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Empirical Formulas For Estimation Of Some Physical Properties Of Gas Concrete Produced By Adding Aluminum Powder

Prof.Dr. Mohammed Mosleh Salman
Civil Engineering Dep.
College of Engineering
Al-Mustansiriya University
Baghdad- Iraq

Lec. Sawsan Akram Hassan
Civil Engineering Dep.
College of Engineering
Al-Mustansiriya University
Baghdad- Iraq

Asst. Lec. Manolia Abed Al-wahab Ali
Material Engineering Dept.
College of Engineering
Al-Mustansiriya University
Baghdad, Iraq.

Abstract

The aim of this study is to produce one types of lightweight concrete which is known as (gas concrete) , four additions of aluminum powder (0.1, 0.2, 0.3, 0.4) % by weight of cement were used to produce gas concrete. Two different ways for curing, air and steam curing, were carried out using (5) cm cubes specimens.

The test results showed that the density and compressive strength of gas concrete decreases with the increase of percentage of aluminum powder (AL).The density of gas concrete was between (1177.1-1524.38) kg/m^{3}and (1246.24-1593.94) kg/m^3 for air and steam curing, respectively when the percentage of aluminum powder was between (0.1—0.4) % by weight of concrete. The addition of (AL) also increases the volume of gas concrete. It was between (13.3- 50.8) % and (18.7 – 61.3) % for air and steam curing respectively when (Al) was between (0.1-0.4) %

The test results showed that the best percentage of (Al) was 0.2% by weight of cement which gives density (1389.98) kg/m^3 and compressive strength (0.26) MPa for air curing and (1431.95) kg/m^{3}and (0.55)MPa for steam curing.

Statistical analysis is done to find mathematical relationships to predict some variables of gas concrete {density, compressive strength, the percentage of expansion and percentage of (Al)} for both air and steam curing concrete .

الخلاصة

تهدف هذه الدراسة إلى إنتاج احد أنواع الخرسانة الخفيفة الوزن والتي تعرف بالخرسانة الغازية (المهواة) . تم استخدام أربع نسب إضافة من مسحوق الألمنيوم (0.1 ،0.2 ،0.3 ،0.4) كنسبة مئوية من وزن السمنت لإنتاج الخرسانة الغازية. تم استخدام طريقتين لمعالجة النماذج الخرسانية وهي طريقة المعالجة العادية بالهواء والمعالجة بالبخار مع استخدام نماذج مكعبة بأبعاد (5) سم .

أظهرت نتائج الفحوصات إن الكثافة ومقاومة الانضغاط للخرسانة الغازية تقل مع زيادة نسبة مسحوق الألمنيوم (Al). حيث كانت كثافة الخرسانة الغازية بين(1177.1-1524.38) كغم/ م^3 وبين(1246.24-1593.94)كغم /م^3 لطريقتي المعالجة العادية والمعالجة بالبخار على التوالي . عندما كانت نسبة مسحوق الألمنيوم بين(0.1 -0.4)% من وزن السمنت . إن إضافة مسحوق الألمنيوم أيضا تزيد من حجم الخرسانة الغازية حيث كانت الزيادة بالحجم بين (50.8 – 13.3)% و(61.3 – 18.7)%للخرسانة المهواة المعالجة العادية بالهواء والمعالجة بالبخار على التوالي عندما كانت نسبة مسحوق الألمنيوم بين (0.1-0.4)% من وزن السمنت.

أظهرت نتائج الفحوصات إن أفضل نسبة لمسحوق الألمنيوم كان0.2 % من وزن السمنت والذي أعطانا كثافة(1389.98) كغم/م ومقاومة انضغاط(0.26)ميكاباسكال بالنسبة للمعالجة العادية بالهواء و(1431.95)كغم/م و(0.55)ميكاباسكال للمعالجة بالبخار.

تم إجراء تحليل إحصائي للنتائج لإيجاد علاقات رياضية تربط عدة متغيرات للخرسانة الغازية (الكثافة ، مقاومة الانضغاط ، نسبة التمدد ونسبة مسحوق الألمنيوم)ولطريقتي المعالجة العادية بالهواء وبالبخار.

Notation

Al=percentage of aluminum with respect to the weight of cement.

D=density in kg/m^3

Fcu=concrete compressive strength at 28 days in MPa

Vi=initial volume in cm^3

Vf=final volume cm^3

V%= percentage of increase in volume $= \frac{vf-vi}{vi}$

w=weight in g

1 – Introduction:-

Concrete is one of the most commonly used structural materials in Iraq.

Concrete made with natural aggregate has a density with the range of 2200-2600 kg/m^3 [1]. Consequently, the self-weigh of elements is high and can represent a large proportion of the load on a structure. Using concrete with a lower density can, therefore, result in significant benefit in terms of load-bearing element of smaller cross-section and a corresponding reduction in the size of foundations as well as the use of concrete with a lower density permits construction on ground with a low load-bearing capacity [2,3]. The concrete which has a lower density than that made using gravel or crushed aggregate is named as lightweight concrete[4,5,6] .

The density of concrete can be reduced by replacing some of the solid materials in the mix by air voids. There are three possible methods which can be used to produce lightweight concrete [1, 7]:-

- By using a lightweight aggregate. This type of concrete is known as lightweight aggregate concrete (LWAC).
- By omitting the fine aggregate from the mix. The resulting concrete being known as no-fine concrete.
- By introducing large voids within the concrete or mortar mass, and producing what is generally known as aerated, cellular, foamed, or gas concrete.

2 – Aerated (gas) concrete:-

As mentioned earlier , one means of obtaining lightweight concrete (LWC) is by introducing gas bubbles into the plastic mix of cement and sand in order to produce material with a cellular structure , the skin of the cells must be able to withstand mixing and compaction[1] .

Gas concrete is obtained by a chemical reaction generating a gas in fresh mortar, so that when it sets it contains a large number of gas bubbles. Finely divided aluminum powder most commonly used, its proportion being of the order of 0.2% of the weight of cement. The reaction of the active powder with a hydroxide of calcium or alkali from the cement literates hydrogen, which forms ting bubbles in the wet mix. The bubbles expand the cement paste or mortar and concrete rises like cake better in an oven .The mix hardens with the voids left by the bubbles intact. The gas leaks out over time [1, 8, 9].

$$Al+2OH^{-}+2H2O \rightarrow A1\ (OH)^{-}_{4} + H2 \uparrow \quad \ldots\ldots\ldots\ldots\ (1)$$

In most cases the concrete has low-density, low – strength materials suitable for non structural insulating concrete. Typical properties of insulating cellular concretes produced commercially are: density: 300 to 1100 kg/m^3, compressive strength. 0.3 to 7.0 MPa: thermal conductivity, 0.1 to 0.3 W/m.k[8].

3 – Scope of a Study:-

This study is a part of a team work to investigate the use of fine aggregate, cement and aluminum powder to produce gas concrete. Therefore this method of production can be considered as relatively new method because the coarse aggregate particles are being omitted. The mean (LWC) properties are being studied in this research:-

1 – Density of the produced (LWC).

2 – The compressive strength of concrete.

3 – The percentage of aeration and expansion.

4 – The percentage of aluminum powder.

5 – More over, attempts were made to combine the four variables mentioned above in a mathematical model for the predication of compressive strength and density of gas concrete.

4 – Experimental Work:-

4.1 Materials

4-1-1 Cement: in this study, ordinary Portland cement was used. Table (1) and (2) show the physical and chemical properties of the representative sample which comply with the Iraqi Standard Specification I.Q.S. No.5, 1984 requirements. [10]

Table (1) Chemical Composition of Cement

Oxides		% by weight#	IQS 5:1984 Limits
Calcium oxide	CaO	60.92	
Silicon oxide	SiO2	22.01	
Aluminum oxide	Al2O3	5.49	
Ferric oxide	Fe2O3	3.68	
Magnesium oxide	MgO	2.32	5 max.
Sulphur trioxide	SO3	2.77	2.8 max.
Loss on Ignition	L.O.I	2.21	4.00 max.
Insoluble residue	I.R	0.60	1.5 max
Lime saturated factor	L.S.F	0.82	0.66- 1.02
C3A		8.10	

All tests were made in the National Center for Construction Laboratories and Research.

Table (2) Physical Properties of Cement

Physical properties	Test result#	IQS 5:1984 limits
Fineness: specific surface, Blaine cm^2/gm	3770	2300 min
Setting time, Vicat's method:- Initial (hrs: min.) Final (hrs :min)	 3:15 4:10	 45 minutes min. 10 hrs. max.
Compressive strength of cement mortar cubes (70.7mm) MPa 3 days 7 days 28 days	 25.3 35.6 51.6	 15 min. 23 min. additional

All tests were made in the National Center for Construction Laboratories and Research.

4-1-2 fine aggregate (sand):

Natural sand from Al-Ukhaidur region with fineness modulus, specific gravity and absorption 2.33, 2.7 and1.5 percent respectively is used in this work. Their grading is shown in Table (3) which confirms with I.Q.S. No.45, 1984 zone 2[(11)]

Table (3) Grading of fine aggregate and SO_3%

Sieve size(mm)	% passing by weight	IQS 45-84 limits zone-2-
10.0	100	100
5.0	97.6	90-100
2.36	91.75	75-100
1.18	81	55-95
0.6	37.5	35-59
0.3	18	8-30
0.15	2.2	0-10
SO_3	0.19%	<0.5%

4-1-3 Tap Water

Tap water (drinking water) was used for concrete mixing and specimens curing.

4-1-4 Aluminum powder:

It was used for the production of gas concrete the fineness of the materials was 5000cm^2/gm

4-2 Experimental Works

A concrete mix having the proportions of (1:1) by weight of ordinary Portland cement and sand with water – cement ratio of 0.6 was used throughout the tests and four proportions of aluminum power (0.1, 0.2, 0.3, and 0.4) % by weight of cement.

The dry cement and sand were mixed for one minute in a horizontal rotating concrete flow mixer .Mixing was continued for a further minute while water was added .The aluminum powder then added to the mixed concrete just before pouring on to the form.

The mixture was then poured into a half of (5x5x5)cm steel moulds. The specimens were left for about 24 hours in the laboratory. After that all the specimens were demolded .

Two ways were used for curing the test specimens, air curing and steam curing. In the first way, the specimens were left in the laboratory at air room temperature until the age of 28 days. in the second way the specimen were kept in steam curing at normal pressure for six hours then left in laboratory air until the age of 28 days .

This way accelerate the hydration of the concrete and spur a second chemical reaction that gives cellular concrete (CC) its strength rigidity and dimensional stability[12] In both ways the specimens were tested at age of 28 days.

5 – Analysis of Result and Discussion:-

5-1 Weight and density

Table (4) contains the values of weight and density for gas (aerated) concrete specimens which produced by using different percentage of aluminum powder and two way of curing. Results show that the weight and density of gas concrete decreases with the increase of the percentage of aluminum powder in both air and steam curing.

Table (4) Weight and density of gas concrete

Al(%) by wt. of cement	Air curing		Steam curing	
	Weight (g)	Density (kg/m^3)	Weight (g)	Density (kg/m^3)
0	210.40	1772.33	218.20	1805.70
0.1	107.90	1524.38	118.00	1593.94
0.2	108.67	1389.98	119.23	1431.95
0.3	109.18	1273.25	119.23	1259.23
0.4	111.30	1177.10	125.67	1246.24

Fig (1) show the reduction of density with the increase of percentage of aluminum powder .This reduction in density is due to the increase of ting bubbles in the wet mix which is formed by aluminum powder, hence reduction in density.

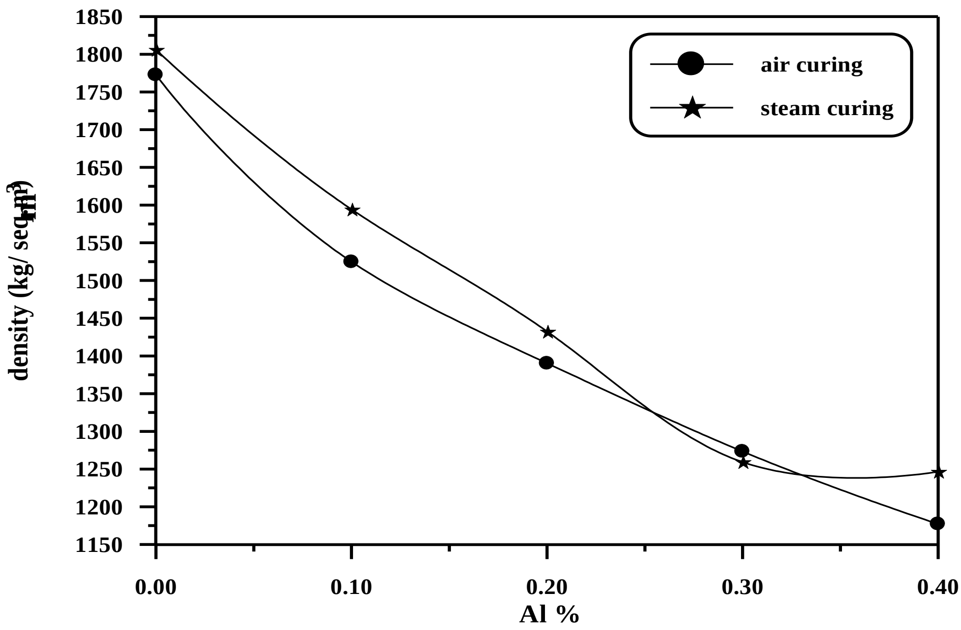


Fig. (1) Density of gas concrete with various content of aluminum powder

The percentage of reduction in density increases from (13.9% to 33.58 %) and from (11.7% to 31%) when percentage of aluminum powder increases from (0.1% to 0.4%) for air and steam curing respectively. This different in reduction is due to the fact that, in steam curing, the degree of hydration of aerated concrete was greater than that in air curing; therefore the microstructure of concrete was denser in steam curing compared with air curing.

5-2 Compressive Strength:-

The compressive strength test results are presented in Table (5) for air and steam curing of gas concrete .The results was within the limits of Mindess[8].Fig.(2) shows the relationship between compressive strength of gas concrete and the percentage of aluminum powder .It is clear that the compressive strength decreases with the increase of percentage of aluminum powder.

Table (5) Compressive strength of gas concrete with various content of aluminum powder.

Al(%) by wt. of cement	Air curing				Steam curing	
	Load (3) (kN)	Fcu(3) (MPa)	Load (28) (kN)	Fcu(28) (MPa)	Load (28) (kN)	Fcu(28) (MPa)
0	8.10	3.24	9.35	3.74	33.83	9.41
0.1	2.80	1.12	2.82	1.13	2.21	0.89
0.2	0.67	0.30	0.65	0.26	1.37	0.55
0.3	0.375	0.15	0.515	0.206	1.04	0.42
0.4	0	0	0	0	0.54	0.22

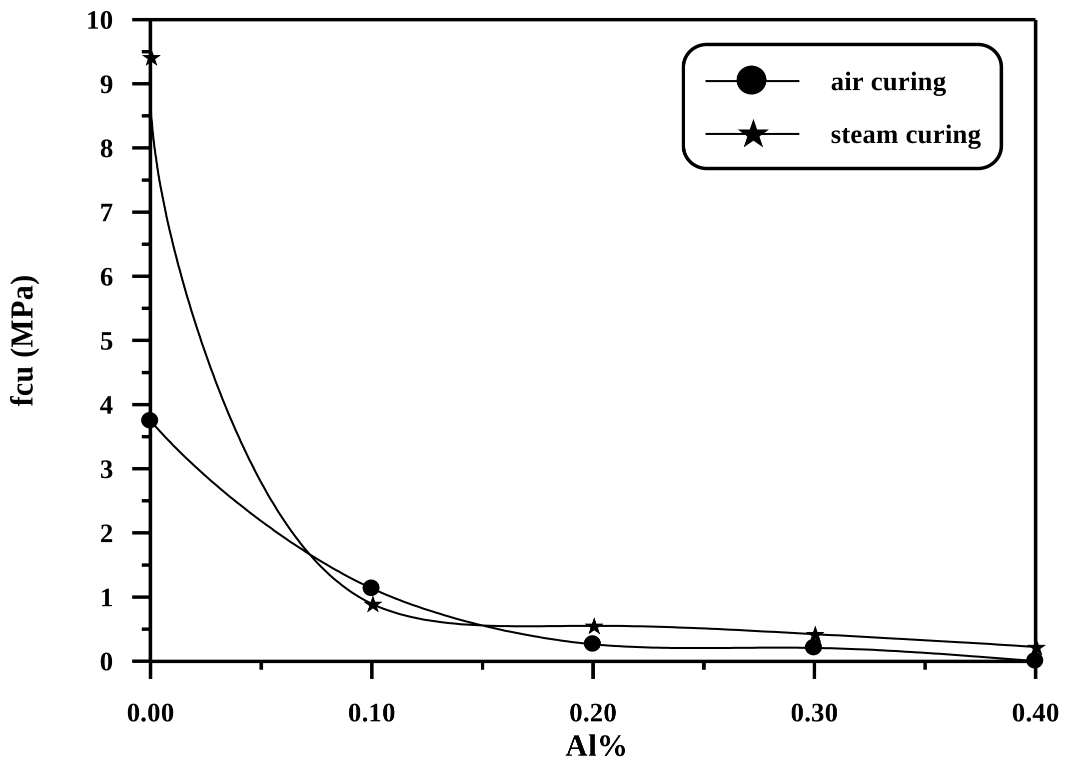


Fig.(2) The relationship between 28-day compressive strength and the percentage of addition (Al)% by weight of cement

From the observation of the mentioned table and figure it can be noticed that

- In general, the compressive strength of specimens exposed to steam curing was more than that exposed to air curing. This is due to the further hydration of cement specimens in steam curing compared with air curing, hence greater density and compressive strength.
- With the addition of aluminum powder, the aerated concrete specimens for both air and steam curing suffered significant decrease in their compressive strength. This reduction increases with increasing the percentage of (Al %) and the compressive strength reach to (0 and 0.22) MPa for the specimens of air and steam curing, respectively when the percentage of aluminum powder reach to 0.4% by weight of cement. It was concluded from these results that the best percentage of aluminum powder was less than 0.2% by weight of cement.

5-3 Volume Change:-

The result of initial volume (immediately after casting) and final volume (after one day from casting and demolding the specimens) of gas concrete for both air and steam curing are shown in Table (6).

Table (6) Initial and final volume of gas concrete with various content of aluminum powder

Al(%) by wt. of cement	Air curing				Steam curing			
	Vi (cm^3)	Vf (cm^3)	Inc.v (cm^3)	Inc.v/vi (%)	Vi (cm^3)	Vf (cm^3)	Inc.v (cm^3)	Inc.v/vi (%)
0	118.75	118.75	0	0	120.83	120.83	0	0
0.1	62.5	70.84	8.34	13.3	62.5	74.17	11.57	18.7
0.2	62.5	78.33	15.83	25.3	62.5	83.33	20.83	33.3
0.3	62.5	85.75	23.25	37.2	62.5	95	32.5	52.0
0.4	62.5	94.59	31.75	50.8	62.5	100.83	38.33	61.3

Fig (3) shows that the relationship between the percentage of volume increase and the percentage of aluminum powder .It is clear that this percentage increases with the increase in the percentage of aluminum powder and reach to 50.8%and 61.3% for air and steam curing respectively when the percentage of (Al) reach to 0.4 % by weight of cement . This is due to the increase in voids within the hardened cement paste which is produced by bubbles of hydrogen that is librated from the reaction between the aluminum powder and a hydroxide of calcium or alkalis from cement, the bubbles expand the cement paste and hence increase the volume of it

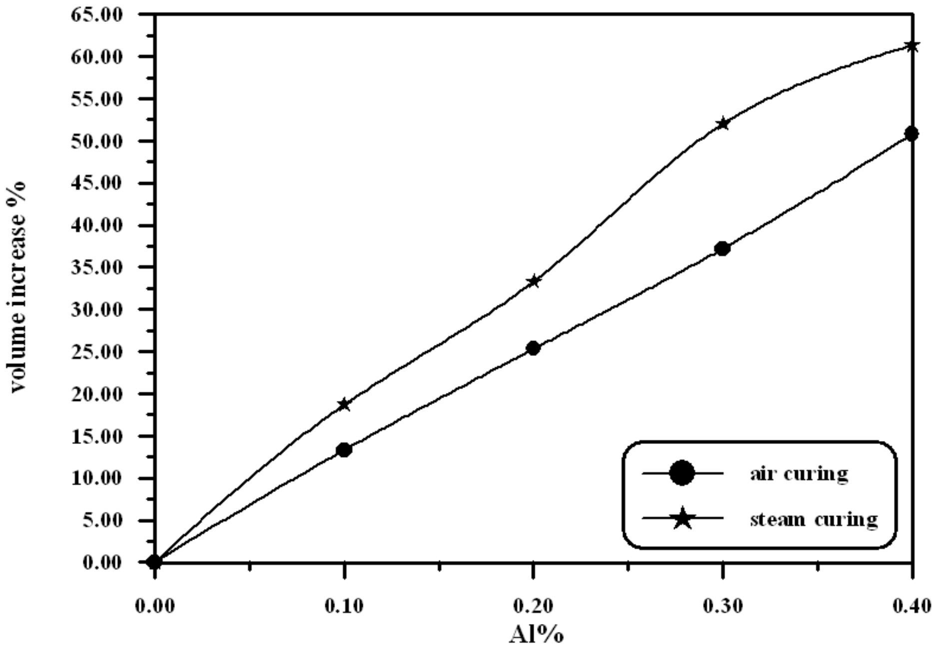


Fig (3) The relationship between the percentage of volume increase and the percentage of aluminum powder of gas concrete

Fig (4) shows the relationship between density and the percentage of expansion of gas concrete. It is obvious that the density is decreased with the increase of the percentage of expansion for both air and steam curing.

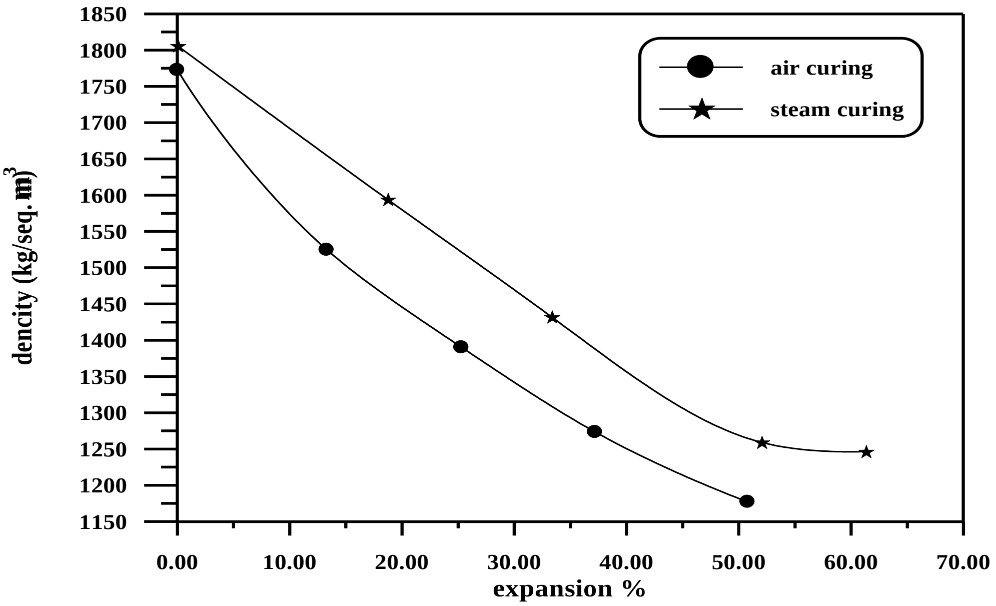


Fig (4) The relationship between density and the percentage of expansion of gas concrete.

The relationship between compressive strength and percentage of expansion are illustrated in Fig (5) it is clear that the compressive strength decrease with the increase in the percentage of expansion. This can be attributed is the increase in voids content within the cement paste which reduce the compressive strength of gas concrete.

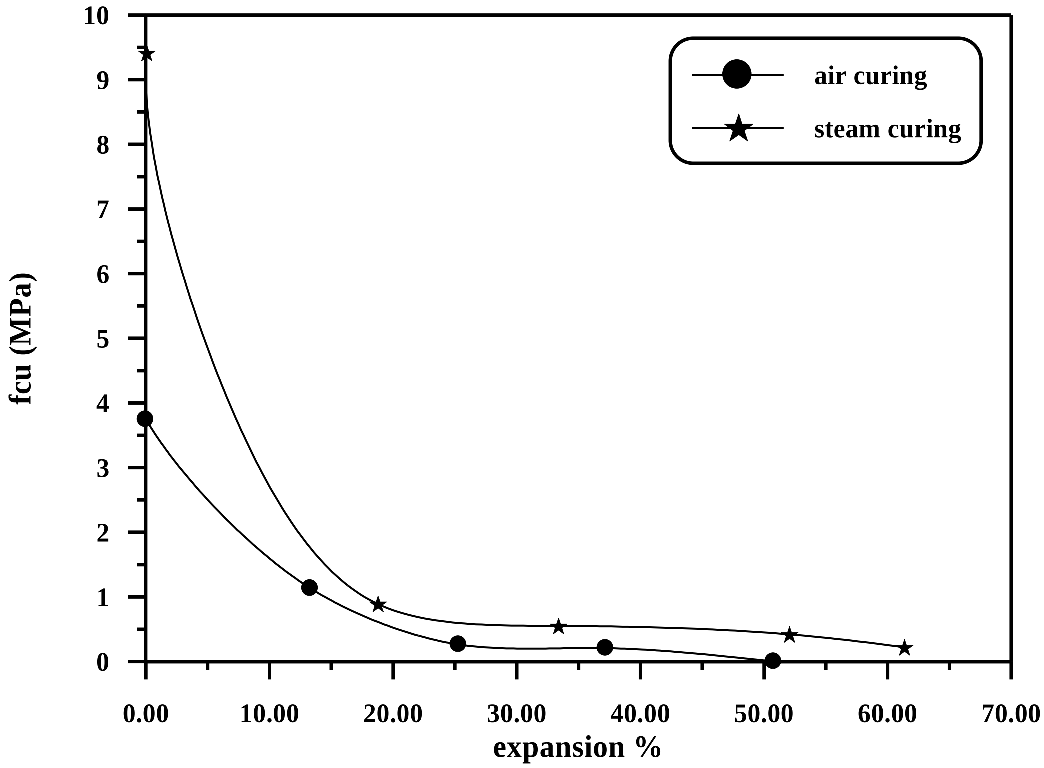


Fig.(5) Compressive strength of gas concrete with the percentage of expansion

6- Statistical Analysis

Statistical analysis are made using (SPSS) program version 10 to find many relationships between the results obtained in the present experimental work to find some of them as a function of the others. These Results are presented in Table (7) for air cured gas concrete and those for steam cured gas concrete in Table (8).

The coefficients of correlation(R) and coefficients of determination (R^2) are also presented in each table. Linear relationships are selected for simplicity.

The equations with low R and R^2 are also presented for comparison and to show the degree of weakness in correlation between the variables connected such as the relation between concrete compressive strength at 28 days and the percentage of aluminum powder in gas concrete using the two types of curing. The variables used in those tables mean:

Table (7) Statistical relationships for air cured gas concrete

Variables	Equations	R(%)	R^2(%)
V%=f(Al)	$V\% = -0.106 + 21.425\ Al$	95.3	90.8
D=f(Al)	$D = 1725.714 - 150820\ Al$	99.1	98.3
Fcu=f(Al)	$Fcu = 2.336 - 50.379\ Al$	76.5	58.5
D=f(V%)	$D = 1625.551 - 647.668\ V\%$	95.5	91.7
Fcu=f(V%)	$Fcu = 1.832 - 1.787\ V\%$	61	37.2
Fcu=f(D)	$Fcu = -3.622 + 0.003485D$	80.5	64.8
Fcu=f(D,Al)	$Fcu = -18.113 + 0.01185\ D + 128.336\ Al$	84.4	71.2
Fcu=f(D,Al, V%)	$Fcu = -28.048 + 0.01794\ D + 103.337\ Al + 5.456\ V\%$	99.9	99.9
D=f(Al, V%)	$D = 1715.692 - 13061.1\ Al - 94.323V\%$	99.2	98.5
Fcu=f(Al, V%)	$Fcu = 2.736 - 131.013\ Al + 3.764\ V\%$	85.9	73.7

Table (8) Statistical relationships of steam cured gas concrete

Variables	Equations	R (%)	R^2(%)
V%=f(Al)	$V\% = 0.0188 + 15.59\ Al$	99.5	98.6
D=f(Al)	$D = 1758.138 - 14536.3\ Al$	97.1	94.3
Fcu=f(Al)	$Fcu = 6.068 - 188.5Al$	74.8	56
D=f(V%)	$D = 1779.75 - 944.76\ V\%$	98.9	97.9
Fcu=f(V%)	$Fcu = 6.466 - 12.608\ V\%$	78.4	61.5
Fcu=f(D)	$Fcu = -18.277 + 0.01402D$	83.3	69.4
Fcu=f(D,Al)	$Fcu = -49.517 + 0.03162\ D + 271.079\ Al$	87.1	75.9
Fcu=f(D,Al, V%)	$Fcu = -91.267 + 0.05748\ D - 244.966Al + 54697V\%$	87.7	77
D=f(Al, V%)	$D = 1798.494 - 18929.157\ Al - 2146.598V\%$	99.7	99.5
Fcu=f(Al, V%)	$Fcu = 7.25 + 791.933\ Al - 62.889\ V\%$	84.6	71.6

7- Conclusions

From the experimental investigation described in this paper, it can be concluded that

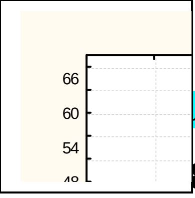
1- Gas concrete can be produced by using aluminum powder as percentage of cement weight. The density of gas concrete was between (1177.10-1593.94) kg/m^3.

2- The weight and density of gas concrete decrease with the increase in the percentage of aluminum powder .The percentage of reduction in density was between (13.9-33.58)% and between (11.7-31)%for air and steam curing respectively when the percentage of (Al)was between (0.1-0.4)% by weight of cement

3- Compressive strength of gas concrete also decreases with the increase in (Al) %. The reduction in compressive strength of specimens exposed to air curing way more than that exposed to steam curing.

4- The volume of gas concrete increases with the increase in percentage of (Al). The percentage of increase was between (13.3-50.8)%and from (18.7-61.3)% for air and steam curing respectively when the percentage of (Al)was between (0.1-0.4)% by weight of cement

5- The optimum percentage of (Al) was less than 0.2 % by weight of cement .This percentage gives us suitable properties for gas concrete which can be used for non structural insulating purposes.



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