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Full Length Research Paper

Effects of rice husk ash on characteristics of the briquette produced for masonry units

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

Key words: Briquette, concrete, rice husk ash, mechanical properties, physical properties.

INTRODUCTION

In all developing and industrial countries, large amounts of industrial and agricultural wastes or by-products accumulate every year. The recycling of these materials are of increasing interest worldwide, due to high environmental impact of the cement and concrete industries (Bertolini et al., 2004). Also, for the production of cement and concrete, very high amount of energy is needed. CO2 (7%) released to atmosphere is appeared during cement production. This state has negative influence on ecology and future of human being (Mehta, 2002).

Harmful effects of building materials on environment can be reduced by producing durable concrete and effective usage of resources. Industrial and agricultural wastes can be used for this purpose. According to ecology concept for sustainable development, waste of one industry may be a raw material for other industries. Therefore, detrimental effects of both industries to the environment can be reduced. For this reason, cost, durability and environmental friendliness are to be used in developing concrete technologies as important criteria (Yuksel and Bilir, 2007).

In case of the usage of these wastes in concrete as aggregate or cement replacement, each of them would be raw material having economical value. Therefore, these wastes will become more valuable, which was not valuable currently.

Rice husk is an agricultural waste material obtained from the threshing of the rice and constitutes about 20% of 650 million tons of rice produced annually in the world (Genctan and Balkan, 2009). It has little commercial value, for example, chicken litter and roughage. Although low in calorific value, rice husk is used as fuel for some industrial and household purposes. The rice husk ash (RHA) obtained from the controlled burning of rice husk has pozzolanic properties. Mehta (1978) reported that RHA in a highly reactive form could be used as a suitable raw material for making hydraulic cement. Rahman (1987) investigated the use of RHA in sandcrete blocks for masonry unit, and the test results showed that up to 40% RHA could be added as a partial replacement for cement without any significant change in compressive strength at 60 days. Oyetola and Abdullah (2006) reported that the compressive strength of the sandcrete blocks decreased as the percentage of RHA content increased, and the optimum replacement level was 20%.

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Figure 1. Top view of the briquette and briquette machine.

Table 1. Produced briquette dimensions in Turkey according to the Turkish Codex 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

Tonnayopas et al. (2008) investigated properties of clay bricks produced by adding different percentages of RHA, and up to 30% RHA addition was found to meet Thai Industrial Standard. It can be utilized in building bricks by taking advantage of low cost and environmental protection.

The RHA 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 rural area of Turkey (Kocaman et al., 2008).

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

MATERIALS AND METHODS

Briquette is a building material made of mixing all-in aggregates, cement water and other additives in a container, shaped using vibration briquette machine (Figure 1) under 15 MPa pressure and drying the mixture under open-air conditions to a required hardness (Yuksel et al., 2008). Briquette is in the shape of a rectangle prism with one open and 5 closed faces. Its empty volume occupies 25 to 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. Figure 1 presents the view of a briquette.

The four main materials, used in this study for making the briquette mixture, are: (i) cement, (ii) RHA obtained from the controlled burning of rice husk, (iii) all-in aggregates, which are commonly used in producing ordinary briquettes and (iv) tap water having the quality parameters defined in Turkish Codex 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.

Rice husk ash (RHA)

The RHA was obtained from rice husk (RH) from the Thrace region where is produced more than half of the rice production in Turkey. The RH was collected and burned at 700°C for 2 hours using a stove (De Souza et al., 2008). Since the particle size of RHA is much larger than that of the cement particle, thus it improved the reactivity by grinding until the particles retained on a 200 µm sieve are less than 5% by weight. The chemical and physical properties of the RHA are given in Table 3.

The Figure 2 shows the microscopic images of the RHA. It was found that the RHA consists of irregular-shaped particles with a sizable fraction showing a porous cellular structure. The specific surface and specific gravity of RHA were 7100 cm^2/g of 2.10 g/cm^3 respectively. Similar finding was also reported by some

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

Chemical composition: Component	%	Physical and mechanical properties		
Insolube residues	1.39	Specific gravity (g/cm^3)		3.07
		Setting time	Initial (min)	153
SO_3	2.61		Final (min)	217
		Soundness (Le Chatelier) (mm)		1.3
Loss on ignition	1.25	Specific surface (cm^2/g)		3259
			2 day	-
Cr	0.0385	Compressive strength (MPa)	7 day	23.80
			28 day	36.08

Table 3. Chemical and physical properties of RHA.

Material properties	RHA
SiO_2 (%)	91.16
CaO (%)	1.25
Fe_2O_3 (%)	0.23
Al_2O_3 (%)	0.36
K_2O (%)	2.49
MgO (%)	0.64
Loss on ignition (LOI)	4.79
Spesific gravity (g/cm^3)	2.10
Specific surface (cm^2/g)	7 100

Figure 2. Microscopic image of the RHA (20x)

investigations (Saraswathy and Song, 2007; Rukzon et al., 2009).

All-in aggregate

Local river sand was used as a fine aggregate. Crushed coarse aggregate with maximum size of 10 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.

Coarse aggregate with the maximum particle size of 10 mm were used in the briquette production as suggested by Ekmekyapar and Orung (1993). Particle size distribution (or granulometry) of all-in aggregate were done by sieve analysis and presented in Figure 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 Turkish Codex TS 802/T2 (1988) adjusting water to cement ratio of 0.45 (by weight), while the mixing ratio of all-in aggregates, cement and RHA were adjusted volumetrically (Ekmekyapar and Orung, 1993). Six briquette classes were defined based on the volume of RHA used (Table 5). However, to produce a C16 level concrete, as described in TS 802/T2 (1988), the volumes of cement and all-in aggregate in the mixture was kept constant in all these six briquette classes. The cement was replaced with RHA at ratios of 5(BR1), 10(BR2), 15(BR3), 20(BR4) and 25(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 slamp 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).

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 Turkish Codex TS 406 (1988). The calculated 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 compressive strength, first the surface of the sample briquettes whose compressive strength was 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

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

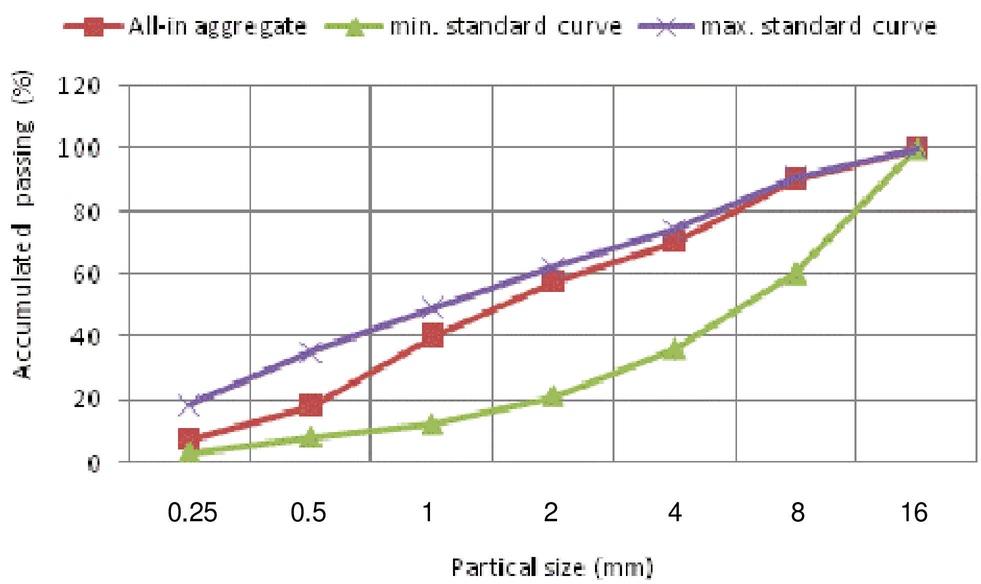

Figure 3. Partical size distribution curve of the aggregates used in briquette production.

Table 5. Volumetric mixing ratio of briquette materials.

Briquette classes	Binding material		Aggregate		W/C (as weight)
	Cement	RHA	Coarse	Fine	
BR0	1	0	3	3	0.45
BR1	0.95	0.05	3	3	0.47
BR2	0.9	0.1	3	3	0.50
BR3	0.85	0.15	3	3	0.54
BR4	0.8	0.2	3	3	0.60
BR5	0.75	0.25	3	3	0.67

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 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

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	+2	+3	1.0
BR1	+1	+2	+3	1.0
BR2	+1	+3	+3	1.3
BR3	+1	+1	+4	0.8
BR4	+1	+2	+2	1.0
BR5	+1	+1	+0	0.8

Table 7. Some physical and mechanical properties of the briquette.

Classes	Oven-dry bulk density (kg/m^3)	Water absorption (%)		Average compressive strength after (MPa)			Thermal conductivity (w/mºK)
		Sw*	Sv*	Before freezing-thawing (28 days)	After freezing-thawing	Loss in compressive strength (%)	
BR0	1330	6.54	8.70	3.51	3.17	9.7	0.694
BR1	1309	6.71	8.78	3.50	3.13	10.6	0.682
BR2	1275	7.09	9.04	3.48	3.05	12.4	0.663
BR3	1264	7.41	9.37	3.33	2.81	15.6	0.657
BR4	1244	7.46	9.28	2.94	2.47	16.0	0.646
BR5	1232	7.51	9.25	2.21	1.73	21.7	0.639

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

statistical analysis (ISO 8894-1, 1987).

RESULTS 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 decreased a little. Expansion due to the heat of hydration and chemical interaction between cement, RHA and aggregates which was caused to shrinkage were mostly responsible for this deviation. Deviations recorded in the briquette classes 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, and compressive strength, freezing-thawing and thermal conductivity after 28 days and the obtained results were presented in Table 7

The average oven-dry bulk density of classes BR0 and BR5 were found to be 1330, 1232 kg/m^3 respectively (Table 7). When BR5 class was compared with BR0, BR5 was 7.5% lighter. This is an advantage in decreasing the dead weight. The variations in the average oven-dry bulk density between the classes were also presented graphically in Figure 4.

As expected, the bulk densities of the briquettes were decreased with increasing volume ratio of RHA in the mixture (Figure 4). This is simply due to higher specific surface and smaller specific gravity of RHA than that of the cement. Therefore, both, amount of water in the mixture and porosity in briquettes increase.

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 RHA in the mixture. The minimum and maximum water absorption ratios were 6.54 and 7.51% for BR0 class and BR5 class respectively. The water absorption increased with the increase in the w/c ratio depending on the amount of the RHA in the mixture. A polynomial relationship was obtained between the oven-dry bulk density and water absorption ratio of

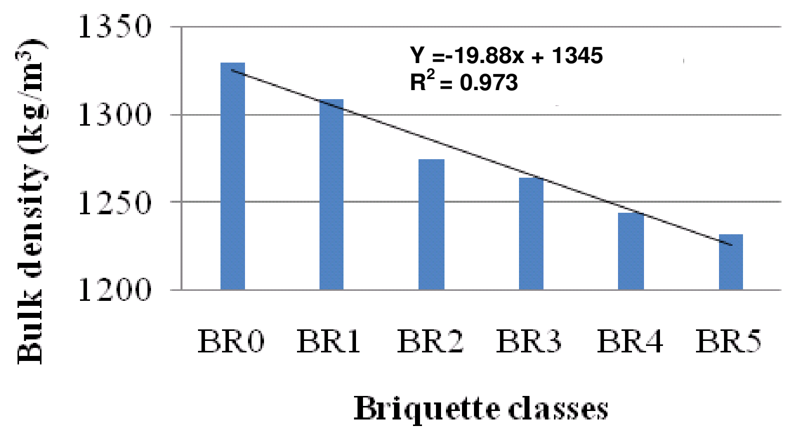

Figure 4. Briquette classes and their oven-dry bulk density.

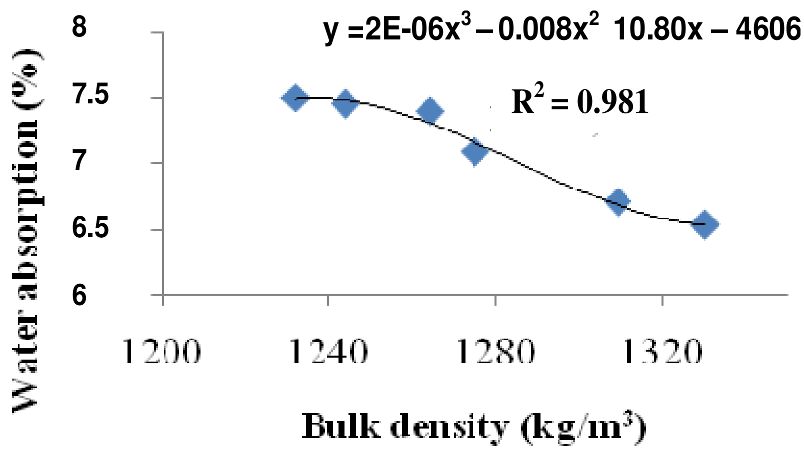

Figure 5. Relationship between the oven-dry bulk density and water absorption ratio.

Table 8. Briquette compressive strength classes according to TS 406 (1988).

Briquette class	Compressive strength (MPa)	
	Average	Minimum
BB2	2.5	2.0
BB4	5.0	4.0
BB6	7.5	6.0
BB12	15.0	12.0

the briquettes, which was shown in Figure 5.

Figure 5 reveals that oven-dry bulk density decreased with increasing water absorption ratio. 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 high 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.

Briquettes are divided into 4 classes according to Turkish Codex TS 406 (1988) regarding compressive strength as shown in Table 8.

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 Figure 6.

Figure 6 shows all briquette classes except for BR5 take place in BB2 class. The compressive strengths of the specimens on day 28 ranged from 3.51 to 2.21 MPa (Table 7).

The highest compressive strength was noted in the control briquette class BR0 (3.51 MPa) followed by BR1 (3.50 MPa) and BR2 (3.48 MPa), as shown in Figure 6, while the compressive strength did not changed too much with increasing RH content until 10% rates (BR1 and BR2), in other briquette classes the compressive strength

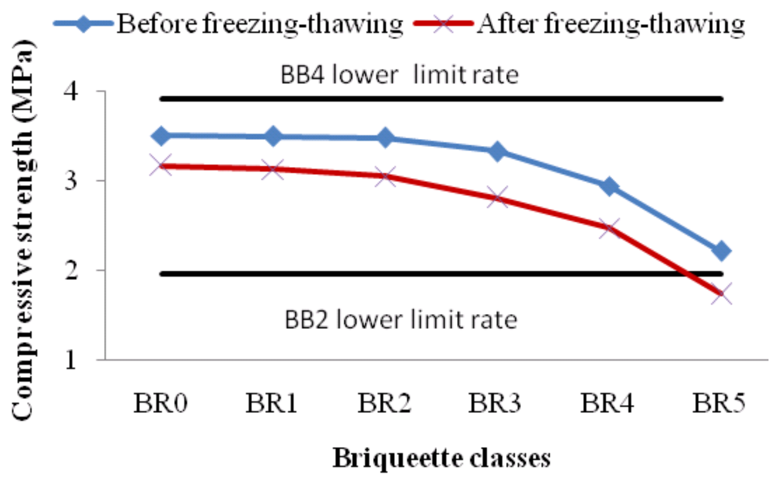

Figure 6. Variations in the compressive strength before and after freezing-thawing tests.

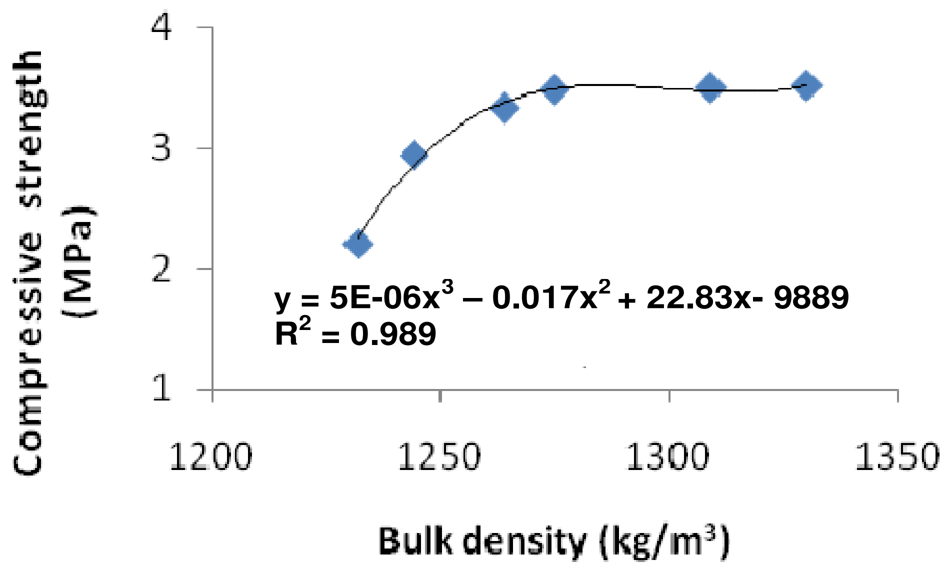

Figure 7. Relationship between the bulk density and compressive strength.

decreased with increasing RH content (BR3, BR4 and BR5). The lowest compressive strength (2.21 MPa) was noted in the BR5 and this briquette class fell below the minimum suggested value of BB2 class briquette as standard.

The data in Figure 6 indicate that incorporation of RHA the 10% rate in plain briquette mixture does not vary its compressive strength. This is because of the high amount of amorphous SiO2 with high specific surface and high activity of RHA, which can react with calcium hydroxide produced from cement hydration (Feng et al., 2004). Additionally, when the amount of RHA in the mixture is higher than 10%, the magnitude of increase in the w/c ratio or increase the water into the mixture as well as increase in the porosity becomes larger.

There is also a significant relationship between the bulk density of materials and compressive strength. Figure 7 shows that there is a polynomial relationship between the bulk densities of the briquette classes and their compressive strength. Increasing the RHA in the mixture decreased both the bulk density of the produced briquettes and compressive strength.

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

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

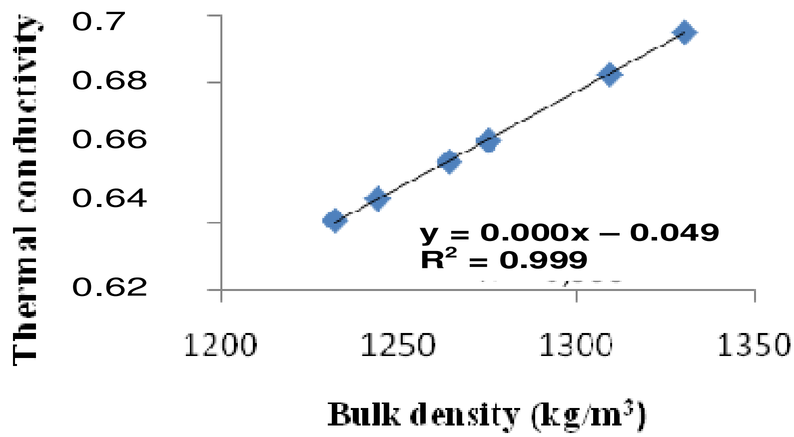

Figure 8. Relationship between the bulk density and thermal conductivity.

in Figure 6.

The compressive strength values after the freezing-thawing cycles shown paralleled to the strength value before the freezing-thawing cycles. The highest compressive strength loss was recorded in BR5 with 21.7% while the least loss was observed in BR0 9.7%. However, all the results were considered together, losses of compressive strength due to freezing-thawing cycles remained well below the maximum losses suggested in the relate standards (TS 406, 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 compressive 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 RHA in the mixture. While the thermal conductivity of BR0 class was 0.694 w/mºK, it decreased to 0.639 w/mºK for BR5 class. This is because RHA have higher specific surface and lighter specific gravity when compared to the cement. Increasing ratio of RHA in the mixture provides advantages of not only lower thermal conductivity but also lightness. There is a strong relationship between the bulk density and thermal conductivity of dry, light concrete (ISO 8894-1, 1987). This relationship is presented for the briquette classes in Figure 8.

CONCLUSIONS AND RECOMMENDATIONS

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

1) The maximum particle size of 8 mm of the aggregates is suitable for briquette production.
2) Dimensional deformation decreased a little with the increasing ratio of RHA in the mixture.
3) The oven-dry bulk density of the briquette classes decreased with increasing ratios of RHA in the mixture. The bulk density of BR0 class, with no RHA in the mixture, was 1330 kg/m3 and decreased to 1232 kg/m3 in BR5 with 25% RHA as binding material. This implies that using RHA in briquette production may decrease the dead load on the building elements by decreasing the bulk density of wall with light briquettes.
4) Water suction ratios of the briquettes classes increased with RHA. It took minimum value of 6.54% for BR0 and maximum value of 7.51% for BR5 briquette classes. Water suction ratios of all briquettes classes were below suggested standard limit of 20%. Therefore, no problem is foreseen using RHA in briquette production regarding water suction ratio. The briquette produced by RHA can be used for insulation in the buildings wall.
5) The compressive strength of the briquette classes decreased with the increasing replacement ratio of RHA in the mixture. Average compressive strength of BRI class, contain no RHA, was 3.51 MPa. However, it was 3.48 MPa for BR2 class, containing 10% RHA and 2.21 MPa for BR5 class, containing 25% RHA. According to their results, briquettes containing 10% of RHA are suggested to be used in the construction of separation walls carrying fewer loads.
6) The minimum and maximum compressive strength losses by compressive strength cycles when compared with the valves before exposing compressive strength were 9.8 and 21.6% for BR0 and BR5 briquette classes. The compressive strength losses for all briquettes classes were below the 25%, suggested standard maximum limit for a normal briquette (TS 406, 1988). Therefore briquette classes in this study can be safely used in terms of compressive strength effect on compressive strength losses.

7) Heat conductivity of the briquettes classes decreased with the increase in the volume of RHA in the mixture. This was 0.694 w/mºK in BR0 class while it decreased to 0.639 w/mºK in BR5 class. This means that use of heat-moisture balance within the required levels is easier for agricultural constructions.

The results of this study have shown that RHA at 20% of the volume of the cement can be used. As conclusion, the use of RHA in the production of briquette would provide an economical alternative to conventional briquette production as well as an environmentally friendly solution of concerns regarding the agricultural waste of rice husk.

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