RELIABILITY-BASED OPTIMAL ASSESSMENT OF GROUND GRANULATED BLAST-FURNACE SLAG AND COW BONE ASH-BASED GEOPOLYMER CONCRETE

OLUWAFEMI, JOHN OLUWATOBI
(16PCI01354)

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BY

OLUWAFEMI, JOHN OLUWATOBI
(16PCI01354)
B.Eng Civil Engineering, Landmark University, Omu Aran
M.Eng Civil Engineering (Structures and Materials), Covenant University, Ota

A THESIS SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF DOCTOR OF PHILOSOPHY (Ph.D) IN CIVIL ENGINEERING (STRUCTURES AND MATERIALS OPTION), COLLEGE OF ENGINEERING, COVENANT UNIVERSITY, OTA, OGUN STATE, NIGERIA

APRIL, 2023

ACCEPTANCE

This is to attest that this thesis has been accepted in partial fulfillment of the requirements for the award of Degree of Doctor of Philosophy (Ph.D) in Civil Engineering (Structures and Materials) in the Department of Civil Engineering, College of Engineering, Covenant University, Ota, Ogun State, Nigeria.

Miss Adefunke F. Oyinloye
(Secretary, School of Postgraduate Studies) **Signature and Date**

Prof. Akan B. Williams
(Dean, School of Postgraduate Studies) **Signature and Date**

DECLARATION

I, OLUWAFEMI JOHN OLUWATOBI (16PCI01354), declare that this research was carried out by me under the supervision of Prof. Adeola A. Adedeji of the Department of Civil Engineering, University of Ilorin, and Dr. Olatokunbo M. Ofuyatan of the Department of Civil Engineering, Covenant University, Ota, Ogun State. I attest that the thesis has not been presented either wholly or partially for the award of any degree elsewhere. All sources of data and scholarly information used in this thesis are duly acknowledged.

OLUWAFEMI, JOHN OLUWATOBI

Signature and Date

CERTIFICATION

This is to certify that this research was carried out by **OLUWAFEMI, JOHN OLUWATOBI (16PCI01354),** and the research has been read and approved as meeting the requirements of the Department of Civil Engineering, College of Engineering, Covenant University, Ota, Ogun State, for the award of Doctor of Philosophy.

Prof. Adeola A. Adedeji
(Supervisor) **Signature and Date**

Dr. Olatokunbo M. Ofuyatan
(Co-Supervisor) **Signature and Date**

Prof. Anthony N. Ede
(Head of Department) **Signature and Date**

Prof. Obanishola M. Sadiq
(External Examiner) **Signature and Date**

Prof. Akan B. Williams
(Dean, School of Postgraduate Studies) **Signature and Date**

DEDICATION

This research is dedicated to the Almighty God, the creator of heaven and earth.

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LIST OF ABBREVIATIONS

AAR	Alkaline Activator Ratio
R2.0	Alkaline Activator Ratio of 2.0:1
R2.5	Alkaline Activator Ratio of 2.5:1
R3.0	Alkaline Activator Ratio of 3.0:1
C-A-S-H	Calcium Aluminosilicate Hydrate
CBA	Cow Bone Ash
CO_2	Carbon dioxide
C-S-H	Calcium Silicate Hydrate
CSR	Cost to Strength Ratio
GGBS	Ground Granulated Blast Furnace Slag
GePoCc	Geopolymer Concrete
MAE	Mean Absolute Error
NaOH	Sodium hydroxide
N-A-S-H	Sodium Aluminosilicate Hydrate
Na_2SiO_3	Sodium silicate
PC	Portland Cement
RMSE	Root Mean Square Error
RSE	Response Surface Method
SEM	Scanning Electron Microscopy
XRF	X-Ray Fluorescence
XRD	X-Ray Diffraction
d_k	Conjugate vector
θ_k and ηk	Conjugate factors for adjustment of conjugate vectors
λ	Final-step length
$\dot{\alpha}$K	Normalized conjugate sensitivity vector
β_k	Reliability Index
$\Delta_g (U_k)$	The performance function gradient vector
$g(U_k)$	The Limit State Function at U_k

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ABSTRACT

Consequent to the knowledge gap in the area of reliability of geopolymer concrete, this research focuses on the reliability-based optimal assessment of ground granulated blast furnace slag and cow bone ash-based (GGBS-CBA) geopolymer concrete (GePoCc). The geopolymer concrete mix was designed using the British DOE (1988) method and the batching was done by weight method. The mixture of sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) of twelve molarity (12M) was used as alkaline activators. The materials used were tested for specific gravity, fineness, and water absorption capacity, and X-ray fluorescence was carried out to understand the chemical composition of cement, GGBS, and CBA. Workability tests were also carried out to understand the fresh properties of the fresh GePoCc. Following this, the effect of varied alkaline activators ratio (AAR) (2.0:1, 2.5:1, and 3.0:1) and varied curing conditions were investigated on the mechanical properties of the GePoCc. The curing of the hardened GePoCc was observed for 7, 14, 28, 56, and 90 days. Compressive, flexural, and split tensile tests were carried out on the hardened GePoCc. The strength of the hardened GePoCc was considered as parameter for prediction, optimization and reliability assessment of the GePoCc. To achieve these, the strength optimization was carried out using the Central Composite Design Response Surface Method and the reliability analysis was carried out using constant failure rate model, a time-dependent reliability method with consideration of the design life of 50 years. The reliability index of the GePoCc was checked against the control experiment for 150 years. Laboratory analyses such as X-Ray Diffraction (XRD), Scanning Electron Microscope (SEM), and Energy Dispersive X-Ray (EDX) were carried out to further understudy the GePoCc while cost-benefit analysis used to establish the economic performance of the GePoCc. The AAR of 2.5:1 yielded the highest mechanical strength across the compressive, flexural, and split tensile strength for all GePoCc mixes. The GePoCc mixes with 40 % to 100 % GGBS composition showed a satisfactory reliability level for AAR 2.0:1, 2.5:1 and 3.0:1 while the mixes with 0 % to 20 % GGBS were not reliable. The mix with 40 % GGBS, 60 % CBA and AAR of 2.5:1 is reliable and suitable for developing GePoCc with 30 N/mm^2 strength, 60 % GGBS and 40 % CBA mix of 2.5:1 AAR is reliable and suitable for developing GePoCc with 35 N/mm^2 strength, and 80 % GGBS and 20 % CBA of 2.5:1 AAR is reliable and suitable for developing GePoCc with 40 N/mm^2 strength. The cost-benefit analyses revealed that the cost-to-strength ratio of GePoCc mixes with 100% to 60% GGBS produced with AAR of 2.0:1, 2.5:1, and 3.0:1 are lower than the Cost to Strength Ratio of the conventional concrete. The results of the mechanical tests, reliability analyses and economic performance analyses establish the mix with 60% GGBS and 40% CBA of AAR of 2.5:1 as the optimum mix in this research.

Keywords: Geopolymer Concrete, Reliability, Optimization, Strength, Regression Models, Cost-Benefit Analysis