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BOND BEHAVIOR OF DEFORMED STEEL REBAR EMBEDDED IN A RECYCLED BRICK AGGREGATE CONCRETE

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Abstract The demolition of old structures creates a lot of waste, particularly in Asian countries, producing brick waste as most of the old structures are made of brick, which needs to be tackled. Researchers have tried to use it as aggregate in concrete and study its effect on different concrete properties. In this study, the bond behavior of steel rebar with recycled brick aggregate concrete (RBC) has been studied and compared with natural aggregate concrete (NAC) and recycled aggregate concrete (RAC). For this purpose, a number of cubes were cast along with cylinders to relate the effect of compressive strength with bond strength. Two types of ratios were chosen: one is R50%-50%, containing 50% coarse and 50% fine aggregate, and the second is R33%-67%, containing 33% coarse aggregate and 67% fine aggregate. A cement content of 20% by weight of aggregate was used. It was found that for the ratios R33%-67% and R50%-50%, the bond strength of RBC is 24% and 13% more than that of RAC, respectively. For the ratios R33%-67% and R50%-50%, the bond strength of RBC is 9% and 60% less than that of NAC, respectively. The practical results were then compared with the equation proposed by Md. Mozammel Haque to find the bond strength of RBC using compressive strength, and the difference was found to range from 0.4 to 0.9 for all the different ratios used. Further, the study showed the direct relation of compressive strength with bond strength: the greater the compressive strength, the greater the bond strength

Keywords- Bond Strength, Concrete, Compressive Strength, Recycled Aggregate

1 Introduction

Concrete is the second most consumed material, by mankind, on earth after water. Global annual production of concrete is around 33 billion tons (ISO, 2016). That's why the construction industry is one of the largest consumers of raw materials. And the demand for building materials, particularly concrete, has risen exponentially. Since the world is moving towards modernization and using modern materials like concrete rather than bricks, although in most Asian countries brick is still used in construction, the demolition of old structures produces a lot of brick waste which needs to be tackled. One of the best ways is to use it as a recycled aggregate, both as fine and coarse aggregate, in concrete. Many researchers have used brick as a recycled aggregate in concrete and found its effect on different properties of concrete.

Paulo B. Cachim [1] in his studies found out that up to 15% crushed bricks can be used as natural aggregates substitutes without strength reduction. And there is a reduction of concrete properties (up to 20%, depending on the type of brick), for 30% of natural aggregate substitution. Mounir M. Kamal et al. [2] have studied the effect of using different ratios of recycled brick aggregate in concrete mix and found that as the amount of recycled aggregate increases, the compressive strength and bond strength decrease. And he summarizes that bond strength of recycled brick aggregate concrete is 8% of its compressive strength. Yang et al. [4] found out that the failure pattern of specimen is "Splitting Failure" without lateral

pressure (confinement), while failure pattern of specimen with different biaxial lateral pressure can be classified as "splitting pullout failure".

The most concerning thing while using recycled brick aggregate in concrete is its bond strength with rebar, because if the concrete does not make a good bond, then under the application of load, the bar will slip or pull out and cause the whole structure to collapse. The bond strength of concrete with rebar plays a pivotal role in every element of structure i.e. beam, column, slab etc. Because of this importance of bond behavior this study will discuss the effect on bond strength by replacing natural aggregate with recycled aggregate (both recycled brick and recycled concrete). and compares with bond strength of natural aggregate concrete.

Further compressive strength of concrete has a great influence on its bond strength. So, this study also finds a relationship between bond strength and compressive strength of concrete. Additionally, it analyzes the equation proposed by M.M. Hoque et al. [5] for the evaluation of bond strength in BAC. The following equation developed by M.M. Hoque et al.

$$U = 0.525\sqrt{f'_c}\left(\frac{c}{d_b}\right)^{0.42}$$

2 Research Methodology:

2.1 Material and Concrete mixes:

Recycled Aggregate Concrete (RAC), Recycled Brick Aggregate Concrete (RBC), and Natural Aggregate Concrete (NAC) were investigated. Concrete mixes were prepared by replacing 100% of natural aggregates with either recycled concrete (RCA) or brick aggregates (RBA) in equal or different ratios, while third mix used 100% natural aggregates for comparison. Meanwhile, to get RBAs & RCAs old bricks and concrete cylinders were manually broken down and then crushed using a roller crusher. The resulting aggregates were sieved to separate coarse and fine aggregates, as shown in *fig 1*.

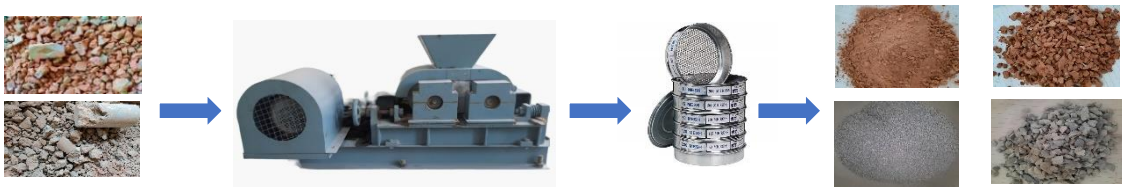


Figure 1: Schematic diagram of producing RBA & RCA

The *table 1* illustrates that the 12 concrete mixes were prepared with weights of coarse and fine aggregates used and on which the direct pull-out and compressive strength test was then performed [5]. RBC-1, RAC-1 represent coarse recycle brick and concrete aggregate, each of them having a ratio of R(33%-67%). Also, RBC-2, RAC-2 represent fine recycle brick and concrete aggregate, each of them having a ratio of R(50%-50%). NAC-1 & NAC-2 represents natural aggregate concrete 33-67% & 50-50% of coarse and fine aggregate, respectively. Also, all coarse aggregate used in saturated surface dry (SSD) condition because of high water absorption capacity of recycled brick aggregate. For this purpose, aggregates were soaked in water for 24 hours before casting and water cement ratio of 0.5 was used.

Table 1: Mix Proportions

Name	Recycled Aggregate Type	Weight in kg/m³			No. of Sample	
		Cement	Coarse Aggregate	Fine Aggregate	Cube	Cylinder
RBC-1	Coarse: Brick	317	523	1061	2	2
RBC-2	Fine: Brick	317	792	792	2	2
RAC-1	Coarse: Concrete	400	660	1340	2	2
RAC-2	Fine: Concrete	400	1000	1000	2	2
NAC-1	Natural Aggregate	400	660	1340	2	2
NAC-2	Concrete	400	1000	1000	2	2

3 Specimen & Testing:

3.1 Pull-out & compressive strength test:

The pull-out test was preferred to directly assess the force required to pull out the rebar. For this test, cube specimens (200mm³) having a 19mm diameter rebar centrally embedded with a bonded length of $5d_b$ [6] were prepared, with the ends unbonded using PVC pipes and silicone tape. A 1000KN Universal testing machine applied load at 0.5 min/mm, recording slip value and peak force automatically. This test was conducted as per ASTM C900-19 [7] for all concrete mixes. Moreover, to assess concrete quality, 75mm x 150mm cylindrical specimens were prepared. Using a 2000KN testing machine per ASTM C39 [8], the compressive strength test recorded the maximum load each cylinder sustained. Two samples from each mix were tested, and their average compressive strength is reported. Casting and testing of samples are shown in *fig 2*.

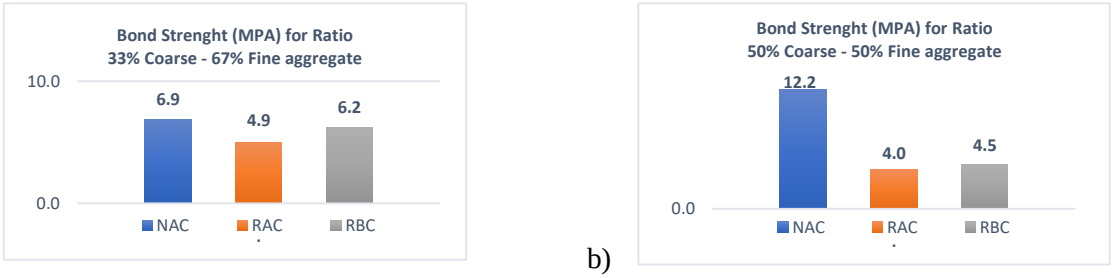
a) b) c)

Figure 2: a. Bar Placement b. Cast Specimens c. Pull-out Test Arrangement

4 Results:

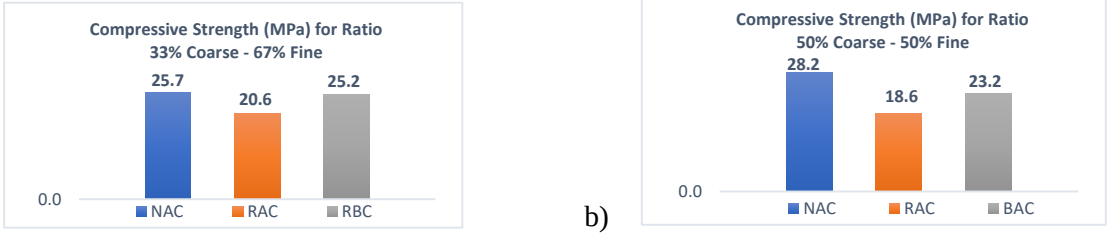
4.1 Bond strength & Compressive strength:

The average peak force obtained was used in the following formula to get the ultimate bond strength values $\sigma_{ult} = \frac{P_{Peak}}{\pi * d * L}$. *fig 4*(a) shows that for 33% coarse and 67% fine aggregate ratio NAC had the highest bond strength among the other mixes having RBC value relatively less. *fig 4(b)* indicates that when coarse aggregate ratio was increased from 33% to 50% more higher value of NAC 12.2MPa was obtained among other mixes. Compressive strength tests were conducted 28 days after casting. *fig 4(c)* shows that for 33%-67% ratio NAC had the highest compressive strength among the other mixes as well and also having RBC value relatively less. *fig 4(d* indicates that when coarse aggregate ratio was increased from 33% to 50% more higher compressive strength value for NAC 28.2MPa was obtained. This shows that bond strength has a direct relationship with compressive strength.



a) b)

Figure 3: Bond strength for a. Ratio 33%-67% & b. Ratio 50%-50%



a) b)

Figure 4: Compressive strength for a. Ratio 33%-67% & b. Ratio 50%-50%

4.2 Relation between Bond strength and compressive strength:

It is clear from the above results that the bond strength is directly related to compressive strength show in *fig 5.* Also, the increased ratio of coarse aggregate influenced negatively on the both the strengths of RAB & RAC. Moreover, the Practical results were also compared with the equation proposed by Md. Mozammel Haque to find bond strength using compressive strength and the difference is found to be range from 0.4-0.9 for all different ratios tested.

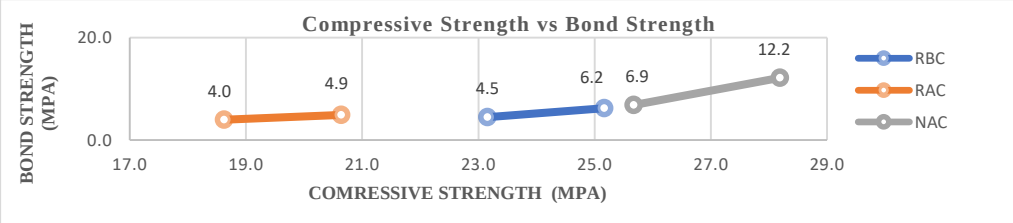


Figure 5: Graphical comparison of the relation b/w bond and compressive strength

5 Modes of failure:

Two modes of failure were observed during pull-out tests. In specimen having strong bond with bar splitting mode of failure was observed (*fig 6b*) due to radial outward forces caused by ribs on the rebar. While in specimen having weak bond with bar, slippage of bar (*fig 6a*) occurred that could be due to various factors, including poor surface preparation, improper bar placement, or inadequate adhesive properties of the bonding material.

a)  b) 

Figure 6: Splitting failure in a) RBC & b) RAC

6 Conclusion & Recommendations:

In conclusion compressive strength of a specimen has direct influence on its bond strength Increasing the recycled coarse aggregate content in the ratio influences the bond strength due to reduction in strength of recycled aggregate. Mozammel Haque equation found useful for measuring bond strength of recycled brick aggregate concrete directly from its compressive strength. Lastly, it is recommended to study the different RBA ratios, bar diameters, and recycled aggregates effects on concrete properties.

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8 References:

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