Research Article

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The mechanical properties of lightweight (volcanic pumice) concrete containing fibers with exposure to high temperatures

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Abstract: Fire is considered one of the main risks leading to building collapse. Lightweight concrete comprises a variety of components, each of which has a distinct behavior under the effect of temperature change. A total of 16 concrete mixtures were investigated in this article. A reference mix of concrete comprising simply ordinary Portland cement and ten mixes having varying percentages of fine and coarse lightweight aggregates (pumice), which were replaced gravel and sand by fine pumice and coarse aggregates pumice by 20, 40, 60, 80, and 100%, respectively. In addition, the study focused on the effects of adding fibers to lightweight aggregate concrete mixtures. Polypropylene fibers, carbon fibers, and steel fibers were employed as fiber additions. The binary mixture had higher density than the remaining mixtures containing one substitute. The behavior of six concrete mixes in addition to the reference mix of ordinary concrete after exposure to temperatures 100, 250, 350 and 450°C for 2 h and then cooled in two ways (water and air) as well as examined directly and the results showed that the concrete mixes containing fiber had better behavior compared to other mixtures, especially at high temperature. If left to cool in the air, the lightweight concrete containing volcanic pumice can recover its compression strength after being exposed to high temperatures.

Keywords: lightweight concrete, pumice, fibers, elevated temperatures

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1 Introduction

Lightweight concrete is a useful alternative to ordinary concrete in the production of lightweight building units because of its comparatively high strength to unit weight ratio. Light concrete, which contains less cement, is gaining popularity as a building material, due to the release of less pollution to the environment. Additionally, lower-density concrete can be used for smaller cross-section load-bearing elements and subsequent smaller foundations. Furthermore, lighter concrete requires less concrete in the foundation to resist less pressure than ordinary concrete, and the overall mass of the materials to be carried is reduced, resulting in enhanced productivity. Low-density concrete is also better at insulating against heat than ordinary concrete. Ordinary concrete, on the other hand, contains more cement than lightweight concrete. However, a relevant cost comparison should be based on the structure's design employing lightweight concrete, rather than just the cost of materials [1]. Pumice is a volcanic sponge-like material made from molten lava that cools quickly and traps millions of tiny air bubbles. Pumice is mainly sourced in Europe from Iceland, Yali in Greece, Rhineland in Germany, and Lipari Island in Italy. It is also available in Iran and Turkey [1]. The use of lightweight aggregate materials like pumice has been limited due to insufficient quantities and lack of industrial interests. In recent years, research has shown that pumice can be used to build structural concrete with a compressive strength up to 25 MPa at a reasonable cost [2]. Pumice is an environmentally friendly natural aggregate found all over the world. Despite the properties of light concrete, its low compressive strength has reduced its uses. As a result, numerous studies have used additives [3–5] and various types of fibers [6–9] to strengthen light concrete.

Fire is one of the most common causes of concrete structure failure. Therefore, fire safety should be considered in structures to improve the resistance to fire. Many studies have looked at the characteristics of concrete after fire exposure [10–13]. Total replacement of volcanic pumice (VP) and fiber addition are the two options for enhancing the fire resistance of concrete structures. In general, concrete structures hold up well in fires, but concrete that has not been severely damaged may lose strength because of the high temperatures. Eidan *et al.* [8] found that polypropylene fibers (PPF) improved the performance of concrete when subjected to high temperatures when compared to normal concrete. To analyze and repair fire-damaged concrete elements, it is necessary to investigate the reduction in the mechanical properties of concrete after fire exposure.

The goal of this research was to prepare a lightweight aggregate concrete mix (LWPC) using VP. Furthermore, to investigate the impact of fiber reinforcements on the strength and fire resistance of LWPC subjected to temperatures of 23, 100, 250, 350, and 450°C. Besides, assess the performance of LWPC after exposure to high temperatures, and evaluate the residual strength of LWPC using two cooling methods (water cooling and air cooling).

2 Materials

2.1 Cement

A locally available cement was used for the lightweight concrete mixes. The cement was obtained from Badoosh manufacture in Nineveh Governorate of Iraq. The specific surface area estimated from Blain's method was 290 m^2/kg, and the setting time from Vicat's method showed an initial setting time of 109 min, and a final setting time of 3.25 h.

The natural river sand used as fine aggregate was supplied from Kanhash region in Mosul. The grading limits are according to ASTM C33-02 [14]. The properties of the fine and coarse aggregate are shown in Table 1.

Figure 1: Lightweight aggregate.

Coarse aggregate with max aggregate size of 12.5 mm obtained from Mosul city was used. This gravel is compatible with Iraqi specification No. 45/2010 [15].

2.2 VP

VP was used in this study. It is a light gray colored coarse aggregate, which floats on water. The density of pumice is 835 kg/m^3 (Figure 1, Table 2).

2.3 Silica fume (SiF)

SiF is specified under ASTM C1240. The specific surface area of SiF used in this research was between 17,000 and 23,000 kg/m^3, as shown in Figure 2. SiO_2 when firing at 1,000°C for 2 h was greater than 99.8%, while the weight loss when drying at 1,000°C for 2 h was less than 2%. In

Table 1: Properties of course and fine aggregate

Type of aggregate	Specific gravity	Density (kg/m^3)	Absorption (%)
Crushed coarse aggregate	2.66	1,600	2.1
Fine aggregate	2.65	1,780	1.93

Table 2: Chemical composition of VP

Compound	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	K_2O	Na_2O
Cement	63	21.2	6.5	2.5	2.75	2.1	0.45	0.24
VP	1.6	71.35	12.9	1.4	0.5	0.1	3.4	3.4

Figure 2: Silica fume.

addition, the pH was less than 1.5 and the retained SiF on a 40 μm sieve was <0.04% with a moisture content of 0.82%. The chemical composition of SiF is shown in Table 3.

2.4 PPF, carbon fibers (CF), and steel fibers (StF)

PPF, CF, and StF were used in the concrete mixes in this study, all of which have a high chemical resistance and low electrical conductivity (Figure 3).

The mechanical and physical parameters of each type of fiber utilized are listed in Table 4.

2.5 Superplasticizer (SP)

SP is "Naphthalene sulfonate based set retarder, high range water reducers, and superplasticizer admixture used to improve the workability by giving rheoplastic property." This SP (Type G) according to ASTM C494 [16] is shown in Table 5.

The permissible range for SP is 1–2% of cement weight, as shown in Table 5, and in our study, 1.5% was within this range. While maintaining the same slump as the control mix, the inclusion of SP decreased the water to cement ratio, because improved workability results in a deluge of lightweight pumice particles, which isolate these materials upwards. In order to maintain the slump value, the water cement ratio was fixed at 0.4.

3 Fresh concrete tests

Lightweight pumice concrete fresh properties consist of a slump test and a test of fresh density.

3.1 Slump test

Workability was measured using ASTM C143 [17]. Workability is described as "The property of freshly mixed or mortar which determines the ease and homogeneity with which it can be mixed, placed, consolidated, and finished."

3.2 Fresh density test

The weight of the empty mold is compared to the weight of the filled mold, and the difference between the weights

Table 3: Chemical composition of SiF

Oxide	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	SO_3	L.O.I
SiF	99.1	35 ppm	0.035	0.006	0.03	52 ppm	0.07	0.7

Figure 3: Fiber types used in this study.

Table 4: Properties of different types of fibers

Type	Length (mm)	Diameter	Aspect ratio	Specific gravity (g/cm³)	Elasticity modulus (GPa)	Tensile Strength (MPa)	Softening point (°C)
PPF	12	0.032 mm	857	2.68	72	600–700	160
CF	10	7 µm	1,140	3.5	230	3,500	3,500
StF	28	—	0.33	7.142	200	3,500	1,482

Table 5: Properties of SP

Color	Brown
Density (kg/L)	1.148–1.208
Chloride content (%)	<0.1
Alkaline content (%)	<5
Dosage	1.0–2.0% by weight of cement

is used to determine the fresh density of the concrete (unit weight). ASTM C138 [18] was used to determine the fresh density. It was calculated by dividing the net weight of freshly mixed concrete by the volume of concrete made at the time of casting.

4 Hardened concrete tests

4.1 Compressive strength test

For measuring the compressive strength of lightweight aggregate concrete, research specimens of 100 mm × 100 mm × 100 mm cubes were used according to BS 1881: part 116 [19,20], average of three cubes was used to determine the compressive strength for each test.

4.2 Flexural strength test

A flexural strength test (modulus of rupture) was performed using concrete prisms (100 mm × 100 mm × 400 mm) according to ASTM C78-02 [21]. The flexural strength was measured using a capacity testing equipment with a capacity of 30,000 kg.

4.3 Water absorption test

An average of three 100 mm × 100 mm × 100 mm cubes were utilized to determine the percentage of water absorption, and the technique was carried out in accordance with ASTM C642 [22].

4.4 Oven dry density test

According to ASTM C642 [22], the dry density of the hardened lightweight aggregate concrete was achieved.

5 Mixing and preparation of specimens

All trail concrete mixes were made in the lab with a drum mixer that met ASTM C192 [23] standards for mixing, casting, and curing. Ordinary portland cement was used with a goal compressive strength of 20 MPa and a maximum aggregate size of 20 mm (ACI 211.1–91) [24]. The reference mixture was compared to ten mixes with VP materials. The VP served as a volumetric replacement for the total volume of the reference mixture in proportions of 20, 40, 60, 80, and 100%, resulting in ten mixes (Table 6). A variety of factors influence the manufacture of a good LWPC, including mixture design techniques and performance in both the fresh and hardened states. As stated in Table 6, these proportions were utilized with VP. Flowchart for the study's experimental procedures.

Replacement of aggregate, mixture design techniques, and performance in a fresh and hardened condition

Table 6: Compositions of trail mixes

Materials	Water (kg/m³)	OPC (kg/m³)	Sand (kg/m³)	Gravel (kg/m³)	Pumice	
					%	(kg/m³)
C1	162.5	325	702	1,235	0	0
C2	169	325	561	1,235	20	43.2
C3	175	325	421	1,235	40	86.36
C4	182	325	281	1,235	60	129.5
C5	188.5	325	140	1,235	80	172.7
C6	195	325	0	1,235	100	215.9
C7	169	325	650	988	20	75.9
C8	175	325	650	741	40	151.9
C9	182	325	650	494	60	227.9
C10	188.5	325	650	247	80	303.8
C11	195	325	650	0	100	379.8

all influence the manufacture of a suitable LWPC. To begin, numerous trial mixes with varying percentages of water/cement ratio and lightweight aggregate (pumice) were created in order to choose the best lightweight concrete mix (C11), as indicated in the subsequent sections. To achieve the slump, the W/C ratio was changed for each ideal lightweight concrete mix (C11). The control mix was chosen based on the parameter of the optimum oven-dry density (less than 2,000 kg/m^3) in this investigation. As a result, the mix (C11) was used as a reference (control) mix. Fibers were also used in the LWPC to create a variety of mixes. After being exposed to high temperatures, the mechanical properties of such LWPC were also examined. Table 7 shows the different volume fractions of PPF, CF, and StF used.

The cement and SiF were blended with sand and pumice aggregate according to the mix proportions, and then water was added to prepare the mixer. The lightweight aggregate concrete was made by adding water with SP to the mix. The fibers were then added to the mix. PPF, CF, and StF were used in proportions of 0.025, 1, and 1% of volume fractions, respectively, as given in Table 7. It took around 4–5 min to get a homogeneous mixture.

The slump test, as defined by ASTM C143 [17], was used to determine the workability of each mix proportion. The fresh density was determined by weighing the generated lightweight aggregate concrete in a pre-weighted standard container of known volume. After the fresh concrete had been mixed, it was immediately poured into the plastic fiber molds. Cubes of 100 mm × 100 mm × 100 mm and prisms of 100 mm × 100 mm × 400 mm were used.

5.1 Heating and cooling procedure

To begin, the specimens were heated using electrical furnaces at varied temperatures of 100, 250, 350, and 450°C at 28 days. Because of the furnace's high heating rate, each temperature was held for 1.5 h to attain the steady burning state. All of the specimens used in this study were cured for 28 days in water before being utilized to test the effect of exposure to higher temperature. The specimens remained at the target temperature for 90 min after achieving it. To guarantee that the samples achieve the surface temperature indicated by the thermometer, the temperature was measured and applied at a heating rate of 15°C/min until the samples reached the maximum thermometer temperature on the surface.

6 Results and discussion

To produce more dependent results, the test results submitted are the average of three samples.

The fresh density and the slump test results are as indicated in Table 8. The slump variation for mixes with various volcanic pumice aggregate (VPA) ratios is also stated in Table 8. In the early stages of mixing, high water absorption by VPA causes cement build-up and loss of stagnation. In the early stages of mixing, VPA absorbs a lot of water, resulting in cement accumulation and a loss of viscosity. Before mixing the concrete, a dry saturated surface set was made to avoid this. The density of volcanic pumice concrete falls as the VPA changes are

Table 7: Compositions of mixes with additives

Mix	W/C ratio	OPC	Sand	Gravel	Pumice	SP	SiF	PPF (%)	CF (%)	StF (%)
C1	0.5	1	2.16	3.8	0	0	0	0	0	0
C11	0.6	1	2.16	0	1.224	0	0	0	0	0
C12	0.4	1	2.16	0	1.224	1.5	0	0	0	0
C13	0.4	1	2.16	0	1.224	1.5	0.1	0	0	0
C14	0.4	1	2.16	0	1.224	1.5	0.1	0.6	0	0
C15	0.4	1	2.16	0	1.224	1.5	0.1	0	1	0
C16	0.4	1	2.16	0	1.224	1.5	0.1	0	0	1

Table 8: Slump and densities of trail mixes

Mix	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Slump (mm)	120	56	70	73	73	70	75	72	75	78
Density (kg/m^3)	2,425	2,379	2,341	2,286	2,261	2,160	2,134	1,981	1,840	1,803

considerable because the lighter VPA replaces the comparison with the entire aggregate. Also, because of the lightweight of the LWPC, which is lower than the rest of the mixed materials and thus floats to the top and generates a mass without homogeneity, the retreat was limited in order to avoid isolation mechanisms. As previously indicated, as the percentage of lightweight aggregate replaced increased, the density reduced (pumice). As previously stated, the weight of lightweight aggregate is more than half that of normal aggregates, and thus has a significant impact on the changes that happened in the mixtures as a result of replacement.

6.1 Hardened properties of lightweight concrete at ambient temperature

The general trend is a decrease in compressive strength with increasing replacement ratios of VP rather than fine material. Besides, as indicated in Figure 4, it is much reduced now that coarse aggregate is being replaced at a higher rate.

SiF is an extra binder that improves the characteristics of concrete. Because of its fineness and its ability to fill voids between the particles, it basically acts as a filler, similar to how sand fills the spaces between coarse aggregate particles and cement grains fill the spaces between fine aggregate particles.

The addition of fibers to C14 and C16 fiber mixtures increased the material's energy absorption capacity and toughness. There is a significant improvement in post-cracking behaviors in concrete containing fibers. When compared to concrete without fibers, fiber-reinforced concrete is significantly tougher and more impact resistant. The failure of fiber-reinforced concrete specimens is primarily due to fiber pull-out or deboning, according to tests. A fiber-reinforced concrete specimen, unlike conventional concrete, does not fail within a short period when the first fracture begins. The compressive strength, which is determined by the area under the load, is increased as a result. The impacts of varying percentages of VPA, PPF, CF, and StF on all trail mixes at 7 and 28 days are shown in Figure 5. The compressive strength of concrete mixtures was increased by adding SP, SiF, and various types of fibers, as illustrated in Figure 5. Compressive strength is improved when PPF and CF are added, 21.4 and 20.8 MPa, respectively. StF, on the other hand, has the highest compressive strength (22.44 MPa).

The addition of SP, SiF, PPF, CF, and StF to LWPC enhanced the flexural strength. When compared to the standard LWPC combination, the use of 1.5% SP increased the compressive and flexural strength by almost 15 and 0%, respectively. The addition of SP lowered the water/cement ratio, while also making the material more workable. However, the bond between the cement and the lightweight aggregate particles is significantly weaker than the bond between the cement and the fine particles (sand). The compressive strength was slightly changed as a result. The lightweight aggregate's many cavities cause the upper portion of the samples to shrink, quickening the separation of the lower portion and causing cracks.

With a 10% substitution of SiF with cement, flexural strength was increased by roughly 11.3%. The addition of fiber to the mix resulted in a significant increase. However, when 0.025% PPF (C14), 1% CF (C15), and 1% StF (C16) were added to the mix (C11), the flexural strength increased by a percentage difference of 39%, 63%, and 83%, respectively, as shown in Figure 6.

The addition of fibers improved the flexural strength of the lightweight concrete, with StF providing the best results due to the fact that StF has the best durability. The major goal of using used fiber is to increase the stiffness and absorbency of the material. This also improves the concrete's flexural properties. Compared to LWPC without

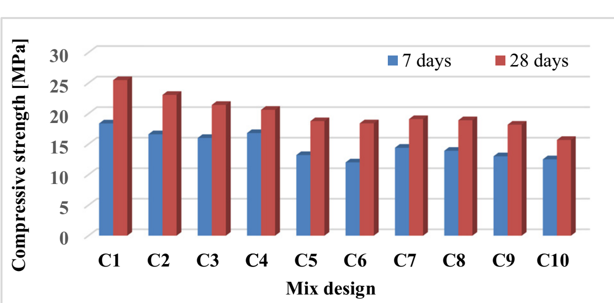


Figure 4: Compressive strength variation for trail mixes.

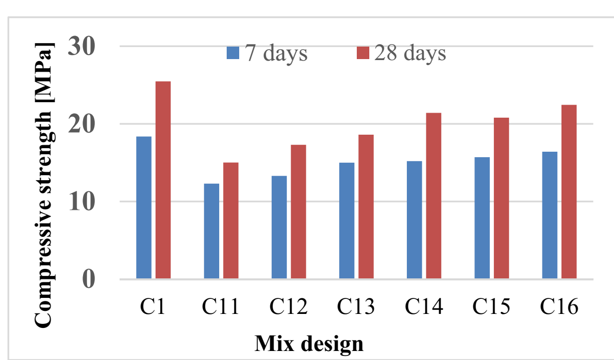


Figure 5: Compressive strength for different mixes.

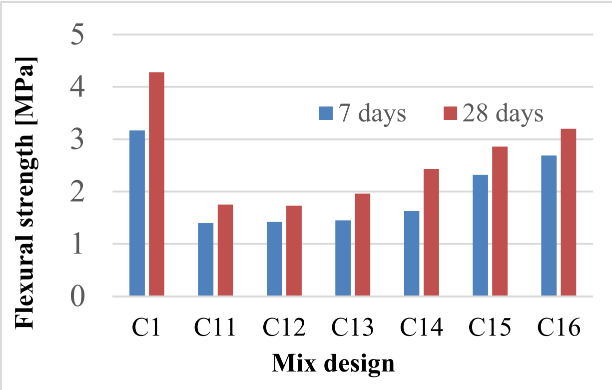


Figure 6: Flexural strength for different mixes.

fiber, fiber-reinforced LWPC is much tougher and more resistant to impact; therefore, there was a considerable improvement in the post-cracking behavior of the concretes containing fibers.

In general, adding SP, SiF, PPF, CF, and StF to LWPC decreased the water absorption, as seen in Figure 7. Although there were small gaps in the lightweight debris itself (mixes C11 and C12), the latter behavior may be attributed to the fact that a better plasticizer helped to reduce the water content and thus reduce the resulting voids after solidification. The SiFs and fiber types may have also played a role in matrix formation. There is a good link between aggregates and cement particles, and as a result, absorption is slightly reduced.

6.2 Hardened properties of LWPC at elevated temperature

Figure 8(a–g) shows the residual compressive strength of the LWPC mix after being subjected to various temperature gradients. The effect of temperature on LWPC samples has been reported to result in a decrease in compressive strength. The strength decreases due to a succession of complex physical and chemical variables, which will be addressed in this section. During the direct test, Figure 8(a–g) shows the decline in compressive strength as the exposure temperature rises. At three distinct temperatures, the findings were 250, 350, and 450°C. The concrete mixtures that have been given directly test the compressive strength approach to carrying water-cooled concrete mixtures with a little variation, and their compressive strength is lower than that of cooled concrete mixtures with air. Internal stresses may have been created by thermal shock and the models' high heat tolerance is one of the causes of the low compressive strength.

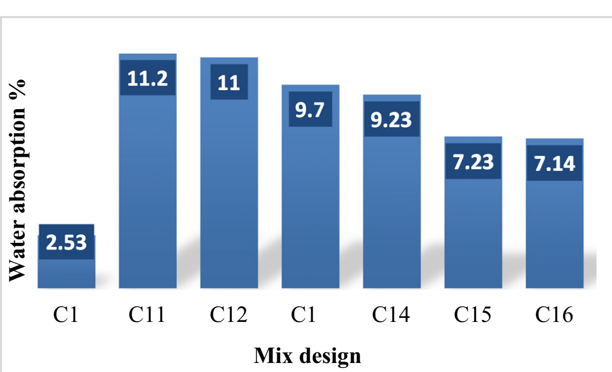


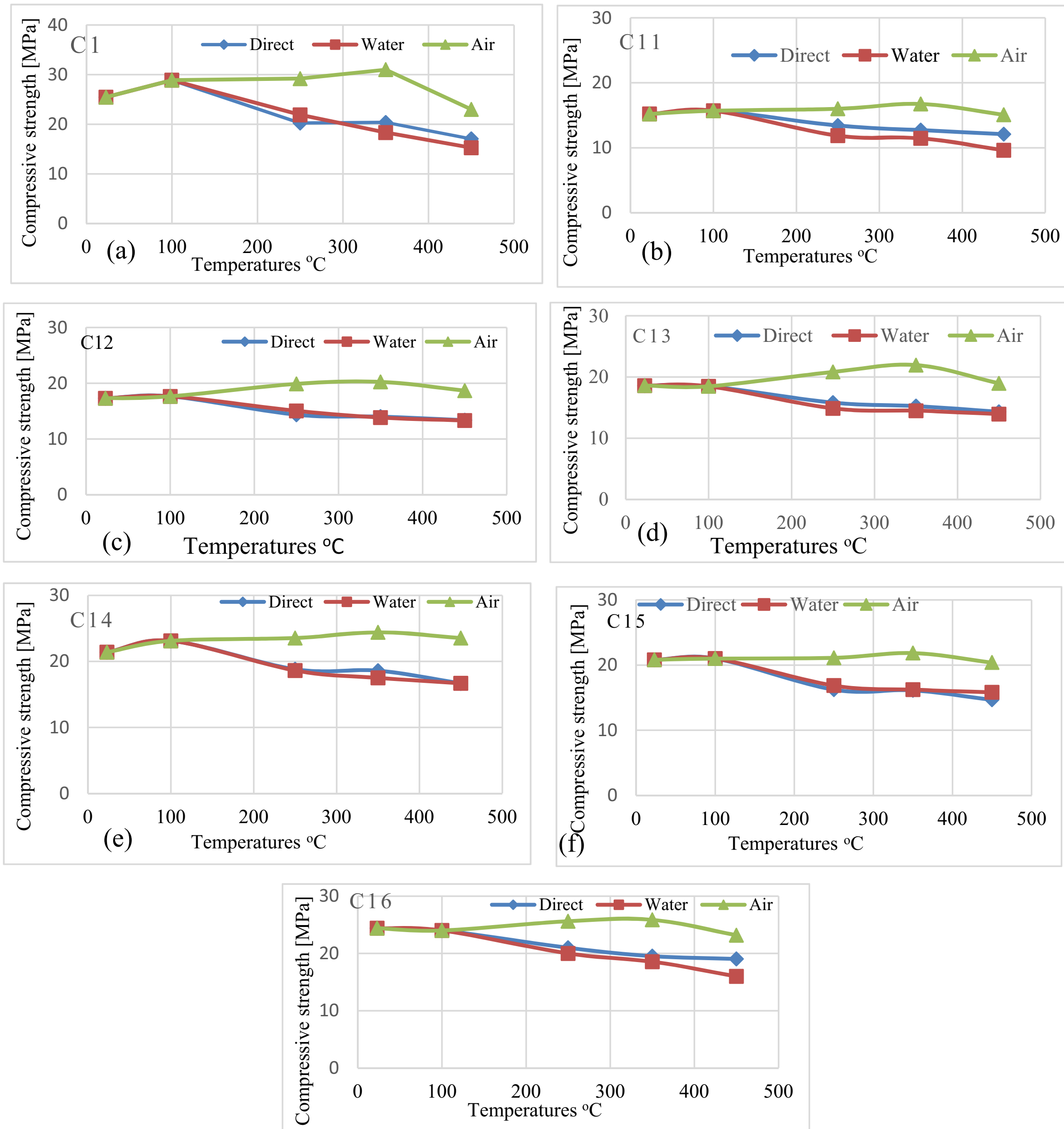
Figure 7: Water absorption for concrete mixes at 28 days.

6.3 Air-cooled specimens

Cases involving water- and air-cooling must be studied. The majority of the buildings in Mosul, Iraq, were in risk of burning because of recent events in 2018. Some of them were put out by water, while others were left to cool off in the air. Therefore, research was required to demonstrate the extent to which the fire affected the buildings in each scenario. Air-cooled specimens showed an increase in residual compressive strength for all concrete mixtures at 250°C. It was 114, 105, 115, 112, 110, 102, and 105% for C1, C11, C12, C13, C14, C15, and C16 mixtures, respectively. At this temperature, the increase in compressive strength can be explained by one of the three hypotheses.

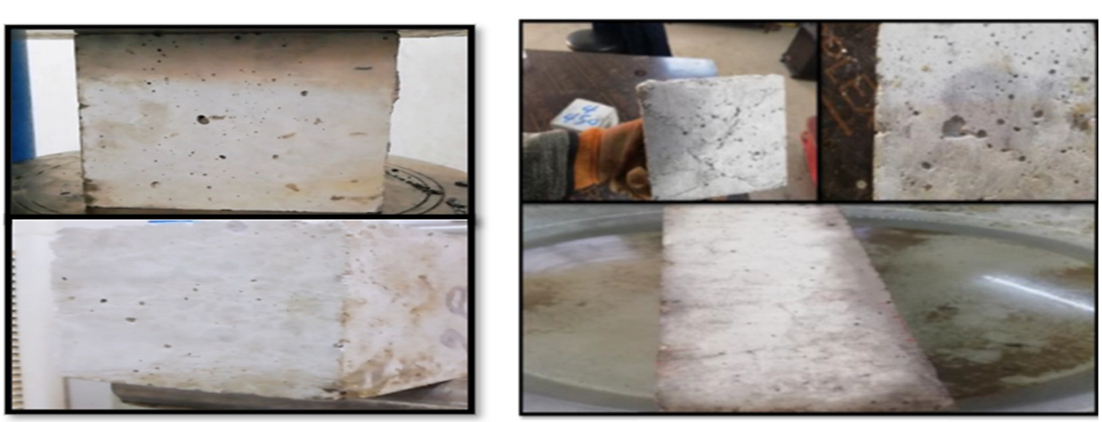
The initial assumption is that the composition is elemental. Because a component of the link between its groups and water has been lost, the surface energies that lead to the rise and improvement of strength may have increased. This rise, according to the second viewpoint, is related to the rehydration of the paste due to the permeability of water in the pores. The third concept depicts the enhanced strength due to the evaporation of free water at this temperature. Because the cement gel layers are close together, the hydro-cement paste would be structured in a fashion that leads upward.

For LWPC, at 350°C, C1, C11, C12, C13, C14, C15, and C16 mixes had relative residual compressive strengths of 122, 110, 117, 118, 114, 105, and 106%, respectively. Each mixture's compressive strength increased at a different rate, ranging from 5 to 22%. When we evaluate the results at 200, 400, and 23°C, we discover that the concrete that has been exposed to high temperatures and then allowed



(g)

Figure 8: (a–g) Residual compressive strength of mixes with different temperatures.



air-cooling *water-cooling*

Figure 9: Visual inspection test of air- and water-cooling affects.

to cool naturally is the best instance. C1, C11, C12, C13, C14, C15, and C16 mixes had relative residual compressive strengths of 90, 100, 101, 102, 108, 98, and 95% at 450°C, respectively. The C16 mixes lose less strength when compared to the C11 mix, as shown in Figure 8(a–g).

6.4 Water-cooled specimens

Figure 8(a–g) shows the decrease in compressive strength as a function of exposure temperature after cooling with water (water spraying). It is easy to see how water-cooled concrete mixtures work.

The air-cooled specimens had developed some strength at this temperature, as previously mentioned, but the situation was different for the water-cooled specimens. There is no increase in residual compressive strength at 250°C. The relative residual strength ranged from 10 to 40% at 250, 350, and 450°C. Due to thermal shocks and internal strains, water-cooled samples have less compressive strength than air-cooled samples, resulting in reduced compressive strength. Thermal shock was induced by spraying water on heated concrete specimens, and it is possible that cracks occurred as a result of tensile stress in the specimens, resulting in a significant drop in compressive strength as shown in Figure 9.

6.5 Weight loss

Due to the hot conditions, each cubic specimen was weighed before and after each temperature cycle, and the percentage weight loss was calculated. The most common cause of weight change was drying of the cement paste. The loss of weight allows the drying of concrete to be measured after each heating. Table 9 lists the results of weight loss. It was discovered that when the temperature of exposure increased, the weight loss of all concrete mixes increased. For C1, C11, C12, C13, C14, C15, and C16 mixtures, the temperature started at 100, 250, 350, and 450°C, respectively.

Table 9: Density loss (kg/m^3) of mixes with temperature variations

	Temperature (°C)				
Mixes	23	100	250	350	450
C1	0	2.1	4.6	1.1	0.2
C11	0	6.0	4.6	7.6	0.8
C12	0	5.6	4.8	8.1	0.8
C13	0	5.6	5.5	7.0	1.1
C14	0	6.2	4.1	7.7	1.5
C15	0	6.3	3.8	8.1	1.2
C16	0	4.8	5.4	7.7	1.2

Dehydration of cement paste, as well as drying of LWA, was one of the main causes of weight change since they retain a lot of water, and their loss of total humidity owing to the increase in high temperatures results in a loss of weight in general. The weight loss results that were provided showed that as the temperature of exposure increased, weight loss increased for all concrete mixes. The evaporation of capillary water, followed by the departure of adsorbed (gel water) and interlayer water, was the primary cause of the high rate of weight loss.

The evaporation of capillary water, followed by the departure of adsorbed (gel water) and interlayer water, was the primary cause of the rapid rate of weight loss up to a temperature of 450°C. The release of chemically mixed water, which is a component of cement hydrate products and is the hardest to evaporate, is related to the moisture loss at this temperature, which results in a somewhat reduced increase rate in mass loss up to 450°C. So, it is expected that the mass loss rate will decline. Further mass loss occurred at 450°C because of the thermal breakdown of hydration product constituents. These factors were further supported by thermogravimetric analysis performed by ASTM C642 [22]. The analysis of cement paste consists of three components: loss of water, dehydration of pentlandite, and decarbonization of carbon ($CaCO_3$).

7 Conclusions

Numerous applications include prefabricated construction as dividing elements like walls or composite construction using iron and building elements like blocks. The following conclusions were made from the present study:

1. Due to the high weight of LWA, increasing the water ratio in the mixture (slump) results in the separation of LWA from the rest of the materials. To avoid LWA separation, the remaining materials should moisten the LWA, lowering the water percentage in the mix.
2. In the compression test, failure occurs first in the material of volcanic coarse aggregate, where voids within the aggregate create compaction. As a result, the compressive strength of the LWPC falls as the amount of LWA (pumice) in the mix increases.

3. The use of 1.5% SP increased the compressive and flexural strength by nearly 15 and 0%, respectively, as compared to the typical LWPC combination.
4. The combination of 1.5% SP and 10% SiF increased the compressive and flexural strength by around 24 and 12%, respectively, as compared to the reference mix of LWPC.
5. The addition of 1.5% SP, 10% SF, and 0.6 kg/m^3 PPF increased the compressive and flexural strength by 42 and 39%, respectively, as compared to the LWPC reference mix.
6. The addition of 1.5% SP, 10% SF, and 1% CF increased the compressive and flexural strength by about 37 and 63%, respectively, as compared to the LWPC reference mix.
7. The use of 1.5% SP, 10% SF, and 1% of StF increased the compressive strength and flexural strength by nearly 49 and 83% compared to the reference mix of LWPC.
8. Exposure of concrete to higher temperatures has two main effects on compressive strength: when LWPC mixes were heated to 250 and 350°C, their strength increased; however, when heated to 450°C, most of the mixes lost some of their original strength.
9. Comparing the relative residual strength of air-cooled and water-cooled mixes, StF LWPC mixes displayed the best residual compressive strength.
10. Water-cooled concrete samples have a lower compressive strength than air-cooled concrete mixes.

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