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Performance Characteristics of The Briquette Containing Natural Zeolite

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This study was carried out to investigate the effect of Natural zeolite (clinoptilolite) (NZ) used in briquette production on physical and mechanical properties of briquettes. To do this, six briquette classes were formed by changing the volume of NZ and the coarse aggregate and porous briquettes were produced for each class according to Turkish Codex no. 406 (TS 406) and tested. Increasing ratio of NZ volume affected the compressive strength, water absorption and losses due to freezing-thawing of the briquettes negatively. As for the bulk densities and heat conductivity decreased and was affected positively. It was concluded that NZ might be used in briquette production replaced the coarse aggregate in certain ratio to make them profitable and lessen their adverse effects on the environment.

Keywords: Briquette, natural zeolite, mechanical properties, physical properties

Doğal Zeolit İçeren Biriketlerin Performans Özellikleri

Bu çalışma, briketlerin fiziksel ve mekanik özellikleri üzerine, briket üretiminde kullanılan Doğal zeolit (clinoptilolite) (DZ) etkisini araştırmak amacıyla yapılmıştır. Bunu yapmak için, DZ ve iri agrega hacimleri değiştirilerek altı briket sınıfı oluşturuldu ve her sınıf için gözenekli briketler Türk Standardı 406 (TS 406)' ya göre üretildi ve test edildi. DZ hacim oranının artırılması basınç dayanımı, su emme ve donma-çözülme nedeniyle oluşan kayıplar olumsuz etkilenmiştir. Kütle yoğunluğu ve ısı iletkenliği değerleri azalmış ve olumlu şekilde etkilenmiştir. DZ'nin, onları karlı yapmak ve çevre üzerindeki olumsuz etkileri azaltmak için belirli oranlarda kaba agrega yerine briket üretiminde kullanılabileceği sonucuna varılmıştır.

Anahtar Kelimeler: Briket, doğal zeolit, mekanik özellikler, fiziksel özellikler

Introduction

By providing the comfort conditions of the buildings of present time, the most costly component is energy. Therefore, the forward coming component of construction designing is heat isolation. In order to take necessary actions concerning heat isolation at the constructed buildings, it is necessary to provide the needed thermal comfort for the shelters in respect of not to be affected negatively from temperature effects and for feeling relax of living beings (Ozturk and Bayrak 2005).

Due to the unit weight and high porosity, at present time, lightweight concrete (LWC) elements are prefered as isolation materials. Comfort temperature value can be provided with lower energy consumption by using LWC in construction elements (Rossingnolo and Agnesini 2001).

Lightweight concrete has been widely used in buildings as masonry blocks, wall panels, roof decks and precast concrete units. Reduction in weight by the use of LWC is preferred, especially for structures built in seismic zones and offshore structures which are mostly used for oil production, require lightweight elements which can be towed easily and have the greatest buoyancy (Hoff 1990, Sarı and Pasamehmetoglu 2005) There are a number of methods to produce LWC. In one of method, the fine portion of the total concrete aggregate is omitted, which is called 'no fines'. Another way of producing LWC is to introduce stable air bubbles inside concrete by using chemical admixtures and mechanical foaming. This type of concrete is known as aerated, cellular or gas concrete. The most popular way of LWC production is by using lightweight aggregate. Such aggregates, natural or artificial, are available in many parts of the world and can be used in producing concrete in a wide range of unit weights and suitable strength values for different fields of applications (Demirboga 2001).

LWC manufactured either from natural or from artificial aggregate is classified by the ACI Committee 213 into three categories according to its strength and density. The first category is termed low strength, corresponding to low density and is mostly used for insulation purposes. The second category is moderate strength and is used for filling and block concrete. The third category is structural LWC and is used for reinforced concrete (Sisman et al. 2008).

The use of lightweight aggregate in concrete has many advantages. These include: (1) Reduction of dead load that may result in reduced footings sizes and lighter and smaller upper structure. This may result in reduction in cement quantity and possible reduction in reinforcement. (2) Lighter and smaller pre-cast elements needing smaller and less expensive handling and transporting equipment. (3) Reductions in the sizes of columns and slab and beam dimensions that result in large space availability. (4) High thermal isolation. (5) Enhanced fire resistance (Kayalı 2008).

The only perceived limitation of the LWC is that it requires manufactured lightweight aggregates (Haque et al. 2004). Lightweight aggregates are naturally occurring (pumice, diatomite, volcanic cinders etc.) or artificially made (perlite, expanded shale, clay, slate, sintered PFA etc.) and LWC can be easily be produced by adding natural zeolite (NZ) (Tanyıldız 2008).

Zeolites are members of a mineral class called tectosilicates, a structure type typified by quartz. The term tectosilicate brings to mind an image of multiple silicate tetrahedra, each bonded to four other silicate tetrahedra. Zeolites have open structures built around large solveted cations such as sodium or potassium. The silicate network forms around the ions resulting in low density materials (2 g/cm^3) containing cavities and channels. The large compensated by the substitution of an aluminum ion for a silicate ion in selected tetrahedra (Grutzeck 2004).

Sisman et al. (2008) were determined that the compressive strengths and oven dry unit weights of the lightweight concrete produced using different rates of natural zeolite (clinoptilolite) (NZ) and normal concrete aggregate changed between 1.36 - 23.04 MPa and between 1500 and 1900 kg/m^3, respectively. All produced concretes were resistant to freezing. Water absorption rates of the concretes were below 8%. In addition, thermal conductivities varied from 0.58 to 0.93 W/mK.

The NZ (clinoptilolite) may be used in the production of briquette, which is a common construction material used around the world as well as in our country, Turkey. Briquettes are made of mixing all-in aggregates, cement and water, and drying the mixture under open-air conditions. The production of briquettes is simple, and they are widely used in Turkey.

The main objective of this study is to investigate the effects of NZ addition replace the coarse aggregate on the physical and mechanical properties of briquettes according to Turkish Standard.

MATERIALS AND METHODS

Materials

Briquette is a building material made of mixing all-in aggregates, cement water and other additives in a container, shaped using vibration briquette machine (Fig. 1) under 15 MPa pressure and drying the mixture under open-air conditions to a required hardness (Yuksel et al. 2006). Briquette is in the shape of a rectangle prism with one open and 5 closed faces. Its empty volume occupies 25-50 % of the total volume. This empty volume makes it lighter and more insulated against voice and heat transmission. It is widely used in the walls of the buildings. The produced briquette dimensions produced in Turkey according to the Turkish codex TS 406 (1988) are given in Table 1. Outside wall thicknesses of a single briquette change from 30 to 45 mm while inside wall thicknesses vary between 30 and 35 mm. Fig. 1 presents the view of a briquette.

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Table 1. Produced briquette dimensions in Turkey according to the TS 406 (1988).

Width (mm)		100	150	200	250	300
Height (mm)		190	190	190	240	240
Length (mm)	Full	390	390	390	490	490
	Half	190	190	190	240	240

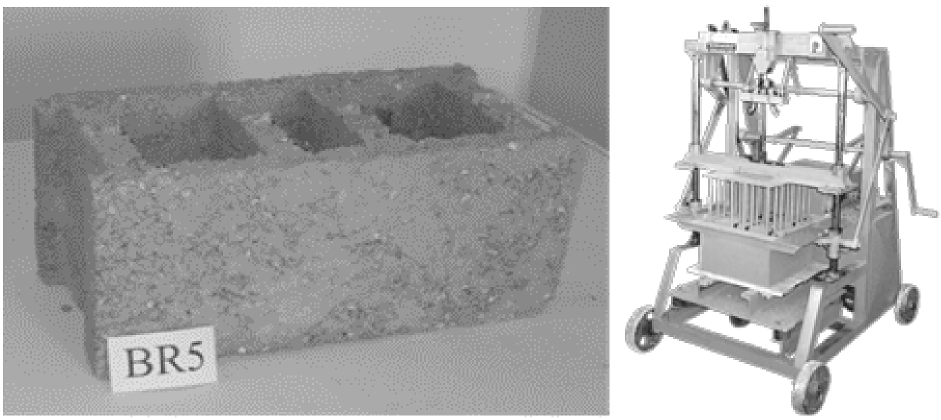

Fig. 1. A general view of the briquette and the vibration briquette machine

The four main materials, used in this study for making the briquette mixture, are: (i) cement, (ii) NZ (clinoptilolite) as coarse aggregate, (iii) all-in aggregates, which are commonly used in producing ordinary briquettes and (iv) tap water having the quality parameters defined in TS 1247 (1984) as the kneading material.

Cement:

The cement used was a blended ASTM Type I (PC 32.5) Portland cement obtained from Betonsa Factory located in the Northwestern of Turkey, having a 28-day compressive strength of 36.08 MPa and specific gravity of 3.07 g/cm^3. Its chemical and physical and mechanical properties are given in Table 2.

Natural Zeolite (Clinoptilolite)

The NZ (clinoptilolite) used was obtained from natural deposits in Manisa region Turkey. The grinded NZ were passes through a 12.5 mm sieve, as suggested by Ekmekyapar and Orung. The NZ with the maximum particle size of 12.5 mm were, then, used in the briquette production. The chemical composition and physical properties of the NZ used in this study are given in Table 3.

The Fig. 2 shows typical and the microscopic images of the NZ. It was found that the NZ consists of irregular-shaped particles with a sizable fraction showing a porous cellular structure. It had high meso- and micro porosity with specific gravity of 1.70 g/cm^3.

Table 2. Chemical composition and physical and mechanical properties of the cement

Chemical Composition		Physical and Mechanical Properties		
Component	%			
Insoluble Residues	1.39	Specific Gravity (g/cm^3)		3.07
		Setting Time	Initial (min)	153
			Final (min)	217
SO_3	2.61	Soundness (Le Chatelier) (mm)		1.3
Loss on Ignition	1.25	Specific Surface (cm^2/g)		3259
		Compressive Strength (MPa)	2 day	-
Cr	0.0385		7 day	23.80
			28 day	36.08

Table 3. Chemical composition and physical properties of NZ (clinoptilolite)

Material Properties	Natural Zeolite
SiO_2 (%)	71.0
CaO (%)	3.40
Fe_2O_3 (%)	1.70
Al_2O_3 (%)	11.80
K_2O (%)	2.40
MgO (%)	1.40
Loose Unit Weight (kg/m^3)	1131
Condensed Unit Weight (kg/m^3)	1205
Specific Gravity (g/cm^3)	1.70
Water Absorption (%)	18

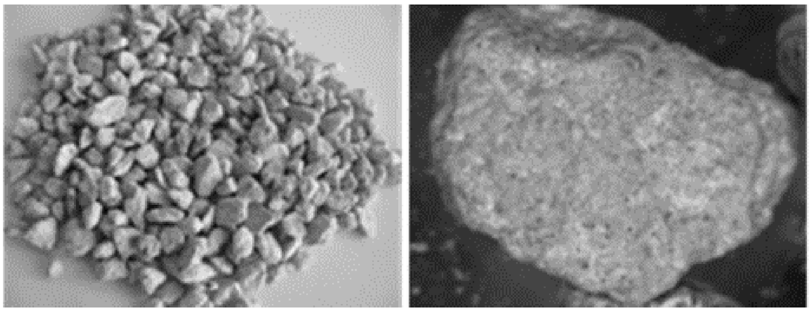

Fig. 2. Typical and microscopic images (by 10x[FN_frame (shut) diameter is 10 mm] [20x]) of the NZ

All-in Aggregate

Local river sand was used as a fine aggregate. Crushed coarse aggregate with maximum size of 12.5 mm was used. The chemical and physical properties of the fine and coarse aggregates are presented in Table 4. The fine and coarse aggregates had specific gravities of 2.70 and 2.79 g/cm^3, and water absorptions of 1% and 0.6%, respectively

Table 4. Chemical and physical properties of the fine and coarse aggregates

Material properties	Aggregate	
	Fine	Coarse
SiO_2 (%)	89.82	43.64
CaO (%)	0.10	18.49
Fe_2O_3 (%)	0.48	12.84
Al_2O_3 (%)	4.89	10.22
K_2O (%)	2.95	0.03
MgO (%)	0.39	7.82
Loose unit weight (kg/m^3)	1540	1462
Condensed unit weight (kg/m^3)	1635	1619
Specific gravity (g/cm^3)	2.70	2.79
Water absorption (%)	1	0.6

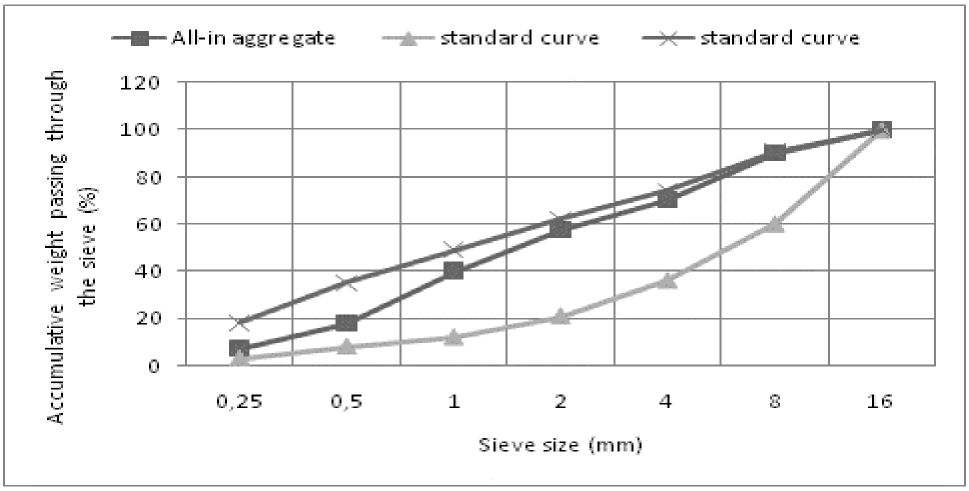

Fig. 3. Grain size distribution curve of the aggregates used in briquette production.

Coarse aggregate with the maximum particle size of 12.5 mm were, then, used in the briquette production as suggested by Ekmekyapar and Orung (1993). Grain size distribution (or granulometry) of all-in aggregate were done by sieve analysis and presented in Fig. 3.

Mix Proportions, Preparation of Specimens and Test Method of Briquette

For making the briquette mixture for briquette production, the amount of tap water was determined according to TS 802/T2 (2002) adjusting water to cement ratio of 0.45 (by weight), while the mixing ratio of all-in aggregates, NZ and cement were adjusted volumetrically (Ekmekyapar and Orung 1993). Six briquette classes were defined based on the volume of NZ used (Table 5). However, to produce a C16 level concrete, as described in TS 802/T2 (2002), the volumes of cement and fine aggregate in the mixture was kept constant in all these six briquette classes. The coarse aggregate was replaced with NZ at ratios of 5 (BR1), 10(BR2), 20(BR3), 30(BR4) and 40(BR5) %. The BR0 was made from the cement and all-in aggregate as a control briquette. The mixture water amounts of the treatments other than control treatment were obtained taking the obtained slump value of control treatment (5±1 cm) constant. After 28 days of production, briquette specimens for each class were examined for physical properties (like bulk density, volumetric and weight based water absorption ratio, and thermal conductivity) and mechanical properties (like freezing-thawing resistance and compressive strength).

Table 5. Volumetric mixing ratio of briquette materials.

Briquette Classes	Cement	NZ	Aggregate	
			Coarse	Fine
BR0	1	0	3	3
BR1	1	0.15	2.85	3
BR2	1	0.3	2.7	3
BR3	1	0.6	2.4	3
BR4	1	0.9	2.1	3
BR5	1	1.2	1.8	3

In briquette production, 10 briquette specimens of 390 x 150 x 190 mm dimensions were produced using pressure-hydraulic machine, under each briquette class mentioned in Table 5.

For the produced specimens, observations of dimensional deviations and physical deformations, and tests of bulk density, compressive strength and freezing-thawing resistance were investigated according to TS 406 (1988). To calculate bulk density, the specimens were taken after 28 days and oven dried at 105°C until the weight became stable and finally it was determined dividing the oven-dry weight by the volume of the specimens. As for the compressive strength, first the surface of the sample briquettes whose compressive strength were measured were leveled plastering over the prepared mortar (one volume cement and one volume sand). Empty spaces were filled with papers to avoid mortar entering into these spaces. After 28 days, briquette samples were loaded by 2000 kN capacity hydraulic press adjusting the cracking time to 60 second. And finally compressive strength were determined from Pmax/A (Pmax: Maximum load, A: Surface area). For freezing-thawing resistance, 28 day briquette specimens were subjected to freezing–thawing cycle in 20±2 °C water tank for 4 hours and in a deep freeze at -15±3 °C for 4 hours following each other 25 times. Then, these specimens were exposed to compressive strength test. In each test, three specimens were taken and averages of the test results were used for statistical analysis. To determine the water absorption ratio, briquette specimens were soaked in distilled water until achieving a constant weight, and then were oven-dried (Ones 1988). The difference between wet and dry weight were divided by dry weight provides an estimate for water absorption ratio. Thermal conductivity was measured using hot-wire technique according to ISO 8894-1. For thermal conductivity tests, each briquette specimens was divided into three parts, which were tested separately, and the averages of the test results were for statistical analysis (ISO 8894-1, 1987).

Result And Discussion

Dimensions And Deviation From The Set-Square

The magnitude of deviation in the dimensions and set-square in the concrete elements produced in forms should range within the allowable deviation limits defined in standards for these elements. Otherwise, some problems may be encountered in the building elements in which produced concrete is used regarding their strength, labour and esthetics.

Deviations in the dimensions and set-square obtained by physical control tests after 28 days for each class of mixture are given in Table 6.

The magnitude of the deviations did not change with the increasing of NZ in the mixture except for BR4 and BR5. Therefore, the minimum and maximum deviations were observed in BR5 and BR0. Expansion due to the heat of hydration and chemical interaction between cement and aggregates and NZ were mostly responsible for this deviation.

Table 6. Average deviation in the dimensions of the briquettes.

Briquette Class	Magnitude of deviation in briquette dimension			
	Width (mm)	Length (mm)	Height (mm)	Deviation from set-square (%)
BR0	+1	+1	+3	0.8
BR1	+1	+1	+1	0.8
BR2	+1	+1	+3	0.8
BR3	+1	+1	+2	0.8
BR4	+2	+2	+2	1.6
BR5	+2	+2	+5	1.6

Table 7. Some physical and mechanical properties of the briquette

Classes	Oven-dry bulk density (kg/m^3)	Water absorption (%)		Average compressive strength after 28 days (MPa)			Thermal conductivity (w/mºK)
		Sw*	Sv*	Before freezing-thawing	After freezing-thawing	Loss in compressive strength (%)	
BR0	1332	6.54	8.71	3.92	3.53	9.7	0,69
BR1	1306	6.97	9.10	3.82	3.39	11.2	0,68
BR2	1258	7.90	9.94	3.64	3.13	14.0	0,65
BR3	1183	8.51	10.06	3.35	2.81	16.1	0,61
BR4	1095	9.57	10.45	2.84	2.29	19.3	0,57
BR5	985	10.87	10.70	2.24	1.70	24.1	0,52

* Sw and Sv represent the weight and volume percentage of absorbed water, respectively.

Additionally, particularly higher water absorption capability of NZ in comparison to all-in aggregates resulted in the increase of mixing water amount. This led in deviation of the dimension. Sisman et al (2008) found that water absorption ratio of LWC was increased from 6.1% to 8.3 % when NZ amount increased from 25% to 100% as all-in aggregates, respectively. Similarly Kocaman et al. (2008)investigated that water absorption ratio increased from 6.1%to 15.73% when the coal clinkers replaced with all-in aggregates from 0% to 100%.

Deviations recorded in the briquette classes except BR5 were within the allowable limits according to TS 406 (1988) (±3 mm in width and length, ±4 mm in height and 2% in set-square).

Evaluation of the Mechanical and Physical Properties

Produced briquette samples for each class were examined. Bulk density, water absorption, compressive strength, freezing-thawing and thermal conductivity after 28 days and the obtained results were presented in Table 7.

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The average oven-dry bulk density of classes BR0 and BR5 were found to be 1332 kg/m^3, 985 kg/m^3 respectively (Table 7). When BR5 class was compared with BR, BR5 was 26% lighter. This is great advantage in decreasing the dead weight. The variations in the average oven-dry bulk density between the classes were also presented graphically in Fig. 4.

As expected, the bulk densities of the briquettes were decreased with increasing volume ratio of NZ in the mixture (Fig. 4). This is simply due to smaller bulk density of NZ than that of all-in aggregates. The loose and pressed bulk density of NZ is classified as light weight aggregates. Sisman et al. (2008) investigated that the bulk density of LWC produced using NZ decreased linearly with the increase in the amount of used NZ. Kocaman et al. (2008) found that bulk density of briquettes depending on the amount of used coal clinkers in briquette production as all-in aggregate and in the case of 100% coal clinkers replacement, the bulk density decreased 997 kg/m^3. Similarly, the bulk density of briquettes using bottom ash decrease to the value of 900 kg/m^3 (Yukesel et al. 2006). Yuksel and Bilir (2007) determined that bulk density of briquettes decreased by 30% by using bottom ash

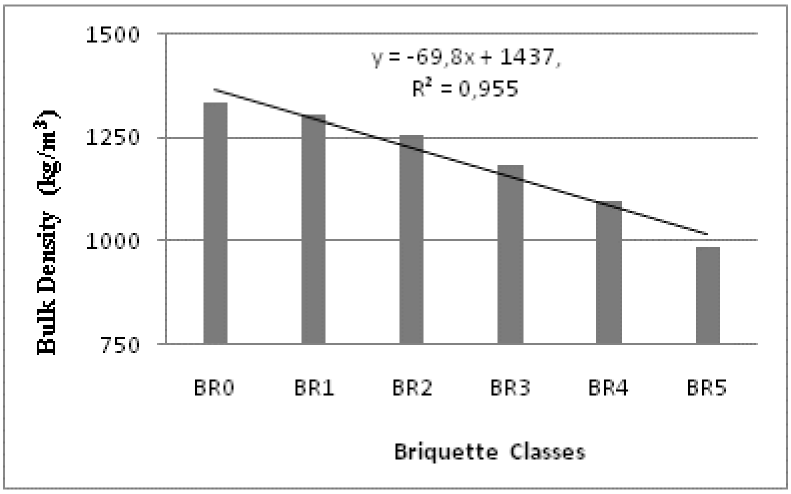

Fig. 4. Briquette classes and their oven-dry bulk density

Briquettes are divided into 12 classes according to TS 406 (1988) regarding bulk density as shown in Table 8. The briquette classes take place in 1.2 and 0.9 class according to TS 406 (1988). Turgut (2007) suggested that briquettes with 1500 kg/m^3 bulk density may be used in structural walls whereas briquettes having the bulk density smaller than this value may be used in wall for insulation purposes.

Volumetric and weight based water absorption ratio, a very important parameter since it directly affects the life-span of the buildings through wetting-drying and freezing-thawing processes following each other, were presented in Table 7. Water absorption ratio increased with the increases in the volume of NZ in the mixture. The minimum and maximum water absorption ratios were 6.54 % and 10.87 % for BR0 class and BR5 class respectively. Kocaman et al (2008) reveals that gravimetric water absorption ratio of briquettes increased from 6.21% to 15.73% depending on the amount of coal clinkers used in briquette production. A linear relationship was obtained between the oven-dry bulk density and water absorption ratio of the briquettes, which was shown in Fig. 5.

Fig. 5 reveals that oven-dry bulk density decreased with increasing water absorption ratio. This is because NZ are light weight aggregate and have higher porosity. The water absorption ratio of all briquette classes remained under the suggested limit of 20 % by Ekmekyapar and Orung (1993). Therefore no briquette class has a water absorption ratio problem and may be used safely in terms of this parameter. In the case briquettes are used in the construction of buildings' walls the water movement into the wall will be prevented significantly when the sides of the inner and outer walls are plastered since the pores are blocked. If a more water-proof wall is intended, preventive additives may be mixed into the plaster mixture.

Table 8. Briquette oven-dry bulk density classes according to TS 406 (1988).

Briquette Class	0.5	0.6	0.7	0.8	0.9	1.0	1.2	1.4	1.6	1.8	2.0	2.2
Oven-dry bulk density (kg/m^3)	500	600	700	800	900	1000	1200	1400	1600	1800	2000	2200

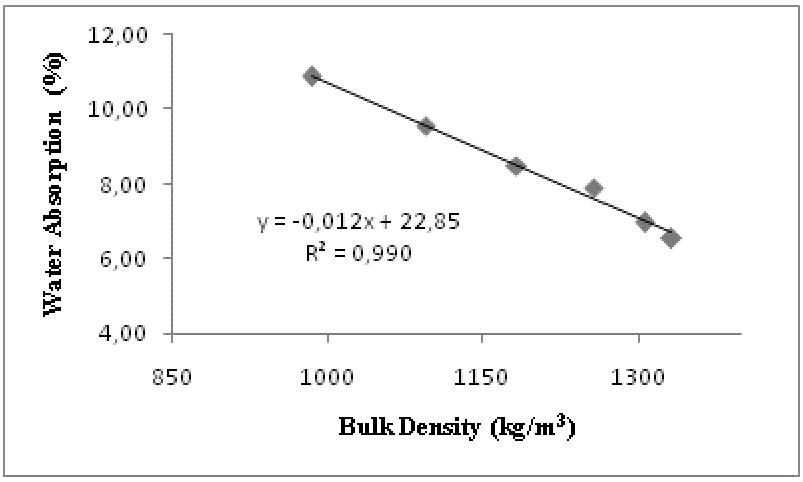

Fig. 5. Relationship between the oven-dry bulk density and water absorption ratio

Briquettes are divided into 4 classes according to TS 406 (1988) regarding comprehensive strength as shown in Table 9. Results on the briquette resistances to pressure before and after freezing-thawing effect and lower limits of BB2 and BB4 class (TS 406 1988) were presented in Fig. 6.

Fig. 6 shows all briquette classes take place in BB2 class according to TS 406 (1988). The compressive strengths of the specimens on day 28 ranged from 3.92 to 2.24 MPa (Table 7).

Table 9. Briquette comprehensive strength classes according to TS 406 (1988).

Briquette class	Comprehensive strength (MPa)	
	Average	Minimum
BB2	2.5	2.0
BB4	5.9	4.0
BB6	7.5	6.0
BB12	15.0	12.0

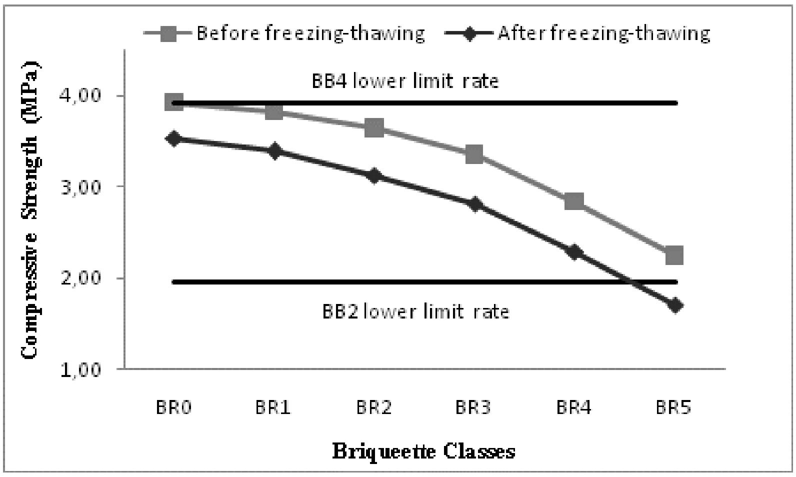

Fig. 6. Variations in the comprehensive strength before and after freezing-thawing tests

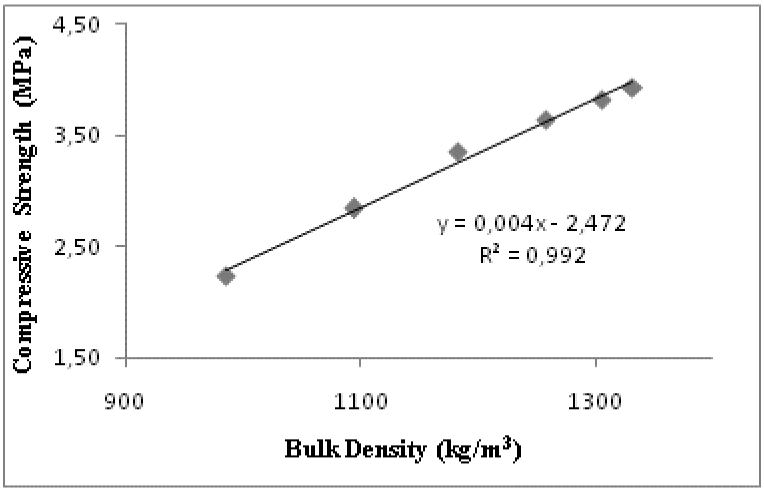

Fig. 7. Relationship between the bulk density and comprehensive strength

The highest compressive strength was noted in the control briquette class BR0 (3.92 MPa) followed by BR1 (3.82 MPa) and BR2 (3.64 MPa). The comprehensive strength of briquette classes were decreased with the increase in NZ ratio in the mixture. This is because the resistance of NZ per bulk density is smaller than that of all-in aggregates. Irregular shape of NZ and higher porosity are also effective in this smaller comprehensive strength. On the other hand, it is well known that the value of compressive strength of the concretes containing NZ is smaller than a normal concrete. Similar finding was also reported by some investigations made on concrete produced with NZ (Feng and Peng 2005, Sisman et al. 2008). Yuksel and Bilir (2007) investigated that 50% replacement of bottom ash with all-in aggregates decreased the compressive strength of briquettes from 6.37 MPa to 1.43 MPa. Similarly, Kocaman et al.(2008) reportat decreases from 3.39 to 2.11 MPa in compressive strength with addition of coal clinkers.

There is also a significant relationship between the bulk density of materials and comprehensive strength. Fig. 7 shows that there is a linear relationship between the bulk densities of the briquette classes and their comprehensive strength. Increasing the NZ in the mixture decreased both the bulk density of the produced briquettes and comprehensive strength.

According to the result, it may be concluded that BR0, BR1, BR2 and BR3 classes give the ideal mixing ratio in terms of bulk density and comprehensive strength.

Resistance of the briquettes to freezing-thawing was determined by looking at the changes in the comprehensive strength. For this reason, comprehensive strength test were realized after the freezing-thawing cycles following each other. The results were presented in Table 7 and graphed in Fig. 6.

The comprehensive strength values after the freezing-thawing cycles shown paralleled to the strength value before the freezing-thawing cycles. The highest comprehensive strength loss was recorded in BR5 with 24.1 % while the least loss was observed in BR0 with 9.7%. The comprehensive strength losses in BR5 briquette class decreased to 1.7 MPa and fell below the minimum suggested value of BB2 class briquette as standard (TS406 1988). However, all the results were considered together, losses of comprehensive strength due to freezing-thawing cycles remained well below the maximum losses suggested in the relate standards (TS406 1988) for a normal briquettes. Therefore, it may be concluded that all briquette classes except for BR5 are qualified suitable to the standards in terms of comprehensive strength.

Thermal conductivity of building materials is also a crucial characteristic for the heat-humidity transfer of the buildings. Low thermal conductivity is preferred to control heat losses. Table 7 shows that the thermal conductivity of the briquette classes decreased with increasing NZ in the mixture.

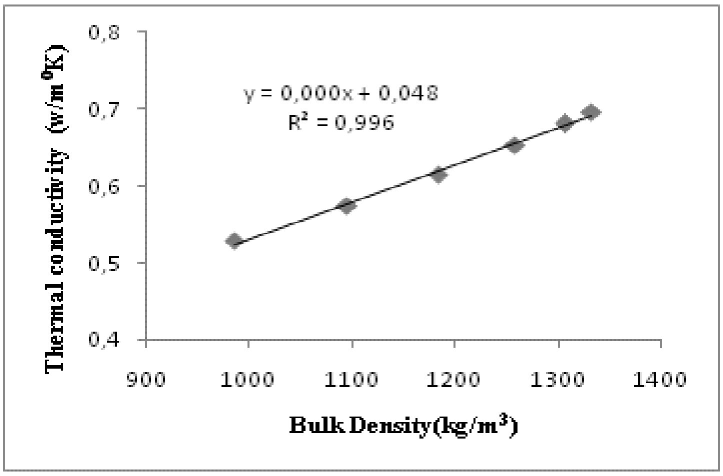

Fig. 8. Relationship between the bulk density and thermal conductivity

While the thermal conductivity of BR0 class was 0.69 W/mºK, it decreased to 0.52 W/mºK for BR5 class. This is because NZ have higher porosity when compared to all-in aggregates. Increasing ratio of NZ in the mixture provides advantages of not only lower thermal conductivity but also lightness. Kocaman et al. (2008) used coal clinkers instead of all-in aggregates in briquette production and found that thermal conductivity of briquettes decreased from 0.39 W/mºK to 0.23 W/mºK. Similarly, Turgut (2007) reported thermal conductivity between 1.07 and 0.90 W/mºK for briquettes producing limestone and glass powder. There is a strong relationship between the bulk density and thermal conductivity of dry, light concrete (Steiger and Hurd 1978). This relationship is presented for the briquette classes in Fig. 8.

Conclusions And Recommendations

Changes in some physical and mechanical properties of the briquettes were examined when using NZ together with the all-in aggregate as coarse aggregate. Six briquettes classes were formed by varying the mixing ratio of NZ and aggregate, analysis were done on the produced samples and finally their suitability for the standards was discussed. The main finding may be summarized as:

- The maximum particle size of 12.5 mm of the aggregates is suitable for briquette production.
- Dimensional deformation decreased a little with the increasing ratio of NZ in the mixture.
- The oven-dry bulk density of the briquette classes decreased with increasing ratios of NZ in the mixture. The bulk density of BR0 class, with no NZ in the mixture, was 1332 kg/m^3 and decreased to 985 kg/m^3 in BR5 with 40% NZ as coarse aggregate. This implies that using NZ in briquette production may decrease the dead load on the building elements by decreasing the bulk density of wall with light briquettes.
- Water suction ratios of the briquettes classes increased with NZ. It took minimum value of 6.54 % for BR0 and maximum value of 10.87 % for BR5 briquette classes. Water suction ratios of all briquettes classes were below suggested standard limit of 20 %. Therefore, no problem is foreseen using NZ in briquette production regarding water suction ratio.
- The comprehensive strength of the briquette classes decreased with the increasing replacement ratio of NZ in the mixture. Average comprehensive strength of BR0 class, contain no NZ, was 3.92 MPa. However, it was 3.82 MPa for BR1 class, containing 5% NZ and 2.24 MPa for BR5 class, containing 40% NZ. According to their results, briquettes containing 20 % of NZ as coarse aggregate are suggested to be used in the construction of separation walls carrying fewer loads.
- The minimum and maximum comprehensive strength losses by

comprehensive strength cycles when compared with the valves before exposing comprehensive strength were 9.7 % and 24.1 % for BR0 and BR5 briquette classes. The comprehensive strength losses for all briquettes classes were below the 25 %, suggested standard maximum limit for a normal briquette (TS406 1988). Therefore briquette classes in this study can be safely used in terms of comprehensive strength effect on comprehensive strength losses.

- Heat conductivity of the briquettes classes decreased with the increase in the volume of NZ in the mixture. This was 0.69 W/mºK in BR0 class while it decreased to 0.52 W/mºK in BR5 class. This means that use of heat-moisture balance within the required levels is easier.

As conclusion, use of NZ as coarse aggregate in the production of briquette provides would be an economical alternative to conventional briquette production.

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