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USE OF HIGH SULFATE FLY ASH IN PUMICE BLOCKS

Serhat DENKTAŞ, Faculty of Engineering and Natural Science, Konya Technical University, Türkiye, serhatdenktas@yahoo.com
(https://orcid.org/0000-0002-5772-7695)
Furkan TÜRK*, Faculty of Engineering and Natural Science, Konya Technical University, Türkiye, fturk@ktun.edu.tr
(https://orcid.org/0000-0002-8156-0354)
Ülkü Sultan KESKİN, Faculty of Engineering and Natural Science, Konya Technical University, Türkiye, uskeskin@ktun.edu.tr
(https://orcid.org/0000-0002-9517-9116)

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*Corresponding author
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Abstract

In order to reduce cement consumption, which is one of the significant factors in man-made carbon dioxide emissions, studies are being conducted on issues such as alternative building materials. Replacing cement with fly ash is at the forefront of cement reduction studies. However, the use of fly ash with a high sulfate content in structural elements is limited by European and American standards. Here the production of pumice stones used as wall material is discussed. Pumice blocks were made by replacing the cement in pumice blocks with high sulfate fly ash. High sulfate fly ash increased the late strength of pumice blocks by about 13%. In addition, as a result of a brief economic analysis for Türkiye, it turned out that wall costs could be reduced by up to 8% thanks to the replacement of fly ash. The mechanical and physical tests performed on the blocks produced concluded that the cement could be replaced with fly ash with a high sulfate content of up to 30%.
Keywords: High sulfate fly ash, Pumice block, Pumice concrete, Sustainable building materials.

BIMS BLOKLARDA YÜKSEK SÜLFATLI UÇUCU KÜL KULLANIMI

Özet

İnsan kaynaklı karbondioksit emisyonlarının ana aktörlerinden biri olan çimento tüketimini azaltmak için alternatif yapı malzemeleri gibi konularda çalışmalar yapılmaktadır. Çimentonun uçucu kül ile ikamesi, çimento azaltım çalışmalarının ön saflarında yer almaktadır. Ancak yüksek oranda sülfat içeren uçucu külün yapı elemanlarında kullanımı Avrupa ve Amerika standartları tarafından sınırlandırılmıştır. Burada duvar malzemesi olarak kullanılan bims blok üretimi ele alınmıştır. Bims bloklarındaki çimentonun yüksek sülfat içeren uçucu kül ile değiştirilmesiyle bims bloklar üretilmiştir. Yüksek sülfatlı uçucu kül, bims blokların geç dayanımlarının yaklaşık %13 artmasına neden olmuştur. Ayrıca Türkiye için kısa bir ekonomik analiz sonucunda uçucu kül ikamesi sayesinde duvar maliyetinin %8'e varan oranlarda azaltılabileceği görülmüştür. Üretilen bloklar üzerinde yapılan mekanik ve fiziksel testler ile çimentonun %30'a kadar yüksek sülfatlı uçucu kül ile değiştirilebileceği sonucuna varılmıştır.
Anahtar Kelimeler: Yüksek sülfatlı uçucu kül, Bims blok, Bims beton, Sürdürülebilir yapı malzemeleri.

Cite

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1. Introduction

Cement, which is responsible for around 7% of man-made CO_2 emissions worldwide [1] and generates quite a lot of energy costs [2], is a material that is very difficult to do without in the construction industry. There are many studies on the environmental risks in the production and consumption of cement, the binder of concrete, a cheap, easily shaped and quickly manufactured building material, and on reducing consumption [3-6]. The most common technique to reduce the amount of cement, especially in concrete mixes, is to replace the cement with pozzolanic additives. Therefore, fly ash, which is a pozzolanic material, is widely used in the literature as a replacement material in mortars [7], brick making [8] and geopolymer mixes [9-12], as well as mixes such as conventional concrete [13-15], lightweight concrete [16, 17] and self-compacting concrete [18, 19].

Pumice, an aluminum silicate of igneous origin and cellular structure [7] with high fire resistance and low thermal conductivity [20], is used to manufacture various building materials, such as lightweight concrete [21]. Considering that 60% of the energy used in buildings is used for space heating and cooling [22], it could be advantageous to use air-entrained pumice stone for thermal insulation in buildings [23, 24].

This paper focuses on producing concrete blocks from pumice stone, which could be used for reasons such as increasing fire resistance of buildings, reducing energy consumption for space heating and cooling and reducing the weight of the building [25]. The cement used as a binder in the manufacture of pumice blocks was replaced with high sulfate fly ash at levels of 20%, 30% and 40%. Physical and mechanical tests were carried out on the produced samples. In addition, an analysis of the cost of the samples produced was also carried out.

1.1. Significance and motivation of research

A large amount of fly ash is released today, posing severe environmental risks as well as storage and disposal costs. Fly ash released from thermal power plants of countries with low-quality lignite deposits, such as Türkiye, cannot be used due to its high sulfate content. ASTM limits the SO_3 content of fly ash that can be used in concrete to 5% and EN to 3%. The reason for this is that the high SO_3 content influences the setting time and strength of the concrete. In addition, various durability issues could arise. However, it is foreseeable that building materials that are not responsible for carrying loads will not be affected by the above problems. For these reasons, the motivation of this study is to demonstrate the economic and environmental benefits of using high sulfate fly ash in wall-building materials that are not expected to support static loads.

2. Material and Method

In this study, 13.5x37.5x18.5 cm pumice blocks containing 20 (FA20), 30 (FA30) and 40% (FA40) high sulfate fly ash were produced, as well as the sample containing 100% CEM I 42.5 R ordinary Portland cement (control). The chemical components obtained by XRF analysis of fly ash and pumice used in the study are presented in Table 1. Pumice stone with a grain diameter of 0-8 mm was used in the study. Fine aggregate was used as aggregate, the grain size of which is indicated in Figure 1.

Table 1. Chemical composition of the high sulfate fly ash and pumice

Component	Quantity (%)	
	FA	Pumice
SiO_2	35.50	35.50
Al_2O_3	12.95	12.95
Fe_2O_3	11.78	11.78
CaO	17.76	17.76
MgO	2.33	2.33
SO_3	13.73	-
K_2O	1.44	1.44
Na_2O	0.15	0.15
Undamped bulk density	-	400-450 kg/m^3
Specific weight	-	2.327 g/cm^3
Mohs hardness	-	5.5-6
Color	-	Light grey

2.1. Production

The manufacture of the pumice blocks made with the mixing ratios given in Table 2 is based on mixing the raw materials, placing them in molds by a compression press and drying them. One hundred ninety-two blocks of pumice were prepared for each mixed sample type.

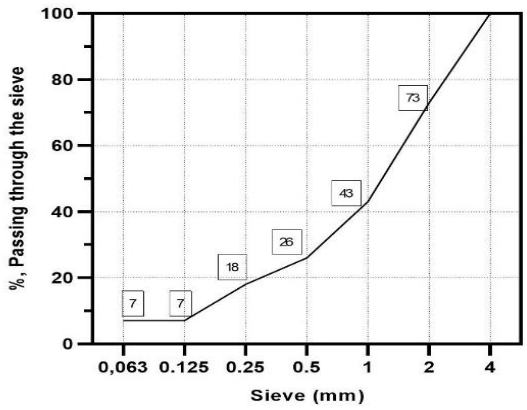

Figure 1. Granulometry distribution of fine aggregate

The production took place on fully automatic machines with computer support (Figure 2a). The prepared mixtures were taken out of the mixer, transferred to the press silo and poured into molds using a pressurized vibratory machine of about 7 tons (Figure 2b, c). The pumice stones formed by molding were picked up on wooden pallets and transported to the hardening room using a fully automated system (Figure 2d)

Table 2. Pumice blocks mixing proportions

Specimen	Aggregate (kg)	Pumice (kg)	Cement (kg)	Fly ash (kg)	Water (kg)
Control	575	2375	240	0	103
FA20	575	2375	192	48	103
FA30	575	2375	168	72	103
FA40	575	2375	144	96	103

Figure 2. Production processes (a) automatic machine; (b, c) produced specimens; (d) curing

2.2. Experimental Study

Dimensional analysis was carried out on the specimens produced within the scope of the study, according to TS EN 772-2 [26] standard and the TS EN 772-16 standard [27]. These standards cover the methods for determining the end-to-end dimensions of the manufactured products, the outer and inner wall thicknesses and the sum of these thicknesses, the depth of the gaps and the plane parallelism of the plate surfaces. In this way it was determined whether each product produced conforms to the standard or not and whether it remains within the tolerance values.

Appearance analysis was performed for each sample produced according to TS EN 772-16, TS EN 772-2 and TS EN 772-20. The different aspects of each sample produced versus the control sample were observed, and it was discussed whether it would be acceptable under market conditions.

The net and gross dry unit weight determination of the specimens was made according to the TS EN 772-13 standard [29]. In addition, at the end of 7 days and 28 days of curing, compressive strength tests were carried out with the help of a 600 kN capacity "Liyatest" press calibrated under the conditions specified in the TS EN 772-1+A1 standard [30].

3. Result and Discussion

3.1. Dimension, Appearance, and Unit Volume Weight Analysis

The dimension (Figure 3) and unit volume weight analysis performed on the specimens are presented in Table 3. Dimensional analyses were performed on six samples, unit weight tests were performed on three samples, and average results were presented. As a result of the dimensional analyses made with the help of calipers and rulers, it was determined that the specimens produced complied with the standards. On the other hand, the results of the appearance analysis expressing the conformity of the produced specimens with shape, surface space, color, and market conditions are presented in Table 4. According to these results, it has been determined that the FA40 specimen is darker in color than the equivalent products and has almost no superficial voids.

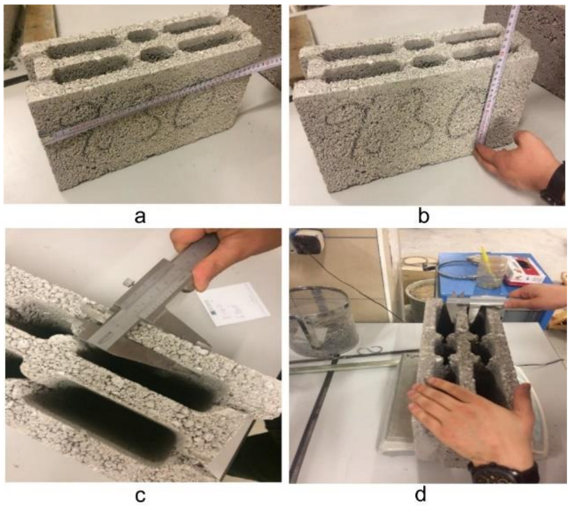

Figure 3. Dimensional analysis, (a) length measurement; (b) height measurement; (c) outer wall thickness measurement; (d) inner wall thickness measurement

Therefore, it was concluded that FA40 pumice blocks would not behave following their intended use in this case. Since the specific gravity of fly ash is lower than the specific gravity of cement, the unit volume weight was lower in specimens with 20% and 30% high sulfate fly ash substituted [31]. In the FA40 specimen, on the other hand, it is thought that better compaction was obtained due to the positive effect of fly ash on the workability [32, 33], and accordingly, a higher unit volume weight was obtained. Considering the strong relationship between unit volume weight and thermal conductivity [34], it is thought that FA20 and FA30 specimens will show better thermal conductivity performance. However, thermal conductivity tests must be performed in order to make an accurate assessment. Furthermore, reducing the unit weight of the walls used in the buildings can reduce the stresses caused by the earthquake effect since the earthquake loads acting on the buildings are proportional to the weight of the building [34]. In this case, it is thought that the use of low-unit-weight pumice blocks with fly ash substituted will also provide an advantage in earthquake resistance.

Table 3. Dimensional analysis results

Specimen	Length (cm)	Width (cm)	Height (cm)	Inner wall thickness (cm)	Outer wall thickness (cm)	Unit volume weight (gr/cm^3)
Control	37.5	13.5	18.5	2.24	2.25	0.714
FA20	37.5	13.5	18.5	2.24	2.25	0.706
FA30	37.5	13.5	18.5	2.22	2.22	0.695
FA40	37.5	13.5	18.5	2.10	2.20	0.713

Table 4. Dimensional analysis results

Specimen	Shape	Superficial spaces	Color	Conformity
Control	Quadrangular	Slightly less	Grey	Acceptable
FA20	Quadrangular	Slightly less	Grey	Acceptable
FA30	Quadrangular	Slightly less	Grey	Acceptable
FA40	Quadrangular	Quite a few	Dark grey	Not acceptable

3.2. Compressive Strength

The 7-day and 28-day compressive strengths of the specimens produced within the scope of the study were determined. In order to ensure uniform stress distribution in the compressive strength test, the upper and lower surfaces of the samples were capped with a mortar mixture of approximately 2 cm thickness and prepared with 1/1 cement and fine sand. In order for the capping mortar not to fill the gaps of the blocks, the sample gaps were closed with pieces of paper that did not affect the compressive strength (Figure 4). Then, the capped samples were subjected to a compressive strength test at a loading speed of 0.6 MPa/s in a fully automatic press machine. 7-day and 28-day compressive strength results determined by the average of three samples from each group are presented in Figure 5.

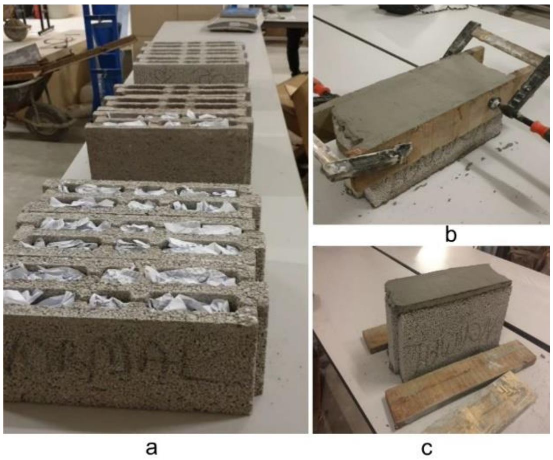

Figure 4. Compressive strength test preparation stages, (a) filling in the blanks with paper; (b, c) capped specimens

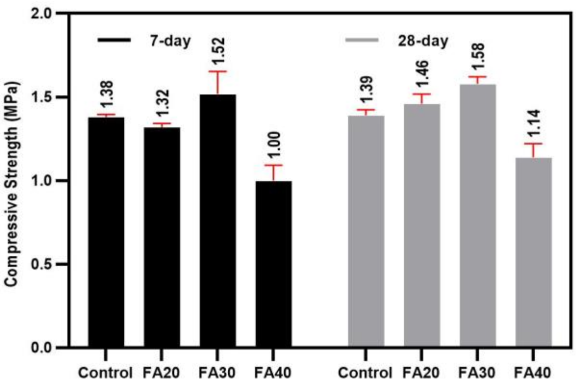

Figure 5. Compressive strength of specimens

Even though the 7-day compressive strength of the 20% fly ash substituted samples remained as low as 3% compared to the control sample, there was an increase of approximately 5% in the 28-day compressive strength compared to the control sample. While an increase of approximately 10% was detected in the 7-day compressive strength of the FA30 sample compared to the control sample, there was an increase of up to 13% in the 28-day strength. The 7-day strength of the FA40 sample was approximately 27% lower than the control sample. It was determined that there was a loss of strength of 18% in the 28-day strength.

When the error bars given in Figure 5 are examined, it is understood that the experimental error may increase with the increase in the amount of fly ash, especially at an early age. Although the compressive strength values are quite low, the experimental results were determined with acceptable errors.

It is known that fly ash reacts with weak hydration products (C-H) in cementitious composites to form strong structures (C-S-H). However, since this reaction takes place more slowly than hydration, which is a cement-water reaction, the rate of strength development also decreases, resulting in lower early strength. It has already been reported in studies in the literature that fly ash reduces the early strength of cementitious composites [35, 36]. However, it is also known that when replaced with cement up to a specific rate (~ 20-30%), it provides an advantage in late strength compared to the control sample [37]. This is attributed to the formation of strong C-S-H and C-A-H bonds as a result of the reaction of amorphous structures with C-H, and the filling effect of ash particles that do not enter the reaction [38]. Supit et al. 2014 [39] reported that ultrafine fly ash has a higher amorphous content than the other fly ash used in their study and has a higher strength-enhancing effect. Moreover, it could be said that the fly ash used in the study positively affects the increase in strength due to its high CaO content [40].

3.3. Cost Analysis for Türkiye

In order to investigate the cost of the products (control, FA20, and FA30), which were determined to be suitable for use within the scope of this study, a cost analysis was carried out according to the current unit prices published by the Ministry of Environment, Urbanization and Climate Change of the Republic of Türkiye in 2019 [41]. Accordingly, the price of fly ash was determined as $5.45/ton, and the shipping cost of fly ash, which is assumed to be 85 km away from the pumice block production facility, was $4.18/ton. CEM I 42.5 R ordinary Portland cement price is taken into account as $40.18/ton. Aggregate and pumice costs were calculated according to the price information obtained from local sources. Accordingly, the aggregate cost is $2.36/ton, and the pumice cost is $6.54/ton.

According to the data of the Turkish Statistical Institute, 180 thousand of housing construction licenses were issued in 2019 [42]. When the wall requirement of a house is calculated as 360 m^2 on average, 65 million m^2 of the wall must be built. Assuming that pumice blocks are used throughout this construction, 993 million pumice blocks are needed. The cost to be incurred if these blocks are 100% Portland cemented and fly ash substituted is presented in Table 5.

Table 5. Wall cost calculation of residential construction in Türkiye in 2019

Specimen	Unit cost ($/piece)	Total cost ($)
Control	0.138	137 million $
FA20	0.13	129 million $
FA30	0.127	126 million $

It is understood from this that the cost is reduced by about 6% in the case of replacing the cement with 20% fly ash in the production of pumice blocks, and the cost is reduced by about 8% in the case of replacing 30% fly ash.

4. Conclusions

As a result of the study, the following conclusions were reached;

- Substitution of 30% high sulfate fly ash to pumice blocks had no effect on the size and appearance of the samples.
- High sulfate fly ash substitution caused a decrease in the unit weight of pumice blocks.
- High sulfate fly ash substitution caused a decrease in early strength and increased late strength of pumice blocks. The reduction of strength at early age could be an obstacle to the immediate use of the blocks after their production. However, the higher strength gained as a result of pozzolanic reactions at late ages improves the properties of the final material.
- In terms of final strength, the highest increase in compressive strength (approximately 13%) was obtained in the sample with 30% fly ash replacement. In the sample with 40% fly ash replacement, approximately 22% strength loss was determined. It is understood that substitutions made at rates lower than 30% will not cause significant changes.
- As a result of the economic analysis, it was concluded that if 20% and 30% high sulfate fly ash is substituted in pumice blocks, a cost reduction of up to 6% and 8%, respectively.

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