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Comparison of Bond Behaviour between Recycled Aggregate Concrete and Steel Bars

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Abstract - *This paper studies the bond stress-slip curve of recycled concretes and the influence of recycled aggregate, which leads to the determination of bond behaviour. In order to perform this analysis, a study of the compressive strength of the recycled aggregate concretes is required, due to the relationship between the bond strength and the mean compressive strength. Pull-out tests were carried out in order to investigate the bond behaviour between recycled aggregate concrete (RAC) and steel rebars. Four recycled coarse aggregate (RCA) replacement percentages (i.e., 0%, 15%, 30% and 45%) and two types of steel rebar (i. E., mild steel, Fe415, Fe500) were considered in this paper. Based on the test results, the influences of both RCA replacement percentages and the rebar surface on the bond strength between the RAC and steel rebars were investigated. The results show that replacement ratio significantly influences concrete properties related to the compressive strength. Change in grade of steel has not yielded any recommended result. For the recycled aggregate concrete, the bond strength between deformed steel rebars and concrete is higher than one between plain steel rebars and concrete.*

Key Words: **Recycled Aggregate, Partial Replacement, MS, Fe415, Fe500, Compressive Strength, Bond Strength, Pull-out, Slip.**

1. INTRODUCTION

Conservation of natural resources and preservation of environment is the essence of any modern development. The use of recycled aggregate concrete (RAC) is one such an attempt and is one way to solve some of the problems in construction engineering. The concept of using RAC is now gaining popularity and research in this field has gained some momentum. Over last decade a significant volume of research in the area of RAC and its possible application in the construction industry was performed. Here, RAC is understood as a concrete in which a part or a total amount of natural aggregate (NA) is replaced by recycled aggregate concrete.

The recycling of concrete coming from demolishing existing structures or from the discards of the precast industry is gaining day by day the attention of the construction industry as it can reduce the costs for supplying the coarse aggregates and of rubble disposal. At the same time, the environmental benefits of using recycled concrete aggregate (RCA) are well accepted. From the beginning it has been considered in main two environmental aspects: solving the increasing waste storage problem and protection of limited natural sources of aggregate. Existing literature indicate that a large amount of experimental works have been carried out worldwide to investigate the RAC. Previous studies were mainly engaged in the processing of demolished concrete, mix-proportion design, mechanical properties, durability aspects and improvements. Recently, structural performances and economic aspects of using recycled aggregate concrete are also analyzed. It was revealed that RAC can be used in reinforced concrete without much inconvenience, but that fine recycled aggregate should be avoided.

For the development of the RAC, it should be reinforced with steel bars. One of the most important requirements of reinforced concrete constructions is the bond between concrete and reinforcement. It is well-known that studies on the bond-slip behaviour between natural aggregate concrete (NAC) and steel bars has arisen wide attention in the engineering world for a long time. It was made clear that the following aspects contribute to the bond behaviour: concrete type, steel bar geometry, loading conditions, construction details etc. However, only a few investigations have been carried out in the field of the bond-slip behaviour between RAC and steel bars.

In this paper, the results of pull-out tests will be presented with the aim of contributing to the experimental database and to a better understanding of the bond behaviour between recycled concrete and rebars. Bond behaviour is analyzed for different types of rebars, with the aim of showing the influence of the rebar surface and concrete strength.

Pull out test provides a standardized procedure for comparison of bond characteristics between concrete and different types of steel reinforcing bars. Such determinations may be made for any purpose, from routine acceptance tests to research testing, in so far as applicable to a particular project. The method is offered as one workable procedure, to be employed either in its entirety or with modifications to meet specific conditions. The method may also be used with some suitable modifications, if necessary) for comparing different concrete mixes for their bond characteristics with steel reinforcing bars.

The bond strength, or the measure of the effectiveness of the grip between concrete and steel, has no standard quantitative definition. In pull-out tests on plain bars, the maximum load generally represents the bond strength that can be developed between the concrete and steel. With plain bars the maximum load is not very different from the load at the first visible slip, but in the case of the deformed bar, the maximum load may correspond to a large slip which may not in fact be obtained in practice before other types of failure occur. It is preferable, therefore, when comparing plain and deformed bars to determine not only the maximum load but also the load at arbitrary amounts of slip and also plot the complete load-slip.

1.1 Need for Study

- To demonstrate that the development of concrete compressive strength is indeed different in recycled and conventional concretes.
- To know not only the maximum bond stress but also the bond stress–slip curve, this will lead to a suitable bond design of concrete under service loads.
- To know how the percentage of recycled aggregate used to replace conventional aggregate influences in this curve.

2. METHODOLOGY

To determine the bond behaviour of recycled concrete to various bars, the bond stress–slip curve is calculated (using concrete compressive strength, age of the concrete, and replacement percentages of recycled coarse aggregate). First, maximum bond strength of various bars to concrete is obtained at different ages using the experimental compressive strength of concrete. A further analysis is required to obtain predictions of time-dependent compressive strength with the same degree of approximation in recycled concrete than in conventional concrete. Accordingly, the experimental: predicted compressive strength ratios are compared to determine if it is necessary to use a modified expression to obtain the time-dependent compressive strength of recycled concrete. As a result, maximum bond strength of various bars to concrete can be calculated at different ages, and therefore the bond stress–slip curve. Similarly to the time-dependent compressive strength, the ratios of bond stress at different slips are analyzed to determine, again, if a modified expression is required to calculate the bond stress– slip curve.

3. MATERIALS

Ordinary Portland Cement (53 grade) confirming to IS: 12269-1987 was used for all the concrete mixtures. The tests were conducted according to IS 4031-1988. Table-1 shows the physical properties of cement.

Table-1: Physical Properties of Cement

PROPERTIES	TEST RESULTS
Specific gravity	3.126
Standard Consistency (%)	33
Initial setting time (minutes)	85
Final setting time (minutes)	275

Two types of coarse aggregates, natural and recycled were used. The maximum size of coarse aggregate used in the concrete mixture is 20mm. Manufactured sand confirming to zone II is used as natural fine aggregate. Tests were conducted according to 2386-1963. Table-2 shows the physical properties of aggregate.

Table -2: Physical Properties of Aggregates

MATERIALS	SPECIFIC GRAVITY	WATER ABSORPTION
Fine Aggregate	2.69	1.2%
Natural Coarse Aggregate	2.58	0.73%
Recycled Coarse Aggregate	2.702	0.3%

Plain bar used is mild steel of 12mm diameter and deformed bar used are Fe415 and Fe500 bars of 12mm diameter. Fe415 is parallel ribbed where as Fe500 is diamond ribbed. Table-3 shows the physical properties of rebar.

Table -3: Properties of Rebars

TYPE	PROPERTIES	
	Yield Strength (MPa)	Ultimate Strength (MPa)
Mild Steel	466.72	583.40
Fe500	498.36	622.96
Fe415	547.77	684.72

4. CONCRETE MIXTURES

The water-cement (W/C) ratio was kept constantly to 0.43 when making RAC under different RCA replacement percentage (RCARP). For this study, four series of concretes with different replacement ratios 15%, 30%, 45% and conventional or control concrete (replacement ratio is considered as 0%), which are referred to here after as R0, R15, R30, R45.

5. TEST SPECIMENS AND PROCEDURES

The experimental program was designed to study the influence of strength of RAC, The type of steel bars (plain or deformed) and the RCARP on bond strength and bond-slip curves. A total of 60 compressive strength specimens and 108 pull-out specimens were prepared. To know the bond strength pull-out test is conducted and it was carried out as per IS: 2770 (Part 1) -1967. Pull-out specimens were cast in $10\times10cm^2$ cubical moulds with reinforcing steel positioned at the centre and ensured that the rebars was in a straight vertical position. The steel bars were rust free. For each concrete batch, the cube compressive strength was determined on $15\times15\times15cm^3$ cubes at 3, 7, 28, 56 days. And pull-out tests were performed at 7, 28 and 56 days. Model of pull out test specimen is shown in Fig. 1

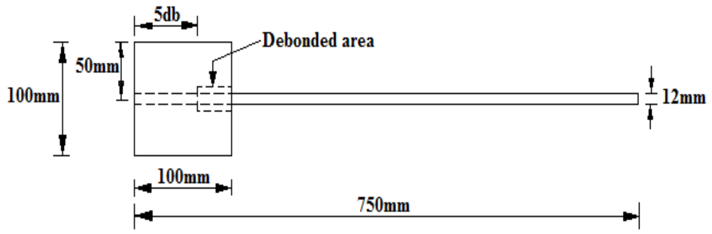

Fig- 1: Model of Pull-out Test Specimen

6. TEST RESULTS AND DISCUSSIONS

Compressive and bond behaviour determined on recycled concretes can be compared with the conventional one made with the same mix proportions.

6.1 Compressive Strength

Cube compressive strength versus mix designation graph was plotted as shown in Chart-1.

The compressive strength of recycled concretes with a replacement ratio of 15%, 30% and 45% showed a decrease compared to conventional concrete.

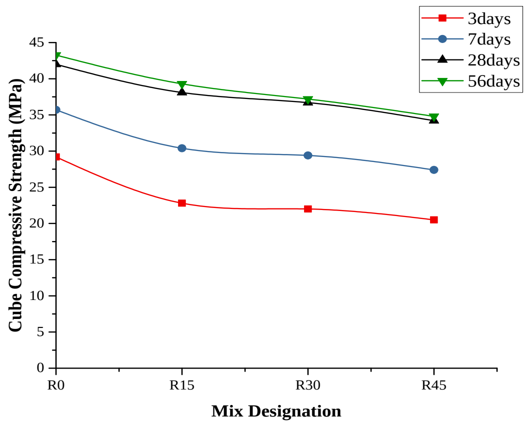

Chart-1: Evaluation of Compressive Strength for Different Mixes

6.2 Time Dependent Compressive Strength

In order to determine the influence of recycled aggregate on this property, the relative strengths were calculated using the compressive strength at different ages compared with that obtained at 28 days as shown in Chart-2.

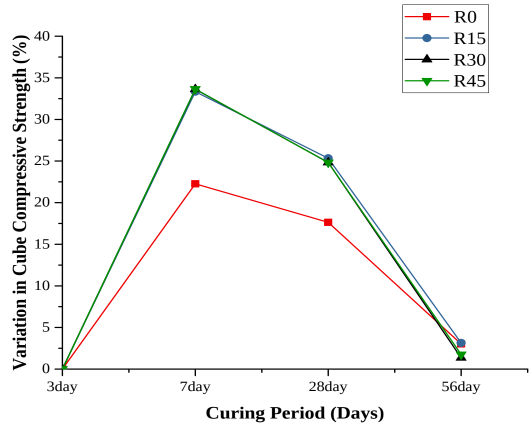

Chart-2: Variation in Cube Compressive Strength Vs Curing Period

6.3 Bond Strength

Under the conditions of these pull-out tests, the bond stress along the whole anchorage length of the steel bar can be considered to be uniformly distributed. The bond strength can be expressed by Eq. (1).

$$\tau_u = \frac{F}{\pi d l_a} \quad (1)$$

Where, τ_u is the peak bond stress in MPa between concrete and steel bar which is also termed as the bond strength. F is the peak load in N, d is the diameter of the diameter of steel bar in mm and l_a is the embedded length of the steel bar in mm.

6.4 Bond Strength Verses Slip Curves

The measured bond stress versus slip curves for the six series of specimens (M. S. at 7, 28 and 56 days, Fe415 at 7, 28 and 56 days and Fe500 at 7, 28 and 56 days) are drawn in Chart- 3, 4, 5, 6, 7, 8, 9, 10 and 12 respectively.

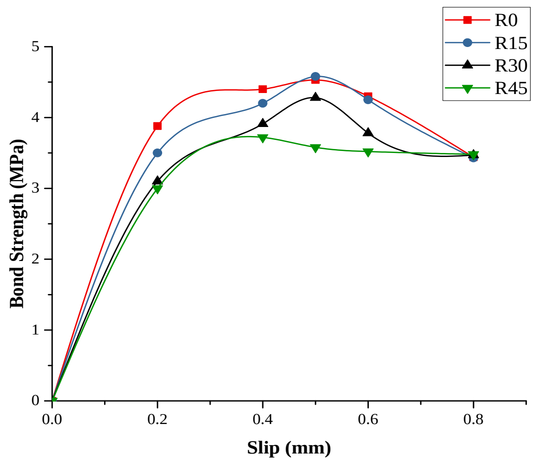

Chart-3: Bond Strength Vs Slip Curve of M.S. on 7 Days of Curing

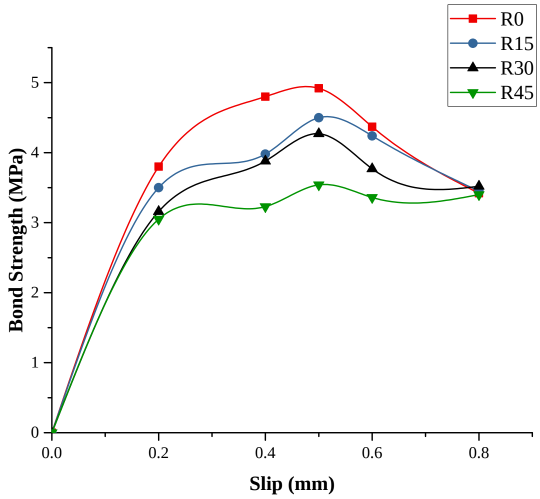

Chart-4: Bond Strength Vs Slip Curve of M.S. on 28 Days of Curing

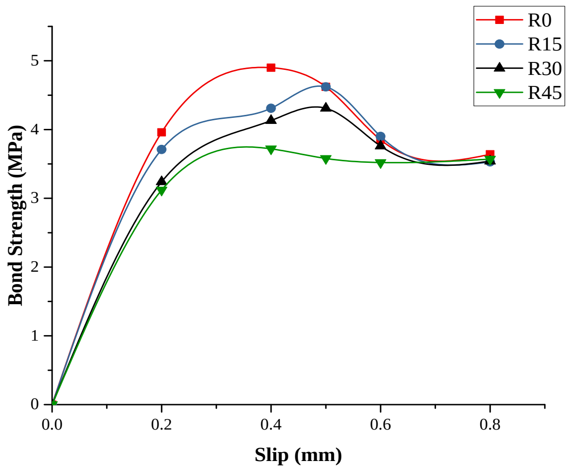

Chart-5: Bond Strength Vs Slip Curve of M.S. on 56 Days of Curing

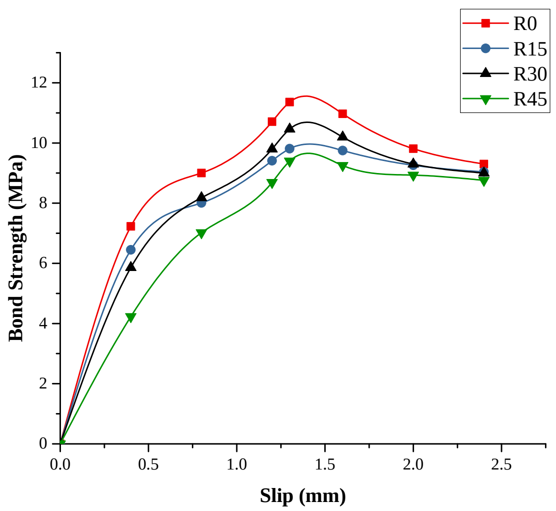

Chart-6: Bond Strength Vs Slip Curve of Fe415 on 7 Days of Curing

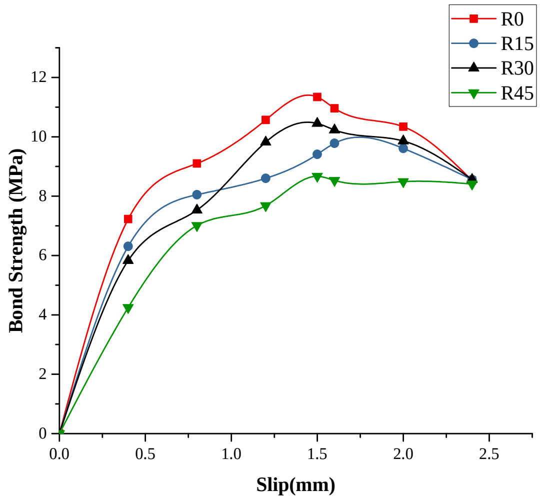

Chart-7: Bond Strength Vs Slip Curve of Fe415 on 28 Days of Curing

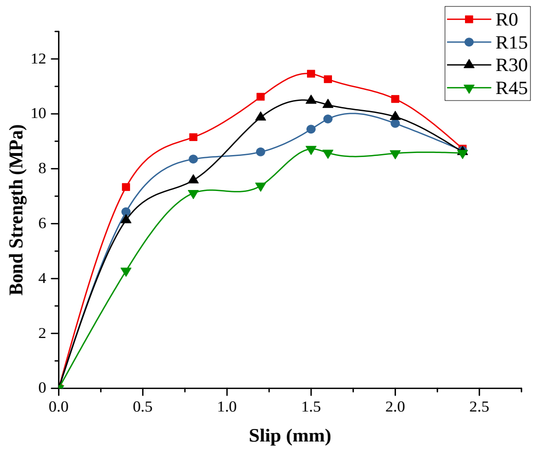

Chart-8: Bond Strength Vs Slip Curve of Fe415 on 56 Days of Curing

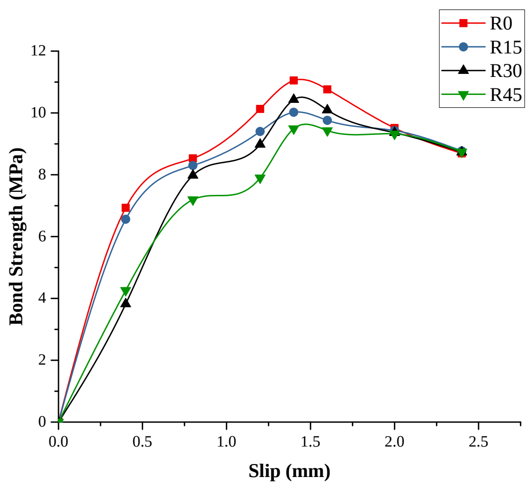

Chart-9: Bond Strength Vs Slip Curve of Fe500 on 7 Days of Curing

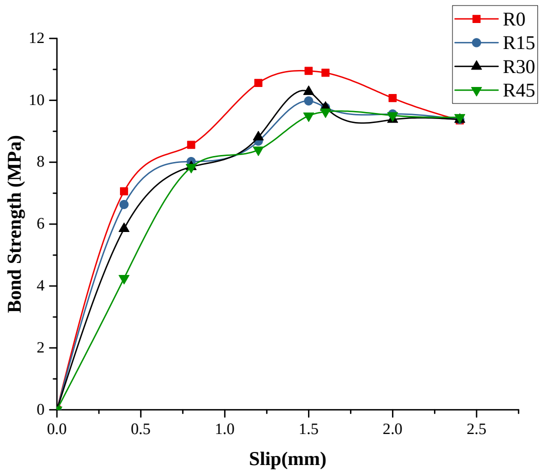

Chart-10: Bond Strength Vs Slip Curve of Fe500 on 28 Days of Curing

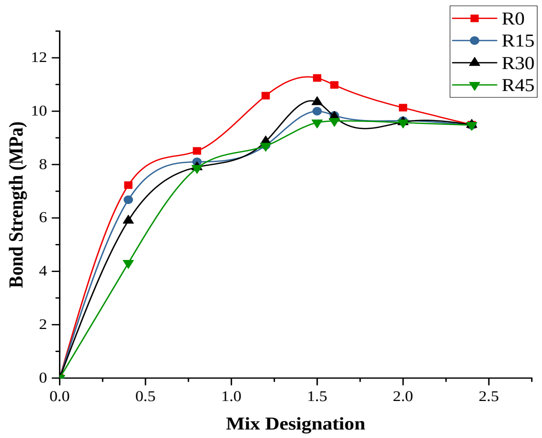

Chart-11: Bond Strength Vs Slip Curve of Fe500 on 28 Days of Curing

Due to difficulties in the test procedure in some groups, some tests failed to show the descending branch of the bond stress versus slip curves. By analyzing the above-mentioned curves it can be seen that the bond development and deterioration process between the recycled aggregate concrete and steel rebars is similar to that between natural aggregate concrete and steel rebars as reported by Edwards and Yannopoulos [11]. Each curve reflects the behaviour at different stages which are micro-slip, internal cracking, pullout, descending and residual. At the micro-slip stage, the load is small and no obvious slip occurs at the free end of the rebar, i.e., the load versus slip curve remains linear. At the internal cracking stage, when the load increases towards a critical value, the free end of the rebar begins to slip, which demonstrates that the adhesion force at the anchorage has nearly been exhausted. After this stage, the rate of the slip begins to increase and the ascending portion of the curve becomes distinctly nonlinear. At the pullout stage, the load reaches the peak load (P_0) and some longitudinal splitting cracks develop along the weakest area of the concrete cover. At the descending stage, the load declines rapidly and the slip increases until the steel bar is completely pulled out. At the residual stage, when the slip of the loading end reaches a certain value, the load becomes nearly constant.

7. CONCLUSIONS

The compressive strength and the bond stress-slip curve of recycled concretes with different replacement percentages of recycled coarse aggregate were determined at different ages. On the basis of these results the following conclusions can be drawn:

- A delay of time-dependent development of compressive strengths of recycled concretes can be seen compared with conventional concretes, especially at 3 and 7days. This effect is attributed to the use of recycled coarse aggregates under pre-saturation conditions, which produces a curing effect (internal curing) and reduces the compressive strength of recycled concretes at early ages.
- The general shape of the bond stress versus slip curve between recycled aggregate concrete and steel rebars is similar to the one for normal concrete and steel rebars, which includes micro-slip, internal cracking, pull-out, descending and residual stages.
- The bond strength between recycled aggregate concrete and steel rebars is higher than one between normal concrete and steel rebars in some situations.
- For the recycled aggregate concrete, the bond strength between deformed steel rebars and concrete is higher than one between plain steel rebars and concrete.
- Change in grade of steel has not yielded any recommended result.

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