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Research Paper

A STUDY OF BOND STRESS DEVELOPED IN RECYCLED AGGREGATE CONCRETE IN PRESENCE OF MINERAL ADMIXTURE

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Construction waste has been dramatically increased in the last decade, social and environmental concerns on the recycling have consequently been increased. Recent technology has greatly improved the recycling process for waste concrete. This paper presents comparison of properties of natural and recycled aggregates and also the effect of mineral admixtures (like Fly Ash, Metakaolin) on behavior of Recycled Aggregate Concrete (RAC). This paper presents the experimental results of RAC prepared with different amount of Recycled Coarse Aggregate (RCA). Six mixes of concrete with 0%, 20%, 40%, 60%, 80%, 100% replacement of natural aggregate with recycled aggregate (RCA) are cast respectively with target compressive strength 25 MPa. In addition to this partial replacement to the weight of cement is done with Fly Ash (20%), Metakaolin (20%) for all mixes. 10 mm, 12 mm, 16 mm diameter bars are used for pull out test (Bond Stress). The bond stress using cylinder specimens and bars having diameter 10 mm, 12 mm, 16 mm are used for pull out test (Bond Stress) and tested at the age of 28 days. Depth of steel bar in cylindrical specimen is considered as 15 times diameter of bar. This paper focuses on the possibility of the use of recycled aggregate as a structural material.

Keywords: C & D waste, Fly Ash, Metakaolin, Recycled Aggregates, Recycled aggregate concrete, Bond stress

INTRODUCTION

The problem of waste disposal has become a major problem in the developed countries as well as developing countries like India. This is due to the enormous increase in the quantity of disposable materials, the continuing storage of dumping sites, increase in the cost of transportation and its disposal. The large-scale depletion of Natural Aggregate (NA) and the increased amounts of construction and demolition waste going to landfill sites are causing significant damage to the environment and developing serious problems denting the public and the environmentalist's aspirations for a waste-free society. Therefore the concept of recycling the waste material and using it again in some form has gathered momentum. Also, recycling not only solves the problem of

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waste disposal but also reduces the cost and conserves the non-renewable natural sources. Demolition waste generated in many countries is no exception to the above problem. And hence, recycling technology is making considerable headway in the recycling of demolished concrete.

In India too, the same trend of depletion of the aggregate reserves. The situation in India is not serious, yet there are some parts of India where crushed stone aggregate are not available within several kilometers of the radius. However, the gravity situation in the future, demands serious rethinking on the part of the Indian community, especially when the volume of concrete construction is expected to increase manifold in coming decades.

EXPERIMENTAL PROGRAM

Materials

The details of various materials used during the study are presented here.

The cement used is Ultratech Ordinary Portland Cement (OPC) of 53 Grade conforming to Bureau of Indian Standard Specifications (IS: 12269-1987) with a specific gravity of 3.15.

The locally available natural sand conforming to grading Zone II (IS: 383-1970) is used in recycled aggregate concrete.

The natural coarse aggregates obtained from the locally available quarries with maximum size of 20 mm and satisfying the grading requirements of BIS (IS: 383-1970) is used during this work.

The recycled coarse aggregates are obtained from the demolished building. The scrap concrete obtained from demolished building is transported to the nearby crusher and recycled aggregates of size less than 20 mm are obtained. The pieces greater than 20 mm are crushed again to the maximum size of 20 mm.

A cementitious material, Fly ash, is used for cement replacement. Pozzocrete 100, a processed ultra fine fly ash obtained from Dirk India Pvt. Ltd. Nashik is used in the present experimental investigation.

A cementitious material, Metakaolin, is used for cement replacement. It is a calcined clay pozzolanic material obtained from 20 microns Pvt. Ltd. Bhivandi used in the present experimental investigation.

Reinforcing bars (ribbed), TATA steel 500 of various diameters are used.

Various physical properties of natural and recycled aggregates are determined prior to concrete mix design. The same properties are listed in Table 1 and Table 2.

Table 1: Properties of Natural Aggregate

Test	Result
Aggregate crushing value	11.26%
Aggregate impact value	11.11%
Specific gravity	2.7
Water absorption value	3.06%
Fineness modulus	3.09

Table 2: Properties of Recycled Aggregate	
Test	**Result**
Aggregate crushing value	15.45%
Aggregate impact value	15.16%
Specific gravity	2.54
Water absorption value	8.7%
Fineness modulus	2.62

Specimen Preparation

During present experimental investigation in all six proportions of concrete mixtures are prepared. One mix is prepared with natural aggregates and is a reference mix.

Remaining five mixes are prepared with 0%, 20%, 40%, 60%, 80%, & 100% replacement of natural aggregates with recycled aggregate by weight. Only a part of natural aggregates, i.e., coarse aggregate is replaced by recycled aggregates. In all six mixes, cement is partly replaced with a processed fly ash (Pozzocrete 100). 20% of total cement quantity is replaced with fly ash.

As the study is intended for utilization of C & D waste in normal structural concrete only, the scope of work is limited to M25 grade (f_{ck} = 25 MPa) of concrete and only 28 days of curing. The mixes are designed according to I.S. 10262-2009. The adopted water cement ratio is modified to cope up with water absorption property of coarse as well as natural aggregates. The mix proportions obtained for various mixes are as given in Tables 3 and 4.

The mixing of concrete ingredients is done using pan mixer in the laboratory. The test specimens prepared are: cylinders with 150 mm (diameter) and 300 mm (height) for Bond stress test. All specimens are prepared and cured according to I.S.516.

Bond Stress (Pullout Test)

Three cylinders with size of 150 mm (diameter) and 300 mm (height) for each proportion are used to determine Bond stress (Pullout test).Bond stress confirming to I.S. 2770 (Part I) 1967 is carried out. Reinforcing bars having diameter 10 mm, 12 mm, 16 mm are used for pull out test (Bond Stress) and tested at the

Table 3: Mix Proportions

Proportion	Cement	Fly Ash /Meatakaolin	Water	Fine Agg.	Coarse NA	Coarse RCA
RCA 0%			202.45		1125.9	0.00
RCA 20%			209.22		990.82	135.11
RCA 40%	285.95	71.49	215.99	768.5	855.71	270.22
RCA 60%			222.76		720.60	405.34
RCA 80%			229.53		585.49	540.45
RCA 100%			236.30		450.37	675.56

age of 28 days of curing. Embedded length of reinforcing bar in concrete is considered as 15 times diameter of bar. The average value of three specimens is taken as the Bond stress of respective mix.

For this test the specimen was kept vertical as concrete was at upper side and reinforcement pointing downwards in universal testing machine with 60 ton capacity, at the rate of 200 kN/min. The Bond stress of the natural and recycled aggregate concretes made with mineral admixture as Metakaolin (20%) and Fly Ash (20%) with use of 16 mm reinforcing bar was determined on 28th day. The bond stress is calculated using following equation.

Bond stress = $P/\pi d L$

where P = Max. pull out load

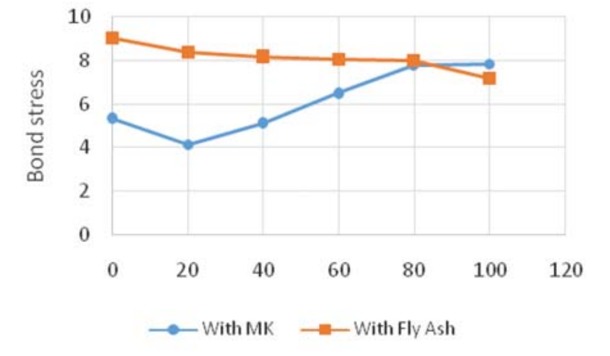
d = Dia. of bar

L = Embedded bar length (i.e., 15*d)

Table 4: Comparison of Bond Stress with use of Recycled Aggregates with Metakaolin and Fly Ash

Percentage of Recycled aggregate replaced (%)	Bond stress of RAC with Metakaolin at 28 days (N/mm^2)	Bond stress of RAC with Fly Ash at 28 days (N/mm^2)
0	5.35	9.04
20	4.14	8.41
40	5.14	8.19
60	6.50	8.07
80	7.77	8.00
100	7.82	7.19

Figure 1: Comparison of Bond Stress of RAC with 16 mm Bar



RESULTS

The Bond stress of the natural and recycled aggregate concretes made with mineral admixture as Metakaolin and Fly Ash with use of 12 mm reinforcing bar was determined on 28th day.

The Bond stress of the natural and recycled aggregate concretes made with mineral admixture as Metakaolin and Fly Ash with use of 10 mm reinforcing bar was determined on 28th day.

Table 5: Bond Stress of RAC with 12mm bar at 28 days

Percentage of Recycled aggregate replaced (%)	Bond stress of RAC with Metakaolin at 28 days (N/mm^2)	Bond stress of RAC with Fly Ash at 28 days (N/mm^2)
0	9.92	9.90
20	9.63	9.33
40	9.45	9.40
60	8.82	8.63
80	8.36	8.26
100	8.013	8.09

Figure 2: Comparison of Bond Stress of RAC with 12 mm Bar

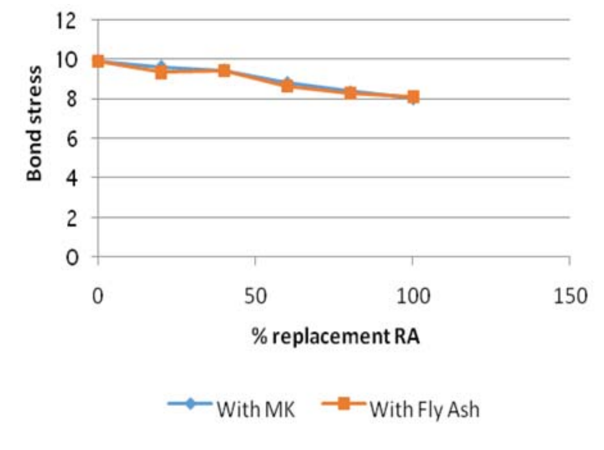
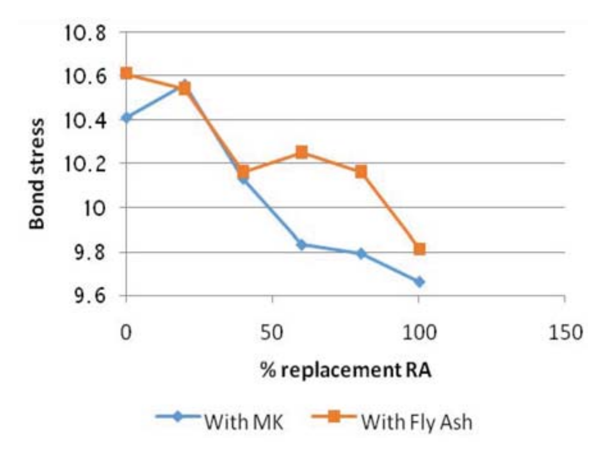


Figure 3 Comparison of Bond Stress of RAC with 10 mm bar



Above graphs shows comparison between bond stresses of RAC using mineral admixtures. Failure occurred due to splitting of concrete for 16 mm bar specimens and for 12 mm and 10 mm bar specimens, failure occurred due to breaking of bar. As the strength of 16 mm bar is much higher than 12 mm and 10 mm bars, concrete failed before breaking of bars.

Table 6: Bond stress of RAC with 10mm bar at 28 days

Percentage of Recycled aggregate replaced (%)	Bond stress of RAC with Metakaolin at 28 days (N/mm^2)	Bond stress of RAC with Fly Ash at 28 days (N/mm^2)
0	10.41	10.61
20	10.56	10.54
40	10.13	10.16
60	9.83	10.25
80	9.79	10.16
100	9.66	9.81

DISCUSSION

Physical properties are compared from Tables 1 and 2 and the salient aspects are as below

Recycled aggregate contains crushed and uncrushed parent aggregate coated with mortar and small pieces of hardened mortar. Hence, the specific gravity is relatively lower for Recycled Aggregates (RA). The major difference between RA and NA is the higher water absorption of RA. The mortar phase has higher porosity than that of aggregate phase hence RA absorbs more water than NA.

Mechanical Properties

As observed the resistance against crushing and impact of RA are relatively lower than NA this is due to the separation and crushing of porous mortar coating on RA during testing.

At the time of testing it is observed that failure occurs due to splitting of specimen

- Comparison of Experimental values of Bond stress with various codal values.

Equations for Bond Stress

The Australian standard 3600 recommends the following equation for Bond stress of concrete from its cylinder compressive strength of concrete as,

$$u = 0.265\sqrt{fc}\left(\frac{c}{db} + 0.5\right)$$

where c = Minimum concrete cover, (mm),

f_c is the concrete compressive strength, (MPa)

and db= diameter of the bar (mm)

The ACI code (ACI -318) defines the relationship between elastic modulus of concrete and cylinder compressive strength for calculating deflection as,

$$vu = 9.5\frac{\sqrt{fc}}{db} \text{ and } vu = \frac{139db\sqrt{fc}}{ld'}$$

where

Vu = Theoretical 28 day bond strength in psi (l psi = 6895 N),

f_c = 28 day concrete cylinder strength in psi,

ld' = Embedment length in inches,

d_b = Nominal diameter of the bar in inches (1 in. = 2.54 cm)

The experimental values of modulus of rupture are compared with the predicted values of AS: 3600 and ACI: 318. The predicted value by ACI: 318 is lower than experimental values in all respect. But compared with AS : 3600, the experimental values obtained for 16mm bar with metakaolin as well as fly ash are higher. The experimental values of 12 mm bar using metakaolin and fly ash up to 40% RA are within the range of values given by AS: 3600. As the replacement level increases above 40% the values goes on decreasing and becomes lower than the predicted values of AS: 3600. The experimental values of 10 mm bar using metakaolin and fly ash are not in the range of values given by AS: 3600

Table 7: Comparison of Bond stress of recycled aggregate concrete using 16 mm bar with values of different Codes

% of recycled aggregate replacement	Experimental value using Metakaolin N/mm^2	Experimental value using Fly Ash N/mm^2	Value by AS Code N/mm^2	Value by ACI Code N/mm^2
0%	5.35	9.04	6.87	2.97
20%	4.14	8.41		
40%	5.14	8.19		
60%	6.51	8.07		
80%	7.78	8.01		
100%	7.83	7.19		

Table 8: Comparison of Bond stress of recycled aggregate concrete using 12 mm bar with values of different Codes

% of recycled aggregate replacement	Experimental value using Metakaolin N/mm^2	Experimental value using Fly Ash N/mm^2	Value by AS Code N/mm^2	Value by ACI Code N/mm^2
0%	9.92	9.90	8.94	3.96
20%	9.63	9.33		
40%	9.45	9.40		
60%	8.82	8.63		
80%	8.36	8.26		
100%	8.01	8.09		

Table 9: Comparison of Bond stress of recycled aggregate concrete using 10 mm bar with values of different Codes

% of recycled aggregate replacement	Experimental value using Metakaolin N/mm^2	Experimental value using Fly Ash N/mm^2	Value by AS Code N/mm^2	Value by ACI Code N/mm^2
0%	5.35	9.04	6.87	2.97
20%	4.14	8.41		
40%	5.14	8.19		
60%	6.51	8.07		
80%	7.78	8.01		
100%	7.83	7.19		

CONCLUSION

In the present experimental investigations the Bond stress of recycled aggregate concrete with metakaolin and fly ash is studied. The basic test variables are replacement ratios for natural aggregates (0%, 20%, 40%, 60%, 80%, and 100%) with recycled aggregates and use of 20% metakaolin and 20% fly ash (separately) as substitution to cement. The combined effect of recycled aggregates and mineral admixtures on the properties of concrete is explored in the present study.

With increasing recycled aggregate content and in presence of fly ash the workability of mixes is observed to be reduced.

- As mortar is attached to the surface of RCA it exhibits low specific gravity and high water absorption than conventional aggregate.
- The recycled aggregate prone to higher water absorption than the natural aggregate care must be taken to maintain the water cement ratio while designing for corresponding strength.
- After crushing the net quantity of the coarse aggregate from the recycling process is collecting to be 60% of the total quantity.
- The results show that with increasing recycled aggregate content bond stress go on reducing. However, it is observed that replacement of natural aggregates up to 40% cause small reduction in strengths. All the specimens with up to 40% recycled aggregates with and without fly ash satisfy the design strength.
- Using Metakaolin 20% in concrete is economical to replace the recycled aggregate to the natural aggregate.
- To replace recycled aggregate 20 to 40% to achieve minimum target strength as compare to conventional concrete.
- For 16 mm and 12 mm bar, the concrete failed before the bar fails.
- In case of 10 mm bar, the bar failed before the concrete fails.
- With some modifications in mix proportions and with use of chemical admixtures a study can be carried out to achieve higher grade concrete using same combination.
- Such a combination of higher recycled aggregate content and high volumes of fly ash may make concrete green and sustainable.

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