Mechanical Properties of Concrete by Partial Replacement of Recycled (Coarse & Fine) Aggregate

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Abstract - *Concrete is essential for any infrastructure development. One of the genuine portions utilized in the concrete generation is aggregate, which is going to diminutive. To support development activities, it is basic to discover options in contrast to the natural aggregate. On the contrary side, the rate of worthless waste is increasing step by step, while the issue of dumping is also extending due to the lack of landfill site availability. This project aims to find recycled aggregate as a sustainable alternate of (coarse and fine) aggregate in concrete mix of M-40 grade. This will provide a safer future for the upcoming generations, as demolition waste is in huge quantity and needs to be reused or recycled. To do this, the project attempts to mix a design of M40 concrete replacing (coarse and fine) aggregate with construction demolished material. Replacing 25-75% of coarse and fine aggregate by recycled concrete waste, testing its properties there was no significant changes in the strength of concrete. also, this method will be cheaper and not compromising with the design compressive strength.*

Key Words: recycled (coarse & fine) aggregate, recycled aggregates replacement ratio, mix design method, mechanical properties.

1. Introduction

According to the research by B.M. Vinay Kumar, H. Ananthan, and K.V.A. Balaji (2017), recycled materials like CRCA and FRCA from concrete waste may be utilised as a 20% substitute for HPC mixes. The findings indicate that the strengths of HPC mixes containing 20% CRCA, 20% FRCA, and 20% are respectively 0.98, 1.18, and 1.02 times greater than those of HPCCM. Strength gain is compensated for by both CRCA and FRCA content. A 20% FRCA content SCC blend produces superior outcomes. Under sulphate attack, HPC mix with 20% CRCA and FRCA performs OK, but when exposed to H2SO4 solution, considerable strength loss is seen **[1]**. The usage of fibres like SF, PPF, BF, and GF in improving the workability and strength of FRAC is discussed in this review paper by Wisal Ahmed and C.W. Lim (2020). The article's conclusion is that recycling C&D waste as RCA is an environmentally benign and sustainable practice that supports the construction industry's adoption of the circular economy paradigm. In weaker RAC, fibre reinforcing enhances fracture energy, ductility, crack pattern, and other strength qualities. The most basic material is SF, which gains compressive strength with volume fractions up to 0.7% and flexural strength and splitting tensile capacity with 1.5%. In cementitious composites supplemented with this type of fibre, PPF, a well-known polymeric fibre, increases mechanical performance and prevents shrinkage fractures. A green, non-polluting fibre called BF efficiently fills in weak RAC fractures to increase its compressive strength, flexural loading strength, and breaking tensile capacity. Compressive strength in RAC is enhanced by GF, which has a volume composition of 0.04%. But the inclusion of fibres in RAC might result in a network structure, which makes concrete less workable **[2]**. According to Preeti Saini (2015), research on recycled concrete aggregates in second-generation concrete needs an easy and affordable technique. The quantity and caliber of adhering mortar are essential factors for determining ultimate strength. For the preparation of high-strength concrete, a technique taking these factors into account is crucial. If there is over 65% attached mortar present, the influence on concrete qualities has not been assessed, however a 25–30% recycled aggregate may not have a major impact on concrete characteristics. Calculating % replacement based on percentage adhering mortar and understanding the tolerance of adherent mortar percentages on recycled concrete aggregates are essential **[3]**. There is potential to enhance the intrinsic qualities of building materials made from solid waste materials such as plastic, wood, metal, paper, glass, and crushed concrete, according to researcher Oriyomi M., Okeyinka (2015), It states that the actual use of these materials is constrained. To further understand their behavior and performance in the formulation of concrete's standard mix design, more research is required. Research should concentrate on enhancing recycled waste materials' acceptability to public and international standards in order to increase their use in building. The goal of this research is to create a lightweight, cement-free, ecologically friendly building block from recycled waste paper that has the right qualities for non-load bearing walling units. The findings will be verified by laboratory testing, energy-efficient machinery, and computer modelling. If this experiment is successful, it may help to reduce environmental pollution, save important landfill space, conserve energy and natural resources, use less Portland cement, and lower construction costs **[4]**. According to L. Evangelista and J. de Brito (2013), the use of FRA in the manufacturing of concrete is now viewed as inappropriate by several scientific societies. But if done properly, it is feasible to produce high-performance concrete using FRA that behaves much like high-performance concrete. The utilization of FRA is a known fact that requires additional research. Before it can be employed at an industrial scale without limitations, though, several challenges must be addressed. These include establishing constitutive relations, stress-strain connections, and mechanical characteristics as well as creating a standard technique for calculating the processes of water absorption and mixing **[5]** The characterization and structural uses of fRCA are reviewed in this article by Marija Nedeljkovic and Jeanette Visser (2021), with an emphasis on the physical and chemical features, composition, and qualities of 43 concrete/mortar mixtures. The initial design and history of the concrete, the recycling process, and storage all affect the physico-chemical properties of FRCA. These variables affect how well concrete mix and cured concrete perform. There are currently no recommendations for the best usage of fRCA in new concrete and insufficient understanding about it. Uncertain hazards on predicted concrete performance and increasing cement contents to compensate for water needs hinder the large-scale deployment and best use of fRCA. It is difficult to employ fRCA and lower cement content since the reuse of fRCA is now experimentally optimized. It is vital to have practical knowledge of appropriate superplasticizers and rheology modifiers for concrete containing fRCA. Advanced quality control of fRCA during and after separation calls for quantitative and qualitative characterization methodologies and recommendations. Priority areas for research should include the relationship between fRCA treatments and physical and chemical properties, ideal cement packing and interaction, and the microstructure and expected long-term behavior of new concrete **[6]**.

2. Literature Review

Recycled Admixtures: Strength and Durability Properties by P. Saravanakumar (2013). To evaluate the strength and durability of aggregate concrete, four series of mixes were created, replacing Natural Aggregate (NA) with Recycled Aggregate (RA) 0–25–50–100% of the time. Chemical and mineral admixtures were utilized as partial replacements for cement in each series at quantities ranging from 40 to 60% of the cement's weight. When NA is replaced with RA from 25 to 100% at the age of 28 days, the rate of compression strength loss varies from 20 to 37%. Similarly, when NA is replaced with RA from 25 to 100% at the age of 28 days, the rate of decline in tensile strength varies from 12 to 32% **[7]**. Jeonghyun Kim (2021) developed the properties of recycled aggregate concrete using an equal mortar volume mix design. Conclusion: By enhancing the mechanical and durability features of RAC and using less raw materials than traditional mix design, the use of the EMV mix design looks to provide a potential contribution to sustainable growth in the building sector. Self-compacting concrete, steel fibre concrete, and reinforced concrete beams are now included in the application of the EMV mix design approach **[8].** Mayara Amario, Caroline Santana Rangel, Marco Pepe, and Romildo Dias Toledo Filho (2017) optimized regular and high strength recycled aggregate concrete compositions using the packing model. Like with regular concrete, the shape of the aggregate, the distribution of the grain sizes, and the amount of free water present in the mixture all play a major role in the RAC's workability. This can be ascribed to the fact that RCA have a rounder shape than natural aggregate due to the crushing method used to produce them, as well as the fact that RCA have fewer fine particles than natural aggregate **[9]**. Bo Wang, Libo Yan, Qiuni Fu, and Bohumil Kasal's comprehensive review of recycled aggregate and recycled aggregate concrete was published in (2021). In this paper, recycled aggregate (RA) and recycled aggregate concrete (RAC) are thoroughly reviewed in terms of their history, processes for recycling, reusing, and manufacturing, inherent flaws (such as the presence of extra interfacial transition zones in RAC), and physical characteristics of the materials. Mechanical characteristics, such as elastic modulus, compressive, flexural, and splitting tensile strength, as well as long-term performance (such as creep and dry shrinkage resistance, alkali-silica reaction resistance, and freezing-thawing resistance), are important **[10]**. Salomon M. Levy and Paulo Helene's (2004) durable concrete with recycled aggregates is a safe path to sustainable development. 20% recycled aggregate from old concrete or masonry is used in place of natural aggregate when replacing natural aggregate. When compared to the reference concrete manufactured with natural aggregates in terms of the qualities examined in this inquiry, the resultant recycled concrete will probably behave similarly, and in some cases even better. This feature motivates the attempts to employ these concretes, which can help to save the environment and can accomplish the same end performance with perhaps lower costs than conventional concretes **[11].** Dan Meng, Xuemin Wu, Hongzhu Quan, and Chongji Zhu (2021) developed a strength-based mix design approach for recycled aggregate concrete, which resulted in improved durability performance. For the regression study of associations between various factors, a total of 30 mixes with cement contents ranging from 300 kg/m3 to 500 kg/m3 and varying percentages of recycled coarse aggregate were created. Results reveal that the freeze-thaw resistance, drying shrinkage, chloride penetration, and carbonization of recycled coarse aggregate concrete matching to this approach are all negatively impacted by adding more of it **[12].** Fresh-state R.V. Silva, J. de Brito, and R.K. Dhir's (2018) performance of recycled aggregate concrete. Analyses are also conducted on the impact of mineral additions and water-reducing admixtures on the initial characteristics of recycled aggregate concrete. The stability (i.e., bleeding and segregation), temperature of hydration, air content, and fresh density of recycled aggregate concrete in its fresh form are also covered. A usual conclusion of using 100% coarse RCA is an average density loss of 5%, which would be advantageous from the standpoint of reducing one's own weight **[13]**. Properties of concrete by Bassam A. Tayeh, Mohammed W. Hasaniyah, A.M. Zeyad, and Moruf Olalekan Yusuf (2019) using recycled seashells as cement partial replacement. The study demonstrates that adding seashell ash to concrete decreased its initial compressive strength. Concrete created with the addition of seashell ash still has adequate strengths for a variety of structural and plastering purposes, even if the compressive strength is mostly reduced by utilizing seashells as a cement replacement **[14]**. Concrete made using recycled aggregate is durable, according to a (2013) study by C. Thomas, J. Setien, J.A. Polanco, and M. Sanchez de Juan. Despite a decrease in the effective water/cement ratio, recycled aggregate concretes prepared with unsaturated recycled aggregate had lower densities than the control concrete. Additionally, the higher porosity of these aggregates is isolated by this action. With the addition of recycled aggregate, the density of concrete with the same effective water/cement ratio drops. Density values are around 5% lower with the inclusion of 20% recycled aggregate than with the control concrete **[15]**. Guoliang Bai, Chao Zhu, Chao Liu, and Biao Liu (2020) evaluated the recycled aggregate characteristics and the mechanical parameters of recycled aggregate concrete. In this review, the quantitative correlations between RA performance at the material level and the amount of old connected mortar were depicted. By using several straightforward and inexpensive methods, such as altering the water-cement ratio, aggregate water content, mixing technique, and additive, the concretes may be enhanced to a certain extent. To meet the quality standards of engineering pairs of concrete, RAC performance can be modified **[16]**.

2.1 Recycled (Coarse & Fine) Aggregate

Ferronickel slag is used as fine aggregate in recycled aggregate concrete, and Jiuwen Bao, Zihao Yu, Jin Wang, Peng Zhang, and Xiaomei Wan (2021) have studied the impacts on transport characteristics. The fine and coarse aggregates in concrete may be made from ferronickel slag (FNS), an industrial by-product, and recycled concrete aggregates (RCAs), which are made from demolition and building debris. Investigating the compressive strength and transport behaviour of RAC containing FNS as fine aggregate is the goal of this work. The results of an experimental examination into the transport and compressive characteristics of FNS-RAC specimens were presented. These conclusions can be derived from the findings and debates given here. FNS, an industrial by-product, is anticipated to become a popular and sustainable building material **[17]**. Sumaiya Binte Huda and M. Shahria Alam (2014) examined the mechanical behaviour of three generations of concrete using just recycled coarse material. Construction and demolition (C&D) debris from demolished concrete has enormous potential for use as coarse aggregate in concrete. This study examines the fresh and hardened qualities of this form of green concrete and repeatedly explores the usage of recycled coarse aggregate in concrete. First, second, and third generations of repeatedly recycled concrete were created. RCA1, RCA2, and RCA3 had bulk densities that were respectively 13.9%, 22.9%, and 26.3% lower than normal. The number of repeats resulted in a reduction in the bulk density and specific gravity of various generations of concrete. At 56 days, all the considered concrete, apart from the RC3, reached the desired strength (32 MPa) **[18]**. Alaa M. Rashad (2016) provides a thorough analysis of rubber recycling as a replacement for fine-four aggregate in conventional cementitious materials. RCA1, RCA2, and RCA3 had bulk densities that were 13.9%, 22.9%, and 26.3% less than normal, respectively. With increasing repetitions, the bulk density and specific gravity of several generations of concrete dropped. Apart from the RC3, all evaluated concrete reached the desired strength (32 MPa) at the age of 56 days **[19]**. By Gombosuren Chinzorigt, Myung Kwan Lim, and Myoungyoul Yu (2020), strength, shrinkage, creep, and durability features of concrete using CO2 treated recycled fine aggregate. Durability, strength development, shrinkage, and creep behaviour of recycled aggregate concrete were studied. Investigations were also conducted on elements like carbonation and chloride ion penetration. Recycling fine aggregate with CO2 treatment increased the strength of recycled aggregate concrete by up to 15%, although shrinkage showed minimal improvement. In standard strength recycled aggregate concrete, the use of both recovered coarse aggregate (RCA) and recycled fine aggregate (RFA) was investigated. Recycled fine aggregate absorbs less water while having a higher density. When compared to similar RCA, the carbonation resistance of RAC with CRFA is further decreased **[20]**.

3. Methodology

It is possible to develop the methodology for upcoming research projects by analyzing the literature review. The experimental work to be undertaken comprises a proposed technique that has outlined in this section. Every component used to create required concrete mixes, including fine aggregate (river sand), coarse aggregates, cement, etc., will be put through testing in accordance with Indian Standards. For standards and testing aggregates for various physical & mechanical properties to determine their eligibility as coarse aggregate, IS 383: 2016 and IS 2386: 1963 shall be used. For specifying and testing cement for various qualities to determine applicability as cement, the IS 4031: 1996 and IS 269: 2015 standards will be used. For concrete mix design, IS 456: 2000 and IS 10262: 2019 will be used as references. The waste materials such as recycle (coarse and fine) aggregate waste will be collected from institute waste material like concrete samples etc. The received raw waste will get break down into pieces by manual hammering action. Then the processed recycle coarse material having the appearance of coarse aggregates will be subjected to sieving through 20 mm and 4.75 mm IS sieves. And recycled fine aggregates will be subjected to sieving through 4.75mm IS sieves. Now, this converted waste will be called as recycled coarse aggregates (RCA) and recycled fine aggregates (RFA). The experimental work will be done in three steps. First NAC will get partially replaced by RCA 25%, 50%, 75%. Second, NFA will get partially replaced by

RFA 25%, 50%. 75%. Third, NCA & NFA will get partially replaced by both RCA & RFA up to 20% and 30%. The mix design of M40 grade concrete is taken as reference concrete. The calculation of various ingredients to be used in concrete mixes will be kept constant for all mixes except coarse aggregates. The substitution of coarse aggregates will be done by volume. The total of 9 concrete mixes must be prepared for this work. There will be 162 specimens to cast, cure and test at 7 & 28 days for various strength properties such as workability, concrete density, compressive strength, splitting tensile strength, and flexural strength. Out of 180 specimens, 60 cubes of 100 mm X 100 mm X 100 mm size, 60 cylinders of 100 mm diameter & 200 mm height, and 60 beams of 100 mm X 100 mm X 500 mm size will be used to find hardened properties such compressive strength, splitting tensile strength, and flexural strength at 7 & 28 days to check the effect on partial substitution of NCA & NFA with RCA & RFA. All the composition of various concrete mixes are given below in table no. 1.

Table -1

The composition of various concrete mixes

Designation of Concrete Mix M-40 Grade	**NCA (%)**	**RCA (%)**	**NFA (%)**	**RFA (%)**
CM-A	100	0	100	0
CM-B	75	25	100	0
CM-C	50	50	100	0
CM-D	25	75	100	0
CM-E	100	0	75	25
CM-F	100	0	50	50
CM-G	100	0	25	75
CM-H	90	10	90	10
CM-I	85	15	85	15

Notation

CM	Control Concrete Mix
RCA	Recycle Coarse Aggregate
RFA	Recycle Fine Aggregate
NCA	Natural Coarse Aggregate
NFA	Natural Fine Aggregate
SP	Superplasticizer

4. The testing of the recycled aggregate proportion on the mechanical properties of concrete

4.1 The compressive strength

According to the guidelines provided in IS 516: 1959, the compressive strength was calculated. Concrete cubic specimens of 100 mm in height were used to measure compressive strength after curing for 7, 28, and 90 days. The specimens were taken out of the curing tank and evaluated right away using a compression testing equipment while they were still wet on the surface. Before the specimen failed, the loading was applied without shock and increased gradually at a rate of 140 Kg/cm2/minute. To calculate the compressive strength, the failure load was measured and divided by the cross-sectional area. Compressive strength is determined by taking the average of three values throughout all curing ages.

Fig.1. Compressive Strength Test of Cube

4.2 The Split Tensile Strength

Concrete specimens with cylindrical shapes (diameter = 100 mm, height = 200 mm) were used to test the splitting tensile strength in accordance with the guidelines provided in IS 5816: 1999. With a speed ranging from 1.2 N/mm2/min to 2.4 N/mm2/min, the cylinders were examined at 7 and 28 days after curing. A failure load was recorded when the load was gradually introduced without shock. At the age of cure, the average of three values has been used as a result.

The splitting tensile strength was calculated using below expression-

$f_s = \frac{2P}{\pi l d}$

Here,

P = Maximum force in Newtons acting on the specimen,

l = length of cylinder (in mm), and

d = diameter of the cylinder (in mm)

Fig. 2. Split tensile strength

4.3 The Flexural Strength

To determine the flexural strength age of 7 and 28 days in accordance with IS 516: 1959, beams with a cross section of 100 mm X 100 mm and 500 mm in length were employed. With no shock applied, a load of 100 KN was applied using a flexural testing equipment, which steadily increased at a rate of 180 Kg/min. Recorded was the failure load. The flexural strength of the specimen (f_b) was determined using the following expressions:

a) If the distance between the fracture line and nearer support 'a' measured on the tension face (in cm) is more than 13.3 cm. Then

$$f_b = \frac{p \, x \, l}{b \, . \, d^2}$$

b) If a < 13.3 cm but a > 11.0 cm. Then

$$f_b = \frac{3p \, x \, a}{b \, . \, d^2}$$

Fig. 3. Testing of flexural strength sample using flexural strength setup on compressive strength testing machine

5. Conclusion

The following conclusions are taken from the experimental study's findings:

The number of recycling facilities that generate high-quality recycled aggregates for concrete and the number of facilities that have earned quality certifications for recycled aggregates for concrete are both increasing. Rising all the time. Consequently, the quality of recycled aggregates is no longer a significant barrier to broad adoption. However, unfavourable public opinions brought on by the usage of unlawful dumping and insufficiently treated recycled aggregate of building trash still exist as an issue. Furthermore, the absence of specific recycled aggregate specifications Products are a common barrier cited by construction workers. practitioners and is one of the obstacles to recycling recycled aggregates. This experimental investigation led to the general conclusion that recycled elements, such as RCA and RFA recovered from concrete waste, may be used at 20% and 30% replacement levels for creating High Performance Concrete mixes. The appropriate range of workability seems to be, concerns for concrete waste recycling are strength and availability.

6. Outcome

Casting of multiple concrete samples and testing their properties. Decreasing cost of construction by utilizing recycled waste. Reusing the waste and hence getting an option to achieve sustainability.

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