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The use of recycled concrete aggregate for concrete production incorporating calcined clay as pozzolanic admixture

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Abstract. Concrete is the most widely used construction material thereby required a lot of raw resources to keep up with its demand. This leads to depletion of raw resources as well as a continuous build-up of demolished concrete wastes (DCW). In most developing nations like Nigeria, the usual way of disposing these DCW is landfilling. However, recycling has become a viable options for conserving the raw resources and reducing greenhouse gases. This study examines the alternative way of reusing concrete wastes for production of fresh structural concrete. The DCW was obtained from the demolition of an existing concrete building and were treated by soaking in water to help reduce the amount of adhered mortar. A mix ratio of 1:1:2 was adopted with a water-cement ratio of 0.25 to attain a relatively high strength concrete and superplasticizer was added to ensure workable mixes. The recycled aggregates (RCA) were used as partial and complete substitute for natural coarse aggregates in percentages of 0, 20, 40, 60, 80 and 100%, while calcined clay was added as pozzolanic admixture into the mixes at 15% and 20% partial replacement for cement. Tests carried out include the physical characterization of the constituent materials and the compressive strength of the hardened concretes were determined after 7, 14 and 28 days of curing in water using cubes of 100 mm × 100 mm × 100 mm. Results showed that the recycled concrete aggregates has high water absorption due to its porous interface. Moreso, results clearly indicate a continual decreasing trend in the compressive strength as the percentages of the RCA increases, however, a significant increase in compressive strength was observed when calcined clay was added as substitute for cement thereby improving the strength development of concrete.

Keywords: Recycled concrete aggregate, Natural coarse aggregate, compressive strength, Sustainability

1. Introduction

The drive for sustainability as regards to our techniques and methods of construction stems from the constant and incessant depletion of the earth's natural resources as well as the adverse effect conventional construction materials (mainly cement) has on the earth's ozone layer due to the emission of CO_2. Concrete is the most widely used construction material in the world and as such a lot of resources are constantly being put into its manufacture. It consists of the earlier mentioned cement as well as fine and coarse aggregate. The coarse aggregate accounts for about 70-80% of the total volume of concrete and this heavily burdens our quarry reserves; hence the need for recycling. The recycling of waste concrete rubbles is a huge step toward sustainability; which entails the development that meets the needs of the present without compromising the ability of future generations to meet their own needs [1]. This concept is vital due to the fact that world population is on the increase every day and to ensure our natural resources do not continue to excessively deplete, sustainable methods/techniques need to be adopted while practicing engineering going forward.

Recycling and reusing of concrete waste as aggregate started since the end of World War II, and its entails the use of aggregates derived from old concrete rubbles which have been processed (to be free from contaminants) for use in the production of concrete. This concept therefore helps to serve as a means of protecting the environment and the earth's natural resources. However, the use of recycled concrete aggregate (RCA) has its drawbacks; the main one being the quite significant reduction in strength (up to 20%) of the resultant concrete as reported by [2]. This loss in strength is dependent on a number of factors including; type of aggregates, the amount of adhered mortar, the curing age, the RCA to natural aggregate (NA) replacement ratio, Parent concrete strength, water absorption, moisture content and the interfacial transition (ITZ) zone [3]. Therefore, over the years, a lot of research has gone into using RCA in partial or full replacement of natural aggregate (NA).

A study by [4] assessed the influence of RCA on the resultant concrete and revealed that the optimum replacement ratio was 25% in order not to compromise the compressive strength of concrete. Another factor that can influence the properties RCA in concrete is the RCA source and this was evident in studies conducted by [5]. Also, in using RCA, its treatment and processing is vital as it dictates vital aggregate properties as water absorption and porosity; which in turn have effect on the compressive strength of the concrete. Studies by [6] and [7] explored various RCA treatment methods including acid soaking method, heating and scrubbing method, coating with cement slurry among others and discovered that all these treatment methods helped improve the compressive strength of RCA but acid soaking method gave the best results. In addition to the RCA treatment methods, the incorporation of pozzolanic materials is a viable way of improving RCA concrete strength. Silica fume [8] and Fly-ash [9] can both be used as they exhibit pozzolanic properties which enables them to react with calcium hydroxide (CaOH) in the matured cement resulting to the production of cementitious material. This therefore increases strength and allows for efficient workability even at low water cement ratios. Other techniques of improving the strength of RCA concrete include the use of limestone filler [10], also with the aim of reducing CO_2 emissions, use of fibers [11], use of ordinary Portland cement (OPC) [12], removal of adhered mortar [13] and the use of nanotechnology [14]; which is a more recent technology. Studies by [15 -18] pointed out that some waste materials can be recycled as alternative construction materials for production of sustainable concrete so as to rid the dump sites of wastes that will be a menace to the environment. The curing method used may also have some measures of effect on the properties of RCA concretes as demonstrated in the study conducted by [19]. Hence, the aim of this study is to investigate the effects of using locally sourced RCA as partial and full substitute of NA in concrete production while incorporating calcined clay as pozzolanic admixture to reduce the Portland cement in the concrete mixes.

2. Materials and Method

Ordinary Portland cement of grade 42.5 was used in this research. The recycled concrete aggregate (RCA) was sourced locally from the environs of covenant University, Ota, Ogun state. The RCA was crushed to the required range of coarse aggregate sizes and were soaked in water for 24 hours prior to their use. This is necessary to help remove some of the adhered mortar as well as reducing the water absorption of the aggregates during the process of mixing. The natural sand used for this study was sourced commercially. Physical tests were carried out on all aggregates, including the determination of the chemical compositions of the Portland cement and calcined clay using the X-ray fluorescence (XRF). Sieve analysis was used to determine the particle size distribution of aggregates used for the concrete production, including the fineness modulus of the materials.

The mix ratio used was 1:1:2 (cement: sand: coarse aggregate) and for all mixes, the cement was partially replaced using 0, 15% and 20% calcined clay as pozzolanic admixture.

Meanwhile, natural aggregates (NA) was partially and completely replaced with RCA at percentage replacements of 0, 20, 40, 60, 80 and 100% at a constant water cement ratio of 0.25 with the addition of superplasticizer to achieve good workable mixes. The mixes were done properly to guarantee even distribution of all constituents. The compressive strength tests were carried out for 7, 14 and 28 days for each replacement of cement with calcined clay and NA with RCA. The moulds used were of dimensions 100 × 100 × 100 mm and were demoulded after 24 hours with adequate caution taken to cover the samples with water proof plastic sheets after casting. The batching of the constituent materials are presented in Table 1.

Table 1. Batching of concrete constituent materials

Materials	**Batching**						
	0%	15%	20%	40%	60%	80%	100%
Cement (kg)	10.0	8.5	8.0	-	-	-	-
Sand (kg)	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Water (kg)	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Calcined clay (kg)	-	1.5	2.0	-	-	-	-
RCA (kg)	0.0	-	4.0	8.0	12.0	16.0	20.0
Granite (kg)	20.0	-	16.0	12.0	8.0	4.0	0.0

3. Results and Discussion

Figure 1 depict the particle size gradation of the constituent materials used in this study. This materials include; RCA, NA, calcined clay, cement, and natural sand. It is evident from the results that Portland cement and calcined clay have similar gradation, which further justify the intent of substituting one for the other in order to have a more sustainable concrete production. Moreover, the particle size distribution and fineness modulus of RCA and the natural coarse aggregate also exhibited extreme similarity, also ensuring the suitability of replacing NA with RCA.

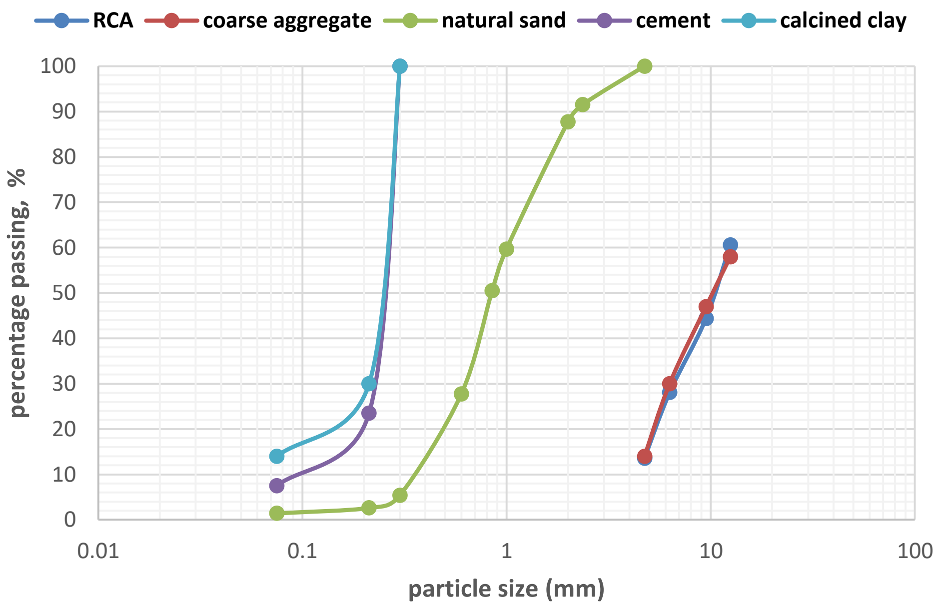

Figure 1. Particle size distribution of RCA, natural aggregate, natural sand, cement and calcined clay

Furthermore, the physical properties of the concrete constituents are presented in the Table 2. The results clearly shows that the RCA absorbs more moisture compare to the natural coarse aggregate (gravel), while the specific gravity is relatively lower compare to the gravel. In order to determine the chemical composition of cement and calcined clay, the X-ray fluorescence (XRF) test was conducted and the results are presented in Figures 2 and 3 for calcined clay and Portland cement respectively. The results revealed that calcined clay has a composition consisting of 55% Silica and 24.9% Alumina, hence, meeting the prerequisite to be refer to as pozzolan. Moreover, following the ASTM C618 recommendation, calcined clay can further be classified as an N pozzolan as the sum of the percentage compositions of Fe_2O_3, SiO_2 and Al_2O_3 (87.3%) is higher than that needed for a class N pozzolan. Contrary to the composition of cement, calcined clay has low percentage of Calcium oxide (CaO) which implies a possible reduction in CO_2 emissions and greenhouse effects. Therefore, the incorporation of calcined clay in concrete production proves to be advantageous and environmentally friendly.

Table 2. Physical properties of concrete components

Properties	Portland Cement	RCA	Sand	Gravel	Calcined clay
Fineness Modulus		5.13	2.69	5.12	
Specific gravity	3.15	2.58	2.62	2.68	3.12
Water absorption (%)		4.22	0.45	1.20	

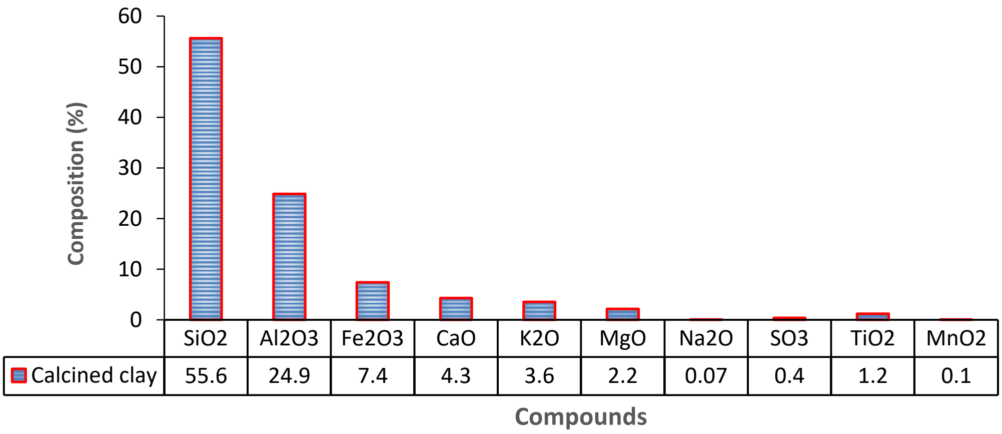

Figure 2. Chemical composition of calcined clay

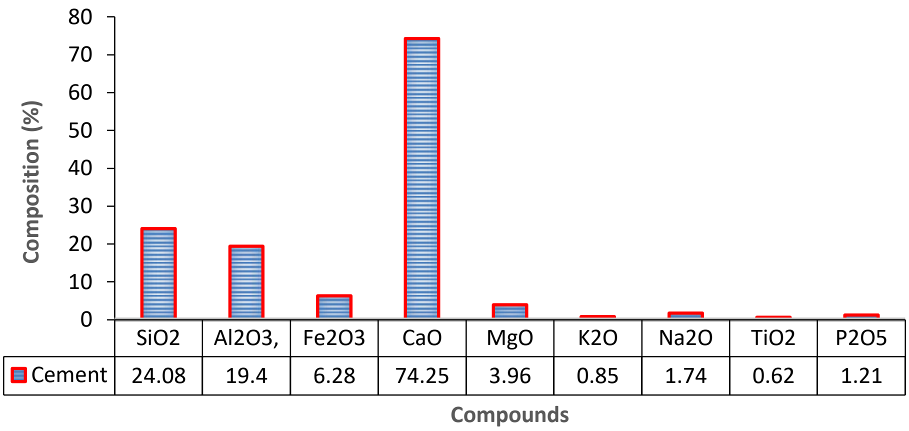

Figure 3. Chemical composition of Portland cement

The results of the compressive strength development with age of the concrete samples are presented in Figures 4 to 6. Figure 4 is the compressive strength results realized by incorporating the different proportions of RCA in percentages (0, 20, 40, 60, 80 and 100%) as replacement for the natural coarse aggregate and calcined clay (15 and 20%) as replacement for cement after 7 days of curing. It was noticed that the replacement percentage of 15% calcined clay gave highest strength across all the RCA replacement percentages. Similar trend was also noticed for 28 days curing age as presented in Figure 5. Meanwhile, it was observed from the results that the highest compressive strength was obtained from RCA concrete containing percentage proportion of 20% RCA replacement for natural coarse aggregate at 15% cement replacement with calcined clay after 28 days of curing.

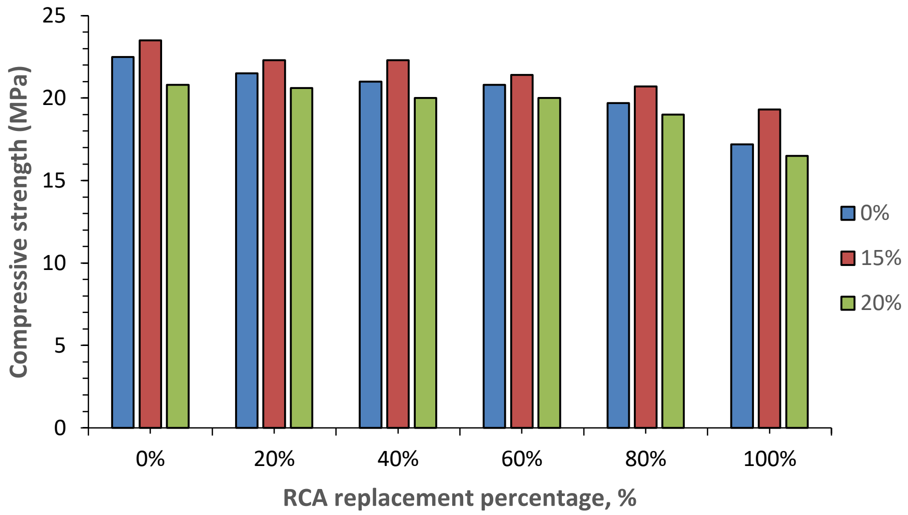

Figure 4. 7-days compressive strength development of concrete containing RCA and calcined clay

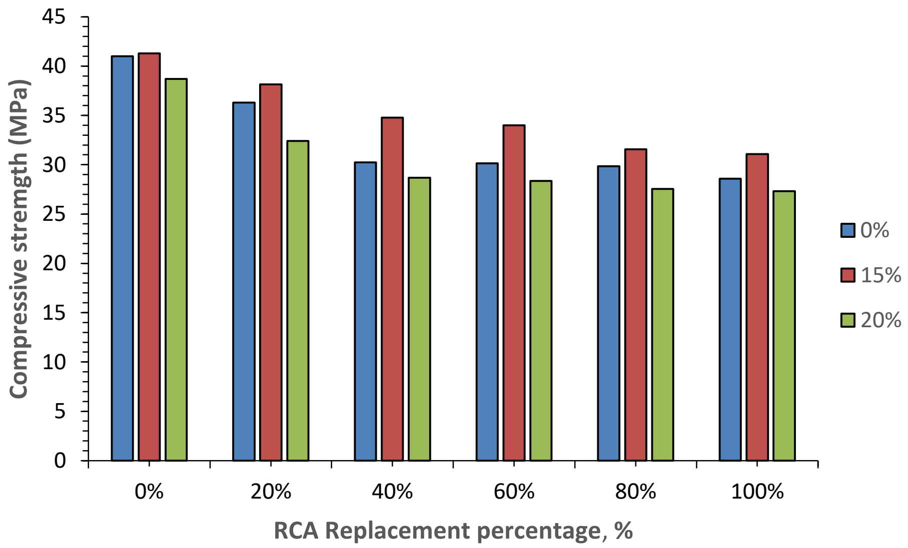

Figure 5. 28-days compressive strength development of concrete containing RCA and calcined clay

Figure 6 shows the progression of compressive strength development as the curing age increases from 7 days to 28 days. The results clearly demonstrate that the concrete strength increases with age. From these results, it can be inferred that 15% is the optimum percentage replacement of cement with calcined clay and 20% RCA replacement will produce a high strength eco-concrete. The results shows that at 20% RCA and 15% calcined clay, the hardened concrete was able to achieve a high strength of about 38.15 MPa compare to the control of 41 MPa after curing age of 28 days.

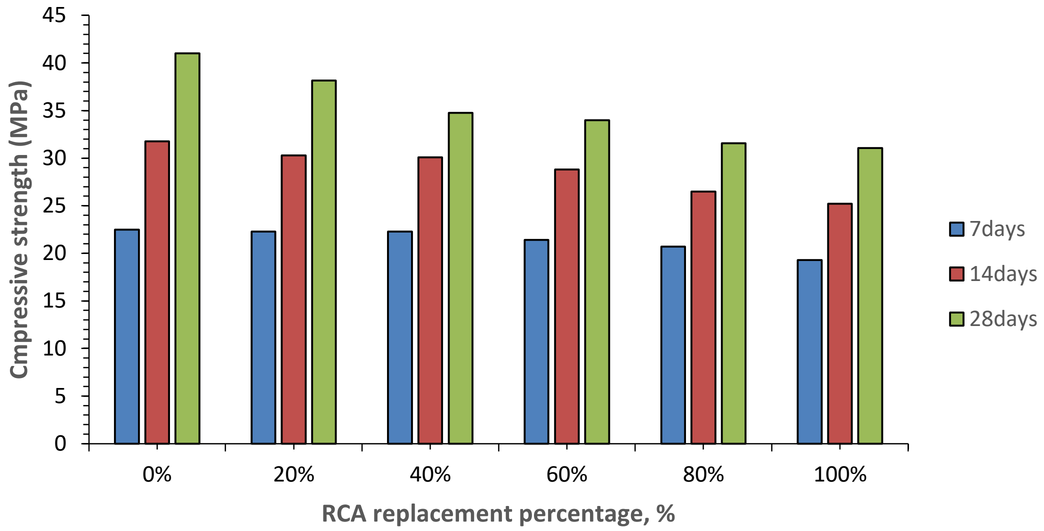

Figure 6. Compressive strength development of concrete after various days

4. Conclusion

This study investigate the sustainable use of RCA for the production of fresh concrete incorporating calcined clay. The following conclusions can be deduced from this study;

i. The chemical composition of calcined clay meets the requirement of an N-pozzolan according to ASTM C618 on pozzolanic materials. Hence, proving that it is suitable for partially replacement of Portland cement.

ii. The results show a steady decrease in compressive strength of concrete with increasing proportion of RCA. However, strength loss is not so steep for 20% RCA replacement, hence, indicating that 20% is the optimum replacement percentage for RCA to replace NA in order not to compromise the strength of concrete.

iii. An improvement in strength was observed with the incorporation of 15% calcined clay as pozzolanic admixture across all mixes, however, a decrease in strength was noticed at replacement level of 20%. Hence, indicating a 15% optimum level of calcined clay can be used for replacing Portland cement in concrete.

iv. Consequently, the most efficient composition for best results will therefore be an RCA replacement of 20% and a 15% calcined clay incorporation. This composition gives a strength loss of about 7.6% as compared with that of NA, thus, proving RCA and calcined clay may be used for fresh eco-concrete production.

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