

Ministry of Higher Education and Scientific Research  
University of Diyala  
College of Engineering  
Civil Engineering Department



# **FLEXURAL BEHAVIOR OF REINFORCED LIGHTWEIGHT FOAMED CONCRETE BEAMS USING GFRP BARS**

**A Thesis Submitted to Council of College of Engineering,  
University of Diyala in Partial Fulfillment of the Requirements  
for the Degree of Master of Science in Civil Engineering**

**By  
Dhamyaa Ghalib Jassam**

**(B.Sc. in Civil Engineering, 2012)**

**Supervised by  
Assist. Prof. Dr. Suhad M. Abd**

## *DEDICATION*

*To her love and patience and her support .....*

*My Mom*

*To my great honor and my idol .....*

*My Dad*

*To their support advice and encouragement .....*

*My Sisters & Brothers*

*To every heart beats with love and faith, To all who wish me  
benevolent....*

*my friends*

*Dhamyaa Ghalib Jassam*

*2018*

## ACKNOWLEDGEMENTS

First and foremost, before anything, I thank Allah for endowing me with health, patience, and knowledge to complete this study.

First, I would like to express my special thanks of gratitude, the inspiration encouragement, valuable time, knowledge and guidance given to me by *Assist. Pro. Suhad M. Abd*, who served as my advisor.

Special thanks are to my colleagues for their assistance and support in the experimental work.

Great thanks are due to the Structural Engineering Laboratory at Engineering College at Diyala University.

I would also like to prove my superior gratefulness to my parents and all my family for their great support during the work.

Finally, I would like to express my sincere appreciation and thanks to everyone who helped me during the preparation of this thesis, and special thanks to my friend Dunya Khalil.

***Dhamyaa Ghalib Jassam***

***2018***

# Flexural Behavior of Reinforced Lightweight Foamed Concrete Beams Using GFRP Bars

By

Dhamyaa Ghalib Jassam

Supervised by

Assist. Prof. Suhad M. Abd

## ABSTRACT

The lightweight foamed concrete (LWFC) applications in the structural building are so restricted due to its low strength and brittleness. The experimental work of this study includes two parts: the first involves improving the mechanical properties for the LWFC using additives and fibers. Eleven mixes were cast and tested for compressive strength, splitting tensile strength, flexural strength, and modulus of elasticity with target density  $1800 \text{ kg/m}^3$ . Two types of fibers were added to LWFC mix, which were steel fiber, and polypropylene fiber, and hybrid fibers (steel+ polypropylene). The test results showed that the fibers addition into the LWFC mix decreases the flowability and enhance the mechanical properties. The hybrid fibers mixed with (0.4%+ 0.2%) of (steel+ polypropylene) fibers gave the best results and used in casting the reinforced concrete beams.

The second part of this work is the experimental study of the behavior of reinforced (Lightweight foamed, Normal) concrete beams using Glass Fiber Reinforced Polymer (GFRP) bars as the main reinforcement under two point flexural loads. This part includes twelve beams with dimensions (200mm x 250 mm x 1500 mm), divided into two groups: six of lightweight foamed concrete and six of normal concrete beams. For each group: three beams reinforced with GFRP bars in three different reinforcement ratios, two beams reinforced with hybrid

(GFRP+steel) reinforcements, and one beam reinforced with steel bars for comparison

The main variables considered are the concrete type (Lightweight foamed concrete, Normal concrete), reinforcement type (GFRP bars, Steel bars), and GFRP reinforcement ratio. The main parameters considered in this stage of experimental work are the ultimate load capacity, deflection, cracks width, concrete strain, and main reinforcement strain at mid-span length. Therefore, the experimental serviceability limitation, load-deflection curve, load-main reinforcement strain curve, load-concrete strain curve, load-neutral axis depth, ductility index and deformability factor are prepared for all tested beam.

The service load is 35% of the ultimate load for each tested beams. At the service load, the stiffness of GFRP reinforced lightweight foamed concrete beams was less than that of the normal concrete beams, thus the deflection of LWFC beams was higher than the deflection of normal concrete beams. According to the ductility index, the deformability factor of lightweight foamed concrete beams is more than that of normal concrete beams.

The experimental test results of ultimate load, deflection and crack width for all tested beams were compared with that estimated by ACI 440.1R-06 and ACI 318M-14 models. The comparison showed a good agreement between the experimental and predicted results such as increasing the reinforcement ratio and increasing the steel ratio in the hybrid reinforcing GFRP/steel. The ratio of predicted results to the experimental results was (1.1) at service load.

## Table Of Contents

Title	Page
Abstract	i
Table of contents	iii
List of Figures	vii
List of Plates	x
List of Symbols	xii
List of Abbreviations	xv
<b>Chapter One</b>	
1. General Remarks	1
1.1 Lightweight Foamed Concrete	1
1.1.2 Application of Lightweight Foamed Concrete	2
1.1.3 Characteristics and Properties of Foam Concrete	4
1.2 Fiber Reinforced Polymer Reinforcement Bars	5
1.2.1 The properties Fiber Reinforced Polymer (FRP)	6
1.2.2 History and Use of FRP Use	7
1.2.3 FRP Characteristics	9
1.3 Research Significance	10
1.4 Research Objectives	12
1.5 Scope Of The Study	13
1.6 Outline of the Thesis	14
<b>Chapter Two</b>	
2.1 Lightweight foamed concrete (LWFC)	15
2.1.1 Definition and History of (LWFC)	15
2.1.2 Material Used to Produce Lightweight Foamed Concrete:	16
2.1.2.1 Base Mix	16
2.1.2.2 Additives	16
2.1.2.3 Foaming Agent	17
2.1.2.4 Fibers	18
2.1.3 Mix Proportion of Lightweight Foamed Concrete	18
2.1.4 Previous Studies on The Lightweight Foamed Concrete (LWFC)	19
2.1.4.1 The Effect of Additives materials on (LWFC)	19
2.1.4.2 The Effect of Fibers Addition in (LWFC)	20
2.1.4.3 Reviews of Structural Application of Lightweight Foamed Concrete (LWFC)	23

2.2 Fiber Reinforced Polymer (FRP) Reinforcement	25
2.2.1 American Design Guideline (ACI 440.1R-2006)	25
2.2.2 Flexural Design philosophy for FRP and Failure mode	26
2.2.3 Previous Studies of Flexural Behavior of FRP Reinforced Concrete Beams	27
2.2.4 Hybrid System of Reinforcement (GFRP/Steel)	31
2.3 Serviceability Limit State	33
2.3.1 Limitations of Materials stress	33
2.3.2 Crack width	34
2.3.3 Deflection	34
2.4 Effective Moment of Inertia ( $I_e$ )	35
2.5 Ductility of FRP reinforced Concrete Beams	37
2.5.1 Energy Based Method and The Ductility Index	38
2.5.2 Deformability Based Method and Deformability Factor	39
<b>Chapter Three</b>	
3.1 Introduction	42
3.2 Materials	44
3.2.1 Cement	44
3.2.2 Fine Aggregate	44
3.2.2.1 Silica sand for (LWFC)	44
3.2.2.2 Sand for Normal Concrete	44
3.2.3 Coarse Aggregate for Normal Concrete	45
3.2.4 Silica fume	46
3.2.5 Water	46
3.2.6 Superplasticizers (Sika Viscocrete-5930)	46
3.2.7 Foaming Agent	47
3.2.8 Fibers	47
3.2.8.1 Steel Fiber	47
3.2.8.2 Polypropylene fiber	47
3.2.9 Glass Fiber Reinforced Polymer (GFRP) Bars	48
3.2.10 Steel Reinforcement	49
3.3 Preparing Foaming Agent	49
3.4 Concrete Mix Design	50
3.4.1 Lightweight Foamed Concrete	50
3.4.2 Normal Concrete	51
3.5 Concrete Mixing Procedure	52
3.5.1 Lightweight Foamed Concrete	52
3.5.2 Normal Concrete	54

3.6 Test Program for Mechanical Properties of Trail Concrete Mixes	54
3.6.1 Fresh concrete mix properties	54
3.6.1.1 (Flow Table Test for Lightweight Foamed Concrete Mix)	54
3.6.1.2 Slump Test for Normal Concrete Mix	55
3.6.2 Tests of the Hardened Concrete Mixes	55
3.6.2.1 Compression Test	55
3.6.2.2 Splitting Tensile Strength Test	56
3.6.2.3 Modulus of Rupture (Flexural Test)	56
3.6.2.4 Modulus Of Elasticity	57
3.7 Test Program for the Beams Specimen	58
3.7.1 Molds of the Beams	58
3.7.2 Beams Details	59
3.7.3 Beam Identification	60
3.8 Casting and Curing	63
3.9 Instrumentations	63
3.10 Beam Specimen Preparations and Test Procedure	64
<b>Chapter Four</b>	
4.1 Introduction	65
4.2 Mechanical Properties	65
4.2.1 Properties of Fresh Concrete	67
4.2.1.1 Flowability	67
4.2.2 Properties of Hardened Concrete	68
4.2.2.1 Compressive strength	68
4.2.2.2 Tensile Splitting strength	69
4.2.2.3 Modulus of Rupture (Flexural Strength)	72
4.2.2.4 Modulus of Elasticity	75
4.3 Selection of the Optimized Mix for Beams	77
4.4 Experimental Results of the Tested Beams	78
4.4.1 General behavior	79
4.4.2 Experimental Service Load	80
4.5 Failure Modes	85
4.6 Load- Midspan Deflection Behavior	89
4.6.1 Effect of Concrete Type	89
4.6.1.1 GFRP Reinforcement	89
4.6.1.2 Hybrid GFRP/Steel reinforcement	92
4.6.1.3 Steel Reinforcement	92
4.6.2 The Effect of Reinforcement Type on the load-deflection curve	92
4.6.2.1 Lightweight Foamed Concrete	93



4.6.2.2. Normal Concrete	93
4.6.3 Effect of Reinforcement Ratio of GFRP Bars	94
4.7 Strain Results	95
4.7.1 Reinforcement Strain	98
4.7.1.1 The Effect of Concrete Type on The Reinforcement Strain	98
4.7.1.2 The Effect of GFRP Reinforcement Ratio on Reinforcement Strain	99
4.7.1.3 Strain in Hybrid GFRP/Steel Reinforcement	100
4.7.2 Concrete Strain	102
4.7.2.1 The Effect of Concrete Type on Concrete Strain	102
4.7.2.2 The Effect of GFRP Reinforcement ratio on Concrete Strain	103
4.7.2.3 Effect Reinforcement Type on the Concrete Strain	105
4.8 Neutral Axis Depth	107
4.9 Cracks and cracks width	108
4.10 Ductility Index and Deformability Factor	114
4.11 Comparison The Experimental with Predicted Load Capacity	119
4.11.1 Prediction of Mid-span deflection	120
4.11.2 Prediction of Crack Width	125
<b>Chapter Five</b>	
5.1 General Remarks	129
5.2 Conclusions	129
5.2.1 Part One: Lightweight Foamed Concrete	129
5.2.2 Part Two: Flexural Behavior of the Tested Beams	131
5.3 Recommendations and Future Work	134

## List of Figures

<b>Chapter Three</b>	
Title	Page
(3-1) Schematic description of Experimental Work.	43
(3-2) Sieve Analysis of sand.	45
(3-3) Grading of natural gravel.	46
(3-4) Beam Reinforcement Details.	60
(3-5) Flexural Test System.	64
<b>Chapter Four</b>	
(4-1) Flow Test Results	71
(4-2) Compressive Strength Results	72
(4-3) Tensile Splitting Strength Results.	74
(4-4) Comparison Experimental Tensile Splitting Strength Test Results With Suhad Equation.	74
(4-5) Flexural Strength Test Results.	76
(4-6) Comparison Experimental Flexural Strength Test Results With Suhad Equation.	77
(4-7) Modulus of Elasticity Test Results For All Mixes	78
(4-8) Comparison Experimental Modulus Of Elasticity Test Results With ACI 318-14 Equation.	79
(4-9) Loading Capacity Of All Tested Beams.	82
(4-10) Crack Width Of All Tested Beams At Service Load.	79
(4-11) Deflection Of All Tested Beams at Service Load	79
(4-12) Stiffness Of All Tested Beams At Service Load.	85
(4-13) Load-Deflection Curve of Beams FG1 and NG1	92
(4-14) Load-Deflection Curve of Beams FG2 and NG2	92
(4-15) Load-Deflection Curve Of Beams FG3 and NG3	92
(4-16) Load-Deflection Curve Of Hybrid GFRP/steel Reinforced Beams FGS1 and NGS1	93
(4-17) Load-Deflection Curve Of Hybrid GFRP/steel Reinforced Beams FGS2 and NGS2.	93
(4-18) Load-Deflection Curve Of Beams FS and NS	94
(4-19) Load-Deflection Curve Of Beams FG1 and FS.	95
(4-20) Load-Deflection Curve Of Beams NG1 and NS.	95
(4-21) Effect Of Reinforcement Ratio On Load-Deflection Curve For LWFC Beams and Normal Concrete Beams.	96
(4-22) Load-Deflection Curves Lightweight Foamed Concrete (LWFC) Group.	98

(4-23) Load-Strain Curves of Normal Concrete Group.	99
(4-24) GFRP Bar Strain For Beams FG1 and NG1.	100
(4-25) GFRP Bars Strain For Beams FG2 and NG2.	101
(4-26) GFRP Bars Strain For Beams FG3 and NG3.	101
(4-27) GFRP Bars Strain For Beams FS and NS.	101
(4-28) Effect The GFRP Reinforcement Ratio On Bar Strain In LWFC Beams.	102
(4-29) Effect The GFRP Reinforcement Ratio On Bar Strain In Normal Concrete Beams.	102
(4-30) Effect Addition Of Steel Bars On Bar Strain In LWFC Beams.	103
(4-31) Effect Addition Of Steel Bars On Bar Strain In Normal Concrete Beams.	103
(4-32) Load-Concrete Strain Curve For Beams FG1 and NG1.	105
(4-33) Load-Concrete Strain Curve For Beams FG2 and NG2.	105
(4-34) Load-Concrete Strain Curve For Beams FG3 and NG3.	105
(4-35) Load-Concrete Strain Curve For Beams FS and NS.	106
(4-36) Load-Concrete Strain In LWFC Group.	106
(4-37) Concrete Strain In Normal Concrete Group.	107
(4-38) Load-Concrete Strain Curve For Beams FG1 and FS.	108
(4-39) Load-Concrete Strain Curve For Beams NG1 and NS.	108
(4-40) Load-Concrete Strain For LWFC Beams Reinforced With Hybrid GFRP/steel Bars.	109
(4-41) Load-Concrete Strain For Normal Concrete Beams Reinforced With Hybrid GFRP/steel Bars.	109
(4-42) Neutral Axis Depth For LWFC Beams.	110
(4-43) Neutral Axis Depth For Normal Concrete Beams.	111
(4-44) Crack Width Of LWFC and Normal Concrete Beams.	113
(4-45) Load-Crack Width Of Beams FG1 and FS.	114
(4-46) Load-Crack Width Of Beams NG1 and NS.	114
(4-47) Crack Width of LWFC Beams Reinforced With Hybrid GFRP/steel Bars.	115
(4-48) Crack Width of Normal Concrete Beams Reinforced With Hybrid GFRP/steel Bars.	115
(4-49) Crack Width Of Beams Reinforced With Steel Bars.	116
(4-50) Ductility Index Based On Energy Method.	117
(4-51) Deformability Factor Based On Deformability Method.	119
(4-52) Experimental Load Capacity VS The Predicted Load Capacity	120
(4-53) Predicted Model Of ACI 440.1R-06 Code and Experimental Load-Deflection Curves For Beams FG Group and NG Group.	123

(4-54) Predicted Model Of ACI 440.1R-06 Code and Experimental Load-Deflection Curves For Beams Reinforced With Hybrid GFRP/steel Bars.	124
(4-55) Predicted Model Of ACI 318-14 Code and Experimental Load-Deflection Curves For Beams FS and NS.	124
(4-56) Ratio Of Predicted To Experimental Deflection At 15% and 35% Of Ultimate Load.	126
(4- 57) Ratio Of Predicted To Experimental Crack Width At Service Load.	126
(4- 58) Predicted Model Of ACI 440.1R-06 Code And Experimental Load-Crack Width Curves For FG Group and NG Group.	128
(4- 59) Predicted Model Of ACI 440.1R-06 Code and Experimental Load-Crack Width Curves For Beams Reinforced With Hybrid GFRP/steel Bars.	129
(4- 60) Predicted Model Of ACI 318-14 Code and Experimental Load-Crack Width Curves For Beams FS and NS.	129

## LIST OF PLATES

Title	Page No.
(1-1) Application of lightweight foamed concrete fill in Sioux city, Iowa.	3
(1-2) The use of LWFC in Al Hussain Quran School in Karbala city, Iraq, 2017.	3
(1-3) The first concrete footbridge in Europe reinforced with only FRP bars (ACI committee 440.1R, 2006).	8
(1-4) The use of GFRP in the sea walls in Yancheng city, China, 2016	8
(1-5) GFRP use in the underwater tunnel of Weisan road in Nanjing, China, 2016.	9
(2-1) Energy Based Approach.	37
(3-1) Standard Fine Silica Sand.	44
(3-2) Graded natural sand (Al-Ukhaider).	44
(3-3) Natural coarse aggregates with a 10 mm maximum size.	45
(3-4) Superplasticizer (Sika Viscocrete-5930).	47
(3-5) Steel Fiber Geometry.	48
(3-6) Polypropylene Fiber Geometry.	48
(3-7) The Geometry of GFRP Bars Used In This Work.	48
(3-8) Foam Generator	49
(3-9) Foam output	49
(3-10) Density of foam test.	49
(3-11) a homogeneous balls.	52
(3-12) a homogeneous mix.	52
(3-13) Adding of Steel Fiber.	53
(3-14) Adding Foam.	53
(3-15) Foamed Concrete Density Checking.	53
(3-16) Flow Table Test.	54
(3-17) Slump Test for Normal Concrete Mix.	55
(3-18) Compression Test.	55
(3-19) Splitting Tensile Test.	56
(3-20) Modulus of Rupture Test.	57
(3-21) Modulus of Elasticity Test.	58
(3-22) Beam Mold	58
(a) Geometry with reinforcement.	58
(b) Control specimen molds.	58
(3-23) Casting of Beams Mold and Control Specimen Molds.	63

<b>Chapter Four</b>	
(4-1) flexural strength test specimen.	68
(a) Complete failure of control specimen without the inclusion of fiber	68
(b) flexure failure of specimen with fiber inclusion	68
(c) Cross section of samples with fiber after test	68
(4-2) Tested Beams of LWFC Beams Group.	82
(4-3) Tested Beams of Normal Concrete Beams Group.	83
(4-4) Cracks width form.	105
(a) LWFC cracks.	105
(b) Normal concrete cracks.	105
(C-1) TML strain gauge types.	C-1
(a) Type (PFL-30-11-3L)	C-1
(b) Type (FLA-10-11-3L)	C-1
(C-2) Preparing and Install of Strain Gauges.	C-2
(C-3) CN adhesive	C-2
(C-4) Vertical Dial gauge.	C-3
(C-5) Microscope Crack Meter.	C-3

## List of Tables

No.	Title	Page
1-1	Advantages and disadvantages of FRP reinforcement	7
1-2	The Characteristics of GFRP bars and Steel bars	9
3-1	Lightweight Foamed Concrete Mix Proportion.	48
3-2	Normal Concrete Mix Proportions	48
3-3	Beams Details.	58
4-1	The Results of All Tested Trail Mixes.	62
4-2	Tensile Splitting Strength Test Results.	67
4-3	Flexural Strength Test Results.	69
4-4	Modulus of Elasticity Test Results.	72
4-5	Properties of Selected (LWFC) and Normal Concrete Mixes.	73
4-6	Result of Tested Beams.	75
4-7	Service Load for Each Serviceability Limits.	76
4-8	Serviceability Limit for Deflection and Cracks Width at Service Load	77
4-9	Ductility Index Based on Energy Method.	110
4-10	Deformability Factor Index Based on Deformation Method.	111
4-11	Experimental and Predicted Mid-span Deflection at Service Loads 15% and 35% of Ultimate Load of All Tested Beams.	118
4-12	Experimental and Predicted Crack Width at Service Load.	119
A-1	Chemical composition and main compounds of cement	A-1
A-2	Physical properties of cement	A-1
A-3	The sieve analysis of Silica Sand	A-2
A-4	Grading of Fine Aggregate for Normal Concrete.	A-2
A-5	Grading of Coarse Aggregate.	A-2
A-6	Physical properties of Coarse Aggregate	A-3
A-7	Silica Fume Properties.	A-3
A-8	Properties of Superplasticizers	A-4
A-9	Properties of Foam Agent.	A-4
A-10	Steel Fibers Properties	A-4
A-11	Polypropylene Fibers Properties	A-5
A-12	Properties of the Reinforcing Steel Bars	A-5

## LIST OF SYMBOLS AND TERMINOLOGY

$P$	Applied load indicated by the testing machine in N
$A_f$	Area of tension FRP reinforcement
$A_s$	Area of tension steel reinforcement.
$E_e$	Area of the triangle formed below line S, up to the point of failure load
$d_1$	Average of four readings in flow test, in mm.
$S$	Bar spacing (center to center) in mm
$L, l$	Clear span length in mm
$k_b$	Coefficient related to bonding of FRP bars
$I_{cr}$	Cracked moment of inertia in GPa
$M_{cr}$	Cracking moment in kN.mm
$f_{cu}$	Cube compressive strength of concrete in MPa.
$f_c'$	Cylinder compressive strength of concrete in MPa.
$D_{0.001}$	Deflection at concrete strain 0.001
$D_u$	Deflection at ultimate for ductility index based on deformability
$E_f$	Design or guaranteed modulus of elasticity of FRP defined as mean modulus of sample of test specimens in MPa
$f_{fu}$	Design tensile strength of FRP
$c_b$	Distance from extreme compression fiber to neutral axis at balanced strain condition in mm
$c$	Distance from extreme compression fiber to the neutral axis
$\mu_E$	Ductility Index Based on Energy Method
$d$	Effective depth in mm
$I_f$	Effective moment of inertia in MPa
$P_{exp}$	Experimental failure load



$P_{s,s}$	Experimental values for the service load for maximum concrete stresses
$P_{s,c}$	Experimental values for the service load for maximum permissible crack width
$P_{s,d}$	Experimental values for the service load for maximum permissible deflection
$\beta_1$	Factor relating depth of equivalent rectangular compressive stress block to neutral axis depth
$n_f$	FRP modulus ratio: FRP modulus of elasticity to concrete modulus
$\rho_f$	FRP reinforcement ratio
$\rho_{fb}$	FRP reinforcement ratio producing balanced strain conditions
$I_g$	Gross moment of inertia in MPa
$h$	Height of the rectangular cross section in mm
$P_{0.001}$	Load at concrete strain 0.001
$P_u$	Load at ultimate
$\varepsilon_1$	Longitudinal strain ( $\varepsilon_1$ ) of (0.000050)
$\varepsilon_2$	Longitudinal strain produced by stress $S_2$
$w_{max}$	Maximum crack width in mm
$M_a$	Maximum moment in member at stage deflection is computed in kN.m
$\lambda$	Modification factor reflecting the reduced mechanical properties of lightweight concrete, which is (0.85) for sand-lightweight concrete.
$E_c$	Modulus of elasticity of concrete in MPa
$E_s$	Modulus of elasticity of steel in MPa
$f_r$	Modulus of rupture in MPa
$N.A$	Neutral axis depth in mm.
$M_n$	Nominal moment capacity in kN.m

$d_2$	Original inside base diameter in flow test, in mm.
$k$	Ratio of the neutral axis depth to reinforcement depth
$\beta$	Ratio of, distance between, neutral axis and tension face to distance between neutral axis and centroid of reinforcement
$\beta_d$	Reduction factor
$a$	Shear span in mm
$f_{ct}$	Splitting tensile strength for concrete in MPa
$n_s$	Steel modulus ratio: steel modulus of elasticity to concrete modulus
$\rho_s$	Steel Reinforcement ratio
$\varepsilon_c$	Strain in concrete
$S_1$	Stress corresponding to 40% of ultimate load
$S_2$	Stress corresponding to a longitudinal strain ( $\varepsilon_1$ ) of (0.000050)
$f_f$	Stress in FRP reinforcement in tension in MPa
$d_c$	Thickness of cover from tension, face to center of closest bar mm
$E_t$	Total energy computed as the area under the load-deflection curve
$\Delta_u$	Ultimate Deflection
$\varepsilon_{cu}$	Ultimate strain in concrete
$w/c$	Water to cement ratio
$b$	Width of rectangular cross section in mm

## List of Abbreviations

Abbreviations	Descriptions
ACI-318-14	American Concrete Institute: Building Code Requirements for Structural Concrete and Commentary
ACI 440.1R-06	American Concrete Institute: Guide for the Design and Construction of Structural Concrete Reinforced with FRP Bars
AFRP	Aramid Fiber Reinforced Polymer
FB	Base Foamed Concrete mix
BS	British Standards
CAN/CSA-S806-12	Canadian Standards Association: Design and Construction of Building Structures with Fiber-reinforced Polymers
CFRP	Carbon Fiber Reinforced Polymer
$P_{exp}$	Experimental load of tested beams
FRP	Fiber Reinforced Polymer
FSTP1	Foamed Concrete mix with (0.2% Steel fiber+0.2% Polypropylene fiber)
FSTP2	Foamed Concrete mix with (0.2% Steel fiber+0.4% (Polypropylene fiber
FPP1	Foamed Concrete mix with (0.2%) Polypropylene fiber
FST1	Foamed Concrete mix with (0.2%) Steel fiber
FPP2	Foamed Concrete mix with (0.4%) Polypropylene fiber
FST2	Foamed Concrete mix with (0.4%) Steel fiber
FSP5	Foamed Concrete mix with (0.5%) Superplasticizer
FSP8	Foamed Concrete mix with (0.8%) Superplasticizer
FSF10	Foamed Concrete mix with (10%) Silica Fume
FSF5	Foamed Concrete mix with (5%) Silica Fume
GFRP	Glass Fiber Reinforced Polymer
I.Q.S	Iraqi Central Organization for Standardization and Quality Control
LWFC	Lightweight Foamed Concrete
$P_{s,d}$	Service load of beam at which the deflection equal to $L/240$
$P_{s,c}$	Service load of beam at which the maximum crack width equal to 0.7mm
$P_{s,s}$	Service load of beam that corresponding to 0.6 of the ultimate compressive strength of concrete.
SLS	Serviceability Limit State

## **Chapter One**

### **Introduction**

#### **1. General Remarks**

##### **1.1 Lightweight Foamed Concrete**

According to ASTM C330/C330M which uses density to classify lightweight concrete into three categories depending on its application. These categories include non-structural concrete with a low-density (300 to 800 kg/m<sup>3</sup>) used for thermal insulation. Secondly, structural lightweight concrete with a density (1120 to 1920 kg/m<sup>3</sup>) with the compressive strength above 17.0 MPa and used for structural applications, and concrete with moderate strength placed between the above two classes with a compressive strength (7.0 MPa to 17.0 MPa) (ASTM C330\C330M, 2009).

Lightweight foamed concrete is considered as type of concrete which can be described as a mix of cement, sand, water and enter the air into it which leads to increasing the mixture volume and reduces its weight.

According to ACI 523.2R-96 the material, which is commonly referred to as cellular or aerated concrete, is defined as:

“A lightweight product consists of Portland cement and/or lime with siliceous fine material, such as sand, slag, or fly ash, mixed with water to form a paste that has a homogenous void or cell structure. The cellular structure is attained essentially by inclusion of macroscopic voids resulting from a gas releasing chemical reaction or the mechanical incorporation of air or other gases (autoclave curing is usually employed)” (ACI Committee 523.2R, 1996).

Thus, the foamed concrete defined as a highly aerated mortar with an air content higher than (20%) by volume of the mixed mortar which entered foam (Brady et al., 2001).

The aim of sustainable construction is to decrease the environmental effects on a structural building along its lifetime and optimizing its economic viability and the safety and comfort for its residents. The sustainable construction principles are applied to the whole life period of the construction, during the designing, construction and operation process of building projects.

Lightweight foamed concrete has feature properties that make it as a sustainable construction material by reducing resourcing consumption and using recyclable resources where its production consists of the recycled material such as fly ash and silica fume. Also, the low in self-weight of foamed concrete contributes to reducing the reinforcement, member size, and saving in transportation and handling.

### **1.1.1 Applications of Lightweight Foamed Concrete**

The use of lightweight foamed concrete in the construction of building reduces the reinforcements, member cross-sections, and foundations size. Foamed concrete is distinguished by significant properties such as low in self-weight, self-leveling, thermal and sound isolation, and fire resistance, thus it has exceptional application for different objectives. The foamed concrete applications have become common in the worldwide, especially in the adverse weather regions, earthquakes, and storms.

In 2011, lightweight foamed concrete was used for filling in walls along the west edge to accommodate additional lanes adjacent to big Sioux and Missouri River on the west and railroad to accommodate additional lanes.



Plate (1-1): Application of lightweight foamed concrete fill in Sioux city, Iowa.

In the south of Iraq, lightweight foamed concrete is used in the roof as a layer of leveling over the roof slab directly because of its lightweight instead of using dirt. Also it is used in the floors under the tiles where it is casting at one level without any differences in the level and then set the finishing material of marble or porcelain with an adhesive material as seen in the plate (1-2).



Plate (1-2): The use of LWFC in Al Hussain Quran School in Karbala city, Iraq, 2017.

### 1.1.2 Characteristics of Foam Concrete

1. **Lightweight:** It is light weight in comparison with the normal concrete with a dry density of ( $300.0 \text{ kg/m}^3$  to  $1900.0 \text{ kg/m}^3$ ) that decreases the dead load of the structure.
2. **Flowability:** The flowability of foamed concrete is defined as self-compaction concrete with no need for vibration, and free flowing.
3. **Workability:** foamed concrete has a high workability that makes it desired dimension including angles and any shapes.
4. **Thermal and Sound Insulation:** because of the air voids in foamed concrete, which dampen heat and sound transfer.
5. **Fire resistance:** Lightweight foamed concrete supply approximately twice the fire resistance of the normal concrete.
6. **Sustainable material:** Low aggregate usage (reduce resource consumption), and foam concrete production consists of the waste material such as fly ash and silica fume.
7. **Reducing the damages of the earthquake risk:** The earthquake loads influencing the structures are proportional to the mass of those structures.

Many studies focus on enhance lightweight foamed concrete durability and mechanical properties with various types of additions and replacements. Lightweight foamed concrete is a very brittle anisotropic material with high strength to weight ratio. The inclusion of steel fibers into LWFC is one approach to enhance its mechanical properties.

The adding of silica fume to the foamed concrete improves the its mechanical properties by filling the area between cement granules that leads to increase the density and the strength of the foamed concrete mixture and also to improve the bonds between cement and aggregate due to the pozzolanic action of the silica fume which leads to improve the bond

between the aggregate and concrete matrix to give a better overlap between the aggregates and the cement paste.

Lightweight foamed concrete has a low self-weight compared with normal concrete. This leads to reducing the dead load in the construction building and a smaller loads of column which directly leads to reducing the applied loads on the foundation, and this contributes to the reduction in all cost of building. Lightweight foamed concrete has a high strength to weight ratios which also contributes to having longer spanning of beams and also using a lesser number of the intermediate column which that leads the possibility of opening up more free spaces (Brady et al., 2001).

## **1.2 Fiber Reinforced Polymer Bars (FRP)**

In the steel reinforced concrete structure, the steel bars corrosion is the most significant problem. To avoid this problem, the use of fiber reinforced polymer (FRP) bars instead of traditional steel bars presents a very effective solution. The corrosion process ultimately causes concrete deterioration and loss of serviceability (Maranan et al., 2015).

“Fiber reinforced polymer (FRP) bars are composite materials made of fibers embedded in a polymeric resin such as glass, aramid and carbon. FRP bars have an alternative properties such as being light in weight, noncorrosive, and nonmagnetic (thermally and electrically non-conductive) material, and high tensile strength, that make them suitable for use as structural reinforcement” (ACI Committee 440.1R, 2006).



**1.2.1 The Properties of Fiber Reinforced Polymer (FRP):**

The FRP composites have many advantages over conventional steel reinforcement (ACI Committee 440.1R, 2006), in terms of:

- 1. Lightweight material:** FRP bars have a low weight comparing with the conventional steel bars that contribute to reducing the dead load that increases the live load capacity.
- 2. Good durability:** FRP bars have a great resistance to salts and other chemicals materials which prevent the corrosion of reinforcement, concrete cracking, and spalling related in the steel reinforced concrete.
- 3. Long service life:** the construction reinforced with FRP bars have a perfect performed in severe conditions for many years with a low maintenance.
- 4. Easy installation:** FRP reinforcement is fast in proceeding due to its low weight, no need for welding, and easy in the handling.
- 5. Fatigue and impact resistance:** FRP bars have high fatigue duration and impact resistance.

The FRP reinforcement advantages and disadvantages of for concrete structures listed in Table (1-1), as compared with conventional steel reinforcement (ACI Committee 440.1R, 2006).

Table (1-1) Advantages and disadvantages of FRP reinforcement

FRP Reinforcement Advantages	FRP Reinforcement Disadvantages
Height tensile strength	No yield before failure.
Height Resistant to Corrosion	Low transfer strength
Non magnetic	Low modulus of elasticity.
Low weight ( about 1/3 to 1/4 of steel weight)	Susceptibility of damage to polymeric resins and fibers under ultraviolet radiation exposure
High fatigue resistant	Low durability of some glass and aramid fibers in an alkaline environment
Low electric and thermal conductivity	High coefficient of thermal expansion of fibers relative to concrete. Maybe responsive to fire depending on the type and thickness of concrete cover

### 1.2.2 History and Use of FRP Bars

The properties of FRP reinforcement must be considered when deciding whether or not the FRP reinforcement is proper or important in a specific structure.

In the middle of the 1990s, the most applications of FRP reinforcement were in Japan with more than 100 trade projects (ACI Committee 440.1R, 2006).

During the 1970s, the use of FRP reinforcement in the construction of bridges to prevent the deterioration due to corrosion in the U.S. has become apparent. (ACI Committee 440.1R, 2006).

In 1986, the FRP reinforcements were first used in Germany with the construction of pre-stressed FRP Highway Bridge. (ACI Committee 440.1R, 2006).

In 1996, the first completely footbridge reinforced with FRP project was installed in the EUROCRETE in the United Kingdom as seen in the plate (1-3) below (CEB-fib, 2007).

In 1997, GFRP bars were used in the Crowchild Bridge deck construction in Canada (ACI Committee 440.1R, 2006).

In (2016), GFRP bars were used in China in the construction of sea walls in Yancheng city and underwater tunnel of Weisan road as seen in the plate (1-4) and (1-5).



Plate (1-3): The first concrete footbridge in Europe reinforced with only FRP bars (ACI committee 440.1R, 2006).



Plate (1-4) The use of GFRP in the sea walls in Yancheng city, China, 2016



Plate (1-5) GFRP use in the underwater tunnel of Weisan road in Nanjing, China, 2016.

### 1.2.3 FRP Characteristics:

FRP bar is anisotropic material and can be manufactured using a different techniques such as braiding, and weaving. The properties of FRP bar depend on many factors such as the volume of fiber, type of fiber, resin type, fiber adjustment, dimensional effects, and quality control during manufacturing (ACI Committee 440.1R, 2006). Table (1-2) shows the physical and mechanical properties GFRP and steel bars.

Table (1-2): The Characteristics of GFRP bars and Steel bars.

Characteristics		GFRP	Steel
Specific Weight		1.25 to 2.1	7.9
Nominal Stress of Yield (MPa)		N/A	276 to 517
Tensile strength (MPa)		483.0 to 1600.0	482 to 692
Elastic modulus, $\times 10^3$ GPa		35 to 51.0	200
Strain of Yield, %		N/A	0.145 to 0.253
Strain of Rupture, %		1.2 to 3.1	6.0 to 12.0
Coefficients of Thermal Expansion $\times 10^{-6}/^{\circ}\text{C}$	Longitudinal, $\alpha_L$	6.0 to 10.0	11.7
	Transverse, $\alpha_T$	21.0 to 23.0	11.7

### **1.3 Research Significance**

In the concrete structures, a high percent of the overall weight of structure comes from the concrete self-weight. Thus the reducing its density leads to a significant benefit. The use of lightweight concrete in the concrete structure is one of the most efficient ways to reduce the dead weight of the structure. The use of lightweight foamed concrete in the structure leads to reduce the beams, columns and foundation size, because it reduces the dead weight. This leads to the reduction in the overall cost. Also, the good thermal insulation of the lightweight foamed concrete contributes to the reduction of the operating costs such as heating and air-conditioning.

The lightweight foamed concrete features a good thermal and sound insulation. Therefore, its use in construction provides a comfortable and convenient condition inside the building, which reduces the consumption of energy sources in heating and cooling.

The use of lightweight concrete is considered appropriate for the seismic design of the building. The lateral forces of the earthquake on the building structure is directly proportional to the weight of the structure, so the use of lightweight foamed concrete in construction structure will reduce the dead weight, and therefore the earthquake effect on the building will be less.

The FRP bars have a lighter weight compared with steel bars which reduces the cost of transportation including the easy of handling the bars in site.

Few studies were found at the local universities and around the world about the use of lightweight foamed concrete beams.

The ACI guidelines for the design and construction of FRP bars reinforced concrete, ACI440.1R-06, stated that the flexural and shear theories were developed for normal concrete. This study aims to investigate the flexural behavior at serviceability and ultimate limit state of GFRP bars of lightweight foamed concrete (ACI Committee 440.1R, 2006).

The FRP bars are a significant importance in the structures where non-metallic properties reinforcements are required like in the surroundings of some medical devices.

Also, the FRP bars is important in the constructions where the high ratio of weight to strength is required.

The use of steel fiber and polypropylene fiber in lightweight foamed concrete beams reinforced with FRP may present an effective solution to overcome the problem of ductility in the construction reinforced with FRP bars.

The FRP bars can be a sufficient alternative to the traditional steel reinforced concrete structure in corrosive environments or when the electromagnetic effects fields may be attended (Barris et al. , 2013).

The FRP reinforcement is a non-conductive material, thereby the demand increased for it to use in the construction of medical. Other FRP bars uses are improved due to the fact that non-corrosive advantages became best accepted and desired, specifically in constructions of the seawall, reactor bases, runways of the airport, and electronics laboratories (ACI Committee 440.1R, 2006).

## **1.4 Research Objectives**

The main objective of this research is to investigate the flexural behavior of lightweight foamed concrete beams reinforced with GFRP bars. The study objectives can be stated in two parts:

### **Part One: Trail Mixes**

Many experimental trial mixes of lightweight foamed concrete were casted and tested. The additives and two types of fibers (Steel fiber and polypropylene fiber) were used in these foamed concrete mixes in order to:

1. Investigate the effect of these additives and fibers on the mechanical properties of (LWFC) including, compressive strength, tensile splitting strength, flexural strength, and modulus of elasticity.
2. Producing lightweight foamed concrete suitable for structural applications and then choose appropriate mix for use in casting the beams.

### **Part Two: Reinforced Concrete Beams**

1. Investigating flexural behavior of lightweight foamed reinforced concrete beams. Testing all beams under flexural load until failure in order to examine failure modes, deflection, cracks patterns, cracks width, concrete strain and main reinforcement strain that can help to correctly understand the overall behavior of beams under the serviceability requirements.
2. Experimentally testing the two types of concrete beams, lightweight foamed concrete and normal concrete, reinforced with different reinforcement ratios of GFRP bars as a main reinforcement. Comparing

the results to show the difference in the flexural behavior between the lightweight foamed concrete and normal concrete.

3. Studying and analyzing the results to decide the feasibility of using light weight foamed concrete as structural material and GFRP bars as main reinforcement in concrete structures.
4. Studying the serviceability limit state SLS and ductility of GFRP reinforced concrete beams.
5. Comparing the experimental deflection and cracks width with the predicted results estimated by equations of ACI-440.1R code.



## **1.6 Outline of the Thesis**

**Chapter One:** Gives an introduction to the thesis. The chapter starts with the description for lightweight foamed concrete and its properties. Also, this chapter describes the GFRP properties and its applications with significance, objectives and scope of this research.

**Chapter Two:** contains a summarized review of relevant literature on the properties lightweight foamed concrete and reviews on the using of the FRP reinforcements in the field of constructions and researches in the field of the concrete beams reinforced with GFRP bars.

**Chapter Three:** at first details with the properties of the materials used and introduces the details of the experimental program. Design the mixes with or without admixtures, additives and fibers and conducting tests for the mechanical properties of all mixes such as compressive strength, tensile splitting strength, flexural strength and modulus of elasticity. Also instrumentation used in the tests are detailed.

**Chapter Four:** the experimental results are displayed, analyzed and discussed. The failure mode and the cracking patterns are commented on and the deflection behavior is discussed. Strains in the concrete and in the reinforcement are shown. The serviceability limit state SLS issues were studied.

**Chapter Five:** provides the conclusions drawn from this study, recommendations and suggestions for further studies.