STRENGTH CHARACTERISTICS OF CONCRETE MADE WITH RECYCLED CONCRETE AGGREGATE (RCA), MICRO-SILICA AND POLYPROPYLENE FIBRE

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Abstract: Recycled concrete aggregate has been widely researched to be capable of replacing natural coarse aggregate in concrete, however, with some inadequacies in its concrete's ability to attain the same feat in mechanical properties as normal concrete. This research work attempts to improve the strength characteristics of concrete containing recycled coarse aggregate with the addition of admixtures (Micro-Silica and Superplasticizer) and Polypropylene fibre. Results showed that admixtures significantly improved the workability and mechanical properties of CRCA at all RCA replacement levels. Addition of PPF had significant effect on the flexural and splitting tensile strengths of CRCA, but not much impact on the compressive strength.

Keywords: micro-silica, polypropylene fibre, recycled aggregate concrete

1. INTRODUCTION

The wholesale extraction of natural coarse aggregate has been a thing of concern owing to sustainability and environmental factors. The process of quarrying natural coarse aggregate has been reported to cause environmental degradation and a lot of energy consumption[1, 2]. The idea of concrete recycling has become more attractive as it eliminates some problems associated with natural aggregates sourcing and waste concrete disposal. So much effort is put in the research of the use of Recycled Coarse Aggregate (RCA) in concrete, some of which have shown promising results [2-4]. Previous research works have reported on the workability of Concrete containing Recycled Coarse Aggregate (CRCA), that the use of RCA in concrete reduces workability [4, 5]. Yang et al. [6] investigated the utilization of crushed clay bricks and recycled concrete aggregate as a replacement for granite in concrete. Their reports showed that workability reduced with increasing RCA content and crushed clay brick contents in the concrete mix.

Salau et al. [2] investigated the effect of water demand on Concrete containing Recycled Coarse Aggregate (CRCA). They recorded the compressive strength of CRCA to be 20% higher than that of normal concrete at the same w/c ratio and opined that RCA does not necessarily have an adverse effect on the strength characteristics of concrete, but the water-cement ratio employed in the concrete mix is highly significant. They also reported the splitting tensile strength of CRCA as 4.0 Mpa at 0.45 w/c ratio, which compares well with that of normal concrete which was reported as 4.44 Mpa at the same w/c of 0.45.

Yongjun et al. [7] in their work on characterization of concrete containing Lithium Slag and RCA revealed that adequate compressive strength and elastic modulus is attainable with 30% RCA content and 20% Lithium Slag

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content. They found that RCA and lithium slag can be used at percentages of 70% and 20%, to achieve the highest result for flexural and splitting tensile strength. An improvement of 9.90% and 48.22%, respectively, was reported, when compared with normal concrete.

Sahoo et al. [8] did an experimental investigation to evaluate how to improve the water absorption, compressive strength and shrinkage of recycled coarse aggregate concrete by addition of bacteria. They reported a 20% increase in compressive strength of CRCA with the cell concentration of B. subtilis as10^6 cells/ml. They also found that incorporation of bacteria reduces the water absorption and drying shrinkage of RCA. Chen et al. [9] studied the hardened properties of concrete containing recycled coarse aggregate. They found that the compressive and flexural strengths of the CRCA were about the same with those of normal concrete.

The strength and deformation characteristics of Concrete containing Recycled Coarse Aggregates (CRCA) over a long term were investigated by Salau et al [4]. Their results indicated that 25% replacement of natural coarse aggregate with RCA recorded about the same values in compressive strength as normal concrete. They also showed that replacement levels beyond 25% caused significant reduction in compressive strength. At 100% replacement level, 27% reduction compared to normal concrete was observed. The shrinkage deformation characteristic of CRCA at 25% RCA content was reported. Basic shrinkage strain of normal concrete was found to be about the same with that of CRCA. The drying and total shrinkage values of CRCA were respectively 1.26 and 2.56 times greater than that of normal concrete.

As mentioned above, many previous researches on the use of RCA as aggregate in concrete have reported CRCA having lower strength compared to normal concrete. They have attributed this to the weak bond within the concrete matrix due to adhered mortar on the RCA used and higher porosity within the mico-structure. To address this, Micro–Silica (MS) was introduced in the concrete mix. Micro–Silica has been reported to significantly improve the mechanical and durability properties of concrete [10]. Shaikh and Kerai [11] in their investigation showed how varying percentage content of micro-silica, fly ash and recycled coarse aggregate can affect the durability and hardened properties of concrete. It was found that incorporating micro-silica at 10% content improved the strength gain at early age. The durability properties of concrete were significantly improved; sorptivity, chloride ion permeability and drying shrinkage properties were found to reduce with up to 10% MS content.

Fibres have been reported to be very effective at improving materials properties such as; ductility, impact resistance, toughness and resistance to fatigue [12, 13]. With its small weight, high tensile strength, and good toughness, PPF is a superb material for durable concrete [14]. When PPFs are added to concrete, it helps to reduce the pores within the concrete and also improves its resistance to crack [15]. As a result, it minimizes the transmission of water and hazardous agents through the concrete, increasing its durability [16].

Lower water absorption, improved impermeability, sulfate, chloride, carbonation and fire resistance are all advantages of PPF-reinforced concrete. Because PPF has a favorable effect on avoiding deformation, it can help reduce drying shrinkage. However, because PPF has a lower elastic modulus than ordinary concrete, it did not diminish the creep of the concrete [12]. Combining PPF with other fiber types, particularly steel fiber, can improve the durability of PPF-reinforced concrete [17].

PPF improves the tensile strength of concrete, enabling it to adequately prevent and control crack initiation [18]. Macro fibres have been found to give internal support to concrete by helping to provide restrain against the propagation of plastic shrinkage [9]. As indicated by Saeed et al. [19] the use of polypropylene (PP) fiber at low quantities, for example, at 0.18% to 0.40% tends to improve compressive strength however when the volume is high similar to 0.55 % to 0.60%, compressive strength may reduce by as much as 3 to 5%.

Ajibola et al. [20] investigated the replacement of natural aggregate with RCA and addition of micro-silica and synthetic macro fibre to advance properties of CRCA. Their results showed a decling in the strength properties of CRCA as the RCA content increased. They also discovered that adding synthetic macro fiber to concrete had no significant effect on the compressive strength of the concrete. In comparison to those without synthetic macro fiber, the concretes containing synthetic macro fibre had higher elastic modulus, flexural and splitting tensile strength. Their findings suggest that the optimum fraction of recycled coarse aggregate in concrete could be increased from 20% to 50%. This article investigates the possibility of improving mechanical properties of CRCA with the use of micro-silica and poly propylene fiber.

2. EXPERIMENTAL SETUP

2.1. Concrete materials

2.1.1. Cement, sand and natural coarse aggregate

The cement for this research work was Ordinary Portland Cement of grade 42.5 N. The specific gravity was 3.15, this meets BS 12 [21]. The fine aggregate used was river sand, it had particles ranging between 2 mm and 150 µm. Granite was used as the coarse aggregate with particles ranging between 20 mm and 2 mm.

2.1.2. Recycled coarse aggregate

Concrete waste was obtained from the demolition at a construction site, the waste was hammered into smaller particles. All forms of impurities and unwanted particles in the rubble were removed. The crushed pieces were sieved, larger particles not passing through 20 mm sieve were discarded, and smaller fractions less than the 4.75 mm size were also discarded. Different sizes of RCA were mixed in a suitable proportion so that the combined RCA were uniformly graded just as the natural coarse aggregate.

2.1.3. Micro-silica

The micro-silica used was sourced from dealer, Purechem Company. Its specific gravity was 2.2, bulk density was 220 kg/m^3 and specific surface was 18 m^2/g.

2.1.4. Polypropylene fibre

The synthetic fibre employed was a polypropylene material cut into small lengths of 6 0mm each. The specific gravity was found to be 1.01 and an average tensile strength of 620 N/mm^2, and conforms to A.S.T.M. C-1116 [22]. Figure 1 shows the PPF as prepared for use in concrete.

Fig. 1. 54mm synthetic macro fibre (Polypropylene).

2.1.5. Superplasticizer

Complast SP 430 was used as chemical admixture for the concrete. It has a specific gravity of 1.06 g/cm³, ph value of 6.5, chloride content and Na_2O equivalent that is less than 0.10 % and 1.00 % respectively.

2.2. Method

The concrete batches were achieved by varying the RCA content from 0 to 100 % in steps of 25 %. The Polypropylene fiber of 60 mm length was added at 0 %, 0.25 % and 0.5% of the concrete volume. Cement-sand-aggregate mix proportion was 1:2:4 and the water-cement ratio was 0.5 for all mixtures. Superplasticizer and micro-silica were added to all the concrete batches at a constant volume of 2 % and 5 % respectively, by weight of cementitious materials. A total of sixty concrete cubes (150x150x150mm), were tested for their compressive strength, sixty beams (500 x 100 x 100 mm) for flexural strength test and sixty concrete cylinders **(**Φ200 x 450 mm**)** were used for the splitting tensile strength test. The tests were carried out as specified by BS EN 12390 [23].

3. RESULTS AND DISCUSSION

3.1. Workability of recycled coarse aggregate concrete contain in polypropylene fibre and admixtures

The slump value results of recycled coarse aggregate concrete containing polypropylene fibre and micro-silica are presented in Table 1. It was found that the reference concrete with admixtures had higher workability than the reference concrete without admixtures. Also at all replacement levels, CRCA with PPF and admixtures recorded higher workability compared to reference concrete without admixture, but lower workability compared to reference concrete with admixture. This implies that the addition of PPF reduced the concrete workability as seen in Figure 2, by an average of 10%. The diminishing trend in slump values can be related to the development of system structure in concrete because the polypropylene fibres increased the surface area of the concrete, making the available paste less adequate and lessening the workability. Also, the non-homogenous dispersion of fiber may additionally prompt a decline in the workability of concrete. In the four categories of concrete mixtures highlighted, workability reduced as RCA content increased in the concrete mix. This is in line with results of previous research [4]. However, recycled coarse aggregate concrete at all percentage replacement of PPF achieved good workability as they all recorded true slump.

Table 1. Workability of CRCA containing polypropylene fibre and micro-silica.

RCA Content (%)	Slump Value (mm)			
	0 % PPF (without admixture)	0 % PPF (with admixture)	0.25 % PPF (with admixture)	0.5 % PPF (with admixture)
0	72	102	98	86
25	65	88	82	77
50	45	76	68	64
75	32	64	63	56
100	24	56	59	45

N.B: Admixture includes micro-silica (5 %) and superplasticizer (2 %).

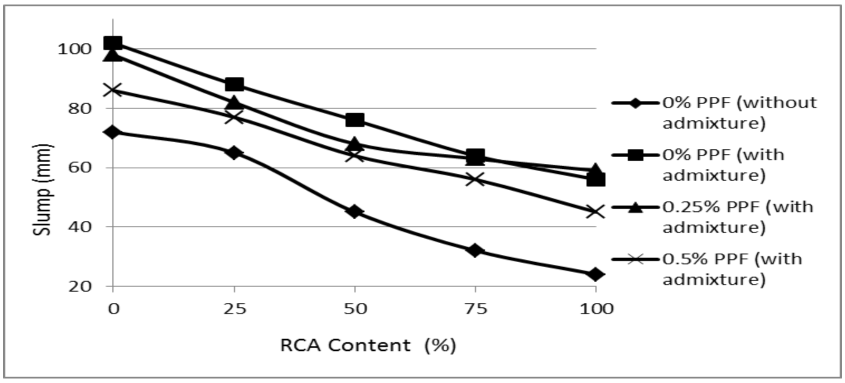

Fig. 2. Slump values of CRCA with PPF and admixtures.

3.2. Compressive strength of RCA concrete containing PPF and admixtures

Table 2 show the results of testing recycled coarse aggregate concrete containing polypropylene fibre and micro-silica in compression. The maximum compressive strength was recorded at 0 % RCA content and 0.5 % PPF content with admixture, as 29.41 N/mm^2, an increase of 29 % compared to 0 % PPF without admixture and only 3.7 % compared to 0% PPF with admixture. As shown in Figure 3, compressive strength reduced as RCA content increased in all the four categories of concrete mixtures highlighted. Compressive strength was improved with addition of PPF but not significantly, only an average increase of 1.4% and 3.7 % was observed for 0.25 % and 0.5 % PPF with admixture, respectively. This is similar with the report of Saeed et al (2006). The compressive strength of CRCA at all RCA percentage replacement levels were significantly improved by the nano-silica added, the increase was as high as 24 % at 100 % RCA content and 25 % at 0 % RCA. The nano-silica acted as a filler for the concrete, filling voids and eliminating pores, helping to achieve a more uniform concrete matrix thereby reducing weak zones and increasing the overall strength of the concrete.

Table 2. Compressive strength results of RCA concrete containing PPF and admixtures.

RCA Content (%)	Compressive Strength (N/mm^2)			
	0 % PPF (without admixture)	0 % PPF (with admixture)	0.25 % PPF (with admixture)	0.5 % PPF (with admixture)
0	22.78	28.53	28.40	29.41
25	21.95	26.95	27.14	27.67
50	19.21	23.62	23.77	24.84
75	18.32	21.38	22.30	23.02
100	16.59	20.61	20.98	22.06

N.B: Admixture includes micro-silica (5 %) and superplasticizer (2 %).

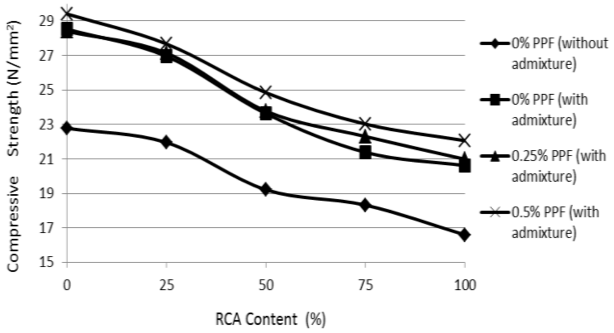

Fig. 3. Compressive strength of CRAC with PPF and admixtures.

3.3. Tensile strength of RCA concrete containing PPF and admixtures

Table 3 present the splitting tensile strength results of recycled coarse aggregate concrete containing polypropylene fibre and micro-silica. The reference concrete containing 0.5 % PPF recorded the maximum tensile strength as 3.14 N/mm^2. At 100 % RCA content with no admixture and PPF, 1.85 N/mm^2 was recorded, this was observed to be the lowest value in the mixes. Addition of admixtures (without PPF) improved tensile strength by an average of 8.34 %. It was also found that addition of PPF has a significant effect in improving tensile strength of CRCA, as an average increase of 3.36 % and 9.0 % were obtained at 0.25 % and 0.5 % PPF content respectively. This means that as the PPF fibre content increased, the tensile strength was improved as seen in Figure 4; this is in line with previous reports that PPF is able to improve concrete ductility [18]. However, similar to the compressive strength result, splitting tensile strength reduced with increase in RCA percentage replacement in the concrete mix, for the four categories of concrete mixture investigated.

Table 3. Splitting tensile strength result of CRCA with PPF and admixtures.

RCA Content (%)	Tensile Strength (N/mm^2)			
	0 % PPF (without admixture)	0 % PPF (with admixture)	0.25 % PPF (with admixture)	0.5 % PPF (with admixture)
0	2.61	2.84	2.93	3.14
25	2.53	2.65	2.80	3.04
50	2.29	2.47	2.51	2.63
75	2.16	2.22	2.32	2.38
100	1.85	2.18	2.22	2.31

N.B: Admixture includes micro-silica (5 %) and superplasticizer (2 %).

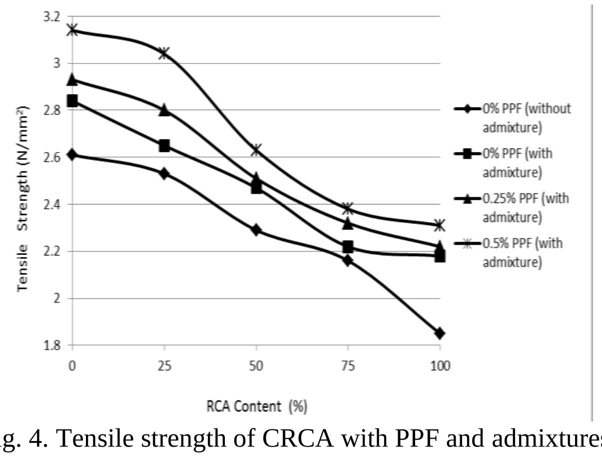

Fig. 4. Tensile strength of CRCA with PPF and admixtures.

3.4. Flexural strength of RCA concrete containing PPF and admixtures

The flexural strength results of RCA Concrete containing PPF and Micro-Silica are given in Table 4 and Figure 5 below. Similar to the splitting tensile strength result, maximum flexural strength was found at 0.5 % PPF (with admixtures) and 0 % RCA content as 7.64 N/mm^2, while the minimum flexural strength was recorded as 2.95 N/mm^2 at 0 % PPF (without admixtures) and 100 % RCA content. It was also found that addition of PPF has a significant effect in improving flexural strength of CRCA, as an average increase of 9.12 % and 28.06 % were obtained at 0.25 % and 0.5 % PPF content respectively. This means that as the PPF fibre content increased, the flexural strength was improved. Fibre reinforcement helped to improve the ductility of concrete and decrease crack depth. This is due to fibers' extraordinary capacity to distribute stress across a fractured portion. It was observed that addition of admixtures (without PPF) improved flexural strength by an average of 37.58 %. Lastly, flexural strength reduced as the RCA percentage replacement increased in the concrete mix, for the four categories of concrete mixture investigated. This was similarly observed in splitting tensile strength and compressive strength results.

Table 4. Results of the flexural strength of CRCA with PPF and admixtures.

RCA Content (%)	Flexural Strength (N/mm^2)			
	0% PPF (without admixtures)	0 % PPF (with admixtures)	0.25 % PPF (with admixtures)	0.5 % PPF (with admixtures)
0	4.36	6.09	6.55	7.64
25	3.81	5.84	6.36	7.41
50	3.40	5.61	6.17	7.28
75	2.95	5.49	5.98	7.13
100	2.35	5.32	5.86	6.82

N.B: Admixture includes micro-silica (5 %) and superplasticizer (2 %).

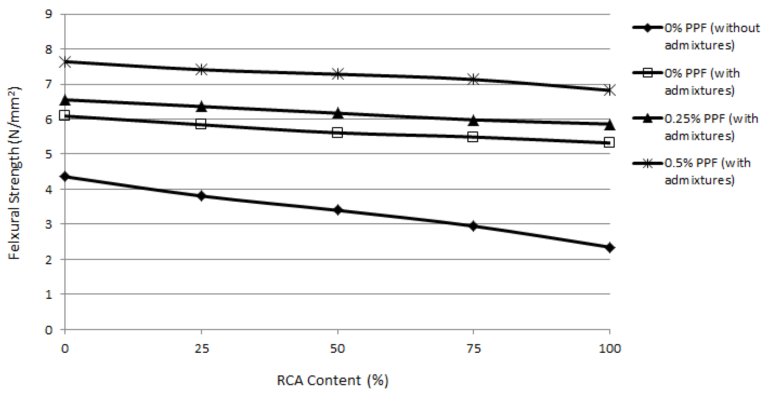

Fig. 5. Flexural strength of CRCA with PPF and admixtures.

4. CONCLUSIONS

Addition of admixtures significantly increased workability of CRCA while the addition of PPF reduced CRCA workability, however, only by an average of 10 %. In the four categories of concrete mixtures (0 % PPF without admixtures, 0 % PPF with admixtures, 0.25 % PPF with admixtures and 0.5 % PPF with admixtures) highlighted, workability reduced as RCA content increased in the concrete mix.

Compressive strength was improved with addition of PPF but not significantly, only an average increase of 1.4 % and 3.7 % was observed for 0.25 % and 0.5 % PPF with admixture, respectively. The addition of admixture significantly increased compressive strength of CRCA at all RCA percentage replacement levels, the increase was as high as 24 % at 100 % RCA content.

It was observed that addition of admixtures (without PPF) improved tensile strength by an average of 8.34 %. It was also found that addition of PPF has a significant effect in improving tensile strength of CRCA, as an average increase of 3.36 % and 9.0 % were obtained at 0.25 % and 0.5 % PPF content respectively.

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Compressive, splitting tensile and flexural strength reduced as RCA content increased in all the four categories (0 % PPF without admixtures, 0 % PPF with admixtures, 0.25 % PPF with admixtures and 0.5 % PPF with admixtures) of concrete mixtures highlighted.

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