



IJEASED

INTERNATIONAL JOURNAL OF EASTERN ANATOLIA
SCIENCE ENGINEERING AND DESIGN

Uluslararası Doğu Anadolu Fen Mühendislik ve Tasarım Dergisi

ISSN: 2667-8764 , 2(2), 337-347, 2020

<https://dergipark.org.tr/tr/pub/ijeased>




Araştırma Makalesi / *Research Article*

Doi: [10.47898/ijeased.790991](https://doi.org/10.47898/ijeased.790991)

Make Use of Volcanic Slag as Aggregate in the Production of Concrete

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Yazar Kimliği / <i>Author ID (ORCID Number)</i>	Makale Süreci / <i>Article Process</i>
*Sorumlu Yazar / <i>Corresponding author</i> : ayse.bicer@ozal.edu.tr  https://orcid.org/0000-0003-4514-5644 , A. Bicer	Geliş Tarihi / <i>Received Date</i> : 05.09.2020 Revizyon Tarihi / <i>Revision Date</i> : 23.09.2020 Kabul Tarihi / <i>Accepted Date</i> : 31.10.2020 Yayın Tarihi / <i>Published Date</i> : 15.12.2020

Alıntı / Cite : Bicer A. (2020). Make Use of Volcanic Slag as Aggregate in the Production of Concrete, International Journal of Eastern Anatolia Science Engineering and Design, 2(2), 337-347.

Abstract

In this study, thermal and mechanical properties of lightweight concretes obtained by using volcanic slag as aggregate are analyzed. Volcanic slag is a natural material that is light and low in thermal conductivity. Such slags have large reserves in many parts of the Eastern Anatolia Region. Volcanic slag obtained from the quarries in Yeniköy district of Elazığ province was used in the production of concrete as aggregate for the study. Samples were subjected to thermal conductivity, water absorption and drying, compressive and tensile strength and abrasion tests. The following results were obtained from this study: i) Volcanic slag is lighter than sand in terms of aggregate, ii) When examined in terms of strength, it can provide BS14 concrete class required by standards. iii) It is a good building material due to its thermal and sound insulation properties.

Keywords: Volcanic slag, Light concrete, Aggregate, Building material.

Volkanik Cürufun Agregası Olarak Beton Üretiminde Değerlendirilmesi

Özet

Bu çalışmada, volkanik cürufun agregası olarak kullanılmasıyla elde edilen hafif betonların ısı ve mekanik özellikleri incelenmiştir. Volkanik cüruf, yapı itibarı ile hafif ve ısı iletkenliği düşük olan doğal bir malzemedir. Bu tür cüruflar Doğu Anadolu Bölgesi'nin birçok yöresinde geniş rezervlere sahip bulunmaktadır. Çalışma için Elazığ ilinde bulunan Yeniköy mevkiindeki ocaklardan temin edilen volkanik cüruf, agregası olarak beton üretiminde kullanılmıştır. Numuneler ısı iletkenlik, su emme ve kuruma, basınç ve çekme dayanımı ve aşınma deneylerine tabi tutulmuştur. Bu çalışma sonucunda i) Volkanik cüruf agregalı betonların maliyet yönünden normal betonlardan daha ekonomik olduğu, ii)

Dayanım yönünden incelendiğinde üretilen betonların standartların gerektirdiği BS14 beton sınıfını sağlayabildiği, iii) Isı ve sese karşı yalıtım özelliği nedeniyle iyi bir yapı malzemesi olduğu saptanmıştır.

Anahtar Kelimeler: *Volkanik cüruf, Hafif beton, Isıl iletkenlik, Yapı malzemesi.*

1. Introduction

The excess of unit volume weight of conventional concrete used in reinforced concrete constructions is generally a significant disadvantage. This disadvantage causes an increase in self weight in reinforced concrete structures. Today, efforts to produce low unit weight lightweight concrete are gaining more and more importance in order to reduce the unit weight of concrete (Yıldırım and Aksoy, 1996). Lightweight concretes are still produced using many methods, but most of these methods fail to achieve the intended economical conditions. The reasons for the use of lightweight concrete in buildings can be summarized as follows: by means of reducing the self-weight of the structure, shrinking its cross-section, reducing the equipment to be used, providing heat and sound insulation along with reliability against earthquake and fire. However, evaluation of the existing light aggregate in regions where normal concrete aggregate is not available makes light concrete production more attractive to be used.

Additionally, the production of natural lightweight aggregate is quite cost-efficient since it does not require any specific technology or fabrication, and the cost of construction elements to be produced with this material also is also more affordable. Today, lightweight concrete has become the most important construction material in the world especially in residential construction (Bicer, 2019-a), (Bicer, 2020).

A number of studies have been carried out on the addition of volcanic slags to cement or on their use in concrete as aggregates. Some of these studies are summarized below;

Lemougna et al., (2020), investigated the effect of ground granulated blast furnace slag on the geopolymerization of low reactive volcanic ash. Contrafatto et al., (2020), studied on concerns the reuse of pyroclastic products generated by volcano Etna eruptions for production of lightweight insulating mortar. Sapci et al., (2014), analyzed the eligibility criteria for use as light aggregate and volcanic ignimbrite formations in and around Aksaray-Taşpınar region. Salazar et al., (2017), investigated the effect of high amount (70%) of natural volcanic pozzolan on alkali activation and the addition of up to 30% granular blast furnace slag on the strength of concrete. Demirdag et al., (2003, 2004), analyzed the usability of volcanic slag aggregates in the building industry. Khan and Amin (2017), investigated the effect of basaltic

volcanic ash which can be found in the eastern province of Saudi Arabia on the compressive strength of concrete as mixed with different percentages. Letelier et al., (2020), investigated the effects of volcanic dust obtained from the last eruption of Calbuco volcano (Chile) on the strength of cementitious concrete added to clinker

Elazığ region has rich volcanic slag reserves as in many regions of the country. There are slags of different petrographic character around Yeniköy, Saricubuk, Karayazi, Serince and Karakocan in the region. It is an important coincidence that most of these volcanic slag reserves are close to Elazığ city center and other settlements (Neville, 1991). The slag analyzed in this study was obtained from slag quarries located in Yenikoy location 5 km south of Elazığ and which was used as an aggregate for concrete production. Due to the low density of the volcanic slag aggregate, the density of the concretes prepared is also low. Especially when it is intended to reduce the weight of the building, light concretes are of vital importance, due to the fact that potential earthquake damages will be able to be minimized.

In this study, after determining the physical properties of volcanic slag with the experiments made according to TS 699, it was divided into two separate groups according to their particle diameters (largest grain diameter $D_{max} = 31.5$ mm and $D_{max} = 16.0$ mm) to be used as aggregate. Volcanic slag has been used as aggregate in lightweight concrete production in two ways. This method of use is either as a whole of the volcanic aggregate or with the addition of natural sand in certain proportions. The prepared samples were subjected to thermal conductivity, water absorption and drying, compression and tensile strength and abrasion tests.

2. Material and Methods

2.1. Materials

2.1.1. Volcanic Slag

The main purpose of using volcanic slag as aggregate, which has a light and porous appearance, is to produce lightweight concrete and to provide energy saving by thermal insulation in buildings. The high energy costs reveal the importance of volcanic slag aggregate concrete. The volcanic slag used in the tests is a blasted rock and has a blackish-gray, hollow and spongy appearance (Figure 1). The rock generally consists of plagioclase microliths arranged in a certain direction and among them olivine crystals and oxidized glassy materials. Olivines are mostly shapeless, sometimes semi-shaped and their grain sizes are differ from each other. Gas cavities in

the material are not filled with any second mineral. Olivine constitutes 25% to 30% of the rock. Therefore, the rock can be named as basalt with olivine. The values as can be seen in Table 1 were determined in the tests carried out on the volcanic slag sample according to Turkish standard (TSE 699, 2016).



Fig 1. Volcanic slag

Table 1. Physical properties of volcanic slag

Physical property	Value	Unit
Compressive strength	18	N/mm ²
Unit volume weight	1.15-1.40	g/cm ³
Specific weight	2.20	g/cm ³
Abrasion (Böhme DIN 52108)	11	%
Loose unit weight (as aggregate)	0.550-0.780	g/cm ³
Porosity	0.35-0.45	%
Water absorption	4.5	%

2.1.2. Cement

PÇ 325 cement obtained from Elazığ cement factory was used in the production of concrete samples (TSE 24, 1974). Table 2 shows the chemical component of cement used in this study respectively

Table 2. PÇ 325 cement components, (%)

Component	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	K ₂ O	LOI	Not avail.
PÇ 325	18.65	6.15	3.25	56.4	2.34	2.91	0.7	2.84	6.75

After pouring the prepared mortars into molds measuring 150x60x20 mm for thermal tests and 100x100x100 mm for strength tests, the samples shown in Figure 2 were prepared and left for the 28-days of drying process.



Fig 2. View of samples

2.2. Methods

2.2.1. Thermal Conductivity

Measurements were made with the “*Shotherm-QTM*” brand device, which measures in the temporary regime and works with the Hot Wire method (Denko, 1990), (Vysniauskas et al. 1988) (Figure 3). With this device measuring according to DIN 51046 norm, thermal conductivity coefficient was measured at 22-25 °C room temperature and 5 different points on each sample and arithmetic averages of 3 values that were compatible with each other were taken from these measurements. The device gives the heat transfer coefficient in the range of 0.02-6 W/mK with 5% accuracy.



Fig 3. Shotherm-QTM unit

2.2.2. Compressive Strength, Tensile Strength and Abrasion Tests

In the compressive strength test of the samples, *Ele* International brand device was used, which can apply force on 3000 kN on a single axis. According to TS 500, compressive strength values are converted to tensile strength results with Equation (1) (TSE 500, 2000).

$$f_{ctk} = 0,35 \cdot \sqrt{f_{ck}} \quad (1)$$

In here, f_{bd} : is the compressive strength (N/mm²) and f_{cd} : is the tensile strength (N/mm²)

In the volcanic slag abrasion (bohme) test, the wear loss value in terms of volume was determined as 11% for 88 cycles.

2.2.3. Water Absorption Test (WAT)

The purpose of this test is to determine the resistance of the materials against the freezing risk at temperatures lower than 0°C and in contact with water. The critical value is that the water absorption rate is less than 30%. Where the water absorption rate exceeds this value, there will be a risk of cracking, breaking and spreading in the material (Bicer, 2019-b), (Ytong, 1985). For this test, the dry weight (W_k) and the water absorbed weights (W_d) of the stones were measured and the water absorption rates were calculated with Equation (2).

$$WAT = \frac{W_d - W_k}{W_k} \cdot 100 \quad (2)$$

3. Results and Discussion

Volcanic slags consist of important natural pozzolanic materials. They are also suitable for use in light concrete production and as a cement additive. They can also be used as a natural rock in the construction of building elements. The increasing energy costs and the fact that the building need does not require sacrifice from the comfort of use reveals the importance of volcanic slag aggregate concrete.

Turkey has rich reserves in terms of volcanic slag. This is an important advantage, and the use of the material for appropriate purposes will provide significant benefits to the national economy. Using the thermal insulation feature of the volcanic slag will provide significant gains in terms of heat energy consumption due to the cold winter seasons.

The volcanic slag has been brought to the brick dimensions and it is possible to use it especially in the construction of filler (partition) walls in buildings. Lightweight briquette blocks produced artificially are still used for this purpose. Where volcanic slag is used as briquettes or bricks, the thermal conductivity coefficient has been determined as 0.260-0.290 W/mK on average. Examining similar studies, the thermal conductivity coefficient was determined by Contrafatto et al

(2020) as 0.154-0.266 W/mK for Etna volcanic aggregates and 0.189-0.227 W/mK for Aksaray ignimbrites by Sapci et al (2014). The heat conduction coefficients obtained following the measurements carried out are slightly higher than these two aggregates. This difference is related to the porosity of aggregates.

When the thermal conductivity coefficients of volcanic slag aggregate concretes of 0.360-0.795 W/mK in this study are compared with the average heat conduction coefficient of normal concretes of 1.4 W/mK (Density: 2307 kg/m³) (Toksoy, 1988), the importance of volcanic slag aggregate can be clearly understood. It can be clearly seen that volcanic slag is a natural material and it also provides a significant cost-efficiency in building expenses and heating costs thanks to having large reserves in the region.

The volcanic slag was broken up to be used in light concrete production as aggregate and was brought to grain sizes specified in TS 1114 (1986). Within the scope of test-based studies, volcanic slag was used as an aggregate in two ways within light concrete production. This method of use is either as the whole aggregate needed or in combination with the addition of natural sand in certain proportions.

When producing lightweight concrete samples for thermal insulation purposes, two separate series samples were prepared based on the granulometric combination, which was foreseen in TS 1114, with the largest grain diameter of the volcanic slag used as aggregate, D_{max} = 31.5 mm and D_{max} = 16.0 mm. The granulometric composition of the samples can be seen in Table 3.

Table 3. Granulometric combination of volcanic slag used

Screen size (mm)	1.5	6.0	8.0	4.0	2.0	1.0	0.50	0.25
Passed Serie I	-	100	76	56	42	32	20	8
(%) Serie II	100	80	62	47	37	26	17	8

In each series, three standard samples were prepared separately for measuring unit volume weight, compressive strength, abrasion, water absorption and drying and thermal conductivity. In concrete samples, Water / Cement (W/C) = 0.40 was kept constant. The results obtained from the tests can be seen in Table 4 and Fig. 4). The compressive strength values of 14.8-19.4 N/mm² measured on the samples are close to or lower (10-32 N/mm²) according to the compression stress value of concrete with Etna volcanic aggregates determined by Contrafatto et al (2020) (According to aggregate grain diameter and cement ratio), the compressive strength (6-6.5 N/mm²) of Aksaray ignimbrites aggregate concretes determined by Sapci et al (2014) is found to be higher.

Table 4. Properties of concrete with volcanic slag aggregate

Serial No	Max. grain diam.(mm)	Unit volume weight (gr/cm ³)	Thermal con. (W/mK)	Compressive st. (N/mm ²)	Tensile st. (N/mm ²)	Water ab. (%)
I	16.0	1.32	0.430	14.8	1.35	5.8
II	31.5	1.25	0.360	13.6	1.29	8.6
Concrete	31.5	2.24	0.795	19.4	1.54	3.1

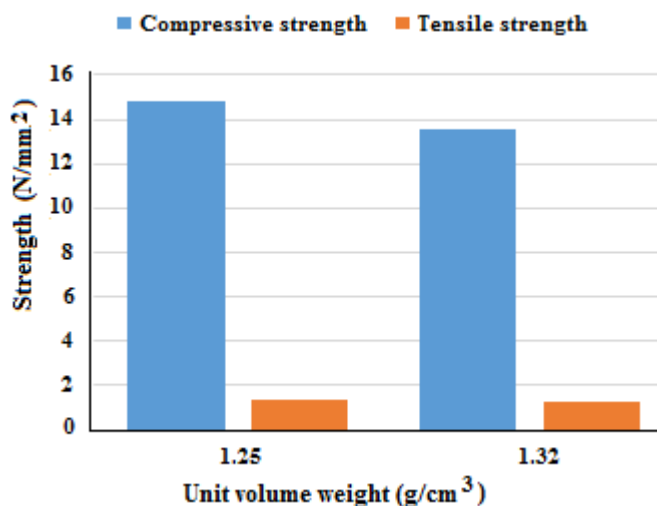


Fig 4. Strengths values versus unit volume weight

The mass change versus time in the water absorption test of the concrete is shown in Figure 5. Water absorption rates below 30% indicate that there is no risk of freezing of the concretes in question at temperatures below 0 °C. In the drying test, as seen in Figure 6, it can be seen that the volcanic slag concrete samples in particular have little breathing ability.

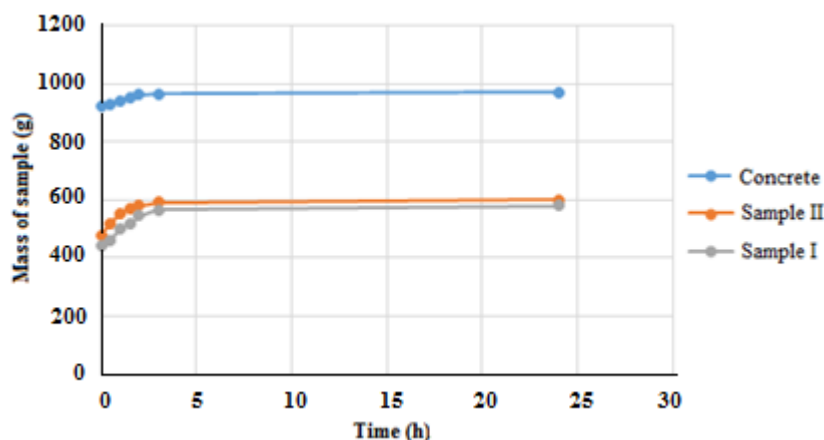


Fig 5. Mass change of samples in water absorption tests

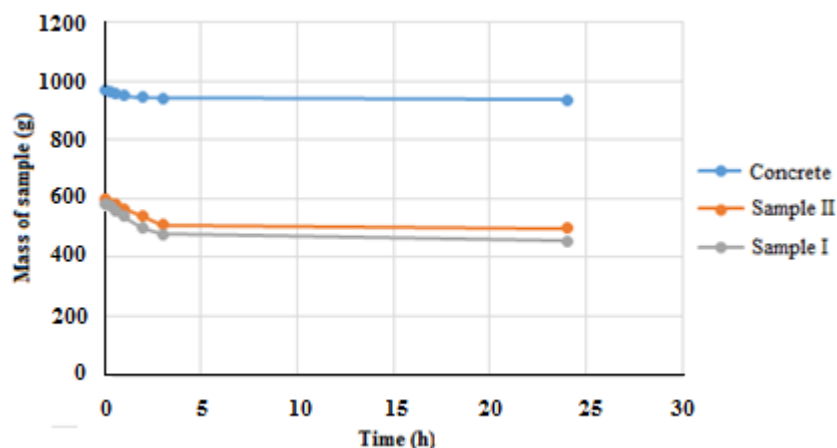


Fig 6. Mass change of samples in the drying test

When producing concrete samples for thermal insulation, it is possible to increase the strength of concrete by adding natural sand to the volcanic slag used as aggregate. However, in this case, the thermal insulation property of the concrete will be negatively affected. The values obtained by adding 8%, 18% and 30% (0-4) mm natural sand to the volcanic slag aggregate are shown in Table 5, Fig. 7 and Fig.8.

Table 5. Properties of volcanic slag + concrete with natural sand aggregate

Sample No	Sand (%)	Unit volume weight (gr/cm ³)	Thermal con.(W/mK)	Compressive st. (N/mm ²)
1	8	1.436	0.480	15.1
2	18	1.583	0.565	16.8
3	30	1.764	0.640	19.4

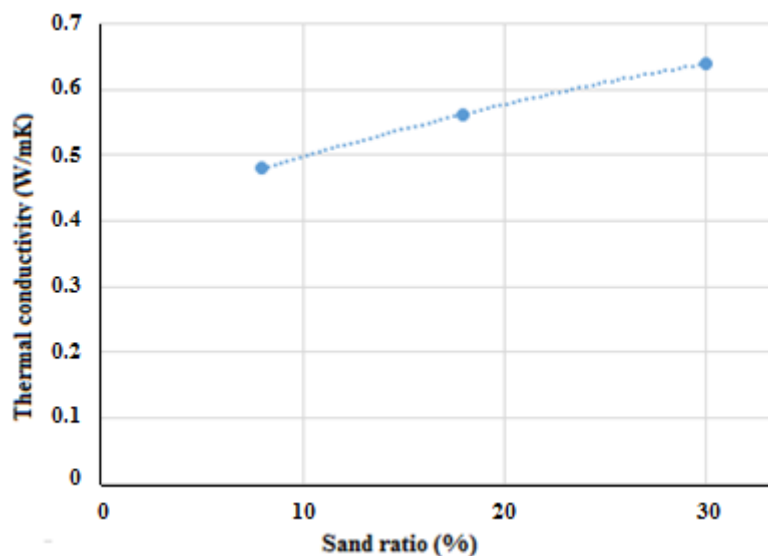


Fig 7. Thermal conductivity variations according to sand in volcanic slag concrete

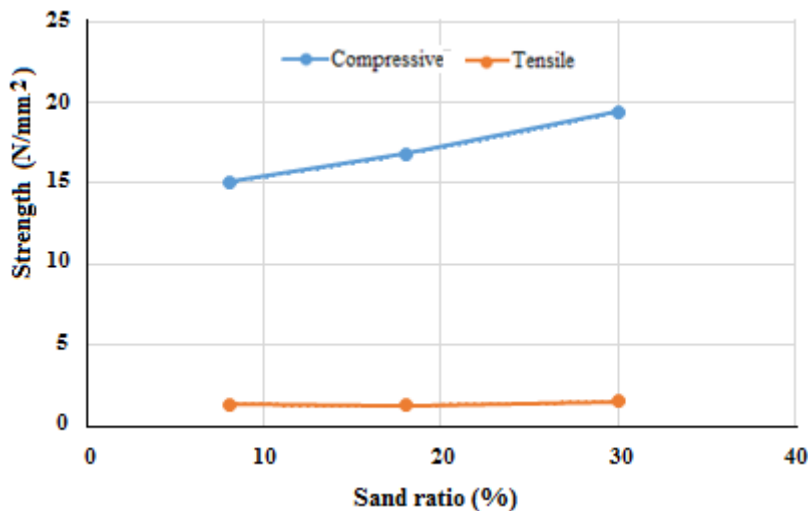


Fig 8. Strengths variations according to sand in volcanic slag concrete

4. Conclusions

The following results were obtained in this work carried out to evaluate the volcanic slag in the Elazig region.

✓ In case the volcanic slag with sufficient zones in the region is used as a partition element in the form of brick or briquette, it will lighten the building weight and reduce heating costs with its light weight and 0.260-0.290 W/mK heat transmission coefficient.

✓ Slag has advantages that can be used as aggregate in light concrete production. In this case, thermal conductivity is reduced by 40-50% compared to normal concrete, and 20-30% reduction in structure self-weight. The compression stresses of this type of concrete are reduced by 15 N/mm² and the heat transmission coefficients as 0.360 W/mK. In this case, earthquake effects will be reduced in terms of building safety due to both building heat and sound insulation and to a decrease in the building self-weight.

✓ In the event that the aim is to increase the strength values of the buildings, volcanic slag + sand mixtures can be used as aggregate. In this case, the compressive strength value of the concrete will be increased by 20 N/mm², while the heat transmission coefficient will increase by 0.640 W/mK.

In conclusion, it can be suggested to use volcanic slag in concrete as potential aggregate material based on this study

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