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Suitability of mortars produced using laterite and ceramic wastes: Mechanical and microscale analysis

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HIGHLIGHTS

- With total replacement of sand with ceramic fines, dry bulk density decreased with increasing ceramic powder.
- Laterite dominated samples have higher water absorption by capillary action.
- Strength increased due to filler action and relative pozzolanic reaction of ceramic.
- Structure of ceramic based concrete appears compacted than conventional concrete.

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ABSTRACT

Using industrial wastes and local materials as artificial aggregates in cement based materials remains a relevant measure for conservation of natural sources. In this study, novel cementitious mixes containing pulverized ceramic blended cement, ceramic aggregate and laterite were systematically combined to produce cement mortars. The mortar specimens were cured in water for a maximum of 28 days. At maturity, nondestructive tests, X-ray CT scan and ultrasonic pulse velocity, were performed on hardened mortars. Thereafter, a series of predefined properties, namely dry bulk density, compressive and flexural strength, water absorption coefficient (due to capillary) of the hardened mortars were determined. Finally, in order to understand the hydration mechanism of the materials as it relates to the strength properties, microscale tests, SEM and XRD, were used to examine the fragments of the selected mortars. From the results, a mortar sample containing 10% ceramic powder and 100% ceramic aggregate as replacements for cement and sand respectively, gave higher strength values than the reference and other mixes. Microstructural analysis of the best mix revealed that it has larger proportions of ettringite, portlandite and calcite than the reference mix, and this could be responsible for the strength gained. Thus, despite the apparent low reactivity of crushed ceramic material, this can improve bonding in cement-based mixture, when used at an appropriate concentration.

1. Introduction

The last few decades have witnessed several investigations involving the use of new materials which can replace the conventional materials for concreting. These new materials are selected for investigation either because they are abundantly available or, in the case of waste materials, because they constitute a nuisance to the environment. Both aforementioned reasons are the motivations for the current study. Laterite is an abundant soil material normally found in sub-Saharan African countries and, for decades, it has been utilized for production of bricks. On the other hand, during production of ceramic tiles, about 30% of the materials used unavoidably end up as waste. Also, ceramic wastes are found as part of construction and demolition rubble. Therefore, the aim of this study is to make use of both laterite and ceramic materials as substitutes for sand and cement in making mortars.

In recent years, mortars made with various modified materials have been investigated [1–15]. Such studies have been conducted in a quest to find alternative materials which can replace depleting natural materials. However, approval for such materials is subject to whether their physical and engineering properties match those of conventional sources.

Due to sharp edges of its particles, broken coarse aggregate is viewed as a hazardous waste. Thus it would constitute an

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environmental benefit if ceramic, which is a hazardous wastes, can be incorporated into making mortar or concrete. Whether it is possible to obtain such a benefit may depend on the particular ceramic supply because, the performance of ceramic products can vary depending on the source. Ceramic products possess varying properties due to the different conditions and composition of materials used in their production.

Studies such as [12,16–18] have explored the suitability of sanitary wares, white and red ceramic as aggregates in mortar and concrete. Thus, it has been established that these ceramic products could replace natural aggregates in concrete, due to the observed strength performance of such concretes. Furthermore, the improved properties of concrete with ceramic can be attributed to the high specific surface of ceramic [13], as well as the high concentration of silica (SiO_2) and alumina (Al_2O_3) in ceramic amorphous phase [19,20]. As a result, the pozzolanic reactivity of ceramic in concrete can be enhanced.

In recent years, advancement in research has led to the innovative use of laterite or lateritic soil as a concrete ingredient, as well as its routine use in brick production. A quantity of laterite ranging from 10 to 30% is recommended for a replacement of natural sand in concrete [21,22], especially when a volumetric mix of 1:1.5:3 (cement; sand; gravel) is to be used. Unfortunately, adding large amounts of laterite to concrete may negate the strength development in concrete, because laterite contains fine clay materials.

Currently, there are quite a number of interesting studies regarding the use of laterite [21,23–25] and ceramics [16,18] as replacement for natural aggregates. However, there are no many studies [21], which have considered using both laterite and kaolin-rich material such as ceramic or marble products in mortar and concrete. Therefore, the current study is aimed at exploring different combinations of laterite and ceramic fines as a replacement for natural fine aggregate in mortars, and also at identifying the significant effects associated with such combinations on strength and microstructure properties of mortars. To help understand the observed behaviour, the study aims to determine the hydration products of the mortars after being cured for 28 days.

2. Materials and method

2.1. Materials

The ceramics, which comprised mainly floor and wall tiles, used in this experimental work were sourced from different construction and demolition sites within Lagos and Ota, in southwestern Nigeria. The ceramic sources are from different manufacturers, but they are originally of stoneware ceramic source. The ceramics were washed with water in order to get rid of debris that stuck to the surface, and subsequently they were air-dried for a few days. Thereafter, a hammer mill was used to grind the ceramic into granular sizes of 2–4.75 mm. Another portion of the ceramics was pulverized to a powder size of about 50 μm. The laterite used in this study was collected at a depth of about 6 m, from the sidewall of an excavated lateritic soil profile, located within the precinct of Ota, southwestern Nigeria. The laterite was classified as A-7-6(7), in line with the American Association of State Highway and Transportation Officials (AASHTO) system of soil classification. The portion of the soil that passed a 4.75 mm aperture size was used for the study. Ceramic powder was substituted for cement at 10%, 20% and 30%, laterite and ceramic fines were substituted for sand fines at different percentages. A grade 32.5 cement was used, which conforms to the regulations of the Standard Organization of Nigeria (SON), regarding mortar production. Also, natural river sand was used as part of the fine aggregates. Finally, drinkable water was used for mixing the mortar constituents. The physical properties of the aggregates are presented in Table 1. As can be seen, the laterite possessed about double the water absorption capacity of river sand or ceramic fines, a result that can be attributed to its high clay content. [26] also made a similar observation while working on laterite stones. However, there is greater closeness in the specific gravity and fineness modulus values of the three materials. The grading curve for the aggregate used is shown in Fig. 1. Also, the particle size gradation for cement and ceramic powder is shown in Fig. 2. The ceramic powder particles are finer than the cement. This will facilitate adequate blending of the two materials [27]. The oxide composition of cement, ceramic powder and laterite was determined using X-ray fluorescence (XRF) and the result is presented in Fig. 3. The pozzolanic potential of the ceramic powder used was established from a preliminary investigation [28], following the ASTM C618 criteria.

Table 1
Physical properties of aggregates.

Properties	Riversand	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

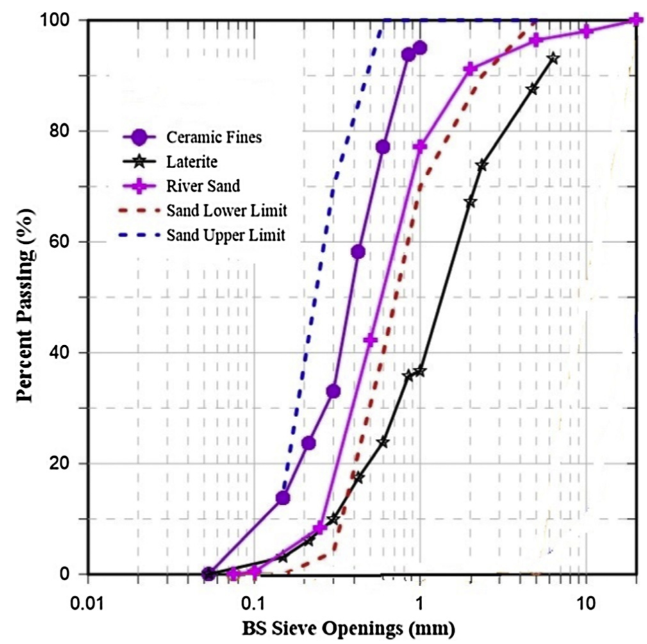

Fig. 1. Particle size distribution for aggregates used.

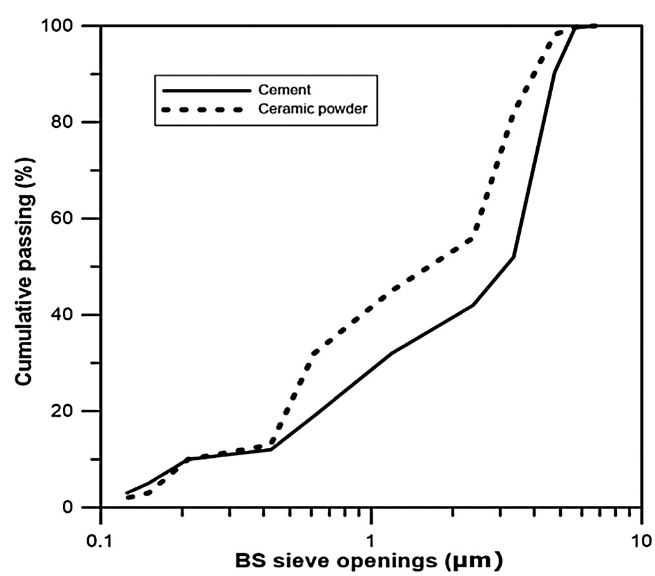

Fig. 2. Particle size distribution curve of cement and ceramic powder.

2.2. Methods

Ten mortar mixes were considered as shown in Table 2, one reference mixture (Mref) – containing conventional materials for comparison, and nine others containing various combinations of ceramic powder, laterite and ceramic fines. A total