Prospect of Recycled Coarse Aggregate for Concrete Production in Nigeria

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***Abstract*:** The non-degradable nature of concrete waste from demolition and collapsed building sites, coupled with environmental degradation and exposure to heavy metals in the process of extracting aggregate constitute hazards to health and the environment. This study focused on the prospect of recycled coarse aggregate for concrete production. The coarse aggregate component of normal concrete was replaced with 25%, 50%, 75% and 100% Recycled Coarse Aggregate (RCA) in a 1:2:4 cement, sand and aggregate mix proportion and 0.5 water/cement ratio. Result shows that workability, saturated bulk density, compressive strength and flexural strength decreases with increase in RCA content in concrete. 100% manually recycled coarse aggregate concrete passed the 17 kN/m^2 compressive strength limit generally acceptable for concrete work of non high strength requirement without additive. The research therefore recommends the use of recycled coarse aggregate concrete for plain low strength concrete elements for buildings. The economic benefit of RCA concrete includes efficient reuse of recovered coarse aggregate from demolished and collapsed buildings and to avert risk to health and the environmental.

***Keywords*:** Coarse aggregate recycled concrete, engineering properties, sustainable construction, Nigeria

1.0 Introduction

Sustainable construction has become of great concern in the construction industry all over the world. This is due to the fact that the construction industry is a massive consumer of natural resources and a huge waste producer as well (Cachim, 2009). The high volume of raw material consumption in the construction industry causes the depletion of natural and mineral resources. Resources such as rocks from which coarse aggregates, sands and ingredients for cements is derived will be depleted as a result of the high demand for them in the construction industry (Mehta, 1999). In addition, the extraction of these materials exposes heavy and radioactive materials that will pose health hazards to people. Therefore, utilizing recycled aggregate may be one of the significant efforts in achieving a sustainable construction. The concept of sustainable development put forward two decades ago, at the 1992 Earth Summit in Reo de Janeiro is now the guiding principle in the construction industry worldwide (Limbachiya, Meddah and Ouchagour, 2012). The benefit of sustainable development leaves no nation in doubt and it has become part of national policies to imbibe the ideas of sustainable development. Recycled Coarse Aggregate (RCA) has very high potential of sustaining the natural deposit of inert granular material use in concrete.

According to Chandra (1996) construction and demolition waste programmes have been established in many parts of the world to allow the use of recycled concrete as an alternative aggregate since 40% of all construction demolition is concrete. Other recovered concrete can come from sources such as site waste, old slump and cubes from destructive strength tests, collapsed buildings debris, as well as prefabricated concrete factory waste. The Netherland is the most responsive nation in this practice with nearly all of its concrete recovered. Europe manages to recover 30% of concrete. The United States recovers 82% of concrete in construction and demolition waste (CSI, 2010).

In Nigeria, there is no record of recycled concrete or coarse aggregate remediation but in recent time, recycled coarse aggregate has become a major source of financial relief to some developers and a means of livelihood to concrete re-cyclists in some Nigerian cities. Site survey in Uyo metropolis (Akwa Ibom State, Nigeria) reveals 100% use of RCA in concrete even in structural elements. Although the wisdom of continued extraction and use of aggregate from natural sources in Nigeria has not been questioned, there is great awareness of the need to protect the environment and conserve resources for future generation. The application of recycled aggregate (RA) nationwide is still low because of low climate change awareness and also because of abundant natural aggregate in certain parts of the country. Most practitioners who recommend the use of RCA are still in doubt about the mechanical properties of RCA in concrete. In addition, there is no acceptable standard recommendation for RA mix design. The objectives of this study therefore are to assess the engineering properties of recycled coarse aggregate in concrete and establish suitable mix design for recycled aggregate concrete (RCA). The significance of this study in Nigeria is to encourage constructive use of RA arising from demolition of buildings and other infrastructure. Others include reduction in raw materials used as aggregate in concrete, elimination of environmental problems caused by demolition waste, health hazards from exposed radioactive materials during extraction of raw materials and cut in cost of transporting raw aggregate materials over long distances between the source and construction sites and cut in energy used to process these materials.

2.0 Literature Review

Aggregates are the major component in concrete in terms of volume and contribute significantly to the cost and engineering properties of concrete mix. Recycling of construction and demolition waste (C&DW) as aggregate for concrete has attracted increased interest from the construction industry worldwide. This is partly because of the risks to health and environmental hazards caused by leaching of heavy metals, and radioactive substances during the extraction of coarse aggregate from its original source and also to minimize non-degradable materials that goes to landfill spaces. The growing interest in substituting natural aggregate with recycled concrete aggregate is further heightened by the considerable amount of energy required in the extraction and crushing processes. According to the report of the World Business Council (CSI, 2010), about 1,300 million tonnes of waste are generated in Europe each year, of which about 40%, or 510 million tonnes, is C&DW. The US produces about 325 million tonnes of C&DW, and Japan about 77 million tonnes. Twenty-seven percent of the total waste generated in New Zealand is C&DW, and of this concrete represents 25%, i.e. seven percent of the total waste (CCANZ,2008). Given that China and India are now producing and using over 50% of the world’s concrete, their waste generation will also be significant as development continues.

Extensive research on the engineering properties and use of recycled aggregate in concrete is ongoing worldwide. Chandra (1996) observed that most common mix proportion of RCA in concrete included 50% of 20mm RCA, 30% fine granite aggregate (10mm) and 20% coarse granite aggregate.

Between 1996 and 2011, many Chinese researchers have engaged in the study of RCA. In one study, researchers built three types of portal frame to perform seismic tests on. One was constructed using concrete comprising of natural aggregate while the other was 50/50 recycled aggregate to natural aggregate and the final mix was 100% recycled concrete aggregate. The result of the study revealed no evident difference in the cyclic lateral loading and the bearing strength of the recycled concrete aggregate compared to normal coarse aggregate (Yuedong, 2007). In Serbia, Grdic, Toplicic-Curcic, Despotovic and Ristic, (2010) investigated the properties of self-compacting concrete prepared with coarse recycled concrete aggregate where three types of concrete mixtures were made, the percentage substitution of coarse aggregate by the recycled aggregated was 0%, 50% and 100%. The results indicate that usage of 50–100% of coarse recycled aggregate decreased the tensile strength tested by bending for 2.49–13.95% and water absorption for 0.15–0.37%. Replacement of 50% of coarse aggregate (whole fraction 8/16) decreased the compressive strength for 3.88%, while 100% replacement of coarse aggregate (fractions 4/8 and 8/16) decreased the compressive strength for 8.55%. The density for 50% replacement of coarse aggregate (whole fraction 8/16) decreased for 2.12%, and for 100% replacement of coarse aggregate (fractions 4/8 and 8/16) density decreased for 3.40%. Grdic *et al.* (2010) concluded that coarse recycled aggregate can successfully be used for making of self-compacting concrete. Olowofoyeku, Agoro and Olowofoyeku (2012) also reported decline in flexural strength as well as workability of the mix with increasing percentage replacement of RCA at 0.4 water/cement ratio in a study of influence of recycled aggregate on the compressive strength of concrete. Similarly, Limbachiya, Wang, Huang, Liu, Wu and Guo (2003) investigated the mechanical properties of recycled concrete in marine environment using 0%, 30% and 60% RA replacement. After immersing the specimen in sea water for 4, 8, 12 and 16 months, the result revealed that recycled concrete peak value and elastic modulus decreased with increase of replacement percentage and corroding time in marine environment.

In a sharp deviation from coarse aggregate, Umoh (2012) used demolition waste sandcrete block as partial replacement for fine aggregate in concrete and found that the 28days compressive strength of 50% crushed waste sandcrete blocks replacement with fine aggregate attained the designed compressive strength as the conventional concrete with zero percent replacement (used as a control). Quarry dust (waste quarry sand or foundry sand) has also been used in concrete related products like bricks, blocks and paving stones (Khatib and Ellis, 2001).

3.0 Research Method

3.1 Materials

Ordinary Portland cement (grade 32.5) with the trade name “Elephant Cement” fully certified by the Standard Organization of Nigeria

(SON, 2003) and in compliance with BS EN 197-1:2011 was used for the research. Physical checks conducted on the cement bag indicate that they were properly sealed and stalked above the floor, eliminating the problem of loss of strength resulting from improper storage.

The fine aggregate used was river-bed sand and meet the specification in BS EN 12620:2013 provision for reference sand. The sieve analysis of sand used indicate that 0% was retained on 2.00mm sieve size, 10% on 1.88mm size, 30% on 600µm size, 30% on 425µm size, 14% on 300µm size, 11% on 150µm size and 5% retained in pan. This shows that the sand is very sharp without silt and clay particles. Tap water was used for the mixing and it was properly examined to ensure that it is clean, free from particles and good for drinking as specified in BS EN 1008:2002.

The recycled coarse aggregate were purchased at Udo Udoma Avenue in Uyo, Akwa Ibom State where manually refined recycled coarse aggregate are sold in bags. This was to ensure that the result obtained in this research is as close to what is obtainable with commercial recycled coarse aggregate. The natural coarse aggregate used is granite of approximately 19mm (3/4 inch) sold in open market by granite suppliers.

3.2 Proportioning, Mixing and Curing

Batching by volume was employed to align the study with current site practice in Nigeria. The concrete ingredients were mixed in 1:2:4 cement sand and coarse aggregate ratio at water/cement ratio of 0.5. Water/cement ratio 0.5 was used because of the excessive dryness of the aggregates. Each mould measuring 100mm x 100mm x 100mm was prepared to produce concrete cubes and for the rectangular beams, the mould measuring 150mm X 750mm X 150mm was used. Recycled Aggregate Concrete mixes from four percentage replacement (25%, 50%, 75% and 100%) exclusive of the control was poured into the wooden mould. Each mould was consolidated on a vibrating table and covered with nylon to avoid losing moisture. After 24 hours, the samples were de-moulded and cured in water. A total of 45 cubes and 15 beams comprising 9 cubes and 3 beams for each percentage replacement were produced. Table 1 shows the proportion of concrete ingredients required for the various percentages replacement. Tests were conducted on the specimen at 7days, 14days and 28days as shown in Table 3.

Table 1: Proportion of Materials Used for Batching

	Recycled Coarse Aggregate Percentage Replacement				
Ingredient	0% RCA	25% RCA	50% RCA	75% RCA	100% RCA
Cement	1	1	1	1	1
Sand	2	2	2	2	2
NA	4	3	2	1	0
RCA	0	1	2	3	4
W/C	0.5	0.5	0.5	0.5	0.5

RCA = Recycled Coarse Aggregate NA = Natural Aggregate
W/C = water/cement ratio

4.0 Results and Discussion

4.1 Grading of Fine Aggregate Used

Results of preliminary test conducted to ensure conformity of the particle size distribution of the sand used to the reference sand recommended by Nigerian Industrial Standard (NIS) were recorded and analyzed as shown in figure 1. The result of the experiment indicates that the sand is very sharp without silt and clay particles, indicating that the particle size of the sand used is within the reference sand particle distribution and therefore could be called standard sand since all other criteria such as zero silt content and moisture content have been satisfied. Hence the sand is absolutely fit for the compressive strength and flexural tests.

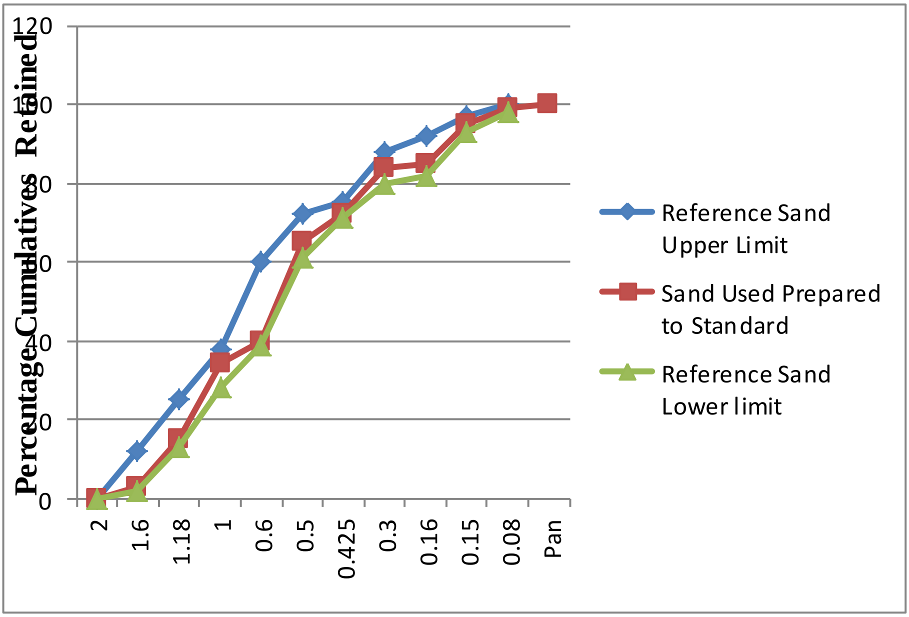

Figure 1: Grading curve of sand used prepared to standard slump test

4.2 Workability of RCA

Slump test was carried out on each sample of recycled coarse aggregate percentage replacement as presented in Table 2.

Table 2: Detail Result of Slump Test on the various percentages of Recycled Coarse Aggregate mix

	Recycled Coarse Aggregate Percentage Replacement				
	0% RCA	25% RCA	50% RCA	75% RCA	100% RCA
W/C	0.5	0.5	0.5	0.5	0.5
Slump (mm)	30	30	25	20	10

RCA = Recycled Coarse Aggregate W/C = water/cement ratio

The result shown in Table 2 indicates that the concrete has good slump with the design water/cement ratio of 0.5. A gentle struck on the side of the slump test sample with rod after the cone was removed and the reading taken shows that the concrete mixes are workable but with slight reduction in workability from 30mm to 10mm as the percentage of RCA increases from 0% to 100%. This finding is consistent with Olowofoyeku *et al.* (2012) and Limbachiya *et al.* (2012). However, there are notable differences in the values of slump obtained and that of Olowofoyeku *et al.* (2012) which report 85mm, 65mm and 55mm slump for 0%, 24.24% and 50% recycled coarse aggregate (RCA) replacement respectively at 0.4 water/cement ratio. Whereas, at 0.5 water/cement ratio 30mm, 30mm, 25mm, 20mm and 10mm were obtained for 0%, 25%, 50%, 75% and 100% RCA replacement respectively. The difference could be attributed to difference in batching process and moisture content of materials used in the experiment. As for the concretes' consistency, the results present a high variability; especially for replacements up to 75% recycled coarse aggregate as indicated in Table 2.

4.3 Saturated Bulk Density

The saturated bulk density of the various percentage of RCA replacement mixes were determined from compressive strength test cubes before crushing.

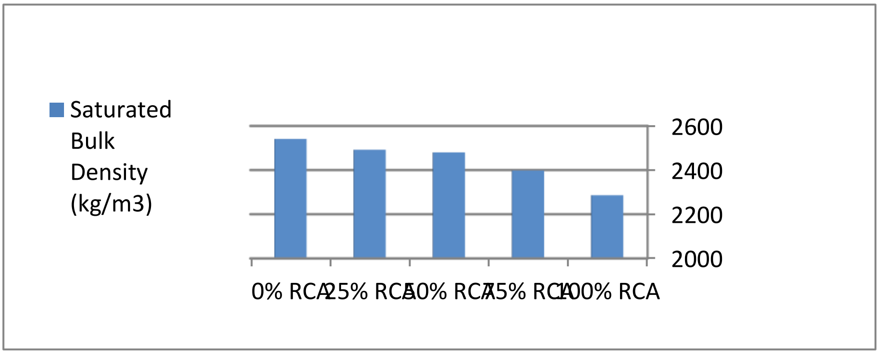

Figure 2: Saturated bulk density (Kg/m^3) of RCA % replacement

Figure 2 shows the declining nature of saturated bulk density with increase in percentage replacement of virgin coarse aggregate with recycled coarse aggregate (RCA). The reduction is as a result of the low specific gravity of recycled coarse aggregate in relation to virgin coarse aggregate.

4.4 Compressive Strength

The results of compressive strength test on the 0% RCA, 25% RCA, 50% RCA, 75% RCA and 100% RCA of the test cubes crushed in the laboratory are presented in Table 3.

Table 3: Compression Strength Test Result

DURATION	Recycled	Coarse	Aggregate	Percentage	Replacement
(KN/m^2	0% RCA	25% RCA	50% RCA	75% RCA	100% RCA
7Days (kN/m^2)	24.15	17.41	16.67	12.00	11.41
14Days (kN/m^2)	22.52	19.92	18.22	13.77	13.63
28Days (kN/m^2)	27.00	25.10	23.50	19.50	18.20

RCA = Recycled Concrete Aggregate

The compressive strength test result in Table 3 shows that there is gradual decrease in compressive strength as the recycled coarse aggregate content increased in the mixes. The concrete mix of all the percentage replacements indicate increase in strength over time which is in line with standing theories of concrete. The control (0% recycled coarse aggregate replacement) experienced sharp increase in strength, 24kN/m^2 on the 7 day, 22.52kN/m^2 and 27.00kN/m^2 for 14 days and 28 days strength respectively, which satisfy 25kN/m^2 British Standard of strength target at 28days. The 0% recycled coarse aggregate replacement results are similar to the 0% RCA works of Limbachiya *et al*. (2012) and Olowofoyeku, *et al* (2012) but with higher compressive strength values at 7 and 14 days tests. This confirms the authenticity of the experimental procedures. At 25% recycled coarse aggregate replacement the result shows a decrease in compressive strength in relation to the 0% RCA replacement of the same mix ratio (1: 2: 4) and water/cement ratio of 0.5. The compressive strength result of the 25% RCA is similar to Olowofoyeku, *et al* (2012) 24% RCA and Limbachiya *et al*. (2012) 30% RCA. However the result is a little higher than Olowofoyeku *et al.* (2012) 24% replacement.

The 50% recycled coarse aggregate replacement concrete mix yield 16.67 kN/m^2, 18.22 kN/m^2 and 23.50 kN/m^2 at 7 days, 14 days and 28 days compressive test respectively. The 50% RCA replacement mix compressive strength test result is lower than those with 25% and 0% recycled coarse aggregate replacement mixes which is in line with findings of some researches in this field. These values are higher than the result of 50% RCA replacement presented in Olowofoyeku *et al.* (2012) with water/cement ratio of 0.4. The higher compressive strength value could be attributed to the higher w/c of 0.5 used in the experiment which offers more water for the highly water absorbing recycled coarse aggregate and enhance better hydration process in the concrete. Also, the values are in close relation with the 50% RCA replacement mix in Limbachiya *et al*. (2012) in which the compressive strength are a little higher. The higher compressive strength in Limbachiya *et al*. (2012) is attributable to the measure used to refine the recycled coarse aggregate, whereas the recycled coarse aggregate used in this work did not undergo much refining process order than the manual breaking of the used concrete. Hence, the recycled coarse aggregate employed in this research may have some impurities, and possible lines of weakness along which the recycled aggregate concrete (RAC) can easily fail. Figure 4 shows the relationship between the compressive strength test result in this work and the works of Limbachiya *et al*. (2012) and 50% RCA replacement recycled aggregate concrete reported in Olowofoyeku *et al.* (2012)

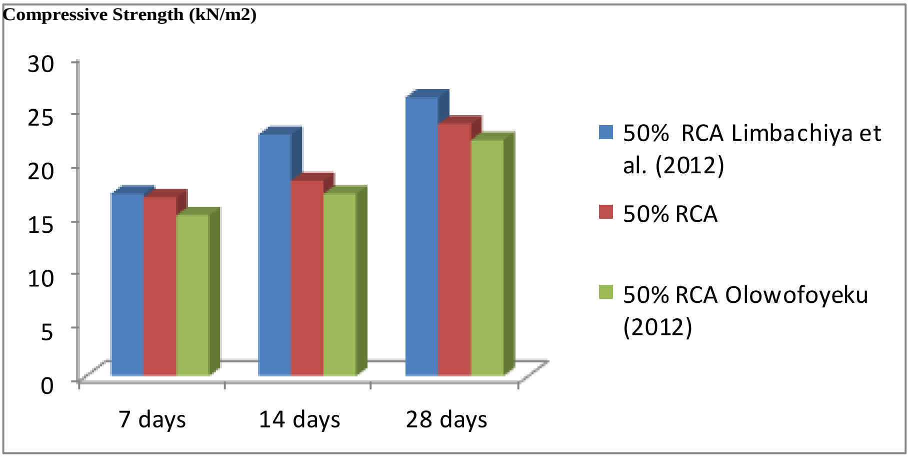

Figure 4: Comparative Analysis of Compressive Strength (kN/m^2) Test at 50% Recycled Coarse Aggregate Replacement in Concrete.

For the 75% recycled coarse aggregate replacement in concrete the result in Table 4 also shows reduction in compressive strength with respect to 50%, 25% and 0% RCA in an increasing order. The reduction in strength is certainly due to the heavy concentration of impurities, and possible lines of weakness in the recycled coarse aggregate (RCA) along which the recycled aggregate concrete (RCA) fails and also insufficient water for proper hydration process.

The 100% recycled coarse aggregate replacement also shows further reduction in compressive strength with 28 days strength of 18.20kN/m^2. The 18.20 kN/m^2 compressive strength is a graceful limp over the 17 kN/m^2 compressive strength minimum limit generally acceptable for concrete work of non high strength requirement as recommended by Kosmatka, Beatrix and Panarese (2002) in union with Cement Association. However, the result is far less than the once gotten by Limbachiya *et al.* (2012). The reason for the difference still remain higher concentration of impurities in the test samples as a result of inadequate refining of the recycled coarse aggregate. Hence, the more the recycled coarse aggregate in the concrete the more the impurities and the less the compressive strength. Table 4 shows the percentage difference in compressive strength among the tested recycled aggregate concrete with the 0% RCA replacement as the control mix.

Table 4: Percentage Compressive Strength of Recycled Aggregate Concrete (RAC) in Relation to 0% RCA Concrete Mix

Decrease in Compressive Strength (%) in Relation to 0% RCA				
Duration	**25% RCA**	**50% RCA**	**75% RCA**	**100% RCA**
7 days	28	31	50	53
14 days	16	19	39	39
28 days	7.7	13	27.7	32.6

RCA = Recycled Coarse Aggregate

The decrease in compression strength is highest (i.e. 53% reduction) at the 100% RCA concrete mix at 7 days curing and gradually reduces to 32.6 % at the 28 days curing. For the different percentages of replacement studied, the decrease in strength compared with the reference concrete (0% RCA) was least at 28 days in comparison to the compressive strength at 7days or 14 days.

4.5 Flexural Strength Test

The result of the flexural strength test carried out on the rectangular beams 150mm X 750mm X 150mm at 28 days of curing are shown in Table 5.

Table 5: Flexural Strength Result at 28 Days

	Recycled Coarse Aggregate Percentage Replacement				
	0% RCA	25% RCA	50% RCA	75% RCA	100% RCA
Flexural Strength (kN/m^2)	3.90	3.10	3.00	2.3	2.00

RCA = Recycled Coarse Aggregate water/cement ratio = 0.5

The result presented in Table 5 indicate that at 28 days of curing, the flexural strength of the control (0% RCA) is $3.90kN/m^2$ while $3.10kN/m^2$, $3.0kN/m^2$, $2.3kN/m^2$ and $2.00kN/m^2$ are for 25%, 50%, 75% and 100% recycled coarse aggregate replacement respectively. The flexural strength result is compared with Limbachiya *et al.* (2012) and requirement standard for flexural strength of concrete as sited in Kosmatka, Beatrix and Panarese (2002) in Figure 5. The figure reveals the widening margin in flexural strength among the minimum standard, Limbachiya *et al.* (2012) and the results of this study as the recycled coarse aggregate content increases in the mix.

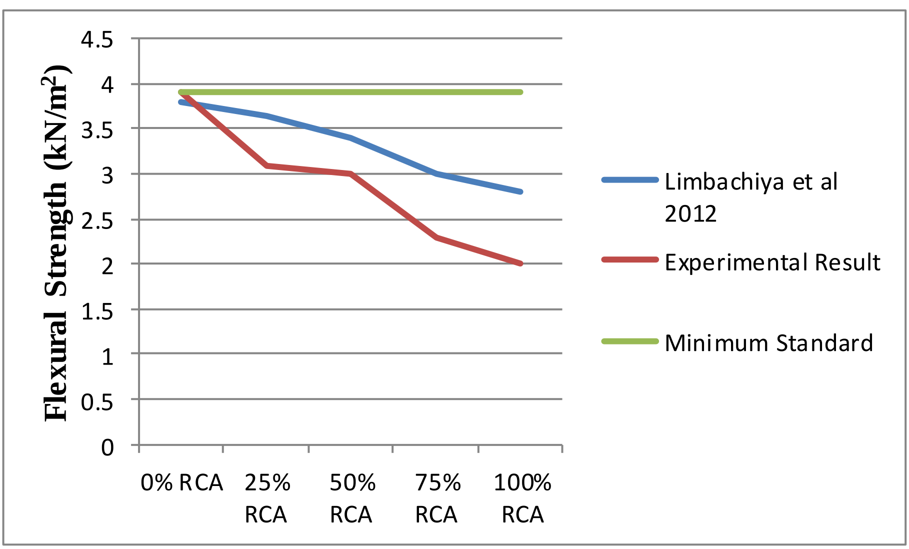

Figure 5: Comparative Analysis of Flexural Strength Test Results with Minimum Standard and Limbachiya *et al.* (2012)

The flexural strength of concrete reduces with increase in recycled coarse aggregate content as seen in Table 5 and Figure 5. This is consistent with Topcu and Sengel (2004) observation. Whereas

Ravindrarajah and Tam (1985) conclude that no significant difference existed in the flexural strength of conventional concrete and recycled aggregate concrete made with RCA. Limbachiya *et al.* (2012) also observed a decrease in flexural strength with increase in recycled coarse aggregate (RCA) at 28 days as shown in figure 5. It is therefore worthy to note that without admixtures and adequate refining of recycled coarse aggregate, concrete made with RCA falls short of flexural strength requirement and hence should not be use in this condition for structural elements and where flexural resistance is of paramount importance, such as pavement.

4.6 Mix Design for RCA

Considering the test results obtained in this research and comparisons with existing researches in this area of studies, it is glaring that using traditional mix design with volumetric method of batching yield better result than batching by mass which was employed in Olowofoyeku *et al* (2012). The result of compressive strength test compared with Limbachiya *et al.* (2012) and Olowofoyeku *et al* (2012) reveals the superiority of using volumetric batching and higher water/cement (0.5) over batching by mass and using lower water/cement ratio (0.4) in production of recycled coarse aggregate concrete (figure 5). The use of volumetric batching yields higher strength because it offers higher cement to aggregate combination and higher water to aggregate ratio thereby providing more water for the high water absorbing recycled coarse aggregate for hydration.

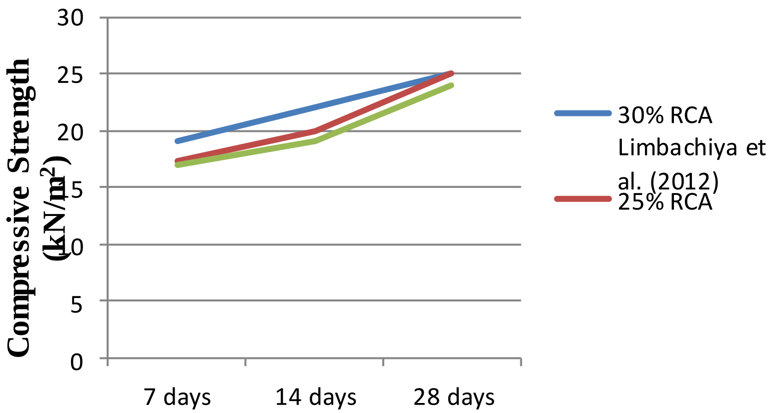

Fig 5 25% RCA Mix Comparison with Limbachiya *et al*. (2012) 30% RCA and Olowofoyeku *et al.* (2012) 24% RCA

The difference in the specific gravity of virgin coarse aggregate and recycled coarse aggregate make more volume of recycled coarse aggregate concrete to be produced in case of partial replacement involving batching by mass. Production and supply of concrete in the construction industry is in volumetric terms, therefore employing volume measurement of ingredients right from batching will enhance simplification of the whole process and reduces wastage.

The compressive strength at 28 days for the 100% recycled coarse aggregate concrete mixture yield just 18.20 kN/m^2 which is a graceful lip over the 17 kN/m^2 compressive strength limit generally acceptable for concrete work of non high strength requirement as recommended by kosmatka, *et al.* (2002) in union with Cement Association. Therefore any mixture lower in cement concentration will produce unacceptable result for 100% use of recycled coarse aggregate in concrete production. Hence, the 1:2:4 cement, sand and coarse aggregate at 0.5 water/cement ratio used in this research forms a bench mark for the application of recycled coarse aggregate that is manually recycled and without admixture in concrete production.

5.0 Conclusion

A sustainable construction has become a great concern in the construction industry all over the world. Resources such as coarse aggregates, sands and ingredients for cements are in disadvantaged position, as these resources are continuously in high demand in the construction industry. Hence, utilizing recycled aggregate is one of the significant efforts in achieving a sustainable construction.

The study found that recycled coarse aggregate influences the properties of concrete negatively. It was observed that there was a reduction in workability, saturated bulk density, compressive strength and flexural strength that are investigated in this research. The workability of concrete reduces with increase in the recycled coarse aggregate content. The reduction in workability with increase in RCA is attributable to the high water absorption of RCA. The saturated bulk density also decreases with increase in recycled coarse aggregate content which was attributed to the low specific gravity of recycled coarse aggregate.

The compressive strength of concrete declines with increase in RCA percentage replacement but increases with increase in duration of curing. At 100% recycled coarse aggregate (RCA) replacement the compressive strength test results reduced by 46%, 39% and 24% for 7 days, 14 days and 28 days respectively in relation to 0% RCA concrete. The gradual reduction in percentage difference is an attribute of the recycled coarse aggregate increase in hydration process overtime spent to partially penetrate and bond the interfacial transition zones in the RCA.

The flexural strength of concrete reduces with increase in recycled coarse aggregate content It is therefore worthy to note that without admixtures and adequate refining of recycled coarse aggregate, concrete made with RCA falls short of flexural strength requirement and hence should not be used in this condition for structural element such as pavement where flexural resistance is of paramount importance.

100% recycled coarse aggregate concrete passed the 17 kN/m^2 compressive strength limit generally acceptable for concrete work of non high strength requirement as recommended by Steven *et al.* (2002) in union with Cement Association.

1:2:4 cement, sand and recycled coarse aggregate at 0.5 water/cement ratio just slightly passed the minimum acceptable compressive strength test. Hence any concrete mix lower in cement concentration will produce unacceptable result for 100% use of recycled coarse aggregate in concrete production. Hence, the 1:2:4 cement, sand and coarse aggregate at 0.5 water/cement ratio with volumetric method of batching used in this research forms a bench mark for the application of recycled coarse aggregate that is manually recycled and without admixture in concrete production.

Based on the current results, it can be said that recycled coarse aggregate may be a viable resource for manufacturing concrete, especially low strength concretes.

6.0 References

Cachim, P. B. (2009). Mechanical properties of brick aggregate concrete. *Construction and Building Materials*, 23, 1292–1297.

CSI (2010). Recycling concrete: Cement sustainability initiative. The World Business Council for Sustainable Development. Retrieved from: http:/www.wbcsdcement.org/pdf/CSI-RecyclingConcrete-FullReport.pdf (accessed 24/10/2014)

Cement and Concrete Association of New Zealand (CCANZ) (2008, July). *Recycled Crushed Concrete in New Zealand (Project 8-H14 Final Report).* Wellington, New Zealand.

Chandra, S. (1996). *Waste materials used in concrete manufacturing* (3rd ed.). Noyes publications,

Grdic,Z. J., Toplicic-Curcic, G. A., Despotovic I. M. and Ristic, N. S. (2010). Properties of self-compacting concrete prepared with coarse recycled concrete aggregate. *Journal of Construction and Building Materials* 24,1129–1133.

Khatib, J. M. and Ellis, D. J. (2001). Mechanical properties of concrete containing foundry sand. *ACI Special Publication*, (SP-2000), 733-748.

Kosmatka, S. H., Beatrix, K. and Panarese, W. C. (2002). *Design and Control of Concrete Mixtures*, EB001, Portland Cement Association,

Available online:http://www.cement.org/tech/faq_strength.asp, accessed 23/10/2014.

Mehta, P.K. (1999). Advancement in concrete technology. *Concrete International*, 21, 27–33

Limbachiya, M., Meddah, M. S. and Ouchagour, Y. (2012). Use of recycled aggregate in fly-ash concrete. *Construction and Building Materials*; 27, 439 -449

Olowofoyeku, A. M., Agoro, M. O. and Olowofoyeku, O. O. (2012). Influence of recycled aggregate on compressive strength of concrete. *The Journal of Building and Construction Management*, 1(3), 125 – 129.

Ravindrarajah R.S and Tam C. T. (1985). Properties of concrete made with crushed concrete as coarse aggregate. *Magazine of Concrete Research*, 37(130):29–38.

SON (2003). Nigerian Industrial Standard for Cement Composition, Specification and Conformity Criteria for common cements. *Designation NIS* 444-1: 2003. Standard Organization of Nigeria.

Yuedong, S. (2007). Experimental research on seismic behaviour of recycled concrete frame under vary cyclic loading. *Tongji daxue xuebao*, 35(8), 1013

Topçu I.B. and, Sengel S. (2004). Properties of concretes produced with waste concrete aggregate.*Cement and Concrete Resource*, 34(8), 1307–1312.

Topcu I. B. and Guncan N. F. (1995). Using waste concrete as aggregate. *Cement and Concrete Research*, 25(7), 1385-1390.

Umoh, A. A. (2012). Recycled demolition waste sandcrete blocks as aggregate in concrete. *Journal of Engineering and Applied Sciences*, 7(9), 1111-1118