ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 8, Issue 11, May 2019

An investigation on properties of foamed concrete by using different mixes

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***Abstract*— This paper investigates an experimental study of foamed concrete (FC) by using organic foaming agent. There are many methods to produce FC. Mixed foaming method is used to produce FC with wide range of concrete densities 1200, 1500 and 1800 kg/m^3. This study concentrates on the effect of high cement (PC) content, using silica fume (SF) as cement replacement and using fly ash (FA) as sand replacement on the fresh and mechanical properties. As well as presenting the thermal conductivity of the three different densities. The foamed concrete mixes achieve (4-19.1) MPa compressive strength at 28-days.**

***Keywords*: Foamed concrete, Mechanical properties, Thermal conductivity.**

I. INTRODUCTION

Lightweight concrete plays important role in the construction industry. There is a general trend to use lightweight concrete. Use of lightweight concrete as an alternative to ordinary concrete in construction works can decrease the building's own weight which leads to use thinner section, smaller size structural members, less reinforcing steel and lower foundation costs.

One of the methods of reducing the weight of concrete depends on the introduction of stable voids within the hardened concrete. A foaming agent introduces the air voids in the concrete while the concrete produced is called foamed concrete. The amount of foam added to the basic cement and sand mixture controls the density of foamed concrete.

Foamed concrete is classified as a lightweight concrete with random air voids created by using foaming agents in mortar. Lightweight foamed concretes have a wide range of concrete densities (400–1900 kg/m^3). Foamed concrete doesn't contain coarse aggregate. Moreover, Foamed concrete is known as its high flowability, low cement content, low aggregate usage [1-3].

Foamed concrete is recognized for some attractive characteristics like, flowability; self-compacting, self-levelling nature, low dimensional change and ultra-low density [4]. The main use of foamed concrete is to reduce the dead load of concrete structures which leading to reduce size of columns, beams, foundations and other load bearing elements [5,6].

Manuscript received: 22 April 2019
Manuscript received in revised form: 17 May 2019
Manuscript accepted: 04 June 2019
Manuscript Available online: 10 June 2019

Moreover, it is an economical, environmentally friendly and it enhances the fire resistance, thermal conductivity [4].

Foamed concrete is not a particularly new material. Historically, the romans first noticed that small air bubbles are formed by adding animal blood in to the mix of small gravel and coarse sand with hot lime and water [7,8]. The first patent of foamed concrete recorded back to early 1920s. According to Sach and Seifert (1999), limited scale production began in 1923 and according to Arasteh (1988), in 1924 Linde pronounced its production, properties and applications [9]. According to [2], The first inclusive review on cellular concrete was presented by Valore in 1954 and a detailed behavior by Rudnai and Short and Kinniburgh in 1963, summarizing the composition, properties and uses of cellular concrete, regardless of the method of formation of the cell structure. Recently, Jones and McCarthy [10] have reported the history of using foam concrete, constituent materials used, its properties, and construction application including some projects carried out worldwide.

The foamed concrete applications for construction works was not known till the late 1970s, when it began to be used in the Netherlands for filling voids and for ground engineering applications [9]. In the last 20 years, rapid development and technological progress in production equipment and good quality of foaming agents has enabled the use of foamed concrete on a larger scale [10]. There is a general trend to use foamed concrete in construction in different countries such as Germany, UK, Philippines, Turkey, and Thailand [11]. Now foamed concrete can be used as increasing number of lightweight on or semi structural application, including filling high volume voids, bridge and arch infills, reinstatement of utility trenches, road sub base, fire protection for structural steelwork, soil stabilization, thermal and acoustic insulation and grouting tunnel walls [4].

II. OBJECTIVES OF THE STUDY

The main purpose of this investigation was studying fresh and mechanical properties at fresh and hardened state. Moreover, conducting thermal conductivity on three control mixes with densities1200, 1500 and 1800 kg/m^3. And comparing all mixes result with replacement material to control mix.

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III. MATERIALS AND PREPARATION METHODS

A. Materials

1. Cement

Ordinary Portland cement was CEM I 52.5 N with physical and chemical properties represented in Table 1. The cement tests were done by the standard details ES4756/1 2013 and BSEN197/1 2011

Table 1: Chemical composition of OPC

Chemical composition of OPC	
Silica (SiO_2)	20.11
Lime (CaO)	62.56
Ferric oxide	3.41
Alumina (Al_2O_3)	5.96
Magnesia (MgO)	2.08
Sulphuric Anhydride (SO_3)	2.14
Loss on Ignition (LOI)	1.64

2. Aggregate

Natural fine aggregate (sand) (S.G.=2.65) compatible with the requirement of Egyptian code of practice [12].

3. Foaming agent

The foaming agent used in this research was sikament SB2 which made by sika company. the chemical composition of sikament SB2 was organic tenside. Foaming agent was used to create small and enclosed air bubbles in the cement paste by using mixed foaming method.

4. Silica fume

Sika fume (2.22 S.G., 97% SiO2) was made by sika company was used to improve the mechanical properties of concrete.

5. Fly ash

Sika ash class F (2.38 S.G., 52% SiO2) was made by sika company was used as partial sand replacement in the production of FC.

B. Mix proportions

In this study, the unit weight of FC should be selected first to determine the mix proportioning. Then the mix was proportioned by absolute volumes methods. The proper dosage of foaming agent should be determined to achieve the unit weight of FC by using trial mixes. In addition, trail mixes were carried out to determine the suitable dosage of superplasticizers. But, After the concrete is poured, bubbles are formed on the concrete surface and a drop of concrete occurs as shown in Fig1. This led to collapse of the concrete because of superplasticizers make the mortar too soft to hold the bubbles which caused loss of bubbles in the concrete due to segregation of the foam form the mix. After 24 hours of pouring the concrete, it noticed that the concrete loss all bubbles, drop of the hardened concrete surface as shown in Fig 2. and lead to increase of concrete density. The explanation of phenomenon is incompatibility between foaming agent and super plasticizers.

Table 2 represents the proportions of eighteen mixes divided to three densities (1200, 1500 and 1800) kg/m^3. Every density consists of 4 groups. The first group is (N) normal strength FC which contains 350 kg/m^3 cement. Second group is (H) high strength FC with 500 kg/m^3 cement without any replacement materials. Third group (H-SF) with (500 kg/m^3) cementitious content is contains silica fume (SF) as partial cement replacement by (10, 15 %). While fourth group (H-FA) with (500 kg/m^3) cementitious content is contains fly ash (FA) as sand replacement by (20,30%).

Fig 1: Formed bubbles on the concrete surface after pouring the concrete

Fig 2: A drop of hardened concrete

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Table 2: Mixture proportions of foamed concrete mixes (kg/m^3)

Mixes	Group	Target Density (kg/m^3)	Cement (kg)	SF %	Sand (kg)	FA %	(W/C)	Water (kg)	Foaming agent (kg)
M1	N-1200	1200	350	-	678.5	-	0.49	171.5	3.5
M2	H-1200	1200	500	-	455	-	0.49	245	5
M3	H-SF-1200	1200	500	10%	455	-	0.49	245	5
M4	H-SF-1200	1200	500	15%	455	-	0.49	245	5
M5	H-FA-1200	1200	500	-	455	20%	0.49	245	5
M6	H-FA-1200	1200	500	-	455	30%	0.49	245	5
M7	N-1500	1500	350	-	973.25	-	0.505	176.75	1.75
M8	H-1500	1500	500	-	747.5	-	0.505	252.5	2.5
M9	H-SF-1500	1500	500	10%	747.5	-	0.505	252.5	2.5
M10	H-SF-1500	1500	500	15%	747.5	-	0.505	252.5	2.5
M11	H-FA-1500	1500	500	-	747.5	20%	0.505	252.5	2.5
M12	H-FA-1500	1500	500	-	747.5	30%	0.505	252.5	2.5
M13	N-1800	1800	350	-	1268	-	0.52	182	0.875
M14	H-1800	1800	500	-	1040	-	0.52	260	1.25
M15	H-SF-1800	1800	500	10%	1040	-	0.52	260	1.25
M16	H-SF-1800	1800	500	15%	1040	-	0.52	260	1.25
M17	H-FA-1800	1800	500	-	1040	20%	0.52	260	1.25
M18	H-FA-1800	1800	500	-	1040	30%	0.52	260	1.25

C. Sample preparation

Foamed concrete was produced in the laboratory by using horizontal mixer by adding constituents' materials to the base of the mixer then adding foaming agent with water. The mixing time necessary to achieve the target density. Density can be determined simply from the weight of a sample in a container of known volume.

The workability of foamed concrete was measured by using a technique called spread ability. A number of standard tests were chosen for investigating the several parameters. Compressive strength test at (7,28 and 56) day was carried out on cube (100 x 100 x 100) mm according to BS EN 12390-3:2002. Beam (10 x 10 x 500) mm was tested for flexural strength at 28 days. IN addition, cylinder (100 x 200) was tested for splitting strength of FC at 28 days. The thermal conductivity was carried out on slab (300 x 300 x 50) by using heat flow meter method (MFM) according to ASTM C-518.

IV. RESULTS AND DISCUSSION

The test results of spreadibility, compressive strength, splitting strength and flexural strength are shown in Table3

A. Workability of FC

The spread ability test was done by slump cylinder with a 75 mm diameter and 150 mm long open-ended as shown in Fig 3. The results of spread ability test for all mixes were presented in Table 3 and Fig 4. It can be seen that increasing the PC content lead to increase the spread ability. In addition, using replacement materials (SF and FA) lead to decrease the spreadibility. The reduction in slump for mixes with replacement materials may be due to using silica fume and fly ash which lead to increase surface area and thus necessitates water demand and thus lead to decrease spread ability.

Fig 3: Spread ability test

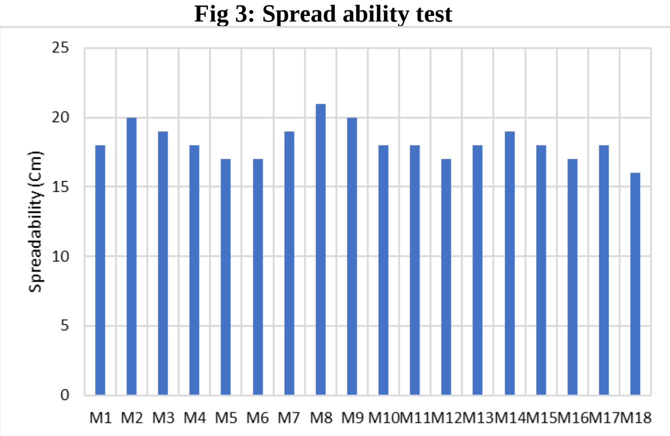

Fig 4: Results of spread ability test

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 8, Issue 11, May 2019

Table 3: Results of fresh and mechanical properties of foamed concrete mixes

Mix	Group	Slump (cm)	Actual Density (kg/m^3)	Compressive strength (MPa)			Splitting strength (MPa) 28 days	Flexural strength (MPa) 28 days	Thermal conductivity (W/m.k) 28 days
				7 days	28 days	56 days			
M1	N-1200	18	1205	1.9	4	4.5	0.49	0.9	-
M2	H-1200	20	1190	2.2	5.5	5.8	0.54	1.1	0.54
M3	H-SF-1200	19	1210	2	6.5	6.9	0.6	1.2	-
M4		18	1183	2	3.5	3.7	0.38	0.9	-
M5	H-FA-1200	17	1216	1.5	4.2	4.5	0.41	0.8	-
M6		17	1169	2.1	5.8	6.1	0.62	1.25	-
M7	N-1500	19	1479	6.1	7.2	8	0.81	1.34	-
M8	H-1500	21	1486	7.3	10.6	11.1	0.89	1.37	0.66
M9	H-SF-1500	20	1483	7.9	11.8	12.4	0.94	1.77	-
M10		18	1490	7.3	8.9	9.3	0.87	1.26	-
M11	H-FA-1500	18	1510	6.4	8.8	9.9	0.78	1.3	-
M12		17	1494	8.8	12.7	13.2	1.16	1.87	-
M13	N-1800	18	1786	12.7	15.8	16.3	1.38	2.19	-
M14	H-1800	19	1826	13.6	16.5	19	1.43	2.3	0.84
M15	H-SF-1800	18	1777	14.1	18.7	21.4	1.54	2.53	-
M16		17	1792	12.6	14.2	14.9	1.37	2.19	-
M17	H-FA-1800	18	1810	11.3	13.4	15.3	1.14	2.25	-
M18		16	1789	14.5	19.1	21.8	1.76	2.58	-

B. Compressive strength

The compressive strength of FC was affected by density; cement content and replacement materials as shown in Table 3. In general, there is a clearly increase in compressive strength at all ages (7, 28 and 56) days by increasing the density of FC and increasing the cement content. In addition, the replacement materials increase the compressive strength at certain dosage as shown in Table 3. The concrete mixes with PC=500 kg/m^3 achieve compressive strength results higher than mixes with PC=350 kg/m^3 as shown in Fig 5. This is due to increase of the cementing material in the mixes which leads to more bond between sand particles. The test results indicate that the optimum range of SF can be used as PC replacement was 10% which increase compressive strength at 28 days by 18.2, 11.3 and 13.4 % compared to control mixes (0% replacement material) for densities 1200,1500 and 1800 kg/m^3 respectively as shown in Fig 6. The increasing range of SF to 15 % lead to decrease the compressive strength compared to control mix (0% replacement material). This is due to the fact that at lower density range it is the foam volume that controls the strength rather than the material properties. On the other hand, FC mixes with FA as sand replacement by 30% enhance compressive strength at 28 days by 5.5, 20 and 21.8 % compared to the control mixes for densities 1200,1500 and 1800 kg/m^3 respectively as shown in Fig 7. but, using FA as sand replacement by 20% lead to decrease the compressive strength at 28 days by 23.6, 17 and 18.8 % compared to control mix for densities 1200,1500 and 1800 kg/m^3. This can likely be as a result of the homogenous nature of FC.

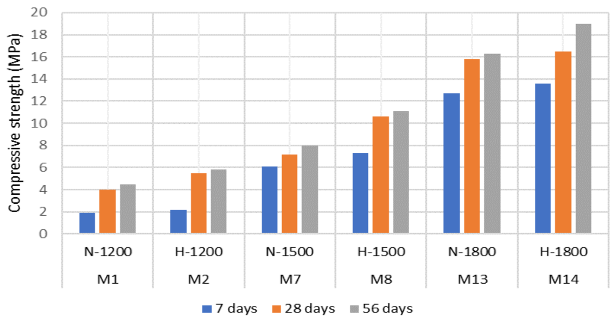

Fig 5: Compressive strength results for normal and high cement content at all ages

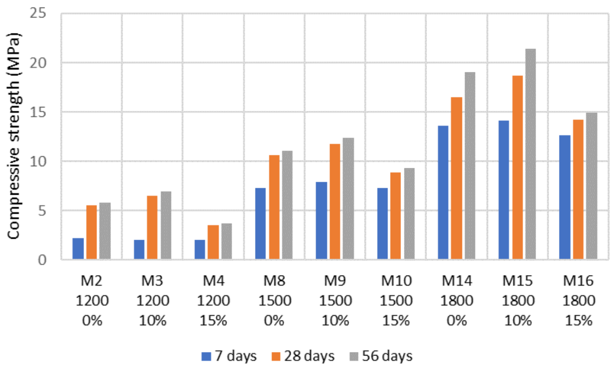

Fig 6: Compressive strength results for SF mixes at all ages

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 8, Issue 11, May 2019

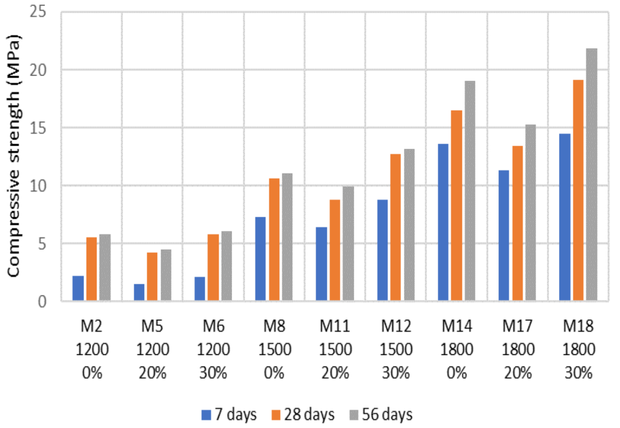

Fig 7: Compressive strength results for FA mixes at all ages

C. Splitting strength

Table 3 and Fig 8 represent the splitting strength results at 28 days for all mixes. Similar to compressive strength, the splitting tensile strength of FC also affected by density, cement content and replacement materials. It can be noticed that the splitting tensile strength associated with compressive strength. the splitting tensile strength increases with increasing compressive strength. It can be observed that using FA as partial sand replacement (30%) achieve splitting strength results higher than using SF as partial cement replacement (10%). Moreover, the optimum percentage of using SF and FA is 10% and 30% respectively.

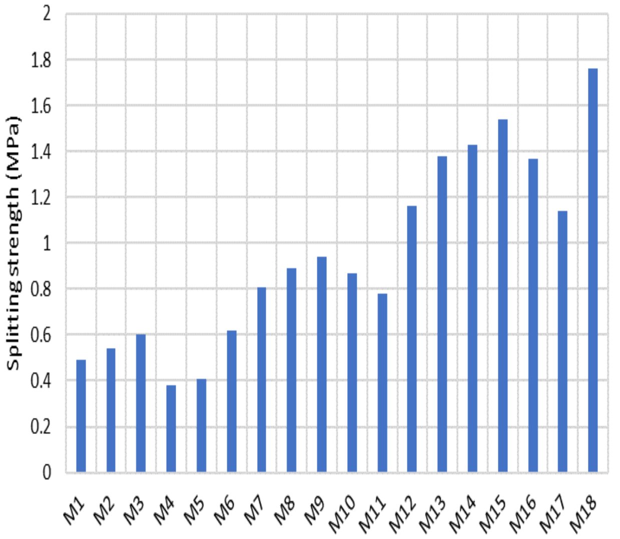

Fig 8: Splitting strength results for all mixes

D. Flexural strength

Table 3 and Fig 9 represent the results of flexural strength at 28 days. Results of flexural strength increased for mixes containing high cement content. Moreover, using SF as cement replacement and FA as sand replacement at certain percentage have clear significant on flexural strength. The optimum level of using SF as PC replacement is 10% and 30% in case of using FA as sand replacement.

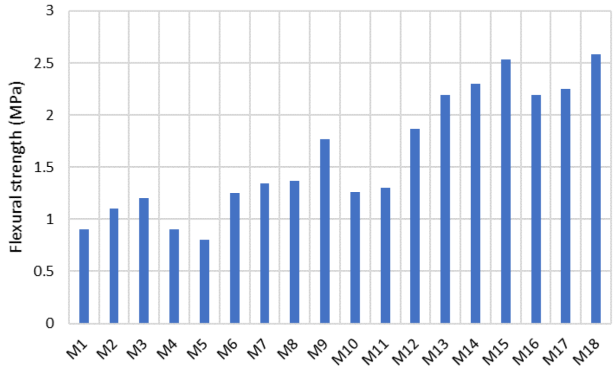

Fig 9: Flexural strength results for all mixes

E. Thermal conductivity

Table 3 and Fig.10 shows results of thermal conductivity for (M2, M8 and M14) which have densities 1200, 1500 and 1800 kg/m3. It was observed that the mix (M2) has the best thermal insulation than the other mixes (M18 and M14). Thermal conductivity increases by 20% and 55% when density changes from 1200 kg/m3 to 1500 kg/m3 and 1800 kg/m3 respectively. It is specified that average of each 100 kg/m3 reduction of density, the thermal insulation will drop by 0.05 W/m.K of the total thermal insulation of foamed concrete. It can be seen that the thermal conductivity is directly proportional to density and the thermal insulation characteristic decreases as soon as the density volume increases. The reason for this is that in the case of foamed concrete, its thermal conductivity depends on the air volume in concrete which air has lower thermal conductivity than water.

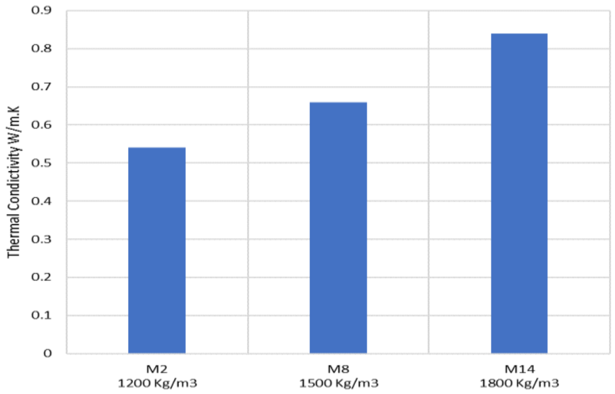

Fig 10: Thermal conductivity test

V. CONCLUSION

1. The higher the density of foamed concrete, the greater the mechanical properties.
2. The density 1800 kg/m^3 is suitable for structural purposes.
3. The density 1200 and 1500 kg/m^3 are suitable for semi structural purposes [filling void, road sub base and etc.].
4. Foamed concrete has a thermal insulation feature. As the density of foamed concrete increase, the thermal

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 8, Issue 11, May 2019

conductivity increase. The density of 1200 kg/m^3 is more suitable for thermal insulation than the other densities (1500 and 1800 kg/m^3).

5. The best replacement percentage for partial replacement of sand by fly ash was 30% for foamed concrete with density 1200 kg/m^3.
6. The best replacement percentage for partial replacement of cement by silica fume was 10%.
7. Superplasticizers should be compatible with foaming agent.

VI. RECOMMENDATION

1. Study the effect of another local replacement materials as cement replacement on the foamed concrete.
2. Study the effect of another foaming agents on the mechanical properties and thermal conductivity.
3. Study the effect of voids ratio on the acoustic insulation.

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