Effect Of Moisture Content On The Structural Properties Of Concrete Containing Recycled Coarse Aggregate (RCA)

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Abstract: This paper investigated the effect of moisture content on the structural engineering properties of concrete made by partially replacing natural aggregate with Recycled Coarse Aggregate (RCA). Seventy-two 150mm concrete cubes were cast to determine the density and compressive strength of Recycled Coarse Aggregate Concrete (RCAC) at two varying percentages of RCA content of 0%, Normal Concrete (NC) and 25% and at different water-cement (w/c) ratios of 0.45, 0.5 and 0.55. Eighteen concrete cylinders (150mm x 300mm) were also cast to determine the splitting tensile strength of RCAC at the same varying w/c ratios as the cubes. The results showed that incorporation of RCA in concrete reduces workability of concrete because of the rough texture of RCA particles, the adhered mortar on the RCA and increased surface area due to the angular shape of RCA. For compressive strength, the maximum compressive strength for RCA concrete was 28.15N/mm^2 at 0.45 w/c ratio while that of normal concrete was 30N/mm^2 at 0.5 w/c ratio. Generally, for RCA concrete, compressive and splitting tensile strength reduces as the w/c ratio increases. The maximum splitting tensile strength recorded for both normal concrete and RCA concrete was at w/c = 0.45 and are given as 4.44N/mm^2 and 4.0N/mm^2 respectively.

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Introduction

Construction and demolition waste accounts for around 900 million tonnes every year just in Europe, the US, and Japan (WBCSD 2012). Recycling concrete not only reduces using virgin aggregate but also decreases the amount of waste in landfills.

One of the greatest problems with the use of Recycled Coarse Aggregate (RCA) is the high porosity of such aggregate which is the result of the presence of old cement mortar in its composition. This old cement mortar, which surrounds natural aggregate, can cause its increased absorption and shrinkage of the concrete. Katz (2002) reports that the total water absorption of concrete made with RCA was about 6.9-7.6%, which was greater than absorption of the reference concrete of about 3.8-3.9%. Also, Olorunsogo et al. (2002), reported that the water sorptivity increased as the proportion of RCA in the concrete mixes increased. The percentage increment of the water absorption of the concrete mixes with 100% RA was about 47.3%, 43.6%, 38.5% and 28.8% for curing days at 3, 7, 28, and 56, respectively.

Salau et al (2014) investigated the shrinkage deformation of concrete containing recycled coarse aggregates using 0.52 w/c ratio for all the mixes. The natural coarse aggregate was replaced by recycled concrete aggregates from 0% to 100% at the increment of 25%. The results of the investigation showed that the basic shrinkage strains of normal concrete is about 1.07 times greater than that of CRCA (with 25% RCA). The drying and total shrinkage strains of CRCA (with 25% RCA) are respectively 2.56 and 1.26 times greater than that of normal concrete.

Omotola *et al.*, (2011) carried out an experimental investigation on the effects of water-cement ratios on compressive strength and workability of concrete and lateritic concrete mixes. In the research five w/c ratios: 0.55, 0.6, 0.65, 0.7 and 0.80 were used with recycled aggregates while 1:2:4 mix proportions were also adopted. The results showed that the compressive strength, weight and density of both normal aggregate concrete and lateritic concrete mixes decreases with increase in the water-cement ratio. However the compressive strength of both concrete and lateritic concrete mixes increases with age. Limbachiya *et al.,* (2004) studied performance of concrete produced with natural and coarse recycled aggregate. The recycled aggregate originated from four different sources: airport pavement, laboratory cast concrete, demolished concrete structures and rejected structural precast element. The results showed that there were no significant variations in the strengths of concrete of RCA from the four sources, indicating no significant effects if adequate provisions for RCA characteristic are made. The study inferred that the density of Recycled concrete aggregates is low while water absorption is about 3-5 times higher when compare to natural aggregates concrete, due to the presence of attached cement paste.

Etxeberria et al. (2007) in their research found that concrete made with recycled concrete aggregates is less workable than conventional concrete. They reported that concrete made with recycled coarse aggregates and virgin fine aggregates typically needs 5% more water than conventional concrete to obtain the same workability. Additional cement is needed for concrete made with 100% recycled aggregates to achieve similar workability and compressive strength as conventional concrete. The shape and texture of aggregates also plays a role in the workability of concrete.

Parekh et al. (2011) reported the basic properties of recycled fine aggregate and recycled coarse aggregate. The results indicated that specific gravity of the recycled aggregates significantly reduces (from 4.6 to 6.5) while there was sharp increase in water absorption.

(from 2.3 to 4.6 times the value of water absorption capacity for natural gravel).

A review of the literature shows that behaviour of natural aggregate concrete has been extensively investigated in the past. Various researchers have carried out work on characteristics of RCA on short and long term behaviour of recycled aggregate concrete. Most of them have indicated that, attached cement mortar of recycled aggregate particles is the main reasons for the modified characteristics of RCAC. A common observation is the higher water absorption accompanied by lower specific gravity values for recycled aggregate. Further, the workability of RCAC is found to be lower in view of higher water demand of RCA due to the porous nature of adhered cement mortar on its surface.

Thus, this study aims to examine the effects of water content on the strengths characteristics of RCAC and to develop a transfer model that can predict the characteristic strength of RCAC at a given water-cement ratio.

Materials And Experimental Procedure

Ordinary Portland cement with a specific gravity of 3.15 was used for this study. The water used was clean and potable. Aggregates include river sand as fine aggregate, granite and recycled coarse aggregate as coarse aggregate. Concrete waste was obtained from Bayeku community secondary school rehabilitation site, the waste was hammered and crushed into smaller particles. The impurities and other particles that stick together with the rubble were removed. The crushed pieces of the used concrete were then separated into two fractions depending on their size; the larger fraction, passing through 20 mm sieve but retained on 10 mm sieve, while the smaller fraction passing through 10 mm sieve but retained on 4.75 mm. The fraction passing through 4.75 mm sieve was discarded. While making RCA concrete, the two different sizes of RCA were mixed in a suitable proportion so that the combined RCA can be uniformly graded just as the natural coarse aggregate. Prior to batching, the recycled concrete aggregate was washed to remove any dust that may increase the water demand, and lower the bond strength. The wet coarse aggregate was then stacked in bags, for at least one day, the pre-wetted recycled aggregate was allowed for absorption of the moisture content to stabilize and the excess water to drain to the bottom of the stacked bag. The recycled concrete aggregate in the bottom portion, about (75mm) of the stacked bag was not used, as it would be too wet from the excess water.

The mix proportion of cement, sand and granite was 1:2:4 but the water-cement ratio was varied at 0.45, 0.50, 0.55. Seventy-two 150mm concrete cubes were cast for compressive strength test, Eighteen concrete cylinders (150x300mm) were also cast for splitting tensile strength of normal and RCA concrete.

Results And Discussion

Physical Properties of Aggregates

Table 1 shows the results of the physical properties of the aggregates used in this study. As observed, the water absorption capacity of recycled coarse aggregate is more than that of natural coarse aggregate, this is due to the adhered mortar of the RCA. The specific gravity and bulk density of RCA were found to be 2.53 and 2365kg/m^3 respectively, which compares favourably with that of natural coarse aggregate.

Table 1: Physical Property of Constituent Materials

Properties	Natural Coarse aggregate (granite)	Fine Aggregate (River sand)	Recycled Coarse aggregate (RCA)	Cement High Alumina (Grade 42.3R Dangote Brand)
Specific gravity	2.75	2.65	2.53	3.15
Water Absorption (%)	1.22	15.34	6.59	-
Moisture content (%)	0.75	6.42	2.12	0.02
Dry density (kg/m^3)	2460	2560	2127	3080
Bulk density (kg/m^3)	2478	2724	2365	3081
Co-efficient of Uniformity (C_U)	1.05	2.89	1.08	-
Co-efficient of Curvature (C_C)	1.02	1.40	0.95	-
Fineness Modulus (FM)	2.53	4.21	2.38	-
Initial setting time	-	-	-	120 minutes
Final setting time	-	-	-	240 minutes
Specific gravity	-	-	-	3.15
Consistency	-	-	-	0.31

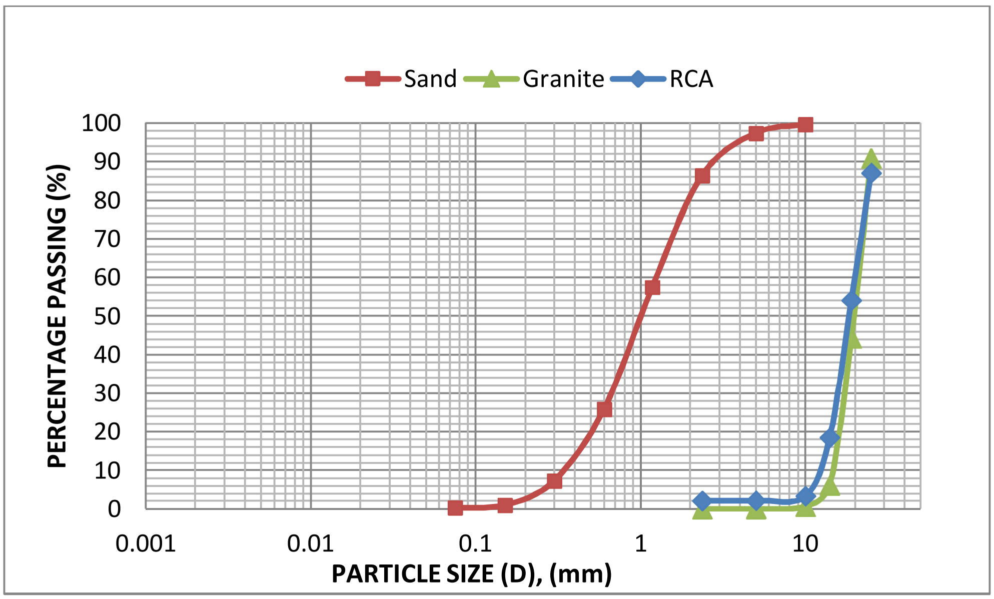

Figure 1: Particle size distribution of aggregates (Sand, natural aggregate and RCA)

The sieve analysis indicated as shown in Figure 1, showed that 87.14% of recycled aggregate passed through 25mm sieve while 2.20% passes through 2.36mm sieve. For the natural aggregate, 90.97% was recorded passing through the 25mm sieve while only 0.10% passed through the 2.36mm. The coefficient of curvature (Cc) and coefficient of Uniformity (Cu) of the natural aggregate are 1.02 and 1.05 respectively, while those of RCA are very close, 0.95 and 1.08 respectively. The results largely, indicate that the fine, normal and recycled aggregate were uniformly graded, but there are more coarse particles in the recycled aggregate than in the natural coarse aggregates.

Workability of Normal and RCA Concrete

Tables 2 gives the results of slump of normal concrete and RCAC at different water-cement ratios of 0.45, 0.50 and 0.55. It can be seen that slump of normal concrete is higher than that of RCAC (25% RCA content). In both normal and RCA concrete; slump values increase as the water-cement ratio increase, with the 0.45 w/c ratio producing the lowest slump and the 0.55 w/c ratio having the highest slump for both concrete mixes. The effect of recycled aggregate and water-cement ratio on concrete workability can be explained as follows: The rough-texture, angular and elongated particles due to old existing cement paste requires much water because of increased surface area than the smooth virgin aggregate, thereby reducing the workability of RCAC, also the texture of recycled aggregate prevent sliding between aggregate, which leads to low natural compaction.

Due to the higher absorption capacity of RCA, the period of time required to reach a saturated surface dry (SSD) condition will be longer than for natural aggregates. Therefore, the additional water reserved for RCA aggregate absorption during pre-wetting may not be fully absorbed by the aggregates in the period between addition of the aggregates to the mixer and placement of fresh concrete. This ensured that the highly absorptive recycled concrete aggregates contained additional water above their SSD condition. Pre-wetting the RCA should have eliminated slump loss due to coarse aggregate absorption of mixing water during batching. Thus, the reduced slump values in the RCA concrete mixtures can be attributed to the more angular shape and roughened surface texture of the recycled aggregates that increased the inter-particle friction in the fresh concrete.

Table 2: Average Slump Value of Concrete Specimens

Sample	W/C Ratio	Slump Value	Workability
NC	0.45	15mm	low slump
	0.50	25mm	
	0.55	35mm	
RCAC	0.45	0	Very low slump
	0.50	5mm	
	0.55	15mm	

Compressive Strength Test

Compressive strengths of all concrete mixes were tested at 7, 14, 21 and 28 curing ages after mixing and the results are given in Table 3. The compressive strength development for all concrete mixes increased as the concrete age increased. The maximum compressive strength at 28days recorded for the normal concrete was 30.0N/mm^2 at 0.50 w/c ratio, and for the RCAC was 28.15 N/mm^2 at 0.45 w/c ratio. The lowest compressive strength at 28days recorded for the normal concrete was 23.56N/mm^2 at 0.45 w/c ratio, and for RCAC was 24.0N/mm^2 at 0.55 w/c ratio.

At 0.45 w/c ratio, RCAC had higher compressive strength values from the 7 days to 28days curing age. The compressive strength at 28days was 28.15N/mm^2, this is an increase of about 20% compared to the 23.56N/mm^2 recorded for normal concrete. At other w/c ratios (0.5 and 0.55), normal concrete had higher compressive strength than RCAC at all curing ages. This means that the available water in concrete significantly affects its strength. The average difference in compressive strength of the normal and RCA concrete at the three w/c ratios (0.45, 0.5, 0.55) is given as 1.37N/mm^2, which shows that the incorporation of 25% RCA in concrete does not necessarily affect the compressive strength adversely, there's only a need to establish an optimum w/c ratio at which the mix should be achieved such that compressive strength is maximum. The significance of moisture in RCAC cannot be overemphasized as factors such as the absorption capacity of the RCA and the (quantity of) adhered mortar on the RCA particles determine the moisture available in the concrete matrix for its workability and the process of hydration.

The lowest w/c cement ratio considered, 0.45, gave the highest value of compressive strength for RCAC, this could be attributed to the pre-soaking of the RCA particles which afforded some more moisture to be available for hydration, and also pre-soaking the aggregates opens the pores of the aggregate particles, this may have enhanced the bonding of the concrete matrix. Also, the rough texture and the angular shape of the RCA, helps the particles of the aggregate to form a stronger bond within the concrete matrix.

Lastly, the trend of strength development in RCAC as shown in Figure 3 is very similar to that of normal concrete. The compressive strength of RCAC increased appreciably with increasing curing age, just as in normal concrete, and this is not determine by w/c ratio. From the results, as presented in Table 3, the compressive strength of normal concrete increased as the w/c ratio increased while in RCAC, compressive strength reduces as w/c ratio increases. The average difference in compressive strength of RCAC at different w/c ratio of 0.45, 0.5,0.55 was given as 3N/mm^2. The pre-soaking of the RCA, afforded the concrete matrix adequate moisture for proper hydration at the optimum w/c ratio (in this case is 0.45) even though the workability at this w/c ratio is low. At higher w/c ratio, (0.5, 0.55), the excess water added was not necessarily needed, for hydration (though good for workability), it thereby had an adverse effect on strength development causing a record of lower compressive strength values. This reinforces the idea of pre-soaking the RCA particles before using it in concrete.

Table 3: Compressive Strength of Normal and RCA Concretes

W/C Ratio	Age of concrete	Compressive Strength of NC (N/mm^2)	Compressive Strength of RCAC (N/mm^2)
0.45	7	18.22	22.14
	14	20.74	24.59
	21	22.67	25.19
	28	23.56	28.15
0.50	7	20.15	19.56
	14	26.07	20.22
	21	29.26	24.36
	28	30.00	26.30
0.55	7	20.22	18.59
	14	22.89	19.04
	21	28.52	23.22
	28	28.81	24.00

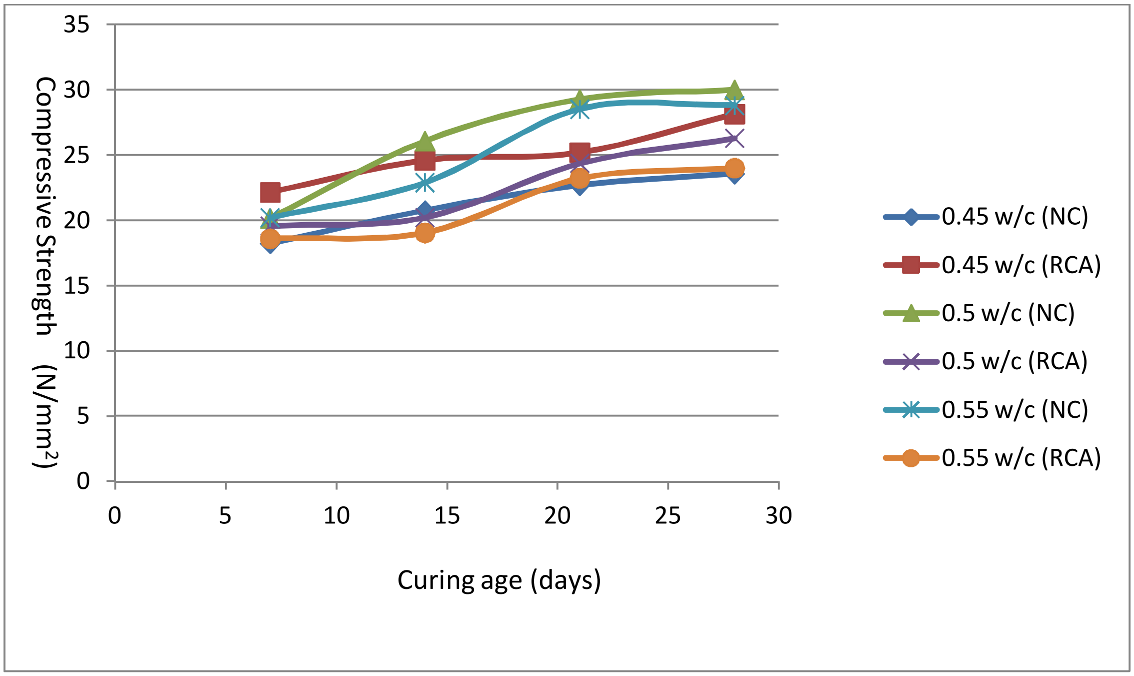

Figure 3: Effects of w/c ratio on Compressive Strengths of Normal and RCA Concrete

Splitting Tensile Strength of Normal and RCA Concrete

Table 4 shows the results of the splitting tensile strength of normal and RCA concrete at 28days. Maximum tensile strength recorded for normal concrete was 4.44MPa at 0.45 w/c ratio, while the maximum tensile strength recorded for RCAC was 4.0MPa at the same w/c ratio of 0.45, this value compare well with that of the normal concrete, having a difference of only 10%. For both normal and RCA concrete, splitting tensile strength reduces as the w/c ratio increases.

Table 4: Splitting Tensile Strength of Normal and RCA concrete at 28days

Samples	W/C Ratio	28-day Cylinder Strength (MPa)	f_t/f_c % (β)
NC	0.45	4.44	0.19
	0.50	3.86	0.13
	0.55	3.82	0.13
RCAC	0.45	4.0	0.14
	0.50	3.85	0.15
	0.55	3.83	0.16

Relationship between the Compressive and Splitting Tensile Strength

In practice, it is easier to access the compressive of the concrete than the tensile strength. Obtaining the ratio between the strengths is very useful for the purpose of quality control, as the tensile strength can be obtained easily (from standard ratio), once the compressive strength has been determined. In this study, the ratio (β) of the tensile strength (f_t) and compressive strength (f_c), for the 25% RCA replacement ratio and for the water/cement ratios as varied at 28 days curing age are shown in the Table 4. The ratio of tensile strength to compressive strength has been reported to be between 5% and 10% of the compressive strength (Yusuf et al, 2013), in this research, the ratio has been found to be between 13% and 19%, thus the value obtained in this research investigation showed improved tensile strength characteristics for recycled aggregate concrete at all the varied water/cement ratios, measured in term of splitting tensile strength.

Conclusion And Recommendations

The physical properties of RCA include specific gravity of 2.53, water absorption capacity of 15.34% and bulk density of 2724kg/m^3.

1. The workability of RCAC compared to normal concrete at the same w/c ratio is low. This is attributed more to the angular shape and rough texture of the RCA particles than the water absorption capacity of the RCA particles, because the RCA particles were pre-soaked and were at a saturated dry state when batched.
2. The maximum compressive strength recorded for RCAC was 28N/mm^2 at 0.45 w/c ratio, this value is 20% higher than that of normal concrete at the same w/c ratio. This means that the use of RCA in concrete does not necessarily have an adverse effect on its strength characteristics, but the water-cement ratio employed in the concrete mix is highly significant.
3. The maximum splitting tensile strength recorded for RCAC was 4.0Mpa at 0.45 w/c ratio, this compares well with that of normal concrete which is 4.44Mpa at the same w/c of 0.45. the ratio of compressive strength to tensile strength of RCAC was found to be in the range of 14%-16%, similar to that of normal concrete which is 13%-19%.
4. The optimum water-cement ratio as found in this research for RCAC is 0.45.
5. RCA can be used in concrete for load-bearing structural elements.

The recommendations are as follows:

RCA that was derived from the crushing of older concrete structures containing negligible amounts of deleterious material can be used as a 25% direct replacement of virgin coarse aggregate to produce structural-grade concrete.

Further investigations should be done to determine how moisture content affects other concrete capacities such as flexural strength, shear capacity and deflection capacity.

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