



Cairo University

MECHANICAL PROPERTIES AND DURABILITY OF FIBER REINFORCED ALKALI ACTIVATED SLAG CONCRETE COMPARED TO ORDINARY PORTLAND CEMENT CONCRETE

By

Ahmed Hamed Anwar Mohamed El-Deeb

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
Structural Engineering

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2022

**MECHANICAL PROPERTIES AND DURABILITY OF
FIBER REINFORCED ALKALI ACTIVATED SLAG
CONCRETE COMPARED TO ORDINARY PORTLAND
CEMENT CONCRETE**

By

Ahmed Hamed Anwar Mohamed El-Deeb

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
Structural Engineering

Under the Supervision of

Prof. Dr. Ahmed Mahmoud Maher Ragab

Professor of Properties and Strength of Materials
Structural Engineering Department
Faculty of Engineering, Cairo University

FACULTY OF ENGINEERING,
CAIRO UNIVERSITY
GIZA, EGYPT
2022

MECHANICAL PROPERTIES AND DURABILITY OF FIBER REINFORCED ALKALI ACTIVATED SLAG CONCRETE COMPARED TO ORDINARY PORTLAND CEMENT CONCRETE

By

Ahmed Hamed Anwar Mohamed El-Deeb

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
Structural Engineering

Approved by the
Examining Committee

Prof. Dr. Ahmed Mahmoud Maher Ragab (Thesis Main Advisor)
Professor of Properties and Strength of Materials - Faculty of Engineering -
Cairo University

Prof. Dr. Mohamed Mohsen El – Attar (Internal Examiner)
Professor of Properties and Strength of Materials - Faculty of Engineering -
Cairo University

Prof. Dr. El Sayed Abd El- Raouf Nasr (External Examiner)
Professor of Properties and Strength of Materials - Faculty of Engineering -
Ain Shams University

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2022

Engineer's Name: Ahmed Hamed Anwar Mohamed El-Deeb
Date of Birth: 26/11/1984
Nationality: Egyptian
E-mail: eng_ahmedeldeeb@hotmail.com
Phone: 002-0100-093-3664
Address: No. 12, Dr.Gamal Noah St., Masr Elgededa,
Cairo, Egypt.
Registration Date: 01/10/2017
Awarding Date: /.... /2022
Degree: Master of Science
Department: Structural Engineering



Supervisors:

Prof. Dr. Ahmed Mahmoud Maher Ragab

Examiners:

Prof. Dr. Ahmed Mahmoud Maher Ragab (Thesis Main Advisor)
Prof. Dr. Mohamed Mohsen El – Attar (Internal Examiner)
Prof. Dr. El Sayed Abd El- Raouf Nasr (External Examiner)
Professor of Properties and Strength of Materials - Faculty of
Engineering- Ain Shams University

Title of Thesis:

Mechanical Properties and Durability of Fiber Reinforced Alkali Activated Slag Concrete Compared to Ordinary Portland Cement Concrete

Key Words:

Geopolymer concrete; Alkali-activated slag concrete; Polypropylene; Mechanical properties.

Summary:

In this research, due to environmental pollution resulted from the production of cement, Geopolymer concrete was investigated extensively as an alternative to cemented concrete, through an experimental program conducted using Alkali activated slag concrete. And all results were compared to conventional concrete.

Disclaimer

I hereby declare that this thesis is my own original work and that no part of it has been submitted for a degree qualification at any other university or institute.

I further declare that I have appropriately acknowledged all sources used and have cited them in the references section.

Name: Ahmed Hamed Anwar Mohamed El-Deeb

Date: / /2022

Signature:

Dedication

To My Mother, Father, Sister, Brother, and My Beloved Wife and kids

**The reason of what I become today,
Thank you for your love, Support and Care.**

To My Family

All my love and respect to you for your care and support.

To My Great Professor

Prof. Dr. Ahmed Mahmoud Maher Ragab

**All my deep respect to you for guiding me,
supporting me, inspiring me and for your deep
effect on me on the ethical, human, and scientific levels.**

Acknowledgments

First of all, I have to thank **Allah** for this great chance. I thank God for giving me the opportunity to meet such helpful and wonderful people those who encouraged and helped me from the beginning of this thesis. All praises to Allah for giving me the knowledge, strength, support and patience to present this work.

I would like to express my deepest sense of gratitude to my respectable Professor and Supervisor; **Prof. Dr. Ahmed Mahmoud Maher Ragab** and **all the Professors of Properties and Strength of Materials - Faculty of Engineering - Cairo University**; who honored and accepted me to be one of their students. I thank them for their continuous advices, sincere guidance and encouragement throughout all stages of this thesis. I also thank them for their valuable caring, endless patience and extraordinary efforts to provide me with an excellent flourishing atmosphere for doing this research. In fact, working under their supervision was the most valuable and unforgettable experience I have got ever. And I cannot forget to thank **Prof. Dr. Mohamed I. Serag**; for the guidance, help, support, and encouragement he has given me at beginning of this work and during the practical stages of my research.

I would like to express my deep gratitude to the staff of properties and strength of materials lab, structural engineering department, faculty of Engineering, Cairo University, for their sincere help and support. I would like to thank all co-workers and members in material lab especially, **Abdelrazek Abd Elhameed**.

I would like also to thank all my colleagues especially **Eng. Sara Ibrahim Mahmoud, Eng. Khaled Moustafa, Eng. Rania Samy, Eng. Salma Saber, and Eng. Adel Abdelfatah**, for their encouragement and support.

Finally, I would like to thank my parents, wife and all family for being beside me, encourage me and praying for me to achieve my goals and complete my research project.

Table of Contents

DISCLAIMER	I
DEDICATION	II
ACKNOWLEDGMENT	III
TABLE OF CONTENTS	IV
LIST OF TABLES.....	VII
LIST OF FIGURES.....	VIII
ABSTRACT	XIII
CHAPTER 1: INTRODUCTION	1
1.1 General	1
1.2 Research Objectives	2
1.3 Scope of Work	3
1.4 Thesis Layout	4
1.4.1 Chapter 1: Introduction	4
1.4.2 Chapter 2: Background & Literature Review	4
1.4.3 Chapter 3: Experimental Plan	4
1.4.4 Chapter 4: Results & Discussion	4
1.4.5 Chapter 5: Summary, Conclusions and Recommendations	4
CHPATER 2: BACKGROUND & LITERATURE REVIEW	5
2.1 General: The Problem.....	5
2.2 Historical Background.....	6
2.3 Geopolymer Systems:.....	9
2.3.1 Role of Source Material	10
2.3.2 Chemistry: Geopolymerization Mechanisms	12
2.3.3 Role of Alkali Metals.....	13
2.3.4 Applications	15
2.3.5 Economic perspective	22
2.3.6 Limitations of Geopolymer Concrete	27

2.4 Fibers:	28
2.4.1 Introduction.....	28
2.4.2 The Concept of Toughness	28
2.4.3 The Use of Fibers.....	29
2.4.4 Types of Fibers	29
2.5 Literature Review: Geopolymer Properties and Fibers Various types Effect.....	35
CHAPTER 3: EXPERIMENTAL PROGRAM.....	71
3.1 Introduction	71
3.2 Section One: Overview of Experimental Program	72
3.3 Section Two: Characterization of Used Materials	73
3.3.1 Cement	73
3.3.2 Slag	74
3.3.3 Fine Aggregate: Sand.....	74
3.3.4 Coarse Aggregates	75
3.3.5 Sodium Hydroxide (NaOH)	75
3.3.6 Sodium Silicate (Na ₂ SiO ₃).....	75
3.3.7 Fibers (Polypropylene fibers).....	76
3.3.8 Admixture (Superplasticizer)	76
3.3.9 Water.....	77
3.3.10 Physical Properties of Used Material.....	77
3.4 Section Three: Samples Preparation	78
3.4.1 Mixes	78
3.4.2 Mixing Sequence	79
3.4.3 Casting procedures.....	81
3.4.4 Curing Regimes	86
3.5 Section Four: Measurements & Testing	87
CHAPTER 4: RESULTS AND DISCUSSION	97
4.1 Introduction	97

4.2 Compressive Strength Test Results	97
4.2.1 The effect of Slag content	97
4.2.2 The effect of Cement content.....	99
4.2.3 The effect of Slag versus Cement content	100
4.2.4 The Strength rate of increase	101
4.2.5 The Effect of Fiber addition	102
4.3 Indirect Tension Strength Test Results	107
4.3.1 The effect of Slag content	107
4.3.2 The effect of Cement content.....	107
4.3.3 The effect of Slag versus Cement content	108
4.3.4 The Strength rate of increase	109
4.3.5 The Effect of Fiber addition	110
4.4 Flexure Strength Test Results	112
4.4.1 The effect of Slag content	112
4.4.2 The Effect of Cement content	113
4.4.3 The effect of Slag versus Cement content	113
4.4.4 The Strength rate of increase	114
4.4.5 The Effect of Fiber addition	115
4.5 Permeability Test Results	118
4.5.1 The effect of Slag content	118
4.5.2 The effect of Cement content.....	118
4.5.3 The effect of Slag versus Cement content	119
4.5.4 The Effect of Fiber addition	120
CHAPTER 5: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS.....	122
5.1 Summary	122
5.2 Conclusions.....	123
5.3 Recommendations.....	125
References.....	126
الملخص.....	

List of Tables

Table 2.1: Chronological listing for some important events in the history of alkali-activated cement	7
Table 2.2: The production cost of one meter cube from geopolymer concrete and cement concrete	24
Table 2.3: Slag chemical composition (%)	44
Table 2.4: Basalt and polypropylene fibers Properties	45
Table 2.5: Mixture proportion of alkali-activated slag concrete	45
Table 2.6: Added fibers and reference of each mixture	45
Table 2.7: Slag chemical composition	51
Table 2.8: Glass, polypropylene, and basalt fibers Characterization	51
Table 2.9: Chemical properties of Na ₂ SiO ₃ and NaOH solution	51
Table 2.10: Fibers mix proportions for (1 m ³)	51
Table 2.11: Geopolymer concrete material standards and proportions	54
Table 2.12: Geopolymer concrete mix design in 1m ³ (14M of NaOH)	55
Table 2.13: Strength alteration of GPC and OPC after 28 days curing	59
Table 2.14: Slag chemical composition	64
Table 2.15: Polypropylene Fiber Properties	64
Table 2.16: Mix Design	65
Table 2.17: Results of Mechanical Strengths	66
Table 3.1: Classification of the mixes of group “A” & “B”.	73
Table 3.2: Chemical composition of ordinary Portland cement (OPC)	73
Table 3.3: Chemical composition of ground granulated blast furnace slag (GGBS)	74
Table 3.4: Sieve Analysis of fine aggregate (sand)	74
Table 3.5: Chemical composition of Sodium Hydroxide (XRF analysis)	75
Table 3.6: Chemical composition of Sodium Silicate (XRF analysis)	76
Table 3.7: Physical and Chemical composition of Superplasticizer (CMD data sheet) ..	76
Table 3.8: Physical properties of the used materials	77
Table 3.9: Mixture’s constituents (% of weight).	78
Table 3.10: Quantities of constituents to produce 1m ³ from each mix.	79
Table 3.11: The types, dimensions, and curing durations of the used samples.	82
Table 3.12: Recording schedule for compressive strength test results.	89
Table 3.13: Recording schedule for indirect tension strength test results	91
Table 3.14: Recording schedule for flexural strength test results	94
Table 3.15: Recording schedule for permeability test results.	96

List of Figures

Figure 1.1: World Portland cement production 1990–2050 [Imbabi, M. S., Carrigan, C., & McKenna, S. (2012). Trends and developments in green cement and concrete technology. International Journal of Sustainable Built Environment, 1(2), 194-216.]	1
Figure 2.1: The Alkali activated system components with all its diversities	10
Figure 2.2: Graphical explanation for treatment process of water contaminated with organic and inorganic pollutants (Heavy metals and Dyes) by geopolymers	17
Figure 2.3: The relation between the mechanical Strengths of geopolymer specimens and curing time	18
Figure 2.4: The relation between the compressive strength and repair rate with repair angle of concrete specimens	19
Figure 2.5: Relation between the flexural strength and Repair rate with molar ration of concrete specimens	19
Figure 2.6: Relation between the compressive strength and influence of curing time with the repairing rate of geopolymer specimens	20
Figure 2.7: The relation between the “PC” content and bending stress of repaired beams with “RM” or “GPM”	21
Figure 2.8: Rate analysis bar chart	22
Figure 2.9: Manufacturing phases and process of fired and geopolymer bricks	25
Figure 2.10: Typical stress-strain curves of fiber reinforced concrete	28
Figure 2.11: Compressive strengths of (AASC) and (OPCC) of different binder contents.	36
Figure 2.12: Compressive strengths of (AAFS) with different GGBFS content.	37
Figure 2.13: Curing temperature influence on the CS of (AASC).	38
Figure 2.14: Different factors effectiveness on the CS of (AASC).	38
Figure 2.15: The Participation percentage for the considered factors on the 7-day and 28-day CS of (AASC)	39
Figure 2.16: Tensile strength Comparison between (AAC) and (PCC)	40
Figure 2.17: Relationship between the splitting TS and CS of (AASC).	40
Figure 2.18: Splitting TS of AACs with different fibers types.	41
Figure 2.19: Bonding stress-slip curves for different steel fibers contents	41

Figure 2.20: Different lengths of basalt and Polypropylene fibers.....	44
Figure 2.21: Compressive strength of both fiber types basalt and polypropylene (a) Cube compressive strength (b) prism compressive strength.....	46
Figure 2.22: Splitting tensile and flexural strength of both fiber types basalt and polypropylene. (a) Splitting tensile strength; (b) flexural strength.....	46
Figure 2.23: Study workflow chart.....	50
Figure 2.24: Basalt, glass and polypropylene fibers of 12 mm length.	52
Figure 2.25: Fracture energy relation with diverse fiber type and dosage.	53
Figure 2.26: Compressive strength of OPC and GPC cured at sunlight temperature.	56
Figure 2.27: Compressive strength of OPC and GPC cured at room temperature.	56
Figure 2.28: Split tensile strength of GPC cured at sunlight.	57
Figure 2.29: Split tensile strength of GPC cured at room temperature	57
Figure 2.30: Flexural strength of geopolymer concrete cured at sunlight.....	58
Figure 2.31: Flexural strength of geopolymer concrete cured at room temp..	58
Figure 2.32: Different activators effect on compressive strength of slag type A.....	60
Figure 2.33: Different activators effect on compressive strength of slag type B.	61
Figure 2.34: Polypropylene fiber effect on water penetration depth.....	66
Figure 2.35: Relation between alkali content and compressive strength for various curing conditions.....	68
Figure 2.36: Alkali-activated slag concretes compressive strengths relation to the binder content and curing time [46].....	69
Figure 3.1: The diagram of experimental program stages.....	71
Figure 3.2: Crushed Dolomite aggregate sieve analysis in comparison to the Egyptian Standard Specifications.	75
Figure 3.3: White Polypropylene fibers	76
Figure 3.4: Effect of ADDICRETE BVF on earlier compressive strength (after 1,2 and 3 days)	77
Figure 3.5: Laboratory mixer used in the study.	80
Figure 3.6: The casted cubic samples to be tested in the compressive strength and permeability tests.	83
Figure 3.7: The casted cylindrical samples to be tested in the indirect tension strength test.	84
Figure 3.8: The casted Beam samples to be tested in the flexural strength test.	85
Figure 3.9: The sink used for (OPCC) samples curing.	86

Figure 3.10: Tinius Olsen Universal Testing Machine.	88
Figure 3.11: Testing a cube sample of (OPCC) mix.	88
Figure 3.12: Compressive strength testing for a cube sample of (AASC) mix.	89
Figure 3.13: Indirect tension strength testing for a cube sample of (AASC) mix.	90
Figure 3.14: Indirect tension strength cylinder samples after testing.	91
Figure 3.15: SHIMADZU universal testing machine with a capacity of 1000 KN.	92
Figure 3.16: Testing of beam sample to measure the flexural strength from three side views.	93
Figure 3.17: The failure view of the tested beam sample during the flexural strength test.	93
Figure 3.18: The permeability test device.	94
Figure 3.19: Installing and testing of cube sample in the device to measure the permeability of concrete before immersing it in the water.	95
Figure 3.20: splintering the cube samples and measuring the water depth in concrete.	95
Figure 4.1: Compressive strength test results after 7-days for (AASC) mixes of different slag contents.	98
Figure 4.2: Compressive strength test results after 28-days for (AASC) mixes of different slag contents.	98
Figure 4.3: Compressive strength test results after 7-days for (OPCC) mixes of different Cement contents	99
Figure 4.4: Compressive strength test results after 28-days for (OPCC) mixes of different Cement contents.	99
Figure 4.5: Compressive strength test results after 7-days for (AASC) mixes in comparison to (OPCC) mixes of different contents.	100
Figure 4.6: Compressive strength test results after 28-days for (AASC) mixes in comparison to (OPCC) mixes of different contents.	100
Figure 4.7: Compressive strength rate of increase after 7 & 28-days for (AASC) and (OPCC) mixes of 350 Kg/m ³ binder content.	101
Figure 4.8: Compressive strength rate of increase after 7 & 28-days for (AASC) and (OPCC) mixes of 400 Kg/m ³ binder content.	101
Figure 4.9: Compressive strength rate of increase after 7 & 28-days for (AASC) and (OPCC) mixes of 450 Kg/m ³ binder content.	102