

INVESTIGATION OF THE EFFECT OF BLACK PUMICE POWDER FROM PUKE KARVEH ON THE PHYSICAL PROPERTIES OF LIGHTWEIGHT FOAME CONCRETE

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ABSTRACT

In this research, in order to reduce the weight of concrete and increase the durability of concrete compared to other light concretes, black pumice has been used along with other aggregates. To perform the tests, 10 different combinations with mixed aggregates were prepared as described in the table, and different sizes of Puke Karveh were used in the composition instead of aggregates, and the resistance and durability tests of concrete, which include compressive strength, Brazilian tensile strength, and carbonation and water absorption was applied to the samples, which according to the results of the concrete samples prepared with samples containing natural aggregates and pumice in different kilo ratios have very interesting results that different ratios have different results in different tests, but in The best

sample was obtained by combining 200 kg of sand gravel with 400 kg of sand pumice.

KEYWORDS: Puke Karveh, lightweight concrete, natural foam, compressive strength, carbonation.

1. INTRODUCTION

Concrete is one of the most widely used materials in the world. Given the need for high-rise buildings and wide-span beams, particularly in the construction industry, lightweight concrete serves as a suitable alternative to conventional concrete, as it reduces the dead load of

buildings, enables the construction of lighter structures, and is environmentally friendly. Lightweight concrete mixes are produced using lightweight coarse aggregates; In some cases, some or all of the fine aggregates may also be lightweight rather than normal-weight. Normal-weight concrete has a density ranging from 2,240 to 2,400 kg/m³. The lightweight aggregates used in structural lightweight concrete are typically made from expanded shale, clay, or slate, which are fired in a rotary kiln to create a porous structure. Other materials, such as air-cooled blast furnace slag, are also used. This concrete has the lowest density, thermal conductivity, and strength. It can be sawn, screwed, and nailed like wood, yet it is non-flammable. For on-site application, common aeration methods involve mixing in stabilized foam or injecting air with the aid of an air-entraining agent.

The engineering properties of normal-weight concrete were compared with those of concrete containing two types of lightweight aggregates (Shafigh *et al.*, 2018); in this study, conventional coarse aggregates in a high-strength, normal-weight concrete mix were replaced by each of the lightweight aggregates, and the effect of this replacement on the properties of fresh and hardened concrete was determined. Steel fiber-reinforced expanded shale lightweight concrete (SFRELC) has been developed using porous expanded shale as both coarse and fine aggregates; the study presents the fundamental mechanical properties of SFRELC under compression and flexure (Zhao *et al.*, 2018). Bauxite residue (red mud), or RM, is a caustic industrial waste product generated during alumina production. Given the economic and environmental challenges associated with cement production and concrete usage, substituting cement with industrial waste appears inevitable. Lightweight concrete (LWC) containing RM exhibits reduced environmental impacts regarding CED, GWP, CO, NO_x, Pb, and SO₂ emissions. Consequently, the reuse of RM, which would otherwise be sent to landfills, represents an environmentally friendly alternative (Nikbin *et al.*, 2018).

1.1. Lightweight expanded clay aggregate as a construction material

LECA stands for Lightweight Expanded Clay Aggregate, also known as Liapor, Leca, or Hydroton. It is produced from a specific type of clay that is free of, or very low in, lime. The clay is dried and then fired in rotary kilns at very high temperatures, approximately 1,100–1,300°C. During heating, gases are released into the pellets and become trapped as they cool; as organic compounds burn off, the pellets transform into a lightweight, porous material with high crushing strength. LECA pellets can expand to five or six times their original volume. Due to the rotary motion of the kiln, LECA particles are roughly round or potato-shaped.

Internally, they contain interconnected voids of varying sizes. Other types exhibit different structures and geometries. This review helps to summarize existing literature and determine areas for future research. Figure 1 illustrates the LECA production flow chart.



Figure 1: LECA production flow chart.

Figure 2 illustrates the performance of LECA in a cementitious material regarding the following parameters: density (27.41% of the total), workability (11.11%), freeze-thaw resistance (15.8%), porosity/water absorption (41.7%), thermal/acoustic insulation (67.6%), shrinkage/cracking tendency (19.5%), and creep (0.74%). Furthermore, for expanded perlite and expanded or regular vermiculite, there is incorrect data concerning water-to-cement ratios when using LECA as an aggregate compared to other similar materials. It is worth noting that approximately 95.5% of all studies on LECA focus on traditional cementitious materials, and only 4.5% pertain to geopolymers.

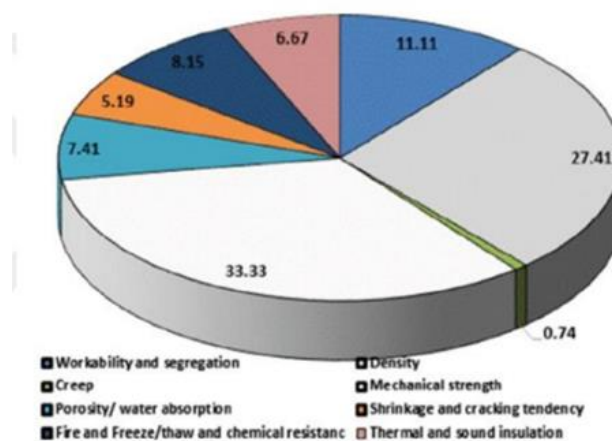


Figure 2: LECA performance.

1.2. Differential Thermal Analysis (DTA) – Thermal Gravimetric Analysis (TGA)

Differential Thermal Analysis (DTA) and Thermogravimetric Analysis (TGA) are used to characterize the thermal behavior, such as glass transition, crystallization, and melting temperature, of 20 mg samples of the raw materials (glass powder, bentonite, and fly ash). Platinum crucibles and Al_2O_3 (as the reference material) are employed, with heating rates of 10 and 20°C/min and a gas flow rate of 40 mL/min. The instrument used is a PerkinElmer Diamond Thermogravimetric/Differential Thermal Analyzer (TG/DTA). In general, DTA confirms and complements the results obtained from XRD analysis. While thermal measurements are significant for sintered materials in certain applications, thermal properties are rarely used to monitor the sintering process itself; nevertheless, they are crucial for understanding the reactions that occur during sintering. For instance, differential thermal analysis is useful for determining the temperature at which initial melting occurs during liquid-phase sintering. As illustrated in Figure 3, differential thermal analysis relies on the benefit of two samples placed in an identical thermal environment. Typically, the samples are surrounded by an inert or protective gas.

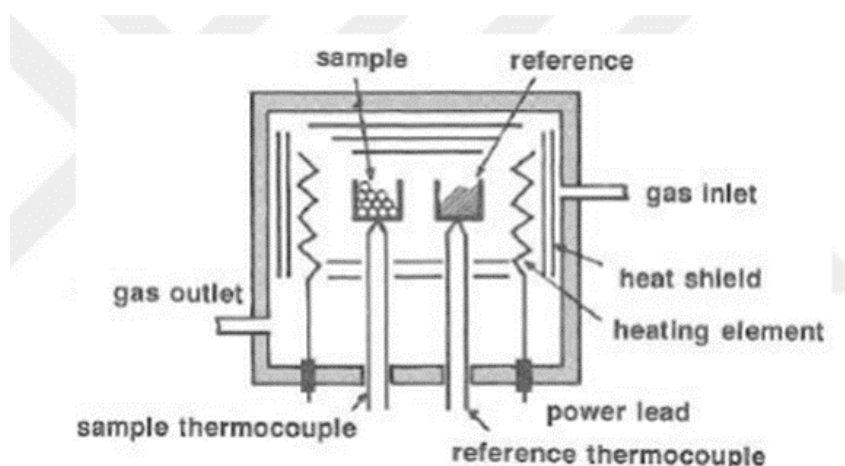


Figure 3: Differential thermal analysis.

1.3. Differential Thermal Analysis (DTA)

Is a technique used to measure the difference in heat flow through a sample. A constant heating rate is applied, and a standard material (typically alumina) that does not undergo a phase change within the temperature range of interest is used as a reference, as shown in Figure 4. The heat flux to the sample is recorded relative to the reference. When the sample passes through the glass transition temperature, a conversion in heat capacity and glass structure appears. The process is endothermic; consequently, the sample absorbs more heat than the standard within this temperature range. When the sample crystallizes, atomic

rearrangement is an exothermic process, and the sample releases more heat than the standard. During a DTA experiment, amorphous glasses undergo a phase transition upon heating above; they may phase-separate or completely form a homogeneous liquid. A single temperature is often used to represent the glass transition point.

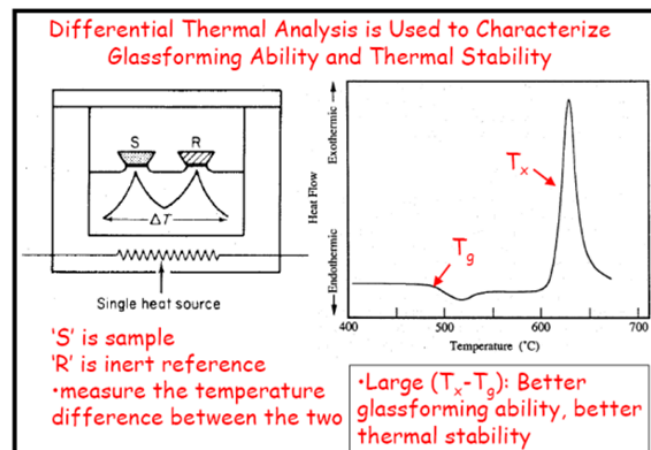


Figure 4: Differential Thermal Analysis.

2. MATERIALS AND METHODS

2-1. Aggregate

It is a dense mass of broken or crushed particles of various sizes, typically up to 100 mm, consisting of natural or artificial minerals, or a combination of both. Figure 5 shows the aggregates used in the research.



Figure 5: Aggregates.

The properties of the aggregates used in this study are presented in Table 1:

Table 1: Amount of aggregates.

Sieve number	Weight of sample remaining on the sieve (gr)	Percentage remaining on sieve	Sieve passing percentage
1/4	722/05	56/11	43/89
4	175/10	13/61	30/19
10	210/1	16/32	13/87
16	47	3/65	10/22
30	89/9	6/98	3/24
50	5	0/38	2/86
100	23/95	1/86	1
Sieve bottom	4	1/08	-

2.2. Cement

Peyvand Golestan's 50kg Type 2 black cement is among the highest-quality cements produced in Iran, fulfilling the ISIRI 389 national standard. Modifications made to the Type 2 formulation have capped the C3A content at a maximum of 8%. Figure 7 illustrates the cement under study. s reduction was achieved by lowering the clay content in the raw materials. The lower C3A level influences a reduced heat of hydration and enhances resistance to sulfate attack. Due to this sulfate resistance, Type 2 cement is commonly referred to as "moderate" cement. Key characteristics of this adhesive include compressive strength, resistance to alkali-chloride reactions, controlled concrete temperature rise (particularly in adverse weather conditions), and the prevention of cracking thanks to the low heat of hydration.

**Figure 7: Cement.**

2-3. Water

The sulfate content of the water must not exceed 2000 mg/L. The water used in this thesis is the municipal water of Gonbad.

2-4. Natural or protein-based foam



Figure 8: Foam.

2.5. Puke Karveh mineral pumice

Puke Karveh pumice is the highest-quality pumice in Iran. Figure 9 shows the mineral pumice used in the experiment. Due to its high quality, sound and thermal insulation properties, and very low weight, Puke Karveh mineral pumice is widely used in the agricultural and civil construction industries.



Figure 9: Shape of the Puke Karveh scoria.

2.6. Compressive strength

Before commencing the strength test, excess water is dried from the specimen surface, and the testing setup is prepared by inspecting the bearing surfaces. Cubic specimens are positioned such that the demand of load application is perpendicular to the direction of concrete casting. The load must be applied to the specimen without impact at a constant rate

of 0.2 to 1.0 MPa/s (N/mm²·s). Loading should persist at the selected constant rate in accordance with the standard until the specimen reaches its maximum load capacity. The peak load reading from the gauge must be recorded.

Test Standard: TS EN 12390-3

2.7. Carbonation

Concrete carbonation is a primary cause of steel corrosion within concrete, affecting its structure over time. This process resembles a chemical and electrochemical reaction in which atmospheric carbon dioxide penetrates the concrete and reacts with the calcium hydroxide present within it. The resulting product is calcium carbonate, which alters the concrete's alkalinity and prevents the proper formation of a protective layer on the steel surface. Concrete carbonation occurs when atmospheric humidity is ideally between 50% and 70%. If humidity falls below this range (less than 50%), there is insufficient water vapor in the atmosphere to dissolve carbon dioxide. Conversely, if humidity is higher (exceeding 70%), the increased atmospheric moisture fills the concrete's pores with water, blocking carbon dioxide from penetrating the material. The humidity range of 50% to 70% poses the highest risk for carbonation, as it facilitates the reaction between carbon dioxide and calcium hydroxide to produce carbonates, a process known as concrete carbonation. Ultimately, this process lowers the concrete's pH level from 13 to 9.

2.8. Water absorption

The water absorption test is known as "water immersion." First, cubic specimens measuring 10 cm in length, width, and height are placed in water maintained at 18 to 24°C for various time intervals: three days, two days, one day, two hours, one hour, half an hour, and ten minutes. After each interval, remove the concrete from the water, thoroughly dry its surface with a cloth, and return it to the water for the next interval. The percentage of water absorbed must be estimated using the following formula after each time interval:

$$\frac{m - m_0}{m_0} \cdot 100$$

2.9. Specific gravity

The concrete unit weight test is performed to verify the accuracy of the mix design or to check the uniformity of the concrete mixture; it requires a specific measuring container. This test is conducted in accordance with either ASTM C138 or ISIRI 3521 standards, which differ from one another.

2.10. Slump

The slump test is the most widely used test for assessing the workability of fresh concrete and serves as a measure of its fluidity (consistency); however, it cannot capture all aspects and facets of workability. The objective of this test is to determine the fluidity of fresh concrete using the slump method. It is illustrated in Figure 10.



Figure 10: Concrete slump.

3. RESULTS AND DISCUSSION

The specimens, prepared according to Table 2 and stored in the tank, were tested, and the results are presented in tables and graphs.

Table 2: Foam concrete mixing plan.

Sample	Pumice powder	Cement	Water	Artificial foam	Protein foam
Refrence	0	500	250	0	0
licch1	50	450	250	1.5	0
licch2	100	400	250	1.5	0
licch3	150	350	250	1.5	0
licch4	200	300	250	1.5	0
licch5	250	250	250	1.5	0
licpn1	50	450	250	0	1.5
licp2	100	400	250	0	1.5
licp3	150	350	250	0	1.5
licp4	200	300	250	0	1.5
licp5	250	250	250	0	1.5

The concrete specimens were demolded after three days and subjected to compressive strength testing in accordance with the relevant standard; the results are presented in Table 3.

Table 3: Compressive strength.

Sample	7 days	28 days
Reference	4.1	5.3
licch1	3.7	4.8
licch2	3.4	4.9
licch3	3.3	4.7
licch4	3	4.2
licch5	3.4	4.7
licpn1	4.1	5.4
licp2	3.9	5.2
licp3	3.5	4.9
licp4	3.3	4.3
licp5	3.2	4.2

Based on the table above and the compressive strength test results, we observe an upward trend in the samples as they aged from 7 to 28 days. As indicated in the table, the lightweight concretes can be compared in two groups based on the quantity of pumice and the type of foam used. In the first comparison, categorized by pumice content, the samples exhibited a loss of strength as the pumice dosage increased; this phenomenon likely stems from the high water absorption of the pumice powder and its lack of pozzolanic activity, factors that, while intended to make the samples more cost-effective, imposed limitations on compressive strength.

When comparing the types of foam used, samples containing protein-based foam exhibit higher strength than those containing synthetic foam; this is attributed to the greater stability of the bubbles formed by the protein-based foam.

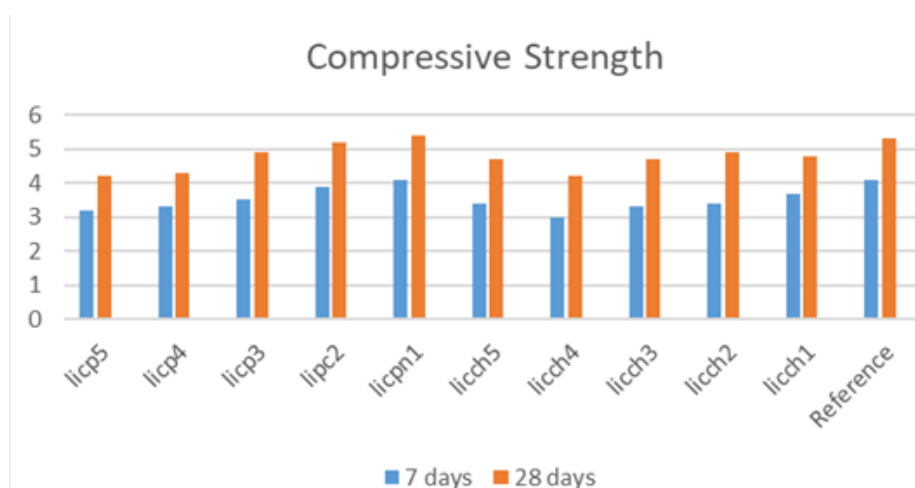


Figure 1: Diagram for Compressive strength.

As shown in Chart 1, sample licpn1 exhibited higher compressive strength at 28 days, approximately 2% greater than the reference sample, while matching the control sample at 7

days. Among the samples containing synthetic foam, sample licch2 achieved the highest strength at 28 days, reaching 4.9 MPa. Table 4 compares the reference concrete sample with the other samples and presents the corresponding variations.

Table 4: Ratio of 7-day to 28-day compressive strength.

Compressive	Ratio
Reference	9.433962
licch1	7.54717
licch2	11.32075
licch3	20.75472
licch4	11.32075
licch5	-1.88679
licpn1	1.886792
licp2	7.54717
licp3	18.86792
licp4	20.75472
licp5	9.433962

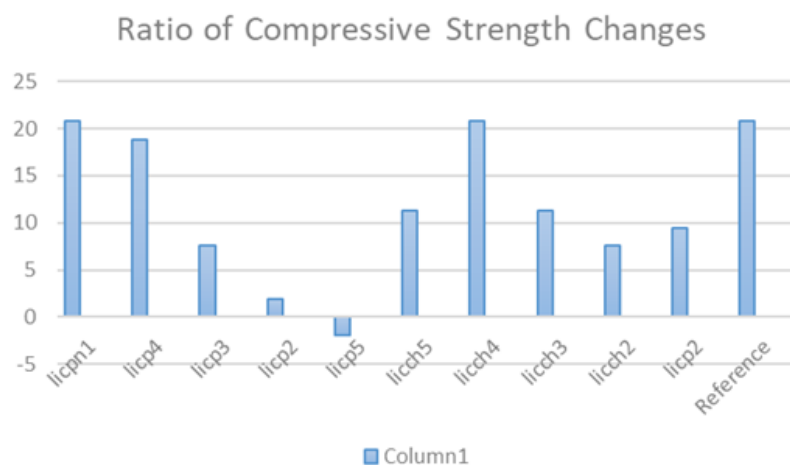


Figure 2: Diagram for Percentage change in strength from 7 days to 28 days.

As shown in the chart above, all samples exhibited a reduction in strength compared to the control concrete; only the licpn1 sample, with a 1.8% increase, outperformed the control concrete.

The acid resistance test was conducted by immersing the samples in acid for 72 hours. After this period, the samples were removed and subjected to a compressive strength test; the results were compared with their initial compressive strength and are presented in Table 5.

Table 5: Resistance of samples after immersion in acid.

Sample	28 days
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Reference	4.6
licch1	3.9
licch2	3.7
licch3	3.4
licch4	3.1
licch5	3
licpn1	5.2
licp2	5
licp3	4.7
licp4	4.1
licp5	3.9

As shown in the table above, all samples were affected by the acid to varying degrees, resulting in reduced resistance. Among the samples, licpn1, licp2, and licp3 yielded the best results with values of 5.4, 5.2, and 4.7, respectively; all three belong to the protein-based group and exhibited higher values than the control sample. It should also be noted that the impact of the acid on the protein-based samples was significantly less than on the chemical samples.

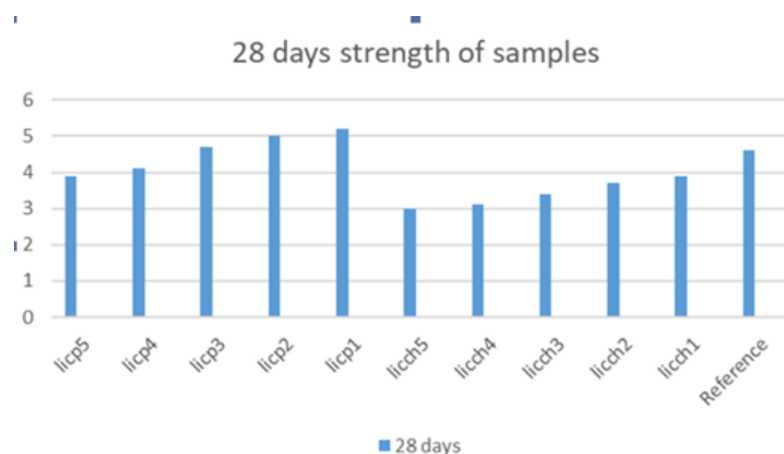


Figure 3: Diagram for Resistance of sample.

As shown in Figure 3, the strength of the samples decreased with increasing amounts of pumice powder; however, the samples containing protein foam exhibited superior and higher strength compared to the other samples.

Table 6 presents a comparison between the initial samples and those subjected to acid exposure. The data indicate that concrete samples produced using chemical foam were significantly more susceptible to degradation than those made with natural foam; specifically, the "licch5" sample exhibited a strength reduction of 36%, whereas the maximum reduction observed in samples made with natural foam was only 7%.

Table 6: Ratio of sample changes in acid relative to initial strength.

Acidic	Ratio
Reference	13.20755
licch1	18.75
licch2	24.4898
licch3	27.65957
licch4	26.19048
licch5	36.17021
licpn1	3.703704
licp2	3.846154
licp3	4.081633
licp4	4.651163
licp5	7.142857

Carbonation tests were conducted on 90-day-old foamed concrete specimens; following a 90-day curing period in a lime-water bath, the specimens were stored in a carbon dioxide chamber for 56 days, and the results are presented in Table 7.

Table 7: Extent of carbonation of samples.

Sample	90 days
licch1	3.1
licch2	2.8
licch3	2.5
licch4	2.2
licch5	1.9
licpn1	2.5
licp2	2.1
licp3	1.8
licp4	1.5
licp5	1.4

As observed in the carbonation table, concrete sample licch1 (3.1 mm) and sample licpn1 (2.5 mm) exhibited the highest levels of carbonation within their respective groups, while samples licch5 and licp5 recorded the lowest values at 1.9 mm and 1.4 mm, respectively.

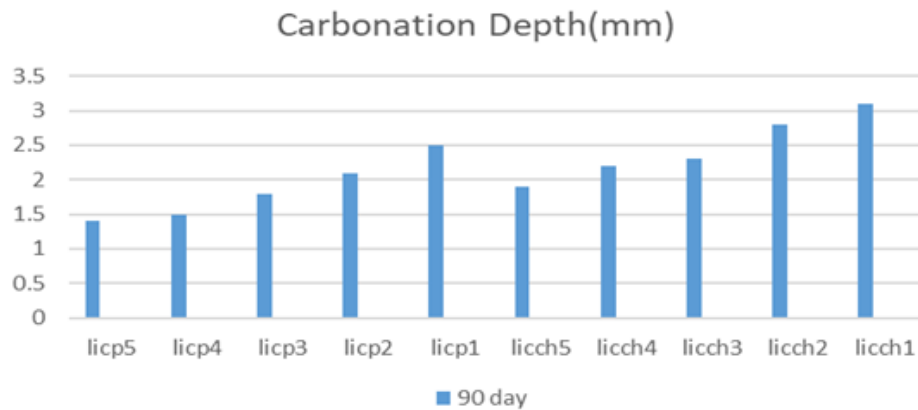


Figure 5: Diagram for Carbonation depth of samples (mm).

As shown in the graph above, the carbonation process exhibits a downward trend with the addition of Puke Karveh black pumice powder; the primary reason for this is the elimination of the key factor driving carbonation, namely, calcium oxide, since increasing the pumice powder content reduces the amount of cement, which contains 56% calcium oxide.

In this experiment, where reducing concrete weight was a primary objective, the specimens were cured in a water tank for 28 days, conditioned in the laboratory environment for one week, and then weighed; the resulting data are presented below. As shown in Figure 6, increasing the content of pumice powder resulted in a decrease in the specific weight of the specimens across both groups containing foam; this trend is primarily attributed to the low specific weight of the pumice powder used to replace the cement.

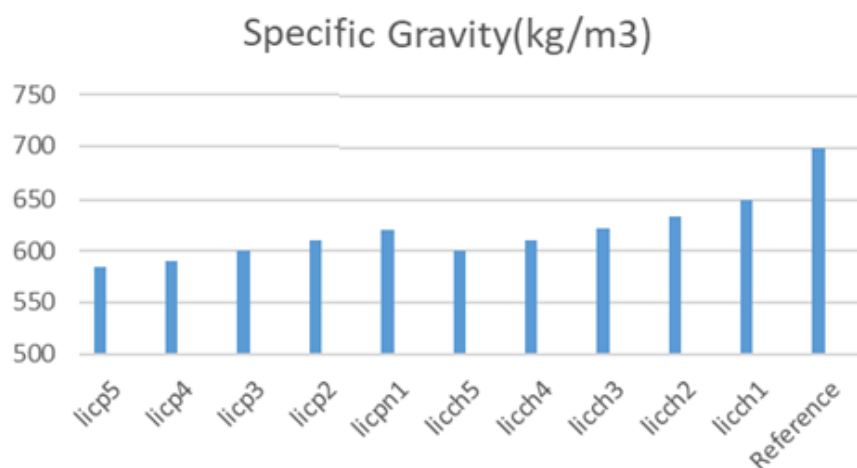


Figure (6): Diagram for Specific Gravity of foam concrete samples (kg/m³).

Table 8 presents the ratio of specific gravity changes in the samples relative to the control concrete. As shown in the table, samples containing chemical foam exhibited less variation

compared to the control sample; a key reason for this is the stability of the bubbles in samples prepared with natural foam, which resulted in a reduction in their weight.

Table 8: Change in specific gravity relative to the control sample.

Reference	Percentage decrease
licch1	9.428571
licch2	11.14286
licch3	12.71429
licch4	15.38462
licch5	11.42857
licpn1	12.71429
licp2	14.28571
licp3	15.71429
licp4	16.42857
licp5	16.37

Water absorption tests were conducted on 90-day-old foam concrete specimens. After being cured under laboratory conditions for 90 days and attaining maximum strength, the specimens were subjected to a water absorption test for 24 hours, continuing until the rate of change fell below 1% over a 3-hour period. Based on Table 9, which presents water absorption percentages, sample LICPN1 exhibited the lowest water absorption (29%) after the reference sample, whereas sample LICCH5 showed the highest value (48%). Regarding the type of foaming agent employed, samples containing chemical foam demonstrated higher water absorption compared to those containing protein-based foam.

Table 9: Water absorption values.

Sample	Absorption 90
Reference	25
licch1	34
licch2	38
licch3	40
licch4	44
licch5	48
licpn1	29
licp2	32
licp3	35
licp4	38
licp5	40

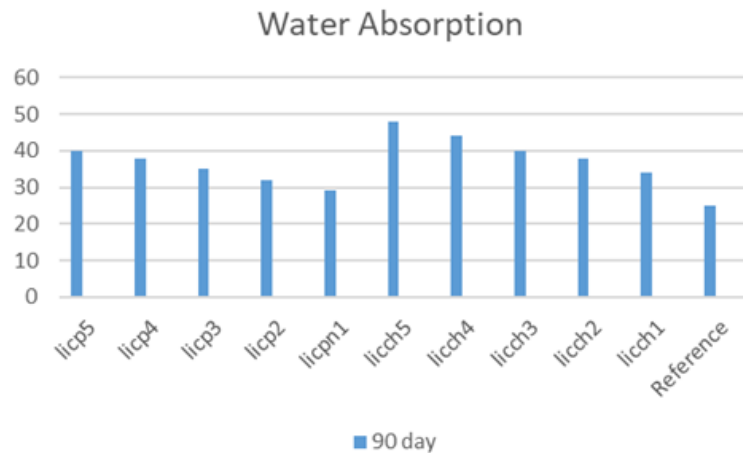


Figure 7: Diagram for Water absorption percentage of foam concrete sample.

As shown in Figure 7, the samples exhibited increased water absorption with the addition of powdered pumice; a primary reason for this is the high water absorption capacity of the powder compared to the cement it replaced.

4. CONCLUSION

To optimize lightweight foamed concrete in this study, two commercially available types of foam chemical and protein-based were utilized. Eleven different mix designs were prepared and tested at various ages, resulting in a total of 240 specimens. Analysis of the compressive strength results revealed that specimens made with protein-based foam exhibited higher strength than those made with chemical foam; This is attributed to the stability of the generated bubbles and the maintenance of a regular cellular structure. Notably, the specimen containing 5% powdered pumice and protein-based foam demonstrated approximately 2% higher strength than the control specimen.

In the acid resistance test, samples produced using protein foam outperformed those prepared with chemical foam; specifically, sample LICPN1 exhibited the best performance with the least alteration, while the other samples showed varying results. Overall, samples containing higher amounts of pumice stone powder were more significantly affected by the acid.

The concrete specimens also exhibited varying results regarding carbonation. Carbonation levels decreased as the content of pumice stone powder increased; the highest level was observed in specimens containing 5% pumice powder, while the lowest was found in those containing 20%. Additionally, the protein-treated specimens yielded better results in this test.

Regarding specific gravity, since lightweight was one of our objectives, samples containing natural foam exhibited lower weight due to bubble stability.

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