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Utilization Of Zeolite And Blast Furnace Slag For The Production Of Autoclaved Aerated Concrete

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ABSTRACT
This study aimed to use zeolite and blast furnace slag (BFS) as main raw materials in the production of autoclaved aerated concrete (AAC). AAC is a light building material obtained by bringing the material of silica sand, cement, gypsum, lime and pore-forming agent together and hardening it in autoclave. In this study, instead of silica sand, samples of AAC were produced using zeolite and BFS. Experimental measurements were carried out to determine the physical, mechanical and thermal properties of the AAC samples. The microstructural investigations were carried out using SEM and XRD technique. According to the obtained results, it has been found that the physical and mechanical properties of the series produced with BFS are better than zeolite. Thermal conductivity coefficients of 630 kg/m^3 bulk density were determined as 0,127 W/mK in series produced with BFS. This value was found to be 0.139 W/mK at the bulk density of 550 kg/m^3 in the series produced with zeolite.

Keywords - AAC, zeolite, BFS, physical and mechanic properties, thermal properties.

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I. INTRODUCTION

AAC is made by introducing air or gas into a slurry composed of Portland cement or lime and finely crushed siliceous filler so that when the mix sets and hardens, a uniformly cellular structure is formed [1].

The first commercial production of AAC was in 1923 in Sweden. Since then, it has now been used in more than 40 countries in Europe, America, Australia, the Middle East and the Far East. The modern uses of AAC in the United States began in 1990 for residential and commercial buildings. AAC masonry blocks can be made as precast building blocks and are used in residential construction, hospitals, office buildings and university accommodations.

AAC masonry blocks have many advantages in comparison to conventional concrete: lighter weight (typically weight one-sixth to one-third of conventional concrete), lower building costs and provides thermal and acoustic insulation [2-4].

Other advantages of AAC are that it can be sawn, it holds nails, and it is reasonably durable for, although its water absorption is high, the rate of water penetration through AAC is low as the large pores will no fill by suction. For this reason, AAC has a comparatively good resistance the frost and can be used wall construction [5].Zeolite tuff–lime mixtures have been widely used in constructions since ancient times [6]. Zeolites are found in nature, and the zeolite mineral stilbite was first discovered in 1756 by the Swedish mineralogist A. F. Cronstedt [7]. Similar to pozzolanic additions such as fly ash, silica fume and metakaolin, zeolite contains large quantities of reactive SiO_2 and Al_2O_3 [8]. Zeolites are used extensively for ion exchange in water purification and softening, as well as in chemistry as drying agents. Many researches investigating these characteristic shown tested the use of zeolites in the concrete industry as a replacement for cement [9].

Slags are by-products of pyro-metallurgical process in the metal and alloy industries [10]. The blast furnace is generally operated at 1500^{0}C. Controlled mixture of limestone, iron ore and coke are fed to the blast furnace. Iron and slag are produced in the molten form when limestone, iron ore, and coke are melted in the blast furnace. The slag in the molten form floats on molten iron due to light weight. Silicates from the iron ore and alumina which are combined with some oxides from limestone are the primary composition of molten slag. The slag in the molten form from the blast furnace is rapidly cooled with powerful water jets, which turned the molten slag into a fine, granular and glassy form known as granulated blast furnace slag [11].

In this study, zeolite and BFS used as mainly raw materials to production AAC. The aim of this work is to investigate the physical, mechanical, thermal and microstructural properties of the AAC produced from zeolite and BFS.

II. MATERIALS AND METHODS

The AAC samples were prepared by the following materials; zeolite, BFS, gypsum, lime, water, foaming agent (Al powder). Zeolite obtained from Manisa Gördes region in Turkey. BFS was obtained from OYAK corporation in Turkey. Cement was appropriate to the TS EN 197-1 CEMI 42,5 R. The chemical composition of cement, zeolite and BFS are given in Table 1**.** Zeolite, BFS and cement blaine fineness (BF) have 2522 cm^2/gr, 2695 cm^2/gr and 3074 cm^2/gr respectively. Laser particle size distribution of the zeolite and BFS are given in Figure 1**.**

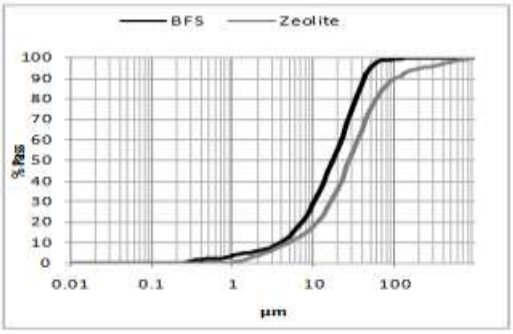

Fig. 1. Laser particle size analysis of zeolite and BFS

Table 1. Chemical composition of materials.

Oxides (Wt %)	Zeolite	BFS	Cement
SiO_2	54	40.1	19.2
Al_2O_3	42	12.8	3.88
Fe_2O_3	0.35	0.9	4.25
CaO	0.01	39.6	62.8
MgO	0.06	4.2	3.42
K_2O	0.2	1.2	0.34
Na_2O	0.13	0.05	2.1

The diameter distribution of zeolite was determined as d_{10}=5.054 µm, d_{50}=28.240 µm and d_{90}=103.200 µm and the diameter distribution of BFS was determined as d_{10}=3.985 µm, d_{50}=17.635 µm and d_{90}=42.623 µm.

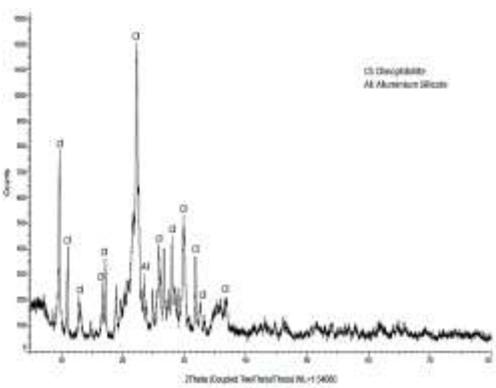

Fig. 2. XRD analysis of zeolite

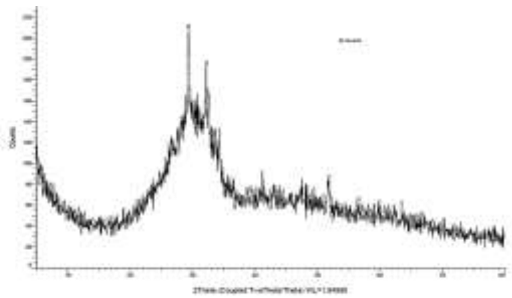

Fig. 3. XRD analysis of BFS

XRD analysis of the zeolite is given in Figure 2. The predominant mineral in the zeolite mineral composition is the clinoptilolite type zeolite mineral. The XRD analysis of the BFS was found to be amorphous. In particular, the hump region in the 2Ө 200 and 300 regions is amorphous. In addition, quartz peaks were observed in the material (Figure 3).

When producing mixtures, mineral materials, cement and gypsum, which were primarily used, were subjected to dry mixing. After the mixtures become homogenous, it was added to the water and the ingredients were mixed with the aid of the mixer. After the consistencies of the mixtures were ready, the mixture of quicklime and aluminium dust were added and mixed with a mixer for 1-2 minutes. The mixtures were then placed in preformed cube molds of 7 cm diameter to fill 2/3 of the mold height. The samples placed in the molds were left in the oven set at 75^0C for 1 hour to continue their swelling and hardening.

The samples were then removed from the molds and cured for 8 hours under an 8 bar vapor pressure in an autoclave at 172^0C, ready for physical and mechanical experiments. The bulk densities of the samples were measured by simply dividing the mass of the samples to their volumes. Bulk density have been determined by oven dry at 105 ± 5^0C until samples tested reached constant weight, and compressive strength have been performed at loading rate of 2.0±0.5 kgf/cm^2/s and on AAC samples. The mineralogical structure of the samples was investigated by XRD technique. SEM techniques were used to identify the microstructural properties. The thermal conductivity coefficient measurements on selected samples were made according to ASTM C 1113-90 [12]. Mixing ratios of AAC samples are given in Table 2.

Table 2. Mixing ratios (by unit weight) (C: cement, Z: zeolite, S: blast furnace slag, G: gypsum, L: lime, W: water, Al: aluminum powder).

Series	C	Z	S	G	L	W	Al
Z1	0.8	1.5	-	0.3	0.3	3.0	0.001
Z2	0.7	1.5	-	0.3	0.3	3.0	0.001
Z3	0.6	1.5	-	0.3	0.3	3.0	0.001
BFS1	0.8	-	1.5	0.3	0.3	2.0	0.001
BFS2	0.7	-	1.5	0.3	0.3	2.0	0.001
BFS3	0.6	-	1.5	0.3	0.3	2.0	0.001

III. RESULTS AND DISCUSSION

The bulk density and compressive strength data of mixtures composed of different components are given in Fig. 4. It has been found that in all series, by the ratio of cement in the mixture decreases and the compressive strength decreases. High-cement ratio, brings more square regular cement paste means strength growth together. The compressive strength values of the samples produced with BFS are were higher than the compressive strength values of the samples produced with zeolite. BFS1 series of compressive strength 3.28 MPa, the bulk density 630 kg/m^3 while Z1 series of compressive strength 1.40 MPa and the bulk density 550 kg/m^3 were determined.

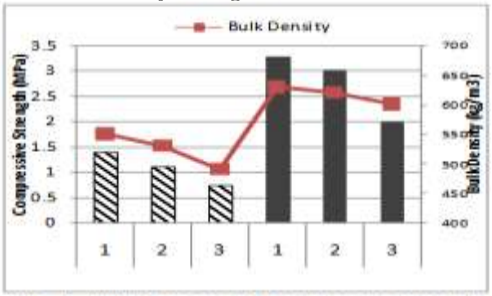

Fig. 4. Bulk density and compressive strength results.

Albayrak et al., [13], they found that the compressive strength values of AAC samples were 1.22-1.34 MPa and bulk densities of 270-500 kg/m^3 respectively, with produced using zeolite. Karakurt et al., [14] reported that when silica sand and zeolite were displaced by 100%, they reached a unit weight of about 500 kg/m^3 and compressive strengths of 0.5-1.0 MPa. These data are similar to the results found in the literature. Compressive strength is closely related to its bulk density [15] which is mainly controlled by the dosage of aerating agent and the specific gravity of constituent materials [16].

In the case of produced from zeolite crystals, for example, dihydrated gypsum from the production process has been identified. However, the presence of the tobermorite phase, which reflects the well-developed CSH structure, has also been identified. The density of the tobermorite phase is at 420 cps (Fig. 5). Furthermore, the presence of the portlandite phase in the analysis is remarkable. This phase is thought to result from the hydration of CaO in the mixture and the early hydration of the C_3S phase from the main components of the cement. In addition to the formation of tobermorite, formation of the etrengite has also been observed. It is thought that C_3A's reaction result from the main components in the cement. The etrengite may be effective in early strenght, but may cause a decline in strength values in older ages.

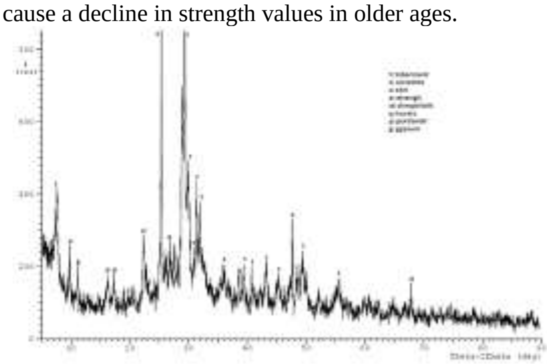

Fig. 4. XRD analysis of zeolite samples

In Figure 6, SEM images of tobermorite structures observed with produced from zeolite samples are given.

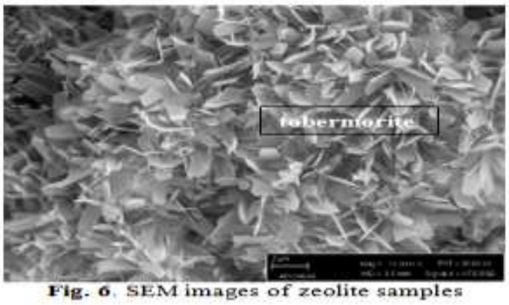

Fig. 6. SEM images of zeolite samples

XRD analysis of the sample produced with blast furnace slag is given in Fig. 7. In the mineralogical study, portlandite, xonotlite, CSH, gypsum, quartz and magnetite phases were found.

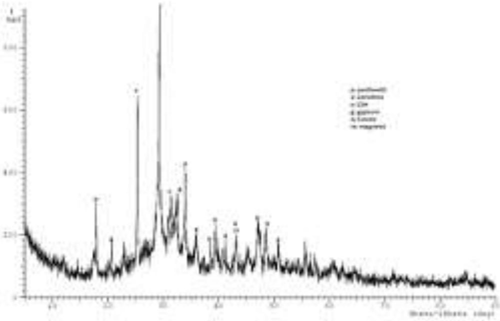

Fig. 5. XRD analysis of BFS samples

SEM analysis of the intense CSH structure is given in Fig. 8. The tobermorite phase observed in the other series was not found in these samples. The presence of the portlandite phase in the analysis is striking. This phase is thought to result from the hydration of CaO in the mixture and the early hydration of the C_3S phase from the main components of the cement.

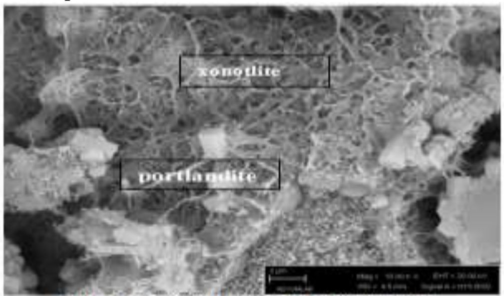

Fig. 8. SEM images of BFS samples

The thermal conductivity coefficient studies were performed on the series with the highest compressive strengths. Measurements were made on samples with dimensions of 2x5x10 cm with a KEM QTM 500 instrument capable of measuring at a temperature range of -10, +200^{0}C and a measurement range of 0.023-11.63 W/mK. The thermal conductivity coefficients of the samples were determined by taking three measurements from the front and back sides. The measured values of the samples and their averages were given in Table 3.

Table 3. Thermal conductivity coefficient measurement values (W/mK).

Series	Place of measurement	Measurement 1	Measurement 2	Measurement 3	Bulk Density kg/m³
Z1	Front sides	0.142	0.138	0.132	550
	Back sides	0.144	0.140	0.138	
	Average	0.139			
BFS1	Front sides	0.121	0.120	0.121	630
	Back sides	0.129	0.129	0.144	
	Average	0.127			

The stagnant air in the pores has little thermal conductivity. Also, as the amount of pores increases, the bulk density of the material decreases. As the bulk density decreases, the thermal conductivity value also decreases. However, when the bulk density and thermal conductivity coefficients of the Z1 and BFS1 series are compared in Table 3, the situation is exactly the opposite. As the bulk density increases, the thermal conductivity coefficient decreases. This is thought to be related to the density of zeolite and blast furnace slag raw materials and the thickness of the shells (walls) that make up the pores in the macropore.

IV. CONCLUSION

The results show that zeolite and blast furnace slag can be used in the production of AAC. Silica sand is extracted from the nature and ground to produce and suitable for production. For this reason, the natural environment leads to destruction and energy consumption. In contrast BFS is a waste material and it is released annually approximately 2.7 million tons in Turkey [17]. The recycling of BFS not only in the production of AAC but also will contribute to the protection of the natural environment as well as economic value.

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