Production of Pumice-Based Lightweight Material using Coal Bottom Ashes from Two Industrial Factories in Niğde (Turkey)

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Abstract— *The production of lightweight material using bottom ash (BA) generated from industrial factories has received further attention because of the economical use of naturally existing raw materials, reuse of waste material, and energy saving approach. In order prevent disposal of waste BAs and turn these wastes into usable construction materials, the study consists of two steps. The pumice-based lightweight materials were produced using the BAs supplied from Bor Sugar Factory and Göknur Foodstuff Co. Nigde Factory sieved through 0.5 mm square mesh sieves in the first and the second steps, respectively. Considering CC-40 and CC-80 concrete classes, mixing that depends on volume basis was applied to the samples since specific bulk densities of the coal BAs and pumices were different from each other. Fine aggregates of the BAs in the volume ranges of 0-25-50-75-100% were displaced with those of the pumice. ÇİMSA CEM I type Portland cement was used. 28 day-axial compressive strengths, specific bulk densities, water absorption percentages, porosities and axial compressive strengths loss percentage after the freezing of the samples that were applied to cure conditions at different mixing ratios were measured from 4.1 to 5.2 MPa for CC-40 and 8.5 to 11.7 MPa for CC-80; from 0.89 to 1.05 g/cm^3 for CC-40 and 0.92 to 1.05 g/cm^3 for CC-80; from 42.5 to 46.9 for CC-40 and 34.1 to 45.1 for CC-80; from 40.1 to 43.0 for CC-40 and 33.2 to 40.7 for CC-80 and from 10 to 25 for CC-40 and 15 to 20 for CC-80, respectively.*

Keywords— coal bottom ash, environment, lightweight construction material, Niğde, pumice, reuse, Turkey.

I. INTRODUCTION

Recycling and reusing of waste materials has become an increasingly important research area in recent years, and it is widely recognized as an effective method for promoting sustainability [1, 2]. Solid waste management in industrialized countries increasingly aims to reduce the amount of waste requiring landfill, by developing viable reuse applications so that wastes are beneficially used as resources [3-5]. The use of various types of waste materials as additives in the production of lightweight material that is intensively used in building construction due to its low thermal conductivity, shrinkage, density and haulage cost [6] and high heat resistance has received substantial attention during recent years [7].

In recent studies, various types of materials such as coal BA have been investigated as Portland cement replacement materials [8-11]. Their substitution in Portland cement has been an interesting subject for research due to environmental and technical reasons. Clearly, different substitution materials will have different effects on the properties of the cement due to their chemical, physical and mineralogical characteristics [12, 13]. Physical properties of lightweight aggregate concrete produced from lightweight aggregate materials such as tuff, pumice and expanded perlite have also been studied [6, 14-17].

It has been well established that the utilization potential of BA from the burning process is mainly determined by its physical characteristic such as grain size distribution, staining potential, and color [9, 18]. The most important properties of BA are the size and shape of the particles and the porosity. Such properties depend on the burning efficiency, the method in which the BA is obtained and the type of combustion [19]. It is necessary to pay due attention mainly to the dosage parameters, for example, to the water/cement ratio [20]. This parameter is directly influenced by the hygroscopic characteristic of the BA and is difficult to control, since it is dependent on the raw material and the burning process, on the dimension of the particles and on the residue being extracted through a process involving a humid system. BA is often used as a low-cost replacement for more expensive sand for concrete production and as a fine aggregate in high-performance lightweight concrete [21] due to its porous structure and particle size distribution is closed to natural sand size.

In light of the above considerations, technical approaches aimed at reusing coal BAs as secondary materials must be strongly encouraged. This may result in two main beneficial effects: (1) reduction of the amount of residues to be landfilled, (2) partial substitution of raw materials in industrial applications. In some cases, it was recognised that the high chemical reactivity exhibited by BA could cause some long-term detrimental effects on the properties of the final product [22]. On the other hand, advantage may be taken from the presence of reactive compounds in BA, such as oxides and alumino-silicates, with a view to the formulation of blended cement. It should also be stressed that in some cases, depending on the composition of the original waste, the combustion technology adopted as well as the combustion conditions, BA may also exhibit pozzolanic activity as a consequence of high contents of amorphous, highly reactive silica [23].

It was reported that pumice aggregate has a higher water absorption of approximately 37% [24]. For the purpose of concrete mix design, it is very important to specify the quantity of water absorption that is required for the aggregates, otherwise, it will create a problem of workability and consistency of the concrete [25, 26] and also lightweight material.

The objective of this study is to compare the physical and mechanical properties of pumice-based lightweight materials produced from the BAs that are supplied from Bor Sugar Factory and Göknur Foodstuff Co. Niğde Factory, Turkey. The paper also examines the effects of BAs additions on the final lightweight material properties as a replacement for fine pumice.

II. MATERIAL AND METHODS

2.1 Material

Materials of this study are BAs supplied from international Göknur Foodstuff Co. Nigde Factory (BA_1: 17000-19000 tons/year) and national Bor Sugar Factory (BA_2: 700-1500 tons/year) sieved with 0.5 mm square mesh sieves and pumice found in concentrated amount in the region. Chemical and physical properties and granulometric distributions were shown in Tables 1-2 and Figs. 1-3. Portland cement (CEM I 42.5 R) was used as binder.

TABLE 1
CHEMICAL PROPERTIES OF THE BAS AND THE PUMICE (ELEMENTAL ANALYSIS)

Elements	Pumice (%)	BA_1 (%)	BA_2 (%)
SiO_2	70.09	27.36	27.98
Al_2O_3	11.92	12.68	10.30
Fe_2O_3	2.72	8.23	8.98
CaO	3.84	39.31	7.97
MgO	0.88	0.74	1.64
SO_3	0.10	5.94	10.35
Na_2O	4.70	1.88	0.46
K_2O	2.71	0.43	0.82
Cl	0.13	0.10	0.10

TABLE 2
PHYSICAL PROPERTIES OF THE BAS AND THE PUMICE

Raw material	Grain diameter (mm)	Unit weight of air dried materials (g/cm^3)	Unit weight of oven dried materials (g/cm^3)	Combustible materials (%)
P_1	0-8	0.78	0.74	4
P_2	0.5-8	0.55	0.51	3
P_3	0-0.5	1.06	0.98	5
BA_1	0-0.5	0.59	0.55	23.5
BA_2	0-0.5	0.74	0.69	24.0

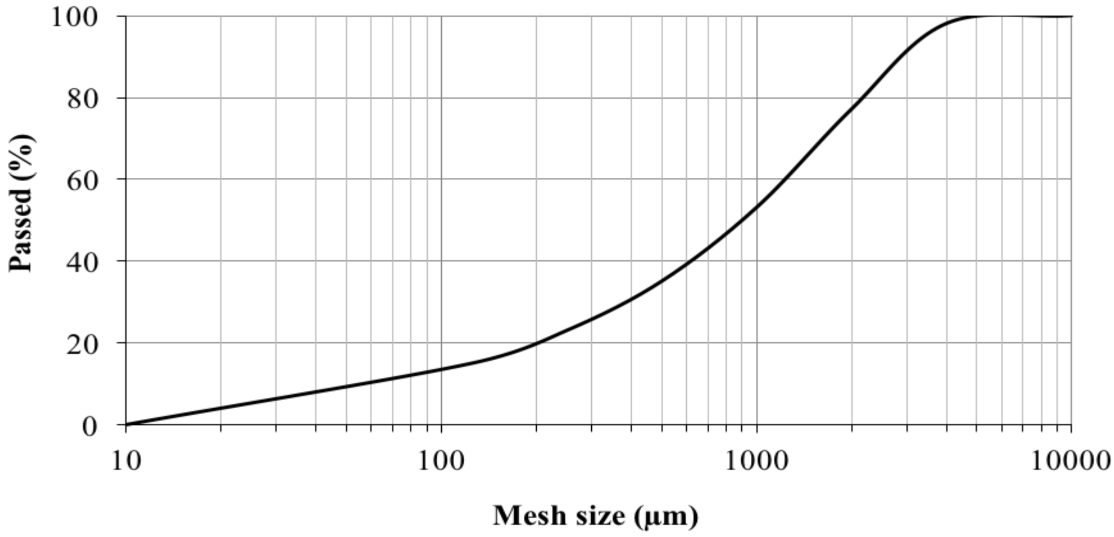

FIGURE 1. SIEVE ANALYSIS FOR THE PUMICE

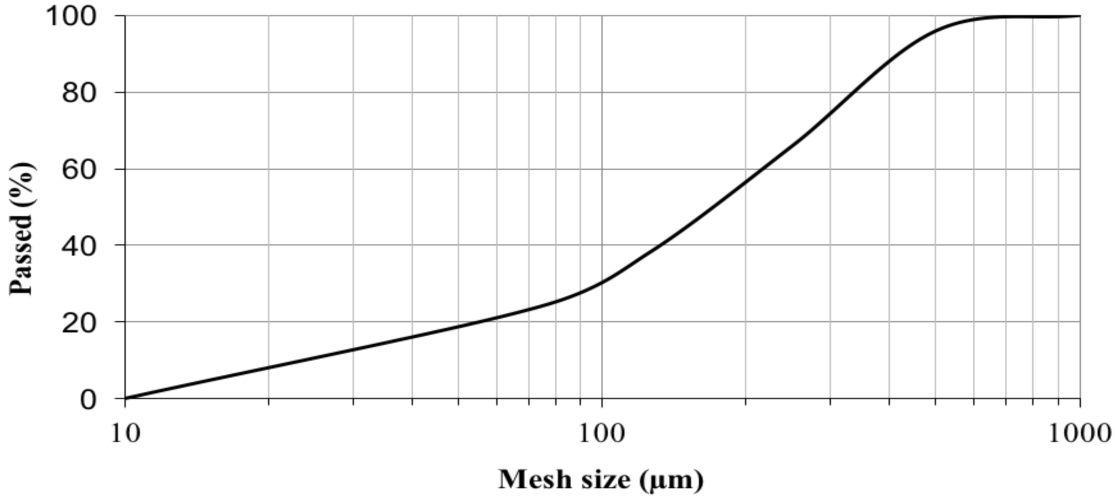

FIGURE 2. SIEVE ANALYSIS FOR THE BA_1

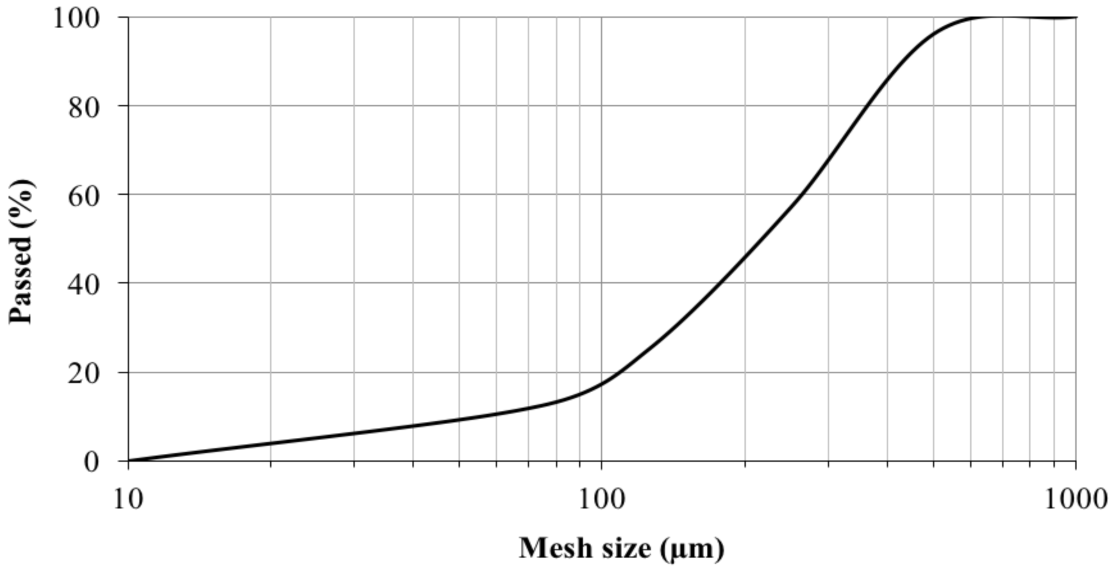

FIGURE 3. SIEVE ANALYSIS FOR THE BA_2

2.2 Method

Turkish Standards (TS) 3234 series were used in this study and lightweight materials of concrete class 40 (CC-40) and concrete class 80 (CC-80) were produced. Pumice was divided into fine and coarse material for each concrete class. Coarse and fine materials were determined as 0.5-8 mm and 0-0.5 mm, respectively. BA_1 and BA_2 that cannot be stored and have 0-0.5 mm grain distribution were sieved with 0.5 mm sieves. P_1, P_1+BA_1, P_1+BA_2 samples were used in order to obtain mixing parameters for CC-40 and CC-80 concrete standards. The ratios of volume changes were 0-25-50-75-100%. Volumetric measurements for each product were difficult, therefore volume weight calculations were done and mixing parameters were given in Table 3. CEM I 42.5 R, as binder, were used in the samples considering CC-40 and CC-80 concrete classes and the amounts that were given in TS 3234.

Sieve analysis were done for the pumice used in the study, and then separate stacks and adjustments of granulometric distribution of these stacks appropriating to TS 3234 were done. As a result of these adjustments, mixtures were calculated by creating stacks of fine and coarse material. The material above 0.5 mm was accepted as coarse material and below 0.5 mm was accepted as fine material. BAs were accepted as fine material after sieving 0.5 square mesh sieves and they were used in this study.

TABLE 3
SAMPLE PARAMETERS

Sample*	Pumice (0.5-8 mm) g	Pumice (0-0.5 mm) g	BA_1 g	BA_2 g	Cement g	Number**
$CC\text{-}40_{BA1+0}$	130	68.8	--	--	40	8
$CC\text{-}40_{BA1+25}$	130	54.7	10.3	--	40	8
$CC\text{-}40_{BA1+50}$	130	36.5	20.6	--	40	8
$CC\text{-}40_{BA1+75}$	130	18.2	30.9	--	40	8
$CC\text{-}40_{BA1+100}$	130	--	41.3	--	40	8
$CC\text{-}80_{BA1+0}$	130	68.8	--	--	65	8
$CC\text{-}80_{BA1+25}$	130	54.7	10.3	--	65	8
$CC\text{-}80_{BA1+50}$	130	36.5	20.6	--	65	8
$CC\text{-}80_{BA1+75}$	130	18.2	30.9	--	65	8
$CC\text{-}80_{BA1+100}$	130	--	41.3	--	65	8
$CC\text{-}40_{BA2+0}$	130	68.8	--	--	40	8
$CC\text{-}40_{BA2+25}$	130	54.7	--	12.9	40	8
$CC\text{-}40_{BA2+50}$	130	36.5	--	25.8	40	8
$CC\text{-}40_{BA2+75}$	130	18.2	--	38.7	40	8
$CC\text{-}40_{BA2+100}$	130	--	--	51.6	40	8
$CC\text{-}80_{BA2+0}$	130	68.8	--	--	65	8
$CC\text{-}80_{BA2+25}$	130	54.7	--	12.9	65	8
$CC\text{-}80_{BA2+50}$	130	36.46	--	25.8	65	8
$CC\text{-}80_{BA2+75}$	130	18.22	--	38.7	65	8
$CC\text{-}80_{BA2+100}$	130	--	--	51.6	65	8

* CC-40 and CC-80: Concrete classes, BA_1 and BA_2: Göknur and Bor BAs, respectively; +0 - +100 %: BA mixing ratio
** Each sample is 4*4*16 cm in size and given amount is for 1 sample.

After having calculating mixing, samples were produced in two stages. In the first step, samples which have 4*4*16 cm in size were produced and all experiments were done on these samples. In the second step, samples were produced in 10*10*10 cm size from the samples having optimum mixing rate for axial compressive strength and unit volume weight obtained from the first step and these samples were compared.

The amount of water on weight basis was calculated as "g" to obtain equal consistence for each sample. BA amounts in 25-50-75-100% ratios of fine material were increased in parallel to water absorption, therefore the water amount was increased in the sequence of 1-2-3-4% to be standardized. Samples were poured into the mold and placed by vibration. 5 units for each sample were produced. The samples remained in the mold for a period of 24 hours after having been poured into the mold. And then, they were taken out from the mold and water cure was applied at 22±2 °C. Their compressive axial strength values were measured twice, on the 7^{th} day and on the 28^{th} day. The selected optimum samples were reproduced in 10*10*10 cm. In addition to the axial compressive strength test, water absorption, porosity, bulk density and compressive strength after freezing tests were done.

2.3 Experimental investigation

Axial compressive strength values were determined on the 7th day and on the 28th day for the samples. Out of 8 samples, 2 samples were used on the 7th day and 2 samples on the 28th day for the axial compressive strength test, respectively; and the other 2 samples were used for the freezing and thawing test. Prior to freeze-thaw experiments on these samples, porosity and bulk density experiments were performed. The last two samples were left as blank samples. Thus, 4 compressive strength values were determined on the 7th day and on the 28th day as compressive strength values after freeze and thaw experiment, and the arithmetic mean was calculated. All products were treated in the same curing conditions and axial compressive strength values were determined in samples in 4*4*4 cm size. Bulk density of samples is oven dried. Obtained results were summarized in Figs. 4-8.

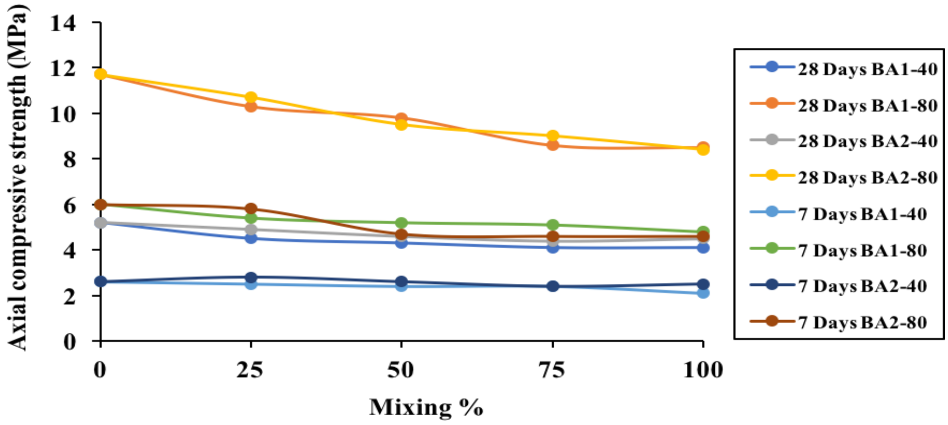

FIGURE 4. ACCORDING TO MIXING RATIOS, AXIAL COMPRESSIVE STRENGTH VALUES OF THE SAMPLES

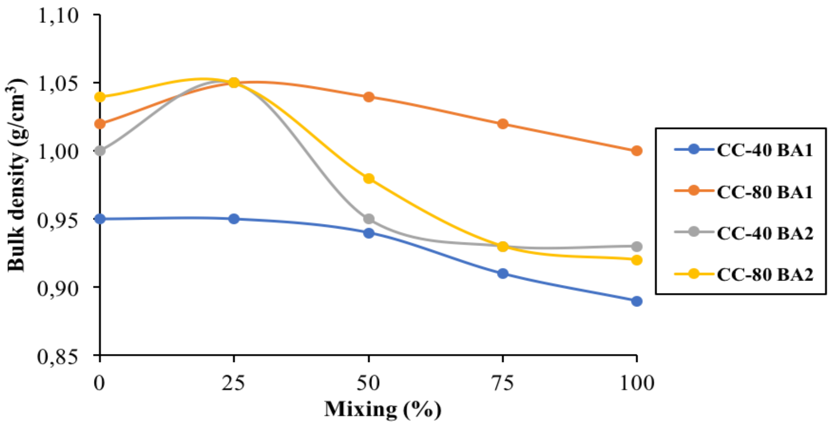

FIGURE 5. ACCORDING TO MIXING RATIOS, BULK DENSITY VALUES OF THE SAMPLES

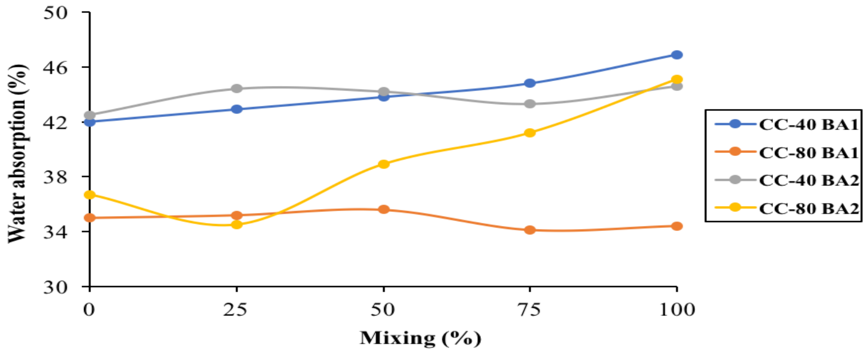

FIGURE 6. ACCORDING TO MIXING RATIOS, WATER ABSORPTION PERCENTAGE VALUES OF THE SAMPLES

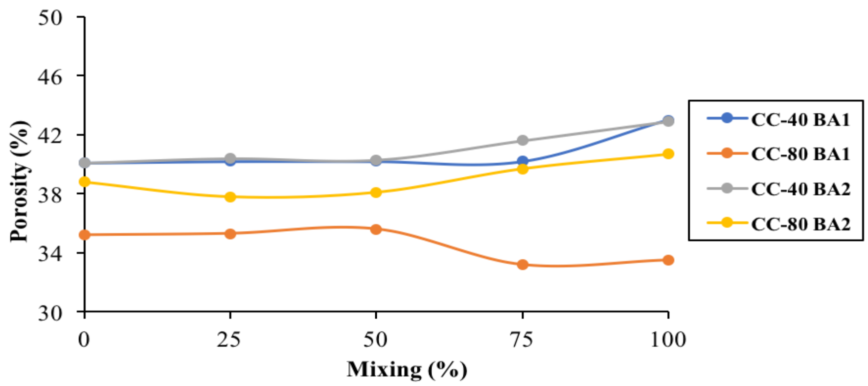

FIGURE 7. ACCORDING TO MIXING RATIOS, POROSITY VALUES OF THE SAMPLES

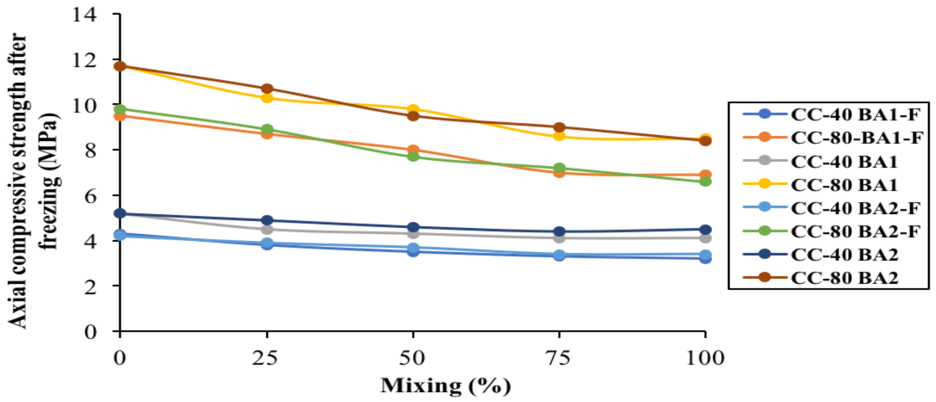

FIGURE 8. ACCORDING TO MIXING RATIOS, AXIAL COMPRESSIVE STRENGTH VALUES OF THE SAMPLES AFTER FREEZING (F: FROZEN)

III. DISCUSSION AND CONCLUSION

In this study, fine aggregates of the BAs that are nondeposit waste in the volume ranges of 0-25-50-75-100% were displaced with those of the pumice used in construction technology very effectively. Following results were obtained from the study:

1. Durable building material was obtained from the study in which the BAs (BA_1 and BA_2) sieved with 0.5 mm sieves, the pumice in 0-8 mm grain size and the CEM I 42.5 R Portland cement was used in different mixing ratios.
2. In the visual inspection, any deformation or cracks wasn't encountered in the obtained products.
3. Maximum axial compressive strength value was obtained in the samples produced of 100% ratio of pumice. 28 days' axial compressive strength values reached the targeted values for the mixtures of CC-40 and CC-80. At the same time, all BA_1 to BA_2 additived products reached the targeted axial compressive strength values.
4. Different fine BA amounts that were added for pumice based samples led to losses in axial compressive strength. These losses reached to maximum value in 100% ratio of BA fine material. They were obtained as 21.1 and 27.3% in BA_1 additived CC-40 and CC-80, respectively. On the other hand, they were also obtained as 13.5 and 28.2 in BA_2 additived CC-40 and CC-80, respectively. This situation led to the conclusion that the BAs were effective on the compressive strength values.
5. Maximum bulk density values were measured in the samples that were produced from 100 % pumice in all mixtures. Bulk density value decreases resulted from different ratios of fine BAs. These decreases were obtained as minimum, 7 and 5% in the samples of 100% ratio of BA, BA_1 additived CC-40 and CC-80, respectively. On the other hand, they were also obtained as 12.3 and 7% in BA_2 additived CC-40 and CC-80, respectively.
6. The measurements of water absorption percentage and porosity values were similar to each other. This is an expected result.
7. After freezing test, 20% of axial compressive strength loss was obtained on average. However, any deformation due to frost effects was not observed in naked eye.

Consequently, in case of evaluating BAs in the world and in Turkey, it was possible not only to produce energy saving building envelop material and cheaper, high quality and durable lightweight construction materials but also to support national economy by reusing of waste material and to protect the environment.

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CONFLICT OF INTEREST

The author declares no conflict of interest.

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