JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Mechanical and Durability Effect of Recycled Aggregate in Concrete

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Abstract

The construction sector generates a significant amount of concrete waste, a type of construction and demolition (C&D) waste, which is typically discarded in landfills. This waste can be recycled into recycled coarse aggregates (RCA) and used as a substitute for natural aggregates in concrete production, potentially aiding environmental conservation. This research investigates the properties of Recycled Aggregate Concrete (RAC) by creating two types of concrete samples: one with RCA and the other with Natural Coarse Aggregate (NCA). Laboratory experiments aim to evaluate the fundamental performance of these concretes. The primary objective is to assess the key characteristics of recycled aggregate materials and determine their viability as replacements for virgin aggregates. The study explores varying substitution rates, with up to 20% of natural aggregates replaced by recycled aggregates, to identify the most effective mix. It is widely acknowledged that incorporating recycled aggregates can diminish the durability and compressive strength of concrete. Various approaches have been tested to address the inferior quality of recycled aggregates in concrete production. This study specifically examines the impact of adding fly ash to the concrete mix as a method to mitigate the drawbacks associated with lower-quality recycled particles.

Introduction

As the global population increases and urbanization progresses, the demand for new buildings and infrastructure rises. Consequently, the construction Industry produces a large amount of trash and uses a large number of natural resources. particularly during demolition and renovation projects. To mitigate the environmental impact of the construction sector, there is a growing interest in utilizing building materials derived from construction and demolition (C&D) waste. This study explores the potential of using C&D waste as a source of coarse aggregate for concrete production, contributing to sustainable development by reducing waste and conserving natural resources. The paper reviews the properties, effectiveness, and environmental implications of employing recycled coarse aggregate in concrete, as documented in the literature. Research indicates that recycled coarse aggregate can produce concrete with mechanical properties comparable to those made with natural coarse aggregate, while also being more environmentally friendly.

The latest data on C&D waste generation and utilization varies by region and country:

United States: The US generated 569 million tonnes of C&D waste in 2018, with 90% originating from demolition, according to the US Environmental Protection Agency. Approximately 25% of this waste, or about 145 million tonnes, was recycled or reused .

European Union: The European Commission reports that C&D waste constitutes about 25% of the EU's total waste, with an annual production of 1.5 billion tonnes. In 2014, the EU recycled around 50% of C&D waste, aiming for a 70% recycling rate by 2020 .

China: A World Bank report states that China produced 1.5 billion tonnes of C&D waste in 2015, accounting for roughly 40% of the nation's total waste. The report also highlights China's low C&D waste recycling rate, estimated to be less than 5% .

India: According to the Ministry of Environment, Forests, and Climate Change, India generates approximately 530 million tonnes of C&D waste annually, but only about 10% is recycled .

Literature review

1. Jinsong Liao looked into A crystalline substance that is permeable was used as reinforcement for Recycled Aggregate Concrete (RAC). Recycled aggregate rate of replacement have been calculated at 0%, 50%, and 100%. The research investigated the mechanical characteristics, slump, and longevity of RAC prior to and following reinforcing. Results indicated that the performance of RAC improved when reinforced with the osmotic crystalline material.

2. Moetaz M. El-Hawary Studies The durability of various types of recycled aggregate concrete was found to be comparable to that of control concrete. The impact of exposure to sea water, soil conditions, and open air for up to one year was generally similar for both recycled and new concretes.

3. Prateek Malik At the age of 28 days, all mixtures reached in terms of compressive strength. The control mix's compressive strength, or m0, is 51.2 MPa. M1's compressive strength is somewhat lowered to 50. Compressive strength for m2 increased to 50.15 MPa, indicating an increase in strength as well. The m3 compressive strength reduced to 49.3 MPa, indicating a drop in compressive strength. Accordingly, test findings indicate that there is no consistent trend in compressive strength from m0 to m3. However, the findings also indicate that, throughout the course of 28 days, compressive strength never fell short of the required strength. This suggests that RCA can be substituted for aggregates in applications requiring compressive strength.

4. Ahmadi et al. (2017) the impact of steel fibers (SF) from used tires on the strength performance of standard and recycled aggregate concretes was assessed in this study. Fibers from steel were added to the concrete mixture at volumes of 0.5% and 1.0%, while natural coarse aggregates were substituted with recycled coarse aggregates at percentages of 0%, 50%, and 100%. The results showed that while the flexural strength increased, the indirect tension and compressive strengths fell as the percentage of recycled coarse aggregate increased. Furthermore, the strength of tensile, flexural strength, and flexural toughness of the reused aggregate concrete were improved by raising the fiber content. 1.0% fiber content produced the highest split tensile and flexural strength ratings. However, the compressive strength of recycled aggregate concrete increased initially when the fiber content was increased to 0.5% and 1.0%, but it then decreased. Thus, 1.0% is the ideal fiber content.

5. Nawaz et al. (2020) The study looked at how recycled aggregate concrete's strength changed when fly ash was used in part instead of regular Portland cement. Recycled coarse aggregate was used at 50%, 80%, and 100% in place of natural coarse aggregate, while fly ash was used at 0%, 10%, 20%, and 30% in place of cement. Workability, fresh density, and compressive strength were the main topics of the inquiry. After 28 and 90 days of curing, the results showed that adding fly ash improves the strength in compression of recycled aggregate concrete and makes up for the loss of characteristics in new RAC. Fly ash also lessens the adverse impacts of RCA on porosity and density. It was determined that when it comes of resistance to chloride penetration, mixes containing 50% RCA and 20–30% fly ash outperform the reference mix.

6. Koushkbaghi et al. (2019) The study looked at how long-lasting reinforced concrete made of steel fibers would be if it contained 20% rice husk ash (RHA) in place of some of the regular Portland cement and 100% recycled aggregate in place of natural coarse aggregate (NCA). The study looked at mechanical properties such as splitting tensile strength and compressive strength, along with long-term durability attributes such as water absorption and chloride resistance. Both fibrous and non-fibrous concrete were evaluated with RHA and recycled coarse aggregate (RCA). The findings indicated that increasing the RCA replacement from 50% to 100% led to a decrease in strength properties and an increase in water absorption, chloride diffusion, and acid attack susceptibility. However, adding RHA to the concrete improved its compressive strength, showing increases of 1.9%, 3.95%, and 8.6% over the control at 28, 90, and 236 days, respectively. Additionally, the inclusion of RHA made recycled aggregate concrete more durable, making up for RCA's generally worse performance. The investigation came to the conclusion that rice husk ash can effectively replace regular Portland cement in the construction of RAC, enhancing the concrete's microstructure and the bond between the concrete and the fibers.

Methodology

Slump Test

As per the Indian IS 1199-1959 standard, the slump cone test is utilized to assess the workability of concrete mixed in a laboratory setting. While the slump value is commonly used to indicate workability and reflect the water-to-cement ratio, it is also influenced by other factors such as the properties of the materials, mixing methods, dosage, and the use of admixtures.

After completing the Slump test, six cubes need to be prepared for further testing using a lab-prepared concrete mix, such as M15, with the appropriate cement-to-water ratio. To create the concrete cubes, start by preparing the mold. Fill the mold with the concrete mixture in four layers, 37evelling each layer with a tamping rod. Use a trowel to remove any excess concrete from the surface of the sample to measure its slump value. Then, quickly lift the mold vertically away from the concrete. The slump value is measured by calculating the difference in height between the tested sample and the mold after its removal.

It's important to note that while the slump test provides an indication of the concrete mix's workability, it doesn't solely determine the overall quality of the concrete. Other factors that influence concrete quality include the properties of the materials, mixing methods, quantities used, and any additional admixtures.

Fig 1: Slump Cone Apparatus

Water Absorption

Water absorption refers to the quantity of moisture absorbed by the aggregate. It is measured under both saturated surface dry and oven-dried conditions. It is noted that the water content in a concrete mix directly impacts concrete's compressive strength and setting time.

Recycled aggregate has a higher water absorption capacity than natural aggregate.Recycled aggregate sourced from four different origins exhibited a water absorption rate 3 to 5 times greater than that of natural aggregate under saturated dry conditions. Particularly, RA4 displayed a higher water absorption rate compared to aggregates made of recycled materials as well as natural aggregate.
RA4 – Recycled aggregate obtained from old demolished building.

Compressive Strength

The compressive strength test, commonly employed to assess the overall strength of concrete, is outlined in IS 516 (1959). Either a cube or cylinder specimen is utilized for the test. To ensure uniformity and absence of voids, a fresh batch of M30 concrete is meticulously poured into a 15 cm by 15 cm by 15 cm mold and compacted. After a full day, the test samples are demolded and immersed in water for curing. It is imperative that the tops of these samples are level and free from irregularities.

After curing for either 7 or 28 days, the samples are subjected to compression testing using a compression testing machine. Until the specimen breaks, the force is progressively delivered at a rate of 140 kg/cm2 per minute. By dividing the force at the site of rupture by the cross-sectional measurement of the specimen, one can calculate the compression strength of the concrete.To ensure accuracy, testing should be conducted on at least six cubes, each measuring 15 cm by 15 cm by 15 cm.

Fig 2: Curing

Fig 3: Compression testing machine

Acid Resistance Test

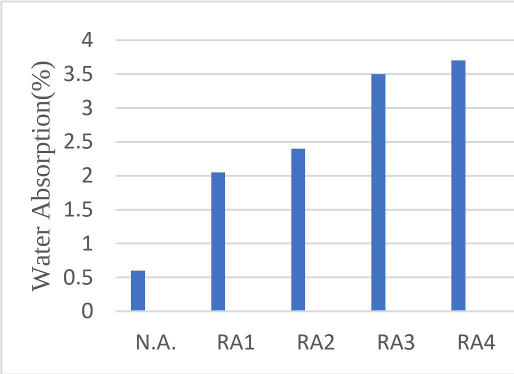
To evaluate changes in compressive strength and mass, 150 mm × 150 mm × 150 mm concrete specimens are formed. After 28 days of water curing, three concrete mixes are tested for acid resistance by measuring the mass change and residual compressive strength after they are exposed to a pH 3 with sulfuric acid (H_2SO_4) solution for 28 and 56 days.

Result and discussion

Water Absorption

	N.A.	RA1	RA2	RA3	RA4
Water Absorption	0.7 %	2.06%	2.5%	3.6%	3.8%

Table No.- 1 Water Absorption of Recycled Aggregate



Graph No.- 1 Water Absorption of Recycled Aggregate

water Absorption of aggregates

Where,

RA1 - recycled aggregate extracted from M25 mix concrete cubes that underwent testing.

RA2 - recycled aggregate that came from M20 mix concrete cubes that were evaluated.

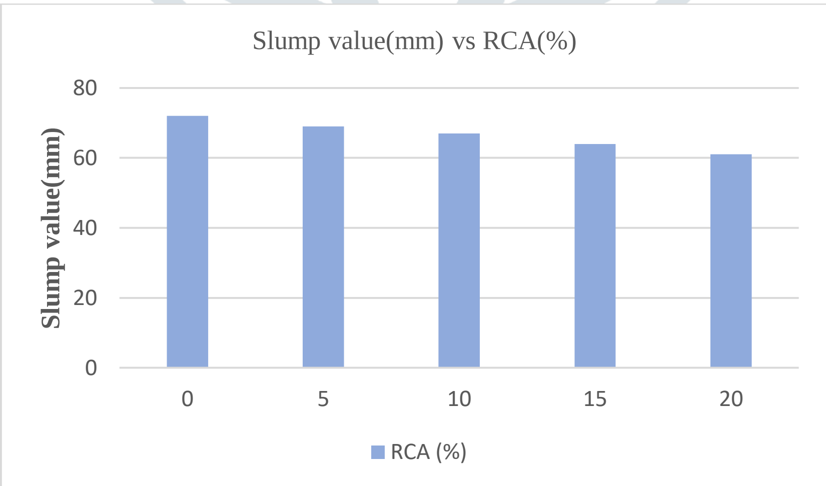
RA3 - recycled aggregate derived from concrete cubes with unknown mix proportions that were evaluated.

RA4 - recycled material taken from an old, demolished structure

Slump Test

The tests demonstrate a declining trend in workability as the substitution of recycled coarse aggregate (RCA) increases in concrete mixtures ranging from 0% to 20%. The higher water absorption of RCA, measured at 2.45% compared to the 0.5% of natural aggregate, may be attributed to mortar adhering to the surface of the aggregate. Superplasticizers can be employed to achieve the desired level of workability.

The results are shown below:



Graph No.- 2 Slump Value

Fig 4 : Slump Test

Compressive Strength

To assess the concrete's compressive strength, we prepared test cubes measuring 150 x 150 x 150 mm. Compressive testing machines (CTMs) were employed for these tests, as determining the concrete's compressive strength is crucial for evaluating its overall strength. Two sets of cubes were utilized: one composed of recycled coarse aggregate (RCA), and the other utilizing new coarse aggregate. Both cube sets were made using M30 grade concrete.

After being prepared, the cubes underwent a 28-day curing process. Once the curing period was complete, the cubes were removed from the curing environment, and any excess surface moisture was meticulously removed. Subsequently, the cubes were placed into the compression testing apparatus, where pressure was incrementally applied until the cubes failed, enabling the evaluation of their strength.

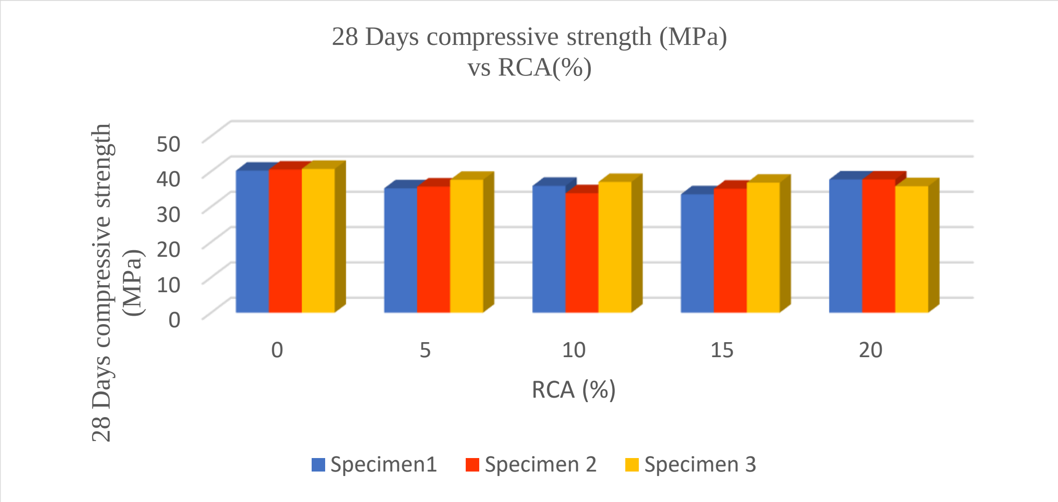
To enhance the precision of our results, we conducted compressive strength tests on three individual cubes. The concrete's compressive strength will be determined by averaging the results of these three tests.

Utilizing fly ash as a substitute for cement in RCA concrete led to a notable enhancement in compressive strength compared to instances where fly ash was not incorporated. This strength improvement is attributed to the pozzolanic characteristics of fly ash, which enhance the resilience and density of the concrete. Furthermore, the reduced need for cement when using fly ash diminishes the environmental consequences associated with concrete production. Thus, incorporating fly ash instead of cement proves to be an effective method for boosting the compressive strength of RCA concrete.

The results are provided as follows:

Specimen	**28 Days compressive strength (MPa)**				
	RCA (%)				
	0	5	10	15	20
1	40.2	35.2	35.9	33.5	37.7
2	40.2	35.7	33.8	35.1	37.7
3	40.7	37.6	37	36.8	35.8

Table No.- 3 Compressive Strength after 28 days



Graph No.- 3 Compressive Strength after 28 days

Fig 5: Testing of concrete

Acid Attack (IS:4456-1987)

From the test results, it is evident that in mixes RAC50 and RAC100, there is a higher weight loss compared to conventional concrete (CC). This weight loss increases as the proportion of recycled aggregate in the mix increases. The cause of this phenomenon is attributed to the weaker bonding between the old mortar present in the recycled aggregate and the new mortar in the concrete mixture.

Mix	28 days	
	Before	After
CC	8.51	8.13
	8.29	7.96
	8.86	8.40
Average	8.55	8.16
RAC 50	8.18	7.75
	8.24	7.81
	8.10	7.63
Average	8.17	7.73
RAC 100	7.98	7.41
	8.01	7.40
	7.89	7.33
Average	7.96	7.38

Table No.- 4 Loss of weight due to Acid Attack after 28 days

Conclusion

- There is a significant reduction observed, despite the slump and compaction factor values falling within acceptable ranges across various concrete mixes. This decrease might be due to the presence of mortar accumulating on the surface, leading to an increase in water absorption and a decrease in workability.
- The compressive strength findings suggest a downward trend, primarily attributed to the higher water absorption of RCA compared to natural aggregates. This results in a significant reduction in the water-to-cement ratio surrounding the aggregates, thereby causing incomplete hydration.
- The results of compressive strength indicate a decline, mainly due to the greater water absorption of RCA in comparison to natural aggregates. This leads to a notable decrease in the water-to-cement ratio surrounding the aggregates, resulting in incomplete hydration.
- In conclusion, recycled coarse aggregate (RCA) can serve as a viable substitute for natural aggregates provided it undergoes appropriate treatment and is supplemented with admixtures like fly ash. Laboratory investigations suggest that RCA can be safely employed up to a certain replacement percentage.

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