



STRUCTURAL BEHAVIOR OF SELF-CURED LIGHTWEIGHT CONCRETE COLUMNS BEFORE AND AFTER EXPOSURE TO ELEVATED TEMPERATURE

By

Eng. Mohamed Ahmed Hassan Ahmed

**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
2017**

**STRUCTURAL BEHAVIOR OF SELF-CURED LIGHTWEIGHT
CONCRETE COLUMNS BEFORE AND AFTER EXPOSURE TO
ELEVATED TEMPERATURE**

By

Eng. Mohamed Ahmed Hassan Ahmed

**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. Mohamed Mohsen El-Attar

Prof. Dr. Ahmed Mahmoud Ragab

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

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

Dr. Dina Mahmoud Sadek

**Associate Professor
Building Materials and Quality Control Institute,
Housing and Building National Research Center**

**FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2017**

**STRUCTURAL BEHAVIOR OF SELF-CURED LIGHTWEIGHT
CONCRETE COLUMNS BEFORE AND AFTER EXPOSURE TO
ELEVATED TEMPERATURE**

By

Eng. Mohamed Ahmed Hassan Ahmed

**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. Mohamed Mohsen El-Attar, Thesis Main Advisor

Prof. Dr. Ahmed Mahmoud Ragab, Advisor

**Dr. Dina Mahmoud Sadek, Advisor
Associate Professor, Housing and Building Research Center**

Prof. Dr. Osama Abdel-Ghafour Hodhod, Internal Examiner

**Prof. Dr. Ahmed Mahmoud Azmy, External Examiner
Head of Civil Engineering Department - Higher Technological
institute**

**FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2017**

Acknowledgments

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

Also, a special acknowledgment to **Dr. Dina Mahmoud Sadek**, my advisor for here insightful discussion, guidance, valuable remarks, critical comments and correction of the thesis. I have been extremely lucky to have a supervisor like her. She encouraged me to not only grow as a researcher and an engineer but also as an independent thinker. For everything you have done for me Dr. Dina, I deeply thank you.

To all my friends, thank you for your understanding and encouragement in many moments of crisis. Your friendship makes my life a wonderful experience. I can't list all the names here, but you are always in my mind.

I'm also grateful to the staff of the materials research laboratories in Housing and Building National Research Center and Cairo University for their assistance.

Finally, a special thanks to my family for their effort and encouragement.

Dedications

**This thesis is dedicated to my
parents, brother, sister, wife
and my daughters**

**For their endless love, caring,
support and encouragement**

Table of Contents

ACKNOWLEDGMENTS.....	I
DEDICATION.....	II
TABLE OF CONTENTS.....	III
LIST OF TABLES.....	V
LIST OF FIGURES.....	VI
ABSTRACT.....	XIII
CHAPTER 1 : INTRODUCTION	1
1.1. GENERAL	1
1.2. THESIS OUTLINE.....	2
CHAPTER 2 : LITERATURE REVIEW	3
2.1. GENERAL	3
2.2. TYPES OF LIGHTWEIGHT CONCRETE	4
2.2.1. Lightweight aggregate concrete	5
2.2.2. Aerated, Cellular, Foamed or Gas Concrete	7
2.2.3. No-Fines Concrete	8
2.3. CLASSIFICATION OF LIGHTWEIGHT CONCRETE	10
2.3.1. Composition and manufacturing of structural lightweight aggregate concrete.....	10
2.3.2. Historical background of lightweight concrete	11
2.4. APPLICATIONS OF LIGHTWEIGHT CONCRETE	14
2.4.1. Using lightweight concrete in Bridges.....	15
2.4.2. Using lightweight concrete in Buildings.....	19
2.4.3. Precast structures	22
2.5. CLASSIFICATION OF LIGHTWEIGHT AGGREGATE.....	24
2.5.1. Natural lightweight aggregates	26
2.5.2. Man-made synthetic lightweight aggregates.....	27
2.6. PROPERTIES OF LIGHTWEIGHT AGGREGATE CONCRETE	27
2.6.1. Fresh properties of lightweight aggregate concrete	27
2.6.2. Hardened properties of lightweight aggregate concrete.....	31
2.6.2.1. Compressive strength.....	31
2.6.2.2. Splitting tensile and flexural strength	35
2.6.2.3. Modulus of elasticity	36
2.6.2.4. Thermal conductivity.....	39
2.6.2.5. Effect of elevated temperatures on structural lightweight concrete.....	41
CHAPTER 3 : EXPERIMENTAL PROGRAM.....	42

3.1. GENERAL	42
3.2. CHARACTERISTICS OF THE USED MATERIALS	43
3.2.1. Ordinary portland cement	43
3.2.2. Normal weight aggregate	44
3.2.2.1. Fine aggregate	44
3.2.2.2. Coarse aggregate.....	45
3.2.3. Coarse lightweight aggregate.....	47
3.2.4. Silica fume	50
3.2.5. Water.....	51
3.2.6. Chemical admixture.....	52
3.2.7. Reinforcing steel	53
3.3. EXPERIMENTAL WORK	53
3.3.1. Concrete mixtures	56
3.3.2. Preparation of reinforced concrete columns	58
3.3.3. Mixing, Casting and Curing.....	61
3.4. TESTING PROCEDURES	65
3.4.1. Slump test	65
3.4.2. Unit weight test.....	66
3.4.3. Compression test.....	66
3.4.4. Effect of elevated temperatures on concrete cubes.....	67
3.4.5. Structural behavior of reinforced concrete columns.....	68
CHAPTER 4 : EXPERIMENTAL RESULTS	73
4.1. GENERAL	73
4.2. BEHAVIOR OF CONCRETE CUBES.....	73
4.2.1. Effect of elevated temperature	73
4.2.2. Effect of concrete type	77
4.2.3. Effect of cement content and silica fume percentage.....	83
4.3. BEHAVIOR OF REINFORCED CONCRETE COLUMNS	86
4.3.1. Structural behavior of reinforced concrete tested at room temperature.....	86
4.3.2. Structural behavior of reinforced concrete columns tested after exposure to elevated temperature.....	88
4.3.3. Effect of elevated temperature	94
4.3.4. Effect of concrete type	98
4.3.5. Effect of cement content and silica fume percentage.....	102
4.4. MICROSTRUCTURAL INVESTIGATIONS.....	107
4.4.1. Effect of elevated temperature	107
4.4.2. Effect of concrete type	110
4.4.3. Effect of cement content and silica fume percentage.....	112
CHAPTER 5 : CONCLUSIONS AND RECOMMENDATIONS	114
5.1. GENERAL	114
5.2. CONCLUSIONS	114
5.3. RECOMMENDATIONS.....	119
REFERENCES	120
ARABIC ABSTRACT.....	

List of Tables

Table 2.1: Test results of concrete used at Raftsundet Bridge.....	18
Table 2.2: Mix Proportion of LWAC.....	29
Table 2.3: Proportion of mixtures and slump	30
Table 2.4: Approximate Relationship between Average Compressive Strength and Cement Content	32
Table 3.1: Physical and mechanical properties of cement	43
Table 3.2: Chemical composition of cement	44
Table 3.3: The characteristics of the used sand	44
Table 3.4: Sieve analysis for sand.....	45
Table 3.5: Characteristics of the used crushed dolomite	46
Table 3.6: Sieve analysis for crushed dolomite	46
Table 3.7: Chlorides and sulfates content in LWA.....	49
Table 3.8: Sieve analysis for LWA	49
Table 3.9: Characteristics of LWA	50
Table 3.10: Physical properties of silica fume	50
Table 3.11: Chemical analysis of silica fume	51
Table 3.12: Chemical analysis of water	52
Table 3.13: Technical data of Sikament-NN	52
Table 3.14: properties of the used reinforcement steel	53
Table 3.15: Concrete mixes proportions	57

List of Figures

Figure 2.1: The Roman temple, Pantheon, built in A.D. 118.....	3
Figure 2.2: Aerated Concrete	8
Figure 2.3: No-fines concrete	9
Figure 2.4: Nordhordland Bridge, Bergen, Norway	17
Figure 2.5: Raftsundet Bridge, Northern Norway	18
Figure 2.6: Wabash River Bridge, USA	19
Figure 2.7: Federal Post Office and Office Building	20
Figure 2.8: The North Pier Tower, Chicago	21
Figure 2.9: Bank of America, Charlotte, N.C.	22
Figure 2.10: Tarsiut Caisson Retained Island	23
Figure 2.11: Hibernia Offshore Platform	24
Figure 2.12: Classification of lightweight aggregate concrete	26
Figure 2.13: Effect of cement content on compressive strength	32
Figure 2.14: The relationship of mean compressive strength of lightweight concrete and volume content of LWA.	34
Figure 2.15: Relationship between 7 day Compressive Strength and Density	35
Figure 2.16: Relationship between Splitting Tensile Strength and 7 days Compressive Strength.....	36
Figure 2.17: Modulus of elasticity	37
Figure 2.18: Relationship between Modulus of Elasticity and 7 days Compressive Strength.....	38
Figure 3.1: Grading curve of sand.....	45
Figure 3.2: Grading curve for crushed dolomite	47
Figure 3.3: Sieving process	48
Figure 3.4: Soaking process	48
Figure 3.5: Grading curve of lightweight aggregate	49
Figure 3.6: Outline of phase (I)	54
Figure 3.7: Outline of phase (II).....	55

Figure 3.8: Details of reinforced concrete columns	58
Figure 3.9: Preparation of reinforcement for placing thermocouple	59
Figure 3.10: Thermocouple on reinforcement	59
Figure 3.11: Strain gauge on reinforcement.....	60
Figure 3.12: Wooden formwork for casting reinforced concrete columns	60
Figure 3.13: Reinforced concrete columns after casting and demoulding	60
Figure 3.14: pan mixer	62
Figure 3.15: Compaction process	62
Figure 3.16: The specimens after casting and surface finishing	63
Figure 3.17: Moist curing process	63
Figure 3.18: Air curing process	64
Figure 3.19: Slump test.....	65
Figure 3.20: Compression test	67
Figure 3.21: Testing of the control columns	69
Figure 3.22: Testing of columns at elevated temperature	70
Figure 3.23: Column after finishing heating.....	70
Figure 3.24: the used equipment tools	71
Figure 3.25: Setup of tested column in furnace.....	72
Figure 4.1: Effect of elevated temperature on compressive strength of NWC....	74
Figure 4.2: Effect of elevated temperature on compressive strength of SCLWC	75
Figure 4.3: Effect of elevated temperature on unit weight for NWC	76
Figure 4.4: Effect of elevated temperature on unit weight strength for SCLWC.	76
Figure 4.5: Effect of concrete type on compressive strength of concrete cubes (350 kg/m ³ cement content).....	78
Figure 4.6: Effect of concrete type on compressive strength of concrete cubes (400 kg/m ³ cement content).....	78
Figure 4.7: Effect of concrete type on compressive strength of concrete cubes (450 kg/m ³ cement content)	79
Figure 4.8: Effect of concrete type on compressive strength of concrete cubes (450 kg/m ³ cement content plus 10% silica fume)	79
Figure 4.9: Effect of concrete type on unit weight of concrete cubes (350 kg/m ³ cement content)	81

Figure 4.10: Effect of concrete type on unit weight of concrete cubes (400 kg/m ³ cement content)	81
Figure 4.11: Effect of concrete type on unit weight of concrete cubes (450 kg/m ³ cement content).....	82
Figure 4.12: Effect of concrete type on unit weight of concrete cubes (450 kg/m ³ cement content plus 10% silica fume).....	82
Figure 4.13: Effect of cement content on compressive strength of NWC	84
Figure 4.14: Effect of cement content on compressive strength of SCLWC.....	84
Figure 4.15: Effect of cement content on unit weight of NWC.....	85
Figure 4.16: Effect of cement content on unit weigh of SCLWC	86
Figure 4.17: Load-displacement curve for NWC.....	87
Figure 4.18: Load-displacement curve for SCLWC	88
Figure 4.19: Effect of exposure duration on the temperature degree inside NWC columns.....	92
Figure 4.20: Effect of exposure duration on the temperature degree inside SCLWC columns.....	93
Figure 4.21: Effect of elevated temperature on maximum load of NWC.....	95
Figure 4.22: Effect of elevated temperature on maximum load of SCLWC	95
Figure 4.23: Effect of elevated temperature on temperature degree inside concrete column of NWC.....	97
Figure 4.24: Effect of elevated temperature on temperature degree inside concrete column of SCLWC	97
Figure 4.25: Effect of concrete type on the maximum load of concrete column at room temperature.....	99
Figure 4.26: Effect of concrete type on the maximum load of concrete column after exposure to 600 °C for one hour.....	99
Figure 4.27: Effect of concrete type on the maximum load of concrete column after exposure to 600 °C for two hours	100
Figure 4.28: Effect of concrete type on temperature inside concrete column after exposure to 600 °C for one hour	101
Figure 4.29: Effect of concrete type on temperature inside concrete column after exposure to 600 °C for two hours.....	101

Figure 4.30: Effect of cement content on the maximum load for column of NWC	103
Figure 4.31: Effect of cement content on maximum load for column of SCLWC	104
Figure 4.32: Effect of cement content on temperature degree inside concrete column of NWC	105
Figure 4.33: Effect of cement content on temperature degree inside concrete column of SCLWC	106
Figure 4.34: SEM micrographs for NWC before and after exposure to 600 °C for 450 kg/m ³ cement content.....	107
Figure 4.35: SEM micrographs for SCLWC before and after exposure to 600 °C for 450 kg/m ³ cement content	108
Figure 4.36: SEM micrographs for NWC before and after exposure to 600 °C for 450 kg/m ³ cement content plus 10% SF	109
Figure 4.37: SEM micrographs for concrete type for 350 kg/m ³ cement content	110
Figure 4.38: SEM micrographs for concrete type after exposure to elevated temperature 600 °C for 450 kg/m ³ cement content.....	111
Figure 4.39: SEM micrograph for NWC cement content mixes.....	112
Figure 4.40: SEM micrograph for SCLWC cement content mixes	113

ABSTRACT

Structural lightweight concrete is an “important in modern construction. This concrete offers technical, environmental benefits, so it’s designed to become material in the millennium. For structural applications of lightweight concrete, the density is often more important than the strength”. A decreased density for the same strength level reduces the self-weight, “foundation size and construction costs. In addition, further benefits such as heat and sound isolation could be gained by using lightweight concrete instead of normal weight concrete. Special type “self-cured lightweight concrete” has been produced to use the voids in lightweight aggregate” water reservoirs for providing water needed for curing.

Experimental work was carried out to study the structural behavior of self-cured lightweight concrete columns before and after exposure to elevated temperatures. The experimental investigation was conducted on twenty-four reinforced concrete columns that were prepared and tested. From each mix, one column was tested at room temperature and two columns were exposed to elevated temperature, as for the cubes it was conducted on ninety-six concrete cubes were prepared and tested at room temperature and after exposure to elevated temperature.

The test variables considered were: concrete type (normal weight concrete and lightweight concrete), cement content (350, 400 and 450 kg/m³), temperature degree (400 and 600 °C) and exposure duration to elevated temperature (1 and 2 hours)

CHAPTER (1)

INTRODUCTION

1.1 General

Sometimes the need to reduce the weight of a structural element has not less importance than increasing its strength, especially in heavy structures such as tall buildings and bridges where the own weight of the structure is one of the main problems that faces the designers. Another important demand in concrete structures is to get monolithic fair-faced concrete, which does not only possess high visual qualities. Monolithic concrete structures are also particularly durable, and the fact that no plastering or cladding is required leads to cost savings and makes buildings more sustainable and easier to recycle. However, due to the high thermal conductivity of normal concrete, fair-faced concrete without insulation causes prohibitive air conditioning costs in cold and warm countries like Germany and Egypt respectively.

Today, Lightweight Aggregates (LWA) is available in a wide range of densities, strengths, and sizes. This makes it possible to design Lightweight Concrete (LWC) with a very wide spectrum, a concrete of very low density for insulation and, at the same time, a high strength lightweight concrete for structural purposes.

Structural lightweight aggregate concrete is need in many and varied applications including multistory building frames and floors, bridges, offshore oil platforms, and prestressed or precast elements of all types. Many architects, engineers, and contractors recognize the inherent economies and advantages offered by this material, as evidenced by the many impressive lightweight concrete structures found today throughout the world. Structural lightweight concrete offers design flexibility and substantial cost savings by providing: less dead load, improved seismic structural response, longer spans, better fire ratings, thinner sections, smaller size structural members, less reinforcing steel

and lower foundation costs. Lightweight concrete precast elements offer reduced transportation and placement costs.

Lightweight Concrete is used instead of the normal weight concrete because it needs more water and also lightweight aggregate is better in water absorption than normal aggregates due to its inner voids.

Therefore, this thesis shows the activities, progress and performance of lightweight concrete such as compressive strength tests and also studying the structural behavior of self-cured lightweight concrete columns before and after exposure to elevated temperature and compare it with normal weight concrete at the same variables.

1.2 Thesis outline

This thesis is divided into five chapters as follows:

Chapter (1): The introduction.

Chapter (2): Literature review, in which a presentation of previous studies and research works, about the definition, types, composition and application of lightweight concrete as well as the mechanical properties of lightweight concrete.

Chapter (3): Experimental program, in which a general outline of the experimental work is presented and the properties of the used materials and conducted tests are also presented.

Chapter (4): Test results and discussions

Chapter (5): Conclusions and recommendations.