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Araştırma / Research

MANUFACTURE OF FIRED CLAY BRICKS CONTAINING AN INDUSTRIAL WASTE (BOTTOM ASH)

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ABSTRACT

Bottom ash is an industrial waste produced by the combustion of coal in industrial plants. These wastes are still under discussion as an environmental issue because of the very restricted field of use. Therefore, numerous studies have been getting performed to reduce the amount of wastes and to reuse the current residues produced by the coal-powered plants. It is a known fact that, there are hopeful developments on usability of industrial wastes in construction technology. In this study, use of bottom ash-obtained at Bor Sugar Factory as by-product, Niğde-Turkey, which contains unburned carbon by about 20% in production of brick as an additive was investigated. The results showed that bottom ash could be used as an additive in producing bricks and this process was found to be a good alternative for recycling such wastes.

Keywords: Bottom ash, lightweight building material, extrinsic brick, reuse of waste, environment

ENDÜSTRİYEL TABAN KÜLÜ ATIĞI İÇEREN KİL TUĞLA ÜRETİMİ

ÖZ

Sanayi tesislerinde taban külü, kömürün yanması ile ortaya çıkan endüstriyel bir artıktır. Söz konusu artığın kullanım alanın çok kısıtlı olması nedeni ile çevresel bir sorun olarak güncelliğini korumaktadır. Bu nedenle, kömür yakan tesislerde artık miktarının azaltılması ve mevcut artıkların değerlendirilmesi için birçok araştırma yapılmaktadır. Özellikle söz konusu artıkların yapı teknolojisinde kullanılabilirliği yönünde ümit verici gelişmelerin olduğu bilinen bir gerçektir. Bu çalışmada; %20'ye varan oranlarda yanmamış karbon içeren, Niğde Bor Şeker Fabrikasının taban külünün tuğla üretiminde katkı maddesi olarak kullanılabilirliği araştırılmıştır. Sonuçta, söz konusu taban külünün, tuğla üretiminde katkı malzemesi olarak kullanılabileceği ve atığın değerlendirilmesinde iyi bir alternatif olduğu belirlenmiştir.

Anahtar Kelimeler: Kazan altı külü, hafif yapı malzemesi, katkılı tuğla, atık değerlendirme, çevre

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1. INTRODUCTION

Fossil fuels are used in modern power plants throughout the world to produce electrical energy. The inorganic residue that remains after pulverized coal is burned is known as "coal combustion by-products" (CCBs) [1]. Fly ash (FA) and, to a lesser extent, bottom ash (BA) are the combustion residues produced and collected during coal burning in a Thermal Power Stations (TPS). In general, coal ash in a power plant consists of up to 25% BA and 75% FA [2]. Heat and electricity used in the process of sugar production process, is obtained from the boiler and the turbine plants located inside the sugar factories. The fuel used in the steam boilers at the sugar factories, is derived from natural gas, liquid petroleum and coal [3].

The construction industry might not be considered an environment-friendly activity since it depletes the supply of natural resources and generates a large amount of waste. This waste has to be properly managed in order not to pollute and deteriorate the urban and rural landscape. Consequently, the growth of the construction industry is restricted by the environment source and sinks' limits. The source limits refer to the finite capacity of the environment to provide resources both renewable and non-renewable, whereas the sinks' limits refer to the capacity of the environment to assimilate the waste caused by the economic growth and development [4]. Use of bottom ash and fly ash in brick making will offer many advantages like consuming large volumes of waste whereby reducing the environmental problems caused by dumping these wastes in landfill and ash ponds, like enhancing the properties of bricks and performance of masonry, and contributing to sustainable development. This will also enable the developers to get green building index (GBI) points. The practice of green building concept shall increase the efficiency of resource use while reducing building impact on human health and the environment during the building's lifecycle, through better sitting design, construction, residence, operation, maintenance, and removal. Green buildings should be designed and operated to reduce the overall impact of the built environment on its surroundings [5]. Combustion of coal is a primary source of energy production in many countries including Turkey, where the lignite coal industry produces over 24 million tonnes of coal combustion residues (CCRs), which consist of roughly 18 million tonnes of fly ash and 6 million tonnes of bottom ash annually. One of the reasons for restricted use of the ash material is its high carbonaceous content. CCRs contain appreciable quantities of carbon-bearing residues [6].

In this research work, an attempt was executed to find out the possibility of using bottom ash in fired clay bricks. Various mixtures of bricks were made using bottom ash. Tests for unit weights, moisture contents, water absorption rates, porosities, compressive strengths, and compressive strengths of frozen samples and losses of ignition were conducted and the results were discussed.

2. MATERIAL AND METHODS

2.1. Material

Clay used in the study was obtained from Kolsuz reserves located in Niğde, Turkey. The chemical analysis of the clay was given in Table 1. Bottom ash obtained from Bor Sugar Plant, Niğde–Turkey, was determined to contain unburned carbon at a ratio of about 20%. Dense unit weight for oven-dried clay was obtained as 1.61 g/cm^3 and for bottom ash as 1.10 g/cm^3 respectively. Clay obtained from Kolsuz reserves was ground by means of a hammer mill to the size of 500 μm. On the other hand, bottom ash from Bor Sugar Plant was classified through a mesh sieve of 500 μm aperture size. Particle size distribution of the clay and bottom ash was given in Figure 1-2.

Table 1. Chemical composition of clay sample

Components	%
SiO_2	50.97
Al_2O_3	11.58
Fe_2O_3	6.77
CaO	8.40
MgO	3.90
Na_2O	1.83
K_2O	2.31
SO_3	0.13
LOI	13.63

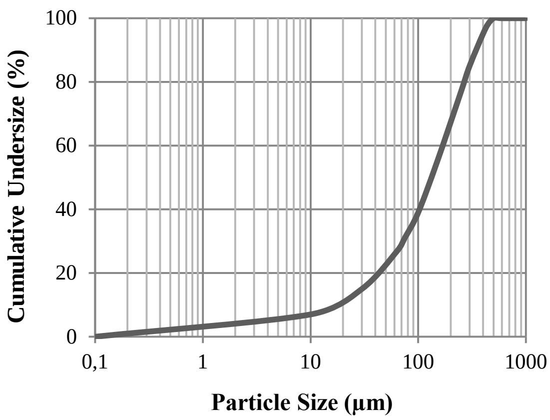

Figure 1. Particle size distribution of clay sample

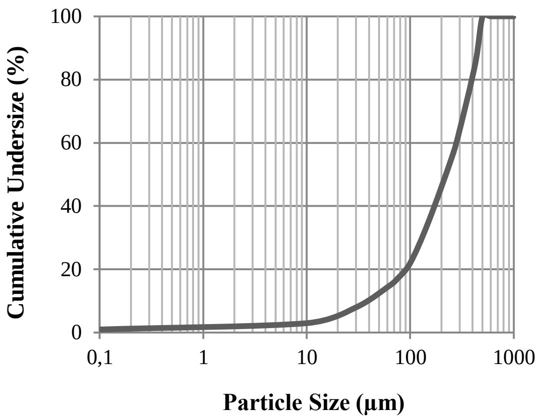

Figure 2. Particle size distribution of bottom ash sample

2.2. Methods

Experimental studies were conducted in two stages. In the first stage, 63 samples of brick which were made of 100% clay were produced. In the second stage, new mixtures were prepared by adding bottom ash to the clay at ratios of 10-15-20-25-30-35-40-45 and 50%. Each mixture was given a code depending on the clay/bottom ash ratio. The compositions of mixtures were presented in Table 2 while the numbers of samples for each mixture and firing temperature were listed in Table 3.

Table 2. Mixture compositions used to produce samples

Bottom ash ratio (%)	**Clay (cm^3)**	**Bottom ash (cm^3)**
0	25200	0
10	23000	2300
15	22000	3300
20	21000	4200
25	20000	5000
30	20000	6000
35	19000	6650
40	18000	7200
45	18000	8100

Table 3. Mixture compositions, firing temperatures and number of samples

Code and BA ratio (%)	**Firing Temperature (°C)**								
	800	**850**	**900**	**950**	**1000**	**1050**	**1100**	**1150**	**1200**
N0*	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**
N10	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**
N15	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**
N20	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**
N25	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**
N30	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**
N35	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**
N40	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**
N45	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**
Total number of samples	63	63	63	63	63	63	63	63	63

*****N represents sample, 0 represents bottom ash ratio and 7 represents the number of samples produced in the related group.

In the study, bottom ash replacement was tried at 50% ratio as well, but large amount of cracks and deformations were observed on the samples, leading to non-recordable results from mechanical tests. Samples fired at 1200ºC also exhibited large amounts of deformations which were concluded to have resulted from having exceeded the melting point of the clay component in the mixtures (Figure 3).

Production of samples was conducted in four stages being blending, moulding, drying and firing. Pastes for each mixture were prepared in a single batch to ensure homogeneity. Moulding was done using one type of cylindrical mould. Wet samples taken out of mould were left to dry under natural medium after getting coded and numbered according to types of mixtures (Figure 4). Then, the samples were oven-dried at 105±5°C. Following this procedure, the samples were fired in the order shown in Table 4.

Figure 3. Samples fired at 1200ºC

Figure 4. Samples dried under natural medium

Table 4. Firing temperatures and groups of samples

Sample group	Firing Temp. (°C)	The number of samples taken by the mixing ratio									
		BA 0%	BA 10%	BA 15%	BA 20%	BA 25%	BA 30%	BA 35%	BA 40%	BA 45%	Total
1. Group	800	7	7	7	7	7	7	7	7	7	63
2. Group	850	7	7	7	7	7	7	7	7	7	63
3. Group	900	7	7	7	7	7	7	7	7	7	63
4. Group	950	7	7	7	7	7	7	7	7	7	63
5. Group	1000	7	7	7	7	7	7	7	7	7	63
6. Group	1050	7	7	7	7	7	7	7	7	7	63
7. Group	1100	7	7	7	7	7	7	7	7	7	63
8. Group	1150	7	7	7	7	7	7	7	7	7	63
9. Group	1200	7	7	7	7	7	7	7	7	7	63

Unit weight tests were performed according to the standard TS EN 772-13, moisture content tests according to TS EN 772-10, gross volume tests according to TS EN 772-16, water absorption tests according to TS 699, compressive strength tests according to TS EN and freeze-thaw resistance tests according to TS EN 772-18.

3. RESULTS AND DISCUSSION

3.1. The Effects of Bottom Ash on the Unit Weight

Unit weight is known as the weight per unit volume of an object including the pores within the body of the object. The smaller this value is the more porous an object or material is. According to Figure 5, the unit weight values of samples with no bottom ash additive are at the maximum. The unit weights of the samples with bottom ash additives decreases linearly with the increasing percentile of the bottom ash. The samples with 45% ash additive and firing temperature of 1150°C gave the minimum value of unit weight which was measured as approximately 1.30 g/cm^3.

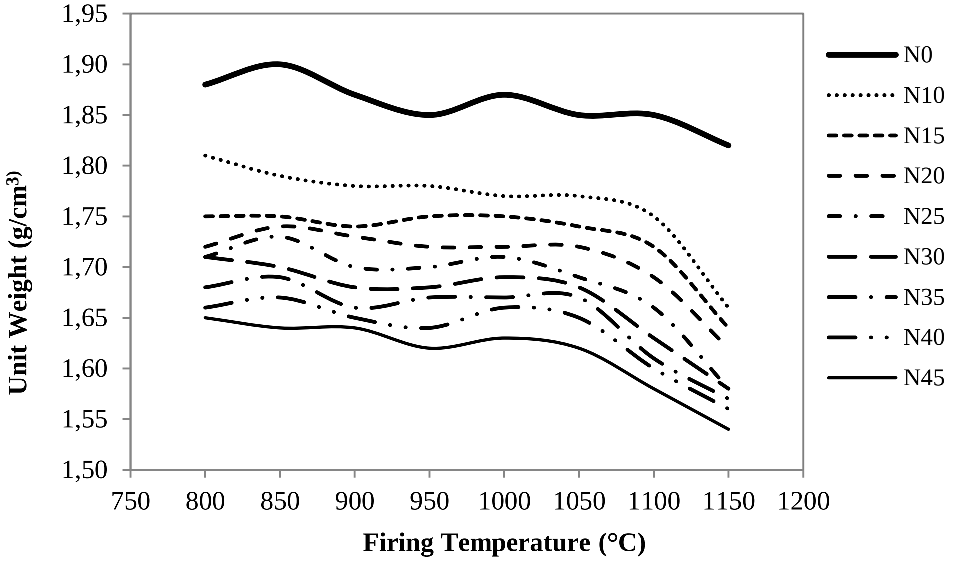

Figure 5. The relationship between bottom ash ratios, firing temperature and unit weights

3.2. The Effects of Bottom Ash on the Moisture Content

Condensation of water vapor within the body of a material emerges as perspiration on the surface and as hidden condensation in the body itself. This phenomenon might cause significant issues such as fall of plaster and fungal growth if necessary precautions are taken especially in the regions where hot and humid climates prevail. Figure 6 shows the relationship between bottom ash ratio, firing temperature and moisture content of the samples. As seen in the Figure 6, moisture content decreases with the increasing temperature of firing at all ash ratios. Samples with 45% bottom ash ratio were measured to have 0.02% moisture content while those with 0.00% bottom ash ratio were measured to have 0.06% moisture content at 1150ºC firing temperature. This is presumed to have sourced from the reaction between the silica content of clay and carbon content of bottom ash to produce a vitreous structure.

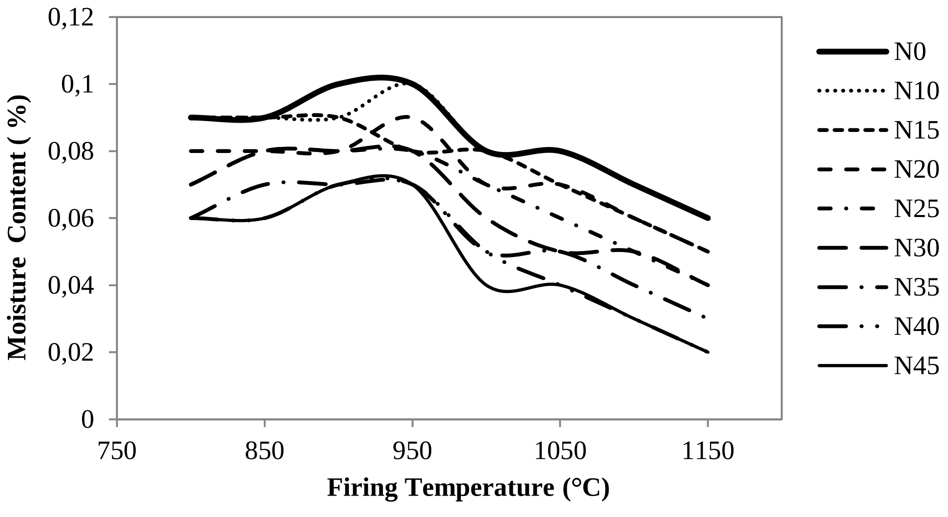

Figure 6. Relationship between bottom ash ratio, firing temperature and moisture content

3.3. The Effects of Bottom Ash on the Water Absorption Rate by Weight

Materials in general have pores within their bodies, visible or invisible. Usually, made of stone materials within the ceramics class, composite materials and lightweight building materials, have heterogeneous pores in their bodies. These pores grant the materials the characteristics called water absorption if they are inter-connected. Pores might function as water repellents when they are not inter-connected, i.e. when each pore is withdrawn into itself. In this step of the study, the effects of bottom ash ratio on the water absorption properties of the samples produced were investigated. As to be understood from Figure 7, samples without ash additive yielded minor water absorption values for each firing temperature. This sources from the low porosity of the body of samples made mainly of clay. Water absorption values of samples with bottom ash additives follows a nearly linear decline trend as the firing temperature increases though they start from relatively higher degrees compared to the pure clay samples. It was concluded that this decline was sourced from the increase in the porosity values of samples due to the reaction of bottom ash and clay at high, sintering temperatures. Here, sintering granted the pores water-repellent characteristics.

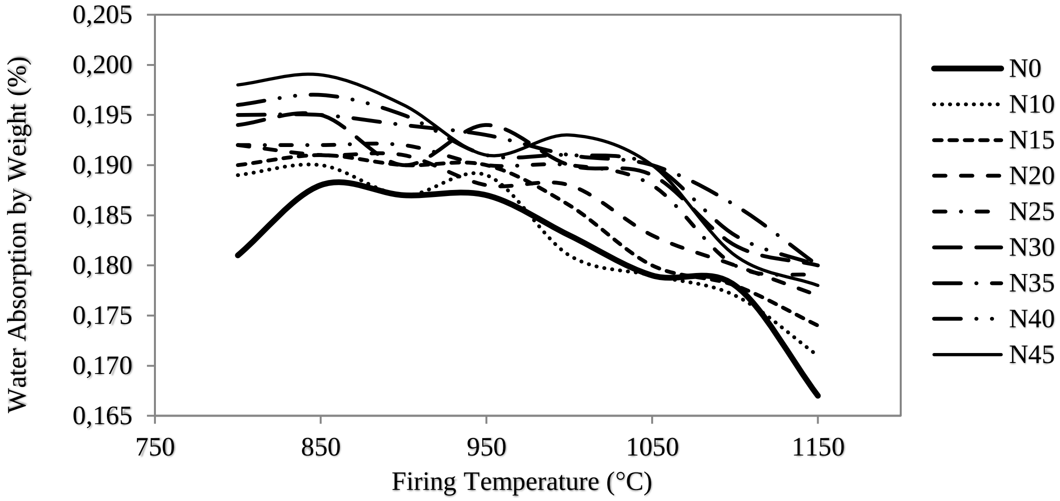

Figure 7. Relationship between bottom ash ratio, firing temperature and water absorption by weight

3.4. The Effects of Bottom Ash on the Porosity

Porosity (p) is described as the rate of cavity volumes to the total volume of a material or an object. This parameter is quite important in terms of heat transfer coefficient in lightweight building materials. The data obtained from porosity tests were introduced in Figure 8. In samples without bottom ash additive, a nearly-linear increase was exhibited in porosity with the increase in temperature, and a value of 23% was obtained at 1150°C. However as seen in the Figure 8, sharp increases were recorded in all the samples with ash additives with the increase in temperatures. The highest porosity value was obtained from the samples with 45% bottom ash additive at 1150°C, as 35%.

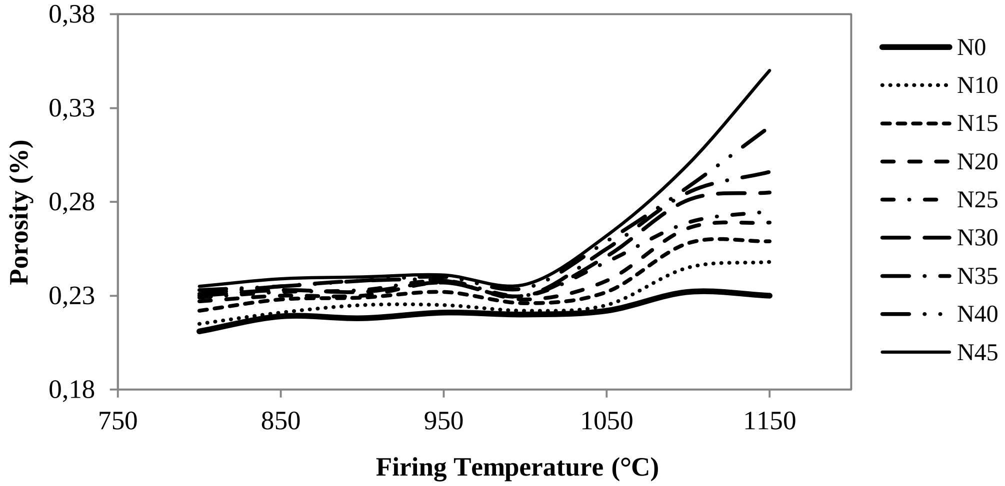

Figure 8. Relationship between bottom ash ratio, firing temperature and porosity

3.5. The Effects of Bottom Ash on the Compressive Strength

There is a close interaction between the chemical composition and mechanical properties of a material. In some cases, chemical composition becomes the most significant factor affecting mechanical strength. Compressive strength of a material is a significant parameter in being preferred especially for load-bearing structures. Figure 9 shows the compressive strengths of the samples produced. Samples with 45% ash additive and fired at 1150 °C yielded maximum strength (approximately 45 MPa). Samples with additives between 10 and 40% followed a similar behavior for firing temperatures between 800-1050 °C, but experienced a sharp rise in the strength values between 1100 and 1150°C. Samples with no ash additive followed a linear increase in compressive strengths and reached to the maximum at 1150°C, being merely 28.58 MPa. Bottom ash additive made a relatively high contribution to the increase in compressive strengths, owing to formation of silicon carbide which was thought to have been composed by the reaction of silica of the clay and non-combusted carbon in the bottom ash.

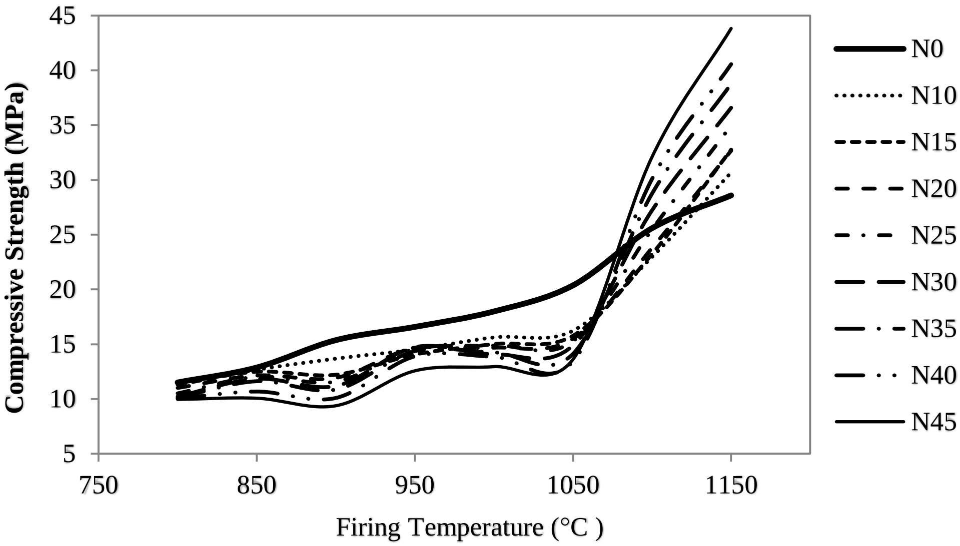

Figure 9. Relationship between bottom ash ratio, firing temperature and compressive strength

3.6. The Effects of Bottom Ash on Compressive Strength of the Samples Exposed to Freeze-Thaw Process

Compressive strength graphics for the samples exposed to freeze-thaw process were presented in Figure 10. The freeze-thaw processed samples without bottom ash additive exhibited a linear decrease in the compressive strengths with the increasing temperature and the maximum strength at 1150ºC was found as 20 MPa. Strengths of the samples produced with ash additives from 10 to 45% showed a linear decrease as well but the decrease made a sharp fall after 1075ºC. The maximum compressive strength was obtained approximately as 36 MPa for the samples with 45% ash additive, and fired at 1150ºC. It could be seen that, after freeze-thaw process, a drop of 29% decrease was observed in the compressive strength of the samples produced from clay without bottom ash additive and fired at 1150ºC, while only a drop of 18% decrease was determined in the compressive strength of the samples produced from with 45% bottom ash additive and fired at 1150ºC. Thus, higher rate of bottom as additive and firing temperature were concluded to have helped the samples keep the fall in compressive strength relatively lower.

3.7. The Effects of Bottom Ash on the Loss of Ignition

As seen in Figure 11, the samples without bottom ash additive have the minimum loss of ignition at all firing temperatures. However, there is a linear increase in values of loss of ignition for all the ash-added samples starting from 10% additive. The samples with 45% bottom ash additive exhibited the maximum loss of ignition with a value of 0.18%, at 1150ºC firing temperature.

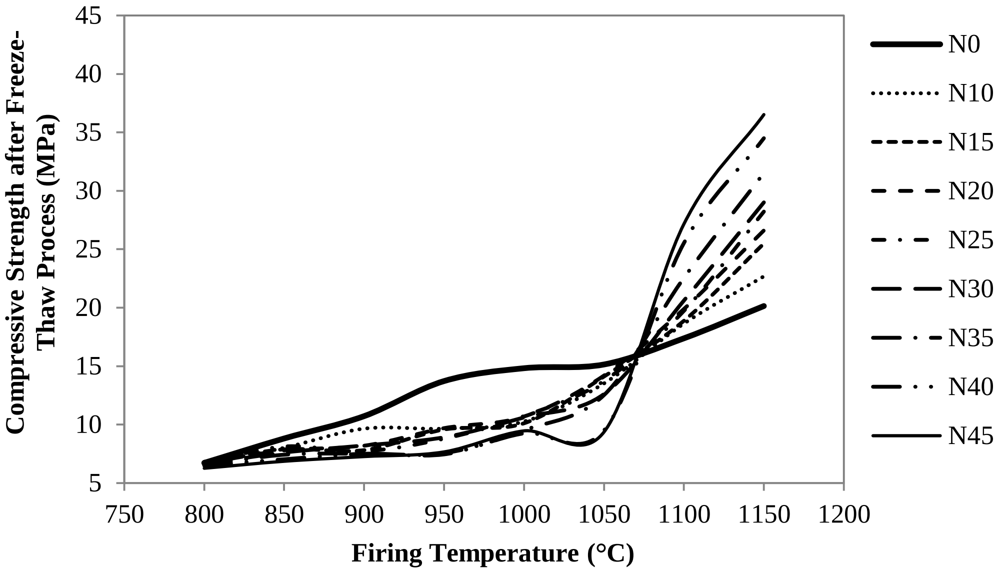

Figure 10. Relationship between bottom ash ratio, firing temperature and compressive strength after freeze-thaw process

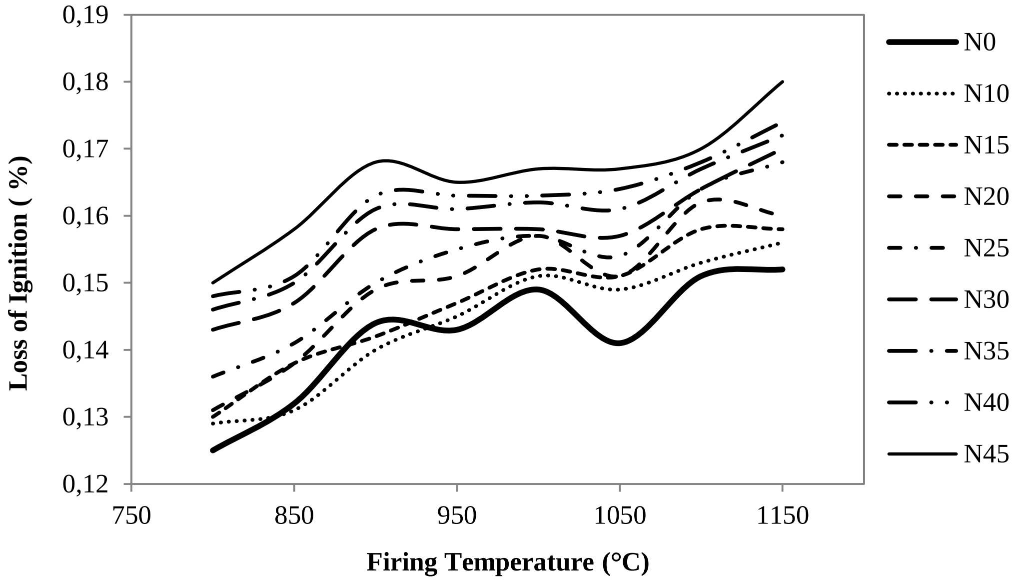

Figure 11. Relationship between bottom ash ratio, firing temperature and loss of ignition

4. CONCLUSIONS

It is a well-known fact that utilization of fly and bottom ash can also reduce the solid waste disposal problem. Bottom ash used as raw material replacing of clay to make fired bricks is an effectively measure in decreasing the wastes. Therefore, this paper reports the results of the investigation conducted on bricks made using bottom ash of a sugar mill (Bor-Niğde Turkey). The results obtained in this study showed that even higher ratios of replacement (45%) of ash could be used as an effective alternative. Best results show that final samples exhibited 1.54 g/cm^3 unit weight, 0.02% moisture content, 0.178% water absorption rate, 35% porosity, 43.82 MPa compressive strength, and 35.52 MPa compressive strength for the freeze-thaw processed. The outcomes indicate that the bottom ash used as raw material replacing of clay to make fired bricks is effective to obtain fired clay bricks.

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