Journal of New Results in Science (JNRS)

ISSN: 1304-7981
http://dergipark.gov.tr/en/pub/jnrs
Research Article
Open Access

Volume: 9
Issue: 1
Year: 2020
Pages: 9-18

***Received*:** 30.03.2020 ***Accepted*:** 09.04.2020

Foam Concrete

Murat Gökçe[a], Burçin Şenol Şeker[b,*]

[a] *Department of Architecture, Faculty of Architecture, Amasya University, Amasya, Turkey*
[b] *Department of Architecture, Faculty of Architecture, Amasya University, Amasya, Turkey*
**Corresponding author, senol.seker@amasya.edu.tr*

ABSTRACT: Today, energy takes the lead in topics that matter the most for all countries. The ever-increasing world population together with growing industry has given way to an unstoppable energy consumption. Some countries have already started working towards saving energy due to reasons such as increasing environmental pollution, fast consumption of existing energy resources and high cost of energy production. Nowadays, to achieve desired benefits by consuming less energy has brought about the issue of insulation and therefore increased the importance given to insulation. In this study, by adding foam (water+foam agent+air) that will be prepared in foam generator into the slurries (cement, water, silica fume, calcite and plasticizer mixture), foam concrete with improved insulation performance has been produced. Bulk density of foam concrete is obtained to be 250 kg/m3 and its heat conductivity to be 0,075 W/mK. The compressive strength of foam concrete is found to be 0,75 MPa.

Keywords – *Foam concrete, Insulation concrete, Thermal conductivity, Foam generator*

1. Introduction

Foam concrete is a type of concrete whose bulk unit weight is reduced by keeping the air voids within. Although foam concrete was first patented in 1923 (Valore, 1954), in the recent years, it is observed that this material is preferred as a construction material produced with a density ranging from 1600 to 400kg/m3 to be used in structural, partition walls and non constructional components because of its distinct characteristics such as superfluidity, low weight, containing minimum aggregate inside, controllable resistance and perfect insulation performance (Ramamurthy and Kunhanandan, 2009). It is understood that the idea of reducing the specific bulk density by making foams in order to create air voids inside the concrete dates back to the 1900s.

The first elaborative compilation about the studies on foam concrete was conducted by Valore in 1954, following that, Rudnai in 1963 and subsequently (Short and Kinniburgh, 1963) presented the contents of foam concrete, its characteristics and areas of use without analysing the methods for creating the air voids. Recently, Jones and McCarthy have published a study on the history of foam concrete, the materials used, their characteristics and its use in constructional applications around the world (Jones and McCarthy, 2005).

Thermal conductivity factor is the amount of heat that passes between two layers or surfaces of $1m^2$ in two perpendicular directions per time unit when the temperature difference is 1°C and its unit is W/mK (Fig. 1).

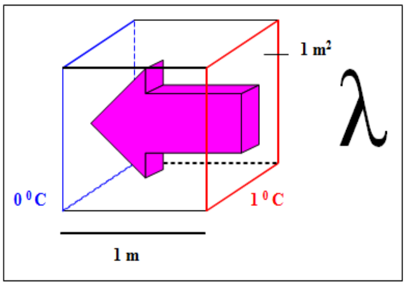

Fig. 1. Thermal conductivity factor

Heat transmission coefficient U (W/m2K) is the resistance towards heat transfer shown by a construction component made up of different materials. U is dependent on thermal conductivity coefficient (λ) of the materials and the thickness in heat transfer direction. the lower the U value, the lower the heat loss is.

However, having a low thermal conductivity coefficient is not a sufficient factor by itself to show its “heat insulation” attributes Heat insulation material should have an adequate thickness besides a low thermal conductivity value.
For heat insulation calculations, Thermal Resistance=R (m2.K/W) value (hence thermal conductivity+thickness value) is used.

Heat Insulation = R = Thermal Resistance= Thickness d (m) / Thermal Conductivity Coefficient [W/(m.K)] = d / λ

Since the purpose of applying heat insulation is to prevent heat losses and heat gains, it is therefore necessary that the resistance which heat insulation material shows against these should be large. The largeness of this value depends upon the thickness of the insulation material and small thermal conductivity coefficient. In insulation materials, thermal resistance increases with the thickness.

According to IS0 and CEN Standards, materials that have a heat conductivity coefficient lower than 0,065 W/mK are classified as heat insulation material and this feature is the most determining factor when choosing heat insulation materials.

The materials are classified as follows regarding their non combustibility degree:
A1 Non Combustible Materials
A2 Non Combustible Materials
B1 Difficult to ignite materials
B2 Normal combustibility materials
B3 Easily ignited materials
C Materials with limited contribution to fire
D Materials with acceptable contribution to fire
E Materials with acceptable reaction to fire
F Materials with indeterminate reaction to fire.

The degrees of fire resistance according to TS EN 13501-1+A1 are listed below.
In relation to their resistance duration;
F 30: Resistance duration between 30-59 minutes
F 60: Resistance duration between 60-89 minutes
F 90: Resistance duration between 90-119 minutes

F 120: Resistance duration between 120-179 minutes
F 180: Resistance duration above 180 minutes for construction components.

In parallel to rising risk factor, materials with a longer resistance duration against fire should be preferred in buildings. Mineral wool was the most preferred insulation material in 2014 in Europe. Since they have a wide range of areas of use, mineral wool types such as rock wool and glass wool make up 58% of the market. In the USA, the total size of the insulation market for heat, sound and fire safety has been stated as 268 million metre cube. 84% of the American insulation market is made up by mineral wools, 10% is represented by plastics and the 6% is constituted by other insulation materials (Şen, 2006).

It can be seen that, especially in America and Europe, for insulation material they use non flammable materials.

Having reduced the dependence on petroleum based materials, foam concrete was first mainly used as an insulation material; however, in recent years it has been also used as a structural component due to its lightweight and insulatory properties.

In past studies, they have mostly analysed topics such as foam agent, foam production, compatibility between chemical additives and foam agent, use of fine coarse aggregate, mixture of foam concrete, its transportation and how it is placed. According to ISO and CEN Standards, materials that have a lower thermal conductivity coefficient than 0,065 W/mK are considered heat insulation materials whereas other materials are classified as construction materials.

Jones and McCarthy (2005) stated that foam concrete with a dry density between 600–1600 kg/m3 has a thermal conductivity that varies between 0.1 and 0.7 W/mK; and when compared to regular weight concrete, it has a 5 to 30% lower thermal conductivity.

Weigler and Karl (1980) has found that the lightweight aggregate foam concrete that is used in structural component production experiences a decrease in thermal conductivity as its dry density decreases: for every 100 kg/m3 reductioın in dry density, its thermal conductivity drops 0.004 W/mK.

The effects of curing foam concrete with saturated Ca (OH)2 water solution have been studied regarding the three methods: immersion in water, spraying water and curing with dry air. In the study where the effects of different curing environments are analysed, it was found that relative humidity significantly affects and increases the compressive strength of low density concrete (Chi et al 2016).

In another study where the effects of curing the concrete with water, air and humidity are investigated, the samples cured with humidity are shown to have the highest compressive strength in 28 days (Alonge et al. 2015).

In some other study where the rheological features of foam concrete were examined experimentally, the viscosity features of foam concrete were examined using viscometer and Marsh cone. It is stated that the Marsh cone provides practical advantage when determining the viscosity, and that the mixture has high viscosity if the flow duration exceeds 1 minute, thereby negatively impacting the mechanical properties (Demir et al. 2017).

In a study where fly as was used in foam concrete, it was found that fly ash has a positive impact on compressive strength (Kılınçarslan and Tuzlak, 2018).

The researchers have found that the density of foam concrete was reduced by 150 kg/m3 and its thermal conductivity coefficient at 0,005 W/mK (Pan et al. 2014). Judging from this study it can be said that foam concrete can be used as an insulation material as well

2. Material and Methods

2.1. Materials

In the production of foam concrete, cement, calcite, silica fume, polycarboxylate-based plasticizer additives and water are used. For creating foam, foam generator is used.

2.1.1. Cement

The type of cement used in this study was CEM I 52.5 R. The chemical properties of cement are shown in Table 1. The density of white cement is measured at 3,06 gr/cm³ and its surface area is 4950 cm²/gr.

Table 1. Chemical properties of white cement

White Cement (52,5 R)	**KK**	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**CaO**	**MgO**	**SO_3**	**Na_2O**	**K_2O**
	2.50	21.16	4.05	0.26	65.7	1.30	3.30	0.30	0.35

2.1.2. Chemical Additives

Polycarboxylate-based super plasticizer chemical additives were used in SCC. The physical properties of polycarboxylate-based super plasticizer chemical additives used in the study are shown in Table 2.

Table 2. The physical properties of the chemical additives

Properties	Polycarboxylate
Density (g/cm^3)	1.06
pH	5.6
Solid matter (%)	25

The physical properties of foam additives are given in Table 3.

Table 3. Physical properties of foam additives

Density(gr/cm^3)	**Appearance**	**pH**
1.05	Light brown	6 ±2

2.1.3. Calcite

Calcite used in the study was sifted through a 75-micron subsieve. The density of calcite corresponds to 2.72 g/cm3 and its specific surface area is 4160 cm2/g.

Table 4. The chemical analysis of calcite

CA	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	**Total**
43.34	0.01	0.07	0.05	53.94	1.93	0.01	0.06	0.13	99.53

The XRD (Fig. 2) and chemical (Table 4) analyses of calcite were performed, as a result of which, the calcite type used within the scope of our study was determined to be 98% calcite.

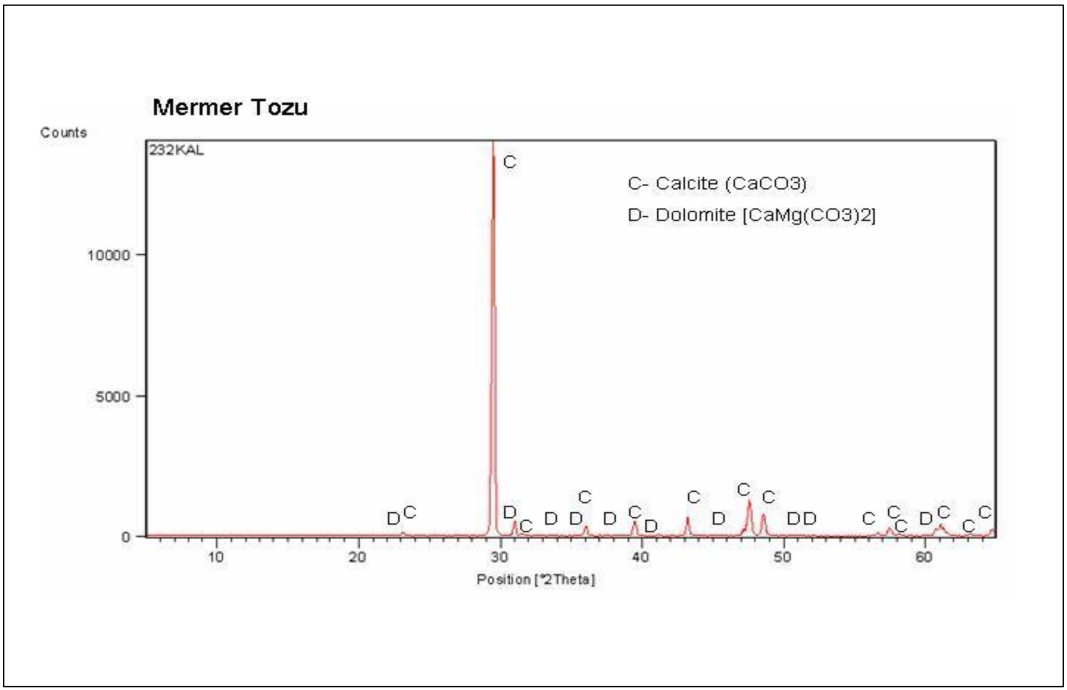

Fig. 2 The XRD diffractogram of calcite

2.1.4. Silica Fume

Silica fume has a density of 2.32 gr/cm³ and silica fume's residue on 45µm sieving is at %4,8. The surface area of silica fume is 15000 cm²/gr. The chemical properties of the silica fume used in this study are given in Table 5.

Table 5. Chemical properties of silica fume

	KK	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O
Silica Fume	4.26	81.4	4.47	1.40	0.82	1.48	1.35	-	-

2.2. Methods

In the production of foam concrete, first the mixture (cement, calcite, silica fume, water and polycarboxylate based additive) is prepared. Later, the foam made in foam generator is added into the mixture.

The most important element in producing foam concrete is the foam that is added subsequently into the mixture, which enables creating closed air voids within. The closed cell air voids that are necessary for producing foam concrete are obtained via creating foam (water + foam additive + air) in foam generator. Thanks to this added foam, there emerge closed cell air voids that are separate from each other within the solidified concrete, as a result the unit weight of the concrete is reduced.

2.2.1. Foam generation

Mixture ratio to be used in foam generation is of high significance. While producing the foam, water and foam additives are added into the tank inside the foam generator. Foam additive/water ratio is taken as 1/40. Then, the compressor located in the foam generator provides the air needed to make foam. The important factor here is the amount of air to be given into the water+additive mixture. An uncontrolled mixture ratio and giving air without control will have adverse effects on the foam generated. For this reason, foam expansion ratio is kept under control. Below is given the formula for foam expansion ratio. The amount of air given in the expansion ratio of foam is checked in accordance with this formula and the desired expansion ratio was achieved.

FER: $V_{foam} / V_{solution}$

FER (Foam expansion ratio)
V_{foam}: Volume of foam to be generated (Air + solution volume)
$V_{solution}$: Foam solution volume (water + foam additive)

Fig. 3. Foam with foam bubbles of differing sizes

As seen in Fig. 3, the foam created does not have homogeneous diameters. The foam concrete that is produced using this form does not have homogeneous density nor do the bubbles inside have homogeneous sizes.

Fig. 4. Foam with homogeneous foam bubbles

Fig. 4 shows the foam generated with foam bubbles that are very homogeneous. When this foam is added into concrete, the air voids within the concrete ended up being more homogeneous as well, and the density of the foam created was measured as 85 gr/litre.

Fig. 5. Making of foam using foam generator

Producing foam made of foam additive and water using foam generator can be seen in Fig. 5. This obtained foam is then added to the prepared mixtures at pre-calculated volume rate.

Table 6. Calculation for foam volume to be added for 1 m^3 foam concrete

Cement	Water	Plasticizer agent	Foam additive	Calcite	Silica fume	Foam volume (lt)	Foam mixture ratios		Desired unit weight (dry)
220	85	1,1	2	15	10	827	1litre foam additive	40 Litre water	300 kg/m^3
160	60	0,8	3	10	10	873	1 litre foam additive	40 Litre water	200 kg/m^3

In Table 6, materials used for 200 and 300 kg/m^3 foam concrete production and the added foam volume values are given. To decrease the unit volume weight in foam concrete, the volume of foam to be added increases as seen.

2.2.2. Preparation of Slurry

In this helix shaped mixer, slurry is prepared by mixing cement, silica fume, calcite, water and super plasticizer additive. At first stage, water, cement and plasticizer additive elements are mixed approximately for 45 seconds. Later, silica fume and calcite are added to be mixed for another 45 seconds. In total, at the end of 90 minutes, slurry is obtained at the desired consistency.

Fig. 6. Helix shaped mixer

For the preparation of slurry, helix shaped mixers are used (Fig. 6).

2.2.3. Adding Foam into Slurry

Foam is added at a pre calculated volume into the prepared surry. The foam added into slurry and the slurry are mixed until they become homogeneous. The mixture is culminated when the added foam is completely encapsulated by the concrete. In order to prevent the added foam from fading or shattering during the mixing stage, the speed of the mixer is adjusted to be 30-40 revolutions per minute.

To place the fresh concrete into molds, a laboratory type concrete pump is used. The operating mechanism of this concrete pump is enabled by materials thrusting each other. By this way, any possible volume loss is prevented before it can happen during pumping. It has been observed in our initial studies that when the pumping is performed with compressed air, there are volume losses in concrete. Foam concrete pumping machine is given in Fig. 7.

Fig. 7. Laboratory type foam concrete pump

The fresh foam concrete that is prepared is transferred into molds and then left to wait in room temperatures (±21°C).

3. Results and Discussion

Compressive strength of foam concrete is found to be 0.75 MPa according to the average calculated from the three samples of 15x15x15 cm in size (TS EN 1354, 2007).
Specific bulk density of foam concrete is measured as 294 kg/m3 when fresh. After 28 days, the specific bulk density of the hardened concrete is measured as 250 kg/m3. Thermal conductivity value of foam concrete is identified as 0,075 W/mK (Table 7).

Table 7. Test analysis of fresh and hardened foam concrete

Fresh specific bulk density (Kg/m^3)	Hardened specific bulk density (Kg/m^3)	Thermal conductivity coefficient (W/mK)	Compressive strength (MPa)
294	250	0,075	0,75

In constructions, foam concrete is attempted to be produced in levelling concrete with insulation screed and partially in the form of structural blocks. The production technology can also be made by the local industry.

4. Conclusion

Foam concrete production is an economical construction material due to its ease of application, use of local resources and its lightweight. In this study, the specific bulk density of foam concrete was reduced to 250 kg/m3. Compressive strength of foam concrete was measured as 0,75 MPa and its thermal conductivity coefficient as 0,075 W/mK. Provided that the specific bulk density of foam concrete is reduced under 250 kg/m3 and that the obtained air voids are closed cells, then the thermal conductivity coefficient could be reduced under 0,065 W/mK, thereby allowing it to be used as insulation material. Since the raw materials used in the production of foam concrete are not flammable, it would not show any combustible properties during a fire.

References

Alonge, O. R., Mahyuddin, B. R., 2015. The Effects of Curing Methods on Early-age Strength of Sustainable Foamed Concrete. Advances in Research, 3(6): 548-557.

Chi H., Hui L., Zhongwei, L., Qingyuan, W., 2016. Influence of Curing Conditions on the Compressive Strenght of Foamed Concrete. International Conference on Power Engineering & Energy, Environment (PEEE 2016), June 25–26, Shanghai, China.

Demir, İ., Başpınar, S., Kahraman, E., 2017. Experimental Investigation of Foam Concrete Rheological Properties. Cumhuriyet University Faculty of Science Science Journal (CSJ), 38(1): 109-118.

Jones, M. R., McCarthy, A., 2005. Behaviour and Assessment of Foamed Concrete for Construction Applications. Eds: Dhir, R. K., Newlands, M. D., McCarthy, A. International Congress 'Global construction: ultimate concrete opportunities', pp. 61-88, July 5-7, Dundee, United Kingdom.

Kılınçarslan, Ş., Tuzlak, F., 2018. Investigation of Strength and Thermal Conductivity Properties of Foam Concrete with Fly Ash. International Journal of Sustainable Engineering and Technology, 2(1): 1-5.

Pan, Z., Li, H., Liu, W., 2014. Preparation and Characterization of Super Low Density Foamed Concrete from Portland Cement and Admixtures. Construction and Building Materials, 72(15): 256-261.

Ramamurthy, K., Kunhanandan Nambiar, E. K., Indu Siva Ranjani, G., 2009. A Classification of Studies on Properties of Foam Concrete. Cement and Concrete Composites, 31(6): 388-396.

Rudnai, G., 1963. Lightweight Concretes. Budapest, Akademikiado.

Short, A., Kinniburgh W., 1963. Lightweight Concrete, Asia Publishing House.

Şen, A. O., 2006. Isolation Systems Applications on Buildings Isolation in World and Turkey. Master's Thesis, Sakarya University, Graduate School of Natural and Applied Sciences, p. 57, Sakarya, Turkey (In Turkish).

Valore, R. C., 1954. Cellular Concrete - Part 1, Composition and methods of production. ACI J. 50. 773–796.

Weigler, H., Karl, S., 1980. Structural Lightweight Aggregate Concrete with Reduced Density – Lightweight Aggregate Foamed Concrete. International Journal of Cement Composites and Lightweight Concrete, 2(2): 101–104.

TS 825, 2013. Binalarda ısı yalıtım kuralları, Türk Standartları Enstitüsü.

TS EN 1354, 2007. Gözenekli hafif beton – Basınç dayanımının tayini. TSE, Ankara.

TS EN 13501-1+A1.Yapı mamulleri ve yapı elemanları, yangın sınıflandırması bölüm 1: Yangın karşısındaki davranış deneylerinden elde edilen veriler kullanılarak sınıflandırma, TSE, 2013.

TS EN 13501, 2013. Yapı mamulleri ve yapı elemanları, yangın sınıflandırması bölüm 1: Yangın karşısındaki davranış deneylerinden elde edilen veriler kullanılarak sınıflandırma, Türk Standartları Enstitüsü.

TS EN ISO 11925-2, 2015. Yapı malzemeleri - Yangın dayanımı deneyleri - Aleve doğrudan maruz kaldığında tutuşabilirlik - Bölüm 2: Tek alev kaynağıyla deney, Türk Standartları Enstitüsü.