American Journal of Engineering Research (AJER)
e-ISSN : 2320-0847 p-ISSN : 2320-0936
Volume-1 pp-01-05
www.ajer.org

Research Paper Open Access

Bond strength of concrete containing crushed concrete aggregate (CCA)

Krishnakumar S. [*1], Anju Sam[2a], Jayasree S.[2c] and Job Thomas[1c]
[1]*Division of Civil Engineering, School of Engineering, Cochin University of Science and Technology, Kochi-682022, Kerala,, India.*
[2]*Department of Civil Engineering, Mar Baselios College of Engineering And Technology, Mar Ivanios Vidyanagar, Nalanchira P.O, Thiruvananthapuram 695015, Kerala, India*

***Abstract:* -** The use of recycled concrete aggregates (RCA) for construction purposes has proved to be a sustainable alternative to the problems of disposal of concrete wastes and depletion of natural aggregates. The variables considered in this study are grade of concrete and percentage replacement of coarse aggregate with crushed concrete aggregate (CCA). In the first stage, optimum replacement of aggregate is determined for M30 grade concrete. The test results indicates that the reduction in strength by replacement of natural aggregates using crushed concrete aggregates up to 40 percent is minimal. The bond strength between the rebar and concrete is determined for control NCA concrete and CCA concrete. The influence of replacement of ratio of CCA on bond strength of concrete is determined. The replacement ratio of 0, 40 and 100 percent was considered for the determination of bond strength of concrete. The strength grades of concrete used are M20, M25 and M30. The variation of bond strength with respect to that of control concrete was found to be minimal for M25 grade concrete containing CCA.

***Keywords:* -** *Bond Strength, Pull out Test, Recycled Concrete Aggregate,*

I. INTRODUCTION

Recycling is process of value addition of material that is otherwise considered as waste. The excessive usage of natural aggregate is an environmental concern among scientist. In order to reduce the usage of natural aggregate, recycled aggregate can be used as a replacement material. Recycled aggregate comprises of crushed, graded inorganic particles processed from the materials that have been reclaimed from constructions and demolition waste. The use of recycled materials in concrete decreases the depletion of virgin raw aggregates. In this study, crushed concrete aggregates reclaimed from a construction site are used as the coarse aggregate in the concrete.

In reinforced constructions, the bond between the concrete and reinforcement is a very important factor affecting the strength of the structure. Bond is basically defined as the force which prevents the slippage between two constituent materials. When a reinforced concrete element is loaded, the load is initially transferred to concrete and it is then to the steel reinforcement and is discussed in the literature by Xiao and Falkner (2007)[1]. The transfer of force from concrete to steel and vice-versa will be effective only if there is proper bonding between steel and concrete. The bond in plain reinforcement bars is mobilized mainly due to the molecular bond strength and friction force. The bond transfer in deformed bars is by frictional bond and bearing at the ribs and is discussed in Butler et al. (2011)[2]. The various factors affecting the concrete-reinforcement bond suggested by Kim et al. (2012)[3] include the strength of concrete, yield strength of steel, diameter of steel reinforcement, surface geometry of reinforcement, depth at which reinforcement is embedded into concrete,

[*] Corresponding author, Research Scholar, M.Tech., Email: skrishna_k@rediffmail.com
[a] B.Tech., Email: anju_sam2@hotmail.com
[b] M.Tech., Email: jayasris71@gmail.com
[c] Ph.D., Email: job_thomas@cusat.ac.in

thickness of concrete cover surrounding the reinforcement and types of aggregate phase on the surrounding concrete. The strength of concrete-reinforcement bond is assessed by pull-out test in which an axial pulling force is applied to pull the reinforcement embedded out of the concrete specimen.

II. AIM OF THE STUDY

The properties of concrete containing natural coarse aggregate (NCA) and crushed concrete aggregate (CCA) is determined. The aim of the study is to find the optimum replacement ratio of CCA concrete. Aim is also to determine the influence of replacement ratio of CCA on mechanical properties of the concrete. The variation of bond strength of concrete with respect to the grade and replacement ratio of the coarse aggregate is determined and compared with the control concrete mix containing NCA.

III. EXPERIMENTAL INVESTIGATION

3.1 Determination of properties of RAC

The constituent materials consist of Portland Pozzolana Cement (PPC) of standard consistency 34 percent, specific gravity 3.0 with 28 day compressive strength 33MPa, Quarry sand confirming to Zone II of IS 383 (1970)[4] as fine aggregate, and coarse aggregate of 20mm nominal size. The water absorption of natural coarse aggregate was found to be 1 percent and that of recycled concrete aggregate was 2.7 percent. Table 1 shows the properties of natural coarse aggregate (NCA) and recycled coarse aggregate (RCA). The water-cement ratio (w/c) selected was 0.48. HYSD steel bar of 12mm diameter was adopted as the reinforcing bar. Concrete was designed as per IS: 10262(2009)[5] and is given in Table 2. The compressive strength of concrete is determined as per IS:516 (2007)[6]. Mechanical properties, namely, compressive strength, tensile strength, modulus of elasticity and modulus of rupture were determined.

Table 1 Properties of coarse aggregates

Properties	NCA	RCA
Specific gravity	2.76	2.57
Water absorption (%)	1.0	2.7
Bulk density (kg/m^3)	1540	1440
Fineness modulus	5.99	5.99

3.2 Mix proportioning

Concrete mixes of strength grades M20, M25 and M30 were designed in accordance with IS:10262 (2009) were also designed for finding the bond strength behavior of concrete using RCA. The adopted mix proportions are given in Table 2.

Table 2 Concrete mix proportions

Grade of concrete	w/c ratio	Mix proportion	Cube compressive strength of NCA control concrete mix (MPa)
M20	0.5	1:2.33:3.92	26.68
M25	0.475	1:2.28:3.84	31.85
M30	0.45	1:1.73:3.03	38.40

The mechanical properties of M30 grade concrete containing CCA are determined and compared the same with control concrete with NAC. Standard cube specimens of 150 mm x 150 mm x 150 mm, cylinders of 150mm diameter and 300 mm height and prisms of size 100 mm x 100 mm x 500 mm were cast and cured using moist burlap. The RCA were soaked for 24 hours to compensate the water absorption. The replacement ratio of 20 to 100 percent was considered in this study. The two-stage mixing approach (TSMA) was used for improving the quality of RAC, in which water content was added in two stages in the process of mixing (Tam and Tam, 2007[7]). The fine and coarse aggregates are mixed for 60 seconds and fifty percent of the water content is added and mixed for another 60 seconds. The cement is added to the partially wet mixture rotating drum mixing machine and mixed for 30 seconds. The remaining fifty percent of water is added and mixed for another 120 seconds. The mix was designed for a slump of 50 mm. The sulphonated naphthalene based super plasticizer was used in this study. The details of M30 grade concrete mix are given in Table 3.

Table 3 Details of M30 grade concrete with various CCA content

Mix designation	Volume replacement ratio	Weight of constituents in kg for one cubic meter of concrete					
		Admixture	Water	Cement	Fine aggregate	NCA	CCA
M30/0	0.0	1.6	180	400	690	1210	0
M30/20	0.2	2.0	180	400	690	968	205
M30/40	0.4	2.0	180	400	690	726	411
M30/60	0.6	2.4	180	400	690	484	616
M30/80	0.8	3.2	180	400	690	242	821
M30/100	1.0	3.2	180	400	690	0	1026

3.3 Preparation and curing of pull-out test specimens

The pull-out test specimens were prepared for bond strength test as given by ASTM C234-91a (1991)[8]. The size of the concrete specimen was 150 mm x150 mm x250 mm in which a single piece of HYSD bar of diameter 12 mm was embedded horizontally at the centre. The concrete is made in contact with the rebar in the middle of the specimen. Poly vinyl chloride (PVC) pipes were provided over the rest of the length of the bar. The concrete was in touch with the PVC pipe and not with the rebar over the pipe length. The details of the pull out specimen are shown in Fig. 1.

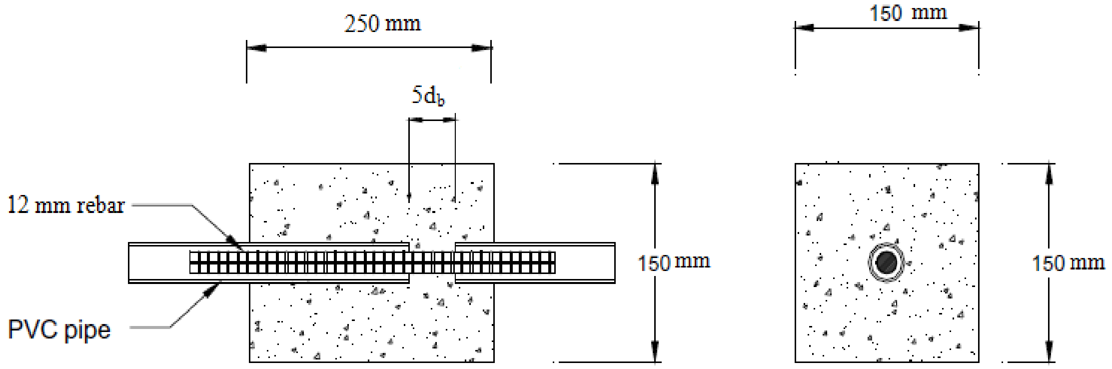

Figure 1 Details of pull-out test

Three specimens were cats and tested and the average strength is reported in this paper. Three grades of concrete, namely, M20, M25 and M30 are use. In all these grades, three replacement ratios, namely 20, 40 and 100 percent, is considered for this study. The partial replacement 40 percent was considered because the variation of compressive strength of M30 grade concrete is found to be less than 10 percent in the preliminary study. The weight of the constituent materials for the M20 and M25 grade concrete is given in Table 4.

Table 4 Details of M20 and M25 grade concrete with various coarse aggregate replacement ratio

Mix designation	Volume replacement ratio	Weight of constituents in kg for one cubic meter of concrete					
		Admixture	Water	Cement	Fine aggregate	NCA	CCA
M20/0	0.0	1.3	152	320	750	1250	0
M20/40	0.4	1.7	157	330	750	750	328
M20/100	1.0	2.6	157	330	750	0	820
M25/0	0.0	1.3	157	330	750	1270	0
M25/40	0.4	1.7	157	330	750	762	340
M25/100	1.0	2.6	157	330	750	0	850

The picture of the pull-out test specimens of M20/0 is given in Fig 2. The fresh concrete filled in the mould and compacted. The top surface is finished using a trowel. The specimens were demoulded after 24 hours and shifted for curing. The specimens are cured by immersing in water. All specimens were tested at an age of 28 days.

3.4 Test setup

Pull-out test was conducted according to the specifications of ASTM C 234-91a. The tests were performed using a universal testing machine with 100 KN capacity. The specimen was placed on the upper cross-head of the UTM. The length of the steel bar protruding from the specimen was clamped tightly by the lower cross-head. This setup was subjected to monotonically increasing load during which the upper head moved upwards thus pushing the concrete while the steel rod remained stationary. Thus, a pullout mechanism was incorporated in the specimen. A linear variable differential transducer (LVDT) was attached to the specimen to record the differential movement between the concrete and steel during the entire loading cycle. The load at which the reinforcement is detached from the test concrete specimen is recorded as pull out load. The test setup for pullout test is shown in Fig. 3

Figure 2 Pull-out test specimens

3.5 Testing of pull-out specimens

Pull-out test was conducted according to the specifications of ASTM C 234-91a. The tests were performed using a universal testing machine with 100 kN capacity. The specimen was placed on the upper cross-head of the UTM. The length of the steel bar protruding from the specimen was clamped tightly by the lower cross-head. This setup was subjected to monotonically increasing load during which the upper head moved upwards thus pushing the concrete while the steel rod remained stationary. A linear variable differential transducer (LVDT) was attached to the specimen to record the differential movement between the concrete and steel during the entire loading cycle. The load at which the reinforcement is detached from the concrete specimen is recorded as pull out load (P). The test setup for pullout test is shown in Fig. 3. The bond strength was calculated by:

$$\tau = \frac{P}{\pi d_b L} \quad (1)$$

where (d_b) diameter of the rebar and (L) is the length of contact between concrete and the rebar.

IV. RESULTS AND DISCUSSION

4.1 Mechanical properties of CCA concrete

The various mechanical properties of CCA concrete are determined and given in Table 5. The cube compressive strength of the control concrete with natural crushed aggregate is found to be 39 MPa. The reduction of compressive strength was found to be approximately 5 percent for every 20 percent replacement of NCA with CCA. Thus, reduction of compressive strength was found to be less than 10 percent for concrete with coarse aggregate replacement ratio of 0.4. The reduction in cylinder compressive strength was found to be nominal up to an aggregate replacement ratio of 40 percent. The variation of cylinder compressive strength, split tensile strength, modulus of elasticity and modulus of rupture is found to be similar to variation of compressive strength. Hence, it may be concluded that the behavior of NCA concrete is similar to that of the CCA concrete.

Figure 3 Pull-out test specimens

Table 5 mechanical properties of CCA and control concrete

Properties	Average strength in MPa corresponding to the coarse aggregate replacement ratio of					
	0.0	0.2	0.4	0.6	0.8	1.0
Cube compressive strength	39.0	37.4	36.5	33.3	30.8	27.3
Cylinder compressive strength	28.8	27.8	27.1	26.4	23.1	21.2
Split tensile strength	4.7	4.2	3.8	3.1	2.8	2.4
Modulus of elasticity	34 x10^3	33 x10^3	28 x10^3	24 x10^3	23 x10^3	22 x10^3
Modulus of rupture	5.1	4.9	4.5	3.6	3.2	3.0

4.2 Bond strength of CCA concrete

The bond strength of CCA concrete is given in Table 6. The reduction in bond strength is found to be nominal for concrete containing 40 percent of CCA aggregate.

Table 6 Bond strength of CCA concrete

Mix designation	Ultimate bond stress (MPa)
M20/0	4.6
M20/40	4.4
M20/100	3.8
M25/0	5.2
M25/40	4.7
M25/100	3.9
M30/0	5.3
M30/40	4.8
M30/100	4.0

The bond strength of M20 grade NCA concrete is 4.6 MPa and that of M25 grade concrete is 5.2 MPa. The bond strength increases with grade of concrete.

V. CONCLUSİON

The reduction in the strength of concrete containing 40 percent (CCA) was found to be less than 10 percent. The bond strength of concrete is directly proportional to the grade of concrete. Based on the experimental study, it may be concluded that 40 percent replacement of natural coarse aggregate with crushed concrete aggregate (CCA) can be recommend.

REFERENCES

[1] J. Xiao, and H. Falkner, Bond behavior between recycled aggregate concrete and steel re-bars, *Construction and Building Materials*, 21, 2007, 395-401.

[2] L. Bulter, J. S. West, and S. L. Tighe, The effect of recycled concrete aggregate properties on the bond strength between RCA concrete and steel reinforcement, *Cement and Concrete Research*, 42, 2011, 1037-1049.

[3] Y. Kim, J. Sim, and C. Park, Mechanical properties of recycled aggregate with deformed steel re-bar, *Journal of Marine Science and Technology*, 20(3), 2012, 274-280.

[4] IS:383 (1970), *Specification for Coarse and Fine Aggregate from Natural Sources of Concrete*, Bureau of Indian Standards, New Delhi, India.

[5] IS:10262 (2009), *Concrete Mix Proportioning- Guidelines*, Bureau of Indian Standards, New Delhi, India.

[6] IS: 516 (1959), *Methods of Tests for Strength of Concrete*, Bureau of Indian Standards, New Delhi, India.
[7] V.W.Y.Tam, and C.M. Tam, "Diversifying two-stage mixing approach (TSMA) for recycled aggregate concrete: $TSMA_s$ and $TSMA_{sc}$", *Construction and Building Materials*, **22**(10), 2008, 2068–2077.
[8] ASTM C234-91a (2000), *Standard Test for Comparing Concrete on the Basis of Bond Developed with Reinforcing Steel*, American Society for Testing and Materials, PA, USA.