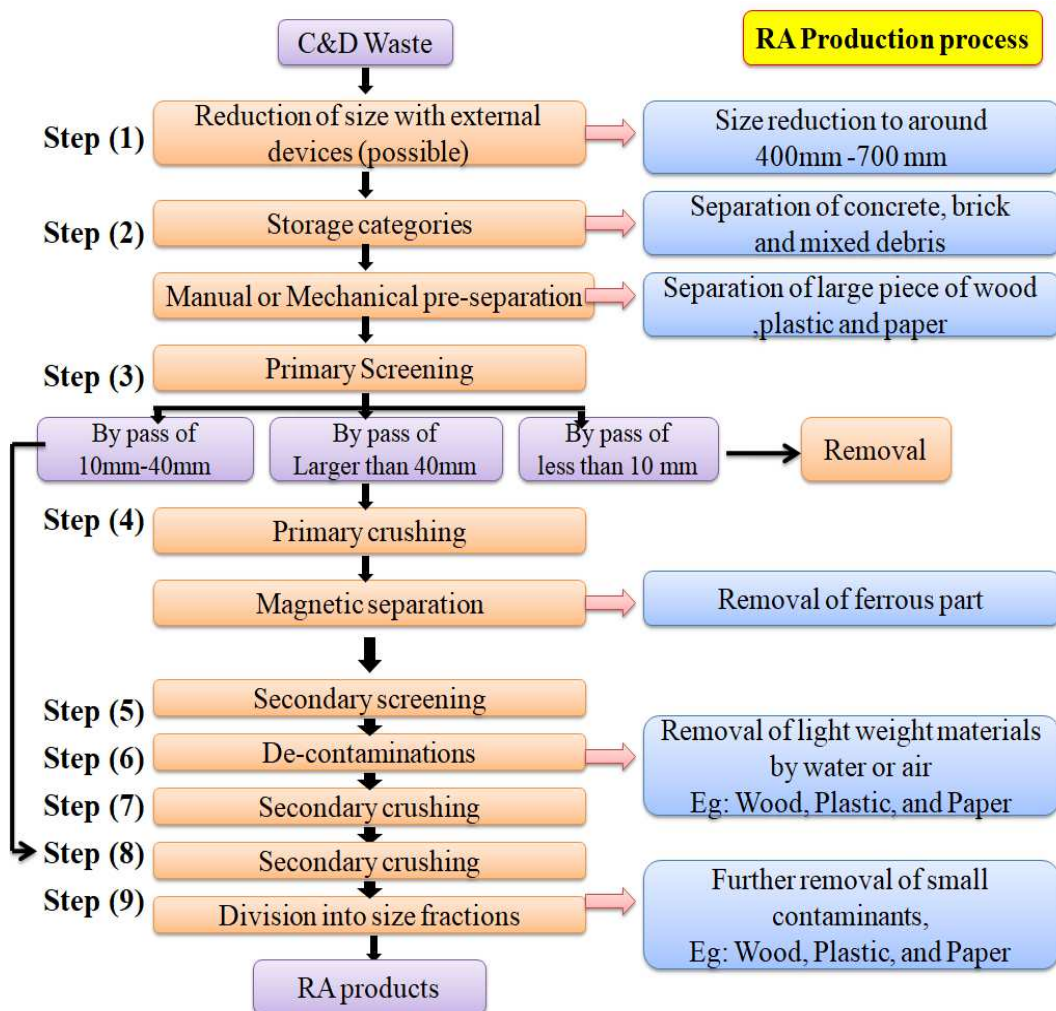


Figure 1 How Recycled Aggregate (RA) is Made

2 DETERMINATION OF ADHERED MORTAR REMOVAL

2.1 Mechanical scrubbing treatment on RCA

To assess the loss of adherent mortar on RCA, the following steps will be taken: (1) RCA was sieved under an IS sieve, traversed a sieve approximately 20 mm., and held onto a 4.75 mm screen; (2) the sieved RCA was put in an oven drying chamber for 24 hours at 105°C and (3) RCA samples weighing approximately 5kg were obtained (M1). The materials were passed through a LAM for 300 spins; (4) the aggregate was sieved 2.36 mm sieve to remove the powder particles; (5) the residual aggregate was washed and drained; and (6) the washed aggregate was placed in the oven to dry at 105°C for 24 hours. (7) The mortar loss percentage was calculated.

Mortar loss (%)

$$= \frac{\text{Weight of RCA before treatment}(M1) - \text{Weight of RCA after treatment}(M2)}{\text{Weight of RCA before treatment } (M1)}$$

$$= \frac{5000-3516}{5000} = 29.68 \%$$

2.2 Sulphuric Acid Treatment on RCA

The method to evaluate the loss of adhered mortar on RCA the actions listed below must be taken; (1) After the RCA was sieved in an IS sieve, it must be remained on a 4.75 mm filter after that passes through a 20 mm sieve.; (2) the sieved RCA shall be placed in oven-drying for 24h at 105°C; (3) then, approximately weight of 5kg RCA samples were taken (M1). The samples were immersed in 0.1 M of sulphuric acid (H₂SO₄) solution for 24 hours, after that the immersed RCA was dried on a tray and put into a LAM for 50 revolutions; (4) After separating the powder particles from the aggregate using a 2.36 mm screen, the remaining aggregate was cleaned and drained.; (5) the washed aggregate shall be placed in an kiln dehydrating for 24 hours at hundred and five degree celcius; (6) following this, aggregates remained separated by using a 4.75 mm screen to make sure only the aggregate will be recollected & weighted (M2); (7) adhered mortar loss of percentage was evaluated based on the following expression.

Mortar loss (%)

$$= \frac{\text{Weight of RCA before treatment}(M1) - \text{Weight of RCA after treatment}(M2)}{\text{Weight of RCA before treatment } (M1)}$$

$$= \frac{5000-4120}{5000}$$

$$= 17.60 \%$$

2.3 Hydrochloric Acid Treatment on RCA

The steps listed below should be followed to evaluate the loss of adhered mortar on RCA; (1) the RCA must be sieved in IS sieve, passing of 20mm sieve & retained on 4.75 mm screen shall be taken;(2) the sieved RCA shall be placed in oven-drying for 24h at 105°C; (3) then, approximate weight of 5kg RCA samples were taken (M1). The samples were immersed in 0.1 M of HCl solution for 1 day, after that the immersed RCA was dried on the tray and placed into LAM for 50 revolutions; (4) hereafter, the aggregate was sieved in 2.36 mm sieve to separate the powder particles, and then the

retained aggregate was washed and drained; (5) the washed aggregate shall be placed 24 hours of 105°C in oven drying; (6) thereafter, the aggregates were sieved and the adhered mortar loss of percentage was considered using the below mentioned equation by confirming that the coarse aggregate will be collected and weighed separately using a 4.75mm screen (M2).

Mortar loss (%)

$$= \frac{\text{Weight of RCA before treatment(M1)} - \text{Weight of RCA after treatment(M2)}}{\text{Weight of RCA before treatment (M1)}}$$

$$= \frac{5000-4376}{5000}$$

$$=12.48 \%$$

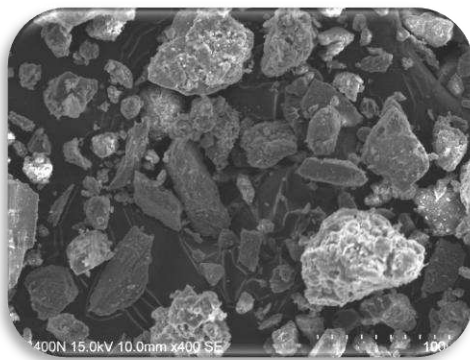
3. INVESTIGATION OF MATERIALS

The cement used was Dalmia 53 grade OPC cement for the entire study confirming to IS: 12269:2013. Amongst the mineral admixtures, silica fume is recognized as an artificial pozzolanic substance. A byproduct of blast furnace the production of molecular silicon or silica alloys is silica fume. Metakaolin (MK) is a dehydrated calcined clay mineral derived from kaolinite (China clay). MK has a finer particle size than cement but is not as fine as SF. Table 1 displays the elemental concentrations of OPC at 53 grades, silica fume, and metakaoline. Sand, which is typically acquired from rivers and ranges in size from 4.75 mm to 75 microns, is considered fine aggregate. In places where river sand is prohibited and demanded, crushed rock dust is used. Nowadays, quarry dust is pretreated, and makes used to manufacture sand (M-sand) [23-27]. Natural River Sand and M-sand SEM images are displayed in Figure 2. Figures 3 and 4 display the particle size distribution of M-sand and natural river sand. Natural river sand and M-sand's elemental concentrations are shown in Table 2.

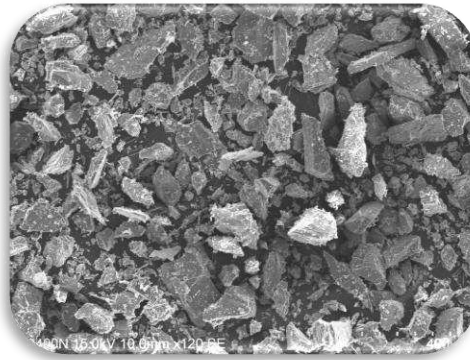
Table 1 Elemental Concentration of OPC @ 53 grades, Silica fume, Metakaoline

S. No	Elemental Concentration (%)	Dalmia Cement	Silica fume (SF)	Metakaoline (MK)
1	Silicon (SiO ₂)	19.15	79.50	66.00
2	Titanium (TiO ₂)	0.37	0.05	1.20
3	Aluminum (Al ₂ O ₃)	4.74	1.27	24.90
4	Iron (Fe ₂ O ₃)	5.42	9.24	4.03

5	Potassium (K ₂ O)	0.86	3.00	1.56
6	Sodium (Na ₂ O)	0.35	0.72	0.17
7	Magnesium (MgO)	0.98	2.70	0.76
8	Calcium (CaO)	64.80	1.20	1.22
9	Phosphorus (P ₂ O ₅)	0.14	0.22	Not Detected
10	Sulphur (SO ₃)	2.86	1.83	0.04



(a)



(b)

Figure 2 SEM Image of (a) Natural River Sand (b) (M-sand)

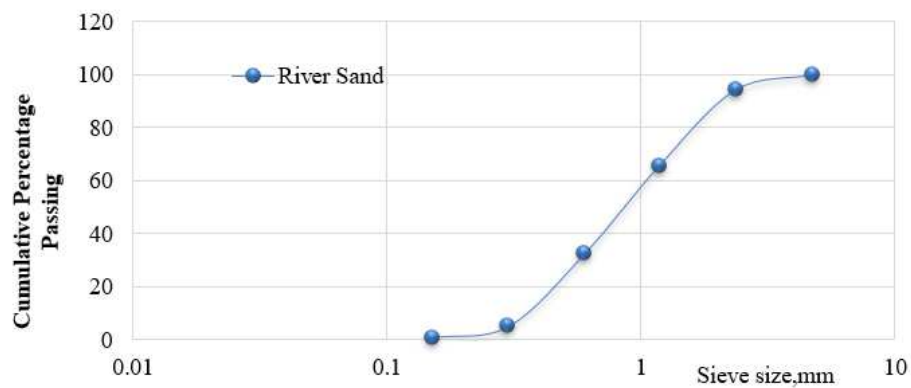


Figure 3 River Sand - Sieve Analysis Graph

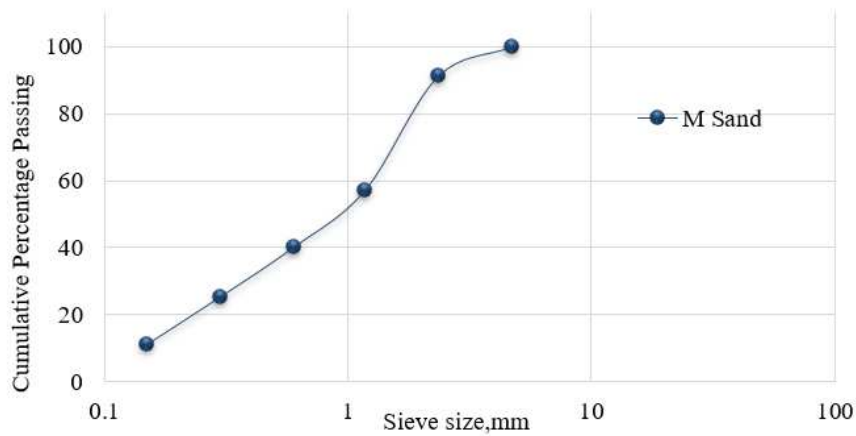


Figure 4 Manufactured Sand- Sieve Analysis Graph

Table 2 Elemental Concentration of Natural sand & M-sand

S. No	Elemental Concentration (%)	Natural Sand	M-Sand
1	Silicon (SiO ₂)	62.00	58.00
2	Titanium (TiO ₂)	1.02	0.82
3	Aluminum (Al ₂ O ₃)	15.10	15.60
4	Manganese (MnO)	0.09	0.11
5	Iron (Fe ₂ O ₃)	5.78	7.96
6	Calcium (CaO)	7.61	7.17
7	Magnesium (MgO)	2.07	3.75
8	Sodium (Na ₂ O)	2.54	4.28
9	Potassium (K ₂ O)	2.24	1.06
10	Phosphorus (P ₂ O ₅)	0.63	0.67
11	Sulphur (SO ₃)	0.59	0.30

All the below-mentioned aggregates were used in this complete work. By observation of cumulative results of RCA (HCl), RCA (H₂SO₄), NCA, RCA (UN), NCA & RCA (MS) would give a clear picture of the properties of aggregate. The SEM images of various aggregates were shown in Figures 5. Figure 6 show the particle size distributions in the different aggregates. Table 3 shows the elemental Concentration

of various aggregate results. Table 4 represents the quantity for mixtures of concrete for M70 grade.

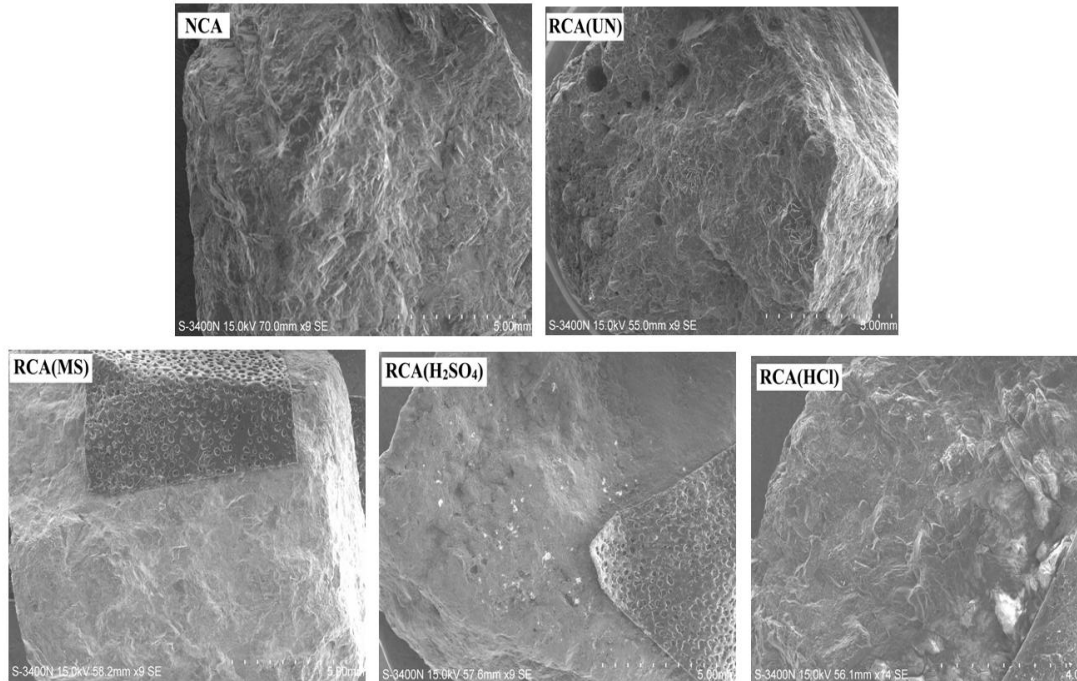


Figure 5 Various SEM Images of Coarse Aggregates

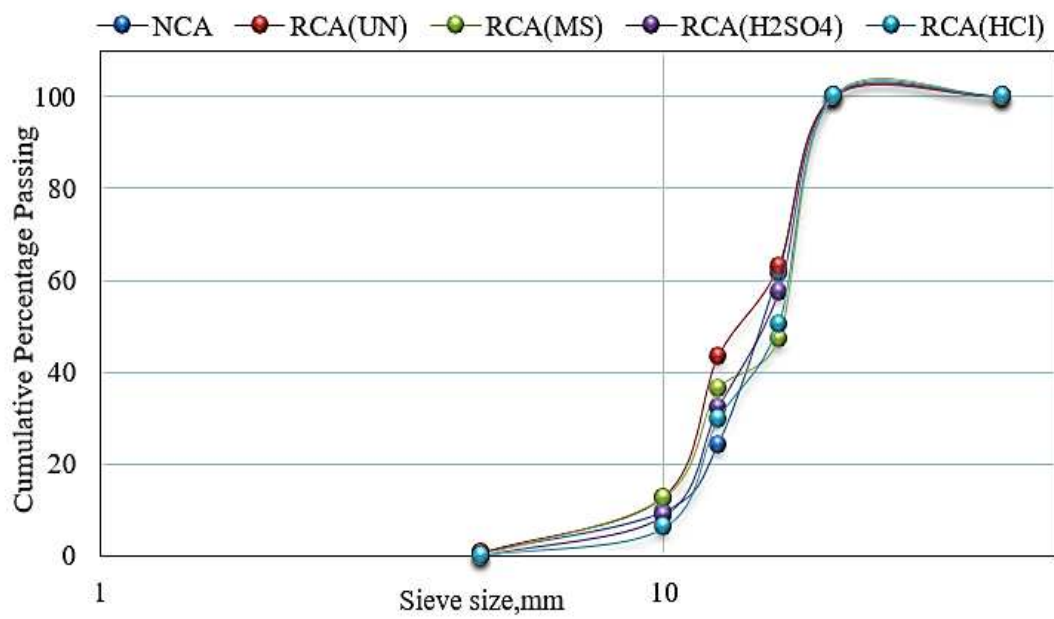


Figure 6 Sieve Analysis Graph of Coarse Aggregates

Table 3 Concentration of Different Aggregate Elements

S.No	Elemental Concentration (%)	NCA	RCA			
			HCl	H ₂ SO ₄	MS	UN
1	Silicon (SiO ₂)	62.50	55.30	48.70	50.70	48.30
2	Titanium (TiO ₂)	1.04	0.71	0.45	0.56	0.53
3	Aluminum (Al ₂ O ₃)	11.40	8.46	7.71	8.02	7.74
4	Manganese (MnO)	0.22	0.14	0.09	0.12	0.10
5	Iron (Fe ₂ O ₃)	8.53	5.67	5.33	5.42	5.71
6	Calcium (CaO)	9.13	23.70	28.40	29.40	30.90
7	Magnesium (MgO)	0.73	1.00	0.84	1.01	1.00
8	Sodium (Na ₂ O)	3.32	1.88	1.51	1.83	1.52
9	Potassium (K ₂ O)	2.04	1.32	1.16	1.27	1.58
10	Phosphorus (P ₂ O ₅)	0.36	0.27	0.19	0.21	0.24
11	Sulphur (SO ₃)	0.45	0.98	5.35	1.17	1.94

Table 4 Ratio for Different Concrete Mixtures for Grade- M70

SL.NO	Description	Mix Proportioning (kg/m ³)					
		NCA	NCMC	UN	MS	H ₂ SO ₄	HCl
1	Cement	441					
2	Silica Fume	53.4					
3	Metakaolin	41.0					
4	Natural Sand	562	-				
5	Manufactured Sand	-	613				
6	NCA	1242		-			
7	RCA	-		1081	1172	1149	1113
8	Water	141					
9	SP	2.67					

4. METHODS

4.1 Slump Cone Test

Four layers, each filling a quarter of the mold, must be $\frac{1}{4}$ of the mold. And use a tamping rod, each layer needs to be tamped by 25 strokes. The tamping of strokes must be consistent, and the second and subsequent layers must penetrate entirely through its depth. Excess concrete needs to be troweled to level after tamping down the last layer.

4.2 Compaction Factor Test

Using a hand scoop, pour the concrete testing sample into the higher hopper. Once the upper hopper is full, the trapdoor must be opened right away so the concrete can fall into the lower hopper. Throughout this procedure, the cylinder must be covered with a trowel. When the concrete reaches the last hopper, the cylinder must be uncovered, the last hopper's trap door must be unlocked, and the concrete must be permitted to fall into the cylinder. The surplus concrete overhead the cylindrical mold was removed with a trowel. The cylinder weight was noted accurately to the nearest 10 grams.

$$\text{Compaction factor} = \frac{\text{Concrete partially compacted weight}}{\text{Concrete fully compacted weight}}$$

4.3 VEE –BEE Consistometer Test

. The cone must be lifted, and the slump must be noted by lowering the cone's top disc while using a graduated rod. The electrical vibrator must be turned on, and once the concrete is allowed to spread into the cylindrical pot, it must continue to vibrate until the concrete has spread evenly.

4.4 Compression Strength Test

The compressive testing machine capacity of 3000 KN shall be utilized to determine the concrete specimen's compressive strength, cube sizes 100×100×100 mm are utilized for all the various mixes in this investigation. The code provisions as per IS: 516-1959 were followed to determine the strength [28-33].

$$\text{Compressive strength, } f_c = \frac{P}{A}$$

where P = Ultimate load in N

A = Cube area in mm²

4.5 Split Tensile Strength Test

The specimen shall be 150mm in diameter and 300mm long utilized to ascertain the split tensile strength and code confirmation as per IS 5816-1999 is followed. The specimen shall be tested immediately after removal of water; if the specimen is in dry condition shall be 24 hours submerged in water before testing. It shall obey the requirements given in IS: 516-1959 except the bearing faces of both plates shall provide a minimum area of loading of 12mm width by the length of the cylinder [34-39].

$$\text{Split tensile strength, } f_{ct} = \frac{2P}{\pi l d}$$

where,

P = Load in N

l = Length in mm

d = Dimensions of the cross-section in millimeters

4.6 Flexural Strength Test

A UTM with a capacity of 2000 KN should be used to assess the flexural strength of concrete. The specimen size needed to estimate flexural strength is 100X100X500

mm, and code confirmation according to IS 516-1959 is used. The specimen must be kept in water at 24°C to 30°C for two days before testing. [40-47]

Flexural strength, $f_{rup} = \frac{PL}{bd^2}$

Where,

b = width of specimen (cm),

d = depth of specimen (cm),

P = Ultimate load (N),

L = Span length

4.7 Modulus of Elasticity

The compressive strength of three specimens should be examined following IS 516-1959. The cylinder must be removed from the water cure immediately, and the extensometer must be fitted while still wet. At a rate of 140 kg/cm²/minute, the load is applied continuously without shock until the stress of (C+5) kg cm² is reached, where C is the cube's average compressive strength that is closest to 5 kg/cm². [48, 49].

4.8 Impact Resistance

Concrete disc specimens were employed for assessing the impact resistance, in accordance with ACI committee 544.1R-82. The impact resistance test is performed for several days. After the curing period was completed, the specimen was removed and cleaned with a dry cloth to eliminate any surface water on the specimen. The utilized sample was 63.5 mm in height and 152.4 mm in dia. Each result represents the mean of three specimen values [50-53].

5. RESULTS AND DISCUSSION

5.1 Slump Cone Test

The slump test is used to ascertain the M70 grade's fresh concrete properties and exposed in Table 5. Old adhering mortar that is remaining on the aggregate's surface

was the reason for the decrease in the RAC (UN) rating. The amount of absorption capacity is extraordinary because the untreated RCA surface contained weak and porous materials. [54-62]. A significant amount of water had been absorbed by the RCA during mixing, and there was inadequate water present. Old mortar's surface was peeled using chemical and abrasion techniques to lower the absorption rate. The rate of water absorption was significantly reduced following different treatments on raw RCA (Revathi et al. and Pandurangan et al.). When compared to RAC (UN), a mechanical scrubbing technique improves slump by removing a significant amount of adhering mortar.

Table 5 Test Results for Slump Cones

S.NO	Description	Slump value (mm)
1	NAC	127
2	NCMC	107
3	RAC (UN)	88
4	RAC(MS)	98
5	RAC(H ₂ SO ₄)	93
6	RAC (HCl)	94

5.2 Compaction Factor Test

The M70 grade concrete compaction factor test was used to determine the workability features. The results of NAC and MCMC mixes were 0.97 and 0.95. The results declined significantly in RCA (UN) was 0.87 due to the low density of RCA. The compaction factor value of the treated aggregate of RAC (MS), RAC (H₂SO₄), and RAC (HCl) was enhanced by 8.04, 5.74, and 4.59% respectively. When compared to naturally occurring coarse aggregate, the porous surface of RCA has a low density. After the removal of adhering mortar that was present on the aggregate surface, the compaction factor value must be raised. When compared to chemical treatments, mechanical scrubbing eliminates the old mortar more effectively. Table 6 give the compaction factor results for the M70 grades [63-67].

Table 6 Results of Compaction Factor Test

S.No	Mixes	Compaction factor (%) M70
1	NAC	0.97
2	NCMC	0.95
3	RAC (UN)	0.87
4	RAC(MS)	0.94
5	RAC(H ₂ SO ₄)	0.92
6	RAC (HCl)	0.91

5.3 Vee-bee Consistometer Test

Table 7 represents the vee-bee consistometer results were measured in seconds. NAC and NCMC required 3 sec for M70 grade concrete. The time was extended significantly in RAC (UN) was 7 sec. The time (sec) difference between RAC (UN) and controlled concrete NAC & NCMC was more different. The difference between NAC and RAC (UN) was 4 sec, and the difference between NCMC and RAC (UN) was also 4 sec. After treatment techniques, the treatments of MS, H₂SO₄, HCl required 4, 5, and 5 seconds respectively, and the time was reduced significantly after treatment when related to RAC (UN). The mechanical scrubbing treatment aggregate required limited time (sec) when compared to other treatment techniques [68].

Table 7 Vee-Bee Consistometer Results

S.NO	Mixes	Vee-bee consistometer (%) M70
1	NAC	3
2	NCMC	3
3	RAC (UN)	7

4	RAC(MS)	4
5	RAC(H ₂ SO ₄)	5
6	RAC (HCl)	5

5.4 Unit weight

From the test results, the unit weight of normal strength M70 grade concrete of NAC and NCMC was 2485 kg/m³ and 2539 kg/m³, the RAC (UN) has reduced drastically by 2395kg/m³ when compared to control concrete. After the treatment process on RCA density was increased, the ratio of RAC (MS), RAC (H₂SO₄), and RAC (HCl) to RAC (UN) were enhanced by 1.011, 1.075, and 1.030 at 3 days of hardened concrete. There might be only marginal differences between treated and untreated concrete density at 3 days. The density ratio of MS, H₂SO₄, HCl to UN(RCA) were improved by 1.014, 1.019, and 1.033 at 14 days and the ratio of density were developed by 1.014, 1.018, and 1.032 at 28 days. The machine-driven treatment RCA has improved density related to other treatments but is still inferior to natural aggregate concrete. Figure 7 show the unit weight results [69-74].

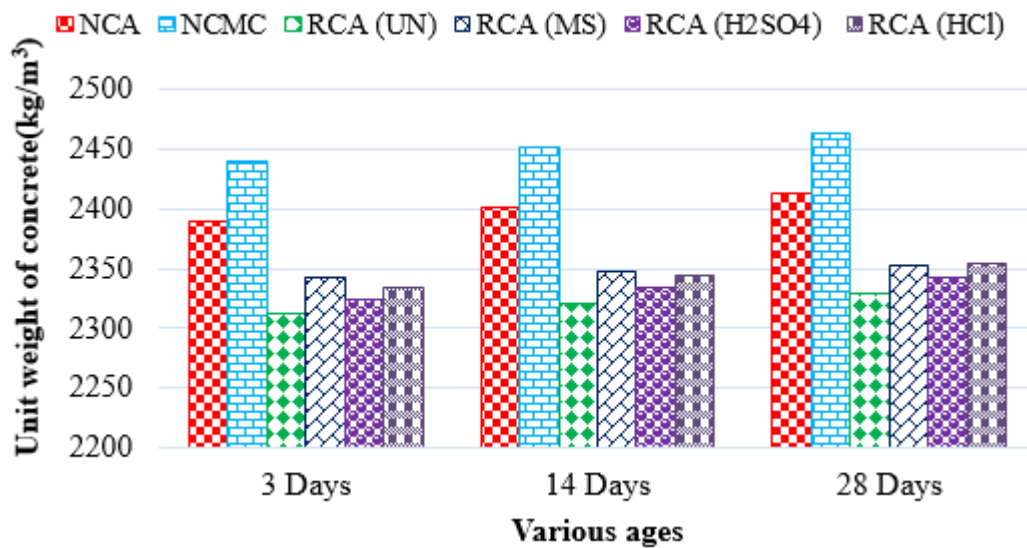


Figure 7 Unit Weight of Concrete

5.5 Compressive Strength of Concrete

After casting the M70 grade high-strength concrete, testing was carried out for specified durations. The results were displayed in Figure 8 and Table 8. When associated to NAC and NCMC, the compressive strength of RAC (UN) considerably decreased by 37.86% and 28.07% at 28 days. The strength of the RAC (MS), RAC (H₂SO₄), and RAC (HCl) improved after undergoing various treatments for the RCA by 24.98, 19.42, and 16.06 percent, respectively, over 28 days. When associated to RAC (UN) at 28 days, the improved compressive strength of the treated aggregate ranges from 16.06 to 24.98 %. The compressive strength was only reduced slightly in RAC (MS), compared to 95.89 % in NCMC and 82.83 % in NAC. Among all the treated concrete RAC (HCl) shows very poor but it was higher than RAC (UN). The removal of adhered mortar was more significant in mechanical scrubbing treatment than chemical treatments, so the compressive strength reduction was low in RAC (MS) compared to other treated aggregate concrete. The sulphuric acid treatment removes attached mortar more when compared to hydrochloric acid[75-82].

Table 8 Compressive Strength of Various Concrete Mixes

Mix Series	Compressive Strength -M70 in N/mm ² in various curing ages					
	3	7	14	28	56	90
NAC	35.40	55.80	75.47	84.50	85.73	88.22
NCMC	29.78	47.88	64.94	72.99	74.91	74.91
RAC (UN)	21.86	36.28	49.50	54.50	55.47	56.55
RAC (MS)	27.51	44.12	59.19	66.50	68.18	70.58
RAC (H ₂ SO ₄)	25.67	41.18	55.11	62.00	64.67	66.49
RAC (HCl)	23.59	37.81	50.64	56.50	58.58	60.24

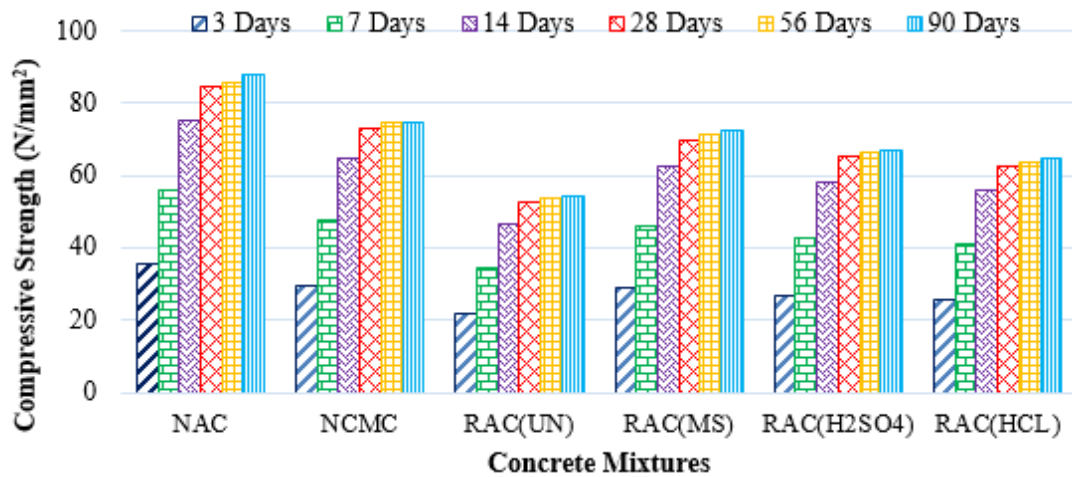


Figure 8 Compressive Strength Results of Various Mixes

After various treatment techniques, the treated RCA concrete enhances the compressing strength of both M70 grade concrete but on another hand, all the treated RCA concrete shows inferior to that of both the controlled concrete NAC & NCMC. Compared to both chemical-treated concrete RAC (H₂SO₄) and RAC (HCl); H₂SO₄ treatment enhances the coarse aggregate properties more than the HCl. Compressive strength results for the M70 grades of RCA (MS) and RCA (H₂SO₄) are quite similar to those for controlled concrete, with RCA (MS) providing the best improvement when compared to all other treated concrete. Due to its weak and loose old mortar particles, the old mortar that was adhering to the RCA was losing compressive strength. The old adhered mortars have a more porous structure so it absorbs a huge quantity of water. After the removal of old attached mortar using various techniques, the concrete gets enhanced. The weak ITZ between aggregate and the old adherent mortar in the RCA is the major cause of the concrete's characteristics degrading. This problem was fixed by removing the aggregate mortars from the aggregate surface. Figure 9 displays failure patterns [83-87].



Figure 9 Failure Patterns of Cubes under Compressive

5.6 Split tensile strength

The M70 grade high-strength concrete was cast and tested over the various curing ages. The split values are presented in Figure 10 for various combinations. When compared to NAC & NCMC, the RCA (UN) gradually decreased by 39.71, 39.26, 40.18, and 40.14 percent, respectively. At 7, 28, 56, and 90 days, the RAC (UN) decreased by 33.26, 30.05, 29.30, and 29.20 percent. The split tensile strength was improved after surface treatment of aggregate; RAC (MS) was improved by 27.21, 23.35, 22.85, and 23.10 % respectively and RCA (H₂SO₄) was enhanced by 21.44, 17.81, 19.11, and 19.20 % respectively and RAC (HCl) was increased by 15.96, 8.89, 8.98, and 9.10% respectively at 7,28,56 and 90 days. Following numerous RCA treatments, the split tensile strength increased by 8.89 percent to 23.35 percent at 28 days. In comparison to all other treatments, NAC and NCMC enhance the split tensile strength of RAC (MS) by 79.25 and 91.26 %, respectively, at 28 days. Figure 11 displays failure patterns [88-94].

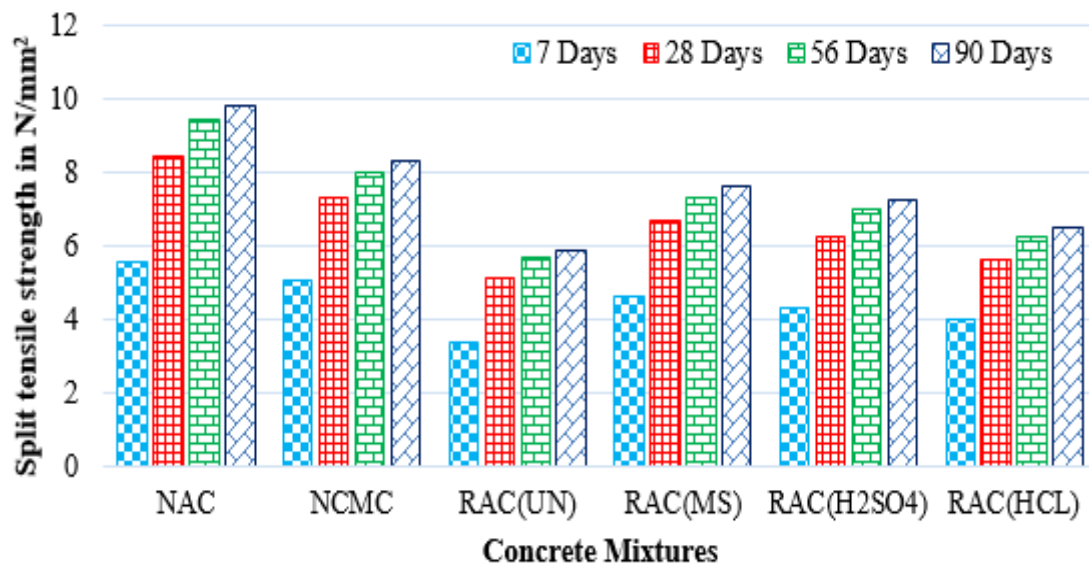


Figure 10 Split Tensile Strength

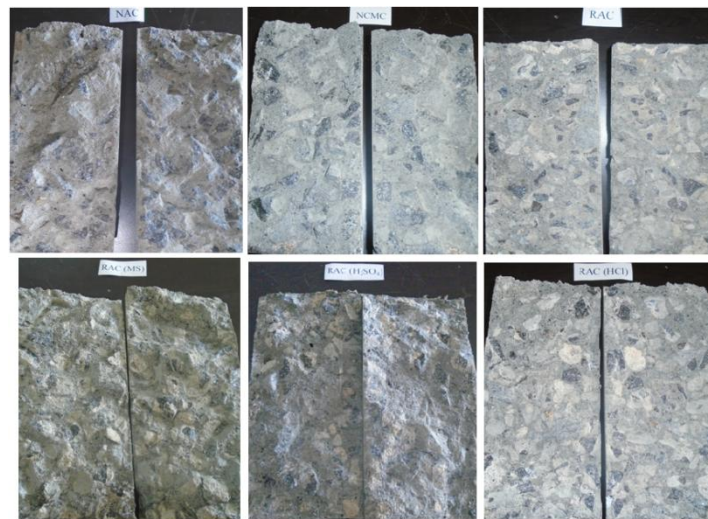


Figure 11 Failure Pattern of Split Tensile Strength

5.7 Flexural Strength Test

The M70 grade high-strength concrete was cast, tested, and evaluated after 7, 14, 28, and 56 days, respectively. Figure 12 show the results of flexural strength and Figure 13 displays failure patterns. The RCA (UN) specimen significantly reduced its flexural strength by 33.60, 34.94, 38.72, and 40.57% when compared to NAC and flexural

strength decreases by about 24.94, 25.26, 27.38, and 30.22% when compared with NCMC mixes. After mechanical scrubbing and acid treatment, the flexural strength of the concrete was improved. When related to RAC (UN), the RAC (MS) was enhanced about 17.43, 16.80, 19.58, and 19.43 % respectively; the RAC (H₂SO₄) was improved at 10.92, 11.97, 12.08, and 15.30 % respectively; the RAC(HCl) was enhanced 3.73, 1.89, 2.48, and 4.14% respectively for 7, 14, 28 and 56 days. Approximately 1.89-16.80% of value was increased after treatment of recycled aggregate. The RAC (MS) improves the flexural strength of 78.21% of NAC and 89.84% of NCMC mixes [95-98].

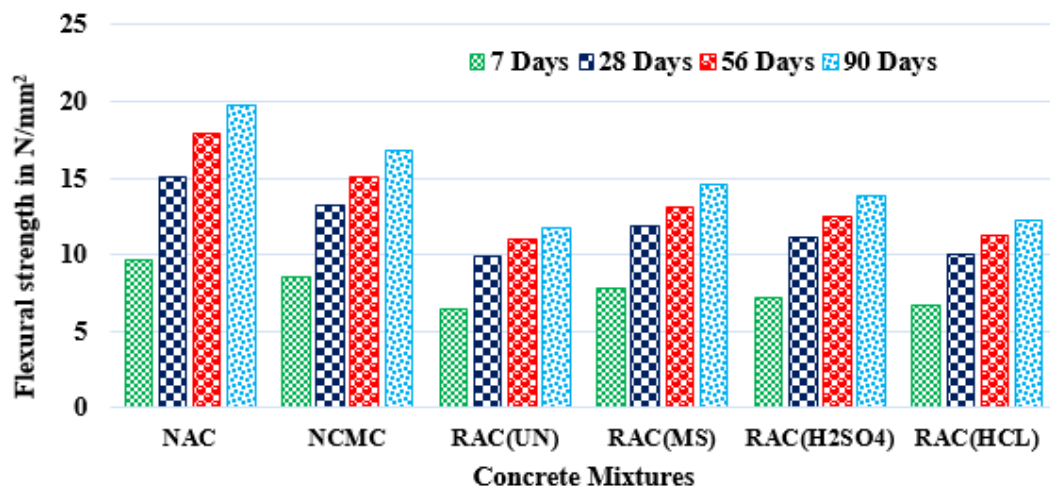


Figure 12 Flexural Strength Results



Figure 13 Failure Pattern of Flexural Strength

5.8 Modulus of elasticity

The M70 grade high strength concrete was cast and tests were run for 28, 56, & 90 days, respectively. Figure 14 both displayed the elastic modulus values. The modulus of elasticity of NAC was 42.83, 45.25, and 46.33 N/mm² and NCMC was 40.63, 43.30, and 44.38 N/mm² respectively at 28, 56, and 90 days. After different actions on RCA, the surface gets enhanced. When related to RAC (UN); the RAC (MS) gets enhanced by 17.22,15.87, and 15.55% respectively, the RAC (H₂SO₄) gets improved by 13.59,11.70, and 14.26% respectively, and the RAC (HCl) gets enhanced by 7.29,6.06 and 8.41 % respectively at 28,56, and 90 days. After mechanical and chemical treatment on RCA, the elastic modulus of gets improved roughly between 7.29 -17.22 % at 28 days, 6.06-15.87% at 56 days, and 8.41-15.55% at 90days when compared to RAC (UN). Failure patterns of modulus of elasticity are shown in Figure 15.

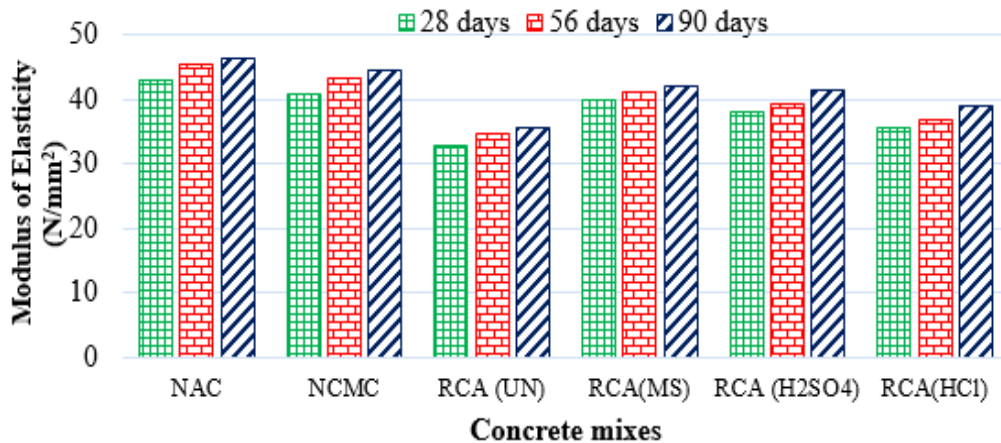


Figure 14 Modulus of Elasticity



Figure 15 Failure Pattern of Modulus of Elasticity

5.9 Impact resistance test

The impact resistance of M70 concrete was assessed in this study at 3, 7, 28, and 56 days, respectively. According to test outcomes, for the NAC mix, the first crack appeared at 56 blows, followed by the final cracks at 68 blows, and for the NCMC mix, the first crack appeared at 53 blows, followed by the last cracks at 63 blows after 28 days. However, in the case of the NAC (UN) mix, the first crack appeared after 29 strikes, and the last one after 33 blows and 28 days. The results of RAC (UN) were reduced significantly, due to the weak and loose mortar layer surrounded by aggregate. After treated aggregate, the impact resistance has enhanced. RAC (MS), RAC (H_2SO_4), and RAC (HCL) all experienced beginning cracks that were 46, 42, and 38 blows each, respectively, and final cracks that were 53, 48, and 44 blows each. After various treatment processes on RCA, all the treated aggregate concrete has required a high number of initial and final blows for the propagation of cracks when compared to RAC(UN). The initial and final crack results of various mixes for M70 was shown in Figures 16 & 17 and the Cumulative initial and final crack for M70 is shown in Figure 18 .

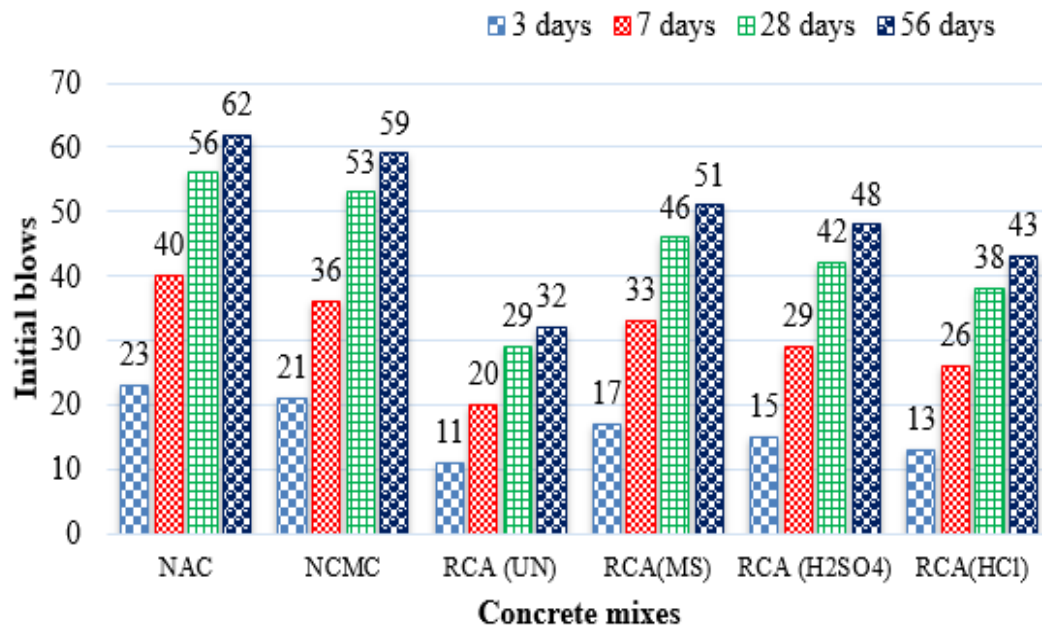


Figure 16 Impact Resistance at Initial Cracks

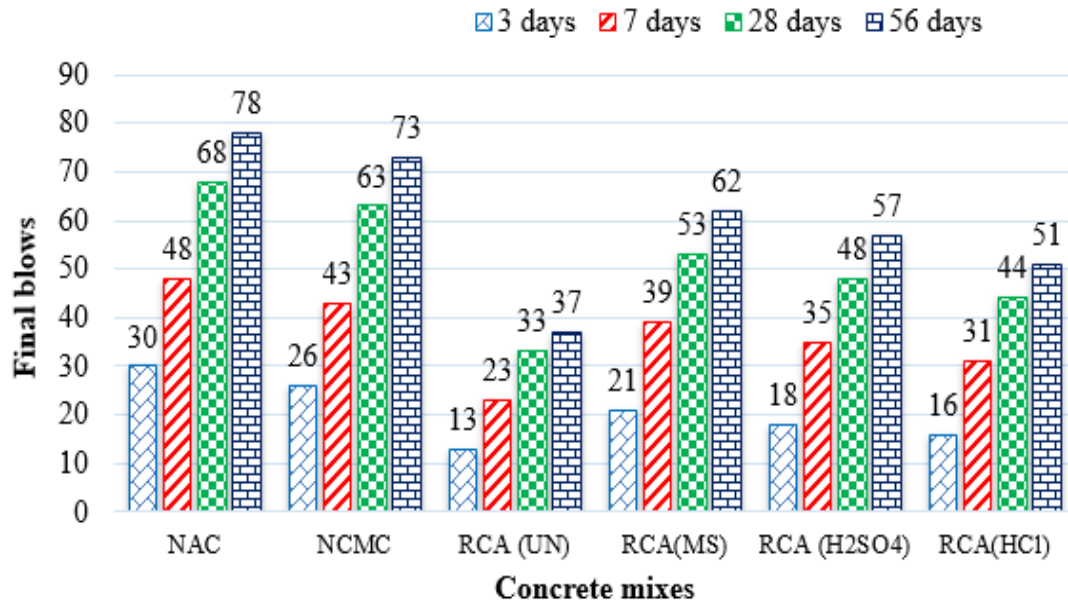


Figure 17 Impact Resistance at Final Cracks

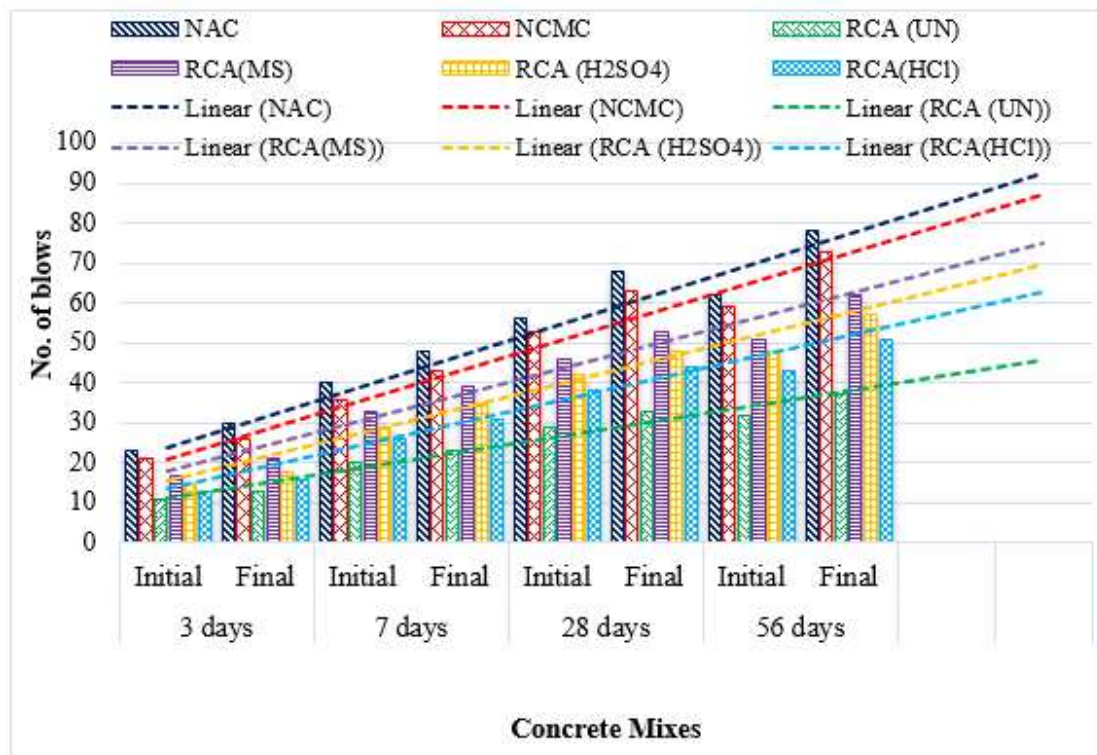


Figure 18 Impact Resistance at Initial and Final Cracks

6.0 Conclusion

The study comes to the conclusion that the presence of attached old mortar, which increases porosity and water absorption, causes untreated recycled coarse aggregate (RCA) to considerably impair the mechanical and durability qualities of concrete. To increase the quality of RCA, a variety of treatment methods were used, but mechanical scrubbing turned out to be the most successful since it removed the most adherent mortar and improved surface properties. Although to a lower degree than mechanical treatment, chemical treatments with hydrochloric and sulfuric acids also enhanced aggregate characteristics. Concrete's workability declined when RCA was left untreated, but it improved after treatment because less water was absorbed. In treated RCA mixtures, compressive, split tensile, and flexural strengths were significantly increased; mechanical scrubbing demonstrated the best results. Following treatment, the modulus of elasticity and impact resistance both rose, demonstrating greater toughness and stiffness. Even treated RCA concrete, however, performed somewhat worse than natural aggregate concrete. Sulfuric acid outperformed hydrochloric acid

in chemical techniques. In general, improving concrete performance requires treating RCA. Therefore, processed recycled aggregates can be utilized in structural concrete as a sustainable substitute.

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Availability of data and materials

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Competing interests

The authors declare that they have no known competing and financial interests or personal relationships that could have appeared to influence the work reported in this paper. The authors declare the following financial interests/personal relationships which may be considered as potential competing interests.

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Authors' contributions

JVMR: Original draft; Formal analysis; Methodology.

KA: Conceptualization; Project administration

MB: editing; Formal analysis.

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