New Light Weight Mortar for Structural Application: Assessment of Porosity, Strength and Morphology Properties

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Abstract. Over reliance on the conventional construction materials majorly contribute to the depletion of the natural sources, this also affects sustainability of the future generation. The natural aggregate sources are being explored at an alarming rate, therefore, the threat of depletion of the natural materials has inspired interest in sustainable construction materials, through utilization of solid wastes and local materials. In this study, an experimental insight on modified mortar, based on strength and microstructural properties, is provided, in an attempt to ascertain the suitability of ceramic industry wastes and laterite as a replacement for conventional aggregates. Various mix proportions were considered, also batching was done by weight when casting the mortar samples. The results showed that there was significant improvement in strength as the ceramic substitution for river sand was increased. However, increasing laterite content beyond 10% negates the strength development in the samples. Overall, the study has developed a suitable lightweight mortar, comprising of 10% ceramic powder, and 100% fine ceramic contents, with strength properties as that of the conventional mixes, and also ecofriendly for use.

Keywords: Sustainability · Mortar · Laterite · Ceramic waste · Microscale analysis

1 Introduction

The demand for affordable materials for building construction is on the increase in developing and underdeveloped countries. The natural aggregate sources are over explored, and this is resulting into high cost of the materials [1], and coupled with instability in economy [2, 3].

However, incessant exploration of these sources creates a number of environmental problems in form of pollution and emission of toxic substance into the environment. On the other hand, numerous solid wastes resulting from industrial and construction activities are investigated for potential reuse for construction [4]. Many of the discarded materials have also been found suitable for solving durability issues in concrete [5]. Despite the advancement in research relating to the recycling of waste materials, ceramic waste has been identified as non- recyclable, yet improper management of this

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kind of materials could result into serious environmental challenges. It has been reported that about 30% of ceramic content ends up as wastes during its production, and this portion of the material is stockpiled and landfilled [6–9]. This is certainly a reason to consider reusing the ceramic wastes.

There are two categories of ceramic wastes, based on the raw material sources [10]. One covers those involving the use of red pastes for product manufacture. While there are also those in form of stoneware.

In recent years, studies have shown that ceramics and other silica rich materials are suitable for making mortars and concrete [11–14], when used as a replacement of the conventional aggregates.

Laterite, on the other hand, has been a famous construction material, mostly used for production of earth blocks [15]. In some sub-Saharan African countries, laterite has been used for building low cost houses, and as earthwork filling material for road pavement and earth dams. However, advancement in research has shown that laterite is a suitable material for making concrete, when it is used as a partial replacement of sand in concrete [16, 17].

On the other hand, Awoyera et al. [18] recently explored the strength properties of concrete containing laterite and ceramic aggregates, the study reported that the new concrete possessed somewhat similar characteristics as the conventional concrete. This is an indication that incorporation of ceramics and laterite as replacement of natural aggregates can be a viable construction innovation.

However, in the current study, an overview on the strength and microstructural properties of modified mortars made with laterite soil and fine ceramics is presented. The strength and microstructural properties of the modified mortars are analyzed.

2 Materials and Methods

Ceramic wastes resulting from construction and demolition activities was used in this study. It is comprised mainly of floor and wall tiles. The ceramics were cleaned to remove dirt on them, before they were crushed using a hammer mill into granular sizes (2–4.75 mm), thus reflecting the sizes of natural fine aggregates. While, certain portion of the ceramics was further grinded and sieved through 50 μ aperture size.

A laterite soil, belong to A-7-6(7) group, of sizes finer than 4.75 mm aperture, was used as part of the fine aggregates. It was sourced within the precinct of Ota, south-western Nigeria. Other materials used include grade 32.5 cement, river sand and potable water. Table 1 presents the physical properties of the aggregates used. The chemical oxide contents of the cement and ceramics (measured by X-ray fluorescence) were determined in a preliminary investigation [19].

Mortar samples, produced with binder-sand ratio of 1:3, and sizes 40 × 40 × 160 mm were investigated. Table 2 shows the mix design for the mortar samples. Curing of mortars commenced immediately after final setting for a 28 days regime. Afterwards, the compressive strengths were determined in line with procedures in BS 1015-11 [20]. However, prior to mechanical tests, void distribution in the samples was measured with the aid of a 2D X-ray CT machine. Also, the morphology of samples having higher compressive strength, and the reference samples were further evaluated using Scanning Electron Microscopy (SEM). This was done to aid understanding and interpretation of the strength development (Table 3).

Table 1. Aggregates properties

Properties	River sand	Laterite	Ceramic fine
Specific gravity	2.61	2.13	2.26
Water absorption (%)	2.24	4.70	2.52
Fineness modulus	2.24	1.80	2.20

Table 2. Chemical composition and physical properties of cement and ceramic powder [16]

Chemical composition	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	Fe_2O_3
Ceramic powder (%)	2.04	15.07	64.56	1.05	2.132	4.148	0.745	6.014
Cement (%)	3.19	19.48	24.09	1.14	0.847	74.211	0.619	6.273

Table 3. Mix design

Binder			Fine aggregates			w/c
Mix	Cement (g)	Ceramic powder (g)	River sand (g)	Ceramic fines (g)	Laterite (g)	
Ref	450	-	1350	-	-	0.6
M10	405	45	-	-	1350	0.6
M20	360	90	-	-	1350	0.6
M30	315	135	-	-	1350	0.6
N10	405	45	-	1350	-	0.6
N20	360	90	-	1350	-	0.6
N30	315	135	-	1350	-	0.6
F25	450	-	-	337.5	1012.5	0.6
F50	450	-	-	675	675	0.6
F75	450	-	-	1012.5	337.5	0.6

3 Results and Discussions

Figure 1 shows the compressive strength of mortars obtained at 28 days curing. The results showed that samples dominated with more fine ceramics (N10, N20, and N30) and mix F75, produced better strength than the control samples. The addition of ceramics to these mixtures contributed to the strength development, in that, ceramics enhanced the compactness of the matrix, and also resulted in less pore structure of the mortars. The mixture with higher composition of ceramics (N10) gave the higher strength. As a result, mix N10 and reference mix was selected for the micro scale evaluation. Also, the appreciable strength developed in the mix N10 could be attributed to possible pozzolanic activities and filler action induced by ceramic powder. Jamil et al. [21] and Chindaprasirt and Rukzon [22], in a related studies, attributed filler actions by supplementary cementitious materials to aiding strength improvement in blended cement based materials. Such actions certainly occurs when the alternative binder material is finer than the cement particles. Figures 2(a) and (b) present the SEM micrographs of the selected mix (N10) and reference mortars, respectively. The structure showed that N10 mortar is dominated by porthlandite ($Ca(OH)_2$) while the reference mortar had large calcium silicate hydrate (C-S-H).

Based on the result, it is evident that there was adequate bonding between the fine ceramics and cement paste. Moreover, there is also a tendency that the ceramic powder contributed to pozzolanic action in the matrix. And as a result, the strength properties was enhanced. However, laterite dominated mortars (M10, M20, and M30) produced minimal strengths, and the later also decreased with increasing laterite content. Such reduction in strength could be a function of large clay content in the laterite. This can be improved by thoroughly washing laterite before use in a cementitious material.

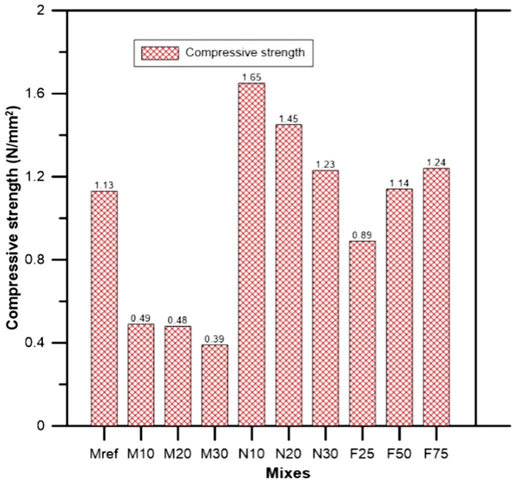

Fig. 1. Compressive strength of tested mortars

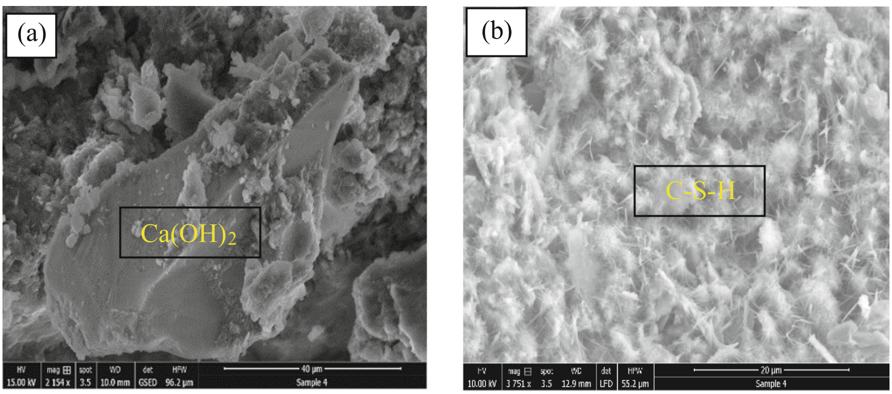

Fig. 2. SEM micrographs (a) N10 mortar (b) reference mortar

The internal structures of both N10 and reference mortars were evaluated using X-ray CT scans, and the images obtained were analyzed using an imaging software, ImageJ. The air void distribution along the heights of the mortars is presented in Fig. 3. From the analysis, it can be deduced that the inherent air void content distribution across the mortars was not homogenous for the samples. In the N10 mortar, the air void distribution appears uniform, however, in the reference mortar three different regions with respect to the void distribution can be measured along the height of the mortars. In the reference samples, there were relatively low void content at the bottom region, high void content at the middle, and low at the top region.

The air void content in this mix is higher than in the N10 sample. This kind of defect can contribute to the failure pattern in cement based material. Yuan & Harrison [23] inferred that the heterogeneous microstructure in a material could influence a significant improvement in the destructive transverse tensile strains when the material is subjected to loading, in which stress concentrations around the pore areas could provide a weakness zone for failure to take place.

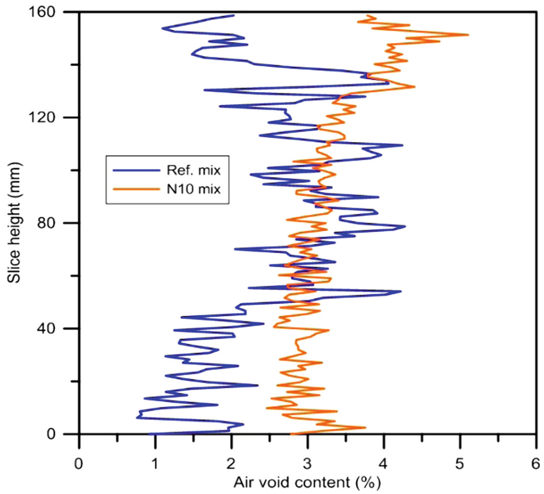

Fig. 3. Air void distribution of the mixtures

4 Conclusion

The influence of incorporating laterite and ceramics as replacement of conventional construction materials for making mortars has been explored. The strength of mortars increased with increasing ceramic content, however adding laterite beyond 10% reduces the strength of mortars. The compressive strength of a mortar mix containing 10% laterite as replacement of sand, and 100% ceramic aggregate was found as comparable to the conventional mortar.

The study also showed that pozzolanic reaction resulting from ceramic addition in the optimum mixture helped to reduce void distribution along the length of the mortar.

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