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Carbon Fiber Effect on Compressive Strength of Lightweight Foamed Concrete

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ABSTRACT

Foam concrete is a type of concrete that is widely used in civil engineering as a high-quality building material with low weights and usually low compressive strength. Improving the compressive strength is the main objective of this paper by supplying this type of concrete with different proportions from carbon fibers. This study included preparing an experimental mixture to produce foam concrete consisting of optimal ratios of water-to-cement ratio (0.35), sand-to-cement ratio (1:1.5), and superplasticizer (1.8 %). The appropriate dosage of foaming agent was selected to obtain lightweight foam concrete with an appropriate compressive strength of up to 17.4 MPa and a target density of (1300-1350) kg/m^3 after 28 days. Adding carbon fibers gave a 1 % highest compressive strength estimated at 9.77 % but the flow rate decreased by about 8.55 % compared to the reference mixture after 28 days. The results indicate that adding fibers contributed to increasing the compressive strength of foam concrete, but it negatively affected the flow rate.

Keywords: Foam concrete, Carbon fibers, Compressive strength.

1. INTRODUCTION

One highly sophisticated civil technology for engineering that can be used in a variety of building constructions is foamed concrete **(Lim et al., 2015).** researchers found Over the past fifteen years, there have been improvements important to remember in the producing techniques of foamed concrete, with the quality of foam agents increasing production and expanding its applications **(Brady et al., 2001; Dolton et al., 2006).** According to the many researches on the materials that have been studied until now, the pore structure, and the mechanical properties (density, water absorption, modulus of elasticity) for foam concrete can all be severely impacted by the performance foam **(Hajimohammadi et al., 2018; Hussian and Aljalawi, 2022)**. Foamed concrete has desirable properties that make it distinct from low self-weight, fluidity, and effective qualities of acoustic and thermal

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insulation. It is produced by preparing stable foam (made separately by aerating a foaming agent solution) with A slurry (mortar) and is combined **(Dhengare et al., 2015; Zhao et al., 2015).** Furthermore, using remanufactured foam or surfactants can form a permeable microstructure in the mixture of concrete, allowing for air bubbles to be trapped, of air bubbles, a process known as Celluer Light Wieght Concrete construction **(Jain et al., 2019).** Concrete is known to be brittle due to its strength of limited impact and relatively poor resistance and fracture toughness. So researchers have incorporated fibers into the concrete to enhance its mechanical properties. Organic materials such as polyvinyl alcohol, acrylic polypropylene, polyolefin, carbon, and alkali-resistant glass were used to reinforce the concrete with synthetic fibers **(Dolton and Hannah, 2006; Dandge et al., 2015)**.

Using fibers in concrete positively affects its properties including fibers in concrete can improve several mechanical properties, such as tensile and flexural strengths, toughness, impact resistance, fracture energy, and ductility **(Dawood, 2011)**. The type and volume of fibers used influence the performance of -concrete. Therefore, using the right type and fiber volume can enhance concrete's mechanical properties **(Moghimi, 2014)**. Producing foamed concrete has been investigated by using fly ash. The study found that the addition of fly ash had a positive impact on the properties of the concrete. Using fly ash as a substitute for fine aggregate or cement significantly improved the properties of the concrete. Achieving a strength of over 25 MPa at a plastic density of 1400 kg/m^3, making it suitable for various building applications due to its high thermal insulating characteristics of 0.50 W/m.K **(Cox et al., 2002; Meyer, 2004)**. Foamed concrete is a practical, low-weight, low thermally conductible material used mainly for filling. However, applications as load-bearing materials are scarce due to low strength parameters, so it is limited applications in Iraq **(Al-Safar, 2012; Jones et al., 2019)**.

A recent study investigated the production of sustainable Foamed Concrete by using limestone dust powder was used as a partial replacement material by weight, of cement (10%, 14%, 18%) after selecting the optimal dosage of foam agent, modified the concrete properties by adding different percentages of polypropylene fibers at (1%, 1.5%, 2%) by concrete volume. The best proportion of polypropylene fibers was 1%, with all mixes consistent content of limestone dust of about 14% by weight of cement resulting in a significant improvement in splitting flexural strength and tensile strength. The splitting tensile strength has increased by about 14.55%, and the flexural strength by 55% at 28 days **(Ali and Fawzi, 2021)**. They have been discussing the results of studies associated with using fibers in concrete such as carbon fibers, fly ash, silica, and foam, to produce lightweight foam concrete, and to determine the ideal combination for high strength and low density. They examined that the best mixture involved 1 kg/m^3 of foaming agent, a 1:1.5 cement to sand ratio, and a water-cement ratio was 0.32 ratio of 1.5% of carbon fiber by this ratio of 1.5% of carbon fiber created significantly improved in the compressive strength for the concrete being 68% and the tensile strength by 200%, and the bending strength by 275% **(Basheer et al., 2019)**. The researchers illustrated how it is possible to produce carbon fiber-reinforced foam concrete. They can produce several mixtures by varying the sand/cement ratio and adding different doses of foaming agents by 0.8, 1, 1.2, 1.4 kg/m^3, and Silica Fume by 10%. The results illustrated that the foamed concrete with carbon fiber reinforcement had acceptable levels of strength, particularly that with 1.9 sand-to-cement ratios. improved significantly the compressive strength of the foamed concrete when carbon fiber was incorporated, by 1%, increasing about 35% to 44% and 16% when using 1.5% carbon fibers **(Tihanon et al., 2016)**. Various tests were conducted including flexural strength, split tensile strength, and compressive strength, workability, results showed that adding fibers to concrete increased its strength, early strength, and support. Flexural specimens with fibers showed a radical improvement in strength compared to those without fibers. were used Fibers that showed in the split tensile test, preventing specimens of concrete from splitting that follow the initial crack **(Hachim and Fawzi, 2012; Muley et al., 2015)**.

The objective of the study is to generate a low-density With appropriate compressive strength foamed concrete by mixing foam agents with water, cement, and sand combinations and then adding carbon fibers in varying amounts. Adding carbon fibers increases the concrete's tensile, compressive, and flexibility strength. Objectives include enhancing the qualities of cellular concrete, lowering self-weight for building, and generating structural concrete from lightweight cellular concrete using environmentally friendly components.

2. EMPIRICAL STUDY

2.1 Materials

2.1.1 Cement

Ordinary Portland cement (OPC) was used in the work. According to physical and chemical requirements (Cem I-42.5 R) meets **(IQS.5, 2019).**

2.1.2 Sand

The work utilized natural sand obtained from AL-Ukhaider as fine aggregate. The sand grading conforms with zone 4 and complies with the specification **(IQS. 45, 1980).**

2.1.3 Water

Tap water was used for mixing and curing all concrete according to **(IQS. 1703, 2018)**

2.1.4 Carbon Fiber

Sika Wrap produces carbon fiber-reinforced materials due to their lightweight, flexible, challenging, and potent properties.

2.1.5 Superplasticizer

Sika Company produces a water-reducer that is recommended to be used with a concrete superplasticizer that conforms to the **(ASTM C494/C494M, 2017),** Type G, the recommended dosage rate for this water-reducer is between 0.5 to 2 liters per 100 kg of cement. This product is used to improve the workability of the concrete.

2.1.6 Foam agent

The lightweight cellular concrete is produced by utilizing a foaming agent that meets the performance standards in (**ASTM C796/C796M, 1997)**. The mix is entrained with air bubbles using Lightcrete-400 foaming agent from Sika Chemistry Factory. A drill and clip are used to generate the required foam.

3. METHODOLOGY

In the beginning, a standard mortar was created without the use of foam agents as part of an experimental effort. The mixture used in the experiment consisted of a cement content of 300 (kg/m^3) along with various ingredients such as sand to cement C:S ratios (1:1.5 and 1:1.8, followed by 1:2.5), with water-to-cement ratios W/C (0.38 and 0.35), and superplasticizer (SP) (0.75 and 1.2, then 1.8%) relative to the weight of the cement**.** Refer to **Tables 1 and 2** for more information.

Table 1. Mix Symbols and their contents,

Symbols	Description
conventional concrete	Sand +cement +water +HRWRA
HRWRA	High-Range Water Reducing Admixture (Superplasticizer)
C:S	Cement to the Sand ratio
W/C	Water to Cement ratio
MSP1	conventional concrete with [1:1.8 C:S + 0.35 W/C + 0.75% HRWRA]
MSP2	conventional concrete with [1:1.8 C:S + 0.35 W/C + 1.2% HRWRA]
MSP3	conventional concrete with [1:1.8 C:S + 0.35 W/C + 1.8% HRWRA]
MSP4	conventional concrete with [1:1.8 C:S + 0.38 W/C + 0.75% HRWRA]
MSP5	conventional concrete with [1:1.8 C:S + 0.38 W/C + 1.2% HRWRA]
MSP6	conventional concrete with [1:1.8 C:S + 0.35 W/C + 1.8% HRWRA]
MS1(MF0)	conventional concrete with [1:1.5 C:S +0.35 W/C + 1.8% HRWRA]
MS2	conventional concrete with [1:2.5 C:S + 0.35 W/C + 1.8% HRWRA]
MF1	MS1 + Foam agent content 0.75 kg/m^3
MF2	MS1 + Foam agent content 1.11 kg/m^3
MF3	MS1 + Foam agent content 2.27 kg/m^3
MF4	MS1 + Foam agent content 3.33 kg/m^3
MF5	MS1 + Foam agent content 4.41 kg/m^3
MF6	MS1 + Foam agent content 5.55 kg/m^3
MF7	MS1 + Foam agent content 6.66 kg/m^3
MF8	MS1 + Foam agent content 8 kg/m^3
MF9	MS1 + Foam agent content 11 kg/m^3
MF10	MS1 + Foam agent content 16 kg/m^3
MF11	MS1 + Foam agent content 22.2 kg/m^3
MC1	MF9 + Carbon fiber 0.5%
MC2	MF9 + Carbon fiber 0.75%
MC3	MF9 + Carbon fiber 1%

3.1 The Processes of Preparing Mixtures for Conventional Mortar

1. Mix the superplasticizer with water.
2. Add the materials (cement and sand) into a mixing machine in a saturated surface dry (SSD) state.
3. Blend the materials for two minutes.
4. Gradually introduce the water with the superplasticizer
5. Into the mixing machine while continuously mixing for one minute.
6. Use a tool to stack the slurry mixture into molds.
7. After molding, wrap the molds in nylon bags for 24 hours to prevent water from evaporating.

8. Unwrap the molds and immerse them in water for 7 or 28 days at a standardized temperature.
9. Follow the curing technique outlined in (**ASTM C192/C192M, 2016).**

3.2 Preparing Foamed Concrete (FC) by Slected Optumim Ratio of Materials

1. Unitized cement with a content of 300 (kg/m^3) was mixed with fine aggregate (SSD) in two stages:(a)First stage, the ratios of 1:1.8 (C:S), with (W/C) of 0.35 and 0.38, and (SP) percentages of 0.75%, 1.2%, and 1.8%. After testing for compressive strength and flow at 28 days, it was determined that the optimal percentage was 1.8% SP, with 0.35 of W/C providing the greatest compressive strength at 28 days. (b) Second stage, C: S ratios of 1:1.5, 1:1.8, and 1:2.5 were used with 0.35 W/C and 1.8% SP. It was determined that a ratio of 1:1.5 achieved the required compressive strength after 28 days. This ratio also ensured homogeneous mixing and excellent workability when W/C was 0.35, and the superplasticizer was 1.8%, as shown in **Table 2.**

Table 2. Trail mix details for Optimum percentage

Mix Symbols	Density (kg/m^3)		Compressive Strength (MPa)	
	7 days	28 days	7 days	28 days
MSP1	2154	2171	28	42
MSP2	2171	2196	32	48
MSP3	2181	2206	35	50.5
MSP4	2150	2165	24	36
MSP5	2167	2186	27	40.5
MSP6	2170	2192	32	48
MS1	2253	2230	34	50

2. After mixing the materials for one minute, the optimal ratio of C:S, W/C and SP was determined, resulting in the desired density according to the mortar mix design. The following stages: (a)Water is divided into two parts: one containing a superplasticizer and the other containing a foaming agent. (b)The remaining water is mixed with the foaming agent using an electric mixer (drill) that rotates at high speed for two minutes until a stable bubble foam is formed.
3. The foam was added to the mixture, and the mortar mix stopped when a homogenous mixture was formed.
4. A small amount of lubricant is applied to the sides and base of the mold and casting is performed in two layers according to **(ASTM C109/C109M, 2016**).
5. Compressive strength was tested using foamed concrete cubes for 7 and 28 days using varying dosages of foam agents **(Abdulrazzaq, 2012).**
6. To find the best percentage of carbon fibers to add to foamed concrete, three different percentages of 0.5%, 0.75%, and 1% were tested. The compressive strength of the concrete was measured after 7 and 28 days by casting cubes. The fibers were mixed manually to ensure they were evenly distributed throughout the mixture and were randomly dispersed. For more details, refer to **Figs. 1 and 2** (**Tihanon et al., 2018).**

4. CURING

After 24 hr after casting, the specimen demoulding and put in the water at room temperature.

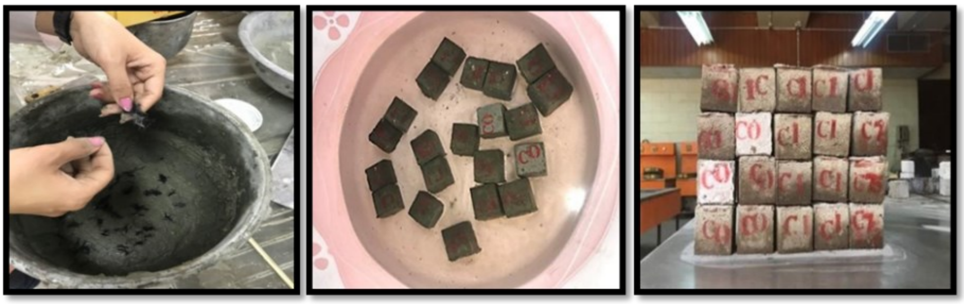

Figure 1. Producing lightweight concrete in the laboratory

Figure 2. Details for casting and curing

5. TESTING

5.1 Testing the Fresh Concrete

The test was conducted according to **(ASTM C230/C230M, 2014)**. Flow test was employed to determine the amount of water needed to achieve standard consistency in both conventional and foamed concrete. This test was done after the final mixing stage and before the mixture was cast into molds. The flow table equipment was used for this test. Adjustments are made to the water-to-cement ratio and dose of foam agent to attain the desired workability consistency.

5.2 Testing of Hardened Concrete

The compressive strength of lightweight fiber-reinforced concrete is a crucial mechanical property that indicates the durability and effectiveness of the artificially produced concrete. To determine this strength, a cubic specimen with dimensions of 50x50x50 mm is used to meet the standard specification **(ASTM C192/C192M, 2016).** The specimen is placed in a compression machine, and a load of 2000 kN is applied constantly and perpendicular to the position of the concrete. The compression forces are measured using an electrical measurement device. The compressive strength is calculated by dividing the failure load by the applied area of the cube. This process is carried out on each cube at the ages of 7 and 28 days, and the failure load of each cube is recorded. The results for each combination are obtained by averaging three cubes. As Eq. (1) represents this calculation:

$$F_{cu} = P/A \tag{1}$$

where F_{cu} is the compressive strength (MPa), A is the area s' face of the cube (mm^2), P is the compressive load at failure *(N).*

6. RESULTS AND DISCUSSIONS

6.1 Determining the Appropriate Amount of Foaming Agent

The test was conducted for foam concrete mixtures, a foaming agent increases the workability of mortar by enhancing its flow characteristics. The foam concrete's flow rate increases with foam agents **(Bing et al., 2012).** After testing the flow rate of conventional mortar with the optimal proportion of MS1, which was 110 mm, we compared it with the foamed concrete mixture MF9 and observed an increase of about 6.36%. However, adding carbon fibers in different percentages had a negative effect, decreasing the flow rate by 8.55% for MC3 with a percentage of 1% when compared to the foamed mixture MF9 **(Dawood et al., 2016; Amran et al., 2020)**. **Table 3** and **Figs. 3 and 4** show the flow test for different mixtures.

Table 3. Flow test for different mixtures

Mix Symbols	Flow Test (mm)
MS1	110
MF1	110
MF2	112
MF3	113
MF4	113
MF5	114
MF6	115.5
MF7	116
MF8	116
MF9	117
MF10	119
MC1	113
MC2	112
MC3	110

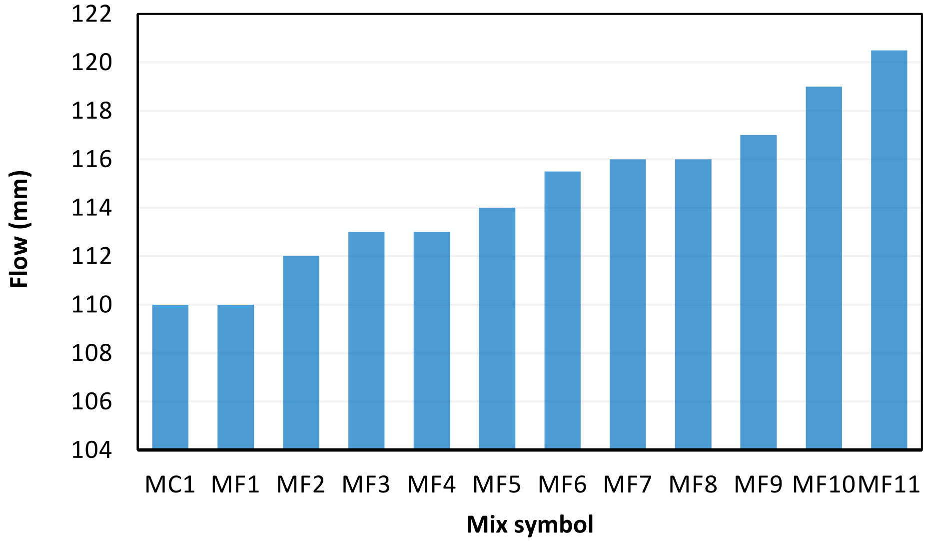

Figure 3. Different mixes have dosages of foaming agent and flow

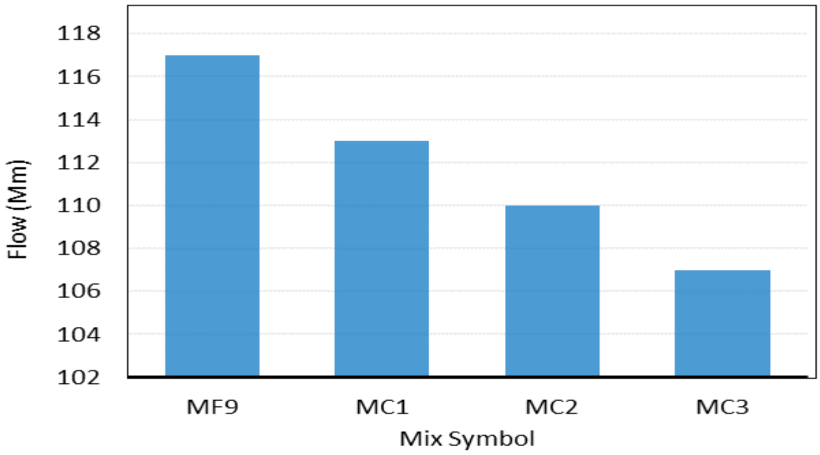

Figure 4. Different percentages of carbon fiber addition to foam concrete

6.2 Effect of Foam Agent on Density and Compressive Strength of LWFC

The effect of the amount of foaming agent on the density and compressive strength of Lightweight foam concrete mixes was investigated. The results showed that a higher amount of foaming agent in the foam concrete mixes decreased dry density at 7 and 28 days. The decrease varied from 2123 to 1025 kg/m^3, while the compressive strength decreased from 40 to 17.4 MPa at 28 days, compared to the control mix. The foaming agent dosage varied in MF1, MF2, MF3, MF4, MF5, MF6, MF7, MF8, MF9, MF10, MF11. The density investigation revealed that all concrete mixtures had high homogeneity, and the target density was achieved in 1343 kg/m^3 within 1300-1350 kg/m^3 for MF9 at 28 days. Cellular Concrete has air gaps controlling porosity, while foamed Concrete has a homogenous void or cell structure controlled by air gaps after hydration **(Jiang et al., 2016).** The increase in total porosity decreases as hydration products have a higher specific volume than anhydrate grains, occupying large pores. Table 4 shows that the 28-day curing process results in an increase in density, and this result agrees with **(Liu et al., 2016). Figs. 5 and 6** provide additional details about different mixes that have varying foaming agent doses with mechanical properties.

Table 4. Different mixes have varying foaming agent doses

Mix Symbols	Density (kg/m^3)		Compressive Strength (MPa)	
	7 days	28 days	7 days	28 days
MF0	2230	2253	34	50
MF1	2100	2123	28.47	40
MF2	2040	2063	27	36
MF3	1872	1895	22	27.8
MF4	1747	1770	19.2	27
MF5	1604	1627	17	22.7
MF6	1520	1543	14.1	19.2
MF7	1460	1483	13.5	19.1
MF8	1400	1423	12.3	18.6
MF9	1320	1343	11.6	17.4
MF10	1034	1057	6.1	9.06
MF11	1002	1025	4.5	6.45

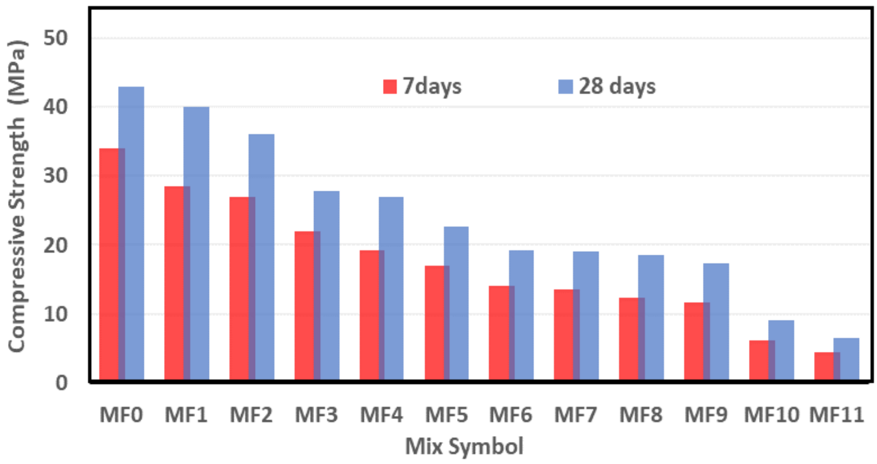

Figure 5. Different mixes having dosages of foaming agents with compressive strength

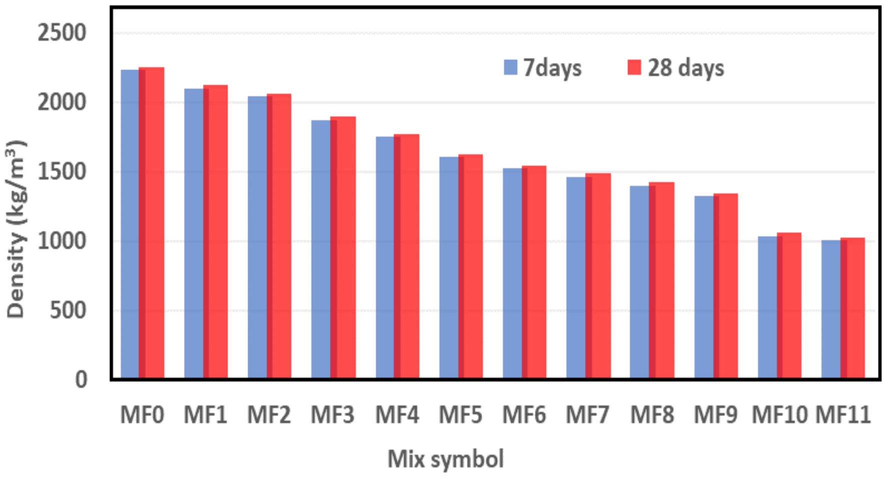

Figure 6. Different mixes have dosages of foaming agents with density

6.3 Carbon Fiber Addition Effect on Compressive Strength of LWFC.

Carbon fibers were added to lightweight foam concrete(LWFC) with different percentages of 0.5%, 0.75%, and 1% by concrete volume. The compressive strength increased by 19.8% with 1% fiber percentage, reaching compared to plain-foamed concrete as given in **Table 5** and seen in **Figs. 7 and 8.** The density of foam concrete increased with a littel affecting of Carbon fibers added

Table 5. Effect of varying percentages of carbon fiber on the compressive strength

Mix. Symbol	**Compressive Strength (MPa)**	
	7 days	28 days
MF9	11.6	17.4
MC1	12.4	18.6
MC2	13.6	19.1
MC3	15.9	20.85

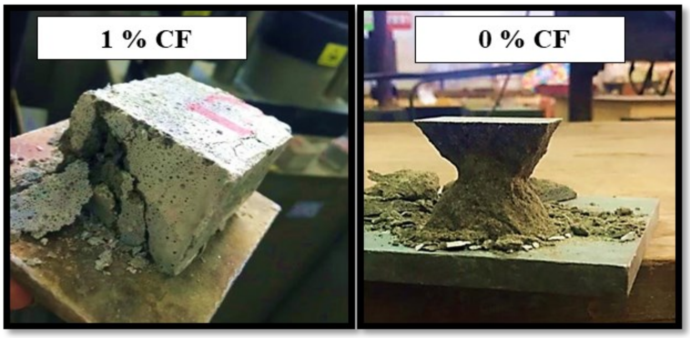

Figure 7. Failure pattern for samples without and with carbon fiber by 1%

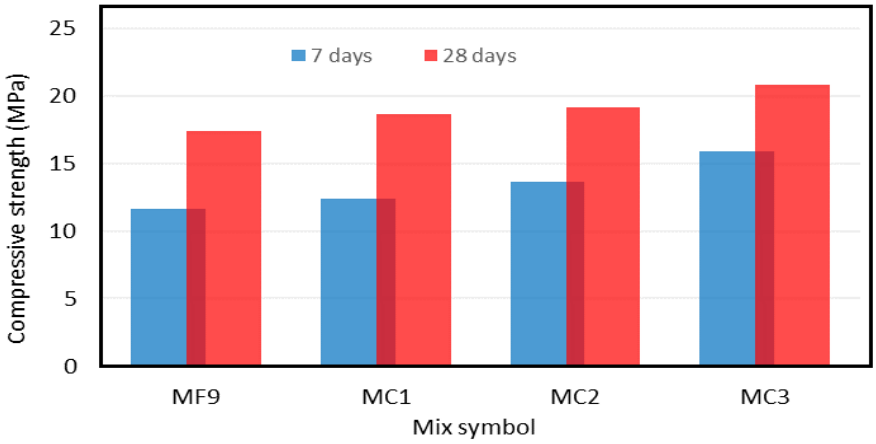

Figure 8. The effect of varying carbon fiber percentages on the compressive strength of foamed concrete at (7,28) days.

6. CONCLUSIONS

In this research properties of the workability and the compressive strength for reinforced lightweight-foamed concrete with carbon fibers were discussed and the following conclusions were drawn:

1) Adding foam increases the flow while maintaining a constant water-cement (W/C) ratio of 0.35. The flow rate increased by approximately 6.36%. However, adding carbon fibers to the mix resulted in a decrease in flow rate, with the optimal ratio being 1%, which decreased the flow rate by about 8.55% compared to the control mix.

2) Experiment with different dosages of a foaming agent to achieve a target density range from 1300-1350 kg/m^3 for 28 days,. After 28 days, the compressive strength and dry density decreased by 65% and 40%, respectively. However, the dry density was 1343 kg/m^3 compared to the control mix.

3) Concrete mixed with different volumes of carbon fiber 0.5%, 0.75%, and 1% showed an improvement in compressive strength for 28 days. The optimal volume of fiber addition was 1%, resulting in an increase in compressive strength of about 19.8 % compared to the reference mix.

NOMENCLATURE

Symbol	Description	Symbol	Description
A	Area s' face of the cube (mm^2)	LWFC	Lightweight foam concrete
CF	Carbon fiber	OPC	Ordinary Portland Cement
FC	Foam concrete	P	Compressive load at failure (N)
F_{cu}	Compressive strength(MPa)	SP	Superplasticizer
FRC	Fiber-reinforced concrete	SSD	Saturated surface dry

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Credit Authorship Contribution Statement

Heba Hatem Abu Al –Hail: Writing – original draft, Validation, Methodology.
Nada Mahdi Fawzi: Review & editing, Validation, Proofreading.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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تاثير الياف الكاربون على مقاومة الانضغاط للخرسانة الرغوية الخفيفة الوزن

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الخلاصة

الخرسانة الرغوية هي نوع من الخرسانة الذي يتم استخدامها على نطاق واسع في الهندسة المدنية كمواد بناء عالية الجودة ذات أوزان قليلة ,عادة ماتكون ذات مقاومه انضغاط قليلة و من اجل تحسين مقاومة الانضغاط وهو الهدف الرئيسي من هذا البحث من خلال تزويد هذا النوع من الخرسانة بنسب مختلفة من ألياف الكاربون . تضمنت هذه الدراسة تحضير خليط تجريبي لإنتاج خرسانة رغوية مكونة من نسب مثلى من نسبة الماء إلى الأسمنت (0.35)، ونسبة الرمل إلى الأسمنت (1:1.5)، والملدن الفائق (1.8 ٪). كما تم اختيار الجرعة المناسبة من عامل الرغوة للحصول على خرسانة رغوية خفيفة الوزن ذات مقاومة مناسبة تصل إلى 17.4 ميكا باسكال وبكثافة مستهدفة ضمن (1300−1350) كغم/م^3 بعد 28 يوم . باضافة ألياف الكاربون أعطت نسبة 1 ٪ أعلى مقاومة انضغاط تقدر بحوالي 9.77 ٪ لكن انخفض معدل تدفق بحوالي 8.55 ٪ مقارنة بالخلطة المرجعية بعد 28 يوماً. حيث تشير النتائج ان إضافة الألياف ساهمت في زيادة مقاومة الانضغاط للخرسانة الرغوية إلا أنها أثرت سلباً على معدل التدفق.

الكلمات المفتاحية : الخرسانة الرغوية, الياف الكاربون, مقاومة الانضغاط