Utilization of Recycled Coarse Aggregates in Concrete Production

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Abstract

The continuous accumulation of solid waste is posing a great threat to the environment globally. The load on Indian dumpsites is increasing everyday as the rate of waste processing is much slower than the rate of wast generation. On the other hand, governments are imposing stringent mining regulations to prevent illegal mining of resources like sand and stones from rivers. These materials are the key constituents in concrete production. Hence, it is becoming difficult for the industry to meet the demand of fresh concrete for ongoing infrastructure projects. Studies focusing on finding alternatives to conventional aggregates have been going on for many years. This will solve two problems, first, appropriate disposal of waste materials, and second, prevention of overmining of natural aggregates (NA). The present paper reviews the effectiveness of using recycled coarse aggregates (RCA) in cement-concrete production and presents a small experimental case study on locally procured RCA used in concrete production.

Keywords : **Alternative materials, concrete, dumpsites, recycled coarse aggre-gates, solid waste, waste generation**

I. INTRODUCTION

Cement concrete is the most extensively used construction material in the building and infrastructure industry and no construction activity can be imagined without it.Today, the world is in a phase of rapid industrialization and urbanization. Due to this, on one hand there is a huge demand of concrete to create infrastructure, and on the other hand, problem of waste accumulation and its disposal is threatening the environment globally.

Sand, gravel, and cement are the main constituents of concrete. Due to stringent mining rules, the industry is facing huge difficulty in meeting the demand of raw materials for cement and concrete production.

Extensive research has been going on for years to find suitable alternatives to natural aggregates and cement. Many researchers have used fly-ash, nano-silica, different forms of blast furnace slag (granulated or powdered), glass wastes, and construction and demolition (C&D) wastes as alternatives to natural aggregates. The potential of these waste materials as alternatives to replace (fully or partially) the natural aggregates or cement depends on their chemical composition and particle size distribution.

The present study explores the potential of recycled coarse aggregates in manufacturing good quality cement

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concrete. This paper would motivate the practicing engineers to select a cost-effective alternative construction material and also help in safe and economical disposal of C&D waste.

II. PROPERTIES OF RECYCLED COARSE AGGREGATES

Recycled coarse aggregates (RCA) are commonly fabricated by crushing C&D waste into desired particle size. C&D waste is actually a mass of old concrete comprising of natural aggregates (coarse and fine), cement, and admixtures. This mass has two main components broadly. One is adhered mortar which is made up of fine aggregates, cement and admixtures, and, the other is the coarse aggregates. Hence, the performance of RCA in making a practically usable concrete, largely depends on water cement ratio (w/c) of the parent concrete mass from which it has been made. [7-8]. Some of the general physical properties of RCA are as follows,

A. Porosity and Water Absorption Value

The existing adhered mortar present in RCA contributes to increase in its porosity, and consequently increases water absorption in recycled coarse aggregates. Based on literature, in surface dry condition the water absorption capacity for NA and RCA are 0.5-1% and 4-4.7% respectively [9]. Moreover, the water absorption capacity of RCA is two to three times higher than NA, and may reach upto 12% [11].

B. Crushing Value and Abrasion Value

The strength characteristics of the parent concrete also has some influence on the abrasion values of the RCA obtained from it. Hasaba, Kawamura, Toriik, and Take-moto[12] observed abrasion values for 5-25 mm size RCA produced from the high-strength concrete and low-strength concrete as 23.0% and 24.6% respectively. The study observed an increase in the abrasion values with a decrease in compressive strength of the parent concrete.

Sagoe-Crentsil, Brown, and Taylor [13] conducted a series of crushing strength tests on the samples of concrete prepared using RCA and NA. Their study reveals that the abrasion resistance and crushing strength of RCA is quite less as compared to natural aggregates. The observed values of crushing strength for NA and RCA were 23% and 15.7% respectively. Shayan and Xu [9] observed a similar trend from crushing strength tests carried out in their study. The observed crushing strength for RCA and NA were 24% and 13% respectively and abrasion values obtained from samples of RCA and NA tested in Los Angeles Abrasion Machine were observed as 32% and 11% respectively.

C. Grading of RCA

In general, RCA is fabricated by crushing the C&D waste in various types of crushers, or sometimes by hammering the waste manually. The method adopted in the crushing process has a strong influence on the physical properties of RCA[14]. The crushing is generally done in two stages, that is, primary and secondary crushing. In primary crushing, the oversized concrete blocks are broken into comparable sized fragments. This is usually carried out in the jaw crusher. In secondary crushing, impact crushers are used to remove the adhered mortar layers to fabricate a lot of better quality aggregates [16]. Practitioners can fabricate RCA into desirable particle sizes using the two successive crushing approaches, that is, primary followed by secondary [15].

Countries like Japan, USA, and Netherlands use advanced techniques to remove adhered mortar to produce better quality RCA. These techniques include presoaking, freeze and thaw, nitric acid dissolution, thermal expansion, microwave heating, heating and rubbing, mechanical grinding, and ultrasonic treatment methods.

D. Toughness and Soundness

The toughness and soundness characteristics of RCA are determined by Los Angeles degradation test. Tabsh and Abdelfatah [25] observed that the percentage loss of the recycled concrete aggregate remained within the acceptable limit of 50% for structural applications, irrespective of its origin. The use of RCA obtained from the recycled concrete with strength equal to 50.38 MPa resulted in comparable compressive and tensile strengths as compared with concrete comprising NA.

III. CONCRETE PRODUCTION USING RECYCLED COARSE AGGREGATES

A number of studies determining the properties of fresh and hardened concrete prepared using RCA have been reviewed. Based on the literature, the utilization of RCA in concrete production affects both the fresh and hardened properties of the final product. Some of the important studies are discussed next.

Workability of the concrete made with RCA is generally lower than that of the concrete made with NA [17]. This is certainly due to high porous nature inherent to RCA because of the adhered mortar. Additionally, other parameters also influence the workability of concrete made with RCA such as aggregate size, shape, water absorption capacity of aggregates etc. The mechanical properties of concrete made with RCA mainly include compressive strength, splitting tensile strength, and flexural strength. All these properties are affected due to the presence of residual mortar on RCA. Researchers have explored the compressive strength of concrete made with RCA and observed that these properties are strongly affected by the content of RCA used. The concrete made with RCA shows upto 30% loss in compressive strength for 100% replacement of NA with RCA [7, 18].

Sagoe-Crentsil, Brown, and Taylor[13] investigated the effect of compressive strength of parent concrete used to prepare RCA on the compressive strength of concrete prepared using RCA as an aggregate. It was concluded that compressive strength of concrete containing 100% RCA can exceed that of control concrete, if RCA belongs to the parent concrete of higher compressive strength. However, Go´mez-Sobero´n [19] observed a 10% reduction in compressive strength, on 100% replacement of NA with RCA. A significant reduction in compressive strength with increase in percentage of RCA in concrete mix was alsoobserved by Xiao et al. [26].

Poon, Shui and Lam [10] and Poon, Shui, Lam, Fok, and Kou [11] studied the influence of various parameters such as interfacial transition zone (ITZ), moisture states of RCA and w/c ratio on compressive strength of concrete prepared using RCA. It was noticed that a relatively dense state of ITZ can be achieved by using good quality RCA which further helps in achieving higher strengths, whereas, use of poor quality RCA could lead to a porous and loose type of ITZ which reduces strength of the final concrete. Investigators also observed that the strength of concrete depends upon the moisture states of RCA to be used in concrete mix, besides ITZ. The compressive strength of 29.0 MPa was obtained by Maier and Durham [20] but this was achieved using full replacement of NA with RCA. Rather, increment in values up to 48.0 MPa and 43.8 MPa was obtained using 50% and 75% RCA respectively. A study conducted by Yang et al.[21] reported the effect of water absorption capacity of RCA on the compressive strength, tensile strength, modulus of rupture and elasticity and unrestrained shrinkage strain of concrete containing RCA.

Specific attention was given to the durability characteristics of concrete made with RCA by Go´mez-Sobero´n [19]. The investigator noticed an increase in absorption and porosity of concrete prepared using RCA with increase in percentage of RCA. Otsuki, Asce, Miyazato, and Yodsudjai [22] observed that the concrete prepared using RCA performed well in comparison to the conventional concrete at high w/c ratios due to further strengthening of old ITZ as compared to the new one. Salem, Burdette, and Jackson [23] observed that the utilization of RCA lowers the freeze-thaw resistance of concrete. However, resistance was found to improve when air-entrainment approach was adopted. Levy and Helene [24] noticed a less carbonation depth when concrete was prepared using 20 to 50% RCA. However, significant improvement was observed on 100% replacement of NA with RCA.

IV. EXPERIMENTAL INVESTIGATION

A. Material and Methods

(1) Materials: Design mix was prepared as per the specifications of Indian Standards[1,3,6] for different percentages of RCA. NA were replaced with 100%, 75%, and 25% of recycled debris (20 mm average grain size).

The physical properties of 43-Grade cement were calculated as per Indian Standards [2]. The specific Gravity, Fineness (%), and Standard Consistency (%) were determined as 3.07, 3.5%, and 34% respectively. Initial setting time has been observed to be 45 minutes and final setting time as 240 minutes. The soundness of 2mm has been observed while 28 days compressive strength has been observed as 42.7N/mm^2.

Sand (fine aggregates) of grading Zone II was procured locally. It was first passed through 4.75 mm BIS-

TABLE I.

PHYSICAL PROPERTIES OF RCA AND NA COMBINATIONS

S.No.	Physical Properties	RCA and NA proportions		
		100% RCA	50%RCA + 50% NA	25%RCA + 75% NA
1.	G_s (Apparent Specific Gravity)	2.66	2.83	2.92
2.	Water Absorption (%)	5.22	4.33	4.206
3.	Moisture Content (%)	0.60	0.703	0.75
4.	FM (Fineness Modulus)	8.19	7.27	7.57

sieve to remove any particles > 4.75 mm. The remaining material was then washed to remove dust or clay particles. The specific gravity was calculated as 2.67 and fineness modulus was calculated as 2.715. The water absorption, moisture content, and bulking values have been observed as 1.020%, 0.155%, and 2.48% respectively. These values have been calculated as per the specifications of BIS [4].

The natural coarse aggregates (gravels)with particle size of 20 mm and fineness modulus as 7.36 were procured locally. The aggregates were washed to remove dust and dirt and were dried to surface dry condition. The apparent specific gravity has been observed as 3.01. Water absorption and moisture content have been observed as 3.806 % and 0.806 %.

Recycled coarse aggregates (RCA) with 20 mm average grain size were fabricated from abandoned pile heads by following a two-stage crushing approach. The physical properties of various combinations of RCA and NA have been reported in Table I.

(2) Methodology: A number of factors influence the compressive strength of concrete, such as water-cement ratio, grade of cement, quality of aggregates, and quality control during production. Cubes were cast in a mold having a dimension of 150 mm x 150 mm x 150 mm and were subjected to compression. After pouring concrete mix into the mould, it was tempered properly to remove any voids. Moulds were then removed after a period of 24 hours and the specimens were kept immersed under water in a curing tank.

These cubes were tested in a compression testing machine at intervals of 7,14, and 28 days of curing cubes as per the specifications of IS 516, 1959 [5]. A gradually increasing load was applied at the rate of 140 kg/cm^2 per minute till failure. The ratio of load at the failure and area of specimen gives the compressive strength of concrete. The compressive strength of concrete was determined using the following equation:

$$f = \frac{P}{A} \tag{1}$$

Where f = compressive strength, P = load at failure, and A = surface area of side of the cube.

Flexural strength also known as bend strength can be defined as the stress in concrete before it yields. Flexural strength of concrete beams is determined using the centre point loading method as per the specifications of BIS [5]. For this, twenty beams with dimensions100 mm x 100 mm x 500 mm were cast. These cubes were tested using flexure testing machine immediately upon their removal from the curing tank. Tests were conducted at 7 days and 28 days curing intervals. A gradually increasing load was then applied at the rate of 400 kg/minute till failure.

The strength and design of structural elements subject to transverse shear, torsion, shrinkage, and temperature effects requires split tensile strength to be determined as per the specifications of IS 5816, 1999 [27]. Moreover, it is widely used in the design of pre-stressed concrete structures, liquid retaining structures, roadways, and runway slabs. A total of 20 cylinders of diameter 150 mm and length 300 mm have been cast. Tests were usually conducted at intervals of 7 and 28 days. Cubes were taken out of the curing tank and tested immediately. Any residual particles and water sticking to the surface of the sample was wiped off and all projecting surfaces were leveled up. The load was applied on the sample without any sudden impact, and increased gradually at a nominal rate between 1.2 mm^2/min and 2.4 mm^2/ min.

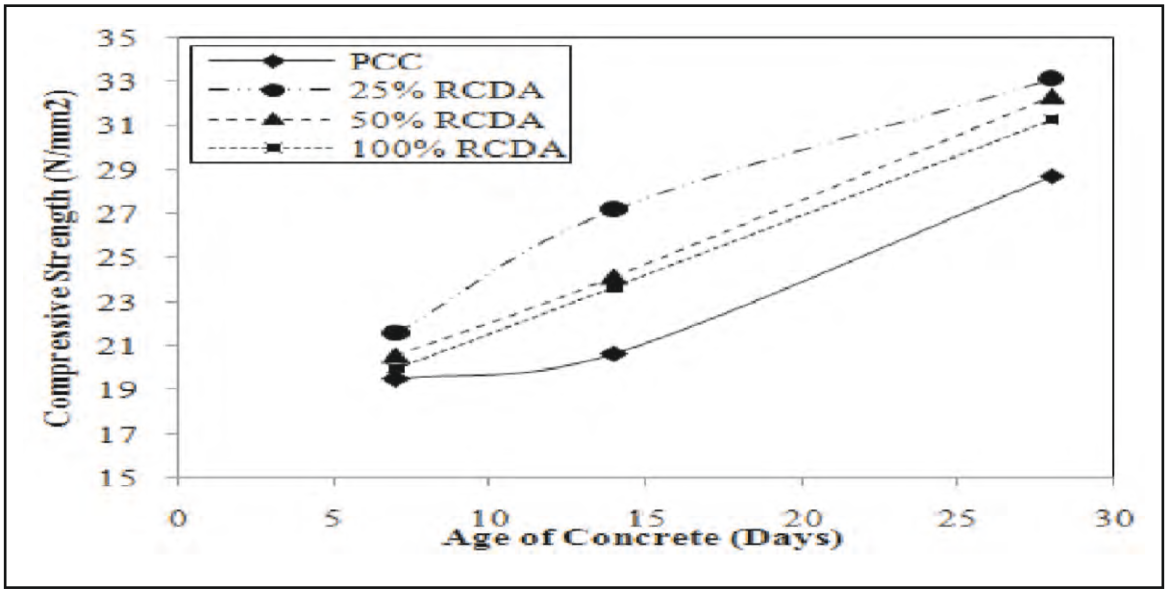

Fig. 1. Variation of Compressive Strength with Age of Concrete for Different Percentages of RCA

V. RESULTS AND DISCUSSION

A. Compressive Strength

A series of compressive strength tests have been carried out on 90 specimens as per the specifications of IS 516, 1959 [5]. The variation of the compressive strength of RCA concrete with age is shown in Fig.1. The 28 days compressive strength of plain cement concrete (PCC) has been calculated as 28.72 N/mm^2. For the concrete with 25, 50, and 100% RCA as coarse aggregates, the compressive strength has been obtained as 33.14, 32.37, and 31.28 N/mm^2. This shows that the concrete prepared using RCA performs better as compared to the control concrete prepared using natural aggregates. It has also been observed that a combination of RCA and NA performs better than RCA and NA used alone as coarse aggregates.

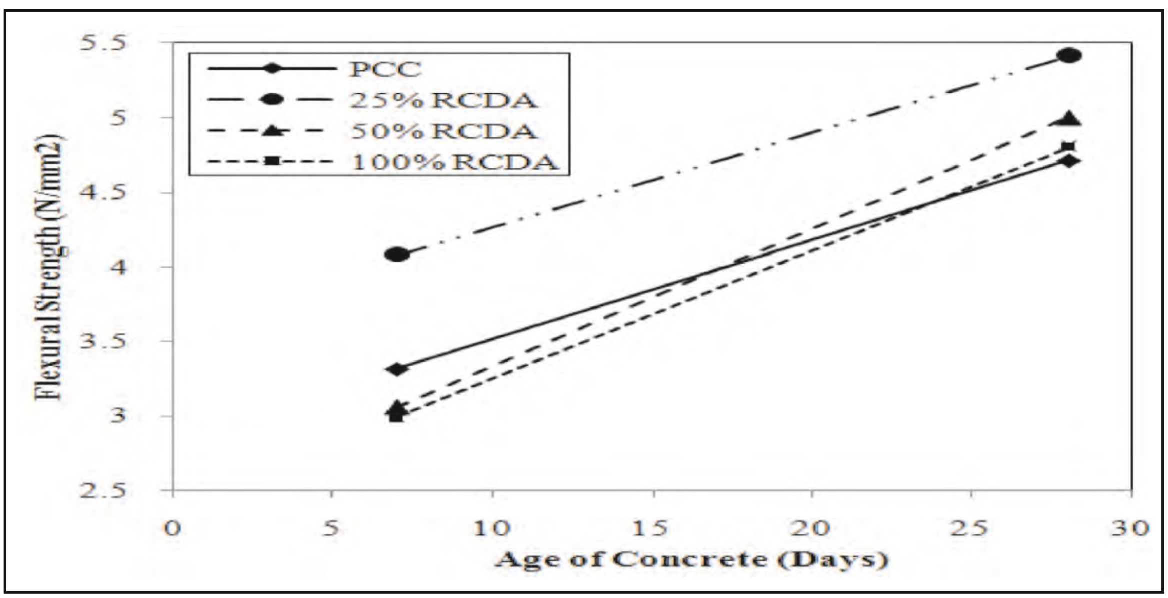

Fig. 2. Variation of Flexural Strength with Age of Concrete for Different Percentages of RCDA

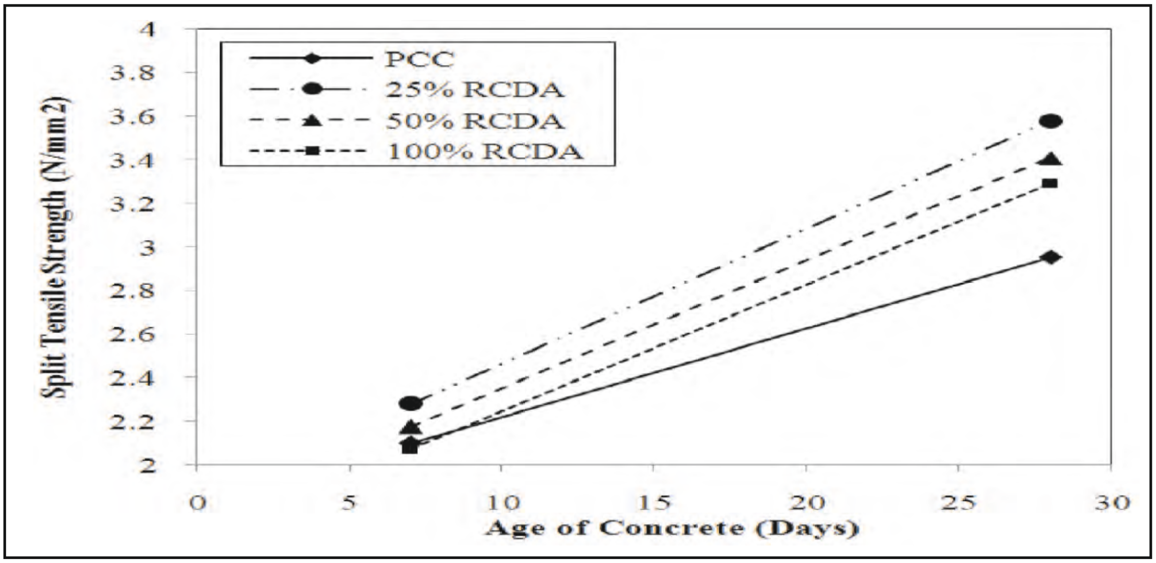

Fig. 3. Variation of Split Tensile Strength with Age of Concrete for Different Percentages of RCA

B. Flexural Strength

A series of flexural strength tests were carried out on 20 beams as per the specifications of BIS [5]. The variation of the flexural strength of concrete prepared using RCA with age is presented in Fig.2. The 28 days flexural strength of PCC was observed to be 4.708 N/mm^2. A significant increase in the flexural strength of concrete was observed on addition of RCA as a replacement of NA and follows the same trend as that of compressive strength.

C. Split Tensile Strength Tests

A number of split tensile strength tests were carried out on 20 cylindrical specimens as per the specifications of IS 5816, 1999 [27]. The variation of the split tensile strength of RCA concrete with age is shown in Fig.3. The 28 days split tensile strength of PCC has been observed to be 2.952 N/mm^2. A noticeable increase in the split tensile strength of concrete was observed on addition of RCA as a replacement to NA. It shows that RCA and natural aggregates also perform better in tension when used in combination and follow the same trend as that of compressive strength and flexural strength.

VI. CONCLUSION

On the basis of results and discussion, the following conclusions were drawn:

(1) There is a significant improvement in the compressive, flexural, and split tensile strengths of concrete prepared using RCA as an aggregate.

(2) Maximum and minimums strength were observed at 25% and 100% RCA content respectively. This shows that RCA and NA perform better when used in combination.

(3) The study shows that the use of RCA in concrete is an effective method to deal with overexploitation of NA.

(4) Utilization of RCA can also solve the problem of disposal of huge stockpiles of C&D waste and ultimately would reduce the load on landfills.

(5) Hence, use of industrial waste in civil engineering applications like concrete production is a beneficial proposition which is economical and environment friendly as well.

AUTHORS' CONTRIBUTION

Mr. Piyush Nandwani carried out all the laboratory experimentation under the supervision of Dr. Upain Kumar Bhatia. Prof. Sandeep Sharma helped in review of literature and correcting the manuscript.

CONFLICT OF INTEREST

The authors certify that they have no affiliation with or involvement in any organization or entity with any financial interest, or non-financial interest in the subject matter, or materials discussed in this manuscript.

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