Effect of silica fume and solid borax waste on compressive strength of fired briquettes

Efecto del humo de sílice y residuos sólidos de bórax en la resistencia a la compresión de briquetas cocidas

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Abstract
It is a well-known fact that industrial solid wastes which are commonly employed in construction sector make a significant contribution in reduction of environmental pollution. In this study, solid borax waste and silica fume were used as additive materials. In the briquette compositions, 3, 5 and 10% proportions of solid borax waste and 2, 5 and 10% proportions of silica fume were used in mixtures. In order to determine material characterization, micro structure (SEM) analyses of solid borax waste and silica fume were performed besides of physical and mechanical tests. Moreover, DTG analyses were implemented to specify material's behavior under high temperature loads. According to the test results, the values of maximum compressive strength and minimum bulk density were obtained using mixtures with proportions of 2% silica fume and 10% solid borax waste. Additionally, it was determined that the briquettes having low density and high compressive strength could be produced using aforementioned all mixtures.

Key words: Clay brick, Silica fume, Solid borax waste.

Resumen
Es un hecho bien conocido que los desechos industriales sólidos que son comúnmente empleados en el sector de la construcción, ya que hacen una contribución significativa en la reducción de la contaminación ambiental. En este estudio, los residuos de bórax sólido y el humo de sílice se utilizaron como materiales aditivos. En las composiciones de briquetas, se utilizaron en mezclas proporciones de 3, 5 y 10% de residuos de bórax sólido y proporciones de 2, 5 y 10% de humo de sílice. Con el fin de determinar la caracterización de los materiales, se realizaron análisis de microestructura (SEM) de residuos sólidos de bórax y de sílice, además de pruebas físicas y mecánicas. Además, se realizaron análisis de DTG para especificar el comportamiento del material bajo cargas de alta temperatura. De acuerdo con los resultados de la prueba, se obtuvieron los valores de resistencia máxima a la compresión y densidad aparente mínima con mezclas con proporciones de 2% de humos de sílice y 10% de residuos sólidos de bórax. Finalmente, se determinó que briquetas que tenían baja densidad y alta resistencia a la compresión se podrían producir, usando todas las mezclas mencionadas anteriormente.

Palabras clave: Ladrillo de arcilla, humo de sílice, desechos sólidos de bórax.

Introduction

Clay bricks are very durable, fire resistant and require very little maintenance. The principal properties of bricks that make them superior building units are their strength, fire resistance, durability, beauty and satisfactory bond and performance with mortar (Lynch, 1994; Hendry & Khalaf, 2001). Clay brick quality mostly depends on properties of raw materials and their compositions, production process, firing method, temperature and duration. Accordingly, sintering provides bonding strength of clay particles, which is succeed under the influence of heat effect (Kornmann, 2007; Sutcu et al., 2014; Cultrone et al., 2005). Conventional bricks have is a wide usage in the clay brick industry around the world. Additionally, the production of conventional materials with waste materials is quite common currently.

Researches have been conducted on production of bricks from waste materials for environmental conservation and sustainable development (Chen et al., 2011; Lingling et al., 2005; Kute & Deodhar, 2003; Chou et al., 2001; Chou et al., 2006; Freidin, 2007; Arioz et al., 2010; Chen et al., 2012; Ahmari & Zhang, 2012; Ahmari & Zhang 2013; Kumar & Kumar, 2013; Roy et al., 2007; El-Mahllawy, 2008; Sengupta et al., 2002; Demir et al., 2005; Samara et al. 2009; Haiying et al., 2011; Eliche-Quesada et al., 2012; Bilgin et al., 2012; Quijorna et al. 2012; Faria et al., 2012; Morchhale et al., 2006; Poon et al., 2002; Shakir et al., 2013). Lingling et al. (2005) investigated the production of fired bricks by using class F fly ash to replace clay at high volume ratios. Kute & Deodhar (2003) studied the bricks manufactured in laboratory using class F fly ash and clay. Chou et al. conducted systematic study on utilization of class F fly ash to replace part of the clay and shale in production of bricks using the conventional kiln firing procedure. Demir et al. (2005) investigated the potential of utilizing kraft pulp production residues in clay bricks. Eliche-Quesada et al. (2012) studied the application of a variety of waste materials together with clay to produce lightweight bricks. Bilgin et al. (2012) investigated the usability of waste marble dust as an additive material in industrial brick. Faria et al. (2012) investigated the recycling of sugarcane bagasse ash waste as a method to provide raw material for clay brick production. Shakir et al. (2013) investigated the production of bricks using fly ash, quarry dust, and billet scale.

As mentioned above, different types of industrial wastes are investigated and used in fired clay brick. In this way, it is provided that production for increasing the plasticity of the clay, increasing the strength and decreasing the bulk density which consequently increases the porosity and therefore the thermal insulation properties. One of the industrial waste materials utilized in clay production is clay waste as inorganic waste material. The waste materials such as solid borax waste having been used in brick manufacturing process. Borax waste is formed during the production of borax from tincal ore in Borax Plant. Tincal dissolved in hot water is separated from clays in colloidal form by gravity settling using some anionic and nonionic polyelectrolytes. Obtained borax waste contains some insoluble and soluble boron minerals with clay. Boron compounds in this waste discharged to land dissolved by rain water and mix with soil. Therefore, it is recognized as valuable industrial raw material. Discharge of this waste causes soil pollution as well as economic loss due to dissolution of the boron compounds by means of rain waters. Although boron is an essential nutrient for plants, it can be toxic to organisms when accumulated in high concentrations. Another waste material preferred in brick content is known as silica fume. Silica fume is an ultra-fine mineral deposit composed of amorphous glassy spheres of silicon dioxide (SiO_2) that are generated in the gas phase in submerged arc electric furnaces as a by-product of the reduction of pure quartz during the manufacturing of silicon and ferro-silicon alloys.

Several studies have been conducted to produce clay bricks using solid borax waste as an additive up to now, however it is not available the study related to use of both borax and silica fume in together in clay brick industry as solid- or porous-briquette. The aim of the study is to determine the effect of silica fume and solid borax waste additions on the micro- and macro-properties of the fired clay briquettes. Different ratios of silica fume and solid borax waste were added to soil. The effect on the macro properties of the briquette such as compressive strength and bulk density after firing were investigated.

Material and Method

Materials

For the analyses, soil (S) with 2.75 g/cm^3 specific gravity which is provided from Manisa, Turkey, solid borax waste (SBW) which is formed in processing of tincalconit ore in Etibor Kirka Borax Company plant and with 2.08 g/cm^3 specific gravity, and silica fume (SF) which is obtained from Antalya, Turkey ferrochromium plants and with 2.32 g/cm^3 specific gravity were used. For each of these two of materials were used in briquettes production adding to soil.

Preparation of the specimens

Mixture proportions of SF and SBW were specified before producing of briquettes specimen. In the mixtures, SBW was used with proportions of 3, 5 and 10% whereas the percentages of SF were 2, 5 and 10%. Water with ratio of 6% (w/w) was added to mixture to provide easily placement of mixture to mould and sufficient machinability and a 200 kgf/cm^2 squeeze pressure was applied to the mixture, which is placed into the mould, in order to make the mixture compress. Briquette samples, which have a cylindrical shape with 3.5×3.5 cm diameter and height, were obtained from prepared mixtures and the samples given their final forms by firing at furnace at 850°C temperature. After this temperature, level was reached, the briquettes were carried away from furnace and their bulk densities and compressive strengths were identified.

Results and Discussion

Sieve analysis

Sieve analysis of soil was performed, primarily, in order to identify grain dimension distribution of material and results were presented in Table 1. According to the results, it was identified that the whole of material could pass through number 4 sieve, whereas 71.54% of material could achieve to pass using number 200 sieve.

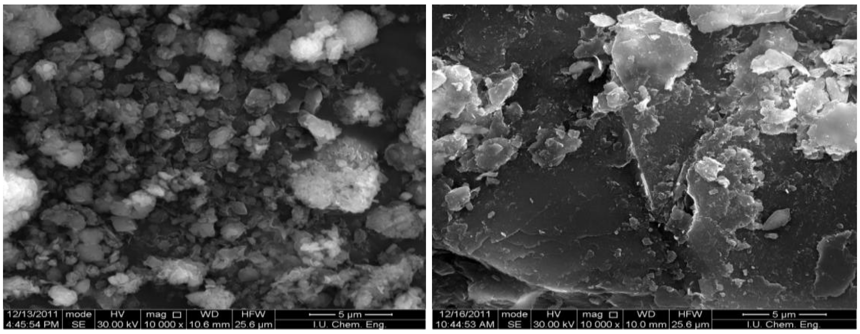
Table 1. Sieve analysis of S.

	Passed	
Seive no#	Weight (g)	%
4	13.00	100.00
10	12.50	96.15
16	12.00	92.31
30	11.60	89.23
40	11.40	87.69
50	11.20	86.15
70	10.80	83.08
100	10.30	79.23
200	9.30	71.54

SEM analysis

SEM analyses were performed to determine micro structure properties of S and SBW materials using FEI Quanta Seg 450 and JSM-5910LV equipped with EDS (Oxford-Inca-7274) devices. If the SEM analyses results of SBW and S, presented in Figure 1, are examined, it could easily have observed that SBW has a granular structure and S has laminated one.

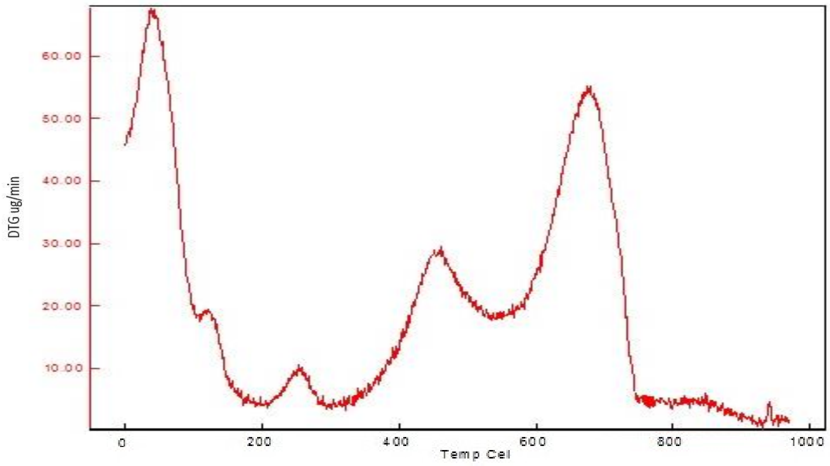
Figure 1. SEM micrographs, (a) SBW (b) S [x10000].



DTG analyses

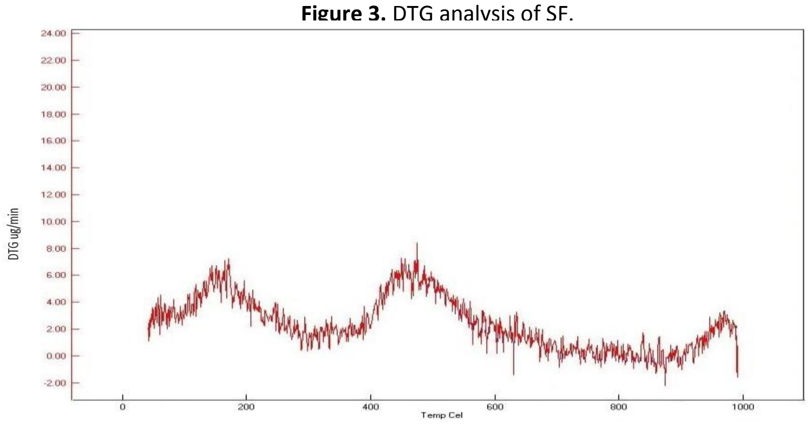
DTG analysis was performed using Seiko, Exstar 6000 TG/DTA 6300 device in order to determine temperature changes of S, SF and SBW. According to DTG analysis results which are shown in Figure 2, the peak value observed at 120°C might be caused by the water loss from the specimen (Darwesh, 2001; Gencel, 2015; Tamilnadu, 2011). The peak values identified at 230°C, 327°C and 550°C could be due to decarboxylation and chemical water loss from the clay minerals whereas the sharp peak value at 774°C is thought to be originated from the loss of OH groups in illite and chlorites (Elbeyli, 2004).

Figure 2. DTG analysis of S.



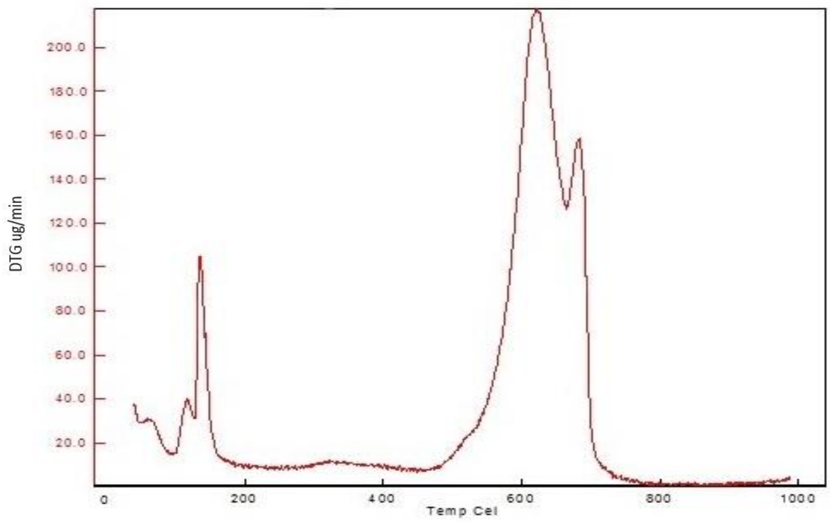
According to DTG curve silica in Figure 3, SiO_2 exists in any form of quartz at temperatures below 573°C and phase transformation to another form occurs below the temperature level, and transformation to tridymite begins at temperature above 894°C point.

Figure 3. DTG analysis of SF.



According to DTG curve of SBW given in Figure 4, the peak at 135° might be related to the loss of tincalconite mineral water in SBW (Elbeyli, 2004). It was observed that the compounds with Calcium and Magnesium, e.g. calcite $CaCO_3$ and dolomite, $CaMg(CO_3)_2$ were decayed in the temperature range of 450-700°C and borax was decomposed in 700°C, completely.

Figure 4. DTG analysis of SBW.



Compressive strength and bulk density

A set of tests were carried out in order to identify bulk density and compressive strength of briquettes which are produced by sintering of mixtures including S, SBW and SF. Compressive strength of briquettes must be greater than 24 MPa according to TS EN 771-1 (TSE, 2011) standard. Maximum compressive strength was obtained from No#3 briquette samples which contains 2% SF and 10% SBW could be observed in Table 2. The main reason of this result might be the proportion of B_2O_3 in SBW and alkali groups, which have melting characteristics, in soil.

In comparison of No#4 and No#1 briquettes which are produced with 5% waste in total, it was ascertained that No#4 briquettes which are produced with 5% SF provide compressive strength with 11% greater than the strength of No#1 briquettes samples. Although a reduction was observed in compressive strength of No#5, 24.09 MPa value of strength is in accordance with the level suggested by corresponding standard. This compressive strength is minimum strength value amount all of briquette samples and, therefore, it also corresponds the minimum bulk density. In bulk density values, the minimum and maximum decreases was obtained from No#5 and No#3 briquettes, respectively. Decrease of bulk density which is 19.34% in No#3 briquettes might be caused from existing calcium and magnesium compounds with higher amount than the other constituents in SBW and mass loss due to decomposition of these compounds.

Table 2. Compressive strength and bulk density of the mixtures.

No#	Soil (S)%	Silica fume (SF)%	Solid borax waste (SBW)%	Compressive strength (MPa)	Bulk density (g/cm^3)		
					Before firing	After firing	Decrease%
1	95	2	3	25.71	2.048	1.795	12.35
2	93	2	5	27.28	2.076	1.795	13.54
3	88	2	10	36.14	2.167	1.748	19.34
4	95	5	-	29.02	2.073	1.823	12.06
5	90	10	-	24.09	2.037	1.836	9.87

Conclusions

In this study, the usage of SF and SBW both jointly and separately in briquette production was investigated and evaluated. For all proportions of mixtures, obtained strength values were above the associated standards for compressive strengths. Accordingly, it is suggested that all mixture proportions used in the presented study could be employed in production of briquettes.

Minimum compressive strength value was found in briquettes which contain 10% SF additives and the whereas the maximum compressive values obtained from No#3 briquettes which are produced with 2% SF and 10% SBW waste material proportions. From No#3 briquettes, 19.34% decrease which is maximum in bulk density was found, as well. Reduction in bulk density indicates pore improvement in briquettes structure. It is clear that the in thermal insulation could be sustained with pore’s improvement.

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