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Enhanced Properties of Foamed Concrete by Incorporation of Pozzolanic Materials

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Abstract

This research studies the effect of different type of Pozzolanic materials on foam concrete properties. A saturated surface dry Porcelanite as the fine lightweight aggregate was used for all mixtures except the control mix. Five pozzolanic materials was partially replaced cement weight by 15%, namely Silica fume, glass powder, fly ash, leaf steam ash, and slag. Therefore, a comprehensive experimental work was conducted that included studying the effect of varying materials constituents on the density of compressive strength and thermal conductivity of foamed concrete. The percentage of a foaming agent to water was kept constant at 3:1 by weight with a foam density of 42 kg/m^3. Results show that foamed concrete in the density range of 1100 to 1290 kg/m^3 with corresponding strengths of approximately 16 to 20 MPa of 28 days can be produced by using different Pozzolanic materials. Also a decrease in the coefficient of thermal conductivity was achieved when using pozzolanic materials as a partial compensation of the weight of

Keywords: Foamed concrete; lightweight concrete; Pozzolanic Materials

الخلاصة:

يدرس هذا البحث تأثير أنواع مختلفة من المواد البوزولانية على خصائص الخرسانة الرغوية. تم استخدام بورسيلانيت جاف مشبع كركام خفيف الوزن لجميع الخلطات باستثناء الخلطة المرجعية. تم استبدال خمسة مواد بوزولانية جزئياً من وزن الأسمنت بنسبة 15٪ ،وهي ابخرة السيليكا ، ومسحوق الزجاج ، والرماد المتطاير ، ورماد سعف النخيل، والخبث. لذلك ، تم عمل تجريبي شامل تضمن دراسة تأثير مكونات المواد المختلفة على كثافة ومقاومة الانضغاط والتوصيل الحراري للخرسانة الرغوية. تم الحفاظ على النسبة المئوية لعامل الرغوة الى الماء ثابتة عند 3: 1 بالوزن بكثافة رغوة 42 كجم / م ^{3}. تظهر النتائج أن الخرسانة الرغوية في نطاق الكثافة من 1100 إلى 1290 كجم / م 3 مع قوة مقابلة تقارب 16 إلى 20 ميجا باسكال عند 28 يومًا يمكن تحقيقها باستخدام مواد بوزولانية مختلفة. كما تم تحقيق انخفاض في معامل الموصلية الحرارية عند استخدام المواد البوزولانية كتعويض جزئي من وزن الأسمنت.

1. Introduction

Due to desirable thermal insulation properties, superior fire-resistant and higher durability, ultra-lightweight foam concretes are recommended to achieve energy efficiency in buildings. Contractors and builders throughout the world are paying an increasing amount of attention to the use of foamed concrete, often referred to as cellular concrete. Growing energy savings and environment-friendly considerations are driving this shift in focus [1]. Formed foam concrete is manufactured by adding foam, prepared by aerating a foaming agent solution, to cement paste or cement mortar [2]. It is an economical, environmentally friendly, lightweight structural material that provides thermal and acoustic insulation as well as fire and termite resistance [1]. The chemical composition and physical properties of foamed concrete were discussed in many investigations by [2-6]. In addition, many investigations have been conducted on the composition, physical properties and application of foam concretes with density of 600–1500 kg/m^3 [2, 7-10]. In recent years, high-strength foamed concrete has been developed with a low water-to-binder ratio using silica fume and ultrafine silica powder, and fly ash without using sand [1, 11, 12]. Generally, aluminate cement, sulphoaluminate cement and other quick hardening cementitious materials are used to control the stability of air-voids in foam concretes. These special cementitious materials are relatively expensive and not universally available, retarding the application and popularization of foam concretes[4].

This paper reports on an effort to develop structural foamed concretes of 1100 to 1290kg/m^3 with corresponding strengths of about 16 to 25 MPa. Foamed concretes containing pozzolanic materials as a cement replacement to improve the paste strength were investigated. In this paper, lightweight foam concrete was prepared using Portland cement, Silica fume, glass powder, fly ash, leaf steam ash, and slag. Factors influencing the properties of lightweight foam concrete were investigated. The results will be very useful to the preparation and application of Portland cement-based lightweight foam concrete, and thus to the energy efficiency in buildings.

2. Literature review

The last few years have seen a good progress in the use of Lightweight Concrete LWC for structural purposes where more and more attention is given to this type of concrete. The decrease in density of LWC is obtained by the presence of voids, either in the aggregate or in the mortar or in the interstices between the coarse aggregate particles. It is clear that the presence of these voids reduces the strength of LWC compared with ordinary, normal weight concrete. But in many applications, high strength is not essential, and in others, there are compensations. LWC can also be classified according to the purpose for which it is to be used:

- ASTM C330-04: distinguished it as structural LWC based on a minimum compressive strength for cylinder at 28 days that should not be less than 17 MPa, the density (unit weight) of such concrete (determined in the dry state) should not exceed 1840 kg/m^3, and it is usually between (1400 and 1800) kg/m^3 [13].
- ASTM C 331-05: distinguished it as masonry unit that has a density between (500 and 800) kg/m^3 and strength between (7 and 14) MPa [14].
- ASTM C332-99: distinguished it as insulating concrete whose coefficient of thermal conductivity should be between (0.15-0.43) J / m^2 sec℃ / m, whilst the density is generally lower than 800 kg/m^3, and strength is between (0.7 and 7) MPa [13].

2.1 Physical properties

1.1.1 Density- Density can be either in fresh or hardened state. Fresh density is required for mix design and casting control purposes. A theoretical equation for finding fresh density may not be applicable as there can be scatter in the results caused by a number of factors including continued expansion of the foam after its discharge, loss of foam during mixing [15]. Many physical properties of foam concrete related to/depend upon its density in hardened state. While specifying the density, the moisture condition needs to be indicated as the comparison of properties of foam concrete from different sources can have little meaning without a close definition of the degree of dryness [16]. The results proposed in literature of dry and fresh density are summarized in Table 1.

Table 1 A review of density ranges of foam concrete.

Previous studies	**Density range, kg/m^3**
Kearsley and Wainwright[12]	1000–1500
Jones and McCarthy [17]	1400–1800
Jones and McCarthy [18]	1000–1400
Durack and Weiqing[19]	982–1185
Regan and Arasteh [15]	800–1200
Hunaiti [20]	1667
McCormick [21]	800–1800
Nambiar and Ramamurthy [22]	650–1350 (Dry density)
Tam et al [23]	1300–1900
Kearsley and Booyens [24]	1000–1500
Tikalsky et al. [25]	490–660

2.1.2 Air-void systems- The air-void distribution is one of the most important micro properties influencing strength of foam concrete. Foam concrete with narrower air-void distributions shows higher strength. At higher foam volume, merging of bubbles results in wide distribution of void sizes leading to lower strength [26, 27]. The use of fly ash as filler helps in achieving more uniform distribution of air-voids by providing uniform coating on each bubble and thereby prevents merging of bubbles. The ratio of connected pores to total pores in foam concrete is lower resulting in lower air permeability compared to gas concrete, finer filler material helps in uniform distribution of air-voids [28].

2.1.3 Drying shrinkage - The shrinkage of foam concrete reduces with density [29-32], which is attributed to the lower paste content affecting the shrinkage in low-density mixes. Foam concrete possesses high drying shrinkage due to the absence of aggregates, i.e., up to 10 times greater than those observed on normal weight concrete [2,18].

2.2 Mechanical properties

2.2.1 Compressive strength- Table 2 presents an overview of compressive strength of foam concrete reported in literature. The compressive strength decreases with an increase in void diameter [5]. Other parameters affecting the strength of foam concrete are cement/sand and w/c, type and particle size distribution of sand, type of foaming agent used, and curing [33, 34]. For a given density, the mix with fine sand resulted in higher strength than the mix with coarse sand and the variation is higher at higher density. Similar behavior was observed when sand was replaced with fine fly ash [22]. The enhancement of strength with fly ash as filler is not pronounced at lower density range (higher% of foam volume) especially at lower ages. Mixes containing expanded shale aggregate produced higher strength value than those containing sand as aggregate

For the same wet density. The use of lime, demolition fines, recycled glass as fine aggregate has little or no effect on compressive strength, while some reduction in strength has been noted when crumb rubber, used foundry sand, china clay sand and quarry fines were employed [35, 36]. In terms of curing method, autoclaving increases the compressive strength. In general, compressive strength of water–cured foamed concrete is reported to be higher than that cured in air [34].

2.2.2 The modulus of elasticity- The modulus of elasticity values *(E)* of normal weight concrete exhibited values up to four times larger than that of equivalent strength foam concrete. Foam concrete with fly ash as fine aggregate is reported to exhibit lower E-value than that of foam concrete with sand. This variation is attributed to the high amount of fine aggregate in sand mix compared to fly ash mix, which contains entirely paste with no aggregate [17]. Use of polypropylene fibers and Plastic fiber has been observed to increase the E-value between two and four times [5, 17].

Table 2 A review of compressive strength ranges of foam concrete.

Previous studies	**Compressive strength at 28 days, MPa**
Kearsley and Wainwright[12]	2–18
Jones and McCarthy [17]	3.9–7.3
Jones and McCarthy [18]	1–2
Durack and Weiqing[19]	1–6
Regan and Arasteh [15]	4–16
Hunaiti [20]	12.11
McCormick [21]	1.8–17.6
Nambiar and Ramamurthy [22]	2-19
Tam et al. [23]	1.81–16.72
Kearsley and Booyens [24]	2.8–19.9
Tikalsky et al. [25]	0.71–2.07

2.3 Functional Properties

2.3.1 Thermal insulation- The thermal conductivity values are 5–30% of those measured on normal weight concrete and range from between 0.1 and 0.7 W/mK for dry densities values of 600–1600 kg/m^3, reducing with decreasing densities [37]. A decrease of concrete dry density by 100 kg/m^3 results in a reduction of thermal conductivity by 0.04 W/mK of lightweight aggregate foam concrete [38].

2.3.2 Fire resistance- Fire resistance tests on different densities of foam concrete indicated that the fire endurance enhanced with reductions in density. While reviewing earlier studies on fire resistance, Jones and McCarthy[17], summarized that, for lower densities of foam concrete, the proportional strength loss was less when compared to normal concrete. As compared to vermiculite concrete, lower densities of foam concrete is reported to have exhibited better fire resistance, while with higher densities, this trend is stated to be reversed [33].

2.3.3 Acoustical properties- Valore[39] states that cellular concrete does not possess significant sound insulation characteristics. Foamed concrete is stated to be less effective than dense concrete in resisting the transmission of air-borne sound [40], because the Transmission Loss (TL) of air-borne sound is dependent on mass law, which is a product of frequency and surface density of the component.

3 . Experimental Work

3.1 Materials

In this experimental study, sulphate resisting Portland cement with specific gravity of 3.15. Its chemical composition and physical properties are given in Tables 3 and 4 respectively. The test results show that the cement conforms to the provisions of Iraqi specification No. 5/1984. A saturated surface dry Porcelanite as a fine lightweight aggregate LWA was used for all mixtures except the control mix (Clt). Five pozzolanic material was partially replaced from cement weight by 15%, Silica fume SF, glass powder GP, fly ash FA, leaf steam ash LA, and slag. Physical and chemical properties of the Pozzolana materials are given in Tables 5 to 14.Superplasticizer (SP) known commercially as (BETONAC®-1030) designed to produce self-compacting concrete was used, it was used to achieve the target workability by flow test 200 ± 2 cm according to ASTM C230.Foaming agent type EUCO from Swiss Chemistry Factory was used to produce lightweight concrete by entraining a controlled amount of air bubbles to concrete mix.it was brought from Ideal Building Corner (IBC) in Iraq.Foaming agent was used with portable water in a ratio of 3:1 by weight achieving 42 kg/m^3 density by using high speed mixer. Reference cement mortar is consisting of cement: natural sand of (2:1) by weight, the complete details of the concrete mixes are presented in Table 15.

Table 3 Chemical and main compounds of cement used

Compound composition	**Abbreviation**	**Percent by weight**
Lime	CaO	62. 8
Silica	SiO_2	19.63
Alumina	Al_2O_3	4.29
Iron oxide	Fe_2O_3	5.41
Magnesia	MgO	2.38
Sulfate	SO_3	2.31
Loss on ignition	L.O.I	1.85
Insoluble residue	I.R	0.54
Lime saturation factor	L.S.F	0.96
Free lime		0.9
Total		98.67
Main compounds % by weight		
Name of compounds	**Abbreviation**	**Percent by weight**
Tri calcium silicate	C_3S	59.55
Di calcium silicate	C_2S	11.59
Tri calcium laminate	C_3A	2.22
Tetra calcium alumina ferrite	C_4AF	16.44

Table 4 Physical properties of cement used

Physical properties	**Limits of cement**	**Limits of IQS No. 5/1984**
Fineness, cm^2/g	3998	≥ 2500
Initial setting time, (min)	140	≥45
Final setting time, (h:min)	4:25	≤ 10:00
Compressive strength, MPa		
3 days	16	≥ 15
7 days	27	≥ 23

Table 5 Chemical and physical properties of Silica Fume used.

Compound composition	Percent by weight	Limit of ASTM C1240
L.O.I.	2.14	≤6
SiO_2	93.47	≥85
Al_2O_3	2.15	
Fe_2O_3	0.65	
SO_3	Nil	
Total	99.79	
Physical properties	Results	Requirement of ASTM C1240
Retaining on sieve 45µm, %	6	≤10
strength activity index	125	≥105

Table 6 Chemical composion of Glass Powder used

Compound	Percent by weight %
SiO_2	68
Al_2O_3	7
Fe_2O_3	1
CaO	11
MgO	1
K_2O	1
Na_2O	12
SO_3	0.4

Table 7 Pozzolanic Activity results of Leaf steam Ash

Concrete mix	Compressive strength, MPa	
	7days	28 day
Reference	55.5	79.67
Leaf stem ash	53.67	72
Strength activity index% (S.A.I)		
Leaf stem ash	96.7	90.37
ASTM C618-03 limitation	Min 75%	

Table 8 Chemical properties of Leaf steam Ash used

Compound	Weight, %
SiO_2	52.36
Al_2O_3	12.34
Fe_2O_3	2.64
CaO	10.19
MgO	5.77
SO_3	0.39
L.O.I	16.3

Table 9 Physical properties of Fly Ash

Physical properties	results
Fineness, cm^2/g	3800
Strength activity index% (S.A.I)	
7 days	87
28 days	93.5
Retaining on sieve 45µm, %	23.78
Specific gravity	2.59

Table 10 Chemical composition of Fly Ash.

Oxide composition	Abbreviation	Oxide content, %	ASTM C618 limitation
Silica	SiO_2	61.38	Min. 70%
Alumina	Al_2O_3	9.72	
Iron Oxide	Fe_2O_3	0.63	
Lime	CaO	10.19	-
Magnesia	MgO	1.98	-
Sulfate	SO_3	3.72	≤ 5%
Loss on ignition	L.O.I	9.10	Max. 10

Table 11 Grading of sand used.

Sieve opining, mm	Cumulative passing, %	I. Q. S Limit NO.45\1984 Zone No. 2
4.75	100	90-100
2.36	100	85-100
1.18	83	75-100
0.600	60	60-79
0.300	24	12-40
0.150	4	0-10

Table 12 Physical and chemical properties of sand

Property	Specification	Result	Boundary of Specification
Bulk Specific of Gravity*	ASTM C128 -15	2 .54	-
Water absorption, %*	ASTM C128 -15	1 .42	-
Dry loose density, Kg/m^3*	ASTM C 29 - 15	1 585	-
Sulfate content, SO_3**	IQS No. 45\1984 and adaptation No. 2 for 2010	0.14	≤ 0.5 %
Materials finer than 75μm, %*		2.7	5.0 (max.)

Table 13 Physical and chemical properties of Porcelanite rocks.

Property	**Test According to**	**Result**
Specific of Gravity	ASTM C127-15	1.65
Absorption, %	ASTM C127-15	29.5
Dry-loose density, Kg/m^3	ASTM C29-15	625
Dry-rodded density, Kg/m^3	ASTM C29-15	734
Aggregate crush	:1990	16
Sulfate content as (SO_3) %	Bs3797:part2:1981	0.39

Table 14 Grading of Porcelanite

Sieve opining, mm	**Cumulative passing, %**	**I. Q. S Limit NO.45\1984 zone 1**
4.75	99.3	90-100
2.36	70	60-95
1.18	40	30-70
0.600	19	15-34
0.300	9	5-20
0.150	2.5	0-10

Table 15 Mix proportions of foam concretes prepared in the present study, kg/m^3.

Mixture ID	Cement	Pozzolanic materials					Fine aggregate		SP	Water	Foam details	
		SF	GP	FA	LA	Slag	Sand	Porcelanite*			Foaming agent	Water
Ctl.	1000	-	-	-	-	-	500	-	15	228	21.4	7.1
RP	1000	-	-	-	-	-	-	260	20	261.7	21.4	7.1
MS	850	150	-	-	-	-	-	=	20	305	21.4	7.1
MG	850	-	150	-	-	-	-	=	20	276	21.4	7.1
MF	850	-	-	150	-	-	-	=	20	301.7	21.4	7.1
ML	850	-	-	-	150	-	-	=	20	272	21.4	7.1
M-slag	850	-	-	-	-	150	-	=	20	314	21.4	7.1

***Saturated surface dry Porcelinite**

3.2 Methodology

As the experimental program was aimed at studying the effect of pozzolanic materials on the properties like density, strength and thermal conductivity of foam concrete, the following mixes were investigated by keeping the percentage of foaming agent to water constant at 3:1 by weight. Foamed concrete was produced in a laboratory using a paddle mixer by adding the preformed foam to a base mix. The foam was generated by mix foaming agent in mixer at high speed. The foam generated added immediately to the base mix and mixed for a minimum duration until there was no physical sign of the foam on the surface and the foam was uniformly distributed throughout the mix. The actual mix density was measured by filling a pre weighted standard container of known volume with the produced foam concrete and weighing it [1], 42 kg/m^3 of the mix foam was added. After determination of unit weight of the foam, calculated weights of the foam were added into constant volume of ordinary/blended cement paste in a container in order to theoretically ensure above mentioned foam contents for the fresh state of the mixtures. The foamed pastes were mixed for about 3 min to obtain a visual homogeneity. There is no particular target density in the design of the mixtures. Thus, the density values obtained by the designed mix proportions were only assessed in this study. Six of 50 mm cube specimens, as per the recommendations in ASTM standards [41], were cast for the study of each parameter. See appendix A

4. Results and Discussion

4.1 Unit weight

Figure 1 shows the results of density for all mixtures compared with control mix at 28 days. The density of foam concrete decreases when using Porcelanite as fine aggregate (RP) by about 22% as compared with mixes using normal sand (Ctl) ;the reason because, first, the increase in these percentages leads to an increase in the voids volume; second, the density of Porcelanite is little compared to natural fine aggregate; and third, the added Porcelanite leads to excessive water content, which leaves voids in the foamed concrete structure instead of water when it is dry [5, 42, 43] .

The densities of Porcelanite-foam concrete indicate that for the same percentage of replacement using different pozzolanic materials values were found to be in the range of 1100 to 1290 kg/m^3. The obtained results show that the density of MS,MG,MF and M-slag mixes were decreases by (14,8.6,8.2 and 6) %, respectively while a slight increase was showed for ML as compared to RP mix. These results were compatible with the other previous studies [2, 22] showed that the type of filler material such as fly ash or fine sand may affect the density of the mixture. Owing to its finer particles, fly ash resulted in a more uniform distribution of air voids by providing a well and uniform coating on each air bubble and preventing merging of the bubbles [26]. Kearsley and Wainwright [44] studied the foam concrete mixtures having densities in the range of 773–1751 kg/m^3. It was concluded that the fineness of filler material affected the density of the foam concrete. However, the effect of SF that is extremely finer than FA on the density is contradictory due to complexity of the air-void system arisen from either foam and SF content of the mix [45].

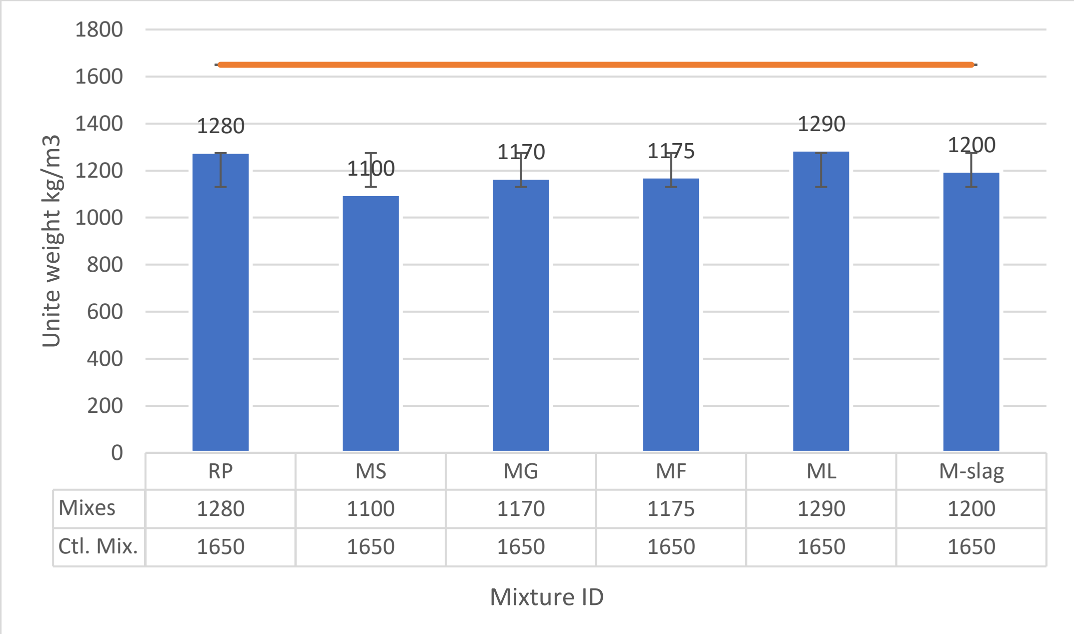

Figure 1 Effect of Pozzolanic materials on unit weight of foamed concrete.

4.2 Compressive strength

The compressive strengths of foamed concretes with different pozzolanic materials are presented in Fig. 2 and Table 16. Compressive strength of foam concrete decreases when using Porcelanite as fine aggregate at early ages of curing as compared with mixes using normal sand but, at 28 days the deference began to minimized between the two mixes, that because continuing hydration of cement as the water in Porcelanite released .In another word, its act as internal curing for cement which enhanced compressive strength

The strength of foamed concrete for 28 days appeared to decrease with pozzolanic replacement, except ML mix which showed a slight increase (about 5%). Concretes containing blended cements should be cured thoroughly and for a longer period than for PC concrete (46).It is thought that the characteristic feature of its pozzolanic reaction is firstly slow, with the result that heat of hydration and strength development would be accordingly slow.

Fig. 3 shows the development of compressive strength with age for foamed concrete. The compressive strength of foamed concrete in almost all mixes displayed a continuous increase with age. The rate of strength development was greater initially and decreased as age increased. However, a comparison of strengths at 7 days revealed that concretes with Pozzolanic materials developed almost 62.5- 85% of the 28-day strength, while those containing RP developed almost

86% of the corresponding 28-day strength. This is may be due to that foam can work more compatible with binder materials having low specific gravity and small particle size in terms of segregation, pore structure and uniformity of the mixtures. Thus, the characteristics of the binder materials as given in Table 16 cause significant variations in compressive strength results of the mixtures [45]. Moreover, pozzolanic reaction in mineral admixture-bearing systems results in the formation of low Ca/Si ratio CSH which has higher strength than that of conventional CSH [47]. Fig. 4 presents the relationship between density and compressive strength, in foam concrete it is desirable to minimize the density meanwhile, to maximize the strength.

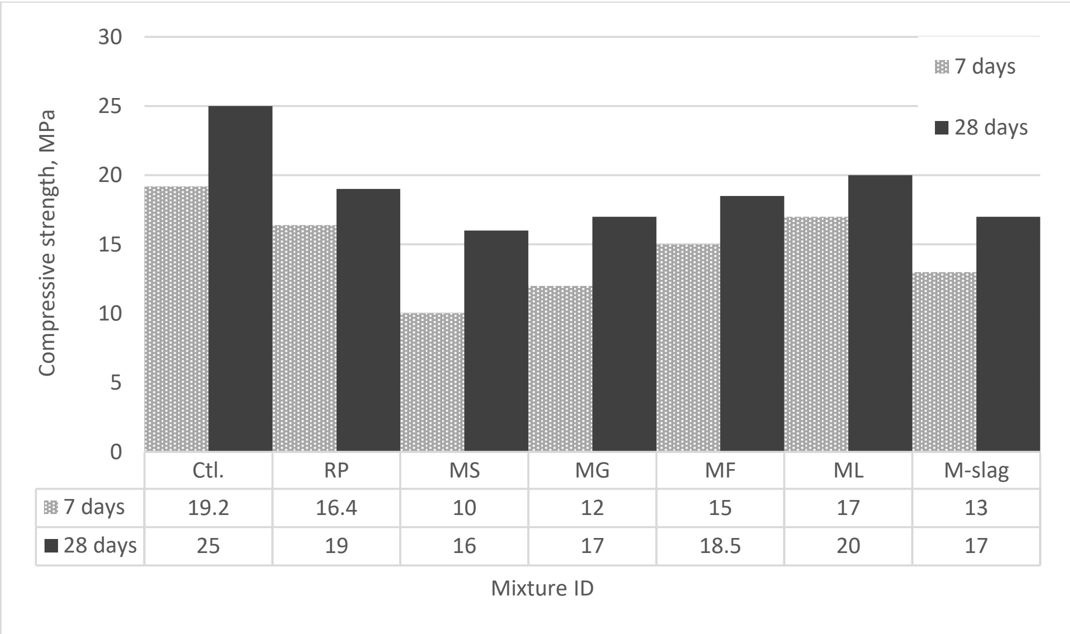

Figure 2 Effect of Pozzolanic materials on compressive strength of foamed concrete.

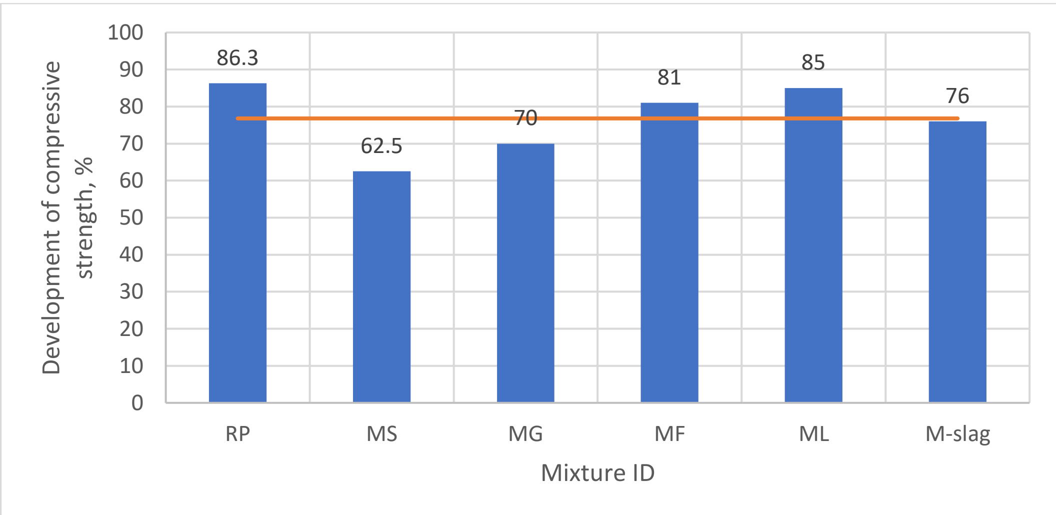

Figure 3 Effect of Pozzolanic materials on development strength of foamed concrete.

Table16 Compressive strength of foamed concrete containing defferent Pozzolanic materials.

Mixture ID	Compressive Strength, MPa 7 days	Change ratio as compared to RP-mix*	Compressive Strength, MPa 28 days	Change ratio as compared to RP-mix*
RP	**16.4**		**19**	
MS	**10**	**- 39**	**16**	**- 15.7**
MG	**12**	**- 27**	**17**	**- 10.5**
MF	**15**	**- 8.5**	**18.5**	**- 2.6**
ML	**17**	**+ 3.6**	**20**	**+ 5.3**
M-slag	**13**	**- 20.7**	**17**	**- 10.5**

(-) referred to a reduction (+) referred to an increase

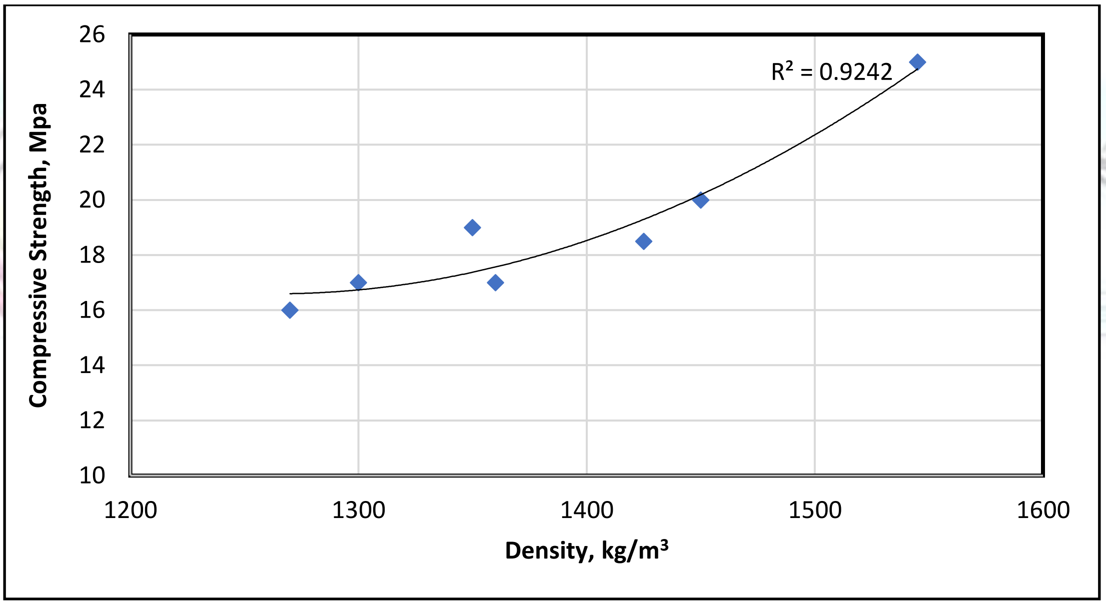

Figure 4 Relationships between density-compressive strength

4.3 Thermal Conductivity Test

This test was carried out on slab specimens of size (200×100×50) mm at age of 60 days, using (Kyoto Electronics QTM 500) as seen in Fig5. to measure thermal conductivity (K) and thermal conductivity factor (U).

Figure 5 Thermal conductivity device

Table (17): Thermal conductivity of foam concrete mixes

Mixture ID	Thermal conductivity (W/m.K)	The decreasing ratio in thermal conductivity % as compared to control mix	The decreasing ratio in thermal conductivity % as compared to RP mix
Ctl.	0.3207	-	-
RP	0.2740	14.56	-
MS	0.1776	44.6	35
MG	0.1945	39.35	29
MF	0.2156	32.77	21.3
ML	0.2521	21.4	8
M-slag	0.2289	28.6	16.45

The thermal conductivity results for specimens of foam concrete mixes cured in water and tested at ages 60 day are presented in Table 17.It can be seen from this Table that using Porcelanite as fine aggregate compared with mixes using normal sand have a positive effect in reducing the amount of transmitted heat through the thickness of the specimens of foam concrete. The reduction in thermal conductivity reached about 14.5 % and this reduction is due to the light weight of Porcelanite compared to natural sand.

More reduction was observed due to the use of pozzolanic materials. The reduction varies from (8 to 35) % as compared to Porcelanite-foam concrete without pozzolanic materials (RP).

Foamed concrete is one of the lightweight concrete materials that consist of closed-cell structure which has thermal conductivity of up to 0.66 W/mK at 1600 kg/m3 density. Normal concrete has thermal conductivity of 1.6 W/mK at 2200 kg/m^3; 59% higher than foamed concrete resistance. It was observed that the thermal conductivity reacts proportionally with a density and the thermal insulation characteristic decreases when the density volume increases. In another study by Jones and McCarthy .It was shown that the thermal conductivity ranges between 0.23 and 0.42 W/ m K at dry densities of 1000 and 1200 kg/m^3 [48].

5. Conclusions

Based on the findings of the experimental work presented previously, the following conclusions were drawn:

1. The reduction in density upon replacing natural sand with LWA of foamed concrete was around 22%. Moreover, the use of 15% replacement cement with SF or slag by weight was found to be beneficial in decreasing unit weight.

2. Structural foamed concrete in the density range of 1100 to 1290 kg/m^3 with corresponding strengths of approximately 16 to 25 MPa can be produced by using deference Pozzolanic materials.

3. A compressive strength of approximately 20 MPa was achieved at 15% replacement of cement with Leaf steam ash.

4. The thermal conductivity of foam concrete mixes are arranged in the following order:

Ctl. (0.3207 W/mK) > RP (0.2740 W/mK) >ML (0.2521 W/mK) > M-slag (0.2289 W/mK) > MF (0.2156 W/mK) > MG (0.1945 W/mK) > MS (0.1776 W/mK).

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Appendix A

Lab.tools used to prepare foam conrete mixes

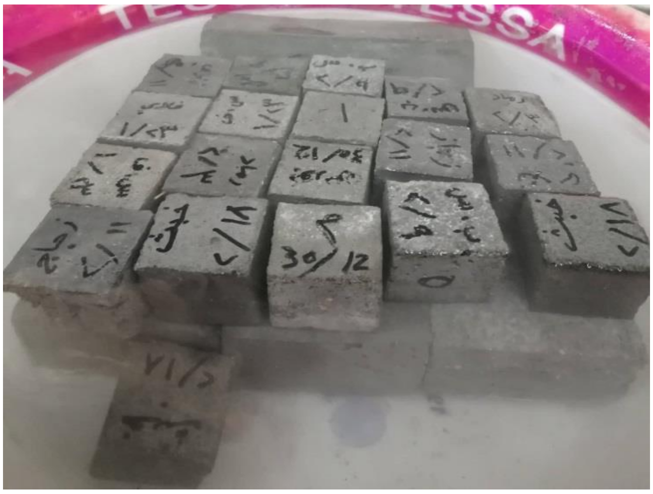
the Drill used to performed the foam

Preparing Foam concrete mixes

Followability of mortar used to prepare foam concrete

According to ASTM C 230

The Mold used to cast samples for thermal conductivity test



Curing of the samples