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Compare The Mechanical Properties Of Concrete Using Construction Waste To Achieve Sustainable Development

Nawab Ali Siddiqui [1], Siddiqui Fahad Asif [3], Mohd Shahnawaz Isha[3], Anwar Ahmad[4], Juned Ahmad[5]

1 Student, Department of Civil Engineering, Integral University, Lucknow, U.P., India

2 Student, Department of Civil Engineering, Integral University, Lucknow, U.P., India

3 Student, Department of Civil Engineering, Integral University, Lucknow, U.P., India

4 Faculty, Department of Civil Engineering, Integral University, Lucknow, U.P., India

5 Faculty, Department of Civil Engineering, Integral University, Lucknow, U.P., India

Abstract

In this study, the performance of recycled coarse aggregate (RCA) concrete was analyzed. The results showed that as the replacement level of RCA increased (12%, 24%, and 36%), the compressive strength decreased by 4.70%, 9.14%, and 21.05% respectively. The ultrasonic pulse velocity (UPV) also decreased slightly with higher RCA replacement. Flexural strength and tensile strength exhibited continuous reductions as the RCA replacement increased. Water permeability met the specified range at 12% RCA replacement but exceeded it at higher replacement levels. These findings provide insights into the performance of RCA concrete, indicating reduced strength properties and potential challenges with permeability at higher RCA replacement levels.

Keywords: Recycled concrete aggregate, Compressive strength, split tensile strength, Flexural strength, Ultra pulse velocity, Rebound hammer, Water permeability.

1. Introduction

The concept of sustainable construction was introduced in response to the pressing environmental concerns surrounding the construction industry's substantial use of natural resources and generation of waste. Concrete, as one of the most widely used construction materials, is a significant contributor to the depletion of natural resources. However, due to its composite nature and widespread application, it presents an ideal opportunity for incorporating waste materials, enabling large-scale recycling efforts. As aggregates form a significant proportion of concrete's volume, reducing their consumption can have significant positive impacts on the environment. Sustainable construction endeavors to address these challenges by promoting resource efficiency and waste reduction in concrete production, thereby contributing to a more sustainable and environmentally conscious future [1].The replacement of natural aggregates (NA) with recycled coarse aggregates (RCA) in concrete mixes has shown negative effects on both the durability and mechanical properties of the concrete. These effects can be attributed to various factors, including the high absorption capacity and surface cracks present in RCA, as well as the presence of an old mortar layer surrounding the recycled aggregate, which creates a weak interfacial transition zone (ITZ). However, researchers and scholars have proposed several treatment procedures to overcome these issues. These procedures aim to improve the properties of RCA, such as washing to reduce absorption, removing surface cracks, and enhancing the bond between the old mortar layer and the new concrete matrix. By implementing these treatment methods, the negative impacts on durability and mechanical properties can be mitigated, making the use of RCA a viable option in concrete production [2,4,5].

Rapid population growth and urbanization have transformed the construction sector into a major consumer of natural resources. The extraction of 32-50 billion tons of river sand annually, coupled with the production of over 4 billion tons of cement each year, poses significant environmental challenges and threatens ecosystem preservation. Factors such as mining activities, scarcity of raw materials, and the release of greenhouse gases further exacerbate these issues. Notably, cement production alone accounts for 12-15% of total industrial energy consumption and contributes to 5-8% of all human-caused CO2 emissions. Addressing these concerns is crucial to mitigate the environmental impact associated with the construction industry [3]. In comparison with NA, RA has a lower density and a higher water absorption capacity. This is due to the high porosity of the mortar adhering to the RA [4-5]. The recycled coarse aggregates employed in the study exhibit a lower density and higher water absorption ratio, approximately 6%, compared to the natural coarse aggregates. This difference in properties is a result of the recycled aggregates' composition and previous exposure to moisture. The lower density and higher water absorption of the recycled coarse aggregates should be taken into account when designing concrete mixtures to ensure appropriate adjustments are made to maintain the desired performance and durability of the resulting concrete [6].

Bilal S. Hamada et al. conducted a study on normal and high strength concrete mixes using different replacement percentages of natural coarse aggregate (NCA) with recycled coarse aggregate (RCA). study found that there was no significant effect on the plastic state slump and an average reduction of approximately 10% in the hardened mechanical properties for both levels of concrete compressive strength [7]. A study focused on investigating the properties of M30 grade concrete using tile as a replacement for natural aggregate at various percentages. A significant number of specimens, including 100 beams, were cast and tested according to IS 516 (Part 1) standards. The constituent materials underwent quality testing, and after confirming their acceptability, the mechanical properties of the concrete, particularly its flexural strength, were observed and tabulated. The findings of the study provide insights into the potential use of tile as an alternative aggregate in concrete production [8]. It is investigated the influence of using recycled coarse aggregate (RCA) and well water (WW) on the mechanical properties of high-strength concrete. Results showed a decrease of approximately 16.0% in compressive strength for concrete with natural coarse aggregate (NCA) using well water. Well water also caused reductions in strength for concrete containing different percentages of RCA. Regression analysis aided in formulating constitutive relationships considering WW and RCA effects [9]. The aim of this paper is to compare the mechanical properties of concrete using construction waste as a means to achieve sustainable development. The study intends to evaluate how incorporating construction waste as a replacement for traditional aggregates affects the mechanical characteristics of concrete. By assessing the mechanical properties of the resulting concrete, the goal is to determine the feasibility and sustainability of using construction waste in concrete production.

2. Experimental detail

2.1. Materials

The materials utilized in this study were readily accessible within the local region of Lucknow, India. Properties of all materials shown in Table-1.

2.2. Cement

In this study, Portland Pozzolana Cement (PPC) was utilized as the cementitious material. The specific gravity of the PPC was determined to be 2.627. PPC is a commonly used type of cement that incorporates pozzolanic materials, such as fly ash, to enhance its properties and performance.

2.3.Aggregate

In this study, natural sand and natural coarse aggregates were utilized in the concrete mixtures. The fine aggregate used in this work is zone-1, and coarse aggregates ranged in size from 5mm to 20mm, as determined through sieve analysis. The recycled aggregates used in the study were obtained by crushing tested concrete cubes, which were originally construction waste sourced from the material testing lab at Integral University in Lucknow, India. A photograph of the recycled concrete aggregate and natural coarse aggregate is shown in (Fig. 1) and (Fig. 2). It is worth noting that recycled concrete aggregates (RCA) exhibit high water absorption capacity, which significantly influences the concrete mixing process.

2.4.Chemical Admixture

In this work, the admixture CeraPlast 300PS was employed. CeraPlast 300PS is a dark brown liquid solution composed of Naphthalene formaldehyde. The specific gravity of the admixture was determined to be 1.20±0.02, indicating its density in comparison to water. Additionally, the pH value of CeraPlast 300PS was measured to be 7±1, indicating its neutrality or near-neutrality on the pH scale. These properties of the admixture are crucial factors to consider when incorporating it into the concrete mixture.

Table-1
Properties of materials

S.No.	Property	Results
1	Fineness of Cement	2%
2	Specific gravity of cement	2.627
3	Standard consistency of cement	34%
4	Initial setting time	131 min
5	Specific Gravity of fine aggregate	2.487
6	Water absorption of fine aggregate	2.448%
7	Fineness modulus of fine aggregate	3.425 mm
8	Specific gravity of coarse aggregate	2.582
9	Fineness modulus of coarse aggregate	7.036 mm
10	Water absorption of coarse aggregate	0.7862%
11	Water absorpton of recycled coarse aggregate	6.5%
12	Specific gravity of recycled coarse aggregate	2.13

Fig. 2. RCA

Fig. 1. NCA

2.5.Mix proportion

The mix design for this experiment followed the guidelines of IS-10262:2019 [10] and IS-456 [11]. Four mix samples were prepared, each with different proportions. For each mix, a total of 9 cube specimens, 3 prism specimens, and 3 cylinder specimens were prepared. The first mix served as the conventional reference with 0% replacement of recycled concrete aggregate (RCA). The second mix incorporated 12% partial replacement of coarse aggregate with RCA, while the third mix used 24% partial replacement of coarse aggregate with RCA. A super plasticizer dosage of 0.8% of cement was used. The mix proportions for 1m3 are presented in Table 2.

Table 2
Mix Proportion

Sample	Cement (Kg)	Fine Aggregate (Kg)	Coarse Aggregate (Kg)	Recycled Aggregate (Kg)	Water (Kg)	Admixture (ml)
NCA	418.91	616.9	1041.75	0	182.91	2481
RCA12%	418.91	616.9	916.74	125.01	190.41	2481
RCA24%	418.91	616.9	791.73	250.02	197.91	2481
RCA36%	418.91	616.9	666.72	375.03	205.41	2481

2.6.Slump test

In order to assess the workability of fresh concrete, the slump test, as per the IS 1199-2018 standard, is performed. The test involves using a specially designed mould known as a slump cone. The cone has a base diameter of 200 mm and a smaller opening at the top measuring 100 mm in diameter and 300 mm in height. The cone is filled with concrete in three layers, with each layer being compacted 25 times using a 16 mm diameter rod to eliminate any air voids. The top surface of the concrete is leveled, and then the cone is carefully removed. The height of the slump, or the deformation of the concrete, is then measured to determine its workability [Fig.3].

The results of slump test was 110 mm, 102 mm, 95 mm, 82 mm for NCA, RCA12%, RCA24%, RCA36% respectively.

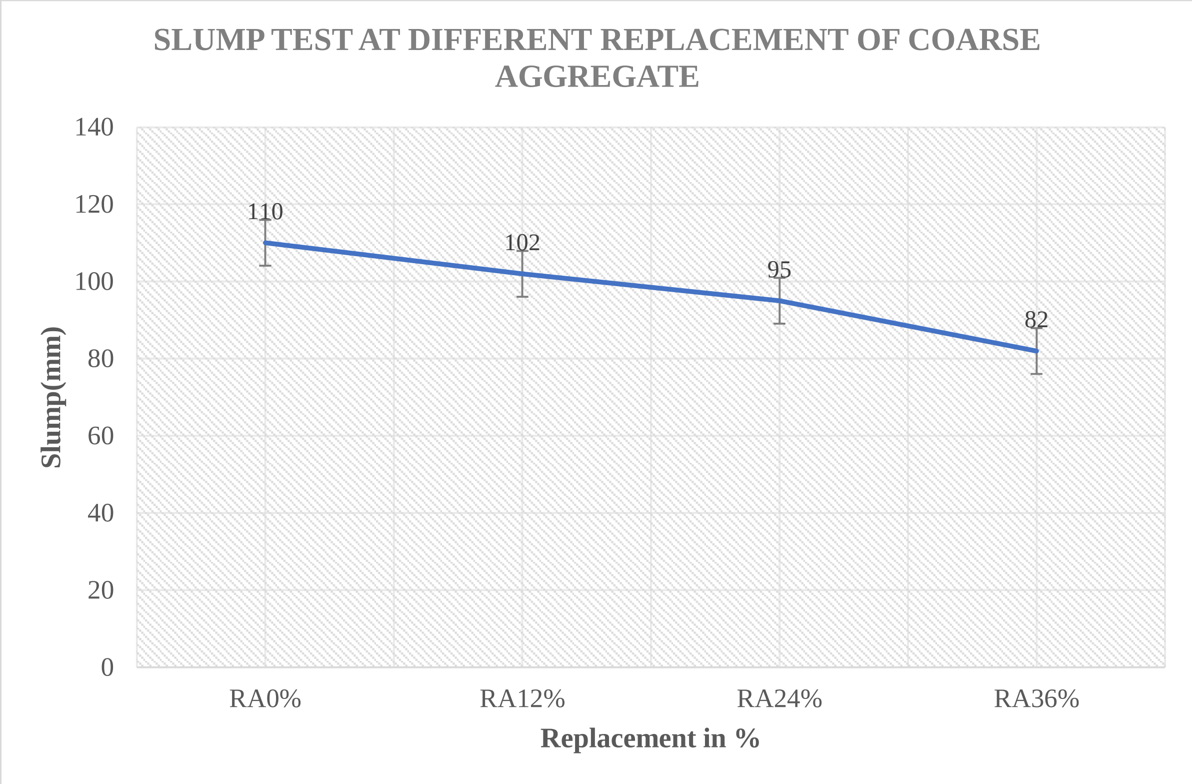

Fig. 3. Slump test

2.7.Test Setup

For the experimental testing, cube moulds with dimensions of 150×150×150 mm were used to measure the compressive strength of the concrete. Additionally, prism moulds with dimensions of 100×100×50 mm and cylinder moulds with dimensions of 150×300 mm were employed to determine the flexural and tensile strength, respectively. A total of 36 cubes were produced, with 24 cubes used for compressive strength testing and 12 cubes for water permeability testing. The cubes were cured for 7 and 28 days before testing. Furthermore, non-destructive tests such as the rebound hammer test (as per IS 516 [PART 5/SEC 1]) and ultrasonic pulse velocity (UPV) test (as per IS 516 [PART 5/SEC 1]) were conducted on the cubes. Water permeability tests were also performed on 3 cubes for each mix according to IS 516 [PART 2/SEC 1] 2018 or DIN 1048 PART 5. Fig. (5 – 6) presented the testing method for hardened concrete (Compressive, Splitting tensile and Flexural strngth).

Fig. 4. Slump test

Fig. 5. Spliting tensile testing

Fig. 6. Compression testing

Fig. 7. Flexural testing

3. Results and discussion

3.1.Compressive strength

Fig. 6. depicts the compressive strength results of cubic specimens containing recycled concrete aggregate (RCA) for a water-to-cement ratio (w/c) of 0.41. The specimens were tested at 7 and 28 days, respectively. The findings indicate a decrease in compressive strength when natural coarse aggregate (NCA) was substituted with RCA at varying percentages. On the 7th day, replacing NCA with 12% RCA resulted in a reduction of compressive strength by approximately 7.89%. Similarly, replacing NCA with 24% RCA led to a decrease of around 16.68%, and replacing NCA with 36% RCA resulted in a reduction of approximately 23.56%. On the 28th day, the compressive strength reduction was observed to be lower compared to the 7th day. Substituting NCA with 12% RCA resulted in a decrease of approximately 4.70%. Replacing NCA with 24% RCA led to a reduction of around 9.14%, and substituting NCA with 36% RCA resulted in a decrease of approximately 21.05%. Rebound hammer test results indicate a decrement in values when replacing natural coarse aggregate (NCA) with recycled concrete aggregate (RCA) at different percentages. The reductions are approximately 6.51%, 10.84%, and 13.23% for 12%, 24%, and 36% RCA replacement, respectively, compared to NCA.

These results highlight the impact of incorporating RCA on the compressive strength of concrete. It is evident that as the percentage of RCA in the mix increases, the compressive strength decreases [Fig.8]. These findings emphasize the need for careful consideration and proper design when utilizing RCA in concrete mixes to ensure the desired strength requirements are met.

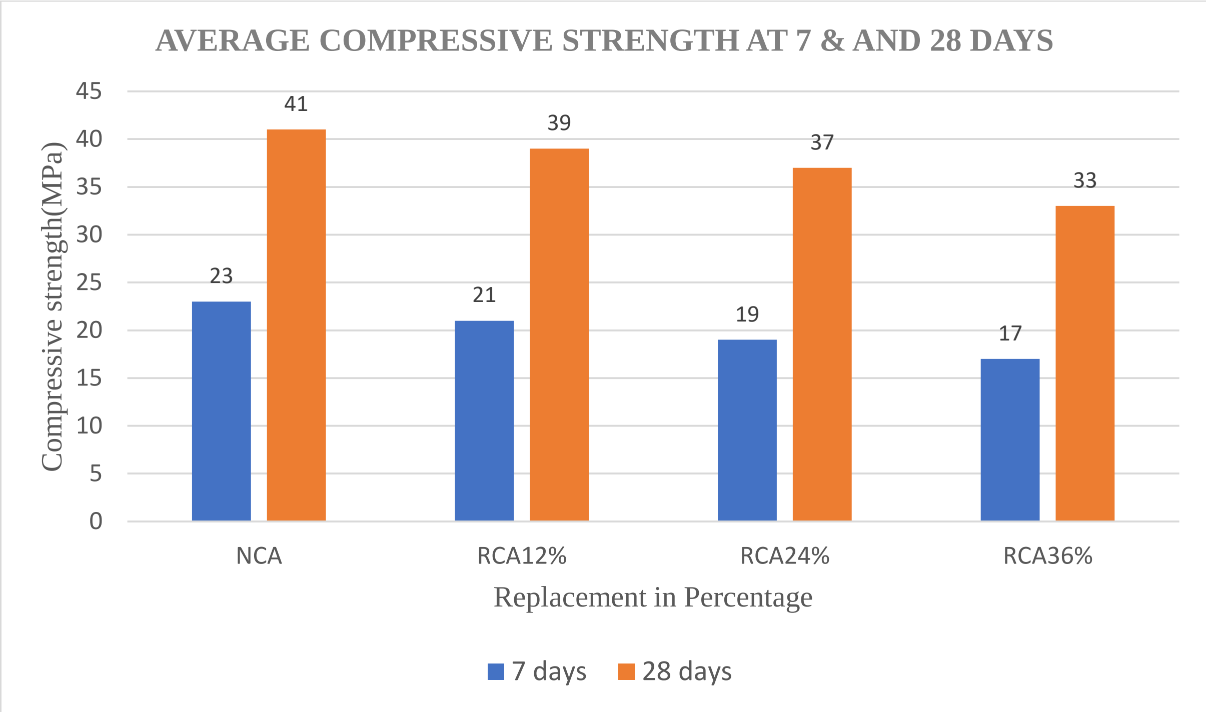

Fig. 8. Average compressive strength at 7 & and 28 days

3.2.Flexural strength

Fig.9. illustrates the flexural strength results of prism specimens incorporating recycled concrete aggregate (RCA) with a water-to-cement ratio (w/c) of 0.41. These specimens were subjected to testing specifically at 28 days. The data reveals the effect of replacing natural coarse aggregate (NCA) with RCA at different percentages on the flexural strength of the concrete. When 12% of NCA was substituted with RCA, the flexural strength exhibited a reduction of approximately 6.74% compared to the control specimens. Increasing the RCA replacement to 24% resulted in a slightly higher decrease in flexural strength, approximately 7.037%. Further increasing the RCA replacement to 36% led to a more significant reduction in flexural strength, with an approximate decrease of 12.58% compared to the control specimens.

The results clearly demonstrate that increasing the percentage of recycled concrete aggregate (RCA) in the concrete mix leads to a decrease in flexural strength. This highlights the significance of carefully assessing the effects of RCA inclusion on the flexural behavior of the concrete. It is essential to make appropriate adjustments in the mix design and consider the structural implications when using RCA in concrete applications, especially when maintaining adequate flexural strength is crucial.

3.3.Split tensile strength

The experimental studies conducted indicate that the tensile strength of concrete is significantly affected by the replacement of natural coarse aggregate (NCA) with recycled coarse aggregate (RCA) [Fig.9]. Specifically, when 12% of NCA was replaced with RCA, the tensile strength decreased by approximately 13.68%. Increasing the RCA replacement to 24% resulted in a more substantial reduction of approximately 21.05%. Furthermore, when 36% of NCA was substituted with RCA, the tensile strength exhibited a significant decrease of approximately 31.57%. These findings emphasize the negative impact of increasing RCA content on the tensile strength of concrete, even at a constant water-to-cement ratio (w/c) of 0.41. Therefore, it is crucial to carefully consider the implications of incorporating RCA in concrete mixtures, particularly when tensile strength requirements are critical, and to make necessary adjustments in the mix design to ensure adequate performance in structural applications.

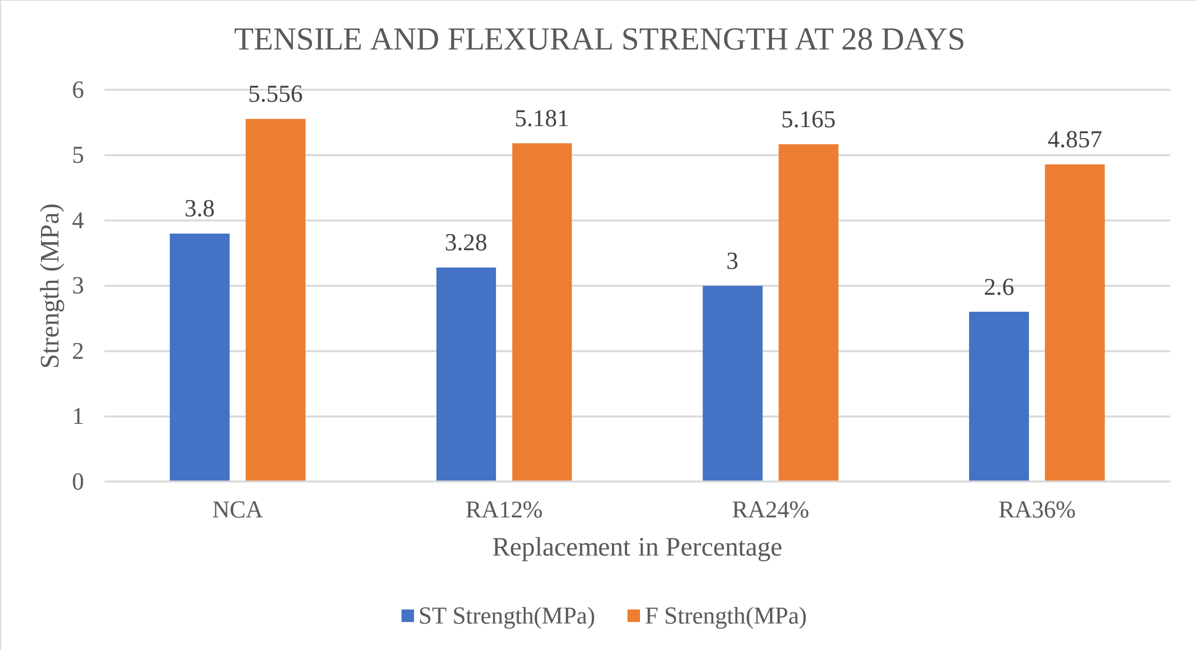

Fig. 9. Average tensile and flexural strength at 28 days

3.4.Ultrasonic pulse velocity (UPV)

The incorporation of recycled concrete aggregate (RCA) in concrete mixtures has been found to have a minor adverse impact on the ultrasonic pulse velocity (UPV) at 28 days. Experimental studies have revealed that as the percentage of RCA in the mix increases, there is a corresponding decrease in UPV values. For instance, when 12% of the natural coarse aggregate (NCA) was substituted with RCA, the UPV decreased by approximately 3.79%. Increasing the RCA replacement to 24% resulted in a slightly higher reduction of around 5.021%. Further increasing the RCA content to 36% led to a slightly larger decrease in UPV, with an approximate reduction of 6.55% [Fig.10]. A photograph of UPV testing shown in Fig. 11.

These results indicate that incorporating RCA in concrete mixtures can have a slight adverse impact on the UPV. It is important to note that UPV is commonly used as an indicator of concrete quality and can be related to various properties such as density, homogeneity, and internal flaws. Therefore, when considering the use of RCA, it is essential to evaluate its effects on the overall quality and durability of the concrete, beyond just the UPV. Proper mix design adjustments and quality control measures should be implemented to ensure that the desired performance characteristics are achieved when utilizing RCA in concrete applications.

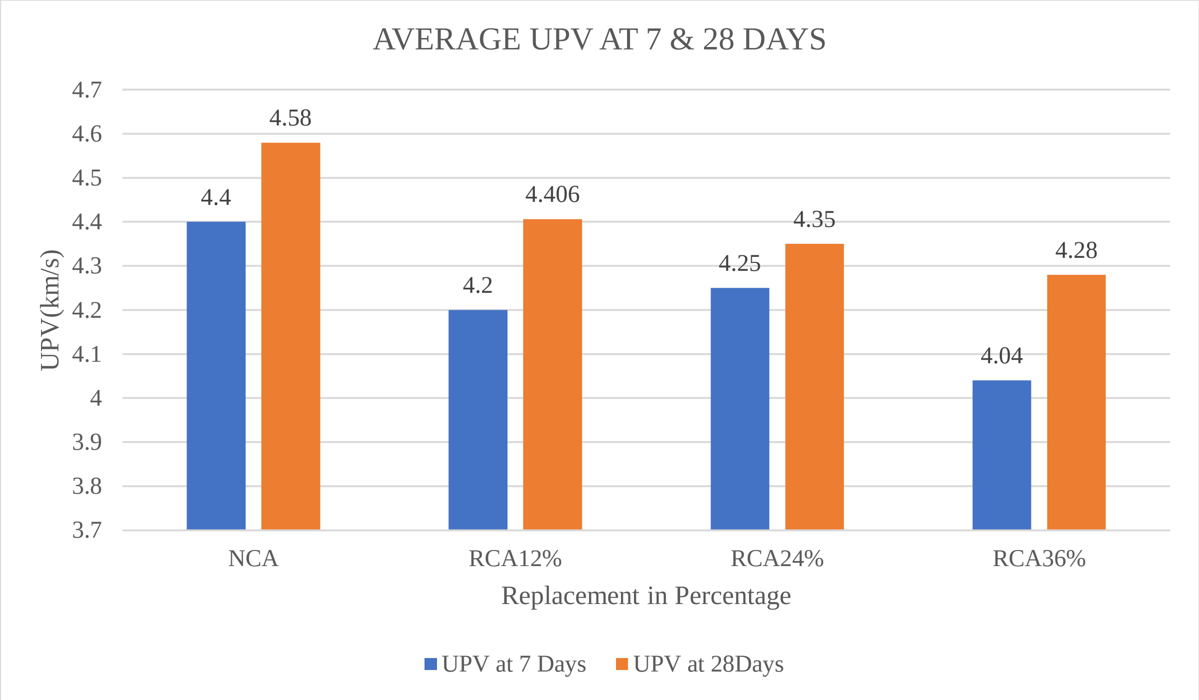

Fig. 10. Average upv at 7 & 28 days

3.5.Water permeability

The water permeability of concrete specimens incorporating natural coarse aggregate (NCA) and 12% RCA replacement falls within the specified range of 25mm, as outlined in Section 1700 of MORTH 5th Revision, specifically Clause 1717.7.5. This indicates that the permeability of the concrete meets the required standards. However, for concrete specimens with 24% and 36% RCA replacement, the water permeability exceeds the 25mm specified range [Fig.13]. This suggests that the higher percentage of RCA in the mix leads to an increase in permeability, potentially compromising the water-tightness of the concrete. It is important to adhere to the guidelines and specifications set forth by regulatory bodies, such as MORTH, to ensure that concrete structures meet the required performance and durability standards. The findings emphasize the need to carefully consider the use of RCA in concrete mixes, particularly when water permeability requirements are critical. Proper mix design adjustments and additional measures may be necessary to mitigate the increased permeability associated with higher RCA replacement percentages, ensuring that the resulting concrete meets the desired water-tightness criteria.

Fig. 11. UPV testing

Fig. 12. Water permeability testing

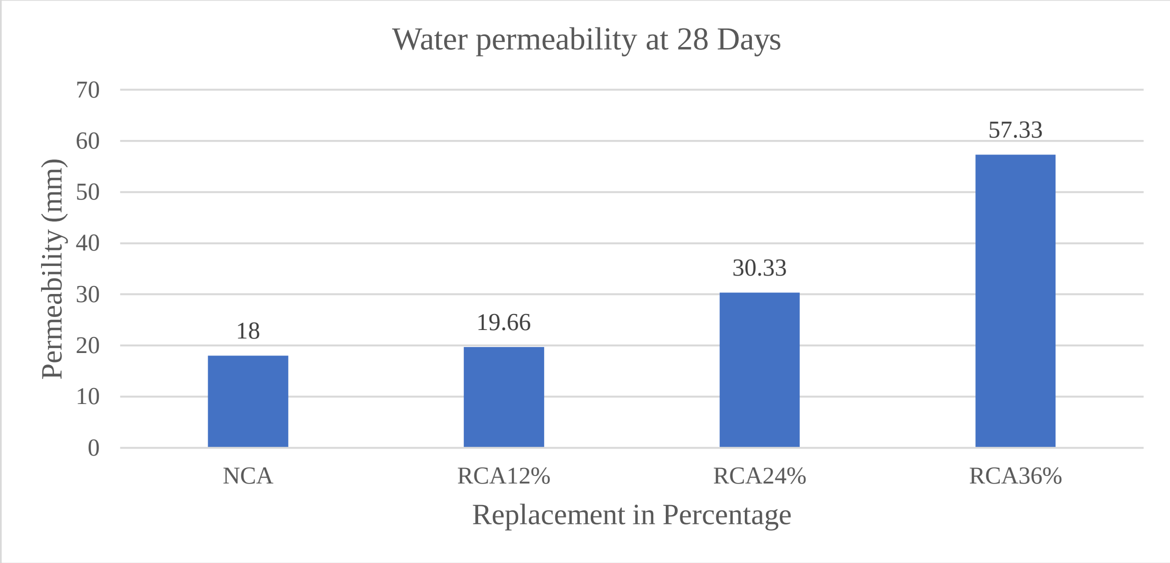

Fig. 13. Water permeability at 28 Days with RCA replacements

4. Conclusion

In summary, the experimental studies presented in the paper highlight the following conclusions:

The compressive strength of concrete decreases as the percentage of recycled concrete aggregate (RCA) replacement increases. The reductions in compressive strength range from 7.89% to 23.56% on the 7th day and from 4.70% to 21.05% on the 28th day, depending on the RCA content.

The flexural strength of concrete is also negatively affected by the inclusion of RCA. The reductions in flexural strength range from 6.74% to 12.58% as the RCA content increases.

The tensile strength of concrete exhibits significant reductions with higher RCA content, ranging from 13.68% to 31.57% at various replacement percentages.

The ultrasonic pulse velocity (UPV) of concrete decreases as the RCA content increases, indicating potential changes in the concrete's density and internal characteristics.

Water permeability meets the specified range of 25mm for concrete specimens with 12% RCA replacement. However, at higher RCA contents (24% and 36% replacement), water permeability exceeds the specified range, suggesting a compromise in the water-tightness of the concrete.

These findings emphasize the importance of carefully considering the effects of incorporating RCA in concrete mixtures. Proper mix design adjustments, quality control measures, and structural considerations are crucial to ensure the desired performance and durability of the concrete, particularly when considering strength, UPV, and water permeability requirements.

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