RESEARCH THESIS

INVESTIGATE THE USE OF SINTERED WATER TREATMENT SLUDGE AS AN INTERNAL CURING FINE AGGREGATE FOR INTERNAL CURING CONCRETE

Pradeep K. I.

198058F

Supervised by: Prof. W.K. Mampearachchi

Degree of Master of Science (Major component of Research)

Department of Civil Engineering

Faculty of Engineering

UNIVERSITY OF MORATUWA-SRI LANKA

June 2021

RESEARCH THESIS

INVESTIGATE THE USE OF SINTERED WATER TREATMENT SLUDGE AS AN INTERNAL CURING FINE AGGREGATE FOR INTERNAL CURING CONCRETE

Pradeep K. I.

198058F

Supervised by: Prof. W.K. Mampearachchi

This Research Thesis submitted in partial fulfilment of the requirements for the degree of Master of Science (Major component of Research)

Department of Civil Engineering

Faculty of Engineering

UNIVERSITY OF MORATUWA-SRI LANKA

June 2021

DECLARATION

I, Pradeep K. I. declare that the research report entitled "Investigate the use of water treatment sludge as an internal curing fine aggregate for internal curing concrete" submitted by me to Department of Civil Engineering, University of Moratuwa in partial fulfilment of the requirement for the award of the degree of Master of Science (Major component of Research) is carried out by me under the supervision of Prof. W. K. Mampearachchi. This is my own work and is submitted in belief that it does not include any material previously published except for those to which acknowledgement is made in the text.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute the thesis, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works.

………………………..

Pradeep K. I.

198058F

Date; 02/04/2023

The undersigned hereby certified that I have read and recommended the thesis for the acceptance in partial fulfilment of the requirements for the Degree of Master of Science (Major component of Research)

…………………………....

Prof. W.K. Mampearachchi

Senior Lecturer,

Transportation Engineering Division,

Department of Civil Engineering,

University of Moratuwa.

Date; 02/04/2023

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my supervisor Prof. W. K. Mampearachchi for providing his invaluable guidance, comments and suggestions throughout the duration of this research study. And also, my special thanks to sir for constantly motivating me to work harder to complete the research project successfully.

Next, I principally am thankful for Accelerating Higher Education Expansion and Development (AHEAD) Operation of the Ministry of Higher Education funded by the World Bank who supported me financially to complete this research study.

Further, my special thanks is extended to Dr. S. U. Adikari who facilitated the use of the Ceramic and Heat treatment laboratory in the Department of Material Science and Engineering. And also, the non-academic staff Mr. Mihranga, Mr. Karunarathne and Mr. Rathnayake of the Department of Material Science and Engineering who supported to conduct experiments during the practical sessions. Non-academic staff (Mr. Uditha, Mr. Pathum, Mr. Roshan, Mr. Lanka, Mr. Leenus, Mr. Piyal) of Department of Civil Engineering whose valuable efforts helped me succeed in my experiments. Another special thanks should go to Head of the Department of Earth Resources Engineering- Dr. D.G. I. Samaradivakara who permitted the use of the rock mechanics laboratory. And also, the non-academic staff Mr. Perera of the Department of Earth Resources Engineering who supported me for experiments during the practical sessions.

Moreover, my special thanks to Plant Managers of Kadana, Biyagama, Kaltuwawa and Labugama water treatment plants who supported me to obtain raw materials for the research. And also, the Plant manager of Dankotuwa Porcelain-Mr. Vinoba and Mr. Demal supported me in the manufacturing of aggregates in a large scale. The plant manager of Sumagi tile factory-Mr Chanaka, Director and deputy director of Lanka Refractories Ltd-Mr Piyasiri and Mr. Kelum, General Manager of Midaya Ceramics (Pvt) Ltd-Mr Anura who gave invaluable support towards me in manufacturing a large quantity of aggregate should be highly admired.

Finally, I would also like to acknowledge Dr. Hasitha Bandara who supported me by sharing knowledge, theory on the research, and my friend Mr, T. Tharshigan who supported me all the time in any practical for the success of this research, and all the Civil Engineering staff and students for their cooperation in numerous ways.

CONTENT

1 INTRODUCTION 9
1.1 General 9
1.2 Problem Statement 10
1.3 Objectives 11
1.4 Significance Of The Research 11
1.5 Scope Of The Study 11
2 LITERATURE REVIEW 12
2.1 Curing Of Concrete 12
2.1.1 Methods For Curing 12
2.2 External Curing 13
2.3 Internal Curing 14
2.3.1 Theory behind Internal Curing 14
2.3.2 Importance of Internal Curing 16
2.3.3 Internal Curing Aggregates 16
2.3.4 Requirements of ICA 18
2.3.5 Internal Curing Concrete 18
2.4 Identification of locally available waste materials 19
2.5 Study on Water Treatment Sludge 21
2.6 Internal Curing Aggregate production 24
2.6.1 ICC Production Process 24
2.6.2 Firing Process 25
2.6.3 Effects of Firing 25
3 EXPERIMENTAL DESIGN OF THE STUDY 26
3.1 Introduction 26
3.2 Selection of Materials 26
3.2.1 Atterberg Limits 27
3.2.2 Thermal Analysis 29
3.2.3 X-ray fluorescence Test 30
3.3 Production of internal curing aggregates in laboratorial scale 30
3.4 Bloating coefficient 35
3.5 Water Absorption 36
3.6 Water Desorption 37

3.7 Relative Density 38
3.8 Microstructure of developed aggregates 39
3.9 Production of Internal Curing Aggregates in industrial Scale 41
3.10 Internal Curing Concrete 44
3.10.1 Mix proportioning for Concrete 45
3.10.2 Casting Concrete 466
3.10.3 Workability 48
3.10.4 Compressive strength 49
3.10.5 Concrete Drying Shrinkage..50
4 ANALYSIS AND DISCUSSION OF RESULTS 52
4.1 Physical, Chemical & Thermal properties of water treatment sludge................................52
4.1.1 Atterberg Limits 52
4.1.2 Thermo gravimetric Analysis of Kadana and Biyagama Sludge 53
4.1.3 Bloating coefficient 55
4.1.4 Chemical composition...56
4.2 Properties of developed internal curing fine aggregates 57
4.2.1 Water Absorption 57
4.2.2 Water Desorption 58
4.2.3 Relative Density 60
4.2.4 Microstructure of developed fine aggregates...61
4.3 Properties of Internal Curing Concrete 62
4.3.1 Workability 633
4.3.2 Compressive Strength of concrete 63
4.3.3 Drying shrinkage of concrete 655
5 SUMMARY AND CONCLUSION 66
6 RECOMMENDATION 67
7 REFERENCES 68

FIGURES

Figure 2.1; Concrete Curing Methods……………………………………………………………..…..13

Figure 2.2; Dried Sludge in Sludge lagoons of Kadana Water Treatment Plant…………………....21

Figure 2.3; Land fill Of Kadana Water Treatment Sludge……………………………………….22

Figure 2.4; Removal of Water Treatment Sludge to Dumping Yards……………………...……22

Figure 2.5; Flow Chart of a Conventional Water Treatment Plant………………………………23

Figure 3.1A; Biyagama Water Treatment Sludge………………………………………………..26

Figure 3.1B; Kadana Water Treatment Sludge…………………………………………………..26

Figure 3.1C; Kaltuwawa Water Treatment Sludge………………………………………………26

Figure 3.1D; Labugama Water Treatment Sludge……………………………………………..…26

Figure 3.2; Casagrandes Apparatus for Liquid Limit……………………………………………27

Figure 3.3; 3mm Sludge Thread for Plastic Limit Test…………………………………………..28

Figure 3.4; TGA-DTA Apparatus………………………………………………………………..29

Figure 3.5; 20mg Sludge Holder for TGA testing……………………………………………..…29

Figure 3.6; Laboratory Ball Mill…………………………………………………………………30

Figure 3.7; Sludge Powder (Particle size < 0.6mm)……………………………………………...31

Figure 3.8; Sludge Paste……………………………………………………………………….…31

Figure 3.9; Laboratory made Piston……………………………………………………………...31

Figure 3.10; 17mm diameter Cylindrical Sludge Samples……………………………………….31

Figure 3.11; Wet Sludge laid on floor and Cut to 75 x 75 mm in Length & Width…………...…32

Figure 3.12; Dried Sludge plates………………………………………………………………....32

Figure 3.13; Laboratory Furnace…………………………………………………………………33

Figure 3.14; Sintered sludge cylinders for 800^0C to 1300^0C temperatures ……………………...33

Figure 3.15; Laboratory Jaw Crusher…………………………………………………………….34

Figure 3.16; Crushed Fine Aggregates…………………………………………………………...34

Figure 3.17; Sintered Fine Aggregates for Different Temperatures……………………………..….34

Figure 3.18; Sintered sludge Cylinders for Different Temperatures…………………….……….35

Figure 3.19; Water Saturated Fine Aggregates for Water Absorption Test…………………...……36

Figure 3.20; Humidity Meter……………………………………………………………………..37

Figure 3.21; Humidity Chamber-Laboratory…………………………………………………….37

Figure 3.22; Pycnometer…………………………………………………………………...….38

Figure 3.23; Scanning Electron Microscope Setup I……………………………………………..39
Figure 3.24; Scanning Electron Microscope Setup II………………………………...……40
Figure 3.25; Sludge Milling Machine…………………………………………………...42
Figure 3.26; Crushed sludge sieving …………………………………………………………42
Figure 3.27; Sludge Plate Molding Machine…………………………………………………..42
Figure 3.28; Fresh Sludge Plates………………………………………………………………42
Figure 3.29; Heating Curve……………………………………………………………………43
Figure 3.30; Sintered Sludge Plates ……………………………………………….……..43
Figure 3.31; Industrial Jaw Crusher…………………………………………….……..44
Figure 3.32; Internal Curing Concrete Cube…………………………………………..……44
Figure 3.33; Raw Materials to Cast Concrete………………………………………...……46
Figure 3.34; Surface Saturated ICFA……………………………………………….……47
Figure 3.35; Homogeneous Mixture with ICFA…………………………………..…..48
Figure 3.36; Measuring the Slump…………………………………………………….……49
Figure 3.37; Cube Casting Molds (150x150x150mm)…………………………………...50
Figure 3.38; Concrete Cubes ……………………………………………………………………50
Figure 3.39; Compressive Strength Test Machine…………………………………………….50
Figure 3.40; Concrete Bars for Drying Shrinkage Test……………………………..……51
Figure 4.1; Graph-Moisture Content versus Number of Blows……………………...…..52
Figure 4.2; Graph-TGA & DTA Curves of Kadana WTS…………………………......……..53
Figure 4.3; Graph-TGA &DTA Curves of Biyagama WTS……………………………..54
Figure 4.4; Graph-Bloating Coefficient versus Temperature……………………………….55
Figure 4.5; Graph-Water Absorption versus Temperature………………………………… 58
Figure 4.6; Graph-Water Desorption versus Time (Kadana WTS)…………………….….. 58
Figure 4.7; Graph-Water Desorption versus Time (Biyagma WTS)…………………...…..59
Figure 4.8; Graph-Relative Density versus Temperature……………………………...60
Figure 4.9; Scanning Electron Micrographs (Kadana WTS)……………………………….61
Figure 4.10; Histogram-Compressive Strength of NCC, ECC and ICC……………..…………64
Figure 4.11; Graph-Drying Shrinkage versus Time of ECC & ICC……………………………..65

TABLES

Table 4.1; Atterberg Limits…………………………………………………………………………53

Table 4.2; Chemical Compositions of WTS……………………………………………….……56

Table 4.3; Mix Design Values for Normal & Internal Curing Concrete………………………...….62

KEYWORDS

ICFA ; Internal Curing Fine Aggregates

ICC ; Internal Curing Concrete

ECC : External Curing Concrete

NCC ; Not Curing Concrete

WTP ; Water Treatment Plant

WTS ; Water Treatment Sludge

ABSTRACT

The thesis reports the investigation carried out in developing an internal curing fine aggregate using water treatment sludge, and studying the changes of concrete properties in using developed fine aggregates in internal curing concrete. The water treatment sludge is converted to burnt clay chips through the process of clay mixing, sintering and crushing. Initially, Thermogravimetric analysis was carried out to identify the thermal behavior of sludge. Also, an X-ray fluorescence test was conducted to identify the chemical composition of the sludge. The firing temperature was made to range from 800^0C to 1300^0C at 100^0C intervals. Water absorption, Water desorption, and Relative density tests were conducted on the developed fine aggregates which were heated to different temperatures to observe the physical properties and requirements in order to satisfy the internal curing property. Furthermore, Scanning Electron Micrographs (SEM) analysis was followed to observe the microstructure of the fine aggregates. To carry out the above experiments, the temperature range which had to be maintained in the sintering process was between 975^0C and 1200^0C. The water absorption of the developed ICFA ranged from 15%-25% for the optimum temperature range, while water desorption rate was recorded to be 90%-95% under the 94% relative humidity at 25^0C room temperature. The relative density of the selected ICFA was recorded to range between 1.7 and 2.0, while the bloating coefficient ranged between 0.8-0.9 for the optimum heating temperature. The latter part of the research was focused on studying the improved properties of ICC using developed ICFA. The mix design was done for grade 30 concrete by referring to BS8110-1983 and ASTM-C1761M codes. Workability, compressive strength and drying shrinkage was compared with normal concrete. Workability and the compressive strength of ICC displayed higher values than that of ECC. Moreover, a significant value deviation was observed in the drying shrinkage of ICC: a 50% reduction in 28 days. Initial studies on water treatment sludge and improved properties of developed ICC confirmed that the sludge can be used to develop an ICFA and that it can be utilized in the construction industry.