University of Baghdad
College of Engineering
JOURNAL OF ENGINEERING

Journal of Engineering

journal homepage: www.jcoeng.edu.iq

Volume 30 Number 5 May 2024

Effect of Expanded Perlite Aggregate and Silica Fume on Some Properties of Lightweight Concrete

Mohammed Jassem[1,*], Nada Mahdi Fawzi[2]

Department of Civil Engineering, College of Engineering, University of Baghdad, Baghdad, Iraq
Mohammed.Jassem2101m@coeng.uobaghdad.edu.iq[1], nada.aljalawi@coeng.uobaghdad.edu.iq[2]

ABSTRACT

The lightweight concrete is manufactured from aggregates (expanded perlite) with a density of 145 kg/m³ and an absorption of 1.65%. This study has two aspects: a theoretical aspect that includes previous research on this concrete and a practical aspect that provides for conducting two groups of mixtures and preparing them according to ACI 211.2-98 design method. The first group includes cement, perlite, and water, and the second group consists of the addition of superplasticizer and silica fume, Each group included five series with three variables for each series. In the first series, the cement content was changed with a content of (275,300,350) kg/m³ with a volumetric mixing ratio (1:4), while in the second series, the aggregate content was changed only with a cement content of (275) kg/m³ with mixing ratios (1:4.1:5, 1:6) with a ratio of water to cement (0.4), and in the third series (superplasticizer) type (F) is added in different proportions, in the fourth series silica fume was added in three proportions (5%, 10%, 15%) By replacing the weight of cement and the fifth series, the optimum contents were determined, which have acceptable workability, low density, and compressive strength commensurate with the density. Tests (flowability, dry density, and compressive strength) were carried out. It was observed that the workability, dry density, and compressive strength decreased with increasing perlite content but improved with the addition of superplasticizer and silica fume. The percentage of increase in density was (9% and 32%) at the optimum value of silica fume in 28.7 days, respectively. As for the compressive strength, the percentage of increase was (30% and 36%) in 7 and 28 days, respectively.

Keywords: Expanded perlite; Silica fume; Lightweight concrete; Compressive strength.

*Corresponding author
Peer review under the responsibility of University of Baghdad.
https://doi.org/10.31026/j.eng.2024.05.11

Article received: 12/06/2023
Article accepted: 16/09/2023
Article published: 01/05/2024

تأثير ركام البرلايت المتمدد وغبار السيليكا على بعض خصائص الخرسانة خفيفة الوزن

محمد جاسم*، ندى مهدي فوزي

قسم الهندسة المدنية، كلية الهندسة، جامعة بغداد، بغداد، العراق

الخلاصة

الخرسانة خفيفة الوزن والتي يتم تصنيعها من ركام خفيف تبلغ كثافته 145 كغم/م^3 وامتصاصه 1.65% .لهذه الدراسة جانبين, جانب نظري يشمل بحوث سابقة عن هذه الخرسانة, وجانب عملي يشمل اجراء مجموعتين من الخلطات وإعدادها بواسطة الطريقة الحجمية وفقًا لـ (ACI 211.2–98) المجموعة الاولى تتضمن السمنت, البيرلايت والماء والمجموعة الثانية تضمنت اضافة الملدن المتفوق وغبار السيليكا , كل مجموعة تضمنت خمسة سلاسل بخمسة متغيرات لكل سلسلة, تم في السلسلة الاولى تغير محتوى السمنت بمحتوى (350,300,275) كغم / م^3 بنسبة خلط حجمية (4:1), اما السلسلة الثانية تم تغيرمحتوى الركام فقط بمحتوى سمنت (275) كغم/م^3 وبنسب خلط (5:1.4:1 , 6:1) وبنسبة ماء الى سمنت (0.4), والسلسلة الثالثة فيتم اضافة (الملدن المتفوق) نوع (F) بنسب مختلفة , السلسلة الرابعة تم اضافة غبار السيليكا بثلاث نسب (5%,10%، 15%) عن طريق الاستبدال بوزن السمنت والسلسلة الخامسة تم تحديد المحتويات المثلى والتي تكون ذات قابلية تشغيل مقبولة وكثافة منخفضة ومقاومة انضغاط تتناسب مع الكثافة. تم اجراء فحوص (الانسياب , الكثافة الجافة ومقاومة الانضغاط). تم ملاحظة ان قابلية التشغيل والكثافة الجافة ومقاومة الانضغاط تنخفض مع زيادة محتوى البيرلايت ولكنها تحسنت عند اضافة الملدن المتفوق وغبارالسليكا. حيث كانت نسبة الزيادة بالكثافة هي (9% ,21%)عند القيمة الملثى لغبار السيليكا في 28.7 يوما على التوالي. اما مقاومة الانضغاط فكانت نسبة الزيادة هي (30% ,36 %) في 7 و28 يوما على التوالي.

الكلمات المفتاحية: ركام البيرلايت المتمدد، غبارالسيليكا، الخرسانة خفيفة الوزن، مقاومة الانضغاط .

1. INTRODUCTION

Since ancient times, man has shown great interest in lightweight and heat-insulating materials. In ancient Iraq, where history began, heaps of plants and wood were used in various forms, such as rice husks and straw mixed with mud or plaster **(Hnaihen, 2020),** as a binder to reduce dead loads in ceilings. The Romans used a lightweight natural volcanic rubble known as peums (pumice) in building the domes of a temple in Rome in the year 28 BC. The dome's diameter is (43 meters), and its traces remain today. There are many types of lightweight aggregates at present, and interest in them has increased in view of their economic benefits in terms of thermal insulation and lowering dead loads, particularly in high buildings. (density less than 1000 kg/m^3) as a layer of lightweight concrete bonding under the ceramic pieces, as well as the secondary ceilings of the conference hall, where fly ash aggregate was used in the lightweight concrete used for these ceilings **(AlJalawi,1997); (Thienel et al., 2020).**

A naturally occurring volcanic rock known as expanded perlite aggregate is used extensively worldwide. When perlite is extracted as rock, it is crushed into various sizes. This classified perlite loses water when heated to 850–1150 °C and explodes due to temperature effects.

The size of the smashed perlite aggregate grows by up to 35 times its initial volume as a result of this explosion. Expanded perlite is the name given to the substance that goes through these procedures. This material melt at 1300 °C and it is white in color. Its density ranges from 32 to 200 kg/m^3, and its thermal conductivity is 0.040 to 0.055 W/mK **(Tapan and Engin, 2019; Wang et al., 2021).** Lightweight concrete (LWC) can be made in a number of different methods. One method, called "no-fines," eliminates the fine portion of the aggregate used in concrete altogether. Another technique for producing LWC involves utilizing chemical admixtures and mechanical foaming to provide stable air bubbles to concrete. Other names for this type of concrete are cellular, gas, and aerated concrete. Utilizing lightweight aggregate is the most popular way to create LWC. These aggregates, which can be natural or artificial, are available everywhere and can be used to produce concrete with different unit weights and strengths suitable for different application domains (**Demirboğa et al., 2001).** The definition of pozzolan is silicon derived and aluminum derived component which, in itself, has little or no cementitious characteristics but which, in particulates shape, in the existence of moisture, chemically responds to calcium hydroxide at ordinary temperature to create compounds having cementitious characteristics **(Thorstensen and Fidjestol, 2015).**

For the concrete industry to advance global sustainability, additional cementing components must be used in place of cement. The two most extensively available supplemental cementing materials, per ASTM C1240-15, are fly ash, a by-product of thermal power plants, and silica fume, a byproduct of silicon metal. Only 10% of the available fly ash in the globe is now used in concrete, despite estimates that 600 million tons of fly ash are available now. Energy consumption worldwide has increased due to the world's rapid economic development and population growth, resulting in a considerable rise in fly ash. As a result, there is now a problem with air and environmental pollution, and recycling has become increasingly popular. Due to their pozzolanic qualities, fly ash (FA) and silica fume (SF) are two of the most widely used components in concrete **(ASTM C1240, 2015; ASTM C311, 2022; ASTM C618, 2019).** Silica fume is considered one of the highly effective pozzolanic materials. It has great importance in the production of concrete as it reacts with calcium hydroxide produced from C3S and C2S hydration to form a cementations gel that reduces the thickness of the interlayer between cement and aggregate, which increases the compressive strength of concrete **(AlJalawi and Hamad, 2009)**. As a reason behind its low weight, whiteness, high susceptibility to water, damping and insulating properties, and being resistant to fire, expanded perlite aggregate (EPA) has a vast range of uses. Besides having these characteristics, it does not affect health. It is frequently used in construction uses, mostly as concrete and mortar, due to its thermal or acoustic insulation, lightweight nature, and fire resistance. Depending on the mix design, EPA concrete has sound dampening and thermal insulating qualities **(Khonsari et al., 2010).** A downside of lightweight concretes is that they have poor mechanical properties despite having excellent qualities like lightness, thermal isolation, freeze-thaw resistance, and fire protection. Numerous researchers have looked at how silica fume (SF) affects the characteristics of conventional concrete and concrete built with a combination of conventional and lightweight particles **(Janca et al., 2019), (Azimi-Pour and Eskandari-Naddaf, 2018).** There aren't enough specifics in the technical literature about how silica fume (SF) affects these concrete' compressive strength, unit weight, etc. Therefore, an experimental investigation is carried out to determine the effects of silica fume (SF) on the density EPAC, and the results have been given **(Demirboa and Gül, 2003).** Structural lightweight concrete (LWC) was created using expanded perlite aggregate (EPA) added at a weight percentage of 0 to 20%. The material's mechanical properties were evaluated by calculating the concrete's unit weight, compressive strength, and flexural strength. A hot plate was used to measure thermal insulation. The outcomes exhibited that the unit weight of concrete was decreased by 20% to 30% when equated with ordinary concrete (NWC). The compressive strength of LWC was adequate to be utilized as structural concrete, chiefly of those mixtures comprising 10% and 15% perlite aggregate. The noticeable effects also comprise the superior thermal insulation properties of LWC equated to NWC **(Ibrahim and Ahmed, 2020).** LWC could be grouped into three groups which are under 2000 kg/m3 and LWC which could be used as structural component and the third is the very low weight type which is not suitable for structural uses (**Fig. 1**) **(ACI 213R, 2014; Abdelfattah et al., 2023)**. LWA is very old and used in the ancient civilizations like scoria and pumice which are naturally derived materials and have high content of silica and alumina **(Ahmed et al., 2023; Karthika et al., 2021; Islam et al., 2022).**

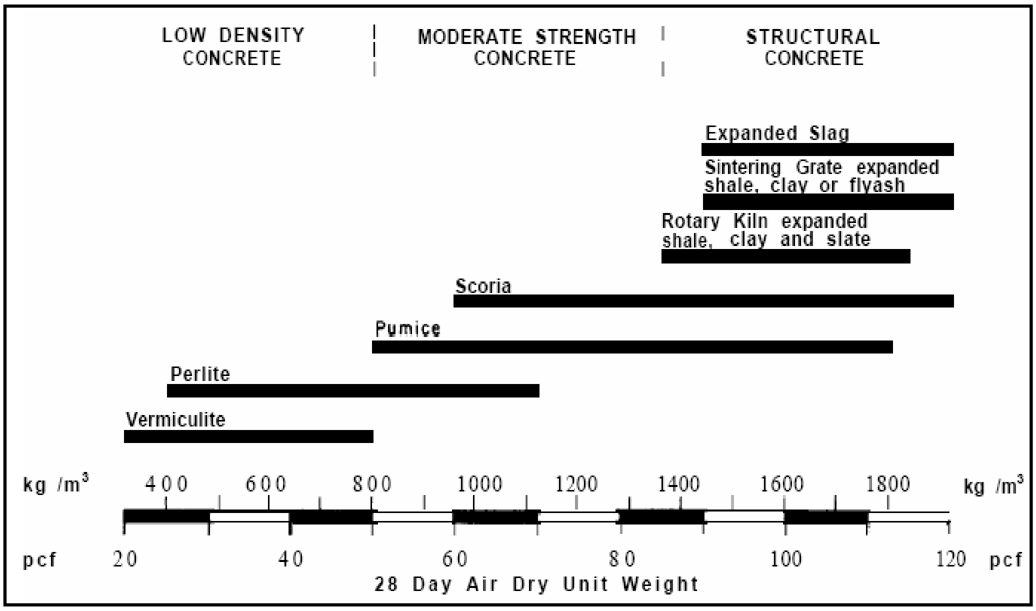

Figure 1. Approximate unit weight and use classification oflightweight aggregate concrete **(ACI 213R, 2014).**

This work goal is to lower dead loads in the constructional segments and, hence, the overall costs of buildings by preparing lightweight concrete and investigating the effect of expanded perlite aggregate on concrete density and compressive strength.

2. EXPERIMENTAL WORK

2.1 Materials

2.1.1 Cement

Ordinary Portland cement (CEM I, 42.5R) was utilized, which follows Iraqi (**IQS No.5, 2019). Tables 1 and 2**. Illustrate the physical and chemical characteristics of the cement.

Table 1. Chemical composition and the main component of the cement.

Oxide Compositions	Wt.%	Limits of **(IQS No.5, 2019)**
Lime (CaO)	63.32	-----
Iron Oxide (Fe_2O_3)	4.16	-----
Alumina (AL_2O_3)	5.22	-----
Silica (SiO_2)	19.84	-----
Insoluble Residue (IR)	0.64	Max (1.5)
Magnesia (MgO)	2.78	Max (5)
Loss on Ignition (LOI)	2.68	Max (4)
Sulfate (SO_3)	2.45	2.8 if $C_3A>3.5$ 2.5 if $C_3A\leq3.5$
*Main Compounds of Cement		
TricalciumSilicate C3S	58.91	---
DicalciumSilicate C2S	13.13	---
Tricalcium Aluminate C3A	6.8	---
TetraCalcium Aluminate –Ferrite C4AF	12.84	

Table 2. Physical characteristics of the (OPC)

Propriety	Test Results	Limits of **(IQS No.5, 2019)**
Soundness by Autoclave Approach (%)	0.17	≤ 0.80
Setting time (Vicat's approach) Initial setting (min)	130min	≥ 45 min
Setting time (Vicat's method) final setting time	260min	≤ 600min.
Compressive Strength (MPa)		
Compressive Strength (2) days	25.55	≥20
Compressive Strength (28) days	45.48	≥ 42.5

2.1.2 Water

Water has been utilized in the mix and curing in this research. Water should be clean and free from harmful should be identical to **(IQS. No.1703, 1992).**

2.1.3 Expanded Perlite Aggregate (EPA)

Expanded perlite aggregate was used in this study as a fine aggregate, which conforms to Iraqi standards **(ASTM C330, 2014; ASTM C332, 2017). Tables 3 and 4** display its chemical properties and physical properties. Sieve analysis results show that perlite in **Table 5.**

Table 3. Chemical composition of EPA from the datasheet (Sika company).

Oxide Compositions	Wt.%
Lime (CaO)	2.5
Iron Oxide (Fe_2O_3)	0.54
Alumina (AL_2O_3)	7.5
Silica (SiO_2)	69.6
Insoluble Residue (IR)	……..
Magnesia (MgO)	0.24
Loss on Ignition(LOI)	5.8
Sulfate SO_3	0.02

Table 4. Physical characteristics of EPA

Size (mm)	3.19
Shape	Particle
Color	White
Moisture (%)	7
Density (kg/m^3)	145
Absorption (%)	1.65

Table 5. Aggregate gradation according to **(ASTM C330, 2014).**

Sieve size (mm)	Passing % wt.	According to **(ASTM C330, 2014)**
4.75	100	100
2.36	81.4	85-100
1.18	40.63	40-85
0.6	27	20-60
0.3	20.3	5-25
0.15	9.33	0-10
4.75	100	100

2.1.4 Silica fume

Silica fume is very fine, sphere-shaped dust utilized as an added material for enhancing concrete properties **(ACI Committee 226, 1987)**. A grey color fine silica is used, its physical and chemical requirements are given in **Tables 6. and 7. Figs. 3. (a,b, c, d), and 4 (a, b, c)** show the flow test and accelerated pozzolanic strength activity index at 7 days, respectively. The outcomes display that silica fume follows **(ASTM C1240, 2015**).

Table 6. Chemical Requirements of Silica Fume (SF).

Oxide Composition	Test results %	**(ASTM C1240, 2015)**
Silicon Oxide (SiO_2)	92.84	Min (85)%
Moisture content %	0.33	Max (3)%
Loss of Ignition	1.59	Max (6)%

Table 7. Physical Requirements of Silica Fume

Physical Characteristics	Test Result	**(ASTM C1240, 2015)**
Flow Test %	117.5	115
Accelerated Pozzolanic Strength Activities Index with the OPC at 7 days, min percent of control (MPa)	107.5	Min (105)

2.1.5 Super-plasticizer

(BETONAC 350, Complies with Type F **(ASTM C494, 1917)**) is a water-reducing agent utilized as a super-plasticizer with a quantity of (800 mL) by weight of cement. Its color is a light brown liquid with a 1.06-+0.02 gm/mL density. **Table 8** shows the characteristics of a superplasticizer from the manufacturing company.

Table 8. Performance data sheet of super-plasticizer.

Appearance	Transparent or light brown liquid
Calcium chloride	Nil
Density (gm/ml)	1.10 ± 0.02
Viscosity	450 c Ps at 20ºC
Setting time	Initial and final setting time depends on the temperature
Dosage	150 -1000 ml / 100 kg of cement

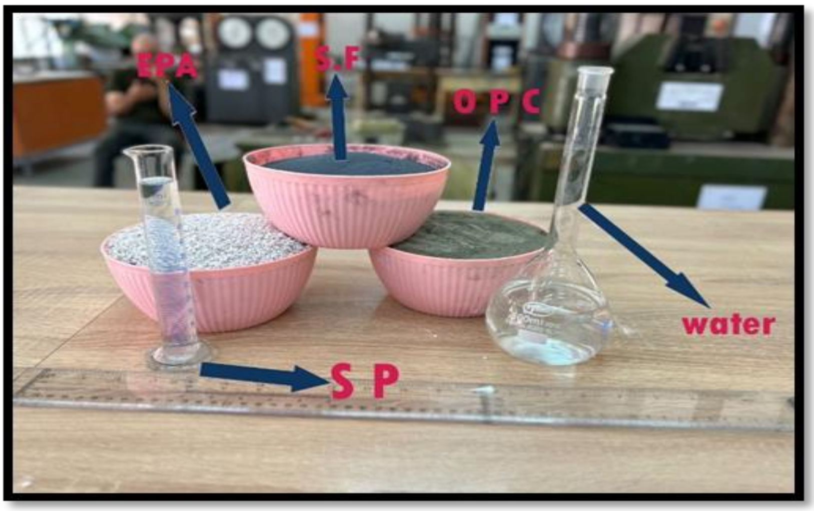

Figure 2. All materials used in this study.

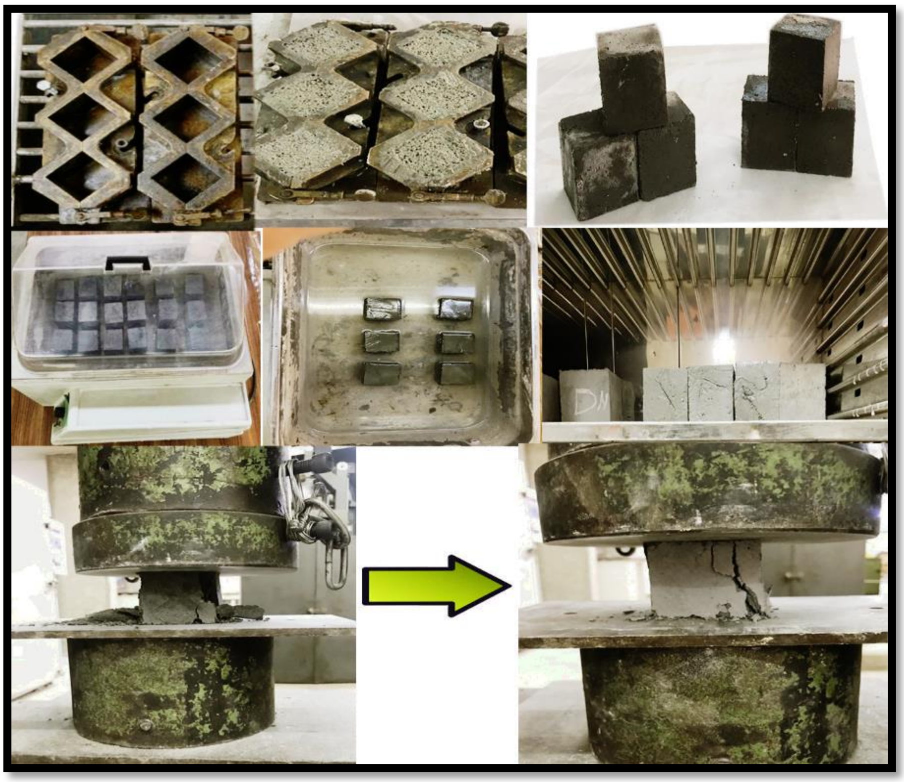

Figure 3. Steps of testing strength activity index for (SF).

2.2 Mix Design

During this study, two groups of lightweight aggregate mixtures were made and set using the volume method in measuring quantities as specified in **(ACI 211.2, 1998).** The first group includes cement, perlite, and water, and the second group comprises cement, water, perlite, superplasticizer, and silica fume. These two groups included five series bearing three variables in each series, as shown in **Tables 9 to 13** the prepared mix was poured in the mold. After 24 hours, the samples were placed in water for curing.

Table 9. The first series only changed the cement content**.**

No. of mix	Ratio by volume	Cement Content(kg/m^3)	EPA content(kg/m^3)	W/C ratio	Super Lit/100kg Cement	Silica fume %
MC1	1:4	275	113.8	0.4	0	0
MC2	1:4	300	113.8	0.4	0	0
MC3	1:4	350	113.8	0.4	0	0

Table 10. The second series only changes the fine aggregate content.

No. of mix	Ratio by volume	Cement Content (kg/m^3)	EPA content (kg/m^3)	W/C ratio	Super Lit/100kg Cement	Silica fume %
MC4	1:4	275	113.8	0.4	0	0
MC5	1:5	275	142.4	0.4	0	0
MC6	1:6	275	170,8	0.4	0	0

Table 11. The third series is the addition of chemicals (superplasticizers) in different proportions.

No. of mix	Ratio by volume	Cement Content(kg/m^3)	EPA content (kg/m^3)	W/C ratio	Super Lit/100kg Cement	Silica fume %
MC7	1:4	275	113.8	0.3	800	0
MC8	1:4	275	113.8	0.3	900	0
MC9	1:4	275	113.8	0.3	1000	0

Table 12. The fourth series is the addition of mineral substances (silica fume) in different percentages.

No. of mix	Ratio by volume	Cement Content (kg/m^3)	EPA content (kg/m^3)	W/C ratio	Super Lit/100kg Cement	Silica fume %
MC10	1:4	261.25	113.8	0.3	800	5
MC11	1:4	247.5	113.8	0.3	800	10
MC12	1:4	233.75	113.8	0.3	800	15

Table 13. Optimum Mix Design.

No. of mix	Ratio by volume	Cement Content(kg/m^3)	EPA content (kg/m^3)	W/C ratio	Super Lit/100kg Cement	Silica fume %
MC1	1:4	275	113.8	0.4	0	0
MC7	1:4	275	113.8	0.3	800	0
MC12	1:4	247.5	113.8	0.3	800	10

2.3 Testing Procedure

2.3.1 Fresh mortar test

The flow table made a workability test for all prepared mixtures following **(ASTM C1437, 2020)**. The flow reduces slowly with the upsurge of perlite. This is because of the high susceptibility of perlite to water. The outcomes of the flowability for different mixes are displayed in **Table 14 (ASTM C1437, 2020)**.

$$(\text{Flow}) = [(A-100)/100] \times 100 \quad (1)$$

A: average of four readings in (mm)

The oven dry unit weight calculated for structural lightweight mortar following **(ASTM C567, 2005)**

$$OM\ (\text{Density, kg/ m}^3) = (D * 997) / (F-G) \quad (2)$$

where:

Om = calculated oven-dry density, kg/m³.

D = mass of oven-dry cylinder, kg.

F = mass of saturated surface-dry cylinder, kg.

G = apparent mass of suspended-immersed cylinder, kg.

2.3.2 Hardened Tests

2.3.2.1 Compressive Strength

The value of compressive strength of the lightweight concrete samples was determined based on **(ASTM C109/C109M, 2016)** using a compression device, and this test was conducted in the Construction Materials lab. (University of Baghdad), the total number of cylinders used in this test was (72) with dimensions (100*200) mm. This test is performed for concrete cubes of age (7, 28) days according to (**ASTM C 109, 2016)**.

3. RESULTS AND DISCUSSION

3.1 Workability

The outcomes of the flow test in **Table 14** show that the flow decreased with the continuous change in the content of the expanded perlite aggregate and that the flow improved with a rise in the silica fume replacement rates by about 5%, 10%, and 15%, and that the top workability was with a silica fume substitution rate of 10%, and that The request for water raised equaled to the reference mixture, and to keep steady workability, a water-reducing superplasticizer was utilized **(Hachim and Fawzi, 2012**).

3.2 Dry unit weight

According to the experiments that were conducted to obtain the appropriate mixture design, it was seen that the dry density of the mixture decreases as the content of lightweight aggregate (perlite) is increased, where it is possible to obtain a low dry density within the range of (740 to 1440) kg/m^3 for lightweight concrete made of perlite aggregate. Dry density values increase when replacing silica fume with cement weight, as silica fume fills all air voids and increases surface area, as shown in **Table 15.** The results were compatible with the findings of **(Mohammad et al., 2010; Nicolas et al. 2011).**

Table 14. Effect of Silica fume and superplasticizer on workability.

No. of mix	Ratio by volume	Cement Content (kg/m³)	W/C ratio	Super Lit/100kg Cement	Silica fume %	Flow ability% ASTM C1437
MC1	1:4	275	0.4	0	0	110.5
MC2	1:5	275	0.4	0	0	106
MC3	1:6	275	0.4	0	0	92
MC4	1:4	275	0.3	800	0	115.8
MC5	1:4	275	0.3	900	0	115.2
MC6	1:4	275	0.3	1000	0	114
MC7	1:4	261.25	0.3	800	5	116.2
MC8	1:4	247.5	0.3	800	10	118.6
MC9	1:4	233.75	0.3	800	15	115.3

Table 15. Dry unit weight.

No. of the mix	Ratio by volume	Cement Content (kg/m³)	EPA content (kg/m³)	W/C ratio	Super Lit/100kg Cement	Silica fume %	dry density (kg/m³)	Increasin g (%)
MC1	1:4	275	113.8	0.4	0	0	883	0
MC2	1:4	275	113.8	0.3	800	0	963	9
MC3	1:4	275	113.8	0.3	800	10	1166	32

3.3 Compressive Strength

By conducting the mixture design experiments, we obtained the results of the compressive strength test for the first group, where the values were confined between (7.8 to 9) MPa, where we note that the compressive strength has decreased. This decrease has increased significantly and within the permissible values for lightweight concrete when increasing perlite content. Therefore, we conclude in the first group, its compressive strength decreases with the increase in the perlite content, and this is due to the presence of air gaps. As for the second group, we notice an increase in compressive strength accompanied by an increase in density. This is due to the role played by silica fume in filling many voids in the concrete structure and dropping absorption and porosity. Thus, it increases concrete's compressive strength and durability, as shown in **Table 16.** Results were compatible with those **(Aljalawi, 2009; Li et al., 2021; Wietek, 2021).**

Table 16. Compressive Strength Results.

No. of mix	Ratio by volume	Cement Content (kg/m³)	EPA content (kg/m³)	W/C ratio	Super Lit/100kg Cement	Silica fume %	Compressive Strength (Mpa)		Increasing (%)	
							7 days	28 days	7 days	28 days
MC1	1:4	No. of mix	113.8	0.4	0	0	7.51	10.2	0	0
MC2	1:4	No. of mix	113.8	0.3	800	0	9.63	11.4	28	30
MC3	1:4	No. of mix	113.8	0.3	800	10	12.55	15.53	11	36

4. CONCLUSIONS

Silica dust possesses nanoscale properties represented in improving the Interfacial Transition Zone (ITZ) and mechanical and physical properties described in filling voids in the concrete structure and generating (C-S - H Gel), so it is used to improve the properties of concrete.

- It is noted that the compressive strength decreases with the increase in the content of perlite aggregates and the workability due to the large porosity and holes in the concrete structure and the high absorption of perlite aggregates.
- Silica fume improved workability and increased compressive strength up to (30% and 36%) for 7 and 28 days, respectively. This increase is due to the significant role that silica fumes play in improving the mechanical properties of concrete and filling voids in the concrete structure, thus increasing compressive strength and durability.
- The increase in perlite content leads to a very sharp decrease in the dry density of concrete due to its very low density, which works to reduce dead loads in construction, which is required for lightweight concrete, but a decrease in the compressive strength accompanies this decrease.
- The silica fume balances the density within the limits required to maintain an appropriate compressive strength. As a result, the density increased by (28% and 11%) in 7 and 28 days, respectively, where it was concluded that there is a very close and direct relationship between the density and the compressive strength.

NOMENCLATURE

Symbol	Description	Symbol	Description
EPA	Expanded perlite aggregate	ITZ	Interfacial Transition Zone
A	Average of four readings in (mm).	SF	Silica fume
Om	Calculated oven-dry density, kg/m^3.	LWA	Light Weight Aggregate
D	Mass of oven-dry cylinder, kg.	C-S-H	CaO-SiO_2-H2O
F	Mass of saturated surface-dry cylinder, kg.	OPC	Ordinary Portland Cement
G	Apparent mass of suspended-immersed cylinder, kg.	LWC	Light Weight Concrete

Acknowledgments

This work was supported by the Department of Civil Engineering, College of Engineering, University of Baghdad.

Credit Authorship Contribution Statement

Mohammed Jassem: Writing – original draft, Validation, Methodology.
Nada Mahdi Fawzi: Review & editing, Validation, Proof reading.

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.

REFERENCES

Abdelfattah, M. M., Géber, R., and Kocserha, I., 2023. Enhancing the properties of lightweight aggregates using volcanic rock additive materials. *Journal of Building Engineering*, *63*, P. 105426.

ACI 211.2, 1998. Standard Practice for Selecting Proportions for Structural Lightweight Concrete.

ACI 213R, 2014. Guide for Structural Lightweight-Aggregate Concrete.

ACI Committee 226. 1987. Silica fume in concrete: Preliminary report, *ACI Materials Journal* March–April, pp. 158–66.

Ahmad, J., Althoey, F., Abuhussain, M. A., Deifalla, A. F., Özkılıç, Y. O., and Rahmawati, C., 2023. Durability and microstructure analysis of concrete made with volcanic ash: A review (Part II). *Science and Engineering of Composite Materials*, *30*(1), 20220211.

Al-Jalawi, N.M., 1997. Properties of Lightweight Concrete with A view to Thermal Insulation and Acoustic Impedance, MSc, University of Baghdad, 1997, P. 13.

ASTM C 109, 2020. Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens).

ASTM C1240, 2015 .Standard Specification for Use of Silica Fume as a Mineral Admixtures in Hydraulic-Cement Concrete, Mortar and Grout‖, Annual Book of ASTM Standards, American Society for Testing and Materials, pp.1-8.

ASTM C1437, 2020.Standard Test Method for Flow of Hydraulic Cement Mortar.

ASTM C311, 2016. Standard Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use in Portland-Cement Concrete,pp. 1-16.

ASTM C330, 2014. Standard Specification for Lightweight Aggregates for Structural Concrete.

ASTM C332, 2017. Standard Specification for Lightweight Aggregates for Insulating Concrete.

ASTM C494, 2017. Standard Specification for Chemical Admixtures for Concrete||, Annual Book of ASTM Standards.

ASTM C567, 2005. Standard Test Method for Determining Density of Structural Lightweight Concrete.

ASTM C618, 2015. Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete, P.1-1.

Azimi-Pour, M., Eskandari-Naddaf, H., 2018. ANN and GEP prediction for simultaneous effect of nano and micro silica on the compressive and flexural strength of cement mortar. *Construction and Building Materials*, 189, 978–992.

Demirboğa, R., and Gül, R., 2003. Thermal conductivity and compressive strength of expanded perlite aggregate concrete with mineral admixtures. *Energy and Buildings*, *35*(11), pp. 1155-1159. Doi:10.1016/j.enbuild.2003.09.002.

Demirboğa, R., and Örüng, İ., Gül, R., 2001. Effects of expanded perlite aggregate and mineral admixtures on the compressive strength of low-density concrete. *Cement and Concrete.Research*, *31*(11), pp. 1627-1632. Doi:10.1016/S0008-8846(01)00615-9.

Hachim, Q.J.A. and Fawzi, N.M., 2012. The effect of different types of aggregate and additives on the properties of self-compacting lightweight concrete. *Journal of engineering*, *18*(08), pp.875-888. Doi: 10.31026/j.eng.2012.08.02

Hnaihen, K. H., 2020. The appearance of bricks in ancient mesopotamia. *Athens Journal of History*, *6*(1), pp. 73-96.

Ibrahim, M., and Ahmad, A., 2020. Durability of structural lightweight concrete containing expanded perlite aggregate. *International Journal of Concrete Structures and Materials*, *14*, pp. 1-15. Doi:10.1186/s40069-020-00425-w.

IQS No.1703, 1992. Water used in concrete, Central Organization for Standardization and Quality Control. Iraqi Specification

IQS No.5, 2019. Portland Cement||, The Central Organization for Standardization and Quality Control. Iraqi Standard

Islam, A. B. M. S., Kutti, W. A., Nasir, M., Kazmi, Z. A., and Sodangi, M., 2022. Potential use of local waste scoria as an aggregate and SWOT analysis for constructing structural lightweight concrete. *Advances in Materials Research-an International Journal*, *11*(2), pp. 147-164.

Janca, M., Siler, P., Opravil, T. and Kotrla, J., 2019. Improving the dispersion of silica fume in cement pastes and mortars. In *IOP Conference Series: Materials Science and Engineering* (Vol. 583, No. 1, p. 012022). IOP Publishing.

Karthika, R. B., Vidyapriya, V., Sri, K. N., Beaula, K. M. G., Harini, R., and Sriram, M., 2021. Experimental study on lightweight concrete using pumice aggregate. *Materials Today: Proceedings*, *43*, pp. 1606-1613.

Khonsari, V., Eslami, E., Anvari, A., 2010. Effects of expanded perlite aggregate (EPA) on the mechanical behavior of lightweight concrete. In *Proceedings of the 7th international conference on fracture and mechanics of concrete & concrete structure (FraMCoS-7), Jeju, Korea,* pp. 1354-1361. https://framcos.org/FraMCoS-7/11-10.pdf.

Li Y.F., Wang H.F., Syu J.Y., Ramanathan G.K., Tsai Y.K., Lok M.H. 2021. Mechanical properties of Aramid/Carbon hybrid Fiber-Reinforced concrete. *Materials*. 2021; 14(19), P. 5881. Doi:10.3390/ma14195881 .

Mohmmad,H., and Nada ,M., and Zeen, A., 2010. Development of Lightweight Heat Insulating Concrete. 28(13). https://www.researchgate.net/publication.

Nada, M., and Aliaa, F., 2009. Product high performance concrete by use different type of local pozolana. *Journal of engineering*, 15(1), pp. 620-632. Doi: 10.31026/j.eng.2009.01.03

Nicolas A., M. Shekarchi, M. Mahoutian, P. Soroushian, 2011. Mechanical properties of hybrid fiber reinforced lightweight aggregate concrete made with natural pumice, Construction and Building Materials, 25(5), pp. 2458-2464, Doi: 10.1016/j.conbuildmat.2010.11.058

Tapan, M., and Engin, C., 2019. Effect of expanded perlite aggregate size on physical and mechanical properties of ultra lightweight concrete produced with expanded perlite aggregate. *Periodica Polytechnica Civil Engineering*, 63(3), pp. 845-855. Doi:10.3311/PPci.12680.

Thienel, K., and Haller, T., and Beuntner, N., 2020. Lightweight concrete from basics to innovations. *Materials*, *pp.13* (5), P. 1120. Doi:10.3390/ma13051120.

Thorstensen, R. T., and Fidjestol, P., 2015. Inconsistencies in the pozzolanic strength activity index (SAI) for silica fume according to EN and ASTM. *Materials and Structures*, *48*, pp. 3979-3990. Doi:10.1617/s11527-014-0457-6.

Wang, X., Wu, D., Geng, Q., Hou, D., Wang, M., Li, L., Wang, P., Chen, D. and Sun, Z., 2021. Characterization of sustainable ultra-high performance concrete (UHPC) including expanded perlite. *Construction and Building Materials*, *303*, p.124245.

Wietek, B., 2021. *Fiber Concrete: In Construction*. Springer Nature. Springer Wiesbaden, Doi:10.1007/978-3-658-34481-8.