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BOND BEHAVIOR OF LIGHTWEIGHT FOAMED REINFORCED CONCRETE

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

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COMMITTEE DECISION

We certify that we have read the thesis entitled (**Bond Behavior Of Lightweight Foamed Concrete**) and we have examined the student (**Rafal Ahmed Hadi**) in its content and what is related with it, and in our opinion, it is adequate as a thesis for the degree of Master of Science in Civil Engineering.

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بسم الله الرحمن الرحيم

﴿ يَرْفَعِ اللَّهُ الَّذِينَ آمَنُوا مِنْكُمْ وَالَّذِينَ أُوتُوا الْعِلْمَ دَرَجَاتٍ وَاللَّهُ بِمَا تَعْمَلُونَ خَبِيرٌ ﴾

صـــــــدق اللـــــــه العظيـــــــم

(من سورة المجادلة – الاية ١١)

DEDICATION

To my parents, whose I miss their presence every day but their soul is still in the sky of my life and I feel with their pride of being their daughter, may God have mercy on them.

To my sister, for her support and encouragement.

Rafal Ahmed Hadi

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Rafal Ahmed Hadi

Bond behavior of lightweight foamed concrete

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ABSTRACT

The lightweight foamed concrete (LWFC) applications in the structural building are very restricted due to its low strength and brittleness. The experimental work of this study includes two parts: the first involves improving the LWFC as structural material using additives and fibers. Where many trial mixes were made based on the density and design compressive strength. Then, the mechanical properties of the ideal mixture (1800kg/m^3, 40MPa) are covered in detail for their effect on the bonding behavior of LWFC. The test results showed that the addition of the fibers into the LWFC mix decreases the flowability by 16.67%, and the other mechanical properties [compressive strength, splitting tensile strength, flexural strength, and modulus of elasticity] are enhanced by 20%, 90.79%, 130.55%, and 113.36% respectively.

The second part of this work is the investigation of bond behavior of (Lightweight foamed, Normal) concrete using (GFRP) bars and conventional deformed steel bars. This part includes 54 specimens of the concrete cube with different dimensions (dimensions=$10d_b$). The main variables considered are the concrete type (LWFC, NWC), reinforcement type (GFRP bars, Steel bars), embedded length ratios (3∅, 4∅, and 5∅) and bar diameters (∅10, ∅12, and ∅16). And, when comparing between the two types of reinforcing bars it was noted that the diameter ∅12 of GFRP bars gives better results as the bond strength ranged (82%-92%) of the bond strength of steel

bars depending while the comparison between the two types of concrete showed that the efficiency of LWFC towards the bond strength is very good and close to the bond strength of NWC and it also surpasses it when using diameter Ø12 regardless of the relatives' embedded lengths, using the shorter embedded lengths ratios of diameter Ø10 and 4Ø embedded length ratio of diameter Ø16. Also, all specimens of foamed concrete failed by pull out and the cracks were less and narrower compared to normal concrete.

Equations with a high correlation coefficient were derived to represent the laboratory results of a pullout test of LWFC for the two types of reinforcing bars.

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LIST OF SYMBOLS AND TERMINOLOGY

Symbols	Terminology
PO	Pullout Test
W/C	Water to Cement Ratio
W/B	Water to Binder ratio
C/S	Cement to Sand ratio
SP.	Superplastisizer
Po	Polyolefin fibers
PP	Polypropylene fibers
Cs	Corrugated steel fiber
Hs	Hooked-ends steel fibers
Ec	Modulus of elasticity of concrete in MPa
Es	Modulus of elasticity of steel in MPa
fr	Modulus of rupture in MPa
fcu	Cube compressive strength of concrete in MPa.

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
BS	British Standard
FRP	Fiber Reinforced Polymer
GFRP	Glass Fiber Reinforced Polymer
I.Q.S	Iraqi Central Organization for Standardization and Quality Control
LWFC	Lightweight Foamed Concrete
NWC	Normal Weight Concrete

Chapter One

Introduction

1.1 General

Lightweight foamed concrete (LWFC) is opposed to masonry and normal weight concrete (NWC), since it is not well studied, known, and widely implemented in the construction sector so, it can be considered relatively as a new building material (De Villiers,2015). According to DIN1045-1, concrete can be classified into three types according to its dry density; (800-2000 kg/m^3) lightweight concrete, (2000-2600 kg/m^3) traditional weight concrete, (>2600 kg/m^3) heavyweight concrete. And according to ASTM C330, lightweight concrete is classified into structural with a compressive strength of ≥17MPa and non-structural with a compressive strength <17MPa. Lightweight foamed concrete is a type of aerated lightweight concrete which can be described in term of binder materials (usually using cement and other chemical additives such as silica fume or fly ash or ground granular blast furnace slag (GGBS)), fine sand and water while the air is represented by a homogeneous foamed that is gradually added to reach the required fresh density. This stable air babbles in foamed concrete replace the coarse aggregate and this is the main difference between lightweight foamed concrete and ordinary weight concrete. The cellular structure of the mix is achieved by the presence of macroscopic voids occurring from a chemical reaction of gas or the mechanical introduction of air or other gasses (autoclave curing is usually employed)" (ACI Committee 523.2R, 1996). The foam used in the production of foamed concrete is a combination of liquid, chemical additives and compressed gases may be nitrogen, natural gas, carbon dioxide, and air which represent 20% by volume of the mix (Brady et al., 2001).

Sustainable concrete is today one of the construction industry's major problems, foamed concrete mix design requirements will help address this. new. challenge significantly, thus upholding the idea of "sustainable building." (Benghida, 2017) by including the foamed concrete mixture with materials that have pozzolanic properties such as silica fume, slag, and fly ash, which are harmful to the environment, thus ridding the environment of these wastes in addition to reducing the use of cement known for its high carbon emissions. Also, using foamed concrete leads to reduce the reinforcement needs for construction, size of structural members, and the ease of its handling and transportation due to its lightweight so, this will reduce the total cost of the construction.

It is a risk to apply the standard specifications for normal weight concrete structural design directly to design structures with lightweight foamed concrete because this will lead to the production of an unsafe structure. This risk is represented by the lack of available information and data on the structural properties of (LWFC). One of these characteristics is the bond behavior between this concrete and the deformed reinforcing bars.

1.2 Characteristics of Foam Concrete

Foamed concrete has many advantages and disadvantages, including that appears during the production process, and others appear later. One of the most important advantages is that it has a high strength to weight ratios in addition to not needing complications during the mixing and production process because it is known as self-leveling concrete because it is free to flow and not need vibratory during casting, a building constructed with this concrete is twice as safe as fire compared to traditional concrete structures. A wide range of densities can be obtained according to the intended purpose of use, as very low densities are used for non-structural purposes which are limited to ground level, thermal and acoustic insulation and sewer, voids filling, swimming pool in filling and in bridges for approach, decks, strengthening... etc. While the high densities of lightweight concrete with 20 MPa compressive strength can be used for construction purposes due to the attractive core properties in terms of its contribution to reducing the dead weight of the structure and thus, making the structure of economic design (Amarnath, and Ramachandrudu, 2013).

While the major defects that foamed concrete suffers are the high porosity as these pores affect the strength of the concrete mainly, in addition to defects that appear during the mixing stage where the foamed concrete mix is very sensitive to the water content added during mixing, as too much water causes the separation of the input foam and thus produces an irregularity in the density of the mixture while adding less water than required makes the cement use the water of foam and consequently the deterioration of the foam, which also affects the density and regularity of mixing (De Villiers, 2015).

It must be noted that the mixing for a long period than usual (with the presence of superplasticizer) causes the components of the mixture to settle down and the foam layer is raised thus, the concrete surface is easily shattered as seen in the plate (1-1). Therefore, always resorting to improving the properties of the lightweight foamed concrete mixture by using different additives such as the use of materials of high fineness with a pozzolanic composition, for example, silica fume, fly ash, and slag, to improve strength, density, and the bond between the ingredient of a concrete mix by filling voids between cement and fine aggregate. In addition to that, some foamed concrete mixtures require enhancement with fibers to increase their engineering properties.

Plate (1-1): The separate and rise up of the foam layer from concrete due to the increased mixing time in the presence of the superplasticizer

1.3 Applications of Lightweight Foamed Concrete

After knew the attractive properties of foamed concrete such as thermal and sound insulation, low consumption of aggregates due to its low dead weight, self-leveling, control low strength... etc. It becomes clear that by incorporating foam into a regular concrete system, the final product can be used in more complex structures and conditions. The application of foamed concrete has become popular all over the world, particularly in bad weather areas, earthquakes, and storms and that depends on its density as seen in the table (1-1) (Mohd Sari and Mohammed Sani, 2017).

Table (1-1): Applications of foamed concrete according to its density

Density (kg/m^3)	Application
300-600	Replacement of existing soil, soil stabilization, raft foundation.
500-600	Currently being used to stabilize a redundant, geotechnical rehabilitation and soil settlement. Road construction.
600-800	Widely used in void filling, as an alternative to granular fill. Some such applications include filling of old sewerage pipes, wells, basement and subways.
800 - 900	Primarily used in production of blocks and other non-load bearing building element such as balcony railing, partitions, parapets, etc.
1100-1400	Used in prefabrication and cast-in place wall, either load bearing or non-load bearing and floor screeds.
1100-1500	Housing applications.
1600-1800	Recommended for slabs and other load bearing building element where higher strength required.

The examples of using foamed concrete as a construction material in Iraq is the city of residential architecture project in the Maysan region in southern

Iraq (Sallal, Ali Kadhim. 2018) the form of the project is presented in table (1-2) below

Table (1-2): Materials of Maysan project (Sallal, Ali Kadhim. 2018)

Oven-Density in KG/m³	400	600	800	1.000	1,200	1.400	1.600	2.316 Conv.concr.
Sand (kg)	-	210	400	560	750	950	1.100	1.815 gravel+sand
Cement (kg) +	300	310	320	350	360	380	400	320
Water in mortar (kg) +	110	110	120	120	140	150	160	180
Quantity of Foam (Ltrs)	(800)	(715)	(630)	(560)	(460)	(370)	(290)	-
Water in Foam (kg) +	64	57	50	45	37	30	23	-
Wet Density (kg/m³)	474	687	890	1.075	1.287	1.510	1.683	2.315
Foaming Agent use (kg)	1,5	1,4	1,2	1,1	0,9	0,7	0,6	-
Water/Cement Ratio	0,58	0,54	0,53	0,47	0,49	0,47	0,46	0,56
Maximum Strength in N/mm²	~ 1	~ 2	~ 3	~ 4	~ 8	~ 12	~ 18	40 +
Average Lambda (W/m x K)	0,096	0,18	0,21	0,32	0,405	0,450	0,550	2,10

(Achieved strength at the lab with optimum sand and cement qualities) More cement will increase strength. Using lightweight aggregate in matrix of Cell. Concrete increases strength up to 500% in overall densities below 1.000 kg/m³

GENERAL REMARKS

Recommended weight of foam	Minimum 80 g/ltr
Crushed Sand might mechanically	destroy part of the foam
Water to process foam	Potable, if possible below 25°C
Dilution of foaming agent	1 part of Neopor to 40 parts of water
Recommended Cement	Portland CEM I 32,5R or higher grade, or similar
Recommended Sand	Washed river sand. Density/Sieve :Up to 1.000/up to 2mm; Up to 1.200/up to 4 mm; Up to 1.400/up to 5 mm; Up to 1.600/up to 6 mm; Minimum 15-18% fines

1 kg of Neopor foaming agent, diluted in 40 parts of water yields approx. 510 litres of foam at 80 grams/litre

Captive densities are oven-dry (24h at 100°C)
Appr. 25% of the total volume of water (in mix and in foam) in relation to the weight of cement used will crystallize and therefore will have to be added to the dry-weight of the cement and sand used to reach the "oven-dry" density.


a


b

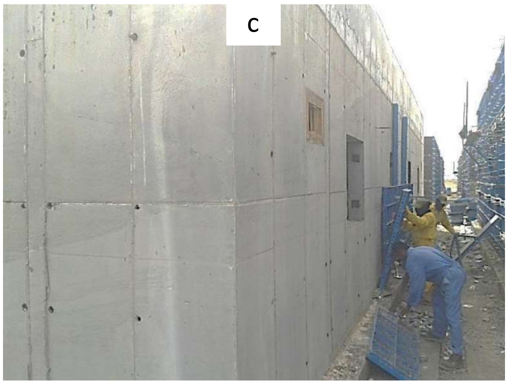

Plate (1-2): (a) Details related to foundations, (b) Installation of molds and casting, (c) Remove the molds after 20 days

Also, it's used for nonstructural application ($f_{c'}$ =<17MPa) as leveling materials in southern Iraq, where because of its lightweight used as leveling layer primarily rather than using waste, besides using it as leveling materials under tiles as it cast in single-level without of any variation in the surface and then adhesives porcelain.

Plate (1-3): The use of LWFC in Al Hussain Quran School in Karbala city, Iraq, 2017.

1.4 Fiber Reinforced Polymer Bars (FRP)

The The Swiss Federal research center for Materials Analysis and Testing (EMPA) was the first laboratory to test and research composites of fiber-reinforced polymer (FRP) for strengthening reinforced concrete members. In 1984 EMPA implemented a test on beams reinforced with CFRP plate (Hussain, et. al., 2018). Later on, this type of bar became popular in the construction environment due to its high tensile strength against its weight, which is lighter than ordinary steel bars. Enabling them to design and fabricate structures of very high load carrying capacities. One of the important problems in the construction sector is the problem of rust and corrosion of steel reinforcement which affect concrete by its deterioration and lost its serviceability (Maranan, et. al., 2015). To avoid this problem, FRP bars can be used as an alternative to regular steel bars. It also keeps maintains the cost of buildings due to its resistance to corrosion.

Fiber-reinforced polymer bars are formed through the incorporation of fiber into a polymer (resin) mix that binds the fiber together. FRP bars have attractive properties such as lightweight, thermal and electrical insulation, noncorrosive, and nonmagnetic material, and high tensile strength, which makes it a good material in the reinforcement of structures (ACI Committee 440.1R, 2006).

1.5 Research Significance

Very limited studies related to the bond behavior of foamed concrete were found around the world. Although it is a very important property for this type of concrete as it can study the behavior of the reinforced concrete (RC) structures, since it assures the stress transfer between the two materials (reinforcement and concrete), also the bond is one of the main keys to assessing the performance of reinforced concrete (RC) structure against a seismic load.

The current study focuses on investigating the bond behavior of foamed concrete according to (RILEM, 2006) by using two types of bars which are steel and GFRP. It is important to know the bond behavior between foamed concrete and FRP, as this type of reinforcement not affected by weather factors as it does not rust or corrode by the action of moisture so it can be entered into many design fields. On the other hand, reinforcing foam concrete with some types of fibers such as steel and polypropylene fibers can contribute to enhancing its strength and various properties, especially concerning tensile strength, and thus solve the problem of brittleness.

1.6 Research Objectives

The main objectives of this research are:

1- Investigate the mechanical properties of the proposed foamed concrete mix.

2- Investigate the bond behavior of LWFC with GFRP bars and conventional steel bars.

3- Comparison of the results of bond strength for LWFC with the bond strength results of normal weight concrete.

1.7 Outline

Chapter One: It gives an introduction to lightweight foamed concrete in terms of its identification, various applications, and its properties, in addition to addressing a brief to define the reinforcing bars made of polymer, as well as the significance and objectives of the research.

Chapter Two: Briefly summarizes the previous studies related to the field of studying the bonding behavior of lightweight concrete by addressing the studied variables, methods adopted in the test and the results previously reached.

Chapter Three: The first part of this chapter deals with the trail mixes using different construction materials to produce a mixture of lightweight foamed concrete with good mechanical properties in terms of compressive strength, flexural, tensile strength, and elastic modulus. While the second part of this chapter includes a detailed explanation of preparing the proposed specimens for conducting the bond test according to the (RILEM, 2006).

Chapter Four: The results of the study are presented in this chapter and the discussion was conducted in detail on the results of the bond behavior, slip, and mode failure for the specimens of study. Besides representing the practical results for bond behavior of LWFC by linear equations with a high correlation coefficient. Also, commented on the results related to the mechanical properties of foamed concrete.

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