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NOVEL CONCRETE MIXTURE USING SILICA RICH AGGREGATES: WORKABILITY, STRENGTH AND MICROSTRUCTURAL PROPERTIES

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The persistent reliance on traditional construction materials is of no gain to the future generation. The rate at which the natural aggregate sources are explored is alarming, and as a result, the threat of depletion of the natural materials has inspired interest in sustainable construction materials, focusing on construction and demolition wastes and local materials. In this study, an experimental insight on modified concrete, based on workability, strength and microstructural properties, is provided, in an attempt to ascertain the suitability of silica-rich aggregates (ceramic industry wastes and laterite) as a replacement for conventional fine and coarse aggregates. Various mix proportions were considered, and material batching was done by weight for concrete casting. The workability test, using slump, indicates that the flowability of the modified concrete mixes is achievable at a water-binder ratio of 0.6. The strength properties of the concrete increased with the increasing ceramic substitution for granite while increasing laterite content beyond 10% negates the strength gain by the concrete. A concrete mix containing 90% ceramic fine and 10% laterite, as fine aggregate, and 100% of cement and ceramic coarse, as binder and coarse aggregate, respectively, gave higher compressive strength (22.5 MPa), and split-tensile strength (3.6 MPa), and these results were found as comparable to the conventional concrete.

Keywords: Compressive strength, Hydration, Interfacial transition zone, Morphology, Recycled aggregate, Split-tensile strength.

1 INTRODUCTION

The high growth rate in world population and increasing urbanization, are major, among many factors that are contributing to the scarcity of construction materials, and this has caused the cost of natural aggregates to rise in some parts of the world (Karthik *et al.* 2017). Thus, more volume of aggregates is needed to be able to meet the current world demand. The attention of researchers are drawn towards the use of solid wastes resulting from industrial and construction activities for construction, so as to prevent an event of total depletion of the natural aggregate sources, and moreover, to reduce the environmental nuisance caused by the disposal of solid wastes (Murthi *et al.* 2018). Ceramic wastes sourced from production (Juan *et al.* 2010), and those sourced from construction and demolition (García-González *et al.* 2015, Awoyera *et al.* 2018), have been considered as a partial replacement for conventional aggregates and cement. Those studies showed that ceramic aggregate addition to concrete could improve both its physical and mechanical properties. There are also investigations that showcased the pozzolanic reactivity of ceramic products (Elkhadiri and Puertas 2008).

On the other hand, laterite as a local soil material has been studied (Awoyera *et al.* 2017) to explore its potential as a replacement for river sand; most studies reported that the strength properties of concrete containing laterite were near that of conventional concrete. Laterite is often regarded as a marginal material, and only a 10 – 30% of it can be added to concrete (Awoyera *et al.* 2016). However, despite the extensive studies on the use of ceramics and laterite in concrete, there is still scanty information regarding combined addition of these two materials in concrete. Therefore, this study investigates the use of ceramic tiles sourced from construction and demolition sites, and laterite, an abundant soil material in sub-Saharan African countries, as a replacement for natural aggregates in concrete. The strength properties and some microscale properties of the concrete are determined.

2 EXPERIMENT

2.1 Materials and Methods

The ceramic tiles, comprising of mostly floor and wall tiles, used in this study was sourced from construction and demolition sites in Ota, Ogun State, Nigeria. The ceramics were crushed using a hammer mill, and subsequently pulverized and graded to reflect natural aggregates, using British standard (BS) sieves, into coarse (12.7 mm) aggregate and fine (0 – 4 mm) aggregate categories. Laterite was sampled at a depth of 10 meters in a borrow pit located within the precinct of Covenant University, Nigeria. The soil has been exposed to several borrowing activities by land fillers and construction workers. The coarse ceramic aggregate was substituted for granite, while its fines, and laterite were substituted for river sand. Ordinary Portland cement conforming to standards (BS 12 1989) was used as a binder. The aggregates were air-dried for a few weeks before use. A mix proportion of 1:1.5:3 (binder, fine aggregate: coarse aggregate), and a constant water/binder ratio of 0.6 was used. The mix proportions for concrete samples are presented in Table 1, and Table 2 shows the physical properties of the aggregates. The properties of both laterite and ceramics are in close range of the recommended standards for natural aggregates.

The morphology of pulverized ceramic and cement was obtained using a Scanning electron microscopy (SEM - Hitachi S4100 equipped with energy dispersion spectroscopy, EDS – Rontec) at 20 kV. The SEM micrographs of ceramic particles and cement are shown in Figures 1a and 1b respectively. These images were captured at high magnification, and the analysis was performed with X-ray microanalysis (EDS). The dominant oxides identified in the ceramics were silica (SiO2) while calcium oxide (CaO) was seen in the cement. Concrete samples produced include cubes of 150 mm dimensions and cylinders of 100 mm x 200 mm. The batching was done by weight while casting the concrete samples. The samples were removed from the mold after 24hrs of casting and cured in water for maximum 28 days. During casting, workability of the concrete mixes, using slump (as per the requirements of BS EN 12350-2 2009), was randomly assessed before placing the concrete in the molds. The slump results for all fresh concrete mixes were in the range 50-60 mm, which represent a true slump condition. Concrete that falls into this category are usually considered for the purpose of casting structural elements such as beam, slabs, columns and foundations.

Strength properties were determined (as per the requirement of BS EN 12390-6 2006), after 3, 7, 14, and 28 days curing, using triplicate samples from each mix. The microstructure of selected samples (obtained from the crushed cubes), comprising of the reference mix, and a sample with optimal strength from the modified mixes, were examined using SEM techniques in backscattered mode. This approach helps to visualize the interfacial transition zone between aggregates and bulk cement pastes in concrete.

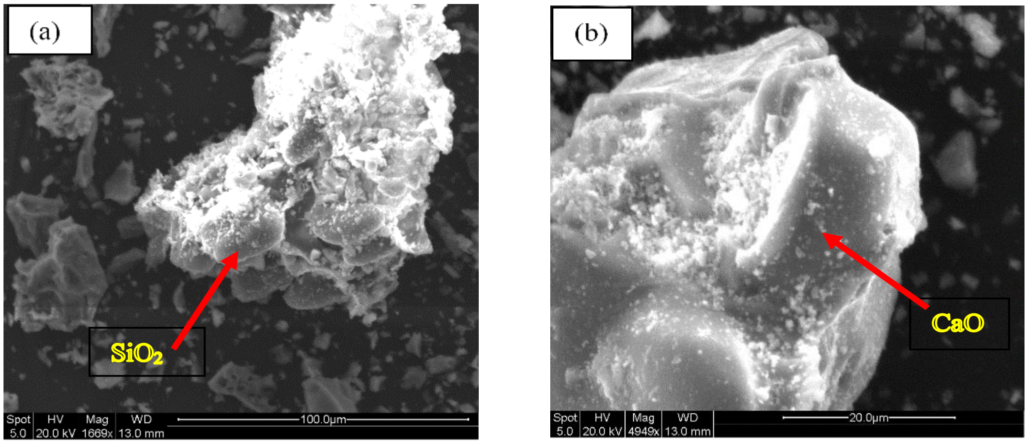

Figure 1. SEM micrograph of (a) Ceramic particles (b) cement.

Table 1. Mix proportion design (%) for concrete samples.

Mix ID	Binder	Fine Aggregates			Coarse Aggregates		w/c
	Cement	Sand	Ceramic fine	Laterite	Granite	Ceramic coarse	
Ref	100	100	-	-	100	-	0.6
M10	100	90	-	10	100	-	0.6
M20	100	80	-	20	100	-	0.6
N0	100	-	100	-	100	-	0.6
N10	100	-	90	10	100	-	0.6
N20	100	-	80	20	100	-	0.6
L0	100	-	100	-		100	0.6
L10	100	-	90	10		100	0.6
L20	100	-	80	20		100	0.6

Table 2. Physical properties of aggregates used.

Properties	**River sand**	**Laterite**	**Ceramic fine**	**Ceramic coarse**	**Granite**
Specific gravity	2.61	2.13	2.26	2.31	2.87
Water absorption	2.24	4.70	2.52	0.55	0.23
Fineness modulus	2.24	1.80	2.20	6.88	6.95
Aggregate crushing value	-	-	-	20.86	34.00
Aggregate impact value	-	-	-	27.00	24.00

3 RESULTS AND DISCUSSIONS

Figures 2 and 3 show the compressive strength and the split-tensile strength respectively, gained through 28 days curing of the samples. The axial compressive strength of all the concrete samples tested increased as the curing age increased, however, the reference sample demonstrated higher strength than the modified mixes. The samples M10, N10, and L10 (containing 10% laterite), gave maximum compressive strength which represented an approximately 11% strength gain over the mixes without laterite. The increased compressive strength could be influenced by the pozzolanic influence of fragments of ceramic aggregate or due to chemical effect of laterite in concrete containing minimal laterite (10%), which apparently contributed to the hydration of the concrete and consequently enhanced the compressive strength.

There was no significant increase in strength as laterite was increased beyond 10%, this could be as a result of retarding effect of laterite on hydration because laterite contains large clay minerals, which may alter the rate of hydration. This effect might be taken care of by curing concrete containing laterite for a longer duration in order to allow it to complete its hydration.

When 28-day strength was considered, sample L10 from the modified mix gave the highest strength among these set, however, this sample had a 9% less strength than the reference mix. The increased strength in the reference concrete suggests that the hydration within the reference concrete matrix reached its peak within 28-days curing. This suggests that an improved interfacial transition zone (ITZ) exist between ceramic aggregate, laterite, and hardened cement paste. Similar to the compressive strength tests, the split-tensile strength of all the samples increased with increasing curing age. Also, mixes M10, N10, and L10 (containing 10% laterite) gave the higher values of split-tensile strength, which represented an approximate 8% strength gain when compared with the samples without laterite. The split-tensile strength also decreased as the laterite content was increased beyond 10%.

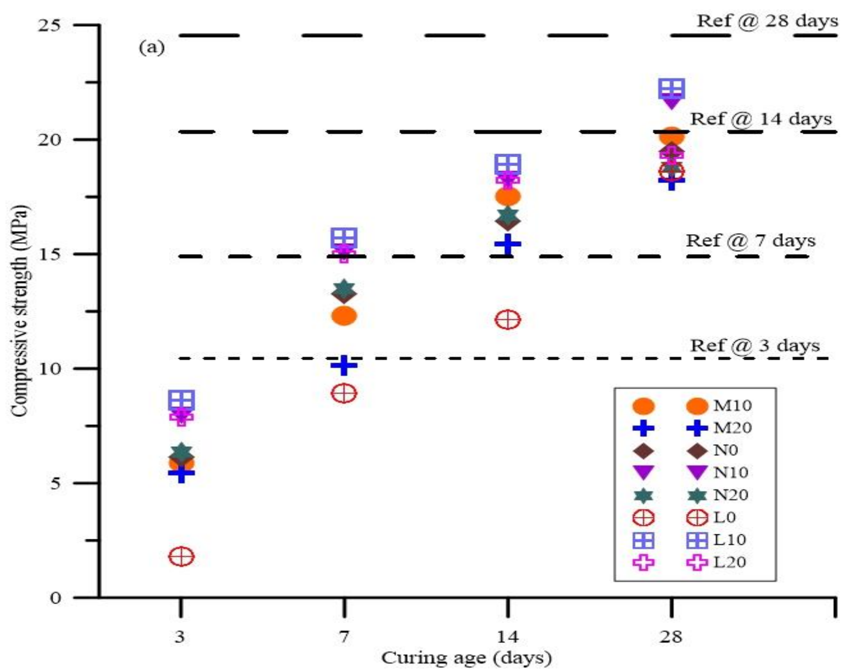

Figure 2. Compressive strength development with curing age.

This increase in the splitting strength of the mixes N10 and L10 may be a result of the considerably higher water content used (Liu *et al.* 2015) because there will be enough water for hydration despite absorptions by ceramic aggregate and laterite aggregates prior to the hydration process.

The SEM micrographs of the mix L10, having higher strength from the modified samples, and the reference concrete is shown Figures 4a and 4b respectively. A relatively well-compacted ITZ can be seen in the reference concrete when compared with the mix L10. Therefore, it can be inferred that the rigidity of the ITZ in concrete depends largely on the hydration mechanism, which in turn influences the strength properties.

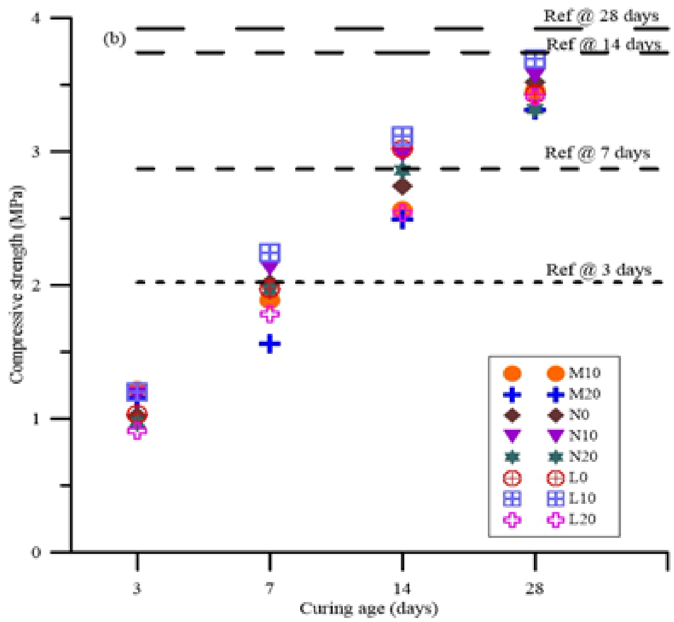

Figure 3. Split-tensile strength development with curing age.

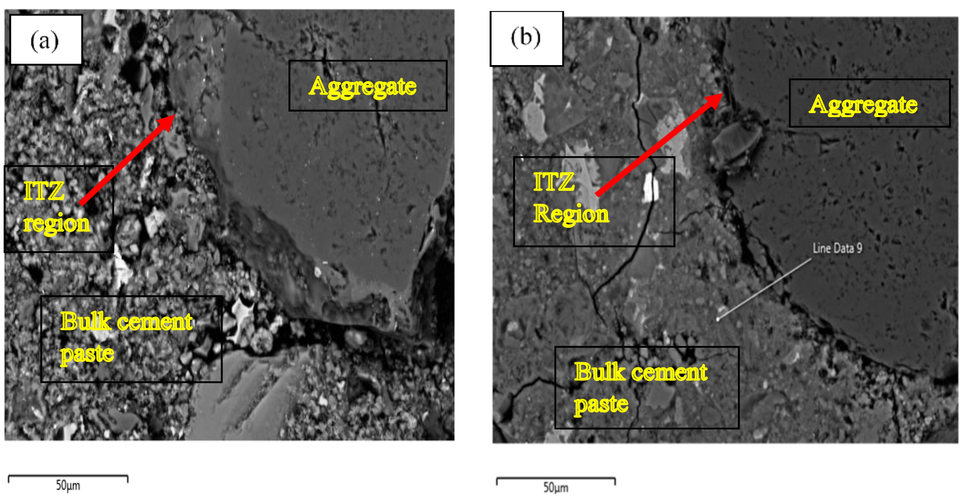

Figure 4. SEM micrographs of (a) optimal modified mix (b) reference concrete.

3 CONCLUSION

The concrete mixes considered in this study demonstrated an increase in both compressive and splitting tensile strengths with increasing curing age. The reference concrete has higher strength properties than the mixes containing alternative aggregates, and this strength increase was attributed to rapid hydration in the concrete. Furthermore, the reference concrete produced higher strength as a result of an improved ITZ.

For the modified mix categories, a ceramic fine and laterite substitution in the proportion of 90% and 10% respectively, for river sand, and 100% coarse ceramics for granite, enhanced both the compressive and splitting tensile strengths.

Acknowledgments

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