# Mechanical Performance of Recycled Aggregate Concrete Containing Lathe Waste Steel Fibre

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***ABSTRACT:*** The increasing demand, diminishing supplies, and growing pressure on natural resources have necessitated recycling and reusing waste. Several kinds of research have been done on the reuse and recycling of debris from building projects. Thus, with a view to the reuse of waste materials, the elimination of environmental contamination, the reduction of overhead costs of concrete, and the extension of the service life of concrete structures, this research aimed to study the feasibility of utilizing recycled concrete aggregate (RCA) with constant inclusion of waste steel fibre (LWSF) in concrete by evaluating its workability, compressive and splitting tensile strengths. A concrete mix ratio of 1:2:4 by weight of cement, sand, and granite was adopted with a water-cement ratio of 0.45. Five different concrete mixes were prepared in this study; one normal aggregate concrete (NAC) and four (4) other mixes with 25%, 50%, 75%, and 100% recycled aggregate content with a constant 1.5% addition of LWSF. The result of workability shows a reduction with an increase in the percentage replacement level. The recycled aggregate concrete (RAC) was characterized by lower compressive strength as compared with the NAC. When the replacement ratio increased from 25% to 50%, a significant reduction of about 14% and 30% were observed in the compressive strength at 7-days, but at 28-days slight increase in the compressive strength was observed. Also, a decrease in splitting tensile strength as the percentage replacement of crushed granite (CG) with RCA is increased was observed. Overall, the findings showed that the RAC-containing LWSF is environmentally sustainable and would significantly reduce the global greenhouse impact and building materials' overall quality.

***KEYWORDS:*** Recycled concrete, lathe waste, steel fibre, compressive strength, tensile strength

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## I. INTRODUCTION

Over the decades, concrete has been the primary construction material in civil engineering applications such as buildings, bridges, dams, and storage facilities. Its primary constituents are cement, fine (sand), coarse aggregates (granite), bonded together with water. The quantity of coarse aggregate in concrete production is believed to make approximately 60% of the composition. Hence, the increase in its cost, environmental impact, energy consumptions, increasing demand, declining reserve, and heightened pressure on natural resources have necessitated waste recycling and reuse with effective construction methods (Afolayan and Alabi, 2013).

The sources of recycled concrete aggregates (RCA) as reported by Ramadevi *et al*. (2017), Hunashikatti *et al*. (2018), and Alabi and Mahachi, (2020) are majorly from construction and demolition wastes (C&DW), and laboratory tested specimens (LTS). Its reuse appears to be the most economical and sustainable solution to both the problem of heightened pressure on natural resources and landfilling (Lau *et al*. 2014; López-Gayarre *et al*. 2009 and Murali *et al*. 2012). The research on recycled aggregate concrete (RAC) has accelerated over the past years to develop a possible replacement for normal coarse aggregates (NCA). RAC's most popular and widely-accepted applications are bedding materials in road constructions and non-structural concrete (Arul *et al*. 2016).

However, it has been found that the use of RCA in the production of RAC is limited because it does not meet minimum strength and durability requirements for structural elements (Wagih *et al*. 2013; Behera *et al*. 2014; Tabsh and Abdelfatah 2009; Verian *et al*. 2018; Ahamed *et al.* 2020; Cantero *et al*. 2020; Zhu *et al*. 2019; Gborbani *et al*. 2019; Kazmi *et al*. 2020; Sasanipour and Aslani, 2020; Zhu *et al*. 2020). RAC's strength characteristics are comparatively low compared to that of NAC, as it has undergone specific loading (Jianzhuang *et al.* 2004). The guideline for the use of RCA by RILEM TC 121-DRG (1994) categorized them into three groups, aggregates extracted from masonry rubble, aggregates obtained from concrete debris, and a blend of natural aggregates (>80%) and residue from the other two groups above. This shows the uncertainties associated with the grading of RCA (Katz, 2003). Based on the RCA's physical and mechanical properties, Thomas *et al*. (2016) recommended that a 20% substitution of CG with RCA can be used to prepare structural concrete.

Furthermore, RAC made with RCA has also be found to be weak in tension and it is adversely affected by several other

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factors such as the higher replacement ratio of RCA (Ajdukiewicz and Kliszczewicz, 2002; Xiao *et al*. 2005; Rao *et al*. 2007; Yang *et al*. 2009; Malesev *et al*. 2010; Behera *et al*., 2014), the type of parent aggregate and its physical and mechanical properties (Gomes *et al*. 2015), age and exposure condition of parent concrete, the procedure of extraction of recycled aggregate and number of crushing stages involved (De *et al*. 2016). Other factors like the volume of mortar adhered on RCA and aggregate surface texture also affect RAC's mechanical properties (Lopez-Gayarre *et al*., 2009; Butler *et al*., 2014). In this regard, researchers have employed different mixed design approaches to improve the quality of RAC.

Different forms of fibres such as carbon, cellulose, aramids, and steel have been incorporated into the mixture to improve RAC's mechanical properties. Lathe waste steel fibre (LWSF) is a potential fibre to be incorporated into the concrete. This is found in abundance at the Mechanical Engineering Laboratory of the Federal University of Technology, Akure (FUTA), Nigeria. Vytlacilová (2011) and Fang-Yuan *et al*. (2018) confirmed the improved mechanical performance (i.e., compressive and tensile strength) of RAC with the addition of plastic fibre. Nguyen (2013) reported that fibres aligned in the tensile stress direction significantly improve the tensile strength, as high as 133% for 5% of smooth, straight steel fibres. Therefore, this study presents the feasibility study on recycled aggregate potential from laboratory tested specimens (LTS) to incorporate LWSF in concrete.

## II. MATERIALS AND METHODS

### *A. Materials*

#### *1.) Aggregates*

In this study, three types of aggregates were used, which include river sand as conventional fine aggregate (CFA), crushed granite (CG), and crushed concrete cubes as recycled coarse aggregate (RCA); this was collected from Structural Engineering Laboratory and crushed using a jaw crusher. The fine aggregate was local river sand, having a fineness modulus of 3.0, specific gravity of 2.49, and saturated surface dry (SSD) water absorption of 2.56%. The aggregate sieve analysis and physical properties are shown in Figure 1 and column 2 of Table 1. The fine aggregate is found to satisfy the requirement of BS 812 (1985). As given by BS882 (1992), the overall grading limit requires percentage mass passing between 0 – 15% for sieve size 150 μm. The results show that the soil sample does not satisfy the overall grading limit as given by BS882 (1992). The percentage of mass passing is about 17%, which indicates that the sand contains finer particles than the one recommended by standard.

Crushed granite (Figure 1) as coarse aggregate was used in concrete production, with a maximum of 20 mm. The overall grading and physical properties are shown in Figure 3 and Table 1, respectively. This aggregate's particle shape and surface texture were found to contribute to lower values of strength properties of concrete produced in Akure. Recycled concrete aggregates, RCA (Figure 2) with a maximum size of 20 mm, and a minimum size of 10 mm, sourced from concrete cube debris at the structural laboratory, were used to cast the RACs concrete. Overall, RCA consists of about 70% of crushed concrete, with about 30% of mortar paste adhering to its surface. The particle distribution and some physical properties were presented in Figure 3 and column 4 of Table 1. Based on the specific gravity, impact, and crushing values, it was observed that the RCA is very weak when compared with CG under mechanical loadings.

**Table 1: Physical properties of aggregates.**

| Property | Sand (Fine aggregate) | Granite (coarse aggregate) | Crushed concrete cubes (coarse aggregate) |
|---|---|---|---|
| Fineness (%) | 3.00 | - | - |
| Specify Gravity | 2.49 | 2.58 | 2.26 |
| Maximum size (mm) | 4.75 | 12.5 | 19 |
| Water absorption (%) | 2.56 | 1.8 | 4.08 |
| Aggregate crushing value (%) | - | 30.4 | 35.3 |
| Aggregate impact value (%) | - | 22.76 | 23.1 |
| Shape | - | Smooth on all sides | Smooth all sides with paste adhered |

#### *2.) Cement*

The ordinary Portland cement (OPC) of grade 42.5R produced according to BS EN197 – 1 (2000) standard was used. The results of the chemical composition of the OPC are presented in Table 2. From this table, it was observed that the sum of the percentage composition of the oxides in the OPC is 96.5%, which conforms to the recommendation of ASTM 1994. The specific gravity of OPC is 3.15.

**Table 2: Oxides composition of the OPC.**

| Common Name | Oxide | OPC (%) |
|---|---|---|
| Lime | CaO | 61.52 |
| Silica | $SiO_2$ | 21.02 |
| Alumina | $Al_2O_3$ | 5.78 |
| Iron | $Fe_2O_3$ | 3.28 |
| Magnesia | MgO | 2.08 |
| Alkalis | $Na_2O$ | 0.78 |
| Potassium | $K_2O$ | - |
| Sulfuric anhydride | $SO_3$ | 2.04 |
| Consistency time (min) | - | 10 |
| Initial setting time (min) | - | 30 |
| Final setting time (min) | - | 60 |
| Specific gravity ($S_g$) | - | 3.15 |

**Table 3: The five different mix design used for this project.**

| Notation | Concrete mix design |
|---|---|
| **RC-SF0** | Control mix using 100% CCA in the concrete |
| **RC-SF1** | 25% replacement of CCA with RCA in concrete with a constant 1.5% addition of LWSF |
| **RC-SF2** | 50% replacement of CCA with RCA in concrete with a constant 1.5% addition of LWSF |
| **RC-SF3** | 75% replacement of CCA with RCA in concrete with a constant 1.5% addition of LWSF |
| **RC-SF4** | 100% replacement of CCA with RCA in concrete with a constant 1.5% addition of LWSF |

**Figure 1: Conventional coarse aggregate (granite).**

**Figure 2: Recycled coarse aggregate (laboratory tested specimens).**

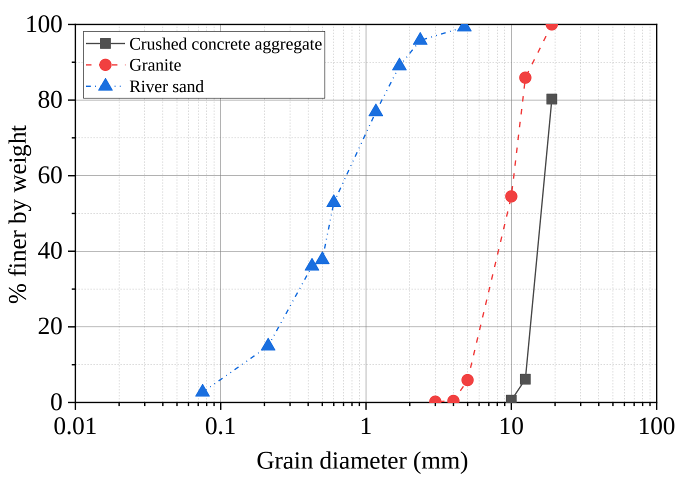


**Figure 3: Particle size distribution of river sand (solid line with square); crushed concrete cube (solid line with a triangle) and granite (dash-dotted line with a cross).**

*3.) Lathe waste steel fibre (LWSF)*

The lathe waste steel fibre (LWSF) (Figure 4) used for the study is the high yield steel chips (a by-product of machined high yield steel on a lathe machine). LWSF is spiral with a diameter around 0.29 mm and length between 25 mm and 38 mm.

**Figure 4: Lathe waste steel fibre.**

*4.) Water*

The water used for mixing and curing is portable water, free from any constituent that can affect both the fresh and hardened state's concrete properties.

*B. Methods*

A concrete mix ratio of 1:2:4 by weight of cement, sand, and granite was adopted with a water-cement ratio of 0.45. The detail of the concrete mix design is presented in Table 3. Five different concrete mixes were prepared in this study; one NAC and four (4) concrete mix with 25%, 50%, 75%, and 100% RCA content with a constant 1.5% addition of lathe waste steel fibre (LWSF) to compare the properties of RAC with CAC. A total of 45 test samples were prepared and tested according to BS1881: Part 111 (1995) using standard dimensions of 100 mm x 100 mm x 100 mm to determine the compressive strength. Nine (9) were cast with natural aggregates (as the control samples), and 36 were cast with 25%, 50%, 75%, and 100% RAC replacements.

For splitting tensile tests, 45 cylinder samples were cast and tested, of which nine specimens were cast with natural aggregates as control samples. All the prepared specimens were standard dimensions, 150 mm (diameter) x 300 mm (height). All specimens were water cured after casting until the testing day (i.e., 7, and 28-days). All samples were air-dried before testing. For every test, three samples were tested to produce an average. Comparisons among the test results were carried out to determine the influence of RAC replacement levels on concrete compressive strength.

## III. RESULTS AND DISCUSSION

*A. Concrete Workability*

Upon mixing the concrete, a slump cone was used to measure the fresh concrete's workability and consistency. Figure 5 shows the results of a slump test on the different concrete mixes. From the figure, the slump values ranged from 40 mm to 60 mm. It is observed that the slump values decreased as the percentage replacement of RCA with CG increased. This could be attributed to the fact that mixing water increases due to RCA's higher porosity and absorption capacity in the concrete. At all percentage replacement levels, the high level of water absorption is well noticed as the slump value decreases due to adhering mortar to the RCA aggregates.

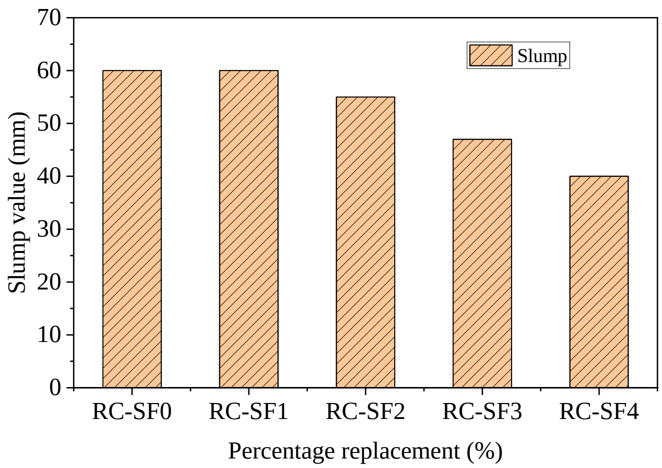


**Figure 5: Results of slump test for different mixes.**

*B. Compressive Strength*

Figure 6 shows the compressive strength at 7-days and 28-days for all recycled concrete with steel fibre (RC-SF) (i.e., RC-SF0 – RC-SF4) prepared from RCA and CG The strength of control samples at 7-days was observed to be fast and almost attain the strength at 28-d. The difference between the strength at 7-d and 28-d for all concrete mixes was observed to be 4.4%, 19.35%, 33.7%, 28.92%, and 18.52%, respectively. This may be due to the lower water absorption capacity of the aggregates used. From Figure 6, it can be seen that the RAC is characterized by lower compressive strength when compared with the NAC. In other words, a decrease in the compressive strength was noticed as the RAC % replacement increases from 0% to 100%. Lower compressive strength observed may be attributed to the source and the RCA history using RAC production.

The quality of concrete cement, the adhering of old mortar to the RCA aggregates, and fine aggregate (sand) may have contributed to the observed strength reductions. When the replacement ratio increased from 25% to 50%, a significant decrease of about 14% and 30% was observed in the compressive strength at 7-days, but at 28-days slight increase in the compressive strength was observed. The reduction in compressive strength for 75% replacement of CG was 37% at 7-days and 9% at 28-days. At full replacement of CG with RCA, the reduction in compressive strength ranging from 2.5% to 11% at 7-days and 28-days respectively were observed.

Most of the noticed significant reduction in the compressive strength was at 7-days. This could be attributed to the difference in the physical and mechanical properties of the recycled coarse aggregates used in the concrete production, sourced from different original concrete of varying strength. Generally, there may not be the possibility of using the concrete produced for major structural applications from the results. The concrete can still be improved using a better mixing method and treatment of the RCA used in concrete production. However, the compressive strength is better using a 25-50% RCA level of replacement. In other words, the compressive strength was more significant than the values obtained for 0% replacement (control samples) when the RCA replacement level was between 25% and 50% RCA replacement, after which compressive strength obtained reduced between the control for all days. This observation was in agreement with the study by Waigh *et al*. (2013).

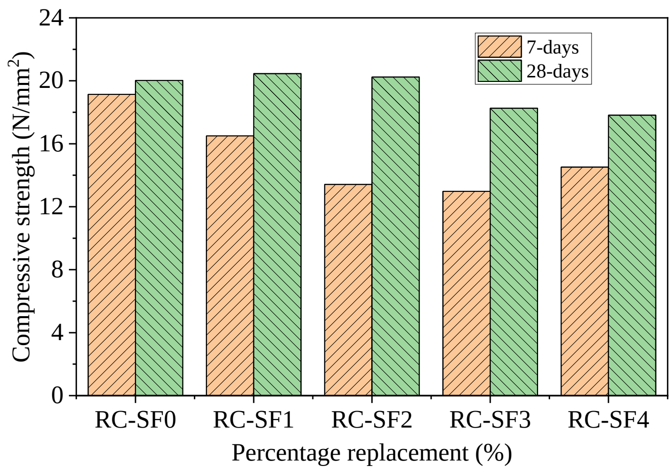


**Figure 6: Compressive strength at 7-days and 28-days for different concrete mixes.**

*C. Splitting Tensile Strength*

Figure 7 shows the splitting tensile strength of NAC and RAC mixes at 7-d and 28-d. A decreasing trend of tensile strength when the percentage replacement of CG with RCA is increased was observed from the figure. At 7-days and 28-days, the concrete specimen with 100% RCA had the lowest tensile strength of 1.5 N/mm$^2$ and 2.4 N/mm$^{2,}$ respectively. The reduction in tensile strength ranged from 10.7% to 46.4% as compared to NAC specimens. The higher decline could be attributed to fibre's effect on the interfacial zone between new and old mortar paste adhere to RCA. This may be due to poor bonding between the fibre and recycled aggregate.

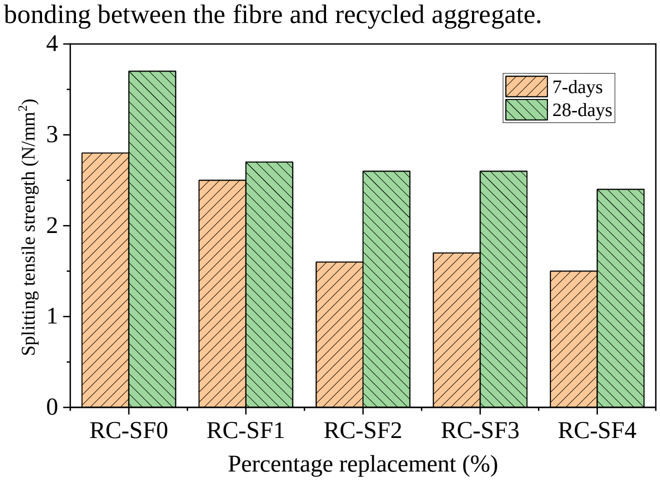


**Figure 7: Splitting tensile strength at 7-d and 28-d for all the mixes.**

## IV. CONCLUSION

This study presented the feasibility study using recycled aggregate from the laboratory tested specimens as coarse aggregate with the constant incorporation of the lathe waste steel fibre in the concrete. The workability reduces with an increase in the percentage replacement level of CG with RCA.

RAC's compressive strength at 25% and 50% replacement level with 1.5% constant addition of LWSF performed better than the NAC. As the percentage level increased beyond 50%, both the compressive strength and workability were affected by recycled aggregates' quality. The reduction in RAC's mechanical properties may be due to many adhered mortar on the recycled aggregate used in concrete production, leading to more porous concretes.

The addition of steel fibre was observed to have little effect on the compressive and tensile strength, resulting from a low interfacial zone bond between new and old mortar adhered to the aggregates. The reduction in recycled aggregate concrete's mechanical performance could also depend on the original concrete's history, which was visually observed to be of low quality.

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