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PERFORMANCE OF BOND STRENGTH BETWEEN RECYCLED AGGREGATE CONCRETE AND STEEL BAR

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ABSTRACT

This paper presents an experimental investigation to improve the performance of bond behavior between recycled aggregate concrete (RAC) and deformed bar. The bond behavior between RAC using 100% recycled coarse aggregate (RCA) and 16 mm diameter deformed bar is performed for concrete with normal mixing approach (NMA) as well as with three stage mixing approach (TSMA).The load vs slip curves are plotted for both type of mixing approaches by conducting five different experiments in each case. The bond test results are also compared for virgin aggregate concrete (VAC) and found similar load vs slip curve for concrete with TSMA. Hence, this experimental investigation increase the motivation for using the construction and demolition (C&D) waste for new reinforced cement concrete (RCC) work in construction industries and for conservation of natural resources.

Keywords: C&D Waste, Deformed Bar, NMA, Pullout Test, RAC, Silica Fume, TSMA, VAC

I. INTRODUCTION

The random and uncontrolled disposal of construction and demolition waste creates several environmental impacts and to achieve sustainability in construction the uses of waste concrete as recycled aggregate concrete (RAC) is an important focus for construction industries. The conservation of natural resources and preservation of environment is the essence for development of a country. Adequate bonding between reinforcing bars and concrete is essential for the satisfactorily performance of reinforced concrete structure.

Research and experimental studies has been carried out in the past by the several researchers for the structural performance of RAC but still there is lack of proper guidelines and recommendations in bond behaviour between the RAC and steel bar. Hence, to popularize and maximum use of recycled concrete aggregate obtained from C&D waste, it is necessary to analyze the development of the bond strength between steel bar and RAC. A number of studies have been carried out by several researchers in recycled coarse aggregate concrete and they found that the strength is 10-25% lowers than that of conventional concrete, this has been extensively studied by Tabsh and Abdel fatah [1]. Etxeberria et al. [2] observed that the compressive strength made with 100% recycled coarse aggregate is 20-25 % lower than that of conventional concrete at 28 days with same w/c ratio and quantity of cement Tam et al [3,4] concluded that due to attached mortar in recycled concrete aggregate, it has higher water absorption capacity which result in decrease of workability, compressive strength, durability and bond strength. They suggested the two stage mixing approach (TSMA) for improving the performance of recycled aggregate concrete. In the first stage of mixing, Tam et al. suggested to mix for 60 seconds by adding half of total mix water and in second stage of mixing remaining part of water is added for creating a strong interfacial transition zone (ITZ) , which leads to improve the performance in the recycled aggregate concrete. Ajdukiewicz and Kliszczewicz [5] reported that there is no significant difference between the bond strength of re-bars embedded in NAC and RAC. They investigated that there was considerable difference between the bond behaviour of plain and deformed bars under equivalent mix proportions. It was also concluded that the presence of admixtures influences the properties of recycled aggregate concrete. The value of bond stress at failure for recycled aggregate concrete was lower than that of NAC, particularly for plain round bars. They also observed that the concrete made from 100% RCA, there is 20% drop in bond strength. While the concrete made from 100% fine recycled aggregate there is 8% drop in the bond strength. Xiao and Falkner [6] investigated the bond behavior between recycled concrete aggregate and steel bars (deformed and plain rebar).They found that bond strength between the recycled aggregate concrete and the plain bars decreases with an increase of the RCA replacement percentage, whereas the bond strength between the RCA and the deformed rebar has no clear relation irrespective of the RCA replacement percentage. Based on their test results, they recommended a development length for re-bars similar to ordinary concrete with the conditions of having similar compressive strength of concrete. They concluded that the bond strength between RAC and steel re-bar generally lower than conventional concrete as because of weak aggregate matrix interface bond. Choi et al. [7] investigated and concluded on the bond behavior between recycled aggregate concrete and rebar having replacement percentage 0%,30% ,50% and 100% and they found that bond strength has negligible effect up to 50% replacement percentage. Fathifazl et al. [8] tested the beam-end specimens made from deformed steel bars and recycled aggregate concrete. They reported that the bond performance of RAC is 18% to 33% lower than the virgin concrete. Robert Prince and B.Singh [9] investigated the bond behavior by using different size of deformed bars and having five types of RCA replacement ratios (0%, 25%,50%, 75% and 100%) and compared the bond failure between natural aggregate concrete and recycled aggregate concrete. It is also observed that the relative bond strength increases with RCA replacement levels and the highest value is obtained for 100% replacement of natural coarse aggregates. Butler et al. [10] studied the two sources of RCA by incorporating two types of concrete grade M-30 and M-50 and tested the beam end specimens. They observed that the bond strength of concrete made from recycled coarse aggregate is 9% to 19% lower than the virgin aggregate concrete under equivalent mix proportions when coarse recycled aggregates is used 100%. There are no literatures for improving the bond strength by following different established mixing approach. The main objective of this paper is to investigate the bond strength between RAC and reinforcing bar by following TSMA along with silica fume.

II. EXPERIMENTAL PROGRAM

2.1 Materials

Cement: In this study, Ordinary Portland cements conforming to IS: 8112-1989 with fineness: 335m^2/kg is used.Table-1 shows the chemical composition of Portland cement.

Table.1.Chemical Composition of Cement by XRF

Cement	SiO_2	Al_2O_3	CaO	Fe_2O_3	TiO_2	MgO	P_2O_5	SO_3	K_2O	Na_2O	LOI
% by weight	28.17	14.10	44.43	1.64	0.72	5.93	0.03	4.88	0.67	0.43	1.02

Sand: River sand is used as per IS: 383-1970 (Zone-II)

Water: Potable water is used in the experiment.

RCA and VCA: The Recycled coarse aggregate (RCA) is collected from 40 years old demolished building of civil court Dhanbad. The virgin coarse aggregate is obtained from Dhanbad, Baliapur quarry. The maximum 25 mm coarse aggregate size is taken in the experiment. In Table-2 listed the fundamental physical properties of RCA and VCA.

Reinforcement: 16 mm dia, deformed bar (HYSD-Fe500) is used.

Table.2.Physical Properties of VCA and RCA

Coarse aggregate	Bulk density (Kg/m^3)	Specific gravity	Impact value (%)	Crushing value (%)	Water absorption (%)
VCA	1525	2.95	8.89	18.66	1.02
RCA	1487	2.62	19.25	22.98	7.03

Silica fume: The chemical characteristics of additives materials silica fume (SF) arepresented in Table.3

Table.3.Chemical Composition of Silica Fume by XRF

SF	SiO_2	Al_2O_3	CaO	Fe_2O_3	TiO_2	MgO	P_2O_5	SO_3	K_2O	Na_2O	LOI
% by weight	88.80	6.59	0.55	0.44	0.21	0.61	1.36	0.12	1.31	0.00	-

2.2 Three Stage Mixing Approach (TSMA) and Silica Fume (SF)

In this approach slurry is first prepared by mixing total water, half of cement and silica fume (SF) together and in the second stage the total recycled aggregate is poured in the slurry for surface coating of the recycled aggregate and mixed for 2 minutes. In the third stage of mixing the half of cement and the total fine aggregate is added and mixed for 3 minutes to get final product. The flow diagram of TSMA is presented in Fig.1.

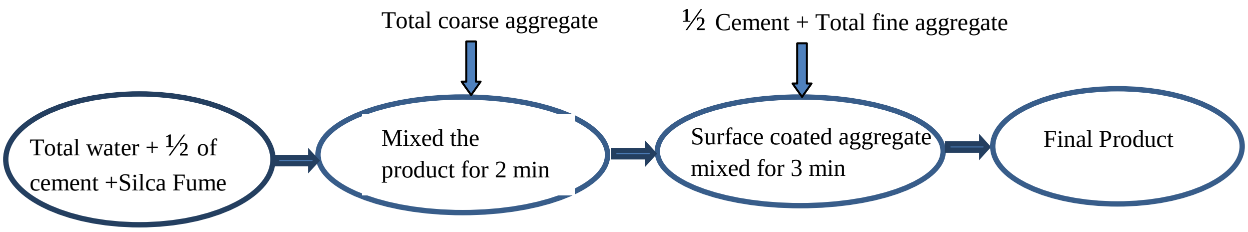

Fig.1.Three Stage Mixing Approach (TSMA)

2.3 Mix Proportions and Test Parameters

The mix proportion is designed as per IS: 10262-2009 for M-25 grade of concrete for all the proposed mix. The VAC is mixed by normal mixing approach (NMA) whereas, RACSF-100 is mixed by TSMA and by adding 8% silica fume. The water cement ratio is constant in all the cases i.e 0.44.The mix proportions are presented in Table-4.

Table.4.Mix Proportion of NAC and RAC (Kg/m^3)

Mix ID	Cement (Kg/m^3)	Sand (Kg/m^3)	Aggregate(Kg/m^3)		Water (Kg/m^3)	Silica Fume (Kg/m^3)
			VCA	RCA		
VAC	312	751	1357	0.00	137	0.0
RACSF-100	312	751	0.0	1357	137	25

2.4 Test specimens

10 (ten) cube specimens of size 150 mm x150 mm x150 mm are casted by embedding concentric deformed bar of size 16 mm dia which is presented in Fig.2. The embedded length of bar is five times of the reinforcing bar and the free end of the bar is set in insulator for bond breaker. The cubes are cured at room temperature for a period of 28 days.

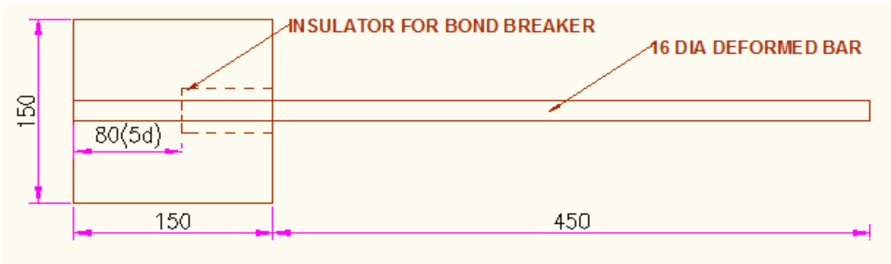

Fig.2. Details of Pull out Specimens (mm)

2.5 Test Setup and Procedure

Pullout tests are carried out in Civil Engineering Department at ISM, Dhanbad by using universal testing machine (UTM) with capacity 1000 kN. The test is carried out by giving pulling load to the embedded rod in upward direction .The specimens are loaded monotonically in increasing manner up to failure and the applied maximum load (P) and corresponding slip (s) is measured by load linear variable differential transducer (LVDT).

III. TEST RESULTS AND DISCUSSIONS

The test results presented in Table.5 indicate the advantage of use of TSMA and silica fume. The bond strength of RACSF-100 is equivalent to NAC. The load vs slip curve is presented in Fig.3 is similar trend in both case and resemble with Xiao and Falkner (7). Three stage mixing approach (TSMA) helps to improve the quality of the recycled aggregate by filling the cement paste in the cracks, pores and voids and also addition of silica fume helps to densify the RAC by improving interfacial transition zone (ITZ) between recycled aggregate and cement mortar.

Table.5. Details of Specimens and Test Results

Mix ID	Diameter of Bar	f_c (MPa)	P_{max} (kN)	τ_{max} (MPa)	Slip (mm)
VAC	16	38.50	54.30	13.43	0.887
RACSF-100	16	38.33	55.43	13.79	0.893

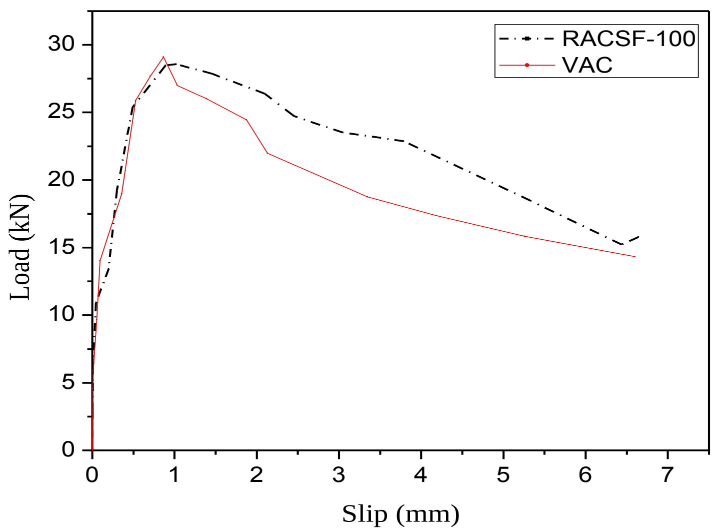

Fig.3.Load Versus Slip Curve: RACSF-100 and NAC

IV. CONCLUSIONS

The following observations and conclusions are drawn on the basis of experimental study:

1. The general shape of the load versus slip curve between recycled aggregate concrete and steel bar is similar to that of virgin aggregate concrete and steel bar.
2. The experimental results show that there is equivalent compressive strength and bond strength at failure for both TSMA with 100% RCA and NMA with 0 % RCA.
3. Three stage mixing approach (TSMA) helps to improve the performance of the recycled aggregate by filling the cement paste in the cracks, pores and voids which improve the ITZ. This improvement of ITZ gives strong bond strength.

4. The experimental results help the structural engineers for using C&D waste in reinforced cement concrete work for achieving sustainable issues in construction industries.

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