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The effect of recycled aggregate quality on concrete properties reinforced by natural sisal fibers

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ABSTRACT

One of the most common types of waste generated worldwide is waste from construction and demolition processes. The objective of this study is to reduce the environmental issues caused by the disposal of construction and demolition wastes. To determine the suitability of sisal fiber (SF) reinforced recycled concrete for use in construction works, this paper compares the results of experiments done on the properties of fresh and hardened concrete materials with various replacement ratios of normal and recycled coarse aggregate reinforced by natural SF. It also examines the impacts of the various replacement ratios on the compressive and flexural strengths of the resulting mixes. For this study, waste concrete from construction projects was crushed to create recycled aggregate. Two different types of concrete combinations, one composed entirely of normal aggregate as a control concrete, and the other containing different percentages of recycled coarse aggregate (25%, 50%, 75% and 1.5% SF. To assess the compressive strength of the main characteristics of the hardened concrete, 24 specimens were prepared and used. The flexural strength of concrete beams manufactured from various types of concrete was also examined. In this study, recycled aggregate (RA) concrete performed satisfactorily and did not significantly differ from the performance of the control concrete regardless of the replacement ratio utilized, while the workability of SF-containing concrete was severely impacted. However, it is crucial to use high-quality recycled concrete coarse aggregate and to follow the precise guidelines for creating this kind of new concrete. The test findings demonstrated that the sisal-fiber-containing concrete sample provided excellent compressive strength as well as high flexural strength. These strengths were contrasted with samples that lacked sisal fiber in terms of strength.

Keywords: Recycled aggregate, Sisal fibers, Recycled aggregate concrete, Mechanical properties, Flexural test, Comprehensive strength

INTRODUCTION

Recycling is the process of utilizing used materials to make new products. The vast amount of waste from construction projects that seem to be growing annually has recently become a source of increasing concern. Global waste accumulation is a problem; the majority of waste is either illegally discarded or used as landfill material. On the other hand, using this waste in a more environmentally friendly manner can lessen the impact [1]. Environmental protection is greatly aided by the use of natural resources and wastes. Waste disposal has been a significant issue for the previous few decades. High transportation costs and tipping fees are associated with using waste as landfills. To reduce the cost of concrete and its impact on the environment, scholars have suggested the use of waste materials as partial replacements for normal aggregate in concrete. One of the numerous strategies to lessen the carbon footprint of the construction sector is to employ renewable resources and building materials. When aging and failing structures are destroyed, the main component of the generated waste is stone fragments. These stone pieces are referred to as recycled coarse aggregates (RCA) after recycling. These RCA are granular substances made by processing inorganic building materials and reusing them for construction [2]. One of the most common materials used in construction across the globe is concrete. It is used in all types of construction projects, including infrastructure, high and low-rise structures, etc. However, concrete can be made from recycled materials using recycling methods. RAC has gradually become more popular over the past 20 years, and it is now utilized in road construction, asphalt concrete, lightweight concrete, and concrete exposed to high temperatures. Researchers have created a number of cutting-edge methods to improve the performance of RAC; these methods, which can enhance the performance of RCA, include surface treatment [4], the use of mineral admixtures [5, 6], and the use of fibers [7, 8, 9]. Crushed waste has been used as concrete aggregate in Europe since the Second World War [3]. Crushed waste was used after the Second World War to construct many buildings in Japan in order to reduce costs and hasten building projects. These structures are still in good working order today. RAC can be used to solve problems associated with excessive waste materials as long as the finished product meets the required standards for quality. It opens up new possibilities for material reuse in the construction industry. Utilizing RA in concrete can also lessen environmental impact and enhance ecology [4]. Studies have shown that construction waste can be properly treated to produce recycled aggregates that are usable. Utilizing unwashed RA reduces the strength of concrete. Since the bonding is stronger when washed RAs are used, the overall strength of the concrete is higher when using washed RA [5]. Recycling is the process of preparing used materials for use in the creation of new goods. Increased infrastructure development makes it possible to intensify the usage of natural aggregate. Aggregates can be used as replacement materials in both their natural and recycled forms. RA is made up of both graded and crushed inorganic particles that were obtained from construction waste and building materials. Natural fibers can be added to strengthen recycled concrete while reducing its drawbacks. The qualities of recycled concrete can be improved by using coconut fibers. Tensile strength, specific tensile strength, and density of coconut fibers were examined in the study by Rao et al. [5] who noted that the density was 1150 kg/m3, while the tensile and specific tensile strengths were 500 MPa and 0.43 MPa, respectively. Considering the poor quality of the materials in Libya, RA is not frequently used in concrete as the aggregates are low in density and exhibit a high absorption rate. As a result, RAs are seldom used in structural constructions due to the wide range in their quality [6]. Concrete wastes gathered from demolished structures were physically crushed into tiny bits of various standard sizes of coarse aggregates for the investigation. To test the strength of the concrete produced, standard samples were formed using recycled concrete coarse aggregates in various replacement ratios. Some of these samples had natural SF reinforcement instead of the more costly steel, glass, or polyester fibers.

Test Program

To assess the effects of replacing regular coarse aggregate with RCA, several investigations were carried out to identify the qualities of the coarse aggregates and the resulting concrete from only coarse aggregates. The RCA in this study was used as a replacement for the stone aggregates at different replacement percentages of 25%, 50%, and 75%; all the other components remained the same (see Figure 1). The test samples were separated into M1, M2, M3, and M4 groups, totaling eight groups. The letters "M" stand for "concrete mix," and the subscript "%" stands for "percentage of RCA used to replace stone aggregate"; the reinforced samples are M5, M6, M7, and M8. Each group received 24 (150x150x150 mm) concrete cubes for the compressive strength test (Table 1). Another 16 prisms (100×100×500 mm) were also cast to test for the flexural test; the prisms were divided into two prisms per group.

Fig. 1: Type of Recycled Concrete Aggregate

Table 1: Recycled Concrete aggregate

Property	Natural aggregate	Recycled aggregate
Crushing value	26.5%	29.5%
Impact value	24.5%	28.5%

Materials Used in This Study

The coarse aggregate is made up of concrete mixtures comprised of Ordinary Portland Cement (OPC), crushed stones, and sea sand. Different percentages of RCA and water are used to prepare the replacement aggregate. The preparation process followed the ASTM standards as the OPC and local sea sand were used with a specific gravity of 2.66. The coarse aggregate made from crushed stones has a specific gravity of 2.65. The ASTM guidelines were followed to conduct the sieve analysis of the coarse aggregate. The waste RAC was collected and crushed in the lab to make the recycled concrete that was used as coarse aggregate. After that, the recycled concrete was manually sieved and crushed into different sizes. The small fragments were eliminated. The aggregates (coarse and replacement) were sorted to a maximum size of 14mm. The sisal fibers (SF) utilized in this study were provided by a regional fiber company in Libya and are currently commercially available as flakes with a length of 500 mm. Table (2) displays the properties of the utilized SF in this investigation.

Fig. 2: Sisal Fiber

Table 2: Chemical Composition of Sisal Fiber

Cellulose	65%
Hemicelluloses	12%
Lignin	9.9%
Waxes	2%%
Total	100%

Mix Design

The ratios were randomly mixed; the combination ratio of 1:2:3 was used to mix the cement, sand, and RCA. Table 3 lists the mix proportions and the concrete's characteristics (refer to Table 3).

Table 3: Mix Proportion of Concrete

Mix No	Cement Kg/m^3	Fine Agg Kg/m^3	Normal Coarse Agg Kg/m^3	Recycle Agg Kg/m^3	Water Ltr	Sisal fiber %
M1	350	700	1050	0	157.5	----
M2	350	700	787.5	262.5	157.5	----
M3	350	700	525	525	157.5	----
M4	350	700	262.5	787.5	157.5	----
M5	350	700	1050	0	157.5	1.5
M6	350	700	787.5	262.5	157.5	1.5
M7	350	700	525	525	157.5	1.5
M8	350	700	262.5	787.5	157.5	1.5

Experimental Work

The concrete laboratory of the faculty of engineering at Bani Waleed University in Libya served as the site of the experimental testing. Twenty samples of concrete, both with and without RCA, were produced in the concrete laboratory. Eight prisms with a flexural strength of 2.65 Mps and 12 side cubes (150 mm) with a compressive strength of 30 Mpa were utilized as samples in this study. To provide consistent workability across all samples, the nominal "mixing ratio of (cement: sand: coarse aggregate) by weight with a slump of (180 ±5) mm as a base was designed. After being soaked in water for 24 hours, the RCA was dried to achieve saturated surface dry conditions. Concrete was mixed with sand, cement, and either regular coarse aggregate or recycled aggregate before the required amount of water (0.45%) was added and completely mixed. Prior to casting, oil was brushed onto the wooden mold's interior surfaces. Using a typical compact immersion vibrator, three layers of concrete were poured into the mold and fully compacted. A trowel was used to dress the top surface. After 24 hours, the samples were taken out of the mold and cured for 28 days in water. The samples were removed from the curing tank and tested immediately for compressive and flexural strengths using a-3000 kN compression testing equipment in accordance with the BS EN 12390-3" guidelines [4].

Fig. 2: Flexural Test

RESULTS AND DISCUSSION

The fresh and hardened concrete were subjected to several tests; compressive and flexural strength tests were conducted on hardened concrete while a slump test was performed to assess the workability of the fresh concrete. The outcome of the slump test on the RCA was displayed in Table 2. The information gathered was utilized to establish a link between slump and the replacement rate of recycled material in concrete. Figure 3 shows a graph of the slump values for concrete mixtures using various amounts of recycled material. The graph displayed the slump for various RCA mix percentages; the graph clearly showed that slump increased significantly as the aggregate replacement percentages gets higher. However, the addition of SF altered the observation as the graph showed random slump values with constant addition of SF (1.5%). The SF-containing concrete mixes (M5, M6, M7, and M8) generally displayed values that were lower than those of a conventional mixture (M1) refer to Table (4).

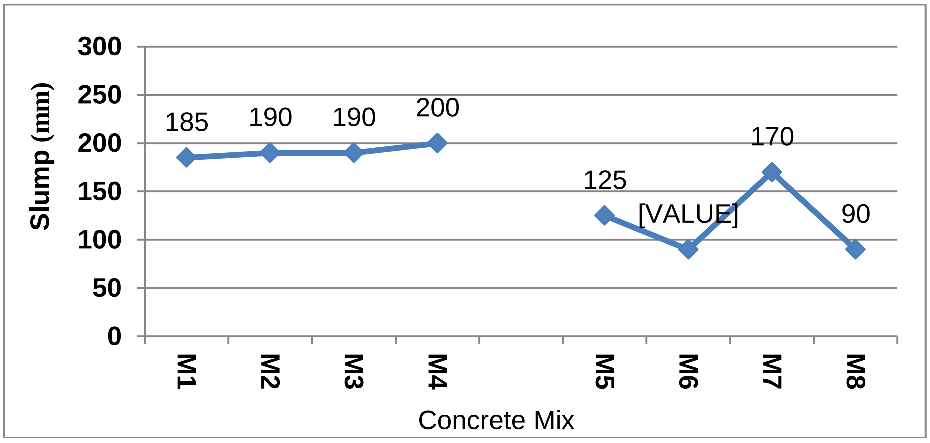

Fig. 3: Slump Results of samples

Table 4: Mechanical Properties Test Results

Concrete Mix	Aggregate Replacement Ratio (%)	Slump Mm	Compressive Strength Mpa	Flexural Strength Mpa
			28 Days	28 Days
M_1	0	185	30.08	2.65
M_2	25	190	30.89	2.67
M_3	50	190	31.06	2.96
M_4	75	200	32.06	3.42
M_5	0	185	30.19	3.64
M_6	25	95	34	3.71
M_7	50	90	35.35	4.2
M_8	75	90	36	4.49

The results of the tests on concrete cube samples with/without RCA, as well as with SF addition, were displayed in Figure (4).

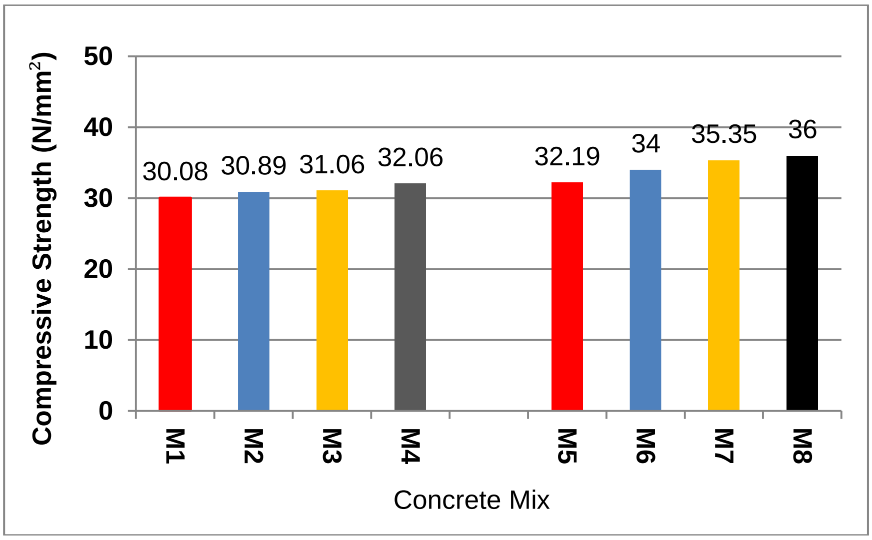

Fig. 4: Compressive Strength for Different Percentage of Recycled Aggregate Concrete

The outcomes showed the average of the three samples at 28 days of age that satisfied the requirements of BS: 1881: Part 3: 1970 and 1881: part 4: 1970. This graph unequivocally demonstrated the positive impact of adding RA to concrete in terms of improved compression strength. The use of higher strength RC could yield stronger concretes. Additionally, Figure 4 showed that as the ratio of RAC to coarse normal aggregate increased, the compressive strength slightly improved. However, at 28 days, the compressive strength of cubes made with RAC and marked M2, M3, and M4 showed significant improvements. The measured compressive strengths (compared to M1 (control)) were 30.89 MPa (M2), 31.06 MPa (M3), and 32.06 MPa (M4). As the proportion of RA in concrete was increased, the compressive strength proportionally increased. Although there was a gradual increase in compressive strength with the introduction of natural fibers in mixes M5, M6, M7, & M8, it was significantly higher than those of samples without SF. The sample with the highest RA content (M8) achieved the highest compressive strength value of 36 MPa. When the proportion of RCA in the concrete mix is increased, there was a corresponding increase in the value of the flexural strength though the improvement in strength was gradual. In comparison to the control (M1) which produced a strength value of 2.65 MPa, the graph reveals higher flexural strength values (3.64, 3.71, 4.2, and 4.49 MPa) for samples M5, M6, M7, and M8, respectively (see Figure 5).

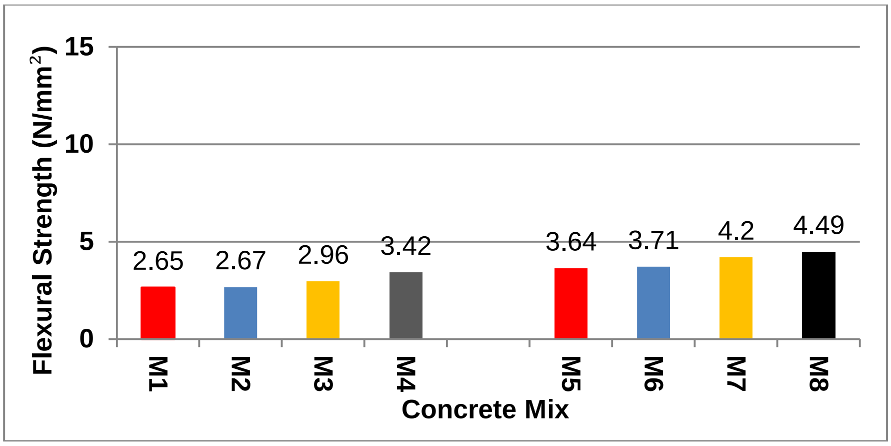

Fig. 5: Flexural Strength for Different Percentage of Recycled Aggregate Concrete

CONCLUSION

This study has demonstrated that RAC can be successfully used as a replacement for coarse aggregate in concrete production as the test results revealed that concrete samples containing different ratios (25%, 50%, and 75%) of recycled aggregates as a replacement for natural coarse aggregate offered both sustainability and economic benefits. Furthermore, the addition of natural SF into the concrete mixes improved the compressive and flexural strength values significantly. The workability of the concrete was also influenced by the quantity of recycled aggregate used during the concrete mixing. Even though the SF-containing mixes showed a range of workability values, these values are generally lower than those of concrete with normal and recycled aggregate that achieved almost similar workability values. The cement and aggregates do not adequately bind with an increase in RA percentage and 1.5% of SF in all the concrete mixtures, leading to a very poor combination of concrete that has a brittle-like texture rather than a clayey texture. The concrete's compressive strength was based on the recycled aggregate's quality; if high-quality aggregate from crushing stronger concrete is used to make fresh concrete, the compressive strength of the resulting RA will be affected, regardless of the replacement ratio of regular coarse aggregate with recycled aggregate. The same factors also have an impact on the concrete's flexural strength. The use of a fresh cement paste in the mixes implies that the link between the RAC and regular aggregate is insignificant. The concrete mixtures showed an excellent improvement in compressive strength, with the best values being achieved by mixes containing RA and 1.5% SF. Therefore, the addition of SF improved the compressive strength of the resulting mixtures (M8) e by about 19.8% and 11.8%, respectively, over M1 and M5. The addition of SF also improved the flexure strength values of the concrete. The strength data demonstrated that the introduction of SF into the mixes significantly increased the values of the flexural strength as the maximum strength value of 4.49 MPa was achieved by the SF-containing M8. For RAC made from high-quality recycled aggregate from demolished structures with good mechanical properties as used in this research, the data from the studies on the properties of the fresh and hardened concrete, as well as the performance of the beams subjected to bending tests, supported the conclusions drawn from the observations. This study showed that concrete from construction sites can serve as a good building material. Additionally, the addition of SF positively affected the characteristics of concrete and increased its compressive and flexural strengths. Hence, RAC can be considered an acceptable substitute for regular concrete when there are economic and environmental concerns. When normal coarse aggregate generated from fresh rocks is not readily accessible, RAC can be used in place of the normal coarse aggregate to produce concrete.

Recommendations For Future Studies

- To determine the strength of recycled aggregates that can be used in concrete, more testing and research on the material is strongly advised. The following suggestions are necessary for future studies in this regard.
- It is advised to add admixtures, such as silica fume and super-plasticizer to the mixture to increase workability, even though higher strength and performance can be achieved by lowering the cement/water ratio.

- The strength of recycled aggregate needs to be investigated further in the laboratory. Beams, concrete slabs, and walls made from recycled aggregates can be tested to determine the strengths.
- The use of some mechanical properties, such as creep and abrasion as indicators of strength is also recommended.
- Different outcomes and high-quality RAC can be achieved by conducting more tests with RA particles of various sizes and replacement percentages.

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