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Utilization potential of rice husk ash as a construction material in rural areas

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Abstract

Rice husk ash (RHA) obtained from uncontrolled combustion was used as an alternate construction material for concrete and bricks. Each year large quantity of RHA produced and is an environmental concern. However, RHA contains silicate which is in turn a characteristic of pozzolanic materials. Attempt has been made to use this RHA as a cement replacement for concrete and clay replacement for bricks. Experimental results on concrete and bricks were presented in a normalized way. Normalization was done based on the control specimen i.e. specimen does not contain any RHA. Economic constraint restraints the rural people from conventional constructional materials, however, RHA which is abandoned in rural area can offer a solution. From the normalized plot one can estimate the percentage of RHA that can be used based on the load demand. The objective of this study was to shed light on the utilization potential of RHA as a construction material. The study of economic impact of RHA is beyond the scope of this study.

Keywords: Rice husk ash; pozzolanic materials; concrete; brick; setting time; compressive strength; water absorption

1. Introduction

Rice husk ash (RHA) is the woody sheath surrounding the kernel or grain and consists of two interlocking halves. The rice grain must be removed from the husk after harvesting either by hand threshing or milling. Thus husk is the byproduct of the process of obtaining grain. According to Food and Agricultural Organization (FAO) world rice production in the year of 2009 is about 678 million tons and according to Bangladesh Bureau of Statistics (BBS) annual production of all kind of rice in Bangladesh in year 2009-2010 is about 31975 thousand metric tons. Beagle (1978) assumes that husk to paddy ratio is about 20% and Velupillai et.al (1997) assumes a ash to husk ratio of 18%

results 24.4 million tons of RHA worldwide and 1151.1 thousand metric tons of RHA production annually in Bangladesh. Typical chemical composition of RHA found in Bangladesh is given in Table 1 where it can be seen that the predominant component of RHA is silica. This silica enters the rice plant through its roots in a soluble form, probably as a silicate or monosilicate acid and then moves to the outer surface of the plant where it's become concentrated by evaporation and polymerization to form a cellulose-silica membrane. Materials containing reactive silica are known as pozzolans and are commonly used in cement production and the manufacturer of concrete. Pozzolans can also be defined as a siliceous or siliceous and aluminous material that in itself possesses little or no cementitious value, however, if divided very finely and in the presence of water, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties (Halstead 1986). Therefore this RHA has been used in making concrete for many years all over the world. The reactivity of RHA depends on its surface area, and that surface area depends on the environment and temperature of the combustion chamber (Al-Khalaf and Yousif 1984; Anwar et al. 2000; Della et al. 2002; Nehdi et al. 2003; Salas et al. 2009). Ordinary cement concrete hardens because of a reaction between water and the cementitious compounds to form several types of calcium silicate and calcium aluminate hydrates. A by-product of the initial reaction is calcium hydroxide, which in solution reacts slowly with pozzolanic materials such as RHA. The product of this reaction is of same type and characteristics of the initial reaction, thus additional bonding product will be available and additional strength will be developed (Chindaprasirt et al. 2007; Ganesan et al. 2008; Givi et al. 2010; Ikpong and Okpala 1992; Ismail and Waliuddin 1996; Jauberthie et al. 2003; Rodrguez de Sensale 2006; Van Tuan et al. 2011). RHA has also been reported to use in making bricks. Bricks which are produced from clay soil using the adhesive properties of soil and then burnt in the kiln. As RHA contains silicate which in turn reacts with calcium hydroxide and produce bonding substances, therefore RHA can be used as an alternate to clay in brick production (Chiang et al. 2009; Cook et al. 1977; Rahman 1987).

Table 1
Chemical composition of RHA (Rashid et al. 2010)

Constituent	% Composition
Fe_2O_3	1.38
SiO_2	90.20
Al_2O_3	0.85
CaO	1.18
MgO	1.21
Loss on ignition	3.95

This paper investigated the possibility of using RHA as an alternate construction material mainly in the use of cement, concrete and brick production. The target beneficiaries of this study are the rural people. Economic constraints of these peoples prevent them from using the conventional constructional materials, whereas each year huge amount of rice husk is being used as a source of energy. The resulted RHA is another source of hazard from environmental point of view. The load demand for rural infrastructure is low therefore does not required high quality of materials. Therefore considering the cementitious nature of RHA, attempt has been made to use it as a construction material. RHA is available from rice milling where it is burnt in an uncontrolled environment, therefore RHA obtained from uncontrolled combustion used in this study. Use of RHA along with the conventional materials will certainly decrease the construction cost therefore will encourage the rural people to build safe infrastructure.

2. Material properties

The main objective of this study is to find out the utilization potential of RHA as a construction materials. RHA was collected from a local rice mill and then processed. Collected RHA was in fair condition and almost free of any coarse impurities. Moisture content of RHA was removed by leaving the RHA on direct sunlight for hours and then grinded using the conventional hand grinder. Grinding followed by sieving through #200 sieve. The particle that remains on sieve was again grinded until it passes through the sieve. Figure 1 shows the prepared RHA used in this study. Once the RHA is grounded, its particle size distribution was measured using the hydrometer analysis. Figure 2 shows the grain size distribution of RHA used in this study. Commercially available stone chips and sand were used as coarse aggregate and fine aggregate in this study and. Ordinary Portland cement was sued as conventional binder. The specific gravity of coarse aggregate, fine aggregate, cement and RHA were determined and is shown in (ASTM Standard C 128).

Figure 1. Rice husk ash after drying and sieving

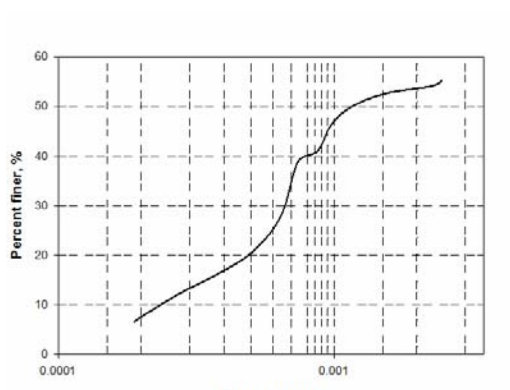

Figure 2. Grain size distribution of RHA used in this study

3. Specimen preparation and testing

Once the materials were prepared and properties were determined, specimens were then prepared and tested according to the standard procedure. The main objective of this study is to use RHA as an alternate construction material, and scope was limited of using RHA in cement, concrete and brick. For cement and concrete the RHA was used as a replacement of cement by 0%, 5%, 10% and 15%. And for brick production RHA was used as replacement of clay in the amount from 15% to 45%. Reaction of RHA with calcium hydroxide is slow as compared to other cemetitious compound; therefore addition of RHA in cement will affect its workability and setting times. Thus normal consistency which is a measure of workability of cement, and initial and final setting times of cement were measured following the standard procedure for different percentage of replacement of cement with RHA and is given in Table 3 (ASTM Standard C 191)(ASTM Standard C 191). The second objective of this study is to find the effects of RHA addition on the behavior of concrete. The mix design used for making concrete is given in Table 4. It is to be noted here that no admixture was used in this study. Cement in the concrete was replaced by RHA up to 15%. Concrete was tested for water absorption, compressive strength and splitting tensile strength. For this 6 in. x 12 in. concrete cylinder were casted and tested at 7th and 28th days for different engineering properties. For water absorption the cylinder were first oven dried at 105º C and weighted in air until a constant weight is achieved, after that the cylinder were soaked into water for 7 and 28 days and then again weighted. Difference between soaked weight and dry weight is the amount of water the specimen absorbed. This absorbed water is then divided with the dry weight to get the water absorption. Compressive strength of the cylinder specimen were tested following the (ASTM Standard C 39) standard and tensile strength were determined following the (ASTM Standard C 496) standard both for 7 days and 28 days. Water absorption, compressive strength and tensile strength of concrete cylinder for 7 and 28 days are given in Table 5. Third objective of this study was to find the effects of RHA addition in brick manufacture. Clay was replaced by ungrounded RHA from 15% to 45% in making the bricks. The prepared bricks were dried in the sun and then burnt in a nearby brick field with the help of natural gas. Figure 3 shows the prepared cylinder and bricks used in this study. The processed bricks were then tested for size and shape, specific gravity, water absorption and compressive strength. After that bricks were crushed and impact value was measured following the (ASTM Standard C 131) standard. Details of experimental results on brick specimens are given in Table 6.

Table 2
Physical properties of cement and rice husk ash

	Cement	RHA	Fine aggregate	Coarse aggregate
Specific gravity (gm/cm^3)	3.08	2.16	2.58	2.96

4. Results and discussions

Rice Husk Ash (RHA) was used as a partial replacement of cement in concrete and as a partial replacement of clay for bricks. Addition of RHA affects the engineering properties of cement, concrete and bricks. The effects of RHA on these materials are described in three manifolds. First the effects of RHA on the engineering properties of cements are described, second the engineering properties of concrete made of cement that was partially replaced by RHA is described and lastly effects of RHA on the engineering properties of bricks are described.

Table 3
Experimental results of normal consistency, initial setting time and final setting time of cement for different degrees replacement of cement with rice husk ash

Percentage of RHA	Normal consistency (%)	Initial setting time (min)	Final setting time (min)
0	32	145	290
5	35	218	485
10	40	245	529
15	43	286	544

Table 4
Concrete mix proportion

Binder	Fine aggregate	Coarse aggregate	w/b
1.0	1.33	2.77	0.42

Table 5
Effect of RHA on the water absorption, compressive strength, and splitting tensile strength of concrete at different ages

Sample designation	% replacement of cement by RHA	Water absorption (%)		Compressive strength (psi)		Splitting tensile strength (psi)	
		7 Day	28 Day	7 Day	28 Day	7 Day	28 Day
A	0	0.86	1.18	3602	5970	1295	1932
B	5	0.99	1.17	3495	5666	1163	1276
C	10	1.22	1.80	3077	4192	1133	1244
D	15	1.43	2.22	2707	3491	1038	1186

Table 6
Effects of RHA on the various properties of bricks

Treatment	% of RHA	Actual size of brick	Volume of brick (in^3)	Water absorption (%)	Crushing strength (psi)	Impact value (%)	Specific gravity
T-1	15	9.47*4.5*2.63	112.08	19.12	1675	42.90	1.86
T-2	20	9.49*4.5*2.70	115.30	19.33	1582	45.60	1.85
T-3	25	9.46*4.52*2.74	117.16	20.81	1437	47.63	1.83
T-4	30	9.53*4.48*2.63	112.29	22.50	1352	50.12	1.81
T-5	35	9.62*4.5*2.59	112.12	24.90	1194	52.31	1.79
T-6	40	9.62*4.49*2.69	116.19	26.33	1068	55.91	1.76
T-7	45	9.57*4.49*2.57	110.43	27.00	969	58.86	1.73
T-8	0	9.71*4.42*2.68	115.02	18.36	2526	40.50	1.91

4.1 Cement

Ordinary Portland cement was used in this study. The grounded RHA was used as a partial replacement of this cement. Amount of cement replaced by RHA varied from 0% to 15%. It was expected that addition of RHA will affect the plasticity of normal cement, which in turn will affect workability of concrete and also setting times of cement. Figure 4 shows effect of RHA on normal consistency of ordinary Portland cement. Value of normal consistency was normalized based on virgin cement consistency value. Virgin means cement which does not have any RHA replaced. It can be seen from Figure 4 that addition of RHA increased the normal consistency value as much as 35% with addition of 15% RHA. However, rate of increase of normal consistency with addition of RHA is not linear, rather follows a typical S-shaped curve. Value of normal consistency in this study obtained from a limited number of experiments and trials and also a narrow range of (15%) RHA has been used; therefore nonlinear variation of normal consistency with various percentage of RHA is not guaranteed. Increase of normal consistency indicates more water is needed to impart certain amount of plasticity in RHA added cement paste, which will eventually increase the setting times of cement.

Effect of RHA on the initial setting time of cement is shown in Figure 5. Initial setting time was normalized with the virgin cement i.e. no RHA was added. It can be seen here that addition of RHA increase the initial setting time of cement about 100% with addition of 15% of RHA. Increase of initial setting time gives more time of the concrete to properly mixed, compacted and finished. Thus RHA acts as a retarder in the cement paste. Reason behind this increase in initial setting time may be due to the chemical reaction of RHA with water. That is RHA particle is not as chemically active as cement particle. Fineness of RHA particle which is less than cement particle may also contribute behind this. Increase of initial setting time with RHA does not follow a linear trend, rather follows a nonlinear S-shaped curve. However, based on limited number of experiments, the nonlinear relationships between initial setting time of cement and RHA is also not guaranteed. Effect of RHA on the final setting time of cement is shown invFigure 6. Final setting time of cement is normalized here with final setting time of virgin cement. Final setting time of cement indicates time required for a cement paste to attain certain hardness so that it can withstand some amount of load. Therefore addition of RHA in cement paste may be detrimental in such cases where rapid hardening of concrete is required and also for under water concreting. Relationship between RHA and final setting time of cement does not follow the same trend of normal consistency and initial setting time. From Figure 6 it can be seen that up to 6% of RHA, final setting time increases proportionately, beyond that final setting time increases at a very slow rate with RHA. Reason behind this very slow increase of final setting time with RHA beyond 6% is not clear and further study is needed to substantiate it.

(a) Cylinder with partial replaced of cement with RHA (b) Brick with partial replaced of clay with RHA

Figure 3 Prepared cylinder and bricks for experimental study

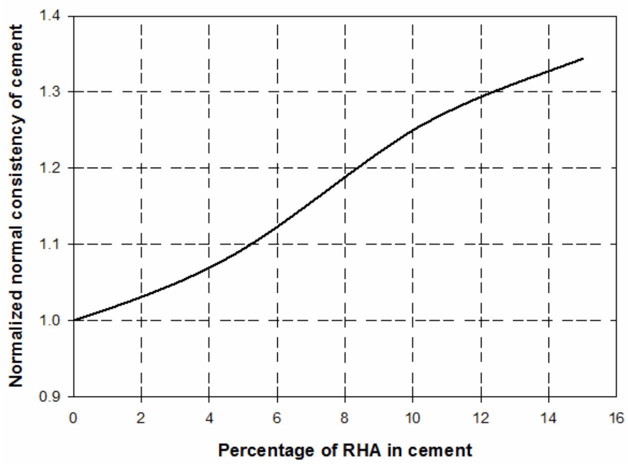

Figure 4 Effect of RHA on the normal consistency of cement

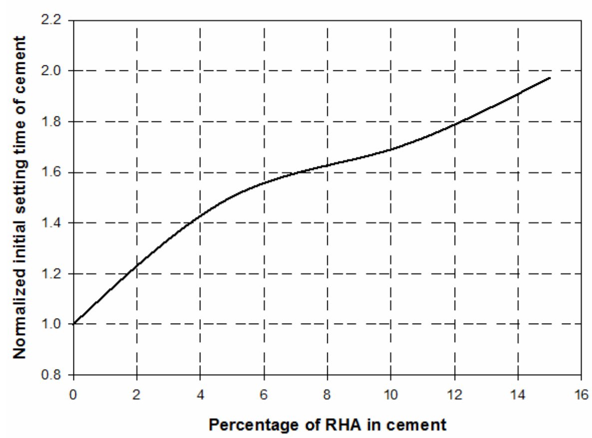

Figure 5 Effect of RHA on the initial setting time of cement

4.2 Concrete

Once the engineering properties of cement were tested and effects of RHA on these properties were determined, the same cement was used to produce concrete. Effects of RHA on different engineering properties of concrete were determined. Effects of RHA on rate of water absorption of concrete, concrete compressive strength and splitting tensile strength of concrete were determined in this study. Figure 7 shows the effect of RHA on water absorption of concrete. Water absorption is related to the porosity of concrete and also an indicator of how good a concrete is. Addition of RHA increases water absorption of concrete as can be seen from Figure 7. Water absorption for concrete specimen is normalized here based on the control specimen i.e. specimen made of cement that does not contain any RHA. Water absorption was determined for 7-days and 28-days concrete specimen. It can be seen here that rate of water absorption for 28-day concrete specimen is more than 7-day concrete specimen. However, up to 5% of RHA, rate of water absorption for both 7 and 28-day concrete specimen is same. After that, water absorption for 28-day concrete specimen increases at a greater rate than 7-day concrete specimen. Effect of RHA on concrete compressive strength is shown in Figure

78. 7-day and 28-day concrete compressive strength is normalized here based on the control specimen. Control specimen mean concrete made with cement that does not contain any RHA. It can be seen here that up to 4% of replacement of cement with RHA, compressive strength of concrete changes very small amount. However, beyond that, compressive strength decreases both for 7-day and 28-day concrete specimen. It is to be noted here that compressive strength for 28-day concrete decreases at a much higher rate than that of 7-day concrete. That means compressive strength of RHA added concrete specimen does not developed with time as that of control specimen. The difference between 7-day and 28-day compressive strength also indicates that, with time chemical activities of RHA added concrete ceases. Effect of RHA on splitting tensile strength of concrete is shown in Figure 7 9 where 7-day and 28-day tensile strength of concrete is normalized here based on control concrete specimen. For 7-day concrete, splitting tensile strength follows three distinct phase. Up to 5% of RHA, tensile strength decreases rapidly, and then from 5% to 10% of RHA, tensile strength remains somewhat same, and beyond that tensile strength again decreases at a higher rate. However, for 28-day concrete, decrease of tensile strength follows two distinct phase. Tensile strength decreases rapidly up to 6% of RHA, and then it remains somewhat same irrespective of amount of RHA. It is to be noted here, that 28-day tensile strength of concrete decreases more than that of 7-day concrete tensile strength, which is also an indication that strength development in RHA added concrete specimen ceases with time.

4.3 Brick

Ungrounded RHA was used as a substitute of various percentage of clay in making bricks. Inclusion of RHA in bricks affects its engineering properties. Volume changes of bricks, water absorption, crushing strength of bricks were investigated to find out the effects of RHA on these properties. These bricks were crushed to produce aggregates, and specific gravity along with impact values of these aggregates was also determined. Figure 10 shows effects of RHA on the volume change of bricks. It was anticipated that inclusion of ungrounded RHA as a partial replacement of clays in bricks will affects its size and shape. Because when brick is burnt in kiln, RHA will expand and will cause distortion of the bricks.

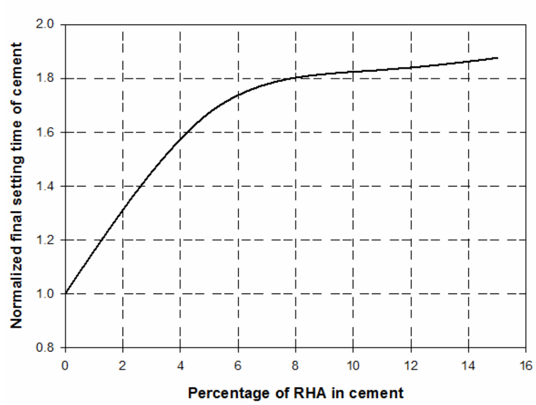

Figure 6. Effect of RHA on the final setting time of cement

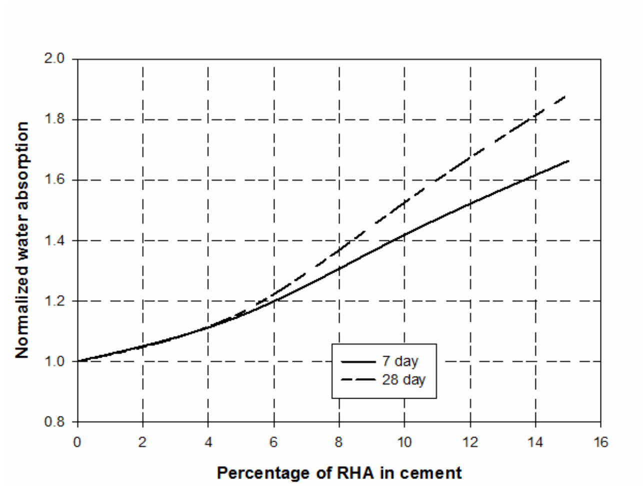

Figure 7. Effect of RHA on the water absorption of concrete

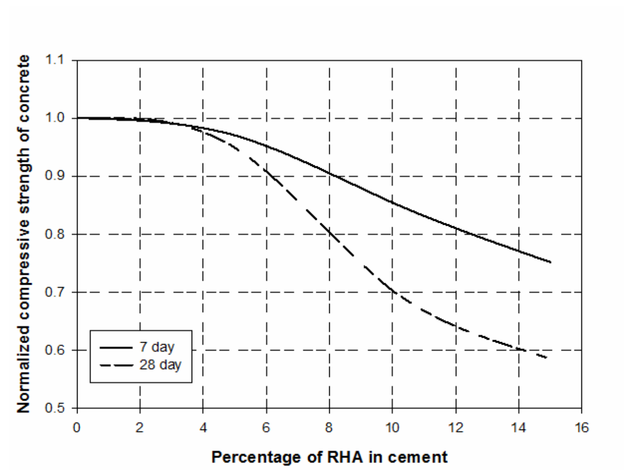

Figure 8. Effect of RHA on the compressive strength of concrete

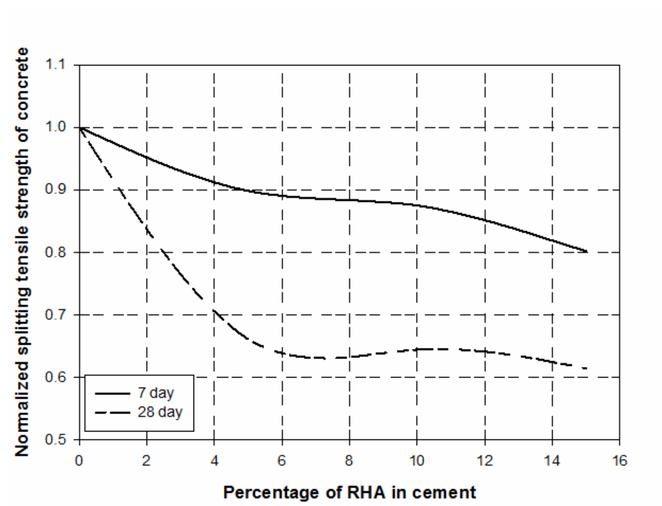

Figure 9. Effect of RHA on the splitting tensile strength of concrete

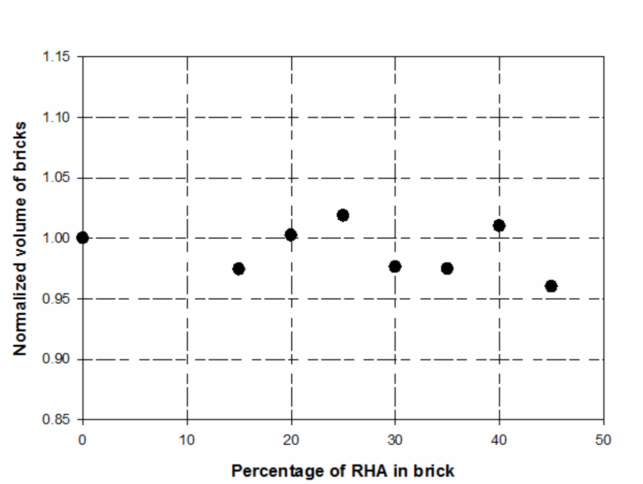

Figure 10. Effect of RHA on the volume of bricks.

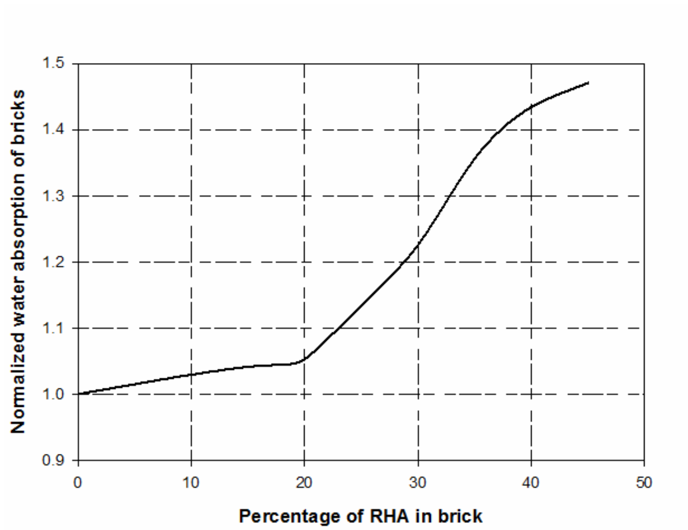

Figure 11 Effect of RHA on the water absorption of bricks.

Therefore brick volumes were determined for each cases of RHA addition. However, from Figure 10 it was found that there was no definite relationship between percentages of RHA and change of volume. Volumes for different percentage of RHA were normalized with volume of control bricks. Control means brick with no RHA added in it. Size and shape of bricks were not affected with addition of RHA as a partial replacement of clay.

Figure 11 shows effects of RHA on water absorption of bricks. Porosity is one of important indications of good quality of bricks. Less porosity will result less water absorption thereby good quality. It can be seen from Figure 11 that water absorption of bricks increase with increase percentage of RHA. However, rate of increase is not same, up to 20% of RHA water absorption increases as a slower rate. Beyond that water absorption increases at a higher rate. Water absorption of bricks presented here as a normalized value with respect to control bricks. Normalized crushing strength of bricks for various percentages of RHA is shown in Figure 12. Values of crushing strengths were normalized based on control bricks. It can be seen from Figure 12. that the relationship between crushing strength and RHA has two distinct phases. Crushing strength decreases at higher rate up to 20% of RHA addition, beyond that crushing strength decreases at slower rate. With addition of 20% RHA crushing strength of bricks were found to be around 63% of strength of control bricks.

Same bricks were then crushed to produce aggregates and engineering properties of that aggregates were determined. Due to the funding limitations only specific gravity and impact values of aggregates were determined. Figure 13 shows effects of RHA on specific gravity of brick aggregates. It can be seen from Figure 13 that specific gravity of aggregates decreases with increase amount of RHA. Specific gravity values of aggregates for various percentages of RHA were normalized with control brick aggregates. Control brick means, brick which does not any RHA mixed in it. Therefore general sense is that addition of RHA makes brick lighter. Normalized brick aggregate impact value for various percentage of RHA is shown in Figure 14. Impact values of brick aggregate were normalized with respect to control bricks. It can be seen from Figure 14 that impact value of brick aggregates increases with increase percentage of RHA; however, rate of increase was not same. Up to 20% of RHA impact value of aggregates increases at a slower rate than the rate of increase beyond 20% of RHA. In a general sense it can be said that aggregate impact value increases with increase percentage of RHA.

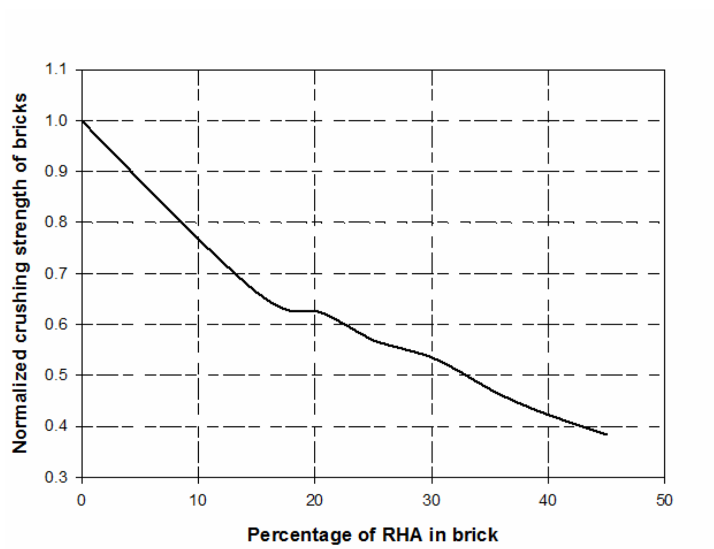

Figure 12. Effect of RHA on the crushing strength of bricks

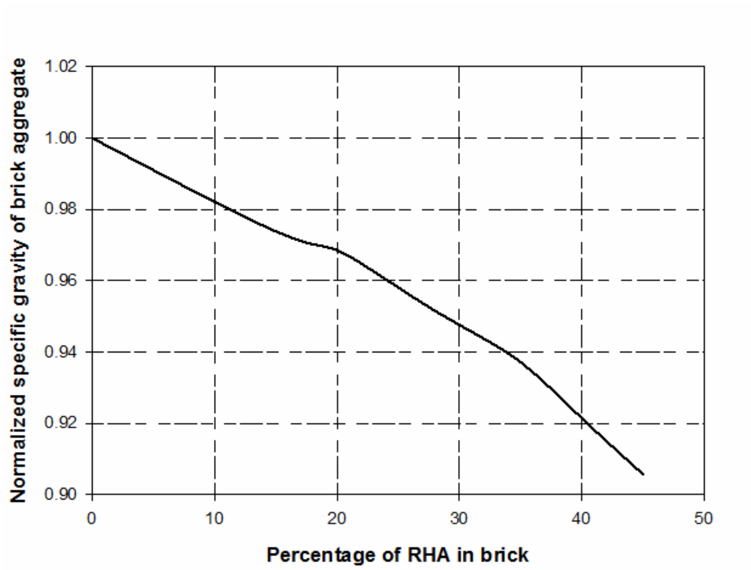

Figure 13. Effect of RHA on the specific gravity of brick aggregate

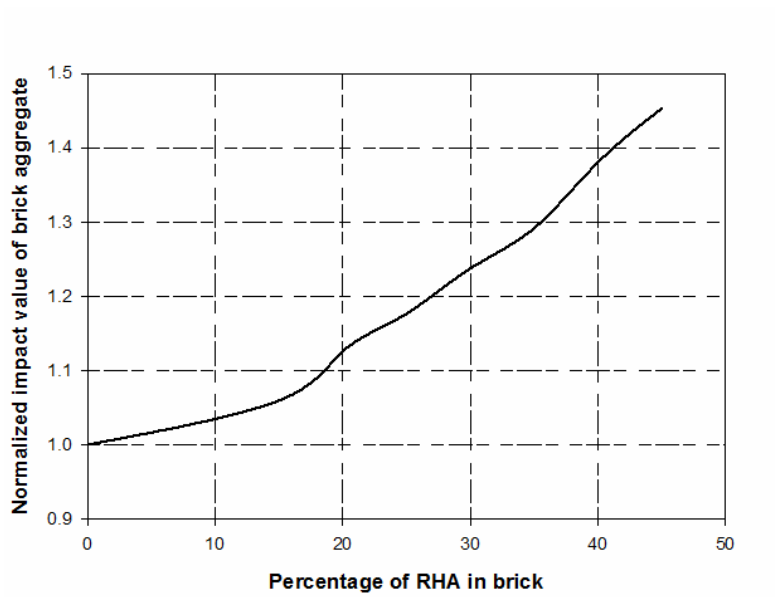

Figure 14. Effect of RHA on the impact value of brick aggregate

5. Conclusion and recommendations

Grounded RHA was used as a partial replacement of cementatious material in concrete and engineering properties were determined. Ungrounded RHA was used as a partial replacement of clay in bricks and some engineering properties of bricks and brick aggregates were determined. Effect of RHA on engineering properties of cement, concrete and brick are presented in a normalized way. It has been found that addition of RHA in cement increases its normal consistency and setting times. However, rate of increase is not same for each percentage of RHA. Addition of RHA increases water absorption of concrete i.e. porosity of concrete increases, which in long term detrimental to concrete. Addition of RHA in concrete decreases both of its compressive and splitting tensile strengths. It has also been found that addition of RHA in brick does not affect its shape and size, therefore volume of brick remains unchanged. However, inclusion of RHA in brick increases its water absorption and decreases its crushing strengths. RHA also decreases specific gravity of bricks and increases impact values of brick aggregates. All the experimental results are presented in a normalized way. Results were normalized with respect to control specimen i.e. specimen without any RHA in it. Therefore one will be able to determine how much cement or clay can be replaced with RHA, based on design criteria for any particular project.

One of the short coming of this study is that workability of fresh concrete with different percentage of RHA was not determined, and the authors believe that addition of RHA in concrete will affects its workability. Therefore workability determination of fresh RHA included concrete is recommended for future study. Concrete was produced with only one mix design and the author believes that normalized value of engineering properties will not be affected by mix ratio. However, the author suggests that other mix ratio also be investigated. Coarse aggregate in concrete used in this study was stone chips, and the author suggest that aggregates made from RHA included bricks be used in making concrete and its engineering properties be determined. Time and budget constraint prevent the authors to perform other engineering properties of RHA included brick aggregates like crushing value and 10% fines value, and is recommended for future studies. Since addition of RHA in concrete and brick increases its porosity, therefore durability of concrete and brick needs to be determined and also recommended for future studies. How inclusion of RHA in concrete and brick will affect economically was not determined and is recommended for future study.

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