*Available online www.jsaer.com*

***Journal of Scientific and Engineering Research*, 2022, 9(1):70-76**

**Research Article**

**ISSN: 2394-2630**
**CODEN(USA): JSERBR**

# Bond strength of rebar and recycled aggregate concrete made with crumb rubber of different concentrations

**Robert Ataria, Orumu S. T.**

Department of Civil Engineering, Niger Delta University Wilberforce Island, Nigeria
robertataria@yahoo.com

**Abstract** Globally, there has been an urgent call to develop methods of reusing waste materials (recycled aggregates and crumb rubber from motor vehicles) in the construction industry in order to meet sustainability targets while reducing carbon emissions. There has been a lot of research done on the mechanical properties of concrete made with recycled aggregates or crumb rubber, but very little on rubber recycled aggregate concrete. This study investigates the bond strength of concrete containing recycled aggregates and crumb rubber of 5% and 15% concentration. The results of the tests shows that the compressive strength of the concrete made with recycled aggregate and crumb rubber is lower than that of the conventional concrete. However, the bond strength of the recycled aggregate concrete without crumb rubber was found to be higher than that of the conventional concrete with 16.3%. With the addition of crumb rubber in the recycled aggregate concrete, the bond strength reduces compared to the conventional concrete. However, if the bond strength is normalized to the compressive strength, the bond strength of the recycled aggregate concrete did not suffer any loss. Finally, this study suggests that the concentration of crumb rubber in recycled aggregate concrete be limited to 5% in order for the concrete to adequately transfer forces to the embedded reinforcement.

**Keywords** Recycled aggregates, Crumb rubber, Recycled concrete, Compressive strength, Bond strength

## 1. Introduction

The preservation of natural resources and the environment is at the heart of any modern development. One such attempt is the use of recycled concrete and crumb rubber to solve some of the problems in construction engineering. The use of recycled aggregate concrete and rubberized concrete is becoming more popular, and research in this area is gaining traction [1-10]. However, structural applications of recycled concrete with or without crumb rubber have yet to gain popularity, owing to concerns that its properties may be inferior to those of concrete made with natural aggregates.

The structural use of recycled concrete to advance the sustainability agenda would be interested in knowing how the behaviour of this concrete under various actions compares to that of conventional concrete. Bond is a critical structural parameter of reinforced concrete that refers to the adhesion between reinforcing steel and the surrounding concrete that is responsible for the transfer of axial force between these two elements [11-13]. Although the bond behaviour of conventional concrete and steel rebars has been extensively studied, relatively few studies on the bond between recycled concrete and steel reinforcement have been published [11-16].

The results of all existing research studies suggest that using recycled aggregates in concrete does not lead to reduction in the bond strength between recycled aggregate concrete and reinforcement regardless of the effects of recycled aggregates on other mechanical properties [12, 14, 16]. In fact, at the same concrete compressive strength, the [16] and [12] studies revealed that the bond strength for recycled aggregate concrete is higher than for natural aggregate concrete, owing to the more irregular shapes of recycled aggregates compared to natural aggregates, resulting in a better bond between cement matrix and aggregates.

If the bond strength is normalised to the compressive strength of concrete and expressed as a ratio of bond strength to the square root of compressive strength, using recycled aggregate concrete yields higher values. In conclusion, using recycled aggregate concrete would not affect bond strength. As a result, the same anchorage length for deformed reinforcement bars as in natural aggregate concrete can be used in recycled aggregate concrete[11, 16].

However, little is known about the bond strength of reinforcing bars in recycled aggregate concrete containing crumb rubber, which will be investigated in this paper.

## 2. Experimental programme

### 2.1 Materials

CEM 11/B-V 32.5N Portland fly ash cement complying with [17] was used for this study. In this work, uncrushed natural aggregates of 10mm size and recycled aggregates containing bricks and stones were used. The recycled aggregates used in this study are of low quality RC80 (Recycled aggregates obtained from concrete products with 20 percent impurities), according to [18]. Table 1 displays the water absorption rates and densities of both recycled and natural aggregates.

**Table 1:** Water absorption rates and densities of natural and recycled aggregates

| Type | Apparent particle density | Particle density on oven dry bases | Particle density on saturated and oven dry bases | Water absorption (%) |
|---|---|---|---|---|
| Natural aggregate | 2.69 | 2.62 | 2.65 | 1.05 |
| Recycled aggregates (RA) | 2.61 | 2.27 | 2.40 | 5.77 |

Figure 1 depicts the grading of natural aggregates and recycled aggregates.

Crumb rubber of 8 mm length and 2mm thickness with an aspect ratio of 4 from worn out vehicle tyres, as shown in Figure 2 was used in this study. The crumb rubbers were free from steel.

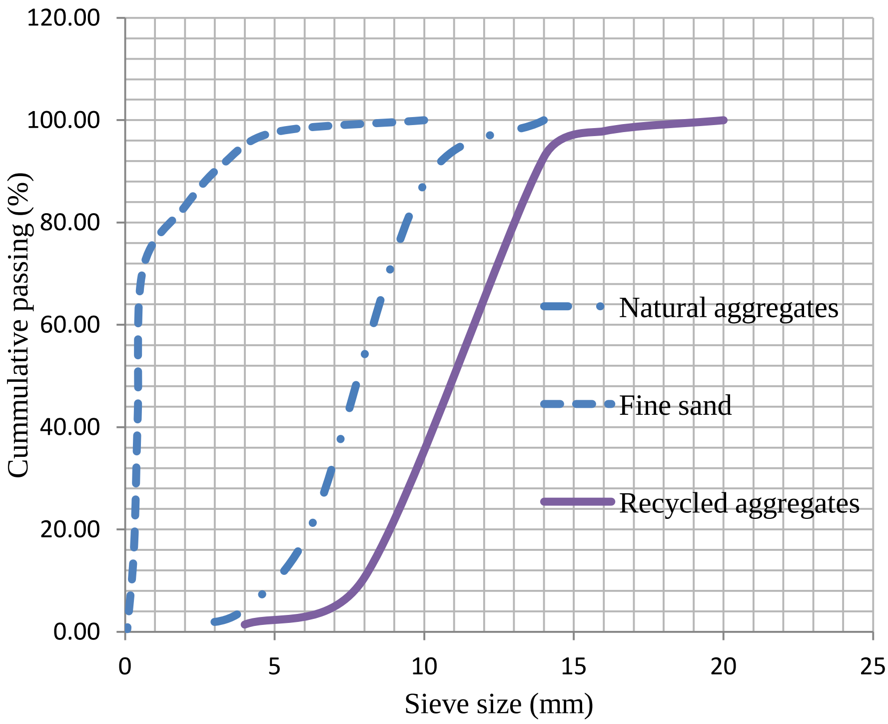


*Figure 1: Grading of natural aggregates, recycled aggregates and fine sand*


*Figure 2: Crumb rubber (8mm length) particles from worn out tyres*

**2.2 Concrete mix and specimen preparation**

This study designed a reference concrete with a cylindrical compressive strength of 40MPa, as shown in Table 2. Crumb rubber was used in various concentrations to replace coarse aggregates (5%and 15%). The experimental programme in Table 3 allows for the systematic investigation and comparison of the bond effects of different proportions of crumb rubber in recycled aggregate concrete to those of natural aggregate concrete (NAC). The percentages of replacement of recycled aggregates by crumb rubber were carefully chosen based on the recommendations made by [10, 19-21]for the rubberised recycled aggregate concrete to achieve a substantial proportion of the mechanical properties of the reference concrete. To achieve a workable concrete, a superplasticizer (1% of cement weight) was added to the recycled aggregate concrete with and without crumb rubber.

**Table 2:** Concrete mix composition of the reference concrete

| Mix type | Cement (kg) | Water (kg) | w/c | Sand (kg) | Coarse aggregates (kg) |
|---|---|---|---|---|---|
| NAC | 550 | 220 | 0.4 | 626 | 939 |

**Table 3:** Experimental programme

| Specimen Designation | Natural aggregates (% by weight) | Recycled aggregates (RA) (% by weight) | Crumb rubber (% by RA weight) | Sand (% by weight) |
|---|---|---|---|---|
| NAC | 100 | - | - | 100 |
| RAC | - | 100 | - | 100 |
| RRAC5 | - | 100 | 5 | 100 |
| RRAC15 | - | 100 | 10 | 100 |

NAC- Natural aggregate concrete; RAC- Recycled aggregate concrete; RA- Recycled aggregate; RRAC5, and RRAC15 - Rubber recycled aggregate concrete with 5 and 15 percent of crumb rubber content respectively of recycled aggregate weight.

The recycled aggregates and fine sand were mixed for 60 seconds in the concrete mixer, followed by crumb rubber and 50 percent water for another 60 seconds. The cement was then added for another 30 seconds, and the remaining water was added in 120 seconds to achieve a uniform concrete mix.

### 2.3 Pull out specimens

The pull-out test was performed on cylindrical specimens 150mm in diameter and 300mm in length, with the deformed bar placed concentrically. This test was chosen because of its ease of fabrication and setup. To avoid rebar yielding during the pull-out test, the embedded steel length was 5 times its diameter. Figure 3 depicts the pull-out test specimen, which shows contact between the rebar and concrete beginning 20mm below the surface to avoid compressive struts. This was accomplished by inserting a soft plastic tube at a depth of 20mm and filling the space between the rebar and the plastic tube with a clay material that was eventually removed after curing. Prior to testing, the specimens were cured for 40 days. In order to ensure the accuracy of the results, three samples were cast for each specimen.

As shown in Figure 4, the pull-out tests were carried out using a hydraulic frame rigidly connected to a universal tensile test machine. The specimen was fixed to a steel base that was bolted to the top plate. The top plate was held in place by bolts and nuts to ensure uniform distribution of the applied load and to reduce friction during loading. The test was carried out by pulling the 12mm diameter ribbed bar upwards, and the applied load was measured using a pressure sensor, the output of which was eventually fed into an automatic data acquisition system, as shown in Figure 4.

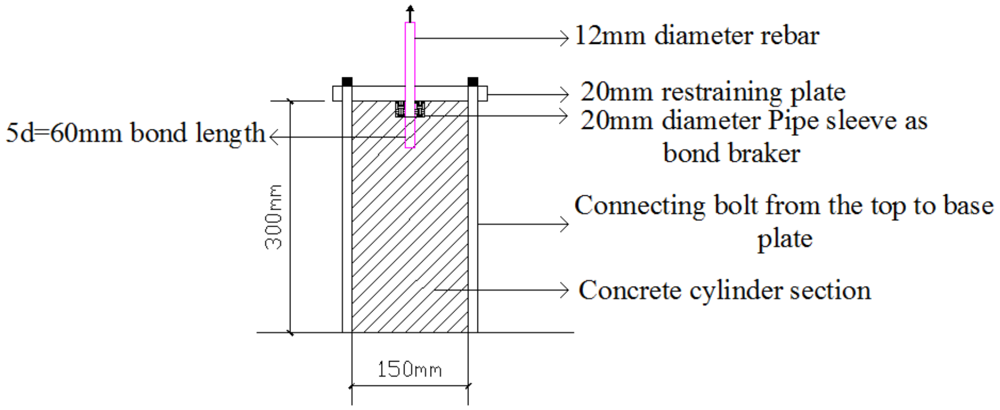


*Figure 3: Cross sectional view of the pull-out specimen*

The end slip was measured by LVDTs. At the point of maximum load, the specimen was unloaded in order to measure the descending branch of the load slip relationship.

*Figure 4: Test set up and instrumentation*

## 3. Results and Discussion

The bond strength was estimated using Equation 1, assuming the stress was uniformly distributed over the total embedded rebar length in concrete.

$$\tau_{max} = \frac{\rho_{max}}{\pi dl} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

where are the maximum bond stress and peak load between the concrete and rebar while d and l are the diameter (12mm in the test) and the embedded length (60mm in the test) of the rebar. Table 4 compares the compressive strength and bond strength of recycled aggregate concrete with and without crumb rubber to conventional concrete. The average bond stress slip relationships of all specimens are shown in Figure 5.

**Table 4:** Compressive strength and pull-out bond strength of concrete types

| Concrete type | $f_c$(Mpa) | $P_{max}$(KN) | $\tau_{max}$ (Mpa) | $\tau_{max}/(f_c)^{0.5}$ |
|---|---|---|---|---|
| NAC | 42.1 | 19.7 | 8.7 | 1.34 |
| RAC | 35.06 | 23.5 | 10.4 | 1.75 |
| RRAC5 | 30.2 | 22.4 | 9.9 | 1.8 |
| RRAC15 | 20.3 | 17.4 | 7.7 | 1.71 |

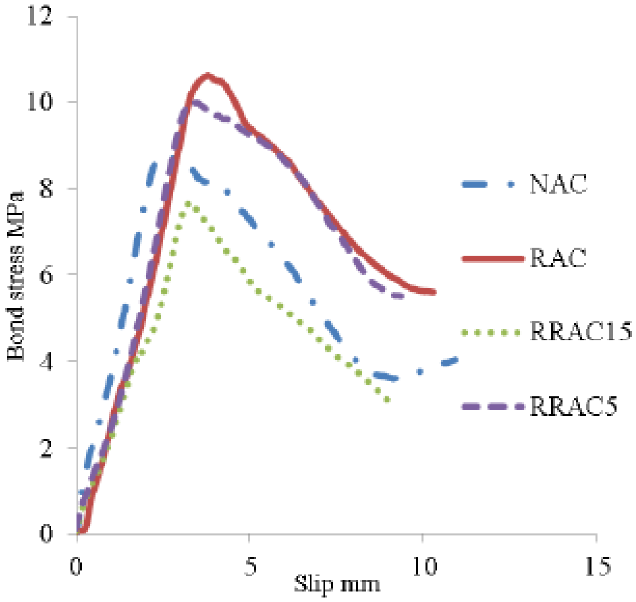


*Figure 5: Average bond stress v slip relationships from pull-out tests*

According to the results in Table 4, the bond strength of recycled aggregate concrete without rubber particles was 16.3 percent greater than that of natural aggregate concrete (NAC). This is due to the more irregular shapes of recycled aggregates, which provide better interlocking resistance. The results are consistent with the findings of [11, 16]. Using crumb rubber particles decreased the rebar pull-out bond strength, due to a lack of resistance of the rubber particles. However, if the crumb rubber concentration is limited to 5% (RRAC5), the bond strength of recycled concrete is comparable to that of natural aggregate concrete, as shown in Figure 5. Furthermore, if the rebar bond strength is normalised to the strength of concrete, as determined by $\tau_{max}/f_c^{\ 0.5}$, then incorporating rubber particles has not reduced the bond strength of the concrete, as evidenced by the results in Figure 6. However, according to this study, crumb rubber in recycled aggregate concrete should be limited to 5% of the weight of the recycled aggregates.

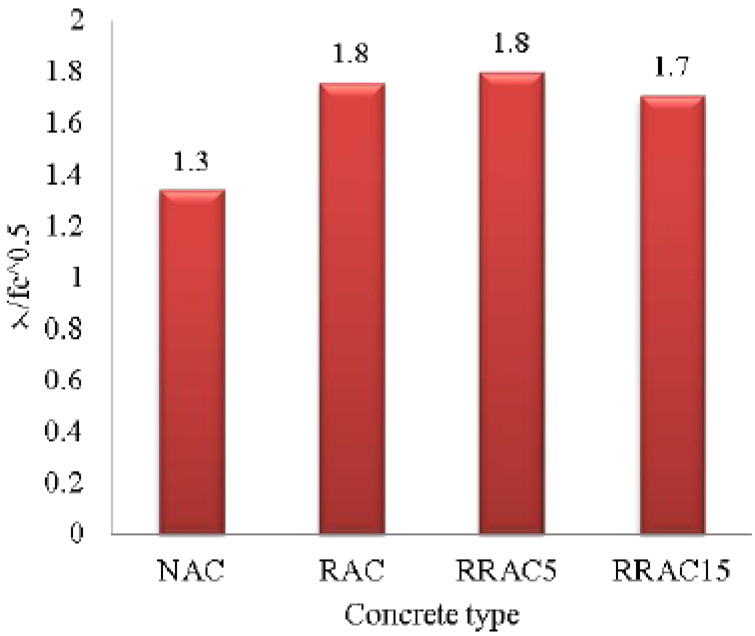


*Figure 6: Comparison of normalized bond strength to concrete shear strength*

## 4. Conclusion

The results of the experimental tests of concrete made with recycled aggregate and crumb rubber compared to the conventional concrete are summarized as follows.

1. The bond strength of the recycled aggregate concrete was found to be higher than the concrete made with natural aggregates by 16.3%. This was attributed to the irregular shape of the recycled aggregates resulting to a better grip with the embedded reinforcement.
2. Addition of crumb rubber in recycled aggregate concrete decreases compressive strength and bond strength respectively.
3. If the bond strength is normalized to the compressive strength of concrete, then the recycled aggregate concrete with crumb rubber did not suffer loss in bond strength.
4. This study recommended the concentration of the crumb rubber in recycled aggregate concrete to be limited to 5% in order to maintain sufficient bond needed to transfer forces.

## References

[1]. Manzi, S., C. Mazzotti, and M.C. Bignozzi, *Short and long-term behavior of structural concrete with recycled concrete aggregate.* Cement and Concrete Composites, 2013. 37: p. 312-318.

[2]. Yadav, S. and S. Pathak, *Durability Aspects of Recycled Aggregate Concrete: An Experimental Study.* International Journal of Civil and Environmental Engineering, 2018. Vol:12, No:3, 2018.

[3]. Gulrez, W. and P.D. Julie Ann Hartell, Aff.M.ASCE2, *Effect of Aggregate Type and Size on Surface Resistivity Testing.* ASCE, 2019.

[4]. Matias, D., et al., *Durability of Concrete with Recycled Coarse Aggregates: Influence of Superplasticizers.* American Society of Civil Engineers, 2014.

[5]. Azarsa, P. and R. Gupta, *Electrical Resistivity of Concrete for Durability Evaluation: A Review.* Advances in Materials Science and Engineering, 2017. Volume 2017, Article ID 8453095: p. 30 pages.

[6]. Richardson, A., K. Coventry, and J. Bacon, *Freeze/thaw durability of concrete with recycled demolition aggregate compared to virgin aggregate concrete.* Journal of Cleaner Production, 2011. 19(2-3): p. 272-277.

[7]. Guo, Y.-C., et al., *Compressive behaviour of concrete structures incorporating recycled concrete aggregates, rubber crumb and reinforced with steel fibre, subjected to elevated temperatures.* Journal of Cleaner Production, 2014. 72: p. 193-203.

[8]. Sara Sgobba, et al., *Use of Rubber Particles from Recycled Tires as Concrete Aggregate for Engineering Applications.pdf*>. Coventry University and The University of Wisconsin Milwaukee Centre for by-products Utilization, 2013.

[9]. Long, G., et al., *Self-Compacting Concrete Reinforced by Waste Tyre Rubber Particle and Emulsified Asphalt.pdf*>. Sustainable Construction Materials, 2012.

[10]. Holmes, N., A. Browne, and C. Montague, *Acoustic properties of concrete panels with crumb rubber as a fine aggregate replacement.* Construction and Building Materials, 2014. 73: p. 195-204.

[11]. Prince, M.J.R. and B. Singh, *Bond behaviour between recycled aggregate concrete and deformed steel bars.* Materials and Structures, 2013. 47(3): p. 503-516.

[12]. Prince, M.J.R. and B. Singh, *Bond strength of deformed steel bars in high-strength recycled aggregate concrete.* Materials and Structures, 2014. 48(12): p. 3913-3928.

[13]. Desnerck, P., G.D. Schutter, and L. Taerwe, *A local bond stress-slip model for reinforcing bars in self-compacting concrete.* Fracture Mechanics of Concrete and Concrete Structures, 2010.

[14]. Butler, L., 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, 2011. 41(10): p. 1037-1049.

[15]. Ahmad, S., et al., *Bond–slip behaviour of steel bars in low-strength concrete.* Proceedings of the Institution of Civil Engineers, 2015.

[16]. Xiao, J. and H. Falkner, *Bond behaviour between recycled aggregate concrete and steel rebars.* Construction and Building Materials, 2007. 21(2): p. 395-401.

[17]. EN197-1, B., *Composition, specifications and conformity criteria for common cements.* BSI Standards Publication, 2011.

[18]. BS_EN12620, *Aggregates for concrete.* BSI Standards Publication, 2013.

[19]. Khaloo, A.R., M. Dehestani, and P. Rahmatabadi, *Mechanical properties of concrete containing a high volume of tire-rubber particles.* Waste Manag, 2008. 28(12): p. 2472-82.

[20]. Turatsinze, A., S. Bonnet, and J.L. Granju, *Mechanical characterisation of cement-based mortar incorporating rubber aggregates from recycled worn tyres.* Building and Environment, 2005. 40(2): p. 221-226.

[21]. Najim, K.B. and M.R. Hall, *Mechanical and dynamic properties of self-compacting crumb rubber modified concrete.* Construction and Building Materials, 2012. 27(1): p. 521-530.