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Effect of Recycled Coarse Aggregate on the Compressive Strength and Modulus of Rupture of Concrete

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

Original Research Article

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ABSTRACT

The paper investigated the compressive strength and rupture modulus of recycled aggregate concrete when recycled aggregates from the regulated industry such as laboratories is used as partial substitute for natural coarse aggregates. The work determined and compared the compressive strength of recycled aggregate concrete with that of natural aggregate concrete. It applied the laboratory investigated technique. A standard mix ratio of 1:2:4:0.5 representing; cement, fine aggregate, coarse aggregate and water/cement ratio was used to produce the test cubes and beams, with subsequent 0%, 30%, 50%, 80% and 100% substitution of natural coarse aggregates with recycled coarse aggregates. The results showed that as the percentage content of recycled coarse aggregate in the mix increased, the compressive strength decreased. The natural coarse aggregate concrete gave a compressive strength of 43.6 N/mm^2 and the recycled coarse aggregate concrete, 29.5 N/mm^2, a decrease of 40%. At early stages of substitution, there was no significant change in the modulus of rupture but at higher percentages of substitution, it became significant. The natural coarse aggregate concrete gave a modulus of rupture of 5.67 N/mm^2 while the recycled coarse aggregate gave 3.84 N/mm^2. Recycled concrete has been shown to be a viable option to decrease the demand on high quality natural resources and to limit the amount of waste that is disposed in landfills.

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1. INTRODUCTION

The use of waste materials for new products is a global trend undergoing rapid development and the recycling of materials allows for a more efficient life cycle contributing to environmental protection Claudio and Angel [1]. This also plays an important role to preserve the natural resources Young and Teo [2]. For instance, agricultural waste such as palm kernel shell has been used as material in the production of light weight concrete Alengaram et al. [3]. Recycled aggregates (RA) are aggregates obtained from rubles of demolished or collapsed concrete structures. Concrete demolition waste has been proved to be an excellent source aggregates for new concrete production. Recycling materials contribute to material sustainability, reduce environmental impact of demolished materials, and can have positive financial implication of up to 15% Orie [4]. The cost of a project could decrease if concrete does not have to be hauled and dumped, and instead be used to replace a portion of natural aggregates (NA) in the new concrete structure. The mechanical properties of recycled aggregate concrete RAC have been shown to predominantly depend on the quality of the cement matrix of the new concrete Katz [5]. Ng et al. [6] stated that the poor performance of RA resulted from its higher porosity due to cement mortar remains, attaching to the RA surface. An increased recycled aggregate content in concrete has been shown to produce a decreased workability Nelson [7]. As the amount of RCA increases, density, workability, Schmidt hardness, ultra sound velocity and compressive strength decreases Topcu [8]. The compressive strength of concrete is reduced with an increase in the content of recycled concrete aggregate Domingo [9]. It has been reported that RAC show lower compressive strength than normal aggregate concrete (NAC) but they however have the same durability properties (Claudio and Angel [1]). The volume of void and water absorption of RAC is 2.61 and 1.82% higher than those of normal concrete due to the high absorption capacity of old mortar adhered to RA Chakradhara et al. [10]. The compressive strength and the prismatic compressive strength of RAC are higher than those of natural concrete but reduces with increase in recycled aggregate content and the elastic modulus is lower than that of natural concrete Yahan and Quanchng [11].

Poon et al. [12] examined the behaviour of recycled high performance concrete, recycled normal concrete and natural aggregates. They reported that the compressive strength of the concrete prepared with natural aggregates was higher than that of the recycled aggregate concrete. Agere (2010) investigated the self compacting ability of coarse RCA using four types of concrete mixes with different cement content at two different w/c ratio (0.4 and 0.5) and percentage substitution of coarse aggregate by the recycled aggregate of; 0,25%, 50% and 100%. The results indicated that the properties of these concretes have only a slight difference, and that recycled concrete can successfully be used for making a self-compacting concrete. Rahal [13] observed 20%, 30% and 45% decrease in compressive strength of RAC made using 30%, 50% and 100% of coarse aggregate substitute respectively. Tam et al. [14,6] reported that because of the large amount on mini-cracks in the recycled aggregate, the concrete samples with recycled aggregate substitution had lower values of physiochemical reactions than those without recycled aggregate replacement. They posited that the mini-cracks absorbed some of the required water and thereby reduced the amount of mixing water, thus hindering hydration of the concrete and consequently its compressive strength. An investigation by Oti et al. [15] of the engineering properties and microstructure of concrete incorporating slate waste aggregates as substitute for limestone aggregates showed that, concrete, produced with limestone aggregate tended to fail predominantly through the interfacial zone between the aggregate surface and the cement paste and mortar without any aggregate fragmentation. While, the concrete made with slate waste aggregate showed signs of failure emanating from both the interfacial zone as well as from the cracking and subsequent fragmentation of the aggregates.

The present work examined the response of the compressive strength of concrete and the modulus of rupture of rectangular concrete beams to the use of recycled coarse aggregate obtained from the regulated industries such as laboratories of schools, research Institutes and Companies. It provided information on the density properties of recycled aggregate modified concrete.

2. MATERIALS AND METHODS

Potable water was used in conformity to BS3148:1980. The ordinary Portland cement randomly sourced from the open market. The fine aggregate was sourced from Okhuahe River in Benin City, Nigeria. Crushed rock of maximum size 20 mm obtained from Ifon, Nigeria was used as coarse aggregate. Recycled coarse aggregates obtained from crushed concrete cubes from the University of Benin structural engineering laboratory were used to simulate aggregates from demolished sites. The materials were sieved with a BS 410-1962 sieve to retain a maximum coarse aggregate size of 20mm.

The test cubes were prepared by partially substituting the coarse aggregate in a standard concrete mix of 1:2:4:0.5 representing; cement, fine aggregate, coarse aggregate and water/cement ratio, by 0%, 30%, 50%, 80% and 100% recycled coarse aggregate consecutively. Mixing was achieved with a mixing machine. The BS cube moulds measured 150mm x 150mm x 150mm and the flexural test moulds measured 100 x 100 x 500mm. the moulds were filled with each mix after they had been oiled. Excess concrete at the top of the moulds were scooped away using a hand trowel and the top smoothened. The specimens were then vibrated by means of a vibrating table. The specimens were kept for 24 hours in moderate temperature of 20ºC before demoulding. The samples were stored in a curing tank until they were due for testing. The one point or central point load testing method was adopted. The specimens and experimental set-up are shown in Figs. 1a and b. The compressive strength of the cubes and the modulus of rupture of the beam samples have been obtained by,

$$\text{Compressive strength} = P/A \text{------------------------} (1)$$

Where P = Failure Load and A = Area (mm^2).

$$F_b = \frac{3aP}{Bd^2} \text{--------------------------------} (2)$$

Where; F_b = modulus of rupture (kN/mm^2), P = load applied on specimens (kN), b = width of bean (mm) (effective width = 400mm), d = depth of beam at failure point (mm) and a = distance between the crack and nearest support (mm).

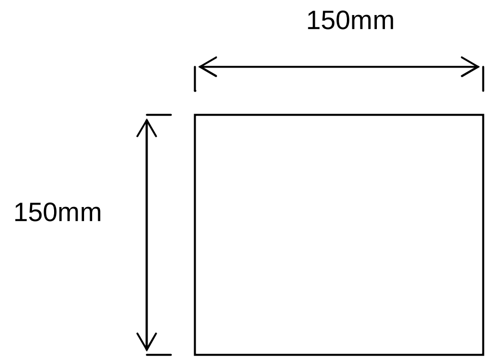

Fig. 1a. Cross-section of cube samples

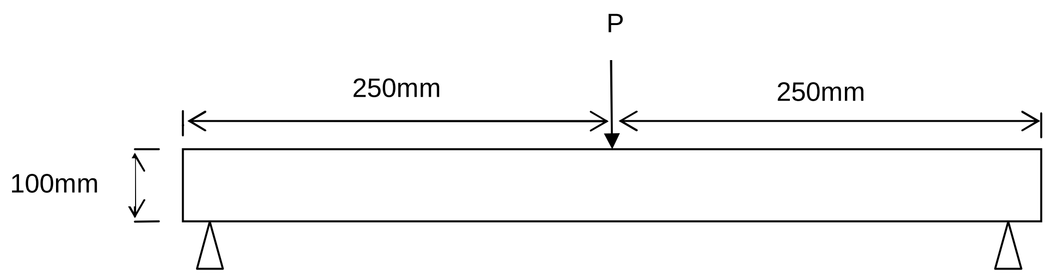

Fig. 1b. Beam experimental set-up

3. RESULTS AND DISCUSSION

The results of the laboratory experiments are presented in tables and figures. Table 1, presents the density and compressive strength of the test cubes. The results showed that the variation in the percentage content of recycled coarse aggregate in the mix caused no significant change in the density of the concrete. At 0% substitution, that is the mix contained only natural coarse aggregate, the density was found to be 2.45 kg/m^3 and at 100% substitution, the average density was 2.41 kg/m^3. The variation of the density of the concrete with respect to the percentage content of recycled coarse aggregate is presented in Fig. 2.

During the flexural tests, it was observed that the beams failed by crack initiation at the bottom fibre. These cracks propagated towards the top fibre until failure occurred. The relationship between the compressive strength and the percentage RCA content is shown in Fig. 3. The results compares favourably with the literature Domingo, [9] and Chakradhara et al. [10] which explained that the leftover surrounding mortar on the surface of the RCA constitute an encuberance to the new mortar paste and hence formation of a loose bond in the matrix occurs. Fig. 3 revealed that up to 80% by weight substitution of NCA with RCA can be used to produce 32N/mm^2 quality concrete with a reduction of only 19.75% in compressive strength. The apparent approximate straight line nature of the graph showed that there was a direct relationship between the recycled aggregate content and the compressive strength of concrete.

The results of the flexural properties of recycled coarse aggregates concrete in comparison with natural coarse aggregate concrete is shown in Table 2 and their relationship is described in Fig. 4. The figure showed that there was no significant deference in the rupture modulus between 0% and 30%, when it changed from 5.67N/mm^2 to 5.47N/mm^2. The modulus of rupture of the 100% recycled aggregate concrete was 3.84N/mm^2 which showed a reduction of about 32.28% when compared with the control samples. This is in line with the literature Yahan and Quanchng [11] which stated that the elastic modulus RAC is lower than that of natural aggregate concrete. However, the difference between the literature and the present work is appreciated in the RA being simulated by concrete waste generated from labouratories which are regulated environments rather than the uncontrolled environment of the industry.

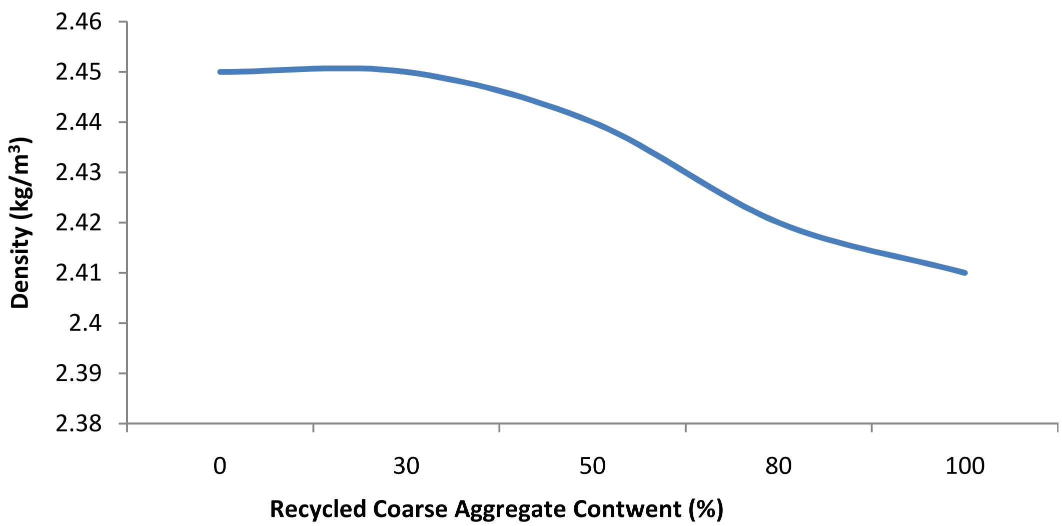

Fig. 2. Variation of density with recycled coarse aggregate content

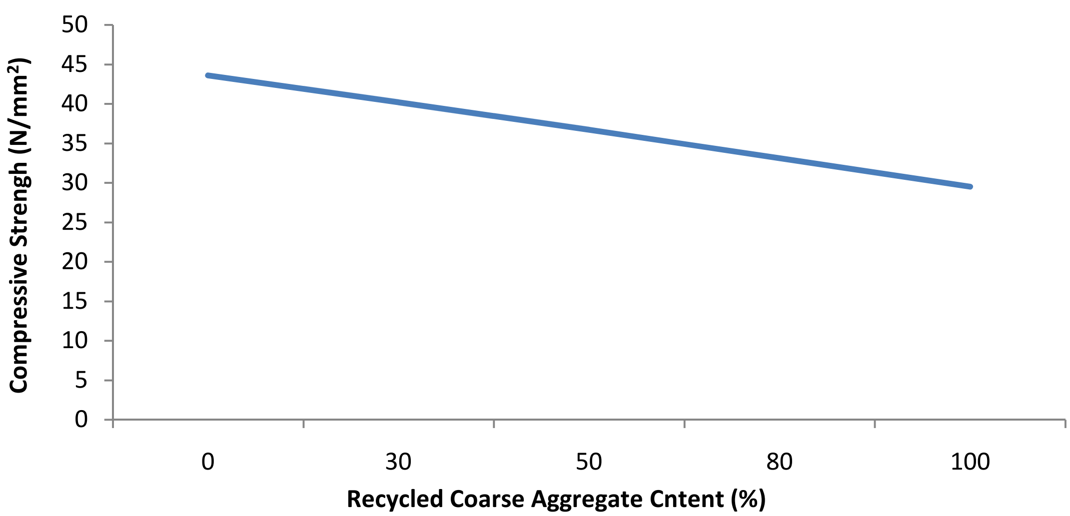

Fig. 3. Variation of compressive strength with recycled coarse aggregate content

Table 1. Compressive strength of recycled aggregate concrete

Repl. of NA with RA (%)	Weights of cube (kg)	Density (kg/m^3)	Av. Density (kg/m^3)	Crushing Load (kN)	Area (mm^2)	Comp. strength (N/mm^2)	Av. Comp. strength (N/mm^2)
0	8638	2.44	2.45	949.5	22500	42.2	43.6
	8673	2.45		1007.9		44.9	
	8607	2.46		983.3		43.7	
30	8624	2.46	2.45	895.5	22500	39.8	40.2
	8633	2.46		906.8		40.3	
	8602	2.44		911.3		40.5	
50	8638	2.44		893.7		39.8	
	8637	2.44	2.44	751.6	22500	33.5	36.7
	8655	2.45		744.9		36.8	
80	8611	2.42	2.42	776.3	22500	34.5	33.1
	8593	2.41		715.5		31.8	
	8580	2.43		742.5		33.0	
100	8531	2.41		696.2		31.0	
	8497	2.40	2.41	630.0	22500	28.0	29.5
	8512	2.43		663.8		29.5	

Table 2. Flexural strength of recycled aggregate concrete

Replacement of NA with RA (%)	Beam Area (mm^2)	a (mm)	Failure load (kN)	Modulus of rupture, F_b (kN/mm^2)	Average modulus of rupture (N/mm^2)
0	50000	182	10.05	5.49	
		191	10.19	5.84	5.67
		189	10.00	5.67	
30	50000	189	9.32	5.23	
		192	9.43	5.43	5.47
		196	9.47	5.57	
50	50000	194	8.89	5.17	
		191	7.60	4.36	4.77
		189	8.41	4.77	
80	50000	193	6.77	3.92	
		188	7.32	4.13	4.12
		194	7.41	4.31	
100	50000	186	7.22	4.03	
		189	6.42	3.64	3.84
		195	6.56	3.84	

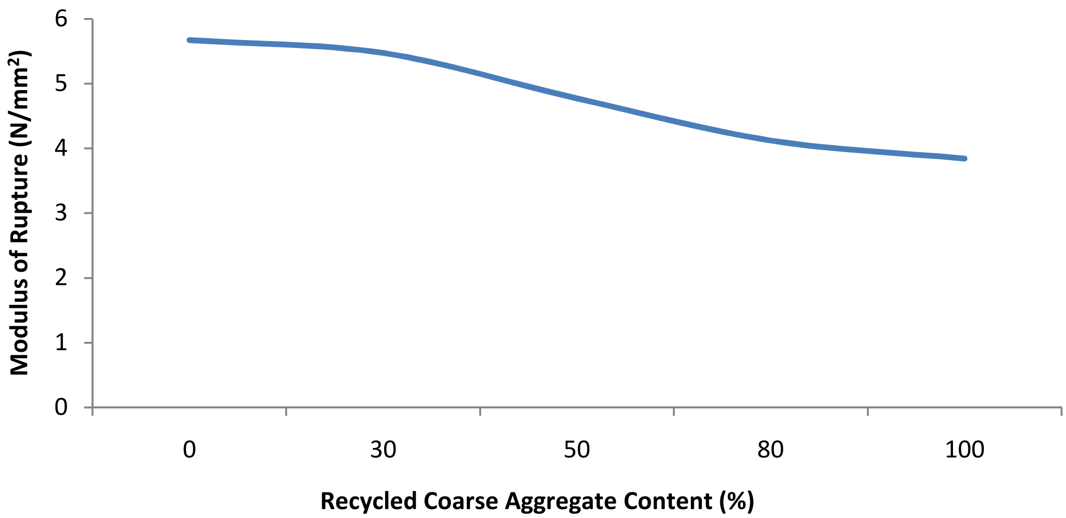

Fig. 4. Variation of modulus of rupture with recycled coarse aggregate content

Table 2 showed that there was a decrease in compressive strength when the natural coarse aggregate was substituted with recycled coarse aggregate. At 0% substitution (control samples) the compressive strength was 43.6 N/mm^2 and at 30%, 50%, 80% and 100%, the compressive strengths were; 40.2 N/mm^2, 30.7 N/mm^2, 33.1 N/mm^2 and 29.5 N/mm^2 respectively.

4. CONCLUSION

Recycled aggregate content has been shown to affect the mechanical properties of concrete. An increase in the content of recycled aggregate in concrete led to a decrease in the compressive strength from 43.6N/mm^2 at 0% substitution to 29.5N/mm^2 at 100%, it has been shown to be a viable option to decrease the demand on high quality natural resources and to limit the amount of waste that is disposed in landfills since the use of up to 30% of recycled coarse aggregate as substitute for natural coarse aggregate caused no significant change in the modulus of rupture of the concrete. At 0% substitutive, the rupture modulus was 5.67N/mm^2 and at 30% it was 5.47N/mm2.

The work suggests a useful application for the waste currently generated by destructive testing of experimental test cubes which are daily produced in Research Institutes. Recycled aggregate concrete will be more economical than its natural aggregate counterparts since the coarse aggregate content or part of it, is generated from the reuse of waste. RAC will be useful in parts of structures where high strength is not a prerequisite such as in mass concreting of pavements and foundation beds.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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