Study of Production and Some Properties of Foamed Concrete

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الخـــــــلاصة

تضمن هذا البحث ثلاث مراحل رئيسية. تضمنت المرحلة الأولى، إنتاج الخرسانة الرغوية وقسمي إلى قسمين ؛ تم في القسم الأول توضيح تصميم الخلطة أي إيجاد نسب المواد الأولية الداخلة في تكوين الخرسانة الرغوية، أما في القسم الثاني فتم توضيح طريقة الخلط. أما المرحلة الثانية فتضمنت إعداد النماذج وكانت موزعة كما يلي: القولبة،إنهاء السطح، الإزالة من القوالب،والمعالجة.تم في المرحلة الثالثة إجراء عدة فحوصات على المنتج النهائي وتم مناقشة العوامل المؤثرة على خصائصه. وهذه الخصائص هي الكثافة، مقاومة الانضغاط،مقاومة الشد بالانفلاق،ومقاومة الانثناء. تبين من خلال النتائج بأن مقاومة الانضغاط بعمر (٢٨ يوم) للخرسانة الرغوية بكثافة (٨٠٠ كغم/م٣) هي بين (١,٣٣٤ إلى ٢,٣٢٣ ميكاباسكال) بينما للخرسانة الرغوية بكثافة (١٦٠٠ كغم/م٣) فكانت مقاومة الانضغاط بعمر (٢٨ يوم) بين (٧,٠١٥ إلى ٩,٥٩١ ميكاباسكال). للخرسانة الرغوية بكثافة (١٦٠٠ كغم/م٣) كانت مقاومة الانثناء بعمر (٢٨ يوم) بين (١,٠٨ إلي ٢,٢٠٥ ميكاباسكال).

SUMMARY

This research work includes three main experimental stages. The first stage includes the production of foamed concrete. It is divided into two parts; in the first, mixing design (determination of the proportions of the raw materials) according to the required density was presented and in the second part, the mixing procedure has been illustrated.

The second stage includes preparation of samples,(i.e. molding, finishing surface, removal from molds and curing). The third stage includes several tests to estimate properties of the final product and factors influencing them . These

properties include density , compressive strength , splitting tensile strength and flexural strength.

For foamed concrete with 800 kg/m^3 density, the 28-day compressive strength is from (1.334 MPa) to (2.323 MPa), while with 1600 kg/m^3 density, the strength is from (7.015 MPa) to (9.591 MPa).

For 1600 kg/m^3 density foamed concrete, the 28-day flexural strength range is from (1.08 MPa) to (2.205 MPa).

1-Foamed Concrete

Foamed concrete is a light building material with good strength as well as low thermal conductivity and easy workability. Because it contains air bubbles, the weight of foamed concrete is considerably lowered [(1)].

Foamed concrete is produced by adding to the mix a foaming agent (usually some form of hydrolyzed protein or resin soap) which introduces and stabilizes air bubbles during mixing of high speed. In some processes a stable pre-formed foam is added to the mortar during mixing in an ordinary mixer [(2)] .

Pre-formed foam method was developed in the early 1950$_s$, in which, simple and precise control of the volume of the air cells produced mechanically by means of special foaming agents, results in controlled density over a broad range from 320 to 1920 kg/m^3[(5)].

Each foam bubble is surrounded by a tough protein membrane that insures its stability while mixing and handling. The membrane will eventually break down, so mixing and placing should be completed [(3)].

2-Raw Materials Used

Figure (1) illustrates the raw materials used to produce foamed concrete, which may be explained in the following:-

2-1 Fine Aggregate

Natural sand from AL- Habaniya region in AL-Anbar Governorate was used with a maximum size (2.38mm) and it conforms to ASTM – Designation : C 144-87 [(4)] .

The specific gravity and absorption of the fine sand used were calculated according to ASTM – Designation : C 128- 88 [5] and they are equal to 2.68 and 3% respectively.

2-2 Cement

Cement type I (ordinary Portland cement) of Kubaisa factory for cement production was used in this study.

2-3 Water

Ordinary drinking water was used in all mixes.

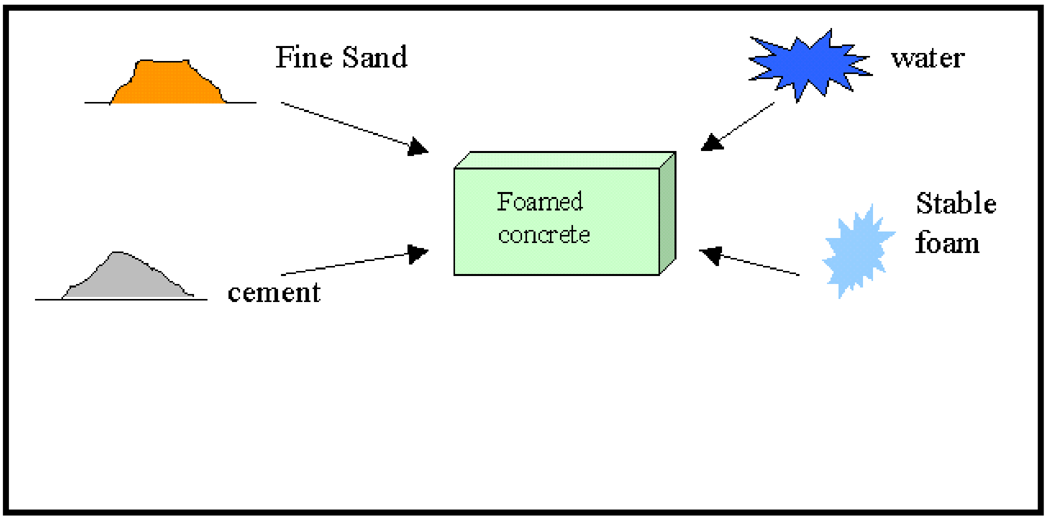

Fig. (1) Raw materials used to produce foamed concrete.

2-4 Stable Foam

It was produced by diluting a foaming agent with water and then mixing this mixture by a blending device (mortar mixer).

The quantity of foaming agent required is determined by trial and depends on the type of it, mixing time, mixer efficiency, and the density of concrete desired [6]. Euco- foaming agent is the trade name of the liquid material that has been used to produce pre- formed foam for this study .The specific gravity for it is (1.01). According to ASTM – Designation: C796- 87 [7] the unit weight of foam usually ranges from 32 to 64 kg/m^3 and the foaming solution in the foam will be considered as part of the total mixing water.

From the laboratory work, in order to make one liter foam, (2.5) ml of chemical foaming agent has been diluted in (40) g of water.

It can be seen that the expansion rate is about 24 times[$\frac{1}{(42.5/1000)}$]

Therefore, the unit weight of foam is equal to:

$$\frac{\frac{40}{1000}kg+\left(\frac{2.5}{1000}L\times10^{-3}m^3\times1000kg/m^3\times1.01\right)}{\frac{1L}{1000}m^3}=\frac{0.04kg+2.525\times10^{-3}kg}{0.001}=42.525kg/m^3$$

The air content in (1) liter of foam is :

$$1L-\frac{40}{1000}L-\frac{2.5}{1000}L=0.9575L$$

$$\frac{\text{Air volume}}{\text{Foam volume}}=\frac{0.9575}{1}=0.9575$$

That means, the air content in foam produced by mortar mixer using Euco-foaming agent is 95.75 %.

3- Mix Design (Mix proportions)

According to ACI Committee 523,(1986)(6), the mix proportioning begins with the selection of the unit weight of the concrete (wet density) , the cement content, and the water-cement ratio (w/c). Then, the mix is proportioned by the method of absolute volumes.

4- Constituents Proportion.

The properties of the final product depend on the proportions of the raw materials. In this study nine differently proportioned mixes were designed. The nine mixes are divided into three groups, each one includes three mixes.

For all groups, three values of cement content (300,350,and 400) kg/m^3 and three values of water- cement ratio (0.55,0.58, and 0.6) were used.

The density of the first group (mix No.1, No.2, and No.3) is 800kg/m^3, for the second group (mix No.4, No.5, and No.6) it is 1200 kg/m^3, while for the third group (mix No.7, No.8, and No.9) it is 1600Kg/m^3.

Table (1) presents the constituents proportion of the three groups of the selected mixes in this study.

Table (1) The constituents proportion of the selected mixes in this study.

		Group 1			Group 2			Group 3		
		Mix No.1	Mix No.2	Mix No.3	Mix No.4	Mix No.5	Mix No.6	Mix No.7	Mix No.8	Mix No.9
Wet density Kg / m^3		800	800	800	1200	1200	1200	1600	1600	1600
Cement content kg/m^3		300	350	400	300	350	400	300	350	400
W/C ratio		0.6	0.58	0.55	0.6	0.58	0.55	0.6	0.58	0.55
Water content kg/m^3	Mixing water	149.92	174.16	192.21	152.56	177.16	194.85	155.19	149.43	197.43
	Water in foam	25.280	24.800	24.440	19.040	18.56	18.200	12.800	12.320	12.000
	Water in sand	3.20	2.47	1.80	7.20	6.47	5.8	11.20	10.47	9.80
Sand content kg / m^3		323.2	249.47	181.80	727.20	653.47	585.80	1131.20	1057.47	989.80
S/C ratio		1.077	0.712	0.4545	2.424	1.867	1.4645	3.232	3.021	2.4745
Foaming agent	L / m^3	1.580	1.550	1.527	1.190	1.160	1.137	0.800	0.770	0.750
	kg/m^3	1.595	1.565	1.542	1.200	1.170	1.148	0.808	0.777	0.757
Foam L / m^3		632	620	611	476	464	455	320	308	299
F_a / c %		0.531	0.447	0.385	0.400	0.334	0.287	0.269	0.222	0.189

5- Mixing Procedure

After the amount of materials required to make the foamed concrete has been worked out, dry constituents (cement and fine sand) were mixed in ordinary mixer for a few minutes. Mixing water should be added in stages. Pre-formed foam was added to the wet slurry, after the mixing of the latter has been thorough. After it is made sure that the mixing is thorough, pre-formed foam should be added to the wet slurry. It should be noted that foam has been completely mixed with the mortar. Excessive mixing should be avoided because of the possibility of changes in unit weight and consistency (6).

6- Tests and Discussion of Results

6-1 Density

Density is found by weighing the specimen before test and dividing the weight by the measured volume of the specimen.

According to ASTM C796[7], the specimens that are to be load-tested; have not been oven dried.

6-2 Compressive Strength Test

The compressive strength test was carried out on cube specimens 100mm×100mm×100mm, at an age of 14,21,28,and 90 days.

The test was run in conformity with provisions of ASTM – Designation: C513-89 [8].

The compressive strength of foamed concrete is affected by such factors as density, age, cement content, w/c ratio, s/c ratio, foam volume, and curing.

It should be noted that three specimens were tested at each selected age and the results were averaged.

The compressive strength is calculated to the nearest 0.069 MPa[8].

6-2-1 Development of Compressive Strength with Time

The relationships between the compressive strength and the age of foamed concrete are shown in Figures (2), (3), and (4) for densities 800, 1200, and 1600 kg/m^3 respectively. These figures illustrate that the compressive strength (F_c) increases with time. For the selected mixes with 1200 and 1600 kg/m^3 densities , the 90-day strengths show significant increase as compared to that of 28- day value, unlike the mixes with 800 kg / m^3 density, see Table (2).The compressive strength increases with the increase in density. For the same density, F_c increases with increasing in cement content and decreasing of w/c ratio.

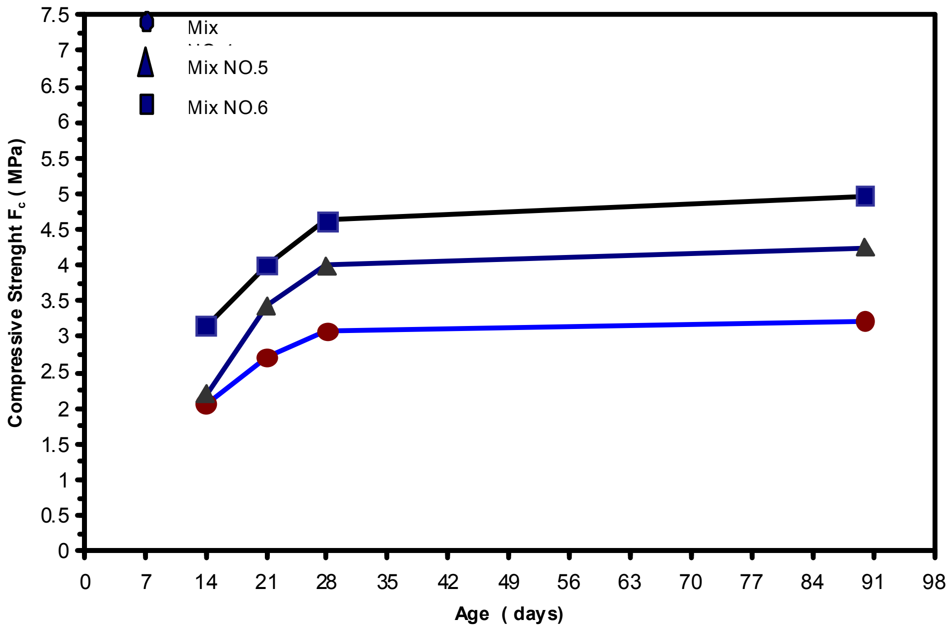

Fig. (2) Relationship between compressive strength and age of foamed concrete with density (800 kg / m^3).

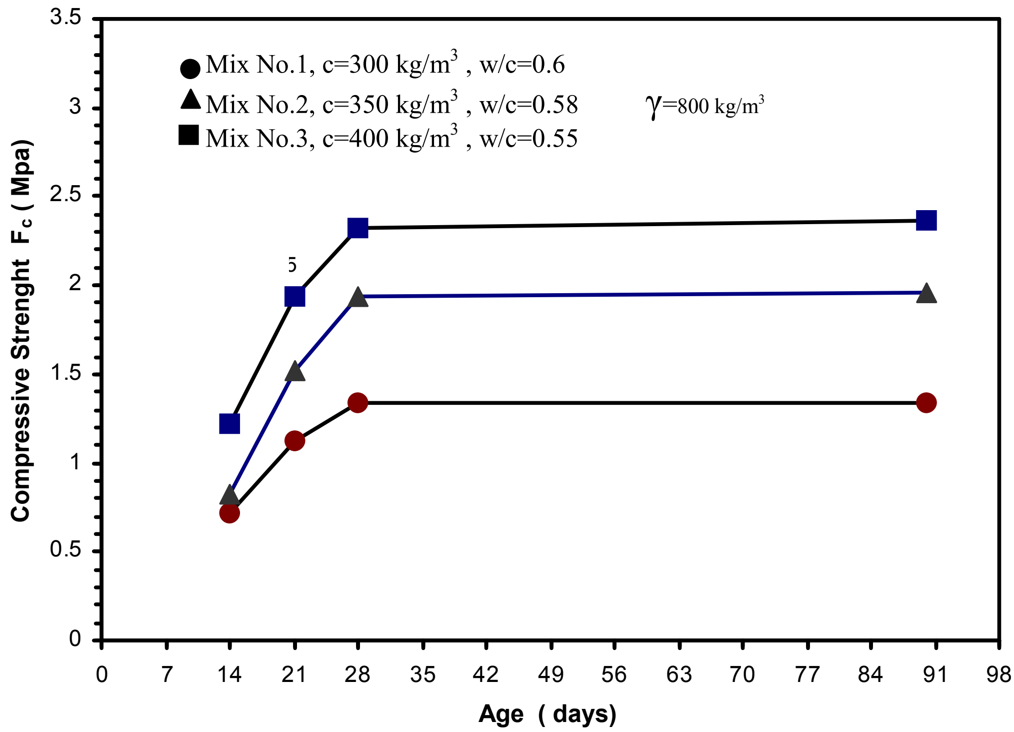

Fig. (3) Relationship between compressive strength and age of foamed concrete with densety (800 kg / m^3).

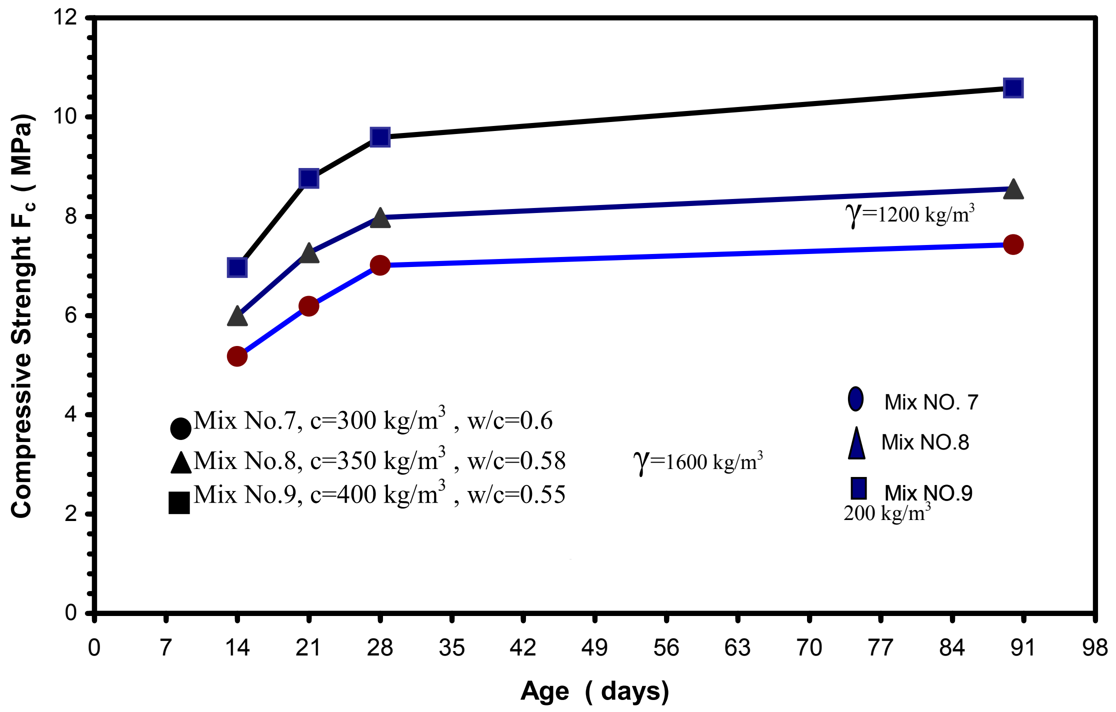

Fig. (4) Relationship between compressive strength and age of foamed concrete with density (1600 kg /m³).

Table (2) The increases of 90-day strengths (%) of 28-day value for the selected mixes.

The Selected Mixes								
No.(1)	No.(2)	No.(3)	No.(4)	No.(5)	No.(6)	No.(7)	No.(8)	No.(9)
0%	1.19%	1.98%	4.4%	6.19%	7.8%	10.59%	10.72%	11.03%

Figure (5) shows the relation between the compressive strength at an age of 28 days for all selected mixes and both density and w/c ratio. It illustrates that the range of Fc at an age of 28 days is from 1.334 MPa for mix No. (1) to 9.591 MPa for mix No.(9).

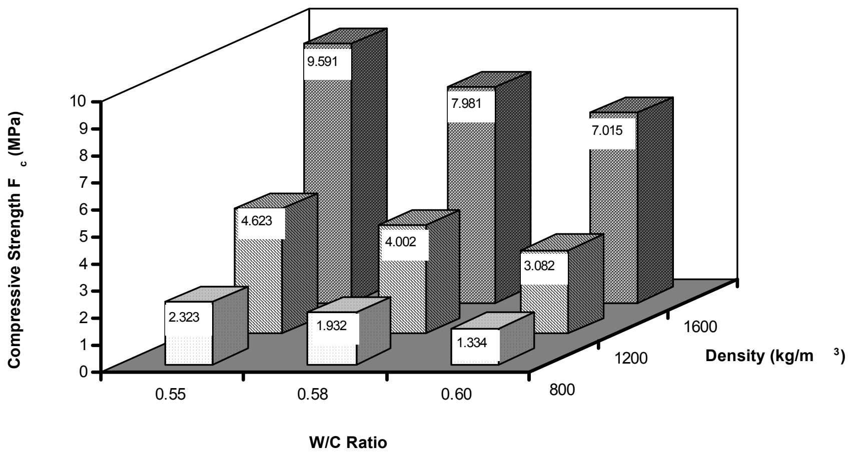

Fig. (5) Effects of both w/c ratio and density on Fc of foamed concrete at an age of 28 days.

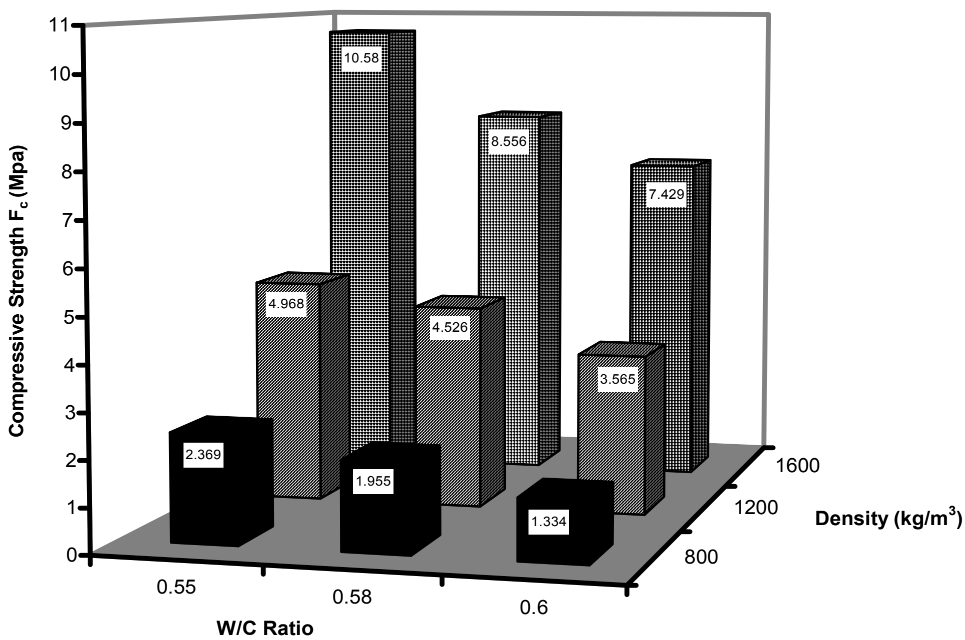

Fig. (6) Effects of both w/c ratio and density on Fc of foamed concrete at an age of 90 days.

6-3 Splitting Tensile Strength

The splitting tensile strength was carried out on cylindrical specimens 150mm×300mm, at an age of 14,21,28,and90 days. This test was done according to ASTM- Designation: C496-86 [9]. Two specimens are tested at each selected age and the results are averaged. Splitting tensile strength (F_{sp}) of the test specimens for all specimens has been calculated as follows[9]:

$$F_{sp} = \frac{2P}{\pi L d} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where:

F_{sp} = splitting tensile strength (M P a),

P= maximum applied load indicated by the testing machine (N),

L= length of specimen (mm),

d= diameter of specimen (mm) .

It should be noted that the splitting tensile strength test results are calculated to the nearest 0.035 MPa . Figure (7) shows the effect of both w/c ratio and density on F_{sp} for the all selected specimens at age of 28 days.

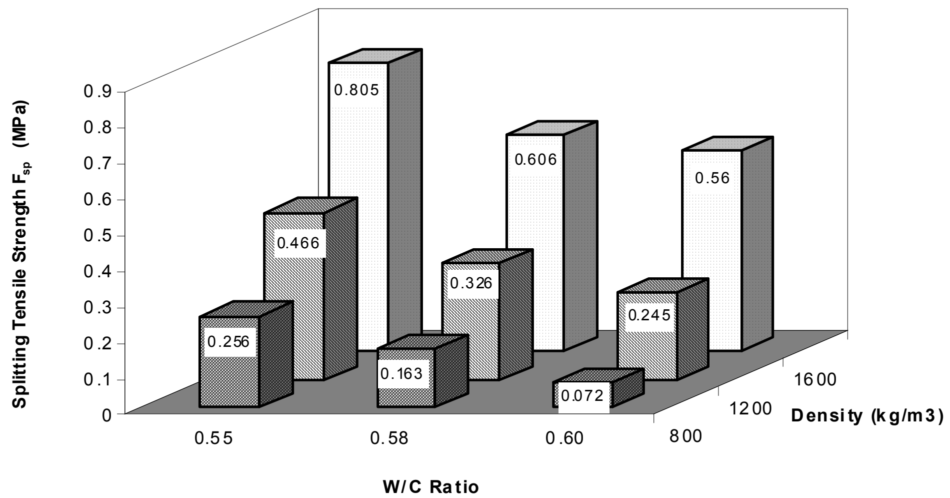

Fig.(7) Effect of both w/c ratio and density on Fsp for the all selected mixes at an age of 28 days .

6-3-1 Development of Splitting Tensile Strength with Time

Figures (8), (9), and (10) show the relationships between F_{sp} and age of the test for foamed concrete with densities 800, 1200, and 1600 kg/m^3 respectively. Unlike other figures, Figure (8) shows that the 90-day strengths did not show any strength development to that of 28-day. This means that at lower densities, almost all strength is gained at 28-days.

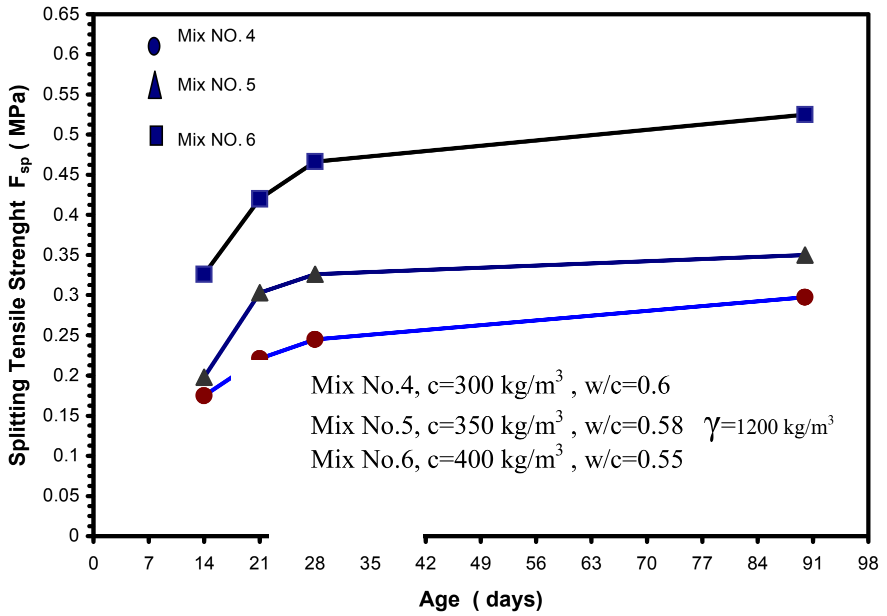

Fig.(8) Relationship between splitting tensile strength and age of foamed concrete with density (800 kg/m^3).

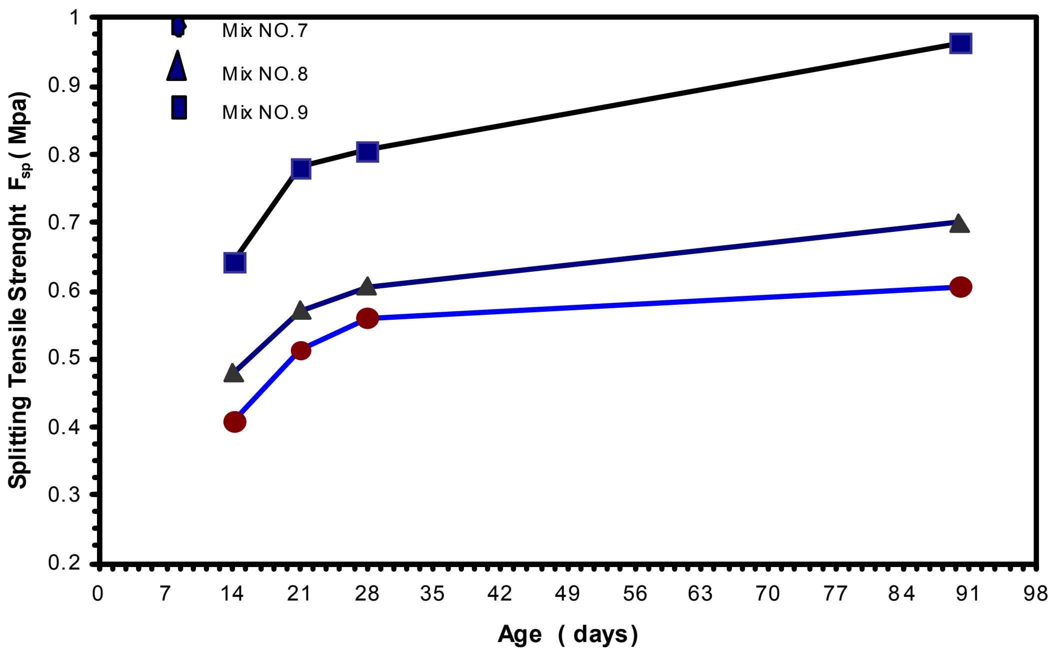

Fig. (9) Relationship between splitting tensile strength and age of foamed

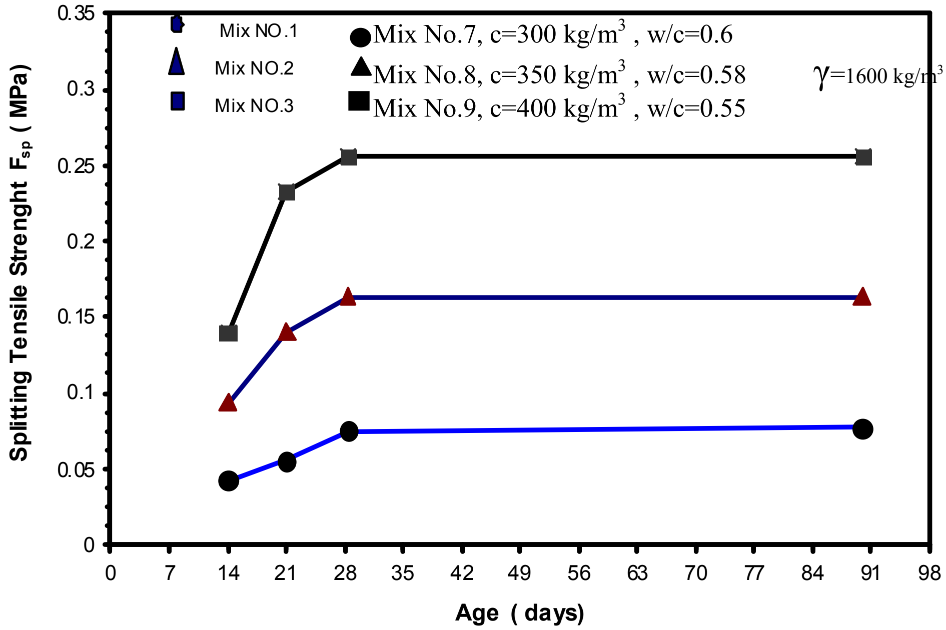

Fig. (10) Relationship between splitting tensile strength and age of foamed concrete with density (1600 kg /m^3).

6-4 Flexural Strength Test

The flexural strength test was done according to ASTM- Designation : C 78 – 84 [10] . The flexural strength test was carried out on prism (100 mm × 100 mm × 500 mm). For mixes (No. 7, No. 8, and No. 9), at each selected age, two test specimens were used for flexural strength test using the simple beam with third – point loading. If the fracture initiates in the tension surface within the middle third of the span length, the modulus of rupture is calculated as follows:

$$Fr = \frac{PL}{bd^2} \qquad \ldots\ldots\ldots\ldots\ldots(2)$$

Where:

Fr = modulus of rupture (MPa)

P= maximum applied load indicated by the testing machine (N)

L= span length (mm)

b= average width of specimen (mm)

d= average depth of specimen (mm)

For the specimens in which the fracture occurs in the tension surface outside of the middle third of the span length, the modulus of rupture is calculated as follows:

$$Fr = \frac{3Pa}{bd^2} \qquad \text{.............} (3)$$

where:

a= average distance between line of fracture and the nearest support measured on the tension surface of the prism (mm).

It should be noted that the flexural strength (modulus of rupture) test results are calculated to the nearest 0.03 MPa . Figure (11) shows the development of Fr with time for foamed concrete with density 1600 kg/m^3. It can be seen that higher voids, lower cement content and higher w/c ratio would decrease the flexural strength.

The development in flexural strength and the effect of w/c ratio on it are shown in bar chart in Figure (12).

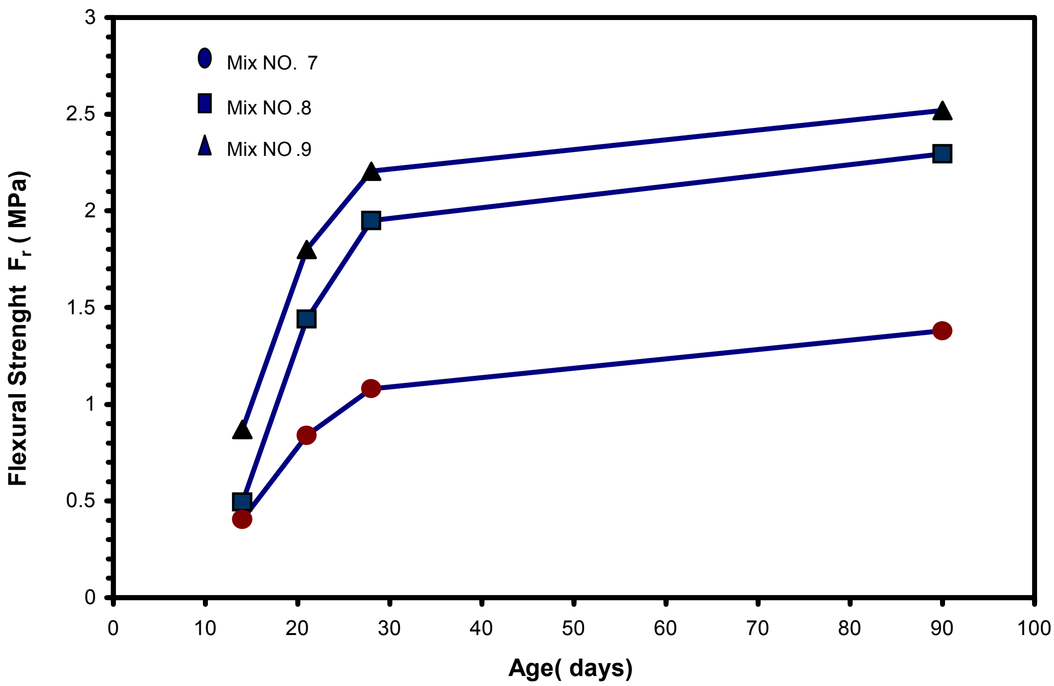

Fig. (11) Relationship between flexural strength and age of foamed concrete with density (1600 kg /m^3).

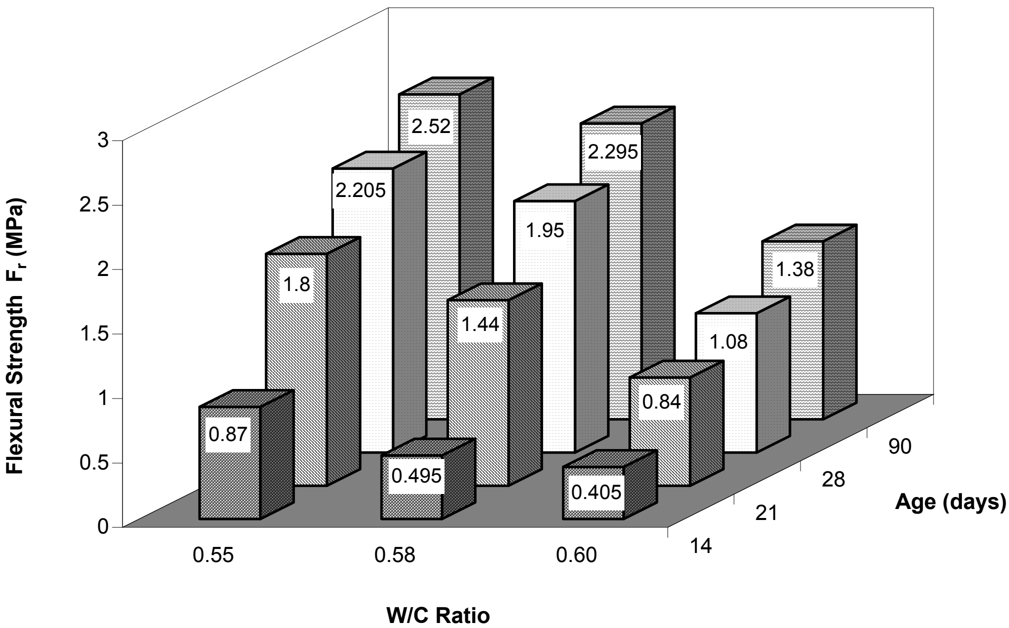

Fig. (12) Effect of both w/c ratio and age of foamed concrete with density (1600 kg/m^3) on flexural strength.

7- Conclusions

According to the experimental work, which includes production and study of properties of foamed concrete, the following conclusions can be drawn.

1- In order to make (1) Liter of foam, (2.5) mL of Euco Foaming Agent had been diluted in (40) g of water by using Automatic Mortar Mixer.
2- The amount of air in foam produced by using Euco-Foaming Agent of this study is 95.75 %.

3- There is possibility to produce foamed concrete with wide range of densities.
4- The presence of air bubbles acts as a lubricant and increases the workability.
5- The compressive, tensile, and flexural strength decrease with increasing air content when both cement content and w/c ratio are constant.
6- For the same density, Fc , Fsp , and Fr increase with increasing cement content and decreasing w/c ratio.
7- The 28- day cube strength was 2.323 MPa to 9.591 MPa for density range 800 kg/m^3 to 1600 kg/$m^{3,}$ with cement content (400 kg/$m^{3)}$ and w/c ratio (0.55).
8- The 90-day strengths did not show noticeable strength development to that of 28-day for foamed concrete with 800 kg/m^3 density.
9- Foamed concrete produced in this study is not recommended to be used for structural applications because highest 28-day strength was only 9.591MPa.
10- The final product of foamed concrete can be sawn by hand saw.

References

1: Internet: Report, “Cellular Concrete Products.”<WWW. Cellular- concrete. Com. E- mail: info @ cellular- concrete. Com.> 2002.

2: Shetty ,M. S.,” Concrete Technology Theory and Practice.” S.Chand and Company , India. 3rd . Ed ., 1988 .

3: Portland Cement Association, “Special Concretes and Concrete Products .”, copyright by J.Wiley. U.S.A. , 1975 .

4: ASTM Committee , C-144. “ Standard Specification for Aggregate for Masonry Mortar . “ 1987.

5: ASTM Committee , C-128. “ Standard Test Method for Specific Gravity and Absorption of Fine Aggregate. “ 1988.

6: ACI Committee 523 , 1986 , “ Guide for Cellular Concretes above 50 pcf , with compressive strengths less than 2500 psi . ACI 523 – 86 . “ Revised 1982 . Reapproved 1987 .

7: ASTM Committee , C-796. “ Standard Test Method for Foaming Agents for Use in Producing Cellular Concrete Using Preformed Foam .”1987.

8: ASTM Committee , C-513. “ Standard Test Method for Obtaining and Testing Specimens of Hardened Lightweight Insulating Concrete for Compressive Strength. “ 1989.

9: ASTM Committee , C-496. “ Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens.” 1986.

10: ASTM Committee , C-78. “ Standard Test Method for Flexural Strength of Concrete (Using Simple Beam With Third – Point Loading).” 1975.