The effect of limestone on the heat resistivity of high-strength lightweight foamed concrete

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ABSTRACT

Lightweight foamed concrete (LWFC) is typically a cementitious substance that includes a minimum of 20% (by volume) of mechanically restricted foam within the mortar blend. It has a higher pore content than conventional concrete.

fifteen concrete mixtures were studied in this thesis. The first section included a reference mixture of cement, sand, water, fly ash, superplasticizer, and foaming agent in different proportions between (1-5) liter/m3 to obtain different densities ranging from (1520 - 1820). kg/m3 A compressive strength of 19.8 MPa has been obtained at 1680 kg/m3 density. The second section consists of a foaming agent of 3 liters/m3 with the reference mixture and limestone in proportions (10%-30%) replaced by sand. The specimens were cured with water. The third section consisted of the same components as the mixtures of the second section, but the specimens were cured with air.

The Specimens were exposed to a temperature of 400 C° for six hours in an electric oven. The compressive strength of the reference mixture decreased after being exposed to a temperature of 400 C° by (10%-13%). As for the mixtures of the second part, the compressive strength of the samples increased by (2.5-3.5) after exposing them to a temperature of 400 C° for six hours. As for the mixtures of the third part, the compressive strength of the specimens increased by (5%-6%) after exposing them to a temperature of 400 C°.

Keywords: Lightweight foamed concrete, Limestone, Heat resistivity, Compressive strength.

1. Introduction

Foamed concrete is frequently known as cellular or lightweight concrete. A typical definition of this material is that it consists of a mortar mix with at least 20% (by volume) of mechanically entrained bubbles. This occurs when air holes are trapped within the structure of matrix using an appropriate foaming agent[1]. Foamed concrete is characterized as aerated concrete containing a higher number of pores compared to conventional concrete, achieved through the addition of preformed foam or chemical reactions post-mixing[2].

Lightweight concrete can be classified into two main groups based on the manufacturing technique. Foamed concrete, also called non-autoclaved aerated concrete (NAAC), and autoclaved aerated concrete (AAC), are types of concrete produced by incorporating foam. The production process of lightweight concrete involves introducing prefabricated, robust foam or mixing a specific air-entraining agent, known as a foaming agent, into the cement paste base mix[3].

There are multiple techniques available for manufacturing lightweight concrete. One method involves excluding the fine portion of the aggregate to produce porous (pervious) concrete. Lightweight concrete (LWC) is produced using mechanical foaming and chemical additives that introduce stable air bubbles into the concrete mix. This type of concrete is also known as gas, cellular, or aerated concrete[4].

Foamed concrete is a type of lightweight cellular concrete categorized under lightweight concrete due to its density ranging from 400 to 1850 kg/m3. It is characterized by the presence of random air voids created by incorporating foam agents into the mortar. This material is recognized for its exceptional flow properties, lower cement content, and decreased aggregate requirements[5],[6].

This research delves into the utilization of limestone as a partial substitute for fine aggregate in concrete manufacturing. Adding limestone to the concrete mixture reduces workability, as evidenced by the slump test, while boosting the water absorption rate of the concrete. The strength obtained after 7 and 28 days of curing indicates that limestone can be introduced into the concrete as a replacement for sharp sand at a rate of 5% to 10%, with a propensity to enhance strength over time[7].

Fire resistance refers to the capacity of concrete to allow structural elements to endure fire or provide protection against it. This encompasses the ability to withstand a fire to maintain a specific structural function or both. Concrete is considered fireproof due to its non-combustible nature and its capability to endure high temperatures without collapsing[8].

As per the BS models, the decline in concrete compressive strength under high temperatures can be categorized into three groups:

1. Category 1: Below 100C°, the concrete strength diminishes gradually, with no significant reduction.
2. Category 2: Between 100C° and 400C°, the concrete's compressive strength is expected to decrease by 25%.
3. Category 3: Beyond 400C°, the concrete's compressive strength decreases steadily until it matches that of the control concrete[9].

While concrete structures typically perform well in elevated temperatures and fire incidents, the intricate composition of concrete undergoes notable changes when exposed to higher heat levels. The primary impacts of fire on concrete involve a decrease in compressive strength and the occurrence of explosive spalling, which involves the forceful detachment of material from the concrete surface[10]. The paper describes an experimental research project that examines the short-term residual mechanical properties of lightweight concrete following exposure to temperatures up to 600C° and its impact on the post-fire load-bearing capacity of various concrete sections. The study involved four different concrete mixes, evaluating mechanical properties immediately after cooling and up to 96 hours after cooling, including compressive strength, ultrasonic pulse velocity, and stress-strain curves. The results indicate that the compressive strength experiences an additional reduction of up to 20% compared to the initial residual strength within the reference period[11]. This study compared the performance of structural lightweight concrete (LWC) and normal-weight aggregate concrete (NWC) by analyzing their compressive strength and weight loss following exposure to high temperatures ranging from 20 C° to1000 C° (20, 100, 400, 800, 1000 C°). Twelve different concrete mixes were created, with some utilizing silica fume (SF) to substitute Portland cement and others incorporating superplasticizers (SP) at a 2% proportion. The research revealed that LWC had a unit weight 23% lower than NWC, and the LWC with 2% SP retained 38% of its initial compressive strength. Moreover, NWC exhibited a higher level of deterioration compared to LWC, particularly at temperatures exceeding 800C°[12]. Limestone maintains its strength up to 400 C° due to its transformation into lime at this temperature. However, after 400 C°, the compressive strength values decrease rapidly. In a study by Koca et al. (2006), there was an unusual increase in uniaxial compressive strength at 200 and 250 C°, contrary to the general trend. The critical temperature for natural stone types such as limestone and marble is 600 C°[13].

II. MATERIALS

The materials utilized in the production of High-Strength Lightweight Foamed Concrete (HSLFC) include sand, cement, water, fly ash, superplasticizer foam agent, and limestone. These components were used to create lightweight concrete mixtures. The study employed Ordinary Portland Cement sourced from the Badoosh Cement Factory, with its chemical composition detailed in Table 1. The cement adheres to Iraqi standards specified in Specifications No. 5/1984[14]. Locally available normal sand from the Kanhash area of Mosul in Iraq was used, with a specific gravity of 2.67, a maximum aggregate size of 4.75 mm, and an absorption rate of 2.9%. A sand sieve analysis was conducted following ASTM C33[15] guidelines.

Table 1. Chemical compositions of cement

Constituent	% by weight	Limits of Iraqi specification No.5/ 1984
SiO2	21.62	------
Al2O3	6.3	------
CaO	62.4	------
Fe2O3	2.7	------
MgO	2.92	< 5.0
SO3	2	<2.8
LOI	3.45	≤ 4.0
IR	0.19	< 0.75
LSF	0.87	------
Free CaO	1.51	------
C3S	35.83	------
C2S	36.92	------
C4AF	8.10	------
C3A	10.45	------

III. METHODOLOGY

has been made a reference mix consisting of cement, sand, fly ash, superplasticizer, and foaming agent at a ratio of(cement, sand, W\C):(C: 1.5C: 0.30C) and foam agent in different dosage from(1-5) L/m3 To obtain lightweight foam concrete with different densities ranging from (1520-1820) kg/m3, we casting the specimens with dimensions(10*10*10) cm for cubes, cylinders with dimensions (10*20)cm, and prisms with dimensions (40*40*160)mm, In the second section, has been chosen the mixture with a density of 1680 kg/m3, a foaming agent of 3 liters/m3, and a quantity of cement of (595,590,585,580,and 575) kg/m3 respectively. with replaced the sand with limestone in proportions of (10%, 15%, 20, 25%, and 30%) and W/C ratios of (0.3. , 0.308, 0.316, 0.324, 0.332) respectively with fly ash 10% of cement and superplasticizer 1% of cement, the specimens have been cured by water for 28 days. In the third section, the same proportions of cement, sand, limestone, fly ash, and foaming agent were chosen, and five mixtures were made as the mixtures of the second section, but in this section, the specimens were cured with air for 28 days. After that, the compressive strength of all sections and all mixtures have been tested. After that, we placed two specimens of all mixtures, for all sections in the electric oven at a temperature of 400 degrees Celsius for six hours, after that the density and compressive strength of all specimens were measured.

The results for all three sections and for all mixtures can be seen in Table2.

Table 2. Density and compressive strength at 28 days of all mixes

Mix	Foam L/m3	Cement Kg /m3	Sand Kg/m3	W/C L/m3	Fly ash Kg/m3	Sup. L/m3	Density Kg/m3	Limestone Kg/m3	Compressive Strength at 28 days Mpa
F1	1	642	963	193	64	6.4	1820	--	22.8
F2	2	620	930	180	62	6.2	1755	--	20.85
F3	3	595	892.5	172.5	59.5	6	1680	--	19.8
F4	4	565	847.5	163.8	56.5	5.7	1590	--	17.1
F5	5	541	811.5	157	54.1	5.4	1520	--	13.6
FLw1	3	595	804	172.5	59.5	6	1680	89	18.70
FLw2	3	590	752	176	59	6	1670	133	21.90
FLw3	3	585	702	179	58.5	5.9	1660	176	21.05
FLw4	3	580	652	182.7	58	5.8	1650	218	20.40
FLw5	3	575	603.5	185	57.5	5.8	1640	259	18.05
FLa1	3	595	804	172.5	59.5	6	1680	89	15.52
FLa2	3	590	752	176	59	6	1670	133	17.34
FLa3	3	585	702	179	58.5	5.9	1660	176	20.50
FLa4	3	580	652	182.7	58	5.8	1650	218	21.32
FLa5	3	575	603.5	185	57.5	5.8	1640	259	18.25

IV. RESULTS AND DISCUSSIONS

Table 3 show the results of the heat resistivity of reference mixtures.

Table 3. Results of the heat resistivity of reference mixtures

Mix	Density Kg/m3	Dry density Kg/m3	Density after 6 hours burning Kg/m3	Comp. stre. at 28 days before burning Mpa	Comp. stre. at 28 days after burning Mpa	% reduc. in comp. Stre.
F1	1820	1780	1655	22.8	20.64	10%
F2	1755	1712	1585	20.85	18.54	11%
F3	1680	1638	1506	19.8	17.44	12%
F4	1590	1547	1412	17.1	15.06	12%
F5	1520	1475	1339	13.6	11.84	13%

In Table 3, it has been noted that the compressive strength of the reference mixtures decreased after the specimens were exposed to a temperature of 400 degrees Celsius for six hours by (10%-13%) for the specimens before they were placed in the electric furnace, with the density decreasing at a rate ranging between (125-136) kg. /m3. This decrease in compressive strength is less than the decrease in compressive strength in ordinary concrete, as mentioned in a previous study entitled (Fire resistance of normal and high-strength concrete with contains of steel fiber)[9]. which decreased in ordinary concrete (25%) from its initial compressive strength If the specimens were exposed to a temperature of 400 degrees Celsius.

Figure 1. Shown the heat resistivity of reference mixture

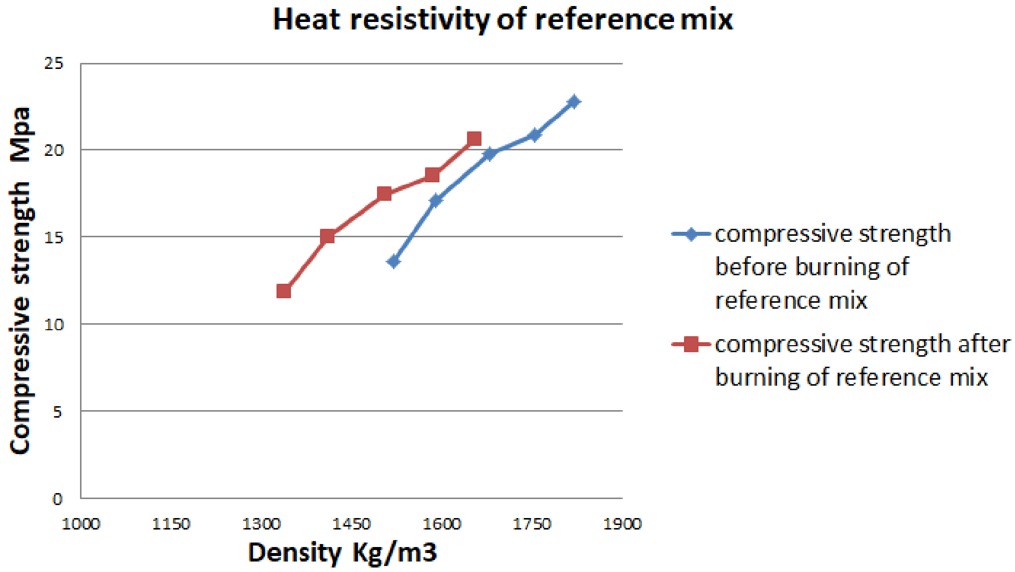

Figure 1. Heat resistivity of reference mixture

Table 4 show the results of the heat resistivity of the second mixture(Mix2) and third mixture (Mix3).

Table 4. Results of the heat resistivity of the Mix2 ,and Mix3

Mix	Dry density Kg/m3	Density after 6 hours burning Kg/m3	Comp. stre. at 28 days before burning Mpa	Comp. stre. at 28 days after burning Mpa	%increase. in comp. Stre.
FLw1	1638	1500	18.70	19.17	2.5%
FLw2	1628	1484	21.90	22.67	3.5%
FLw3	1615	1470	21.05	21.68	3.0%
FLw4	1605	1456	20.40	20.97	2.8%
FLw5	1593	1440	18.05	18.59	3.0%
FLa1	1638	1560	15.52	16.30	5.0%
FLa2	1628	1546	17.34	18.29	5.5%
FLa3	1615	1534	20.50	21.70	5.8%
FLa4	1605	1522	21.32	22.59	6.0%
FLa5	1593	1510	18.25	19.22	5.3%

In Table 4, it has been noted that the compressive strength of the Mix2 increased after the specimens were exposed to a temperature of 400 degrees Celsius for six hours by (2.5%-3.5%) for the specimens before they were placed in the electric furnace. While the density is decreased a rate ranging between (138-153) Kg/m3 ,And have been noted that the compressive strength of the Mix3 increased after the specimens were exposed to a temperature of 400 degrees Celsius for six hours by (5%-6%) for the specimens before they were placed in the electric furnace. While the density is decreased a rate ranging between (78-83) Kg/m3.

The increase in compressive strength of lightweight concrete mixes containing limestone is due to there being no apparent changes in chemical composition and crystal structure. of limestone When the temperature is less than or equal to 400 C°, and The interval between 400 C° to 500 C° represents a threshold temperature range that leads to changes in the pore structure[16]. In another study, it was proven limestone maintains its strength up to 400 C° due to its transformation into lime at this temperature. However, after 400 C°, the compressive strength values decrease rapidly. In another study by Koca et al. (2006), there was an unusual increase in uniaxial compressive strength at 200 and 250 C°, contrary to the general trend[13].

The figure 2 and figure 3. shown the heat resistivity of Mix2 and Mix3.

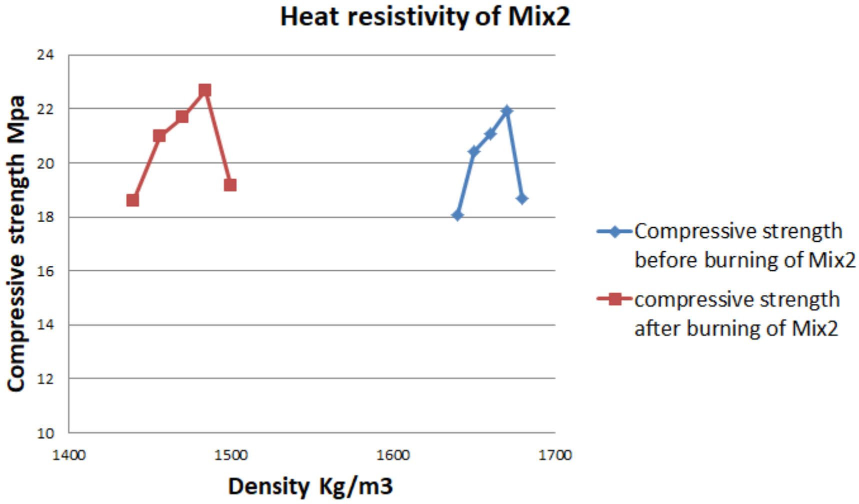

Figure 2. Heat resistivity of Mix2

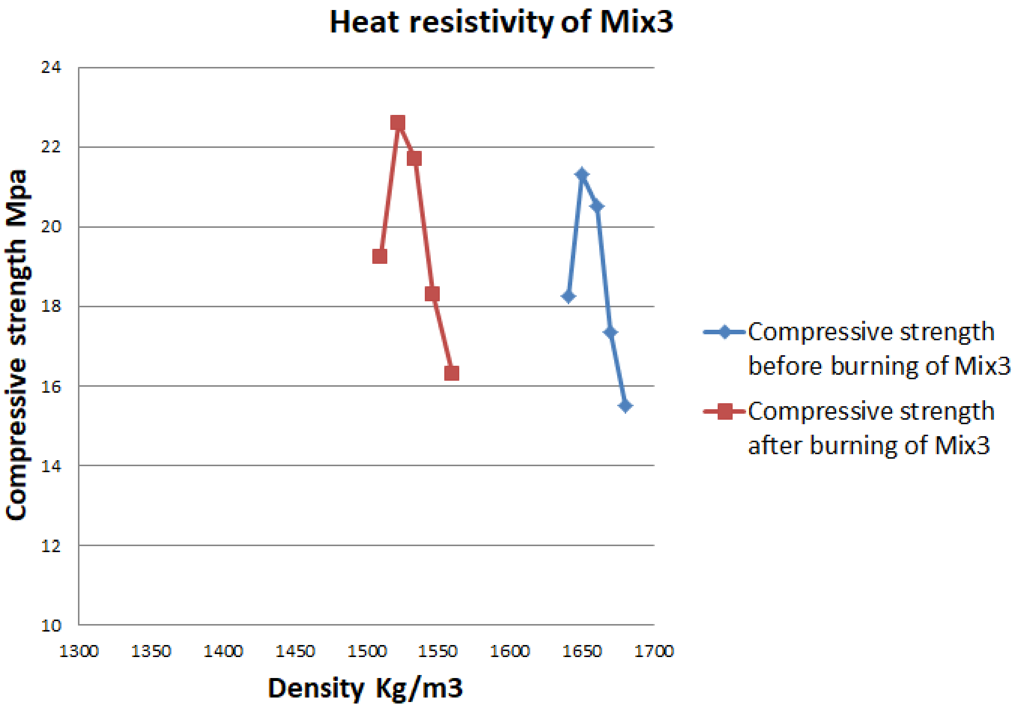

Figure 3. Heat resistivity of Mix3

V. Conclusions

1. Lightweight foam concrete LWFC was created with a density of 1680 kg/m3, and its compressive strength is about 20 MPa.
2. Different densities of lightweight foam concrete LWFC have been obtained (1820, 1755, 1680, 1590, 1520) kg/m3 and foam doses (1, 2, 3, 4, and 5) L/m3, respectively.
3. The possibility of using limestone waste for the production of Lightweight foam concrete LWFC and By the percentage of replacing limestone with sand (10%, 15%, 20%, 25%, and 30%) from sand with high compressive strength, which is (21.9, 21.05, 20.40,)and By the percentage of replacing (15%,20%, and 25%) respectively in the case of curing specimens with water, and The highest compressive strength has been obtained

was 21.9 Mpa when replacing 15% limestone from sand., and (21.3, 20.5) MPa and By the percentage of replacing (25%, and 20%) respectively in the case of curing specimens with air

4. Lightweight foam concrete LWFC that is resistant to high temperatures was obtained. samples of all the mixtures that were poured at a temperature of 400 degrees Celsius for six hours were presented. The results were amazing, as the compressive strength of the specimens that had been cured with water after being placed in the electric oven at a temperature of 400 degrees Celsius for six hours increased by a percentage. 2.5%-3% before placing them in the electrical furnace, as for the specimens that had been cured with air only after placing them in the electric oven at a temperature of 400 degrees Celsius for six hours, increased by a percentage (5%-6%) before placing them in the electrical furnace.

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