



**"MECHANICAL PROPERTIES AND DURABILITY ASPECTS OF
GEOPOLYMER CONCRETE USING GROUND GRANULATED
BLAST FURNACE SLAG"**

**By
Mostafa Mahmoud Boshra Elewa**

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

2018

**"MECHANICAL PROPERTIES AND DURABILITY ASPECTS OF
GEOPOLYMER CONCRETE USING GROUND GRANULATED
BLAST FURNACE SLAG"**

By
Mostafa Mahmoud Boshra Elewa

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 Ragab

Professor of properties of Materials,
Department of Structural Engineering
Faculty of Engineering, Cairo University

Prof. Dr. Mohamed Mohsen El-Attar

Professor of properties of Materials,
Department of Structural Engineering
Faculty of Engineering, Cairo University

Prof. Dr. Mohamed Ahmed Khafaga

Professor of properties of Materials,
Building materials and Quality control
Research Institute, Housing and Building
National Research Center

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2018

**"MECHANICAL PROPERTIES AND DURABILITY ASPECTS
OF GEOPOLYMER CONCRETE USING GROUND
GRANULATED BLAST FURNACE SLAG"**

By
Mostafa Mahmoud Boshra Elewa

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 Ragab

Thesis Main Advisor

Prof. Dr. Mohamed Mohsen El-Attar

Advisor

Prof. Dr. Mohamed Ahmed Khafaga

Professor, Housing and Building National Research Center

Advisor

Prof. Dr. Mohamed Ismael Abd El -Aziz

Internal Examiner

Prof. Dr. Heba Hamed Bahnasawy

Professor, Housing and Building National Research Center

External Examiner

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT

2018

Engineer's Name: Mostafa Mahmoud Boshra Elewa
Date of Birth: 1/1/1991
Nationality: Egyptian
E-mail: Engdarsh82@yahoo.com
Phone: 01065543744
Address: Sidi Salem – Kafr El-Sheikh
Registration Date: 1/3/2014
Awarding Date:/....../2018
Degree: Master of Science
Department: Structural Engineering



Supervisors:

Prof. Ahmed Mahmoud Ragab
Prof. Mohamed Mohsen El-Attar
Prof. Mohamed Ahmed Khafaga
Professor, Housing and Building National Research Center

Examiners:

Prof. Ahmed Mahmoud Ragab (Main Advisor)
Prof. Mohamed Mohsen El-Attar (Advisor)
Prof. Mohamed Ahmed Khafaga (Advisor)
Professor, Housing and Building National Research Center
Prof. Mohamed Ismael Abd El Aziz (Internal examiner)
Prof. Heba Hamed Bahnasawy (External examiner)
Professor, Housing and Building National Research Center

Title of Thesis:

"MECHANICAL PROPERTIES AND DURABILITY ASPECTS OF GEOPOLYMER
CONCRETE USING GROUND GRANULATED BLAST FURNACE SLAG"

Key Words:

Geopolymer concrete, Blast Furnace Slag, Mechanical properties, Durability, Sulfate
Attack

Summary:

The current research aimed to produce a green concrete environmentally friendly without using ordinary Portland cement "Geopolymer concrete" using locally produced ground granulated blast furnace slag in Egypt. The physical and mechanical properties of fresh geopolymer concrete "slump test, setting time, plastic shrinkage" and hardened geopolymer concrete "compressive strength, splitting tensile strength, modulus of elasticity" were studied in this research. Also, durability aspects of geopolymer concrete using slag as water absorption test, water permeability test, resistance of sulfate attack, chloride ion penetration and dry shrinkage were studied in the current research. In addition, comparisons were carried out for the test results with the results of similar OPC concrete mixes.

Acknowledgments

First of all, the most gratitude is to **ALLAH** for his generosity in giving me the strength, knowledge and success to accomplish this research, overcome any obstacles and difficulties I faced during my work.

I wish to thank and express most sincere gratitude and very deep appreciation to my advisor **Prof.Dr. Mohamed Ahmed Khafaga**, professor of properties of materials, building materials and Quality control Research Institute, Housing and Building National Research Center for his thoughtful guidance, his patience, helpful advices, insightful discussion, critical comments, valuable remarks and correction of the thesis. I have been extremely lucky to have an advisor like him. He encouraged me to not only grow as a researcher and engineer but also as an independent thinker. For everything you have done for me **Prof.Dr. Khafaga**, I deeply thank you.

I wish to express my sincere gratitude and deep appreciation to **Prof.Dr Mohamed Mohsen El-Attar**, my advisor for accepting me as an MSc student, for his patience, thoughtful guidance and assistance throughout the development of this thesis.

I wish to express my sincere gratitude and deep appreciation to **Prof.Dr Ahmed Mahmoud Ragab**, my advisor for accepting me as an MSc student and assistance throughout the development of this thesis.

I wish to express my sincere gratitude and deep appreciation to **Prof.Dr Heba Hamed Bahnasawy and Prof.Dr Mohamed Ismael Abd El-Aziz** for their valuable remarks and comments.

I don't find words to express my deep appreciation and gratitude to **my mother, my father, my wife and my brothers** for their continuous encouragement, prayer and support to finish this work.

I wish to express my sincere gratitude and deep appreciation to **Mr. Ramadan Abo El-Gheit** for his assistance to finish this work, continuous encouragement and support.

Thanks to the technical staff of the materials research laboratories in Housing and Building National Research Center at which the experimental program of this study have been carried out.

Finally, to everyone who participated in some way or another, in this research, I owe my thanks and gratitude.

Dedication

I would like to dedicate this thesis to **my mother** for her support, endless love and continuous encouragement for me to success in my work. Also, I would like to dedicate this thesis to **my father, my wife, my brothers and my son** for their endless love and support.

ACKNOWLEDGMENTS.....	i
DEDICATION.....	ii
TABLE OF CONTENTS.....	iii
LIST OF TABLES.....	viii
LIST OF FIGURES.....	x
NOMENCLATURE.....	xix
ABSTRACT.....	xx
CHAPTER (1) INTRODUCTION.....	1
1.1 General.....	1
1.2 Research objective.....	1
1.3 Outline of the thesis.....	2
CHAPTER (2) LITERATURE REVIEW.....	3
2.1 General.....	3
2.2 Historical back ground.....	3
2.3 Terminology and chemistry.....	3
2.4 Materials of Geopolymer concrete mixes.....	5
2.4.1 Pozzolanic (waste) materials.....	5
2.4.1.1 Fly ash (FA).....	5
2.4.1.2 Ground granulated blast furnace slag (GGBS).....	7
2.4.1.3 Silica fume (SF).....	8
2.4.1.4 Rice husk ash (RHA).....	10
2.4.1.5 Meta coaline (MK).....	11
2.4.2 Aggregates.....	12
2.4.3 Alkaline liquid (Activator).....	13
2.4.3.1 Molarity of sodium or potassium hydroxide solution.....	13
2.4.4 Water.....	15

2.4.5 Super plasticizer (SP).....	16
2.5 Mix design & Casting.....	16
2.6 Curing.....	17
2.7 Different types of geopolymer concrete mixes.....	19
2.7.1 Mixes using fly ash.....	19
2.7.2 Mixes using FA& GGBS.....	21
2.7.3 Mixes using other materials.....	23
2.8 Applications of geopolymer concrete.....	26
CHAPTER (3) EXPERIMENTAL WORK.....	28
3.1 Objective and scope of work.....	28
3.2 Experimental program description.....	28
3.2.1 Geopolymer concrete mixes (GPC mixes)	28
3.2.2 Control mixes (OPC mixes).....	29
3.3 Properties of used materials.....	30
3.3.1 Ground Granulated Blast Furnace Slag (GGBS).....	30
3.3.2 Silica fume (SF).....	33
3.3.3 Alkaline liquid (activator).....	34
3.3.4 Aggregates.....	35
3.3.5 Water.....	38
3.3.6 Super plasticizer.....	38
3.3.7 Cement.....	38
3.4 Concrete mixes.....	39
3.4.1 Mix design of geopolymer concrete mixtures.....	39
3.4.2 Mix design of control (OPC) concrete mixtures.....	40
3.4.3 Mixing procedure.....	41
3.4.4 Casting.....	43
3.4.5 Curing.....	44

3.5 Testing procedure.....	46
3.5.1 Fresh concrete tests.....	46
3.5.1.1 Slump test.....	46
3.5.1.2 Setting time test.....	47
3.5.1.3 Plastic shrinkage test.....	48
3.5.2 Hardened concrete tests.....	49
3.5.2.1 Compressive strength test.....	49
3.5.2.2 Splitting Tensile strength test.....	49
3.5.2.3 Modulus of elasticity test.....	50
3.5.3 Durability tests.....	51
3.5.3.1 Water absorption test.....	51
3.5.3.2 Water Permeability test.....	52
3.5.3.3 Chloride penetration test.....	53
3.5.3.4 Resistance Sulphate attack test.....	54
3.5.3.5 Dry shrinkage test.....	54
CHAPTER (4) RESULTS AND DISCUSSION.....	56
4.1 General.....	56
4.2 Fresh concrete properties.....	56
4.2.1 Slump test.....	56
4.2.1.1 Effect of GGBS content.....	56
4.2.1.2 Effect of partial replacement of GGBS with silica fume.....	57
4.2.1.3 Comparison between GPC and OPC.	58
4.2.2 Setting time.....	59
4.2.2.1 Effect of GGBS content.....	59
4.2.2.2 Effect of partial replacement of GGBS with silica fume.....	60
4.2.2.3 Comparison between geopolymer concrete and conventional concrete.....	61

4.2.3 Plastic shrinkage.....	63
4.2.3.1 Effect of GGBS content.....	63
4.2.3.2 Effect of partial replacement of GGBS with silica fume.....	64
4.2.3.3 Comparison between GPC and OPC.....	64
4.3 Hardened concrete properties.....	66
4.3.1 Compressive strength (CS).....	66
4.3.1.1 Effect of GGBS content.....	67
4.3.1.2 Effect of presence of SF as a partial replacement of GGBS.....	71
4.3.1.3 Effect of type of curing.....	74
4.3.1.4 Comparison between Geopolymer concrete and Conventional concrete.....	77
4.3.2 Splitting tensile strength.....	82
4.3.2.1 Effect of GGBS content.....	83
4.3.2.2 Effect of presence of SF as a partial replacement of GGBS.....	85
4.3.2.3 Effect of type of curing.....	86
4.3.2.4 Comparison between geopolymer concrete and conventional concrete.....	89
4.3.3 Modulus of elasticity of geopolymer and conventional concrete.....	90
4.3.3.1 Effect of GGBS content.....	91
4.3.3.2 Effect of presence of SF as a partial replacement of GGBS.....	92
4.3.3.3 Effect of type of curing.....	94
4.3.3.4 Comparison between geopolymer concrete and conventional concrete.....	96
4.4 Durability tests.....	98
4.4.1 Water absorption test.....	98
4.4.1.1 Comparison between geopolymer concrete and conventional concrete.....	98
4.4.2 Water permeability test.....	101

4.4.2.1 Effect of GGBS content.....	101
4.4.2.2 Effect of presence of SF as a partial replacement of GGBS.....	103
4.4.2.3 Effect of type of curing.....	104
4.4.2.4 Comparison between geopolymer concrete and conventional concrete.....	107
4.4.3 Chloride ion penetration.....	107
4.4.4 Resistance sulfate attack test	109
4.4.4.1 Effect of GGBS content.....	110
4.4.4.2 Effect of presence of SF as a partial replacement of GGBS.....	112
4.4.4.3 Effect of type of curing.....	114
4.4.4.4 Comparison between geopolymer concrete and conventional concrete.....	116
4.4.5 Drying shrinkage.....	119
4.4.5.1 Results of geopolymer concrete mixes.....	119
4.4.5.2 Comparison between geopolymer concrete and conventional concrete.....	121
4.5 Comparison between costs of GPC and OPC.....	124
CHAPTER (5) CONCLUSIONS AND RECOMMENDATIONS.....	125
5.1 Conclusions.....	125
5.2 Recommendations for current work.....	125
5.3 Recommendations for future work.....	126
REFERENCES.....	127

CHAPTER (2) LITERATURE REVIEW.....	3
Table (2-1): The physical properties of type's fly ash, [17].....	6
Table (2-2): Classification of FA, [17].....	6
Table (2-3): Chemical structure of type (f) and type (c) fly ashes, [17].....	7
Table (2-4): Classification of GGBS, [21].....	7
Table (2-5): GGBS Physical properties, [17].....	7
Table (2-6): Chemical structure of GGBS, [17].....	8
Table (2-7): SF physical properties, [17].....	9
Table (2-8): SF chemical structure, [17].....	9
Table (2-9): RHA physical properties, [17].....	10
Table (2-10): RHA chemical composition, [17].....	11
Table (2-11): MK physical properties, [17].....	12
Table (2-12): Mix proportion and quantities of materials in this research, [26]....	13
Table (2-13): Results of compressive strength, [26].....	14
Table (2-14): Data for design of GPC using low calcium FA, [1].....	17
Table (2-15): Mix proportion used in current research, [29].....	19
 CHAPTER (3) EXPERIMENTAL WORK.....	 28
Table (3-1): GPC mixes used in current study and their curing conditions.....	29
Table (3-2): OPC mixes for current study and their curing conditions.....	30
Table (3-3): Chemical analysis of GGBS.....	31
Table (3-4): The physical characteristics of used GGBS.....	31
Table (3-5): Chemical structure of the used silica fume.....	34
Table (3-6): Physical characteristics of the used silica fume.....	34
Table (3-7): Grading of used sand.....	35
Table (3-8): Physical characteristics of the used sand.....	36
Table (3-9): Physical and mechanical properties of used coarse aggregate.....	37
Table (3-10): Grading of coarse aggregate.....	37
Table (3-11): Characteristics of sika R 2004.....	38
Table (3-12): Characteristics of OPC.....	38
Table (3-13): Final quantities of mix design of used geopolymer concrete mixtures in kg/m ³	40

Table (3-14): Final quantities of mix design of used control concrete mixtures in kg/m³	40
---	-----------

CHAPTER (4) RESULTS AND DISCUSSIONS.....56

Table (4-1): Results of CS for GPC mixtures at ages 7, 28, 91,180 and 270 days.....	66
Table (4-2): Results of CS for OPC mixtures at ages 7, 28, 91,180 and 270 days.....	67
Table (4-3): Results of splitting tensile strength test for GPC mixes.....	82
Table (4-4): Results of splitting tensile strength test for conventional concrete mixes.....	83
Table (4-5): Modulus of elasticity values for geopolymer concrete mixes and conventional concrete mixes and the percentage between them.....	91
Table (4-6): Results of water absorption test for GPC mixes.....	98
Table (4-7): Permeability coefficient (K) values for geopolymer concrete mixes.....	101
Table (4-8): Results of chloride ion penetration test for geopolymer concrete mixes.....	107
Table (4-9): Results of chloride ion penetration test for conventional concrete mixes.....	108
Table (4-10): Results of resistance sulfate attack test for geopolymer concrete mixes.....	109
Table (4-11): Results of resistance sulfate attack test for conventional concrete mixes.....	110
Table (4-12): Cost study for GPC and OPC mixes.....	124

CHAPTER (2) LITERATURE REVIEW.....	3
Figure (2-1): Chemical structures of polysialates, [15].....	4
Figure (2-2): Fly ash particles at x 5,000 magnification, [17].....	5
Figure (2-3): FA shape, [17].....	6
Figure (2-4): GGBS particles electron scanning microscope at 2100 X, [17].....	8
Figure (2-5): GGBS particles, [17].....	8
Figure (2-6): Silica Fume, [21].....	9
Figure (2-7): Rice husk ash, [17].....	10
Figure (2-8): Metakaolin, [17].....	11
Figure (2-9): Scanning microscope of MK, [17].....	12
Figure (2-10): Compressive strengths for various molarities of mixes, [27].....	14
Figure (2-11): Effect of water-to- geopolymer solids ratio by weight on GPC compressive strength, [2].....	15
Figure (2-12): Effect of different super plasticizer (SP) on the relative slump of FA based on geopolymer paste, [28].....	16
Figure (2-13): Effect of curing time on compressive strength, [18].....	18
Figure (2-14): Values of compressive strength of GPC samples for various curing duration, [26].....	18
Figure (2-15): Compressive strength of geopolymer mortars, [30].....	20
Figure (2-16): Flexural strength of geopolymer mortars, [30].....	20
Figure (2-17): Variation of percentage weight loss for various elevated temperatures, [31].....	21
Figure (2-18): Variation of residual coefficient for compressive strength v/s temperatures (7 Days), [31].....	22
Figure (2-19): Variation of residual coefficient for compressive strength v/s temperatures (28 Days), [31].....	22
Figure (2-20): Compressive strength of geopolymer concrete cured at ambient Temperature at different ages with different BRHA content, [10].....	23
Figure (2-21): Compressive strength of geopolymer concrete cured at 60 °c at different ages with different BRHA content, [10].....	24
Figure (2-22): Compressive strength of GPC which cured at 90 °c at various ages with different BRHA content, [10].....	24

Figure (2-23): compressive strength for GPC mixes having various ratios of silica fume, [32].....	26
Figure (2-24): Brisbane West Well camp Airport (BWWA), [36].....	27

CHAPTER (3) EXPERIMENTAL WORK.....28

Figure (3-1): During water cooling of GGBS in the factory.....	31
Figure (3-2): After finish cooling of GGBS in the factory.....	32
Figure (3-3): Moving of GGBS from the factory.....	32
Figure (3-4): Milling machine of GGBS.....	32
Figure (3-5): Size analysis of GGBS water cooled.....	33
Figure (3-6): Blaine test for GGBS.....	33
Figure (3-7): Activator used in current thesis.....	35
Figure (3-8): Grading of fine aggregate.....	36
Figure (3-9): Grading of coarse aggregate.....	37
Figure (3-10): Dry mixing of aggregates and GGBS and SF.....	41
Figure (3-11): Adding the alkaline liquid and SP to the mixture.....	42
Figure (3-12): Geopolymer concrete produced with GGBS only.....	42
Figure (3-13): Geopolymer concrete produced with GGBS and SF.....	43
Figure (3-14): Casting the specimens of all tests.....	44
Figure (3-15): De-molding the specimens after 24 hours from casting.....	45
Figure (3-16): Steam curing for the specimens.....	45
Figure (3-17): Air curing for the specimens at room temperature.....	46
Figure (3-18): Slump test for geopolymer concrete mixes.....	47
Figure (3-19): Sieving the mortar from the mixture.....	47
Figure (3-20): Determination of concrete setting time by penetration resistance.....	48
Figure (3-21): Plastic shrinkage test.....	48
Figure (3-22): Compressive strength test.....	49
Figure (3-23): Splitting tensile strength.....	50
Figure (3-24): Modulus of elasticity test.....	51
Figure (3-25): Water absorption test.....	52
Figure (3-26): Water permeability test.....	53
Figure (3-27): Chloride penetration test procedure.....	53