Bond strength between the recycled coarse aggregate concrete and rebar

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Abstract— **During the past few years, sustainable resource management and development have been at the forefront of crucial concerns affecting the construction sector. Concrete, one of the most widely used building materials in the world, is made of aggregate, sand, cement, and water, and it can be recycled and used again in a variety of ways. The use of recycled concrete aggregates (RCA) in the production of concrete has a number of benefits, including the possibility of a significant reduction in the demand placed on non-renewable aggregate resources, an extension of the useful life and capacity of landfill and waste management facilities, and a decrease in the carbon dioxide emissions and traffic congestion connected with the transportation of virgin aggregates from distant sites. In this study, the interactions between aggregate characteristics, concrete characteristics, and bond characteristics between reinforcing steel and RCA concrete are examined. Pullout tests were run to examine the binding behavior between steel rebar's and recycled coarse aggregate concrete. Four recycled coarse aggregate (RCA) replacement percentages 0%, 30%, 60%, and 90% are taken into consideration together with water-cement ratios of 0.42, 0.45, 0.48, 0.51, and 0.55. Based on the test results, the effects of the water-cement ratio and the replacement percentages of recycled coarse aggregate on the binding strength between the concrete and steel rebars were examined. It was found that under the equivalent mix proportion (i.e., the mix proportions are the same, except for different recycled coarse aggregate replacement percentages), the bond strength between the recycled coarse aggregate concrete and rebar initially decreases with an increase of the recycled coarse aggregate replacement percentage, whereas afterwards the bond strength increases with increase in replacement level of coarse aggregate.**

Keywords— bond strength, Pull out test, recycled coarse aggregate, replacement percentage

I. INTRODUCTION

Globally, the concrete industry consumes large quantities of natural resources, which are becoming insufficient to meet increasing demands. At the same time, utility of old structure is diminishing, so these building are demolished to pave way for new and modern construction. Building are demolished due to various reasons i.e. reconstruction for better economic gains, natural disasters and war-inflicted damages. The rate of demolition is increasing day by day and at the same time, the cost of dumping is increasing due to non-availability of appropriate site nearby. Beside scarcity of land, other problems associated with the landfill option include their silting; transportation cost and public opposition. Thus, recycling has been gaining wider attention as a viable option for handling of waste concrete. One of the materials that can be recycled in the demolished structure is coarse aggregate. Utilization of Recycled Aggregate in concrete has been engaged due to awareness of society in natural resources protection. The application of Recycled Aggregate as coarse aggregate in concrete mixes has been initiated so as to make effective use of the waste materials. The use of recycled aggregates in concrete opens a whole new range of possibilities in the reuse of materials in the building industry. The application of recycled aggregates is a key to the problem of an excess of waste material. The studies on the use of recycled aggregates have been going on for many years, and none of the results showed that recycled aggregates are disagreeable for structural use (Rakshvir, Barai, 2006). However

Although there is growing emphasis on the use of recycles coarse aggregate for making

new concrete in the West and far Eastern countries like Japan and Korea, there is relatively little awareness of the potential application of such aggregates in India. After China, India is the leading consumer of cement in the world, which by implication means that India is also one of the leading consumers of concrete-making materials like fine and coarse aggregate (Das et al. 2010). Since aggregate sources are not inexhaustible, it is imperative to create awareness about the potential use of recycled coarse aggregate in the manufacture of concrete in India. Figure 1 illustrates the various moisture states of aggregates.

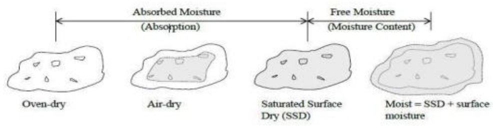

Figure 1: Several moisture states of aggregates (Neville, 1995)

II. ADHERED MORTAR CONTENT

After crushing concrete, the resultant recycled coarse aggregate concrete contains both natural stone and old mortar. This old adhered mortar can account for, about 25 to 60 the percent by volume of the aggregate itself. It was noted that the finer the aggregate, the more the adhered mortar content. The residual mortar content can have negative impacts also on such concrete properties as absorption, density, abrasion resistance etc. The amount of residual mortar present on recycled coarse aggregate depends largely on the crushing process by which the aggregates are produced. As the number of crushing of the aggregates increases, the amount of adhered mortar is reduced. It was also observed that use of impact crusher produces higher percentage of recycled coarse aggregate with less amount of residual mortar and it is also suggests that the adhered mortar in recycled coarse aggregate give lower strength then the fresh mortar produced in new concrete. As a result, it concluded that the adhered mortar in recycled coarse aggregates is the weakest point in concrete produced with coarse recycled coarse aggregates. Several methods have been investigated to determine the percent of residual mortar in recycled coarse aggregate. The most general and commonly used method is taking a sample of oven dried recycled coarse aggregate weighing 100 grams in a plastic container. In this container add 1:3 HCL solution such that the HCL solution surface was 15 mm above the aggregates. And when the level of the HCL falls down after some hours add more HCL in order to maintain the level. After 2 days the constituents of recycled coarse aggregate split up. Transfer the recycled coarse aggregate particles to a new container and add fresh HCL solution as before. Again after 2 days the complete breakdown of recycled coarse aggregate takes place. If it does not, then keep the recycled coarse aggregate immersed for a longer time. After the complete disintegration of recycled coarse aggregate remove the coarse aggregates to a 4.75 mm sieve and wash it with hot water to remove all the HCL. Note down the mass of the oven dried coarse aggregates. The percent of adhered mortar can be calculated based on the following expression:

% Adhered Mortar = (Mass of RCA−Mass of RCA after removal of mortar)/Mass of RCA.

III. MATERIAL PROPERTY

A. *Cement*

Cement is a fine, grey powder. It is mixed with water and materials such as sand, gravel, and crushed stone to make concrete. The cement and water form a paste that binds the other materials together as the concrete hardens. The ordinary cement contains two basic ingredients namely argillaceous and calcareous. In argillaceous materials, clay predominates and in calcareous materials calcium carbonate predominates. Ordinary Portland cement of grade – 43 (Ultra tech cement) conforming to Indian standard IS: 8112-1989 has been used in the present study. The results of the various tests on cement properties are given in Table 1.

Table 1: Physical properties of Portland cement

Sr. No.	Characteristics	Values obtained
1	Normal Consistency	29.5%
2	Initial setting time	115 min
3	Final setting time	220 min
4	Fineness	2.5%
5	Specific gravity	3.18

B. *Fine Aggregate*

The material which passes through 4.75 mm sieve is termed as fine aggregate. Usually natural sand is used as a fine aggregate at places where natural sand is not an available crushed stone is used as a fine aggregate. The sand used for the experimental works is locally procured and conformed to grading zone III. The physical properties are provided in Table 2.

Table 2: Physical properties of fine aggregate

S.No	Characteristics	Value
1	Type	Natural Sand
2	Specific gravity	2.65
3	Fineness modulus	2.50

C. *Natural Aggregate*

The broken stone is generally used as a coarse aggregate. The nature of work decides the maximum size of the coarse aggregate. Locally available coarse aggregate having the maximum size of 20 mm was used in the present work.

D. *Recycled Coarse Aggregate*

To make RCA, the specimens without reinforcement were manually broken down into small pieces and then crushed using jaw crusher. The crushed pieces of concrete were then separated into two fractions depending on their size. The larger fraction, passing through 20 mm sieve but retained on 10 mm sieve was designated RCA20 – 10 mm, while the smaller fraction passing through 10 mm sieve but retained on 4.75 mm was designated RCA10 - 4.75. The fraction passing through 4.75 mm sieve was discarded. While making RCA concrete, the two different sizes of RCA were mixed in a suitable proportion so that the gradation curve of the combined RCA concrete was similar to that of the natural coarse aggregate. The properties of natural and recycled coarse aggregate are presented Table 3.

Table 3: Physical properties of natural and recycled coarse aggregate

S.No	Properties	Natural aggregate	Recycled coarse aggregate
1	Specific gravity	2.34	2.60
2	Water absorption (%)	1.60	2.40
3	Fineness modulus (%)	6.70	7.10

E. *Reinforcing Steel*

High strength deformed steel bar with a nominal diameter of 16 mm of tensile strength 533.412 MPa, is used as main longitudinal reinforcement in all pull out test specimens. Along with the main bar, the cube is reinforced with a helix of 6 mm diameter plain mild steel reinforcing bar conforming to Grade I of IS: 432 (Part I)-1982 at pitch 25 mm pitch, such that the outer diameter of the helix is equal to size of the cube.

F. *Water*

Water is an important ingredient of concrete as it actively participates in the chemical reaction with cement. Since it helps to form the strength giving cement gel, the quantity and quality of water required to be looked into very carefully. Potable water is generally considered satisfactory. In the present investigation, tap water is used for both mixing and curing purposes.

G. Superplasticizer

SikaViscoCrete -SC 001, the superplasticizer supplied by Sika India Pvt. Limited is used in our investigations. It is a third generation highly effective superplasticizer for concrete and mortar. It meets the requirements for superplasticizer according to EN934 -2, SIA 262, ASTM C 494-99/99a Type F and 9103-1999 (amended 2003). The dosage of the superplasticizer is fixed based on the requirements for workability. The technical data related to the superplasticizer used is provided in Table 4. This data is supplied by the manufacturers.

Table 4: Technical data of superplasticizer

S.No	Characteristics	Value
1	Color	Dark brown liquid
2	Specific gravity	1.17
3	Air Entrainment	Maximum 1%
4	pH	7 to 8

IV. MIX DESIGN

Four weight combinations of NCA and recycled coarse aggregate are adopted: 100 % NCA (control mixture), 60 % NCA + 30 % recycled coarse aggregate, 30 % NCA +60 % RCA, 10 % NCA +90 % RCA. The concrete mixture proportions and the corresponding mix designations are presented in Table 5.

. Table 5: Technical data of superplasticizer

w/c ratio	Cement	Fine aggregate	Natural aggregate	Water	Super plasticizer
	(kg/m^3)				%
0.42	486	640	1256	206	1.4
0.45	453	651	1274	206	1.2
0.48	426	657	1291	206	1.0
0.51	400	664	1303	206	0.5
0.55	370	672	1312	206	0

V. CASTING OF SPECIMEN FOR PULL OUT TEST

150mm cube is used to study the compressive strength of various mixes. The cubes are filled with fresh concrete using vibrating table. Immediately after casting cubes, the specimens are covered with gunny bags to prevent water evaporation. Three cubes are casted for each parameter. The compressive strength test is carried out for 7 days and 28 days. Therefore, six identical specimens are casted for each concrete mix such as A1-A5 of 0,30, 60, 90.

The specimen is prepared as per the codal guidelines from IS: 2770 (Part I) – 1967 (Methods of testing bond in reinforced concrete). In this, one rebar of 16 mm diameter is used as concentric reinforcement that will be pulled for finding pull out strength. The pulls out specimens are cast in a vertical position in the laboratory using steel moulds. The embedded length is kept five times the rebar diameter and was so selected to avoid yielding of the steel bar under pullout load. Contact between the concrete and the rebar along the debonded length was broken using a coaxially placed soft plastic tube and the annular space between the rebar and the plastic tube was filled with clay. Along with this, a helix reinforcement (as specified by IS: 2770 (Part I) – 1967) of 6 mm diameter conforming to grade I of IS: 432 (Part I) – 1966 at pitch of 25 mm such that the outer diameter of the helix is equal to the size of the cube. The typical sample specimens are shown in Figure 2.

Figure 2 Pull out test for concrete specimen

VI. CASTING OF SPECIMEN FOR PULL OUT TEST

To carry out test, the rod of 25 mm is welded to lower plate of the setup is fixed in the lower jaw of the machine. The specimen is kept in between the two plates and is fixed by tightening the nut-bolts. The 16mm diameter rebar (embedded in the specimen) is passed through the hole in the upper plate and is fixed to the upper jaw of the universal testing machine. The rebar is pulled out at the rate of 2.25 kg/min for all test specimens. The test setup for pull out test is shown in Figure 3.

Figure 3 Test setup for pull out strength test

VII. RESULTS AND DISCUSSION

A. Compressive Strength

Three cubes (150mm) from each batch of concrete mix are casted and cured for 7 and 28 days in order to determine compressive strength of RCA concrete. All specimens are cast in a single mix and direct weight to weight replacement of natural coarse aggregate is carried out with recycled coarse aggregate at a replacement ratio of 0, 30, 60, and 90 %. The mixes are casted at water-cement ratio of 0.42, 0.45, 0.48, 0.51 and 0.55. This corresponds to range of strength varying from low strength concrete to moderate strength concrete.

This trend of decrease in strength is very prominent at 30% replacement level. It may be due to at 30% replacement level, we have concrete with two types of aggregates (i.e. natural and recycled) therefore, and at this level interfacial transition zone is of mixed characteristic, which is rather playing a negative role in overall behaviour of concrete. It can be concluded that if recycled coarse aggregate are used, they must be used at higher replacement levels. Infact, 90% replacement levels gives the maximum efficient at 28 days.

B. Effect of RCA on Bond Strength

With the increase of recycled coarse aggregate replacement initially bond strength decreases and then increases. Bond strength is maximum at coarse aggregate replacement level of 90%. Similar trend is observed at all water-cement ratios. This increase in bond strength is may be due to same modulus of elasticity of recycled coarse aggregates and the cement paste of recycled coarse aggregate concrete which at the level of concrete microstructure should improve composite action between these two phases and reduce incompatibilities of deformations under applied loads as suggested by Poon et al. (2004).

VIII. CONCLUSION

The 28 day compressive strength of concrete increases as the percentage of recycled aggregate. Increase in compressive strength for 28 days for 90% replacement of coarse aggregates are 7.92%, 21.54%, 24.54%, 24.11%, 34.41 and 51.38% for water ratio 0.42, 0.45, 0.48, 0.51, 0.55 respectively. It shows that major advantage of using recycled aggregates is achieved in low strength concretes made with higher w/c ratio. The bond strength of concrete decreases for 30% replacement and afterwards it increases. Bond strength is maximum at 90% replacement. Increase in bond strength at 90% replacement level is 7.67, 3.70, 6.40, 8.39 and 21.69 for respective water-cement ratio 0.42, 0.45, 0.48, 0.51 and 0.55. Recycled aggregate must be used at higher replacement levels. At this level, maximum benefit in terms of compressive strength and bond strength are achieved. A power series relationship exists between compressive strength and bond strength of recycled aggregate concrete.

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