MECHANICAL AND MICROSTRUCTURAL CHARACTERIZATION OF CERAMIC-LATERIZED CONCRETE COMPOSITE

By

AWOYERA, PAUL OLUWASEUN

Matric Number: 13PCI00544

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AWOYERA, PAUL OLUWASEUN
B.Eng, M.Eng Civil Engineering (Akure)
Matric Number: 13PCI00544

A THESIS SUBMITTED TO THE DEPARTMENT OF CIVIL ENGINEERING, COLLEGE OF ENGINEERING, COVENANT UNIVERSITY, OTA, OGUN STATE, NIGERIA IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF DOCTOR OF PHILOSOPHY (Ph.D) DEGREE IN CIVIL ENGINEERING

May 2018

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ACCEPTANCE

This is to attest that this thesis is accepted in partial fulfilment of the requirements for the award of the Degree of Doctor of Philosophy in Civil Engineering in the Department of Civil Engineering, College of Engineering, Covenant University, Ota.

Philip John Ainwokhai ....
(Secretary, School of Postgraduate Studies) Signature and Date

Prof. Samuel T. Wara ....
(Dean, School of Postgraduate Studies) Signature and Date

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DECLARATION

I, **AWOYERA, PAUL OLUWASEUN** (13PCI00544), declare that this research was carried out by me under the supervision of Prof. Joseph O. Akinmusuru of the Department of Civil Engineering, Covenant University, Ota and Prof. Julius M. Ndambuki of the Department of Civil Engineering, Tshwane University of Technology, Pretoria South Africa. I attest that the thesis has not been presented either wholly or partly for the award of any degree elsewhere. All sources of data and scholarly information used in this thesis are duly acknowledged.

AWOYERA, PAUL OLUWASEUN ....

Signature & Date

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CERTIFICATION

We certify that this thesis titled "Mechanical and Microstructural Characterization of Ceramic-Laterized Concrete Composite" is an original work carried out by AWOYERA, PAUL OLUWASEUN (13PCI00544), in the Department of Civil Engineering, College of Engineering, Covenant University, Ota, Ogun State, Nigeria, under the supervision of Prof. Joseph Akinmusuru and Prof. Julius M. Ndambuki. We have examined and found the work acceptable as part of the requirements for the award of Doctor of Philosophy (Ph.D) degree in Civil Engineering (Materials and Structures Option).

Prof. Joseph O. Akinmusuru ....
(Supervisor) Signature & Date

Prof. Julius M. Ndambuki ....
(Co-Supervisor) Signature & Date

Dr. Anthony N. Ede ....
(Head of Department) Signature & Date

Prof. James A. Osunade ....
(External Examiner) Signature & Date

Prof. Samuel T. Wara ....
(Dean, School of Postgraduate Studies) Signature & Date

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DEDICATION

To the I am that I am, the King of kings, the Ancient of days, the Father of Spirits, the Creator of Heaven and Earth, the One who offered me the privilege of existence, the God Almighty.

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LIST OF ABBREVIATIONS

ACI: American Concrete Institute

Afm, Aft: Ettringite (Aft: mono-sulfate or (Al_2O_3 -Fe_2O_3- mono, Afm: sulfoaluminate hydrates Al_2O_3 -Fe_2O_3- tri)

APD: Average Pore Diameter

ASTM: American Society of Testing Materials

BSE: Back-Scattered Electron

C: Calcite ($CaCO_3$)

C_2S: Di calcium silicate

C_3A: Tri calcium aluminate

C_3S: Tri calcium silicate

C_4AF: Tetra calcium alumino-ferrite

CDW: Construction and Demolition Waste

CEMI: Portland cement (CEM I 52.5R)

CH: Calcium hydroxide

CM: Cement Matrix

CPD: Critical Pore Diameter

C-S-H: Calcium Silicate Hydrate

DEF: Delayed Ettringite formation

DTG: derivative of weight loss

EDS or EDX: Energy-Dispersive X-ray

erf: error function

FA: Fly ash

GGBS: Ground Granulated Blast Furnace Slag

ITZ: Interfacial Transition Zone

l: length

L: Liter

LOI: Loss on ignition

Ma-P%: Macro pores percentages

Mi-P %: Micro pores percentages

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MIP: Mercury Intrusion Porosimetry

NVC: Normal Vibrated Concrete

OPC: Ordinary Portland Cement

P: Intrusion pressure

P: Porosity

Pc: Capillary pressure

r: Pore radius

RCA: Recycled Concrete Aggregate

RHA: Rice Husk Ash

SCMs: Supplementary Cementitious Materials

SE: Secondary Electron

SEM: Scanning Electron Microscopy

SG: Specific Gravity

TGA: Thermo Gravimetric Analysis

v: Apparent velocity of flow of water per unit time per unit area

V: Volume

Vf: aggregate volume fraction

w/c ratio: water to cement ratio

w/b ratio: water to binder ratio

x: depth

XRD: X-ray Diffraction

γ: Mercury surface tension

η: Dynamic viscosity of the liquid

θ: Contact angle (140º)

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ABSTRACT

Ceramics is one of the solid wastes generated from construction and demolition sites, or industries that can constitute nuisance to the environment. Hence, reusing this kind of waste could be of immense benefit not only to the construction industry but also to the environment. This research focused on the mechanical and microstructural characterization of ceramic-laterized composite. The mechanical properties of mortar and concrete elements produced using cementitious composite, comprising of blended ceramic-cement as binders, ceramic aggregate, laterite and conventional aggregates, were determined after the samples have been cured by immersion in water. Non-destructive tests were performed on the hardened mortars, using X-ray CT scan and Ultrasonic Pulse Velocity (UPV) techniques. Also, dry bulk density, water absorption due to capillarity, compressive and flexural strength of mortars were determined. Mechanical properties of concrete such as compressive, split-tensile and flexural strength of concrete cubes, cylinders and prisms were determined. Next, predictive models for determining the compressive and split-tensile strength of ceramic-laterized concrete were developed using the Artificial Neural Network (ANN) technique. The results of compressive and split-tensile strengths obtained from this study and those of related studies were utilized for the model development. Finally, micro scale analysis was performed on mortar fragments from selected mixes, which revealed the hydration mechanism and pore structure of the concrete, as they relate to the strength properties. The concrete specimens were characterized using more advanced analysis techniques, comprising of Scanning Electron Microscopy, in secondary and backscattered electron modes, X-ray Diffractometer, mercury intrusion porosimetry (MIP), and thermogravimetric analysis (TGA). From the results, a mortar sample which was composed of 10% powdered ceramics as cement replacement, and 100% fine ceramics as sand replacement developed better strength characteristics than the reference mortar. The micro scale analysis showed that the best mortar mix developed larger peaks of Ettringite, Portlandite and Calcite minerals than the reference mortar. This could be the cause of its high strength. While for concrete, the reference mix yielded higher mechanical properties than the concrete containing secondary aggregates. However, a laterized concrete mix comprising both 90% of ceramic fine and 10% of laterite as the fine aggregate provided the optimal strength out of all the modified mixes, and this was the case whether the coarse aggregate was 100% granite or 100% coarse ceramics. Although, the strength reduction was about 9% when compared with the reference case, this reduction in strength is acceptable, and does not compromise the use of these alternative aggregates in structural concrete. Thus, this has shown that ceramic aggregate could be adequately used to supplement or totally replace natural aggregate in concrete while laterite could be sparingly used as replacement for river sand.

Keywords: Ceramic wastes; Green concrete; Hydration mechanism; Laterized concrete; Microstructure; Porosity

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