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Araştırma Makalesi / Research Article

Investigation of the Effects of Fly Ash, Fine Sand and Expanded Perlite on the Properties on Foam Concrete

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Foam Concrete;
Mineral Admixtures;
Fly Ash;
Expanded Perlite;
Fine Sand

Abstract

The relevance of concrete is growing in the modern world due to population growth and technological advancement. The necessity for specialty concrete arises from the various usage regions in the constructions. Foam concrete is one of the most useful varieties of special concrete because it offers insulation from heat and sound. The mechanical and physical properties of foam concrete are influenced by a variety of elements. The characteristics of foam concrete are substantially impacted by the mineral admixtures. The physical and mechanical impacts of fly ash (FA), fine sand, and expanded perlite (EP) admixtures on foam concrete were examined in this experimental investigation. On samples made from fly ash, sand, and expanded perlite, 15 various ratios of foam concrete mixtures were tested physically and mechanically (compressive strength, Marsh cone, ultrasonic pulse velocity, and thermal conductivity), as well as microstructurally (SEM). The foam concrete samples' compressive strength values were above 1.5 MPa, which is in compliance with TS 13655. According to the Marsh cone test, the flow duration of all the samples decreased as the weight of the fresh mortar increased. In all samples, the density increased along with the ultrasonic pulse velocity.

Uçucu Kül, İnce Kum ve Genleştirilmiş Perlitin Köpük Beton Özelliklerine Etkisinin Araştırılması

Anahtar kelimeler
Köpük Beton;
Mineral Katkılar;
Külleri Uçur;
Genişletilmiş Perlit;
İnce kum

Öz

Günümüzde nüfus artışı ve teknolojinin gelişmesi betonun önemini artırmaktadır. Yapılarda farklı kullanım alanları özel beton ihtiyacını da beraberinde getirmektedir. Hafiflik, ısı ve ses yalıtımı sağlayan köpük beton, özel betonlar arasında en işlevsel beton türlerinden biridir. Köpük betonun fiziksel ve mekanik özelliklerini birçok faktör etkiler. Mineral katkılar köpük betonun özelliklerini önemli ölçüde etkiler. Bu deneysel çalışmada, uçucu kül (FA), ince kum ve genleştirilmiş perlit (EP) katkılarının köpük beton üzerindeki fiziksel ve mekanik etkileri araştırılmıştır. Uçucu kül, kum ve genleştirilmiş perlit kullanılarak elde edilen 15 farklı oranlı köpük beton karışımları üzerinde fiziksel ve mekanik testler (basınç dayanımı, Marsh konisi, ultrasonik darbe hızı ve termal iletkenlik) ve mikroyapı (SEM) incelemeleri yapılmıştır. Köpük beton numunelerinin basınç dayanım değerleri TS 13655 standardını karşılayan 1.5 MPa'nın üzerindedir. Marsh koni testi, tüm numunelerde taze harç ağırlığının artmasıyla numunelerin akış süresinin azalmasına neden olmuştur. Ultrasonik darbe hızı, tüm numunelerde artan yoğunlukla artmıştır. Uçucu kül ile üretilen köpük beton numunelerinin ince kum ile üretilen numunelere göre daha düşük iletkenliğe sahip olduğu sonucuna varılmıştır. Ayrıca uçucu kül puzolanik özellikler göstererek dayanım geliştirmede etkili olmuştur. Köpük betondaki uçucu kül, ince kum ve genleşmiş perlit katkıları, köpük betonun fiziksel ve mekanik özelliklerini iyileştirmiştir.

1. Introduction

The current rise in global population has created new demands for the construction industry. To raise people's standards and improve their access to housing, transportation, and other necessities, construction technologies must be developed and applied. Due to these factors, concrete has surpassed all other building materials in terms of usage. The concept of special concrete is introduced by producing concrete for the intended purpose.

Studies on thermal insulation are conducted in emerging countries where the building stock is growing to address environmental issues and researchers have looked into many types of insulation materials. A construction material called foam concrete is made by mixing cement mortar with foam produced by a foaming agent (Narayanan and Ramamurthy 2012).

Foam is added to mortar made by mixing water, cement, and aggregate to generate foam concrete, a type of lightweight concrete (Nambiar and Ramamurthy 2007). Seventy-five to eighty percent of its volume is made up of independent closed pores. Foam concrete is an environmentally friendly building and insulating material that contributes to energy savings by satisfying the structure's insulation needs (Ekinci 2014). Its pores, which have a diameter of 0.1 to 1 mm, make it a more effective heat and sound insulator than conventional concrete. Additionally, it is lightweight and lowers the dead load on the buildings because of its porous structure (Wei *et al.* 2014). In comparison to conventional concrete, foam concrete has a number of benefits, including good flowability and reparability. It can be used for a variety of areas, including wall blocks, precast and in-situ casting, sound insulation, floor leveling, roof insulation, bridge construction, and numerous infrastructure applications (Kuzielová *et al.* 2016, Demir *et al.* 2019).

Building safety is put at risk due to the inadequate fire resistance of exterior insulating materials made from petroleum. Consequently, the importance of foam concrete's fire resistance increases (Falliano *et al.* 2020). Foam concrete's utilization is increasing due to its low thermal conductivity and straightforward manufacture (Huang *et al.* 2015). Dry density ranges from 400 to 1600 kg/m^3, and compressive strength is between 1 and 15 MPa. Additionally, foam concrete has adequate strength and durability once it has fully hydrated (Jones and McCarthy 2005).

Rapid hardening cement (Kearsley and Wainwright 2001, De Rose and Morris 1999), calcium sulfoaluminate, and high alumina cement (Turner 2001) can be utilized in order to reduce the setting time and enhance the initial strength of foam concrete. Fly ash and ground granulated blast furnace slag can be utilized as pozzolans to improve durability, and sulfate resistance and reduce the shrinkage of the foam concrete (Jones *et al.* 2003, Pickford and Crompton 1996, Wee *et al.* 2006, Kurugöl 2012, Özvan *et al.* 2012, Bulut 2010). To improve the strength of cement, silica fume up to 10% by weight can be added (Kearsley 1996). Calcium carbonate (De Rose and Morris 1999), concrete waste (Aldridge and Ansell 2001), bottom ash, glass waste, iron foundry sand, stone powder (Jones *et al.* 2005), extruded polystyrene (Lee and Hung 2005), and expanded polystyrene can be utilized in foam concrete. Coarse sand can be used to produce foam concrete with densities ranging from 800 to 1200 kg/m^3 (Regan and Arasteh 1990).

Papayianni and Milud (2005) investigated the drying shrinkage of foam concrete, which used 60% cement instead of FA. When 60% of the fly ash in foam concrete was replaced with cement, the drying shrinkage dropped from 1800 mm to 1200 mm. They also noticed that shrinking decreased as compressive strength increased. In their research, Awana and Kumar (2017) created foam concrete utilizing fly ash and examined the performance in terms of density and compressive strength. The density was lowered by the pores they discovered in the samples. As a result, the samples that contained 1% and 1.2% of foam had higher compressive strengths than the mixtures that contained 1.4% of foam. It has been noted that as the foam concrete's pores grow larger, its compressive strength declines. Chen *et al.* (2021) investigated the fly ash substitution of fine aggregate in foam concrete and found an increase in compressive strength and sulfate resistance. Sharook *et al.* (2020) investigated the effect of expanded perlite substitution on thermal insulation in foam concrete and obtained that the strength decreases with the increase in the amount of expanded perlite, but the thermal insulation increases.

Mineral additives incorporated with the mixtures have a considerable influence on the physical and mechanical properties of foam concrete. In this research, foam concrete samples were produced by adding fly ash, fine sand, and expanded perlite in different proportions. The samples were evaluated by carrying out physical and mechanical tests and microstructure analyses.

2. Materials and Method

The binder was CEM I 42.5 R type ordinary Portland cement, which meets with TS EN 197-1 (2002) standard. Figure 1 demonstrates the particle size analysis graph for the washed and sieved fine sand that 100% of the time passed through the 1mm sieve. Additionally, Table 1 demonstrates the chemical characteristics of the fly ash used in the samples. Fly ash with a total concentration of 88.20% (SiO_2+ Al_2O_3+ Fe_2O_3) is categorized as class F (ASTM C 618). TS EN - 934-2 (2002) compliant polycarboxylic ether-based superplasticizer concrete chemical additive was utilized. Additionally, expanded perlite aggregate, polypropylene fiber to prevent shrinkage cracks, sodium hydroxide to control the effectiveness of pozzolanic activities, calcium chloride to speed up setting time, and tap water were used.

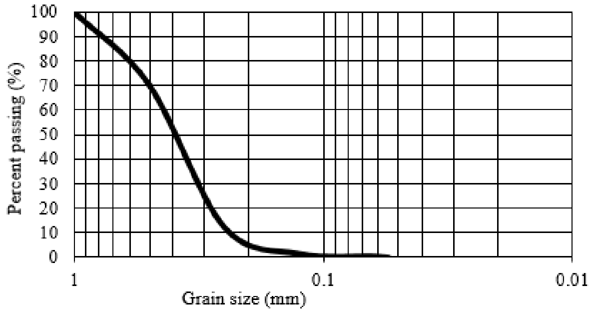

Figure 1. Grain size analysis of fine sand.

Table 1. Oxides of fly ash.

Oxide	(%)
SiO_2	56.02
Al_2O_3	22.34
Fe_2O_3	9.85
CaO	2.11
MgO	3.75
Na_2O	0.19
K_2O	2.08
SO_3	0.58
LOI	1.02

In this study, three different minerals were used as admixtures in foam concrete production, and the results were compared. To observe its effect on the mixing water, a superplasticizer was added to the mixing water between 0.3%-0.4%-0.5% of the cement by weight in the mixture, respectively. Mixing ratios are given in Table 2. CEM I 42.5 R type cement was used as the binder and at least six test samples were produced from each series.

Mixing water with superplasticizer, polypropylene fiber, cement, and mineral admixtures (fine sand, fly ash, and expanded perlite) were added to the pan mixer, respectively. The materials were added proportionally according to their weights. To compare the results, fresh mortar densities were produced at densities between 500-800 kg/m^3. Polycarboxylic ether-based superplasticizer admixture was used 0.3%, 0.4%, and 0.5% of the cement weight.

Table 2. Mixing ratios of the samples.

Sample	C (kg)	FA (kg)	FS (kg)	EP (L)	S (%)	NaOH (g)	FD (kg/m^3)	W/B	FT (s)	FCD (kg/m^3)
U.1	5	1	0	0	0	5	60	0.50	82	600
U.2	5	1	0	0	0.3	5	60	0.48	45	610
U.3	5	1	0	0	0.4	5	60	0.45	38	605
U.4	5	1	0	0	0.5	5	60	0.50	30	600
U.5	5	1	0	0	0.3	5	60	0.46	52	500
U.6	5	1	0	0	0.4	5	60	0.48	43	505
U.7	5	1	0	0	0.5	5	60	0.45	39	500
K.1	5	0	1	0	0.5	5	60	0.50	32	600
K.2	5	0	1.5	0	0.5	5	60	0.50	28	605
K.3	5	0.5	1	0	0.5	5	60	0.50	37	600
K.4	5	1	1	0	0.5	5	60	0.50	40	600
K.5	5	1	1.5	0	0.5	5	60	0.50	38	615
P.1	5	1	0	0.5	10	5	60	0.55	41	500
P.2	5	1	0	1	10	5	60	0.58	52	480
P.3	5	1	0	2	10	5	60	0.62	58	470

C:Cement, FA:Fly ash, FS:Fine sand, EP:Expanded perlite, S:Superplasticizer, FD:Foam density, W/B:Water/Binder ratio, FT:Flow time, FCD:Fresh Concrete Density.

The foam was created at the start of the study by mixing 25 parts water with 1 part of a synthetic foaming agent in the foaming machine. The superplasticizer, NaOH, and $CaCl_2$ were initially added to the water and stirred until the dissolution took place, in accordance with the mixing ratios and materials used in the samples. Once homogeneity was attained, cement, mineral admixtures (fly ash, fine sand, and expanded perlite), and polypropylene fiber were added. By incorporating the foam into the uniform mortar, mixing was continued. The mortar was put into cubic and panel molds after ensuring that the foam had been evenly distributed.

After the samples were taken out of the mold, steam curing was used to increase strength for 8–10 hours at 60 °C. The samples' collapsed or enlarged surfaces were trimmed and adjusted. The samples were stored in a drying oven at 60 °C after the curing procedure was finished until they reached a stable weight in order to calculate their density. The samples were weighed accurately to 0.1 g once the drying procedure was finished, and their densities were computed. The samples underwent the test for ultrasonic pulse velocity. A Heat Flow Meter (HFM-100) equipment was used to measure the thermal conductivity, and a 20-ton cement press was used to assess the compressive strength.

3. Results and Discussion

The results and discussion from the study are presented in this section.

3.1. Flow Time

Figure 2 displays the samples flow time results.

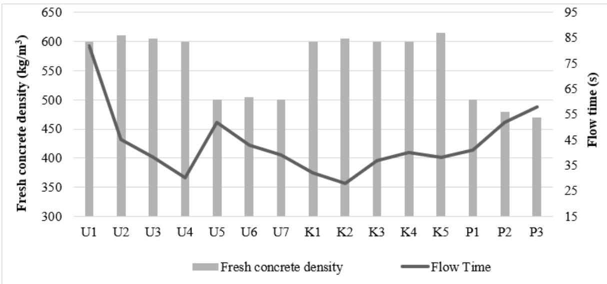

Figure 2. The flow time of the samples.

When the superplasticizer amounts were the same in the U2-U5, U3-U6, and U4-U7 samples, the flow time increased as the fresh mortar weight decreased. Without a superplasticizer, the U1 sample had the longest flow time. The density of fresh mortar increased as the amount of sand increased (Nambiar and Ramamurthy 2006, Arulmoly *et al.* 2021). Fresh mortar density dropped and flow duration increased when the expanded perlite ratio increased (Lanzón and Garca-Ruiz 2008; Demirboa *et al.* 2001; Ibrahim *et al.* 2020). At the same density, flow time decreased as superplasticizer contribution increased. In other words, the superplasticizer made fresh mortar more flowable.

3.2. Ultrasonic Pulse Velocity

The ultrasonic pulse velocity decreases with the increase of the void structure in the concrete. With the decrease in density, a decrease in ultrasonic pulse velocity of samples containing fly ash and expanded perlite was determined (Mendes *et al.* 2020, Lafhaj *et al.* 2006, Bogas *et al.* 2013). On the other hand, the ultrasonic pulse velocity of samples with fine sand, increased with the increase in density (Figure 3).

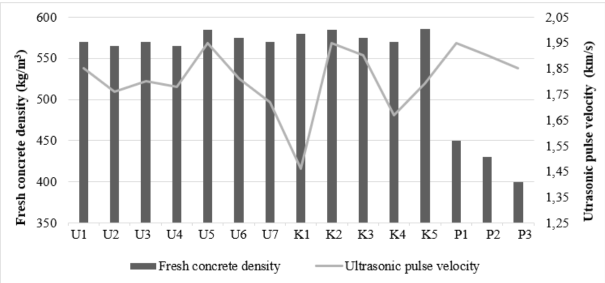

Figure 3. Ultrasonic pulse velocity of the samples.

3.3. Thermal Conductivity

The thermal conductivity of the foam concrete panel samples (30x30x5 cm) was compared with the commercial aerated concrete TS 825 standard (2008). Depending on the porosity of fly ash and its morphological structure, panel samples containing fly ash had lower conductivity than samples with fine sand (Demirboğa and Gül 2003, Bentz *et al.* 2011, Ghosh *et al.* 2018). The samples with expanded perlite had lower thermal conductivity compared to the commercial aerated concrete samples which were attributed to the lightness of the expanded perlite and its partially closed porous structure (Şengül *et al.* 2011, Xiong *et al.* 2021).

3.4. Compressive Strength

The samples with fly ash which meet the compressive strength given as a minimum 1.5 MPa in the standards, were obtained between 2.80 and 3.38 MPa (TS 13655). Furthermore, no shrinkage crack was observed in the foam concrete samples. In other words, it was determined that the fly ash additive improved the strength of the samples due to its pozzolanic property (Doğan and Demir 2021, Gopalakrishnan *et al.* 2020).

Comparing U3 to U1, the compressive strength increased because the superplasticizer in U3 provided less mixing water requirement. Superplasticizer was used in cement at a weight ratio of 0.3% in U2 and 0.5% in U4, both of which have the same density. As the amount of superplasticizer increased and the amount of water in the mixture dropped, U4's compressive strength increased in comparison to U2's.

The increase in the fine sand ratio in the mixture caused an increase in density and strength. Accordingly, the bulk density and the compressive strength of K2 improved compared to K1. Also, as the amount of expanded perlite increased, density decreased. Moreover, there was a reduction in compressive strength due to the light structure of the expanded perlite. As the bulk density decreased, the compressive strength decreased accordingly (Amran *et al.* 2015, Wongkeo *et al.* 2012, Jiang *et al.* 2016). A comparison of the density and strength of samples was shown in Figure 4.

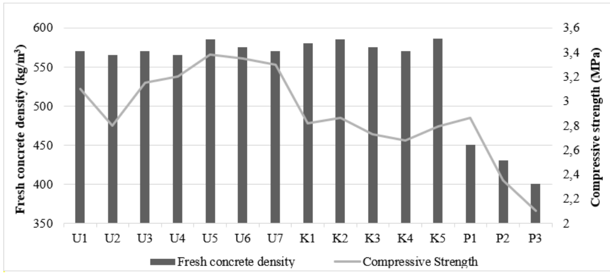

Figure 4. Compressive strength of the samples.

3.5. Microstructural Analysis

Scanning electron microscope (SEM) analysis was used in order to examine the microstructural properties of the selected foam concrete samples. U2, U3, and U5 samples were chosen for the analysis considering the mixture design, compressive strength, and density. The pore sizes varied significantly depending on the density variation of the samples (Figure 5).

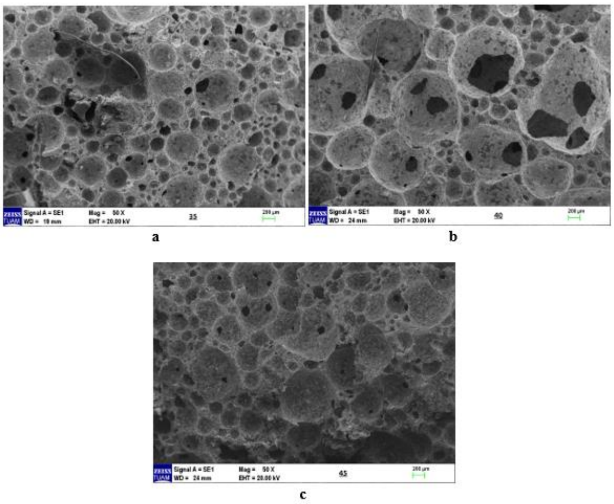

Figure 5. SEM images of U3 (a), U2 (b), and, U5 (c).

It is observed that the pore sizes of the U2 are more significant than the pore sizes of the U3 and U5 (Figure 5). The porous characteristics of cement-based materials are highly related to their mechanical properties (Sychova *et al.* 2019, Liu *et al.* 2019, Lian *et al.* 2011). This increase in the pore size of U2 (Figure 6.a), and leads to lower density and compressive strength. However, the intense presence of the ettringite (AFt) of U2 in SEM images is remarkable. Since the development of ettringite creates expansion forces, it has caused a decrease in strength in the body of U2 (Figure 6.b) (Lubej *et al.* 2016, Güçlüer *et al.* 2015, Kunther *et al.* 2013, Feng *et al.* 2015).

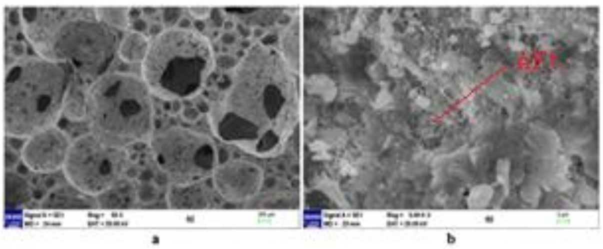

Figure 6. SEM images of the U2 50X magnification (a) and U2 5.00 K X magnification (b).

4. Conclusions

In this investigation, cement, fly ash, fine sand, expanded perlite, and chemical admixtures were used to create foam concrete samples with bulk densities of 400–670 kg/m^3. There is currently no proven way for precisely calculating the mix design in foam concrete manufacture. To make foam concrete with the correct qualities, close monitoring of the mix design and mixing speed is therefore necessary.

According to the results of the Marsh cone test, the flow durations of the samples reduced as the fresh mortar weight increased. The fresh mortar took longer to flow as the mixture's foam content increased. In all samples, the density increased along with the ultrasonic pulse velocity. All series' compressive strength exceeded 1.5 MPa and complied with TS 13655 requirements. According to the literature, fly ash increased the foam concrete's compressive strength. However, adding expanded perlite reduced the foam concrete's compressive strength while enhancing thermal insulation.

The development of the $Ca(OH)_2$ phase with the increase in the cement amount is also remarkable in the U2, U3, and U5 samples. As a result, it has been found that the density of foam concrete has a greater impact on the development of strength than its mineralogical characteristics.

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