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Evaluating performance characteristics of recycled aggregate concrete: A study through experimentation

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Abstract

This study surveys the display characteristics of Recycled Aggregate Concrete (RAC) through experimentation, focusing on key material properties and mix degrees. The RAC blends, signified as R-0 and R-45 addressing various rates of Recycled Concrete Aggregate (RCA) substitution, were examined for new properties, compressive strength, and solidness. The blend extents included concrete (C), fine aggregate (FA), natural coarse aggregate (NCA), RCA, silica fume, water, and superplasticizer (SP). New properties, for example, compaction factor, alongside 28 days compressive strength, were determined for all RAC blends. Sturdiness tests included corrosive opposition, scraped area obstruction, and water penetrability tests. Results showed that RAC displayed decreased compressive strength and expanded weight reduction contrasted with traditional concrete (R-0) when exposed to corrosive assault. Be that as it may, the compressive strength decrease was less articulated in RAC exposed to sulfate assault, credited to the arrangement of ettringite. Scraped area obstruction tests uncovered that R-45 had higher normal misfortune in thickness contrasted with R-0 however remained inside adequate cutoff points. Water porousness tests showed higher profundity of entrance in RAC contrasted with R-0, conceivably because of stuck mortar. Nonetheless, both RAC and R-0 showed satisfactory water assimilation values. The study suggests that RAC could offer viable alternatives in construction applications while addressing sustainability concerns. Further research is recommended to explore RAC's performance under elevated temperatures and correlate split tensile strength with corresponding results.

Keywords: Recycled aggregate concrete (RAC), Compressive strength, Durability, Acid resistance, Sustainability

1. Introduction

Durability is the ability of the concrete to resist the process of deterioration when exposed to the intended service environment [1]. The solidness element of a design is supposed to be sufficient in the event that it acts as per the planned capability and workableness over the normal time of life [2]. As concrete is a permeable material, the development of dampness happens by stream, dissemination, or adsorption [3]. This multitude of modes is significant and is eluded as porousness which gives by and large potential to dampness and particles to entrance into the concrete [4]. The strength of the concrete relies generally upon the simplicity with which liquids, such as fluid or gas, can penetrate through the solidified concrete. In this research, an effort is made to study the durability characteristics of RAC [5]. The durability of concrete is affected by the chemical reaction that causes interaction between aggressive agents that may be present in the external environment and the internal constituents of concrete. These reactions can lead to cracking and spalling of concrete resulting in reduced strength [6].

The effect of compound response on the strength elements of the concrete is concentrated by exposing RAC to corrosive assault, sulfate assault, and saltwater assault. Moisture movement in concrete causes the concrete to swell [7]. This causes carbonation leading to the deterioration of concrete [8]. In this study, moisture movement in concrete was studied by conducting experiments like water absorption test, sorptivity test, permeability test, and rapid chloride penetration test (RCPT) as per relevant Indian standards and ASTM standards. Elevated temperatures up to 800ºC were tested on RAC to understand the residual strength in compression and tension [9]. Resistance to wear due to sliding, impact, and scarping was studied by carrying out an abrasion resistance test on RAC. The dimensional stability of RAC was studied by shrinkage and creep [10]. Durability performances of RAC were conducted and the results are presented [11].

Advancements in science and technology have revolutionized the development of construction materials, necessitating the incorporation of innovative scientific inventions [12]. The rapid pace of technological progress has spurred infrastructure development, increasing the demand for natural resources like sand, rocks, and concrete in civil engineering projects [13]. Notwithstanding, this flood in development movement has likewise prompted a huge age of development and destruction (C and D) squandering, presenting natural difficulties [14].

C & D waste, comprising materials like concrete, brick, and metal, presents disposal challenges as these materials are not biodegradable [15]. Recycling emerges as a crucial solution to efficiently manage C & D waste, conserve energy and resources, and mitigate environmental impacts [16]. Successful use of these materials relies on different factors including their appropriateness for various applications, financial contemplations, and consistency with ecological guidelines [17].

To facilitate reusing endeavors, squandered materials should be arranged into recyclable and non-recyclable classes (Pradhan, 2020). Recyclable materials include petrous-beginning substances like minerals, rocks, glass, and metal, which can be incorporated into development projects [18]. On the other hand, non-recyclable materials like wood, vegetation, paint remainders, paper, and fabric can't be integrated into structures because of their non-petrous nature [19]. Appropriate portrayal and characterization of waste materials are fundamental for maintainable development rehearses and natural stewardship [20].

Using development and destruction (C and D) squander faces difficulties because of lacking awareness of important codes, specifications, and guidelines, as well as restricted data on the accessibility of recycled aggregates [21]. The energy consumption of recycled aggregates must be monitored, and their quality varies depending on factors like the parent concrete and demolition methods [22]. Generally, recycled aggregates have lower quality compared to virgin materials, although performance-based design methods favor their use [23]. Improving technology through experimentation is crucial for enhancing the quality of recycled materials [24]. Machines used for processing recycled aggregates have evolved to meet the demand for aggregates with low water absorption, resulting in lower energy consumption [25].

Despite these challenges, there are several advantages to using C & D waste:

- Reduction of environmental burden: Effective utilization of natural resources reduces depletion [26].
- Energy savings: Fractional supplanting of regular aggregates with recycled aggregates decreases the energy consumed in moving virgin unrefined components [27].
- Mitigation of global warming and pollution: Using recycled aggregates instead of virgin ones can reduce pollution and act as a partial supplement material, thereby contributing to mitigating global warming [28].

- Reduction of landfill accumulation: Utilizing C & D waste reduces the need for landfill space, alleviating the scarcity of landfill areas and promoting a healthier living environment [29, 30].

2. Literature review

Researchers Andreu and Miren drove a preliminary assessment to explore the properties of tip-top execution recycled aggregate concrete [31]. Their audit focused in on assessing the mechanical properties, such as compressive strength and solidness, of RAC stood out from conventional concrete. The revelations suggested that RAC can achieve comparable execution to conventional concrete, highlighting its actual limit as a possible choice being developed. Puthussery, Kumar, and Garg guided a preliminary report to survey the appropriateness of recycled concrete aggregates (RCA) for improvement works. Their assessment planned to review the physical, mechanical, and solid properties of RAC coordinating different degrees of RCA [32]. The results showed that RAC containing RCA met the necessities for various advancement applications, displaying the feasibility of involving recycled aggregates in concrete creation. Purushothaman, Amirthavalli, and Karan investigated the effect of treatment methods on the strength and execution characteristics of recycled aggregate concrete [33]. Their survey researched different treatment strategies, similar to substance and warm medicines, to update the properties of recycled aggregates and in this manner work on the introduction of RAC. The discoveries recommended that fitting treatment techniques can successfully improve the strength and solidness of RAC, accordingly expanding its true capacity for far and wide reception in development projects.

Dilbas, H., Çakır, Ö., and Atiş, C. D. directed a trial examination zeroing in on the properties of recycled aggregate concrete using an improved ball processing strategy. Their review expected to upgrade the nature of recycled aggregates through processing, subsequently working on the presentation of concrete [33]. The discoveries probably give experience into the adequacy of processing processes in improving the properties of recycled aggregates and subsequently the mechanical properties of concrete. Bai, G., Zhu, C., Liu, C., and Liu, B. assessed the attributes of recycled aggregates and the mechanical properties of concrete consolidating these aggregates [34]. Their concentrate probably offers significant experiences into the connection between recycled aggregate properties and the exhibition of concrete. Seeing such connections is significant for upgrading concrete mix designs and achieving accommodating mechanical properties in recycled aggregate concrete. Leite, M. B., and Santana, V. M. coordinated an evaluation of a preliminary mix degree study highlighting conveying concrete using fine recycled aggregate [35]. This focus likely gives significant information on the believability and sufficiency of involving fine recycled aggregates in concrete creation.

Fine aggregates expect an essential part in the concrete show, and understanding their direction in recycled aggregate concrete is central for sensible improvement practices. Kox, S., Vanroelen, G., Van Herck, J., De Krem, H., and Vandoren, B. played out an exploratory appraisal of the extraordinary level properties of recycled concrete aggregates (RCAs) and their application in concrete road asphalt improvement [36]. This concentrate presumably offers critical encounters into the normal purposes of RCAs in essential establishment projects. Understanding the introduction of RCAs specifically applications like road asphalt improvement is crucial for propelling their vast use and understanding the upsides of practical advancement practices. Das et al. conducted a survey focused on evaluating the introduction of polypropylene fiber-upheld recycled aggregate concrete [37]. Their investigation planned to review the mechanical properties and solidness of concrete mixes containing recycled aggregates, with the development of polypropylene strands to overhaul the material's presentation. This concentrate likely adds to understanding the ability to coordinate both recycled aggregates and strands to deal with the essential and strong parts of concrete.

Arezoumandi et al. investigated the shear strength of upheld concrete bars utilizing 100% recycled concrete aggregate (RCA) [38]. Their trial study is expected to survey the underlying way of behaving and execution of concrete components containing completely recycled aggregates. By zeroing in on shear strength, the examination gives important experiences into the underlying honesty and burden-bearing limit of concrete designs developed with recycled materials [39]. Pacheco et al. directed an exploratory examination to investigate the changeability of the real mechanical properties of concrete created utilizing coarse recycled concrete aggregates (CRCA) [40]. Their concentrate probably resolved the issue of conflicting mechanical properties frequently connected with recycled aggregates because of varieties in creation and quality. By understanding the fluctuation of mechanical properties, specialists and professionals can foster methodologies to advance concrete blend plans and guarantee the unwavering quality and execution of designs consolidating recycled materials [41].

3. Methodology

3.1. Recycled coarse aggregate

The RCA expected for the current review was handled physically from the C and D waste. The C and D waste was first pounded and diminished to the necessary size. In the wake of pounding, the recycled aggregates were screened and isolated to show up at aggregates of 20mm and 12.5mm cut back and waste as stuck mortar content was wiped out. Further, the RCA was washed to remove the adhered mortar content. The RCA was then aerated. Hence, RCA of 20mm and 12.5mm size were prepared and used initially. Further, works were carried out by procuring a 12.5mm downsize RCA from the recycling plant. The sifter examinations of 20mm and 12.5mm RCA are contemplated and considered affirming to IS 2386 (Section I): 1963 (Reaffirmed 1990) as displayed in shows the molecule size dispersion of 20mm and 12.5mm RCA and addresses the designing properties of RCA.

Table 1. Sieve analysis

SI. No	Sieve Size	Weight Retained (gm)	Cumulative Wt. Retained (gm)	Cumulative % Wt. Retained	% Wt. passing
1	12.5 mm	8	8	0.8	99.2
2	10 mm	345	353	35.3	64.7
3	8 mm	606	959	95.9	4.1
4	4.75mm	27	986	98.6	1.4
5	2.36 mm	10	996	99.6	0.4
6	1.18 mm	0	996	99.6	0.4
7	600 u	4	1000	100	0
8	300	0	0	0	0
The sum of cumulative % weight retained					829.8

Figure 1. RCA of 12.5mm size

Figure 2. RCA of 12.5mm size

3.2. Modulus of elasticity of RAC

The ratio of normal stress to strain of a material within the elastic range measures the instantaneous elastic deformation. This measure of strain experienced by the material when loaded is the modulus of elasticity of the material. In this study, the experiment is carried out to know the theoretical and practical elastic modulus of RAC. The versatile modulus of the RAC example was led on barrel shaped example of size 100 mm breadths and level 200mm utilizing CTM. The normal compressive strength of the example was recorded, before directing the test for flexible modulus. Compress meters are mounted on the cylindrical specimen on either end of the cylindrical specimen parallel to the axis of the specimen as shown in Figure. The experiment was carried out on 28 days of cured RAC specimens.

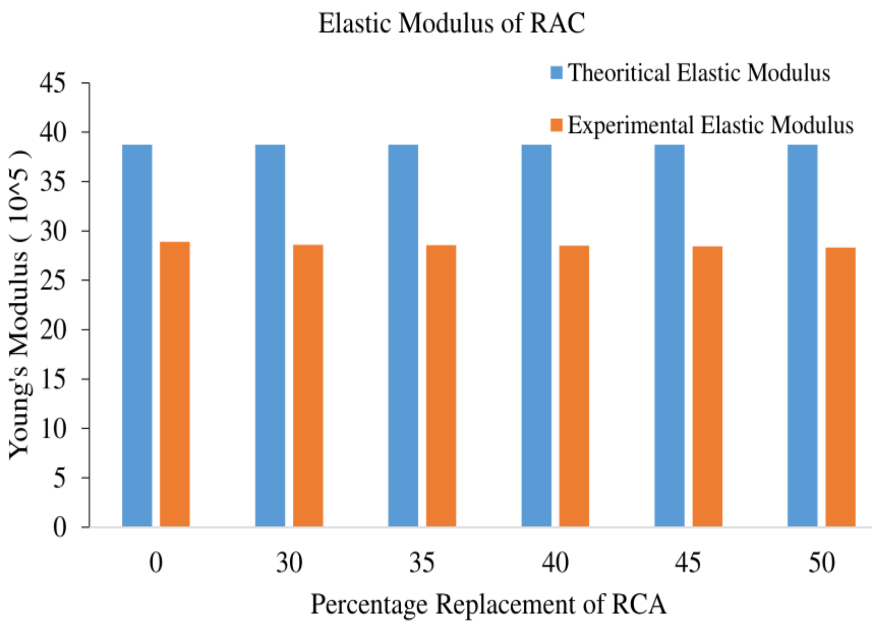

Figure 3. RAC elastic modulus for various replacement ratios

3.3. Predictive analysis of the shear strength of RAC

In this research, the shear capacity of RAC is studied using L-shaped specimens of size 150 × 90 × 60 mm which are tested on CTM of capacity 1000kN. The specimens are subjected to direct shear force which is applied on the shorter span of L specimens, where the load is applied on the area 150 × 60 mm. RAC L-shaped specimens of RAC for M60 grade of concrete were prepared. The compaction of concrete was done using a table vibrator. Examples were relieved for 28 days and 56 days.

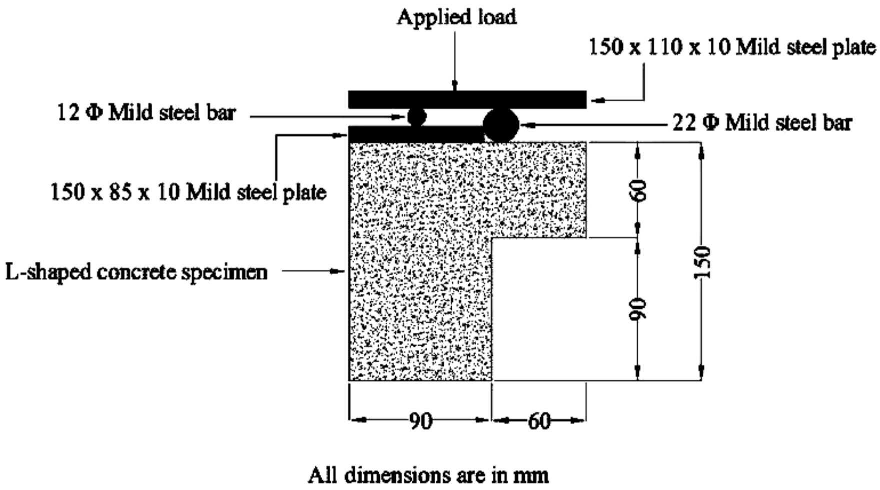

Figure 4. Schematic diagram of push-off specimen of RAC

Figure 5. Push-off specimen tested for shear strength

The shear strength of RAC is studied by considering experimental as well as predictive analysis. In this study, a model is created by considering the following parameters: w/b ratio, compressive strength, and replacement ratio of recycled coarse aggregates. Regression analysis is carried out to predict the relationship between shear strength, water-binder ratio, compressive strength, and replacement ratio of RAC.

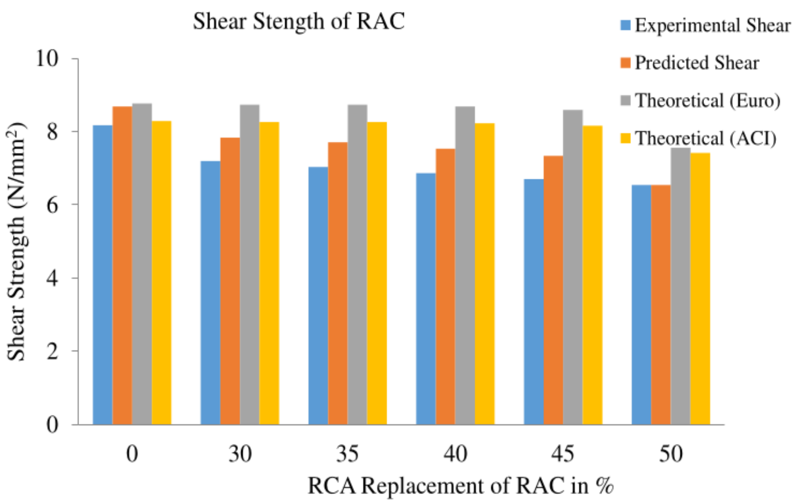

Figure 6. Shear strength of M60 grade of RAC

4. Results

Basic material properties of ingredients used in RAC. The mix proportions used for RAC.

Table 2. Mix proportions for RAC

RCA Replacement %	C	FA	NCA	RCA	Silica Fume	Water	SP
R-0	500	665.53	1000	0	55.55	150	12.5
R-45	500	633.40	550	450	55.55	150	12.5

4.1. Fresh properties and compressive strength

For all RAC mixes, indicate the fresh and hardened properties.

Table 3. Fresh property and compressive strength of RAC

Type of concrete	Compaction factor	Vee- Bee (Sec)	28 days compressive strength (MPa)
R-0	0.883	6	69.2
R-30	0.841	8	68.16
R-35	0.835	9	68.82
R-40	0.83	10	68.25
R-45	0.821	11	67.12
R-50	0.819	12	59.26

4.2. Durability tests

Durability tests are carried out for RAC to know the performance during the anticipated exposure.

4.2.1. Acid resistance test

As concrete is not a completely impervious material, the ingress of acid attacks the calcium hydroxide along with CSH gel. Concrete is susceptible to acid attack when exposed to acid with a pH value below 4.5. Acid attacks rapidly disintegrate the concrete by breaking the compounds of cement and leaching away carbonate aggregate material. The corrosive obstruction test was done by drenching a 150mm 3D shape example at 28 years old days in water weakened with 2N, i.e. 10% by weight of hydrochloric corrosive, for a considerable length of time. The solid shapes were exposed to substitute wetting and drying for at regular intervals. After this the examples were taken out from the arrangement and the typical rate of weight reduction and compressive strength was recorded.

Table 4. Outcomes of submerged RAC cubes in HCl

No. of days of curing in acid	Average weight loss (%)		Average compressive strength (N/mm2)	
(HCl)	R-0	R-45	R-0	R-45
8	0.97	1.106	69.17	67.12
16	1.592	1.761	62.22	66.97
24	2.113	2.268	58.96	64.67
32	2.17	2.387	59.85	59.43
40	2.677	2.738	61.31	56.45
48	2.977	2.98	58.21	58.32
56	3.234	3.413	57.42	55.84

It is seen that the normal compressive strength of R-0 and R-45 diminishes reliably as the number of days increases. With respect to weight loss, it is observed that weight loss becomes more or less the same in both R-0 and R-45 as the number of days increases. The RAC specimens were immersed in an HCl solution.

Figure 7. RAC specimens immersed in different solutions

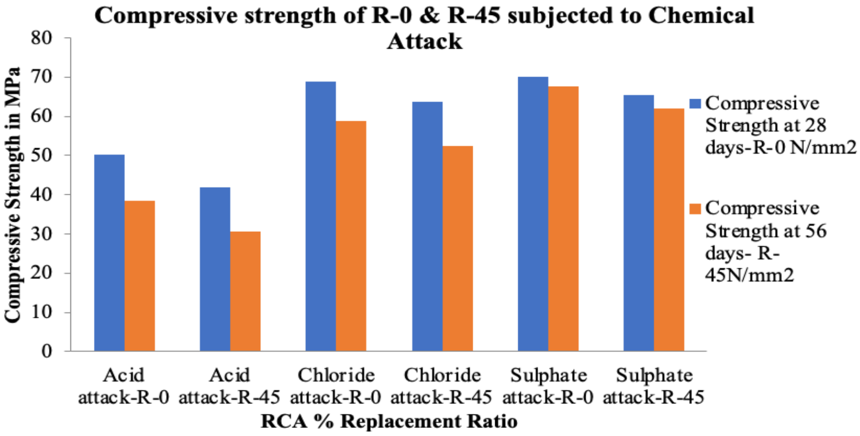

Figure 8. RCA% replacement ratio

The compressive strength of RAC subjected to sulfate attack shows comparatively less reduction in compressive strength than acid attack. This may be attributed to the formation of ettringite which is responsible for forming a good bond between mortar and aggregates. From we can observe that the compressive strength of R-0 and R-45 are lower than the target strength for 28 days by 3.0% and 2.02%. The loss in compressive strength and weight may be attributed to high alkaline levels due to the adhered mortar of RAC which results in reduced resistance to chemical attack.

4.2.2. Abrasion resistance test

Concrete members are subjected to abrasion that occurs due to the wearing of pavements and industrial floor surfaces due to dry attrition or the wearing of surfaces due to the movement of traffic. Abrasion resistance of concrete occurs due to the friction of the wearing surface that causes scarping and sliding of objects on its surface. Abrasions of concrete members are influenced by factors such as compressive strength, surface finish, and aggregate properties. Thus, while considering aggregates, having hard surface aggregates with low porosity and high strength is vital. The scraped area opposition test was done according to IS 1237-2012 code of work, taking into account the example of size 70 × 70 × 35 mm after projecting and relieving for 28 days. Aluminum oxide containing at the very least 95% by mass was utilized as scraped spot powder with a particular gravity of 4 and a hardness of 9 on Mohr's scale.

The scraped spot test was done on RAC with a substitution proportion of 45%, named as R-45. The examples considered were dried for 24 hours before testing, and their dry loads were recorded. The example was set apart with five focuses at the top surface, i.e., four at corners and one at the focal point of the example. Advanced calipers were utilized to quantify the thickness of the example, by setting the example in the attachment. Grating charges are taken care of consistently in the funnel-shaped game plan, where the crushing circle is kicked off at a speed of 30 cycles each moment. The example is exposed to 220 unrests, according to the detail, and the thickness of the example is estimated at determined five places. The wear because of scraped spots was communicated as the contrast between the underlying and last thickness estimated at the five focuses that were chosen, and the distinction in weight was kept in rate weight reduction. The thickness of the example after the scraped area test is gotten utilizing condition 4.1 which gives the typical misfortune in thickness of the examples.

Figure 9. Specimen placed in abrasion testing apparatus

Table 5. Abrasion resistance test results

Sl. No	% Weight Loss		Loss in Thickness(mm)	
	R-0	R-45	R-0	R-45
1	1.48	2.56	1.13	2.45
2	1.57	3.16	0.71	2.65
3	1.82	3.84	0.93	2.97
4	1.80	2.42	0.69	2.24
5	1.29	3.18	0.54	2.67
6	1.79	1.98	0.45	2.18
7	1.91	2.29	0.82	2.22
8	1.77	2.37	1.03	2.28
Average loss	1.68	2.72	0.79	2.46

The typical misfortune in thickness of R-45 because of the scraped spot was around 2.46 mm, while the typical misfortune in thickness of R-0 because of the scraped area was 0.79 mm. The results indicate that the abrasion resistance of R-45 is less than that of R-0, but it is well within the acceptable limits.

4.2.3. Water permeability test

The porousness of concrete that oversees the pace of the stream of a liquid in concrete is one of the basic factors that add to the sturdiness of concrete against forceful specialists. The miniature breaks at the underlying stage in concrete may not influence the penetrability, but rather as these miniature breaks increment with time due to drying shrinkage, warm shrinkage, and because of remotely applied load, the porousness of concrete will increment. In this review, the porousness of R-0 and R-45 were tried utilizing IS: 3085 - 1965(Reaffirmed 2004) code on 150mm 3D shape examples. The examples were relieved for 28 days surface dried for 24 hours and set in a penetrability testing contraption. The outer layer of the R-0 and R-45 specimens was exposed to a water strain of 1 bar (kg/cm2) and the tension was kept up for 48 hours. Then, at that point, the water pressure was expanded to 3 bars in the following 24 hours. Further, the water pressure was expanded from 3 bars to 7 bars in the following 24 hours. Right away, after the test was finished, the examples were parted midway at the mark of the utilization of water under tension, and the profundity of water entrance was estimated and kept in 'mm' and the typical qualities.

Table 6. Depth of penetration

Sl. No	Depth of Penetration (mm)	
	R-0	R-45
1	1	2
2	2	3
3	1	4
4	1	2
5	2	6
6	3	4
Average	1.6	3.5

The average depth of penetration in R-45 was 3.5 mm, while the average depth of penetration in R-0 was 1.60 mm.

5. Discussion

5.1. Durability of RAC due to chemical attack

The weight loss experienced by RAC increases as the age of the concrete increases. The percentage of weight loss experienced by RAC is about 15% more than by R-0. Weight gained by RAC at 28 days is more compared to the weight gained by RAC at 56 days when subjected to NaCl.

Weight acquired by RAC is not as much as R-0 when exposed to sulfate assault. The compressive strength of RAC exposed to sulfate assault shows similarly less decrease in compressive strength than when it is exposed to corrosive assault. This might be ascribed to the arrangement of ettringite which is liable for good connection among mortar and aggregates.

5.2. Abrasion resistance of RAC

The average loss in thickness of RAC due to abrasion was around 2.46 mm, whereas the average loss in thickness of R-0 due to abrasion was 0.79 mm indicating that the abrasion resistance of RAC is less than that of R-0 but it is well within the acceptable limits.

5.3. Moisture movement in RAC

Water Assimilation of RAC is around 3.2% more than R-0 at 28 days; this might be because of the presence of stuck mortar in RAC. The average depth of water permeability of RAC is 3.5mm compared to the 1.60 mm depth of R-0 and it is well within the permissible limits. From the results of RCPT, we can say that RAC exhibits low chloride ion permeability, whereas R-0 specimens show very low chloride ion permeability.

From the sorptivity test, we can see that water ingestion of RAC is higher when contrasted with R-0. This may be due to the fact that RAC contains adhered mortar and is, therefore, susceptible to absorbing more water. However, the water absorption of RAC is well within the acceptable limits. Leftover strength of RAC when exposed to raised temperature. The lingering compressive strength of RAC when exposed to increased temperature is higher than the leftover compressive strength of R-0. This shows that RAC has preferred protection from raised temperature over R-0.

When presented with a raised temperature, RAC has better extra split versatility diverged from R-0. This shows that RAC has favored assurance from raised temperature over R-0. Nonetheless, the qualities are more contrasted with values distributed in the writing. More tests are expected to illuminate this so that split elasticity can be associated with the corresponding outcomes.

6. Conclusion

In talking about the ramifications of our exploration discoveries, it's vital to contextualize the exhibition attributes of recycled aggregate concrete (RAC) inside the more extensive landscape of reasonable development materials. Our review dug into different aspects of RAC, going from essential material properties to strength under various ecological circumstances. These discoveries offer important experiences for practitioners and analysts the same, molding conversations on the practicality and reception of RAC in certifiable development situations. One critical aspect of our examination was the evaluation of RAC's new properties and compressive strength. The noticed decreases in compressive strength and expanded weight reduction of RAC when presented with corrosive assault contrasted with customary concrete (R-0) highlight the significance of understanding its conduct in synthetically forceful conditions. In any case, the moderately relieved decrease in compressive strength in RAC exposed to sulfate assault recommends an expected benefit with regards to solidness, credited to the development of ettringite.

The assessment of scraped spot obstruction uncovered nuanced discoveries, with R-45 displaying a higher typical misfortune in thickness contrasted with R-0, but inside satisfactory cutoff points. This proposes that while RAC might encounter more prominent wear under grating circumstances, it stays a suitable choice for applications where scraped spot obstruction is urgent. Also, the higher profundity of penetration seen in RAC contrasted with R-0 in water porousness tests features the need for cautious thought of RAC's defenselessness to dampness entrance, conceivably because of stuck mortar. These discoveries brief more extensive conversations on the job of RAC in supportable development rehearses. While RAC shows promising execution qualities, including OK scraped area opposition and water retention values, further examination is justified to investigate its conduct under raised temperatures and to lay out thorough execution benchmarks. Furthermore, endeavors to associate split rigidity with corresponding outcomes can give important bits of knowledge into RAC's mechanical properties and illuminate more precise plan contemplations.

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Conflict of interest

The authors declare that they have no conflict of interest.

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