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Analysis of mechanical properties of cement containing boron waste and rice husk ash using full factorial design

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ABSTRACT

In the present study, utilization of industrial wastes, namely boron waste (BW) and agricultural wastes, namely rice husk ash (RHA) were investigated. RHA and BW were added separately and together to cement samples in different ratios. Compressive strength analyzes of the specimens were done after curing for 28 days. Optimization of mechanical properties of cement containing boron wastes (BW) and rice husk ash (RHA) were done by using 2^4 full factorial design. 10% rice husk ash additive specimens gave the highest result with respect to full factorial experimental design. We ensured that the compressive strength results are within the Turkish Standards. Both of these wastes can be used in construction industry with determined percentages.

1. Introduction

Humankind made an impressive jump in technology since the industrial revolution. Because of constantly increasing population and thus demand, supply of several raw materials is becoming less available each day. Mass production is needed to produce large amounts of products in a standard way and it increases the need for raw materials, energy, manpower etc. in return. But also, it produces wastes. These wastes emerge not only in industry but also in agriculture.

Industrial and agricultural wastes lead to environmental problems in Turkey as well as in the world. These wastes can pollute air, water, soil, food supplies etc., so the importance of recycling increases. Waste recycling could help to reduce environmental problems and contribute to country's economy. Some wastes are valuable raw materials in many industries due to their chemical compositions (Ozdemir and Oztürk, 2003).

Turkey is rich in boron mines and approximately 70% of the known world reserves are in Turkey. Eti Mine Works General Management in Turkey supplies the 47% boron demand of the world. There are more than 230 boron minerals in nature and the main ones are; tincal, colemanite and ulexite (Boron Report, 2011). Uncombined boron doesn't exist naturally on earth. In order to get boron from nature, some advanced processes are needed. Firstly, boron ore is removed from the soil, then it passes various stages such as crushing, sieving, washing and grinding, respectively. During the recovery and concentration process of boron, all these stages produce industrial wastes. These wastes have a negative effect on environment and they cannot be recycled by nature itself. They pollute, for example, soil, natural water supplies which are very essential for human life. Therefore, using boron waste in cement production would have important environmental benefits (Olgun et al., 2007; Kula et al., 2002) as well as improving cement properties such as pore structure and low production costs.

One of the important industrial activity is cement production in the way of its contribution to greenhouse gas emissions. According to Li et al. (2012), nearly 5% of global carbon emissions originate from the manufacturing of cement. In order to reduce the greenhouse effect of cement production, various studies are carrying on for an alternative binder or cement replacement materials (Pelisser et al., 2012). Several studies show that i.e. Li et al. (2012), pozzolanic materials would be a good alternative. Since they provide a reduction in the use of portland cement, which is beneficial for the environment because of the reduction of CO_2 emissions associated with the production of Portland cement.

In recent years, agricultural and industrial by-products can be used in cement and concrete production which has been a major research topic because of the pozzolanic activity of ash materials (Sua-iam and Makul, 2013). Pozzolanic materials do not have

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binding properties by themselves but finely divided forms react with calcium hydroxide in humid environments. Consequently, components having binding properties are formed, such as siliceous and aluminous materials (Turgut, 2012). Rice husk ash is one of the promising pozzolanic materials. Rice husk is one of the main agricultural residues obtained from the outer covering of rice grains during the milling process (Givi et al., 2010). Rice husk ash (RHA) is obtained after burning of rice husk around 600 °C. Pozzolanic activity arises due to the presence of silica and there is 85–90% silica in RHA. Due to the feature of binding, RHA can be used as an additive to cement in the construction industry (Bui et al., 2005; Saraswathy and Song, 2007). The utilization of rice husk ash as a pozzolanic material in cement and concrete provide several advantages such as improving durability properties and reduction of the manufacturing cost, the negative environmental effects and carbon dioxide emissions.

The objective of this study is to investigate the possible use of industrial wastes (BW) and agricultural wastes (RHA) as a cement additive. In this study, the experimental system was modeled using 2^4 full factorial experimental design.

2. Experimental details

2.1. Materials

The materials consist of Ordinary Portland cement (OPC), boron waste and rice husk ash. The cement used in this study is commercial grade ASTM Type I. OPC is produced as CEM I cement in Turkey. The chemical composition of the OPC is shown in Table 1. BW used in this study was taken from Eti Mine Kırka Boron Plant of Eskişehir, Turkey. RHA was obtained from burning of rice husk at a temperature of 600 °C in a controlled manner. It was then sieved through a 200 μm sieve to eliminate coarse particles and better mix with cement. BW was grinded using ball mills and then passed through a 100 μm sieve for the same purpose. The chemical composition of the RHA and BW are given in Table 1.

2.2. Mixture proportioning

C series mixtures were prepared as control specimens. B and R series were prepared by BW and RHA with average particle sizes of 200 μm and 100 μm, respectively. 5%, 10%, 15% RHA and 1%, 3%, 5% BW were added to mortar instead of cement. Then, we investigated the effect of binary mixtures (BW and RHA). The proportions of the mixtures are presented in Table 2.

Table 1
Chemical composition of used materials (%).

Chemical composition	OPC[c]	BW[b]	RHA[a]
B_2O_3	–	15.45	–
SiO_2	19.5	11.45	91.2
CaO	63.7	14.52	0.75
MgO	2.3	3.2	0.27
Na_2O	0.3	4.2	0.1
Al_2O_3	5.3	0.55	0.72
SrO	–	0.75	–
Fe_2O_3	3.2	0.06	0.5
K_2O	1.6	0.45	2.2
SO_3	2.5	0.25	–
LOI[d]	60	32.6	1.8

[a] Rice husk ash.
[b] Boron waste.
[c] Ordinary portland cement.
[d] Loss on ignition.

Table 2
Mortar mix proportions.

Symbol	OPC	BW (%)	RHA (%)
C	100	–	–
B_1	99	1	–
B_2	97	3	–
B_3	95	5	–
R_1	95	–	5
R_2	90	–	10
R_3	85	–	15
BR_1	94	1	5
BR_2	92	3	5
BR_3	90	5	5
BR_4	89	1	10
BR_5	87	3	10
BR_6	85	5	10
BR_7	84	1	15
BR_8	82	3	15
BR_9	80	5	15

Water to binder [Cement + RHA], [Cement + BW], [Cement + RHA + BW] ratios of 0.50.

2.3. Preparation of test specimens

Each mixture consisted of 1350 kg/m^3 sand, 450 kg/m^3 cement, 225 ml of water and water to binder ratio (W/B) of 0.5 was used in the mixture (TS EN, 2009). The cement-water mixtures were stirred at low speed for 30 s and then sand was added. The mixture was stirred again at high speed for a total of 3 min. Specimens were prepared for compressive strength test. We used steel moulds which have a size of 40 mm × 40 mm × 160 mm. The cement prism specimens obtained after 24 h of curing at 20 ± 1 °C and 95% water saturated air. The test specimens were cured for during 28 days for compressive strength test.

2.4. Compressive strength

The prism specimens of 40 mm × 40 mm × 160 mm size were used for compressive strength test. Compressive strength of RHA and BW additive cement specimens were tested at the age of 28 days. SEM images obtained from cement mortars with RHA and BW groups (Fig. 1a,b) indicated that the little pores in the mortars that contain rice husk ashes and boron wastes. 28 days samples pore sizes were gradually decreased. CH crystal structure has been transformed into CSH structure. CSH structure provides greater strength of the samples. As shown in Fig. 1a,b, CSH (calcium silicate hydrate) structure so that it is seen like a fiber structure.

2.5. Modeling approach

The factorial design is used to evaluate two or more factors simultaneously. The treatments are combinations of levels of the factors. The advantages of factorial designs over one-factor-at-a-time experiments are that they are more efficient and they allow interactions to be detected Erper et al. (2012). ANOVA is a statistical technique that subdivides the total variation in a set of data into element items relating to specific sources of variation for the purpose of testing hypotheses on the parameters of the model. The statistical significance of the ratio of mean square variation due to regression and mean square residual error was tested using ANOVA method.

3. Result and discussion

According to our experimental data, compressive strength increases by replacing the cement with RHA up to 10% (56.48 MPa).