DEVELOPMENT OF A SUSTAINABLE CONCRETE MIX USING RICE HUSK ASH AND STEEL SLAG FOR 3D PRINTING

N.A. Amarasinghe

199187G

Master of Science Degree in Structural Engineering Design

Department of Civil Engineering

University of Moratuwa

Moratuwa

Sri Lanka

June, 2024

DEVELOPMENT OF A SUSTAINABLE CONCRETE MIX USING RICE HUSK ASH AND STEEL SLAG FOR 3D PRINTING

N.A. Amarasinghe

199187G

The Research Thesis was submitted in partial fulfilment of the requirements for the Degree of Bachelor of Science of Engineering

Supervised by Prof. (Mrs.). J. C. P. H. Gamage

Department of Civil Engineering

University of Moratuwa

Moratuwa

Sri Lanka

June 2024

DECLARATION

I declare that this is my work and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of our knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Also, we hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute our thesis, in whole or in part in print electronic or other medium. We retain the right to use this content in whole or part in future works (such as articles or books)

……………………………………… Date: June 14, 2024

N.A. Amarasinghe

"The undersigned hereby certified that I have read and recommended the thesis for the acceptance in partial fulfilment of the requirements for the Master of Science Degree in Structural Engineering Design"

……………………………………… Date: June 14, 2024

Prof. (Mrs). J.C. P. H. Gamage

ABSTRACT

Three-dimensional printing has emerged as a transformative technology in the construction industry, offering efficiency and reduced reliance on labour. The automated process of 3D concrete construction, particularly through contour crafting, has minimized labour requirements, eliminated the need for formwork, and garnered acclaim for its sustainability. However, challenges persist, with the choice of proper mix design and materials standing out as a critical factor. This research addresses a significant challenge in 3D concrete technology the excessive use of cement and chemical admixtures. While previous studies have explored partial cement substitution, little attention has been given to replacing fine aggregate. This research focuses on substituting rice husk ash for cement, emphasizing the contribution to bio-concrete by offsetting carbon dioxide emissions. The use of rice husk ash, a well-studied material, aims to enhance workability and flowability.

Furthermore, the study introduces the novel concept of substituting fine aggregate with steel slag, a construction waste material. This collaboration between rice husk ash and steel slag presents a unique challenge due to the irregularities in shape, water absorption properties, and porosity of steel slag. The research aims to analyse the behaviour of 3D concrete in both fresh and hardened states when these two components are combined as partial replacements. The research aims to identify the optimum replacement percentage of steel slag as fine aggregate in 3D concrete, supplemented by a partial substitution of a bio-based cementitious compound. The study explores the rheological behaviour of the fresh concrete, laying the groundwork for future modifications. Objectives include introducing 3D concrete to the Sri Lankan construction industry, replacing fine aggregate with steel slag, employing cost-effective testing methods for rheological properties, and incorporating rice husk ash as a partial replacement for cement.

This research contributes to the sustainable development of 3D concrete technology, offering insights into material substitutions that enhance environmental and economic aspects, making it a valuable endeavour for the construction industry.

Key Words:

3D printable concrete, Rice husk ash, Steel slag, Rheology, Sustainable 3DCP

DEDICATION

I would like to dedicate this dissertation to my parents, my husband and my daughter Aarya Pradhi Gamalath

ACKNOWLEDGEMENT

I would like to acknowledge the Department of Civil Engineering, University of Moratuwa, for giving me the opportunity to study the Master of Science degree programme in Structural Engineering design. I want to express my gratitude towards all the staff members of this M.Sc. programme for their excellent guidance in completing my M.Sc. degree successfully.

I want to express my sincere gratitude to my supervisor Prof. (Mrs) J. C. P. H. Gamage of the University of Moratuwa, for her excellent guidance and immense support despite her busy schedule. I am very grateful to my colleague who is also my husband; Eng. H.G.P. Gamalath for sharing the study on 3D concrete and assisting in conducting the tests and related analysis of data. I am also thankful to Prof. L. I. N. De Silva for granting me permission to use the Soil and Mechanics lab to conduct some of the tests related to the research.

Further, I like to express my gratitude to supervisors at Central Engineering Consultancy Bureau (CECB) and Cadigal Group for granting permission to carry out my Master of Engineering degree programme. I thank my family members for the support and encouragement they provided to complete my M.Sc. degree. Ultimately, I make this an opportunity to appreciate everyone who lent a hand in completing this research.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Abbreviation	Description
3DCP	3D Concrete Printing
CECB	Central Engineering Consultancy Bureau
RPM	Rotation Per Minute
SLINTEC	Sri Lanka Institute of Nanotechnology Pvt. Ltd.
SSA	Steek Slag Aggregate
UUCT	Unconfined Uniaxial Compression Test
UOM	University of Moratuwa
VMA	Viscosity Modifying Agent
CS	Control Sample

LIST OF SYMBOLS

Symbol	Description	
Φ	Maximum particle size diameter	[mm]
C_u	Uniformity coefficient	[-]
C_c	Coefficient of curvature	[-]
T	Maximum torque	[kgfcm]
τy	Yield stress	[kgf/cm^2]
H	Diameter of the vane	[cm]
D	Height of the vane	[cm]
θ	Angle of rotation in vane	[degrees]
k	Spring constant of the vane apparatus	[cm/kgf]
A_{thix}	Structuration rate	[kPa/min]
H’	Rising speed of the object	[m/min]
ρ	Bulk density of the mixture	[kN/m^3]
$\tau_{0,0}$	Initial static stress at t=0 time	[kPa]
H	Height of the object	[m]
V	Printing velocity	[m/min]
h_0	Layer height	[m]
L	Contour length	[m]
cP	Centipoise (unit of dynamic viscosity in centimeter-gram-second/CGS)	