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Research Paper,

Mechanical Properties of Recycled Aggregate Concrete related to Source Concrete

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Abstract: *The paper investigated the effect of the use of waste concrete as aggregate on the mechanical properties of concrete with a view to monitoring and evaluation of the construction material. The source concrete used as coarse aggregate was obtained from an Engineering laboratory. Okhuahe river sand was used as fine aggregate, Ordinary Portland cement and clean underground water. Steel moulds measuring 100mm x 100mm x 100mm were used to cast samples from a prescribed 1:2:4 mix. Water to cement (w/c) was kept constant at 0.65 with five different strength groups obtained from the strength of the recycled aggregates. The moulds were demoulded after 24hours and the samples were cured in a curing tank at room temperature and tested for 7, 14 and 28 days compressive strength. The source concrete studied, were grouped according to compressive strength into 60 N/mm^2, 50 N/mm^2, 40 N/mm^2, 30 N/mm^2 and 15kN. The group of 60N/mm^2 gave a compressive strength of 34.33N/mm^2 representing 75% of the strength of the source concrete. The group of 40N/mm^2 – 50N/mm^2 gave a compressive strength of 26.17N/mm^2 representing 53% of the source concrete and the group of 15N/mm^2 – 30N/mm^2 gave a strength of 21.83N/mm^2 which is 45.5% the strength of its source concrete. The results showed that the higher compressive strength source concrete produced higher compressive strength recycled concrete and slump which was in agreement with literature. The paper concludes that high strength source concrete can be recycled for construction purposes.*

Keywords: Aggregate, Waste, Recycle, Compressive Strength and Materials.

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1. Introduction

Modern research has shown the need of constant monitoring and evaluation of materials in other for standards to be maintained (Alabi and Onyeji, 2010, Orie, 2009). Concrete is a construction material widely used in all types of civil engineering works. Its constituents are cement, coarse aggregate, fine aggregate, water and sometimes admixtures (Orie and Anyata, 2012). Due to need for City expansion or other factors used concrete may be demolished. About 850 million tonnes of Construction and Demolition, C and D materials are generated in the European Union (EU) per year, which represents about 31% of the total waste generation (Fisher and Werge, 2009). Recycling aggregate has been proven to be one of the possible solutions of tackling the rising challenges to the construction industry and the environment. Recycling is one of the most cost effective means of C and D materials without compromising the strength and durability of the concrete (Orie, 2008).

Katz (2003) investigated the properties of concrete made with recycled aggregate from partially hydrated old concrete and showed that the use of recycled aggregate led to a reduction of the comprehensive strength of the concrete with the flexural and splitting strengths exhibiting similar trends. Arundeb *et al.* (2011) conducted an experimental investigation on the direct comprehensive strength and elastic modulus of recycled aggregate concrete in the presence of fly ash (as replacement of cement). Their results indicates that 10% addition of fly ash as a replacement concrete marginally increases the unit weight and reduces workability of concrete. They concluded that recycled aggregate concrete with 10% fly ash gives a higher compressive strength over recycled aggregate with cement only and also that the tensile and flexural strength could be improved by adding 10% by replacement of cement by fly ash.

Deshpande *et al.* (2012) carried out an investigation on the strength characteristics of concrete with recycled aggregate and artificial sand. Cement, artificial sand of 4.75mm with approximately 14% dust, coarse aggregate (20mm) and recycled aggregate – which was sourced from demolished parking area (concrete rubble) and cubes casted and tested in the laboratory. They found out target strength of 31.6 N/mm^2 was achieved for M25 grade of concrete by 100% replacement of recycled coarse aggregate with river sand exhibited an increase of 3.82% in compressive strength. Butler *et al.* (2011) showed a significant reduction in the slump of the recycled Aggregate Concrete RCA mixes in comparison to the natural aggregate concrete.

Patel *et al.* (2013) showed that the strength of recycled aggregate specimens were gradually increased up to 40% replacement of recycled aggregate and then it decreased by the 100% replacement of the recycled aggregate after 28 days. Goncalves *et al.* (2001) found out that full replacement of natural aggregate by recycled aggregate leads to a decrease in the concrete compressive strength up to 16%. Limbachiya *et al.* (2004) showed that up to 30% coarse recycled aggregate has no effect on concrete strength but thereafter a gradual reduction with increasing recycled concrete aggregate content reduction of the compressive strength occurs. Berry *et al.* (2012) worked on the properties of pervious concrete incorporating recycled concrete aggregate with recycled aggregate sourced from a stockpile of crushed concrete from a stone recycling area. The work found to have densities within the same general range but with 100 recycled concrete aggregate replacement of 0% - 20% a high compressive strength value and a high hydraulic conductivity was obtained while with a 100 replacement of recycled concrete aggregate resulted to a low compressive strength and low hydraulic conductivity.
Nassar and Soroushain (2011) investigated the strength and durability of recycled aggregate concrete containing milled glass on partial replacement for cement. The work showed that slump increased with the introduction of milled waste glass, the compressive strength of the mix with 50% recycled aggregate and 20% cement replacement with milled glass was higher by 8% than that of 100% cement. They concluded that the use of milled waste glass as partial replacement of cement is estimated to effectively overcome the limitations of recycled aggregate concrete.

Benge *et al.* (2006) investigated the influence of recycled aggregate on mechanical properties of high performance concrete. Test results showed that the control mix had a higher slump than the mixes with recycled aggregates with a decrease in the compressive strength of the mixes with recycled aggregate compared to the control mix. Akbari *et al.* (2011) found out that replacing natural aggregate with recycled aggregate varying from 0% to 50% lead to a decrease in the compressive strength up to 24% as the percentage of the recycled aggregates increased beyond 25%, 23% reduction in flexural strength, 26% reduction in split tensile strength and a noticeable reduction in workability.

Yadav *et al.* (2009) carried out a work on the use of recycled concrete aggregate in making concrete and showed that there was a drop in compressive strength. They showed that with replacement between 0%- 30% the strength variation was permissible compared to the natural aggregate concrete. Flexural strength and split tensile strength were also reduced with the increase in the percentage of recycled aggregate in the mix.

Dolora *et al.* (1998) investigated the performance of recycled aggregate in large concrete beams. And concluded that with 100% recycled aggregates there was a drop in 28 day compressive strength of about 23% and a decrease in the modulus of elasticity of 31% when compared with the mix design made with 100% natural aggregate.

Wang and Cui (2011) investigated the effect of RCA on concrete compressive strength based on the concrete skeleton theory. Results of 28- day compressive strength test showed that the strength of different types of recycled aggregates affects the concrete strength. Obviously, the coarse aggregate added to mortar matrix played a skeleton role and improved its compressive strength. The skeleton effect of coarse aggregate increased with the strength of coarse aggregate increasing, with normal coarse aggregate playing the highest whereas recycled coarse aggregate the lowest strength.

Tavakoli and Soroushian (1996) showed that the strength characteristics of recycled aggregate concrete are influenced by key factors such as the strength of the original concrete, the ratio of top size of aggregate and water absorption of recycled aggregate. Adnan *et al.* (2006) have showed that there is a reduction in the compressive strength of the recycled aggregate concrete compared to NAC, also observed is than a reduction in water-cement ratio of the RAC lead to higher compressive strength.

The present work is aimed at monitoring and evaluation of recycled aggregate concrete as a material in the construction industry.

2. Materials and Methods

Laboratory investigation technique has been used. The materials used include; ordinary Portland cement, Okhuahe river sand, recycled aggregate sourced from waste concrete cubes from an Engineering laboratory and Potable Water. The concrete cubes with predetermined compressive strength were crushed into smaller fractions of average diameter of 20mm using a sledge hammer. A prescribed mix ratio of 1:2:4 was used. The recycled aggregates were separated into five groups; 15 – 30 N/mm^2, 31 – 40 N/mm^2, 41 -50 N/mm^2, 51 – 60 N/mm^2 and above 60 N/mm^2. Batching of concrete materials was done by weight.

The workability of the concrete samples using the slump test was carried out. The apparatus consisted of a cone of height of 300mm, top diameter of 100mm, bottom diameter of 200mm and a tamping rod of about 60mm long. The internal surface of the cone was cleaned and a light coat of oil applied. The mould was placed on a smooth, horizontal, rigid and non-absorbent surface and then filled in four layers with the freshly mixed concrete each approximately to one-fourth of the height of the mould. Each layer was tampered about 25 times with the tamping rod, excess concrete was removed and leveled with a trowel. The mould was removed from the concrete by raising it slowly in a vertical direction. The difference in level between the height of the mould and the highest point of the concrete was measured. The concrete cube moulds measuring 100mm x 100mm x 100mm were oiled for easy striking and placed on the vibrating table for compaction. The samples were demoulded after

24 hours. The cubes were cured in water at room temperature. The cubes were tested at intervals of 7, 14 and 28 days respectively. Preliminary experiments showed that a water/cement ratio of 0.65 was adequate. The compressive strength, CS was determined as,

$$CS = \frac{P}{LB} ---------------------------------------(1)$$

Where, P = load at fracture (N), L = length of cube (mm), B = breadth of cube (mm).

3. Results and Discussion

The results are presented in tables and figures. Table 1 shows the slump of the recycled aggregate concrete. It was showed that the slump was directly proportional to the compressive strength of the parent or source concrete. The higher the strength group, the higher the slump produced. This may be due to low absorption of water by the aggregates haven been coated by a higher concentration of the mortar from the source concrete. The relationship is also described by Figure 1. The most workable concrete with slump of 25 – 40mm was produced by the ranges 41 -50N/mm^2 and 31 -40N/mm^2.

Table 1: Slump of Fresh Recycled Aggregate Concrete

Strength group	Slump(mm)	Water-cement ratio	Concrete mix
Above 61N/mm^2	65	0.65	1:2:4
51N/mm^2 – 60N/mm^2	60	0.65	1:2:4
41N/mm^2 – 50N/mm^2	25	0.65	1:2:4
31N/mm^2 – 40N/mm^2	40	0.65	1:2:4
15N/mm^2 – 30N/mm^2	34	0.65	1:2:4

Table 2: Compressive Strength of RAC source group 61N/mm^2 and above

Age (Days)	7			14			28		
Samples	A	B	C	A	B	C	A	B	C
Mass (kg)	2.41	2.44	2.42	2.49	2.51	2.52	2.42	2.47	2.48
Failure load (kN)	115	170	150	300	260	295	320	350	360
Mean load (kN)	145			285			343.33		
Strength (N/mm^2)	14.50			28.50			34.33		

Table 3: Compressive Strength of RAC Source group 51N/mm^2- 60N/mm^2

Age (Days)	7 days			14 days			28 days		
Samples	A	B	C	A	B	C	A	B	C
Mass (Kg)	2.66	2.53	2.55	2.70	2.78	2.68	2.80	2.85	2.70
Failure load (KN)	120	110	120	190	185	205	285	270	280
Mean load (KN)	116.67			193.33			278.33		
Strength (N/mm^2)	11.67			19.33			27.83		

Table 4: Compressive Strength of RAC Source group 41- 50N/mm^2

Age (Days)	7 days			14 days			28 days		
Samples	A	B	C	A	B	C	A	B	C
Mass (Kg)	2.53	2.58	2.45	2.46	2.50	2.60	2.56	2.68	2.60
Failure load (KN)	110	120	115	160	150	185	250	280	255
Mean load (KN)	115			165			261.67		
Strength (N/mm^2)	11.50			16.50			26.17		

Table 5: Compressive Strength of RAC Source group 31- 40N/mm^2

Age (Days)	7 days			14 days			28 days		
Duplications	A	B	C	A	B	C	A	B	C
Mass (Kg)	2.63	2.51	2.53	2.44	2.74	2.57	2.65	2.51	2.60
Failure load (KN)	100	105	120	150	146	155	220	245	240
Mean load (KN)	108.33			150.33			235		
Strength (N/mm^2)	10.83			15.03			23.50		

Table 6: Compressive Strength of RAC Source group 15N/mm^2- 30N/mm^2

Age (Days)		11.67			19.33			27.83	
Duplications	A	B	C	A	B	C	A	B	C
Mass (Kg)	2.38	2.44	2.40	2.50	2.55	2.43	2.50	2.75	2.68
Failure load (KN)	110	110	90	130	160	115	215	230	210
Mean load (KN)		103.33			135			218.33	
Strength (N/mm^2)		10.33			13.50			21.83	

Table 2 shows the result of the compressive strength for the source strength group of 61N/mm^2 and above. The table showed a compressive strength gain with age. This is correspond with the behaviour of concrete with normal aggregates because of the continued hydration of cement. Between 7 and 14 days, there was an increase of about 96.55% and between 14 and 28 days a 20.45% increment in compressive strength was observed. Table 3 presents compressive strength of RCA made with source strength group of 51-60N/mm^2. There was an increase of 65.63% between 7 and 14 days and 41.38% as the age of 14 days above which, the percentage increase in strength reduced up to 28 days. from 14 days to 28 days of curing. Table 4 shows the compressive strength test result for the strength group of 30- 40N/mm^2.

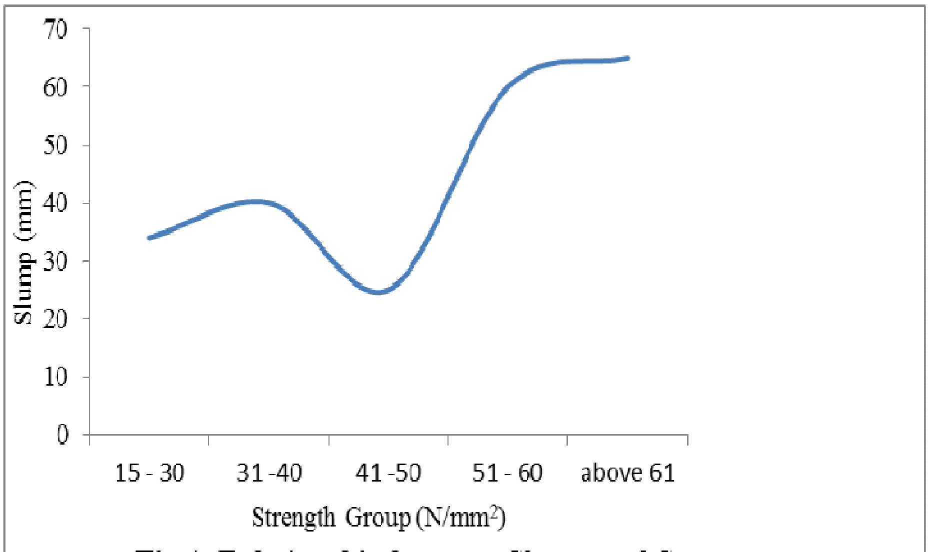

Fig.1: Relationship between Slump and Source Strength Group

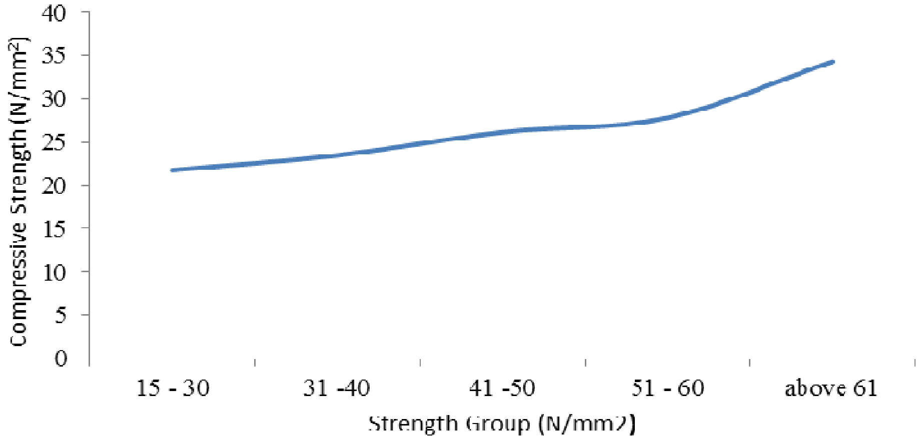

Fig. 2:Relationship between Compressive Strength and Source Group

In Table 4 which shows compressive strength for the group of 41 - 50N/mm^2, there was an increase of 43.47% in the compressive strength from 7 days to 14 days and an increase of 58% in the compressive strength. There was an increase of 38.78% in the compressive strength from 7 days to 14 days and also a 56.35% increase in the compressive strength of the Recycled aggregate concrete from 14days to 28 days. This phenomenon was also observed RAC made with source concrete of group 15- 30 N/mm^2. There was an increase of 30.68% in the compressive strength from 7 days to 14 days and an increase of 61.70% from 14 days to 28 days.

Figure 2 described the relationship between the 28th day compressive strengths of the different strength groups. It showed there was an increase in compressive strength with increase in strength group. This progressive increase in the strength with respect to the increase in strength group is attributed to the strength of the parent (source) concrete caused by more bond between mortar and aggregate of the recycled aggregate. The figure showed that there was a 7.65% increase in the compressive strength of the strength group of the 15- 30N/mm^2. The figure also showed a 13.49% increase in the compressive strength of the group of 31- 40N/mm^2 and an increase of 4.35% in the compressive strength of the strength group 41 - 50N/mm^2. There was an increase of 23.35% in the compressive strength in the group of 61N/mm^2 above and 51- 60N/mm^2.

4. Conclusion

Sources of higher compressive strength recycled aggregate produced recycled aggregate concrete with compressive strength of higher values. Hence, high strength source concrete can be recycled as aggregate in concrete production for construction purposes. This is due mainly to the harder bonds between their parent aggregate and the mortar which held them together.

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