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Sustainable Reinforcement: Investigating the Mechanical Properties of Concrete with Recycled Aggregates and Sisal Fibers

Salahaldein Alsadey, Issa Amaish

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***Abstract*—**Recycled aggregates (RA) have the potential to compromise concrete performance, contributing to issues such as reduced strength and increased susceptibility to cracking. This study investigates the impact of sisal fiber (SF) on the mechanical properties of concrete, with the objective of utilizing SFs as a reinforcing element in concrete compositions containing natural aggregate and varying percentages (25%, 50%, and 75%) of coarse RA replacement. The investigation aims to discern the positive and negative effects on compressive and flexural strength, thereby assessing the viability of SF-reinforced recycled concrete in comparison to conventional concrete composed of natural aggregate without SF. Test results revealed that concrete samples incorporating SF exhibited elevated compressive and flexural strength. Comparative analysis of these strength values was conducted with reference to samples devoid of SF.

***Keywords*—**Sustainable construction, construction materials, recycled aggregate, sisal fibers, compressive strength, flexural strength, eco-friendly concrete, natural fiber composites, recycled materials, construction waste management.

I. Introduction

UTILIZING the natural products and wastes is very much helpful to the environmental protection. SF is the natural fiber extracted from the tree leaves. Utilizing sustainable resources and building materials represents one of numerous strategies to diminish the carbon footprint associated with the construction sector. Another way in which the construction industry contributes to carbon emissions is by the energy used in the operation of buildings [1]. By using building materials with better insulating properties, the requirement for heating in the colder months and cooling in the warmer months is reduced. Buildings can also be designed more competently to use natural light and air circulation. This decreases the energy consumed by the buildings which in turn reduces electricity generation which consumes fossil fuels. The construction of durable structures is also of high importance. The maintenance and restoration of structures due to the degradation of materials and poorly constructed structures leads to further unnecessary consumption of building materials. One of the most common problems today is related to removal of waste and to the discovery of solution for recycling and reusing it. Various waste materials are produced from manufacturing processes, assembling forms, construction and demolition work and municipal solid wastes. Nevertheless, the scarcity of high-quality natural aggregates has prompted the exploration of alternative applications for RAs. The environmental and economic advantages have spurred increased production and utilization of RA concrete in numerous nations. The waste from construction developer industries with a subsidy from construction and demolition waste generates a huge amount of concrete waste deposition [2]. If RAs are practically used during construction, two positive aspects would be expected; the first one is it reduces the cost of construction significantly; the other one is that it reduces the consumption of natural aggregate resources. Around the countries worldwide, the application of RA has already been implemented in construction projects. In comparison to concrete made with natural aggregates, incorporating RAs typically results in higher drying shrinkage and creep, along with reduced compressive strength and modulus of elasticity [3].

To improve the efficacy of RA concrete, scholars have devised various advanced methods, such as surface treatment [4], the use of mineral admixtures [5], [6] and the addition of fibers [7]-[9], which can improve the performance of RA concrete. To increase the strength and minimize the negative aspects of the recycled concrete, natural fibers can be used. Coconut fibers can be beneficial for enhancing the properties of recycled concrete. In the investigation conducted by Rao and Rao, an examination of the tensile strength, specific tensile strength, and density of coconut fibers was undertaken. Their findings indicated that the recorded values for tensile and specific tensile strengths were 500 MPa and 0.43 MPa, respectively, with a corresponding density of 1150 kg/m³ [10]. Subsequently, Baruah and Talukdar delved into a comprehensive study focusing on concrete strength with varying percentages of coconut fibers (ranging from 0.5% to 2%) at a length of 4 cm. Their observations revealed a positive correlation between the volume fraction of fibers and the improvement in compressive strength, splitting tensile strength, modulus of rupture, and shear strength, with increments reaching up to 13.7%, 22.9%, 28.0%, and 32.7%, respectively [11]. They concluded that natural fibers were used in the present study, and concrete wastes collected from demolished buildings were manually broken into small pieces of different standard sizes to serve as coarse aggregates. Recycled concrete coarse aggregates of different replacement ratios were used to cast

Salahaldein Alsadey is Associate Professor with Department of Civil Engineering, Faculty of Engineering, Bani Waleed University, Libya (e-mail: salahalsadey@gmail.com).

Issa Amaish is with Civil Engineering Institute, Peter the Great Saint Petersburg Polytechnic University, Russia (corresponding author, e-mail: issaamaish@gmail.com).

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standard specimens reinforced by natural SFs may be good alternatives to relatively more expensive steel, polyester or glass fibers to examine the strength of the concrete produced.

II. Experimental Investigation

Materials

In this investigation, concrete specimens were prepared using ordinary Portland cement adhering to ASTM C150 [12] standards. The cement originated from a local plant in Zlitan, Libya. Coarse aggregates were derived from crushed stone aggregate (CA) and recycled coarse aggregate (RA). The production of RA involved crushing waste concrete using a jaw crusher and an impact crusher. To ensure the purity of RA, manual removal of impurities such as wood, bricks, and glass was performed. High-pressure water jet technology was employed to eliminate mud and debris from the RA.

Both CA and RA exhibited continuous grains within the 5 to 20 mm range, conforming to ASTM C33-03 [13] standards. Furthermore, both types' specimens underwent testing using the Aggregate Crushing Value (ACV) test in accordance with BS 812 Part 110:1990 to assess their mechanical properties. This examination is intended to ascertain the resistance of substantial aggregates, thereby providing a comparative assessment of their susceptibility to crushing under a gradual pressure load [14]. Additionally, the same samples were subjected to the Aggregate Impact Value (AIV) test in accordance with B.S. 812 Part 112 :1990. This test aims to evaluate the impact resistance of aggregate particles, offering a relative measure of their capacity to withstand impact forces [15]. Table I provides a comprehensive overview of the primary properties of these coarse aggregates. The findings reveal that RC exhibits higher ACV and AIV values, exceeding those of natural aggregate by approximately 11% and 16%, respectively.

Fig. 1 provides a detailed illustration of the size grading for both CA and RA. Additionally, natural sea sand, characterized by a fineness modulus of 2.66, was utilized as the fine aggregate. This meticulous selection of materials aimed to ensure the representativeness of the concrete specimens, aligning with industry standards and incorporating sustainable practices through the use of recycled materials.

Sisal Fiber

The SFs used in the present study, a picture of which is shown in Fig. 2, had been supplied by a local fiber company in Libya, and they are now commercially available in the domestic market as flake into length 500 mm. The properties of SF used in the present study are shown in Table II.

Specimen Details

The mix proportion was provided as per the provisions given by ACI method ACI 211.1-91, for target compressive strength 30 MPa by the proportion 1:2:3 (Cement: sand: aggregate) [16] and water-cement ratio of 0.45 was selected for this experiment. Workability slump test was done as per the procedures given in ASTM C143 [17]. Table III shows different combination of mix proportion set used in this research. 12 numbers of 150 x 150 x 150 mm size standard concrete cubes specimens had to be made for the mechanical strength. 3000 kN compression testing machine used capacity at a rate of 150 kN per minute conforming to BS 1881: Part 116, 1983 [18]. 8 numbers of 100 x 100 x 500 mm size reinforced concrete prism were casted and tested in the Universal testing machine 1000KN capacity as per the guidelines given by ASTM C1018-92 (1992) [19].

TABLE I
AGGREGATE ACV AND AIV RESULTS

Property	Natural Aggregate	RA
ACV	26.5%	29.5%
AIV	24.5%	28.5%

Fig. 1 Recycled Aggregate

TABLE II
CHEMICAL COMPOSITION OF SF

Chemical Composition	Percentage (%)
Cellulose	65
Hemicelluloses	12
Lignin	9.9
Waxes	2
Total	100%

Fig. 2 Sisal Fiber

TABLE III
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)	SF %	Water (L)
M1	350	700	1050	0	0	157.5
M2	350	700	787.5	262.5	1.5	157.5
M3	350	700	525	525	1.5	157.5
M4	350	700	262.5	787.5	1.5	157.5

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Fig. 3 Test Setup for Specimens

III. Results and Discussion

Workability

With the increase of RA percentage with 1.5% of SF in all concrete mixtures, the aggregates and cement are more likely to effectively bond together and hence, producing a very poor mixture of concrete which has a brittle-like texture instead of a clayey texture. Initially, without SF, the slump value was 185 mm. As the SF added to concrete mixture the slump values decreased to 95 mm for M1. Also, for not having enough of a specified quality gradation of the RAs, the values of slump have significantly decreased. In fact, at 1.5% of SF content for aspect ratios 50 and 75, slump values have plummeted to 90 mm in mixes M3 and M4. It contributed to the deterioration of the workability of concrete [20].

Compressive Strength

Table V presents the compressive strength values of both natural aggregate and RA concrete mixes with 1.5% reinforced SF content. The compressive strength value of RA concrete mixes is higher than natural aggregate concrete mixes. The increase in strength may be due to using higher strength recycled concrete with reinforced SF 1.5%. However, it can be seen that the compressive strength value of the M1 mix without SF and with natural aggregate at the age of 28 days, compared with that of the M2, M3 and M4 mix with SF increased the compressive strength 11.52%, 14.90% and 16.44% respectively as shown in Fig. 5. The compressive strength generally increased when SF was added to the mixes.

TABLE IV
SLUMP VALUES OF CONCRETE MIXES

Concrete Mix	Aggregate Replacement Ratio (%)	SF (%)	Slump (mm)
	--	--	--
M1	0	0	185
M2	25	1.5	95
M3	50	1.5	90
M4	75	1.5	90

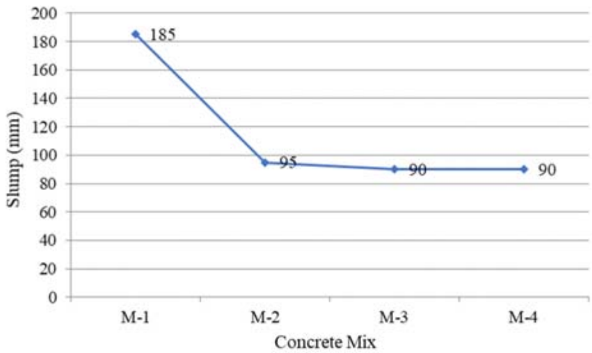

Fig. 4 Slump Results for Concrete Mixes

Compressive Strength

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TABLE V
COMPRESSIVE STRENGTH VALUES OF CONCRETE MIXES

Concrete Mix	Aggregate Replacement Ratio (%)	SF (%)	Flexural Strength (MPa)
	--	--	28 Days
M1	0	0	30.08
M2	25	1.5	34
M3	50	1.5	35.35
M4	75	1.5	36

In order to highlight the effect of RA and SF on the compressive strength of concrete mixtures, the compressive strength ratio of concrete mixes at 28 days was calculated, and the correspondent results were shown in Fig. 5. Nevertheless, it is crucial to highlight that the introduction of SF into Recycled

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Aggregate Concrete (RAC) formulations resulted in a positive impact on the enhancement of compressive strength, aligning with findings reported by Song et al. [21]. Song et al. observed an approximate 11.5% increase in compressive strength when incorporating 0.6 kg/m^3 of nylon fiber into concrete, in comparison to control concrete lacking nylon fiber. Within the concrete mixes containing RA and 1.5% SF, the highest compressive strength was achieved, indicating notable development in compressive strength. The observed trend strongly implies that the incorporation of SF contributes to a notable increase in compressive strength within concrete mixes [21].

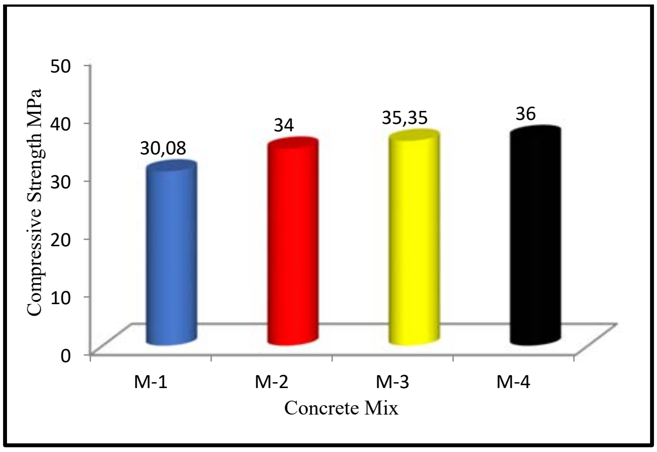

Fig. 5 Compressive strength variation with Aspect Ratio and volume percent of RA

Flexure Strength

The flexure strength values of the plain concrete mix and RAC reinforced with sisal fiber demonstrated a significant improvement. Mixes at 28 days are listed in Table VI. As expected, the values of the flexure strength of concrete were significantly when added SF content. The strength results showed that there was a great increase in the flexure strength values with the addition of SF in the concrete mixes. However, the maximum strength value obtained in the case of the M4 mix was 4.49 MPa for SF content. In the concrete mixes, the maximum improvement examined in the M4 mix with the same SF content, as compared with the unreinforced concrete mix without SF, was flexure strength of mixes increased. These results were in a good agreement with other studies [22], [23].

TABLE VI
AVERAGE FLEXURAL STRENGTH TEST RESULTS

Concrete Mix	Aggregate Replacement Ratio (%)	SF (%)	Flexural Strength (MPa)
	--	--	28 Days
M1	0	0	2.65
M2	25	1.5	3.71
M3	50	1.5	4.2
M4	75	1.5	4.49

The calculated results of the flexure strength (FS) of the concrete mixes were presented in Fig 6. For mixes RAC reinforced with SF, it seems that the addition of SF had much influence on the flexure strength. Within the scope of the present study, it was confirmed that a higher addition of RAC with added SF led to an increase in the flexure strength. Furthermore, this was obvious when SF was applied in the RAC mixes can produced good quality concrete.

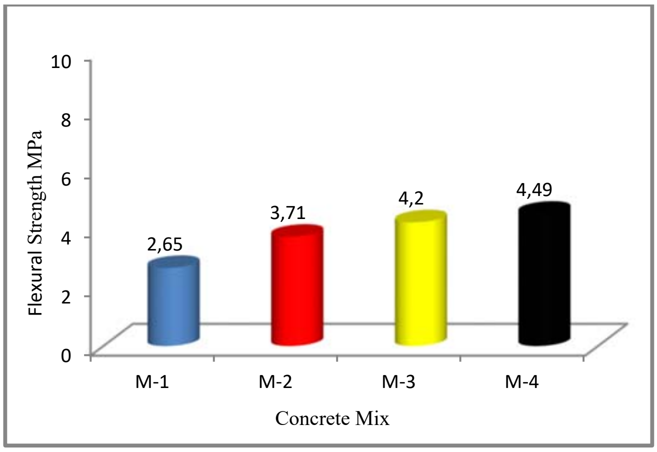

Fig. 6 Flexural strength variation with Aspect Ratio and volume percent of RA

IV. CONCLUSIONS

Experimental works were carried out with the additions of 1.5% of SF in the RAC mixes in order to highlight the effect of SF on the mechanical properties of RAC mixes. The RAC was prepared with a 25%, 50% and 75% replacement of RA. The principal findings derived from the present investigation are as follows:

1- It is found that the use of RA and SF in the concrete decreases the workability of the fresh concrete to some extent. Though the workability decreases, the strength parameters have shown very promising results.
2- Due to the addition of SF led to an increase in compressive strength of RAC mixes. The outcomes of the compressive strength ratio analysis indicate a positive influence of SF on the augmentation of compressive strength.
3- Similar to the observations in compressive strength, a comparable pattern was evident in the flexural strength concerning the SF content. Notably, the experimental results demonstrated a substantial elevation in flexural strength.

Within the scope of this study, it is concluded that the inclusion of SF contributed to the improvement of mechanical properties, particularly in concrete incorporating RA. This enhancement can be primarily ascribed to the bridge effect of SF, facilitating a more pronounced development of strength in the concrete.

V.RECOMMENDATION FOR FURTHER STUDIES

Recommendations for further studies are as mentioned below:

- Though the problem of the reduction in workability of the fresh fiber reinforced concrete and RA is not influencing the strength pattern if the water absorption of fiber is considered while designing the concrete, by adding chemical admixture such as super plasticizer, silica fume or blast furnace slag etc., this problem may be reduced.

- Natural fibers are generally subjected to aging process after certain duration of time, therefore the effect of aging of sisal fiber is to be studied and the strength decrement of fiber reinforced concrete after long term age are to be evaluated.
- The combination of fibers may tend to provide more efficient mechanical properties of structure. Further investigation can be carried out by combination of different types of fibers into the concrete mix.

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