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Effects of Silica Aerogel Produced From Boron Wastes To Compressive Strength And Thermal Performance Of Environmentally Friendly Bricks

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Boron waste,
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Abstract: In this study, the aim is to inspect the effects of silica aerogel produced from boron waster to compressive strength and thermal performance of bricks. Firstly, silica aerogel was produced by using boron waste obtained from Türkiye/Eskişehir/Kırka region. After, silica aerogel produced was mixed into the brick in different proportions (%0 (REF), %15 (AB1), %25 (AB2), %35 (AB3), %45 (AB4)), and was baked in 900 °C and 1000 °C to create mixed brick samples. Finally, samples produced was experimented with compressive strength and thermal conductivity coefficient and SEM (Scanning Electron Microscopy) images were taken. As a result, the increase of aerogel amount caused decrease in compressive strength and thermal conductivity coefficient values in both temperatures. It was observed that amorphous structure increased with the increase of silica aerogel and partial holes and cracks emerged in SEM images. Additionally, when compressive strength was used as basis, it was determined that AB1 sample could be used as load bearing material, while AB2, AB3 and AB4 samples could be used as coating or back filling material in traditional structures. Use of wastes which contain silica such as boron waste in aerogel production is thought to be an appropriate solution for waste disposal.

Bor Atıklarından Üretilen Silika Aerojelin Çevre Dostu Tuğlaların Basınç Dayanımına ve Isıl Performansına Etkileri

Anahtar Kelimeler
Bor atığı,
Aerojel,
Tuğla

Öz: Bu çalışmada, bor atıklarından üretilen silika aerojelin tuğlanın basınç dayanımı ve ısıl performansına etkisinin incelenmesi amaçlanmıştır. Çalışma üç aşamada gerçekleştirilmiştir. İlk aşamada Türkiye/Eskişehir/Kırka bölgesinden temin edilen bor atığı kullanılarak silika aerojel üretimi yapılmıştır. İkinci aşamada, üretilen silika aerojel hacimce farklı oranlarda (%0 (REF), %15 (AB1), %25 (AB2), %35 (AB3), %45 (AB4)) tuğla bünyesine ikame edilmiş, 900 oC ve 1000 oC pişirilerek katkılı tuğla numuneleri üretilmiştir. Üçüncü ve son aşamada ise, üretilen numunelere basınç dayanımı ve ısı iletim katsayısı tayini deneyleri uygulanmıştır. Ayrıca numunelerin içyapısının incelenmesi amacıyla SEM görüntüleri alınmıştır. Sonuç olarak; her iki sıcaklıkta da aerojel miktarının artması ile basınç dayanımı ve ısı iletim katsayısı değerinde azalma meydana gelmiştir. SEM görüntülerinde silika aerojel miktarının artmasıyla amorf yapının artığı ve yer yer boşluklar ve çatlaklar oluştuğu görülmüştür. Ayrıca basınç dayanımı baz alındığında; üretilen numunelerden AB1 numunesi taşıyıcı olarak kullanılabileceği, AB2, AB3 ve AB4 numunelerinin ise kaplama veya geleneksel yapılarda duvar dolgu malzemesi olarak kullanılabileceği tespit edilmiştir. Bor atığı gibi silis içeren atıkların aerojel üretiminde kullanılmaları atıkların bertaraf edilmesi için uygun bir çözüm yolu olacağı düşünülmektedir.

1. INTRODUCTION

Energy crisis, which encourage development of new materials aiming to establish thermal comfort for users and energy efficiency of buildings have been occurring more frequently around the world [1]. Energy demand has been increasing for the last thirty years with industrial improvement and increase of population [2]. The construction industry has been using 42% of the total consumed energy and 50% of the natural resources from earth [3].

A large part of the structures built in the construction sector consists of buildings. Energy consumption in buildings has increased massively in the last ten years due to population growth, necessary interior quality, increase in time spent inside and demand for building functions etc. [4]. While buildings with building envelopes that have less thermal conduction achieve up to 80% energy saving and provide better living and working conditions to inhabitants and users [5]. Additionally, it could be beneficial to extend thermal comfort periods with-out relying on heating and cooling systems, especially during the period between seasons [6].

It has been stated in the literature that depending on the country, approximately 20%-40% of the total energy consumption and globally one in three of greenhouse gas emission consists of buildings [7]. Heat loss in the buildings generally occur through exterior walls, ceiling, floor, windows and air leak [8]. It is also known that building envelope is an important cause of energy loss in constructed area [9]. Generally, the biggest thermal losses related to buildings occur as heat conduction through opaque building envelope [10]. Since materials used in most building constructions have low isolation levels and high heat losses, decreasing energy consumption of buildings is one of the most important requirements [11]. The heat loss through exterior walls are generally recognized as between 10% and 45% [12]. The best way of ensuring energy saving is applying heat insulation to building or using materials with heat insulation features during construction. Brick is one of the construction materials consisting building envelope. Bricks are universal construction materials which have emerged independently in various cultures, evolved through ages and continued its existence through centuries. It is still widely popular around the globe and symbolizes characteristic atmosphere of many different places [9]. Increase of standards such as fire safety, sustainability, heat insulation features etc. has limited the use of traditional bricks as a construction component carrying weight. Today, bricks are used mostly as coating because of their aesthetic look, ease of use and low maintenance surfaces. But if their heat insulation properties improves, bricks will have the potential to be-come desired structural materials one again.

Bricks have been objected to improvement by mixing with various organic (rice husk ash, rice hull etc.) or industrial wastes (silica fume, fly ash, boron waste etc) [13-18, 79-81]. Recently, use of aerogel instead of these wastes gained popularity. The word aerogel consists of two words, air and gel, and contains of nanoparticles that are located in a three-dimensional network with a high porosity (containing 99-95% of the empty volume) [82]. Aerogel was discovered in 1931 [19-22]. Aerogel, which is produced by removing fluids from gels, is a dry gel with high porosity (more than 90%) [23] and less heat conductivity than air [19, 23, 24]. It has a transparent, highly porous, ultra lightweight, low density (bulk density 3-20 kg/m^3) and wide exterior surface area. Porous compound of nano material makes it hard for heat to pass through structure [19, 78].

It decreases high energy demand compared to other materials with same width because of its low heat conduction [26]: It is widely used in aerogels [27], spare parts catalyzator support [28, 29], heat insulation [23], nanoparticle filtration from air [30-33], medicine delivery [34] and aviation industries [35].

The most used type of aerogels, which have different types, is silica aerogels [36]. Silica aerogel, which is a nano structured material is a unique construction material with high porosity, ultra-low density and highly cross-bound three dimensional webs, and consists of silica [37-38]. Silica aerogel consists of amorphous silica structure with air more than 90% and is considered as the most lightweight solid material of the world. Its porous structure enables it to breathe with the clean air passing through [5]. It also has the lowest thermal conduction (0.015 W m-1K-1) among all solid insulation materials on the world [39-40].

Research on silica aerogel, which has lower heat conduction [23-41] when compared to other materials produced through complicated and expensive procedures [23-41], has proved that it has higher potential for thermal and acoustic insulation. Adding silica aerogel into construction materials can decrease their thermal conductivity or k-value significantly and result in thermal performance which was not previously possible [5].

It was observed that aerogels are used intensely in cement [43-45], mortar [1, 46], coating [36,39,42,47-49,50,51], concrete [41,52-56], self-conpacting concrete [57] and light concrete production. But it was determined that aerogel is not used in brick production frequently. Based on this gap, silica aerogel was produced using boron wastes taken from Eskişehir /Kırka region for this study with the aim of mixing silica aerogel product into brick in different percentages and inspect compressive strength and thermal performance. SEM images were used to confirm compressive strength rest results and thermal properties.

2. MATERIAL AND METHOD

2.1. Material

Clay: Clay, which is the main raw material used in the production of brick building material and used in the study, was obtained from Taşköprü district of Kastamonu province. The mineralogy of the clay used is presented in Table 1.

It was observed that there is mostly element silicium (Si) found in blend brick clay examined in Kastamonu University Central Research Laboratory Implementation and Research Center. There were aliminium (Al) calcium (Ca), oxygen (O), iron (Fe) and magnesium (Mg) elements found in clay as well. Raw clay material was grounded in rotary squeezer into a 1mm undersize material before entering production. All additives were subjected to same procedures.

Table 1. Clay mineralogy

Element	O	Mg	Al	Si	Nb	K	Ca	Fe	Others
Weight %	22,53	1. 98	8. 74	42.12	5. 38	0. 94	15,41	6,83	36,07

Table 2. Chemical properties of boron waste

Compound	B_2O_3	CaO	MgO	SiO2	Na2O	Al2O3	Fe2O3	K2O	Ignition Loss
Boron Waste, %	25.5	10.20	14.28	13.60	5. 66	0. 98	0. 41	0. 78	28. 59

Table 3. Chemical Analysis of Seyitömer Fly Ash

Compound	SiO_2	CaO	MgO	Fe_2O_3	Al_2O_3	Na_2O	K_2O	SO_3	Na_2O (eq)	Free CaO
%	52.23	7. 85	5. 92	9. 10	19.03	0. 92	1. 98	2. 52	2. 02	0. 27

Boron Waste: The boron waste used in the study is chemical properties are provided in Table 2. It was observed that it consists of 25.5% boron and silica 13,60 % after examination of the Table 2.

Fly Ash: Fly ash which was used in the study anc chemical compounds of which are provided on Table 3 was obtained from Seyitömer Thermal Power Plant. Type F fly ash with 0,88 g/cm^3 bulk density, 1,58 g/cm^3 specific weight, 0,115 m^2 /g specific surface area and 8,3 pH was used in the experiments.

Mixture water: Kastamonu province city water was used as the mixture water in sample production.

2.1. Medhod

2.1.1. Aerogel production from boron wastes

Sol-gel method was used in production of silica aerogel from boron waste (Figure 1). Production was carried out in three stages: preparation, aging and drying.

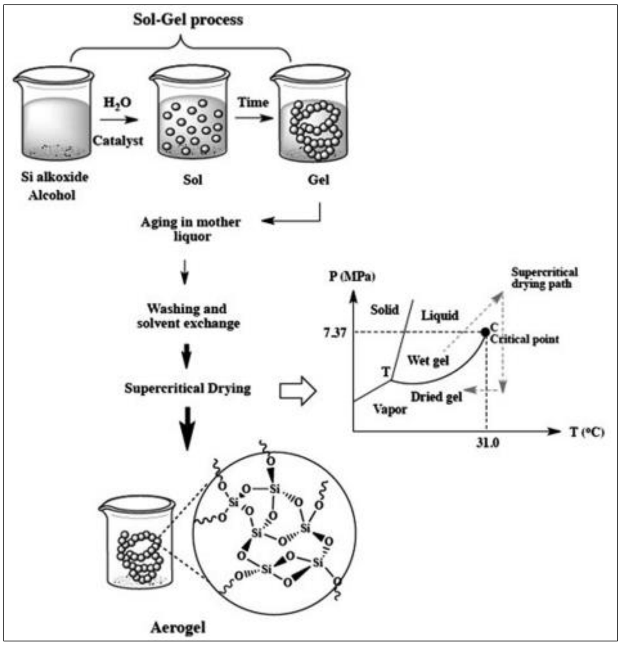


Figure 1. Schematic image of the sol-gel process which was used to prepare aerogels [77].

Preparation of the gel

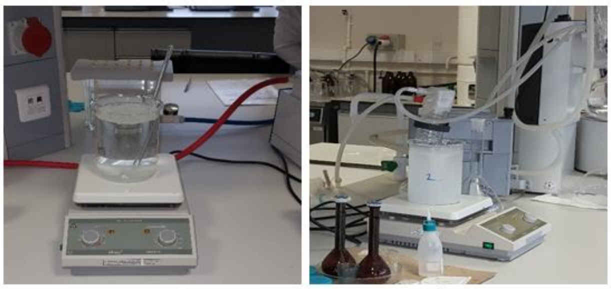
250 ml distilled water, 15 g KOH and 40 gr borax slime was put in 500 ml beaker. Mixed for 4 hour in mixing device with heater, with settings 150 °C, 5 cycles/mins.

After mixing, it was filtered using filter paper. Mixture that passed through filter paper was used in borosilicate aerogel.

Aging the gel

pH value of the mixture that passed through the filter paper was determined. Since the solution was acidic, a mixture of 10 g NaOH and 250 ml distilled water was added slowly and mixed with a stick (Figure 2a) Solution was gelled when it became neutralized (pH:7) (Figure 2b) Mixture was closed with a plastic wrap for the aging process and waited for 4 weeks.

After 2 weeks, in order to rid of salt inside the gel, gel was washed with hot distilled water. Water on the gel was taken with a syringe and mixed again after adding hot distilled water. After waiting for the gel to collapse after mixing, and water on the surface was taken once again. This process was repeated 3 times. Afterwards, beaker was wrapped with wrap once again and waited in 60 ^{0}C drying oven for 24 hours. Gel phase filtered once again and mixed with 20% ethanol and 80% distilled water solution. Beaker was re-wrapped with wrap and waited in 60 ^{0}C drying oven for 24 hours. This process was repeated two times. Afterwards, 100% ethanol was added and waited in 60 ^{0}C drying oven for 24 hours. In order to get the desired chemical mixture of gel, after carrying out a filtering process, 70% Ethanol/TEOS was added and the mixture waited in 60 ^{0}C drying oven for 24 hours. After filtering, it was kept inside 100& n-heptane for 24 hours.



a b

Figure 2. a: Before gelling, b: After gelling

Drying the gel

After filtering the solution, gel was closed and kept in room temperature for 24 hours. Afterwards it was subjected to drying process in 90 °C for 4 hours and 125 °C for 24 hours. Silica aerogel powder produces after the drying process was packaged using leak proof packs and stored to be used in brick production.

2.2.2 Production of aerogel mixed brick

Clay material which was obtained through quartation method was grounded in rotary squeezer into a 1mm undersize material before entering production. Fly ash, which was to be used as additive in experiment was also subjected to the same procedures. Fly ash was added into brick to increase its compressive strength [60]. Formula of the mixture is shown in Table 4. Mixing water was added in 20% of the total weight of the materials in samples to each mixtures. Within the scope of the experiment, a total of 12 samples, 6 for each experiment, were produced.

Table 4. Mixture formula

	Aerojel (%)	Fly Ash (%)	Clay (%)	Mixed Water (%)
REF	---	---	100	20
AB1	15	5	80	20
AB2	25	5	70	20
AB3	35	5	60	20
AB4	45	5	50	20

During sample production, first, aerogel, fly ash and clay, which are dry materials, were mixed with a mixer with 200 rpm speed for 5 minutes. Then the bonding substance water was added and mixed for 10 minutes. After the mixing process, the mixture was pressed with 50 MPa pressure and 40 x 40 x 160 mm samples were produces. Samples waited 24 hours to easily detach from the mold. Afterwards, the samples were dried in drying oven with 105 °C for 24 hours. Dried samples, which are given in Figure 3 were baked progressively in electric oven which had 3°C/s heating feature with 900 °C and 1000 °C. In case of deviations, the six samples were produced for each series. The samples produced were experimented with compressive strength and solid thermal conductivity coefficient experiments.

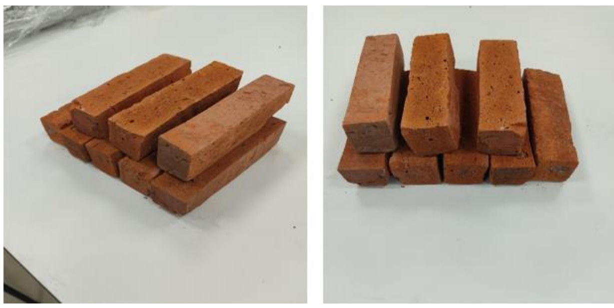


Figure 3. Silica aerogel mixed brick samples

2.2.3 Experiments on samples

The compressive strength values of the aerogel mixed brick products were calculated in accordance with TS EN 771-1, (2012) [61] standard. Thermal conduction device was used to determine the heat conduction constant. Probes of the conduction device were contacted with sample surface, heat conduction value of which were to be determined, and constant was determined by measuring heat change of the material depending on the energy given. SEM images were taken to inspect internal structures of the samples.

3. RESULTS AND DISCUSSIONS

3.1 Compressive Strength

Compressive strength, which is the basis of all structural materials, is the best measurement method to determine the suitability of the material [60].

A material needs to have high compressive strength to be used in a structure. That is why one of the main aims of the studies is to improve compressive strength of the structural materials such as cement [62, 66], concrete [63], mortar, coating, brick [60] etc.

Aerogel is a material with low mechanic properties and high thermal conduction [64]. That is why, aerogel is used in heat insulation generally. In many studies, aerogel is reported to lower the compressive strength [65, 66, 42]. In this study, fly ash has been mixed in order to increase compressive strength.

Compressive strength values of aerogel mixed brick samples are displayed in Figure 4. It was observed that compressive strengths of samples change between 6,8-14,2 MPa in image. It was observed that in both temperatures the highest compressive strength be-longed to reference sample, and lowest compressive strength belonged to AB4 sample. According to TS EN 771-1, (2012), the average compressive strength value is 10 MPa. In this case, among silica aerogel mixed brick samples that baked in both temperatures, AB1 value was above average, and AB2, AB3 and AB4 values were below average. AB1 can be used in residence buildings and restoration works as holder brick, AB2, AB3 and AB4 can be used for coating and decoration purposes. Also, AB2, AB3 and AB4 samples can be used as filling material in traditional residence construction.

In this study, it was determined that compressive strength lowers with the increase of silica aerogel amount. In other words, changing natural aggregates with aerogel caused lower compressive strength. According to this, fragile nature and low resistance of aerogel aggregates as well as their low compound effects result in low mechanic resistance in construction material mixtures with aerogel materials. They effect mechanical properties of AB samples negatively because of their fragile structure as well.

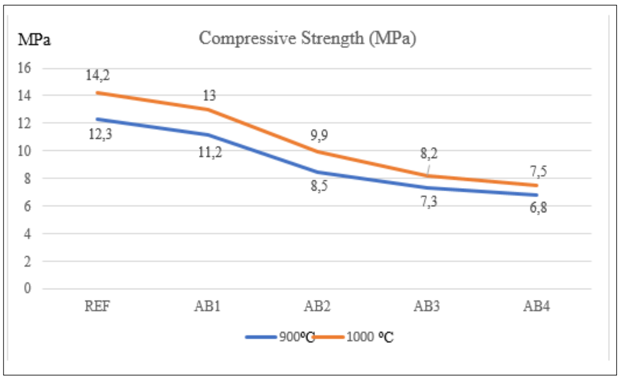


Figure 4. Compressive strength of samples

Moreover, in Table 5, the ratios of decreasing compressive strength values as a result of aerogel substitution are given. It is seen that the highest decrease rate at 900 and 1000 °C belongs to the AB4 sample with 47.18% and 44.71%, respectively. It is thought that the reason for this is that the aerogel additive creates a void in the brick sample. Studies on compressive strength of silica aerogel support our study [41, 45, 55-56].

Table 5. Value of Compressive strength and reduction rate

	900 °C		1000 °C	
	Compressive Strength (MPa)	Reduction Rate (%)	Compressive Strength (MPa)	Reduction Rate (%)
REF	14,2	---	12,3	---
AB1	13,0	8,45	11,2	8,94
AB2	9,9	30,28	8,5	30,90
AB3	8,2	42,25	7,3	40,65
AB4	7,5	47,18	6,8	44,71

3.2 Determination of Heat Conduction Coefficient

Aerogel is a porous material with low thermal conductivity because of its small pores. Thermal conductivity of aerogel mixed brick samples in different temperatures are displayed in Figure 5. It was determined that thermal conductivity coefficient of samples change between 0,52 and 1,7 W/mK. It was observed that thermal conductivity improved with increase of baking temperature. Among all samples, AT4 sample with baking temperature of 1000 °C (0,52 w/mK) had the lowest, reference sample with baking temperature of 900 °C (1,07 W/mK) had the highest heat conduction coefficient. Additionally, higher aerogel in mixtures resulted in lower thermal conductivity. In other words, significant amount of air holes in aerogel pores isolate heat and result lower thermal conductivity in samples. Other studies in literature support data we acquired during our study. Silica aerogel addition was observed to improve thermal conductivity property of structural materials such as concrete, cement, coating etc. as well as brick [6,41,42,45,51,52, 56, 68-72].

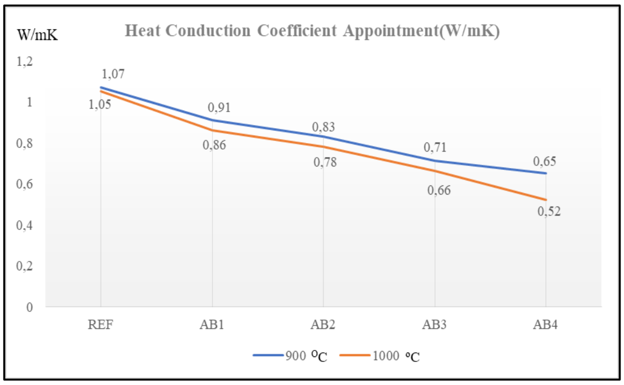


Figure 5. Heat conduction coefficient appointment of samples

The decrease in the heat conductivity coefficients of the airgel-added brick samples at 900 and 1000 °C is given in Table 6. The lowest heat transfer coefficient reduction rate was obtained from the AB4 sample at both temperatures. The reason for this is thought to be that the airgel creates a void in the brick, as in the compressive strength. These voids keep the heat within the brick.

Table 6. Heat conduction coefficient of samples and reduction rate

	900 °C		1000 °C	
	Heat Conduction Coefficient (W/mK)	Reducttion Rate (%)	Heat Conduction Coefficient (W/mK)	Reducttion Rate (%)
REF	1,07	---	1,05	---
AB1	0,91	14,95	0,86	18,09
AB2	0,83	22,42	0,78	25,71
AB3	0,71	33,64	0,66	37,14
AB4	0,65	39,25	0,52	50,47

3.3 SEM Images

Reference and SEM images of silica aerogel mixed brick samples are displayed in Figure 6. It was observed in Figure 6a belonging to reference sample that the amount of crystal structure was higher. This means that sample have high compressive strength. It is a proof that compressive strength test results of reference sample supports SEM images. SEM images of AB1 sample are displayed in Figure 6b. In image, reference sample with crystal structure had partially turned into amorphous structure with silica aerogel mixture. Amount of amorphous structure had increased in Figure 6c displaying SEM image of AB2 and became irregular. Fragile nature of amorphous structure and aerogel [41] lowered compressive strength of the sample. Decrease in compressive strength experiment values of AB2 sample supports SEM images. In Figure 6d (AB3), crystal structure had de-creased significantly and amorphous structure increased. Additionally, partial globule and cavitied structures were observed. In some areas, cracks were observed. In Image 6e (AB4) which had the highest amount of silica aerogel almost all crystal structures were gone and amount of amorphous and cavitied structure were increased. Water/air can be transferred or thicken with these cavities and thermal insulation and mechanical performance of brick can be affected. The fact that AB4 samples, which have the highest amount of silica aerogel have the lowest compressive strength and lowest heat conduction coefficient proves this fact. With the increase of aerogel, which is a fragile material, surface cracks were increased as well.

Literature studies proved that aerogel makes construction materials more fragile [41-42, 73-76]. Research results prove that aerogel is a highly fragile material, it can be crushed easily and have cracks on its surface. It was also stated that cavitied structure de-crease compressive strength of brick and improved thermal properties.

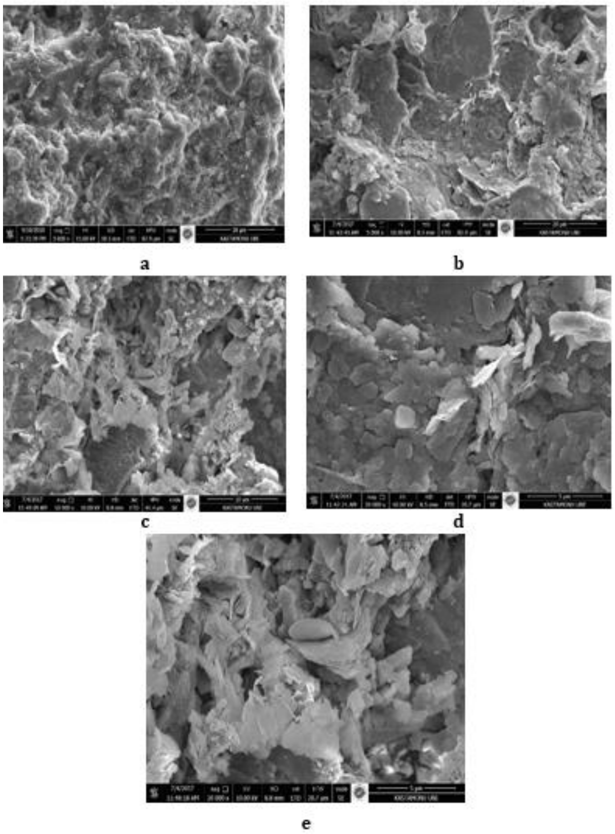


Figure 6. a: Reference sample, b: AB1 sample c: AB2 sample, d: AB3 sample, e: AB4 sample aerogel mixed brick samples

4. CONCLUSION

Energy crisis, In this study, aerogel was produced using boron waste and produced aerogel was mixed into prick in different ratios as additional material. According to the data obtained from experiments;

- Compressive strength decreased with the increasing amount of aerogel.
- AB1 sample had the highest compressive strength in both temperatures among mixed samples.
- Heat conduction coefficient value decreased with the increasing amount of aerogel. Lowest heat conduction coefficient belonged to AB4 sample with 0,52 W/mK.
- It was observed that with the increasing amount of aerogel, the crystal structure of the samples turned into amorphous structure and AB3 and AB4 samples developed gaps and cavities in SEM images of samples.
- Use of boron waste in aerogel production is an appropriate solution to dispose of wastes in environment. With boron waste, all wastes with silica must be encouraged to be used during aerogel production.
- Studies in the future should not focus on academy, on the contrary, their aim should be determination of the properties of aerogel and application.

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