Curing, thermal resistance and bending behaviour of laterised concrete containing ceramic wastes

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Abstract: Recent years have witnessed an increase in volume of construction and demolition wastes generated in some developed and developing countries, which mostly constitute environmental issues. Therefore, it is important to explore the potential of such waste materials, or when used with locally available materials for concrete production. Thus, this research effort aims at determining the effects of curing methods (polythene wrapping and water immersion), and exposure to high temperature, on strength characteristics of laterised concrete samples made with ceramic floor tiles wastes as aggregates. The study also explored the bending behaviour of steel reinforced beam mixes comprising ceramics and laterite. From the obtained results, samples made with ceramic and laterite developed higher strengths when cured with polythene covering than the water cured samples. However, the reference concrete samples developed better strength in normal curing condition (immersion in water). In terms of thermal resistance, the laterised samples had better resistance at elevated temperatures than the reference concrete. Lastly, for the tested beams, the maximum mid span bending strength decreased with increasing laterite content. Overall, it can be considered that ceramic floor tiles wastes with minimal laterite content can be used for concrete production, and by doing so, the negative impact of these wastes on the environment can be controlled.

Subjects: Concrete and Cement; Structural Engineering; Waste and Recycling

Keywords: elevated temperature; flexural strength; laterised concrete; compressive strength; ceramic wastes

1. Introduction

One of the key approach to environmental sustainability is the adoption of locally available waste materials for construction. A wide range of new materials obtained from the local source and from PUBLIC INTEREST STATEMENT

The rapid growth in world population coupled with changing lifestyle has contributed largely to the global demand for concrete. About 7 billion cubic meters of concrete is produced annually, meanwhile the natural aggregate sources suffer persistent exploration, which makes depletion of the materials alarming. Therefore, it becomes pertinent to adopt materials from other sources such as involving the use of construction and demolition rejects for construction. This approach is acceptable to ensure sustainability in the built environment.

On the other hand, the waste materials emanating from construction activities constitute significant effect on the environment. These include global warming potential and the photochemical ozone layer creation. This challenges discredit the disposal of the materials without further processing, or incorporation as a green addition for concrete production, in as much as the properties reflect those of the conventional materials.
solid wastes are constantly explored for use for making concrete (Awoyera, Adekeye, & Babalola, 2015; Emmanuel & Oluwaseun, 2016; Formisano, Desi, & Landolfo, 2017; Formisano, Fabbrocino, Desi, & Chiumiento, 2017; Sathanandam, Awoyera, Vijayan, & Sathishkumar, 2016). This step helps to determine their beneficial use. Research findings have shown that construction and demolition wastes are viable inclusion for production of fresh concrete (de Brito & Alves, 2010; Silva, de Brito, & Dhir, 2014). In order to evaluate the performances of a new concrete developed with local materials, its properties need to be tested for a sufficient number of times and compared with those of the conventional concrete. Both compressive and flexural strengths are the most important properties of concrete, because they are major indicator of its quality. Recently, a number of investigations involving ceramic wastes use as natural aggregate replacement have been conducted (Awoyera, Akinmusuru, Dawson, Ndambuki, & Thom, 2018; de Brito, Pereira, & Correia, 2005; García-González, Rodríguez-Robles, Juan-Valdés, Morán-Del Pozo, & Guerra-Romero, 2014; Medina, Sánchez De Rojas, & Frios, 2012, 2013; Mustafa Al Bakri, Norazian, Kamarudin, Mohd Salleh, & Alida, 2013; Senthamarai, Devadas Manoharan, & Gobinath, 2011; Senthamarai & Manoharan, 2005; Suzuki, Meddah, & Sato, 2009). It has been revealed that both the type and size of ceramic aggregates are highly responsible for the ultimate performance of recycled concrete (Awoyera, Ndambuki, Akinmusuru, & Omole, In press; Behera, Bhattacharyya, Mincho, Deoliya, & Maiti, 2014; Evangelista & de Brito, 2013). Most of the previous studies have shown that the performance of such concretes was as good as the conventional concrete, in terms of workability, strength properties and durability.

There are locally available materials such as laterite which are yet not fully investigated. Occasionally the material has been improved for local indigenous building construction (Akinwumi, Awoyera, & Bello, 2015). Laterite is a product of tropical or sub-tropical weathering which is a readily available local material in sub-Saharan African countries. Until last few decades, when the use of laterite as aggregate in concrete began, laterite has been stabilised for production of bricks, or used in road pavement construction (Awoyera & Akinwumi, 2014).

Olusola (Olusola, 2005) described laterised concrete as concrete in which stable laterite fines are used to replace sand wholly or partially. Balogun and Adepegba (1982) discovered that the most suitable mix of laterised concrete for structural purpose is 1:1.5:3 (cement: fine aggregate: coarse aggregate) by weight, and provided that the laterite content is kept below 50% of the total aggregate content. A number of researchers studied the mechanical properties of concrete made with laterite and other materials. Salau (Salau, 2003) recommended 25% laterite content as fine aggregate for long-term resistance and usage in load-bearing short column members.

Laterite substitution for sand in concrete enhances the workability, but large amount could impair the strength properties of concrete (Udoeyo, Iron, & Odim, 2005). Whereas Oyekan (2008) inferred that 50% laterite content used as replacement of sand with waste glass powder as cement substitute could be used for low cost house development. Laterite is rich in clay, which is a constituent that can absorb heat to be reduced to an active siliceous product. Mathew and Paul (2014) reported that combined use of laterite aggregate and mineral admixtures in concrete might lead to the production of a sustainable concrete for fire protection. However, despite the recent investigations on ceramics and laterite as concrete constituent, it is necessary to evaluate the procedures for achieving optimum performance of the concrete, at normal and severe environment. Thus, among the previous studies, aside the combination of laterite and ceramic wastes for making ceramic-laterised concrete, there are no available data on the effect of curing method, thermal and bending behaviour of these novel mixtures.

The current study therefore focuses on the determination of the influence of curing mode, age and heat treatment on compressive strength of ceramics-laterised concrete. Moreover, the flexural behaviour of reinforced laterised concrete beam elements produced with ceramic wastes was evaluated. Flexural strength, also known as modulus of rupture or bending strength is a mechanical parameter for brittle material which shows material’s ability to resist deformation under loading.
2. Materials and method

The materials used for this investigation were: Ordinary Portland cement, river sand, gravel, 12 mm main reinforcement bar, 6 mm stirrup bars, ceramic tile wastes, laterite and potable water. Ceramic wastes was sourced from construction and demolition wastes generated within Ota community, Nigeria. The ceramic tiles were crushed using a hammer mill and sieved through BS standard sieve in order to obtain the desired sample size of 12.7 mm—to make a good replacement of gravel. Laterite was collected at a borrow pit located within Covenant University, Ota, Nigeria. The physical properties of the aggregates were determined. The laterite was air-dried before use, as a replacement for fine aggregate. The oxide composition of cement, ceramic tile and laterite was determined using X-ray fluorescence, the results are presented in Table 1. As was expected four major oxides of Portland cement, in the decreasing order, CaO, SiO$_2$, Al$_2$O$_3$ and Fe$_2$O$_3$, were found and for both ceramic tile and laterite the main component consist of silica, followed by Al$_2$O$_3$ and Fe$_2$O$_3$ was determined.

Laterite was substituted for river sand at 10, 20 and 30% simultaneously with ceramic coarse aggregate, which was substituted for gravel at 25, 50, 75 and 100%. Table 2 shows the mix proportion for the samples. The physical properties of the aggregates are provided in Table 3.

Concrete cubes of 150 mm dimensions were cast, and cured for 7 and 28 days by both immersions in water and polythene wrapping. The samples cured by immersion in water and polythene covering are shown in Figure 1 (a and 1b).

In order to evaluate the fire resistance of ceramic-laterised concrete, the residual strength after heating were determined concrete cubes cured in water for 28 days, and subjected to compression after a preliminary thermal treatment from 200 to 800 Celsius degrees. After each heat treatment, the samples were air-cooled before determining its compressive strength and subjected to temperatures. Thus, under each method of testing on cube, the concrete samples were prepared in triplicates. Also, reinforced concrete beams of dimensions 100 mm × 100 mm × 500 mm were cast and cured in water for 28 days, after which they were subjected to flexural test. Two (2) samples for each of the beams were cast per every mix considered. A sketch of the reinforcement scheme adopted for the concrete beams is shown in Figure 2.

Based on the mix design, all the concrete samples were cast with mix ratio of 1:1.5:3 (cement: sand:gravel) and water/binder ratio of 0.6. Samples of the beams were removed from the water tank after 28 days curing and left to drain as show in Figure 3a. Meanwhile, the presence of laterite in the concrete mix caused the brownish colour observed in the beam samples (Figure 3a). Thereafter, the beams were subjected to flexural testing under the third-point loading arrangement (Figure 3b.), as recommended in the British Standard code (En, 2003). The maximum loads

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### Table 1. Chemical composition of ceramic tile, cement and laterite

| Element | Concentration (wt %) | Ceramics Tile | Cement | Laterite |
|---------|---------------------|---------------|--------|---------|
| Na$_2$O | 1.689               | 1.743         | 0.67   |
| MgO     | 2.042               | 3.190         | 0.07   |
| Al$_2$O$_3$ | 15.069         | 19.475        | 13.42  |
| SiO$_2$ | 64.557              | 24.094        | 35.87  |
| P$_2$O$_5$ | 1.046           | 1.138         | 0.92   |
| K$_2$O  | 2.132               | 0.847         | 0.338  |
| CaO     | 4.148               | 74.211        | 0.097  |
| TiO$_2$ | 0.745               | 0.619         | 1.180  |
| Fe$_2$O$_3$ | 6.014            | 6.273         | 4.694  |
resisted by the beams were carefully recorded and their corresponding bending strength estimated. Two samples each were cast for every mix and the average peak flexural strength were determined. The flexural strength (or modulus of rupture) was determined using the maximum tensile stress in the beam at peak load given by the Equation. 1.

\[ P = \frac{PL}{BH^2} \]  

(1)
Where: \( P \) = peak load, in Newton; \( L \) = beam span length, in millimetres; \( B \) = beam width, in millimetres; \( H \) = beam height, in millimetres.

Microstructural investigations using scanning electron microscopy (SEM) analyses were performed selectively on the concrete samples which presented the highest compressive strength at 7 and 28 days.

3. Results and discussion

The physical properties of the aggregate used as obtained from the laboratory are presented in Table 1. From the results, it was observed that the properties of both laterite and ceramics are in conformity with the provisions of recommended standards for natural aggregates (BS 882, 1992). In addition, the aggregate crushing and impact values obtained for ceramic coarse aggregate and gravel are within limits of design specifications.

The physical properties show that ceramic possess some durability, however, lower than that of natural aggregate (Elçi, 2016). Laterite appears marginal (Awoyera, Akinmusuru, & Ndambuki, 2016), when its properties are compared with that of river sand.

During the mixing procedure both laterised and the reference concrete had a good workability. Thus, the slump values ranged between 70 and 90 mm, which is an indication of true slump in the mixes. According to Lyons (2007), concrete with slump value within this range is appropriate for the normal reinforced concrete placed with vibration. The compressive strength developed by the concrete cubes in both curing conditions are presented in Figures 4 and 5 for strength developed at 7 and 28 days, respectively. As expected the compressive strength increased with the curing age in all cases due to the hydration-hydrolysis reactions from cement compressive strength increased with the curing age in all cases. From Figure 4, it can be seen that polythene covering enhanced the early strength of the samples. It was deduced that the sealing of the fresh concrete to trap its moisture contribute to its early strength development. At maturity (28 days) the reference (conventional) concrete, cured by immersion in water developed appreciable strength, however, the ceramic-laterised concrete yielded more strength than the control in the polythene covering curing conditions. As a result, it can be inferred that there is a better hydration of ceramic-laterised
concrete when its natural moisture is trapped (as in polythene covering). Mix B4 showed an appreciable strength development from the early stage of maturity. This excellent performance could be influenced by the pozzolanic reaction in the mix, because of silica’s dominance in the composition of ceramic tile and laterite. Trend seen in the result showed that 10–20% of laterite as replacement for river sand, and 75% ceramic coarse aggregate or more would be good for production of normal weight concrete.

Figure 4. Seven days compressive strength development, Figure 5. Twenty-eight days compressive strength development

The result of the compressive strength tests performed on concrete cubes at different temperatures are shown in Figure. 6a, 6b, 6c and 6d. For all the samples, compressive strengths increased with temperature at 400°C. However, there was reduction in strength of the reference concrete at temperature above 400°C. This behaviour could be explained by the loss of water from hydrocompounds that provide mechanical resistance at normal temperature. Calcium silicates hydrates from Portland cement lose the water gradually starting at temperatures below 100°C, while the aluminium hydrates lose the water in stages in correlation with their composition.

All the laterised concrete cubes gained more strength as the temperature was increased to 600°C, the strength gained could be attributed to the influence of laterite in the mix. Laterite and ceramics tends to withstand more heat than the other materials, and as a result their heat resistance improve the residual compressive resistance on the samples.

As can be seen from the figures, mixes containing 10% laterite and various ceramic substitutions yielded higher residual strengths at 600°C. Best ceramic-laterised concrete mix for fire resistance at about 600°C is that with 10% laterite replacement of sand and 75% ceramic coarse replacement of gravel. However, compressive strength of laterised concrete later decreased as the temperature was increased to 700°C, thus the concrete generally lose strength at this temperature level, due to the complete dehydration of hydrocompounds at temperature higher than 600°C, which is in good correlation with the findings of Awoyera (Awoyera, 0000).
Figure 5. 28 days compressive strength development.

Figure 6. (a) Residual strength of ceramic laterised concrete with 25% gravel and 75% ceramic coarse aggregate. (b) Residual strength of ceramic laterised concrete with 50% gravel and 50% ceramics coarse aggregate. (c) Residual strength of ceramic laterised concrete with 75% gravel and 25% ceramics coarse aggregate. (d) Residual strength of ceramic laterised concrete with 100% ceramics coarse aggregate.
The concrete mix B4, which revealed the best mechanical performances, was analysed in terms of microstructure. Thus, at 7 and 28 curing days, from the concrete mix B4, concrete samples were collected, and subjected to SEM analyses and the results are presented in Figures 7 and 8.

The SEM micrographs suggests that a well compacted and dense interfacial zone was present in mix B4 at 7 days and 28 days, this is obvious that hydration process influenced the compactness of the matrix, but it could be also a physical effect of concrete structure densifying due to the advanced fineness of the laterite component. EDX pattern, presented in Figure 9, show the element peaks of the laterised granular hydrates in the B4 concrete mix.

The result of the flexural tests performed on the beam samples is presented in Figure 10. Most of the beams failed at their middle thirds (Awoyera, Ijalana, & Babalola, 2015); an indication that there was no horizontal shear failure at the level of loading in the beams. Also, there was brittle-like form of failure in the laterised concrete beams with ceramics. The flexural strength increased with increasing ceramic aggregate inclusion, however, the influence of laterite was not significant. Further, the maximum mid span bending strength decreased with increasing laterite content, but beams with 10% laterite and 100% ceramic coarse aggregate yielded higher strength than the reference concrete with a variation representing 2.94% increment in strength. This increment could be attributed to the adequate compactness between 100% ceramics and the other constituent materials.

4. Conclusion
This study has provided insight on the use of ceramic wastes as partial replacement of natural aggregates in concrete. The effects of curing mode and age on the strength of laterised concrete made with ceramics was evaluated. From the results, it can be deduced that laterised concrete develop appreciable strength under polythene covering curing method, but the reference concrete developed higher compressive strength under the water immersion curing method. Also, the effects of high temperatures on the compressive strength of laterised concrete was evaluated. It was deduced that ceramic-laterised concrete performs better than normal concrete at elevated temperatures. These kind of local and waste materials are recommended for construction of
buildings in fire prone regions. Consequently, it becomes a gain to use laterite and ceramic wastes beneficially for concrete making than landfiling them which constitute threats to the health of the environment. Lastly, the flexural behaviour of laterised reinforced concrete beams made with ceramic aggregates was determined. Result revealed that a substitution level of 10% laterite for river sand and 90% ceramic aggregate yielded flexural strength similar to the reference concrete. Thus, using these materials in place of the conventional materials would not impair the flexural strength of concrete beams. Moreover, with the numerous environmental challenges which result from accumulation of solid wastes; reusing the materials remain the only positive solution to sustaining the fast depleting environment. Over all, using wastes and local materials such as

Figure 8. SEM micrograph of mix B4 at 28 days.

Figure 9. EDX pattern of the laterised granular hydrates in the mix B4 concrete ITZ.
ceramic wall tiles and laterite remains a positive approach to solving the problem of sustainability of the depleting natural aggregate sources.

Acknowledgements
The authors gratefully acknowledge Covenant University, Ota, Nigeria for supporting this research.

Funding
This work was supported by Covenant University, Ota, Nigeria.

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Citation information
Cite this article as: Curing, thermal resistance and bending behaviour of laterised concrete containing ceramic wastes, Paul Awoyera, Anele Wisdom, Ojuh Chukwudi, Kenechukwu Ekedum, Aderoba Adediran & Cornelia Mebitaghan, Cogent Engineering (2018), 5: 1485476.

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