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UTILIZATION OF RICE HUSK ASH AND CERAMIC WASTES IN MANUFACTURING OF DEVELOPED CEMENT BRICKS

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ABSTRACT

Huge quantity of rice husk ash (RHA) and broken ceramics in Egypt are produced as wastes and become of great threat to the environment, causing damage to the land and the surrounding areas in which it is dumped. In addition, production of cement is responsible for about 7% of all CO_2 generated in the world. For that, the aim of the present research is to produce modified cement bricks by replacing cement partially by RHA and broken ceramic wastes, to bring a substantial reduction for CO_2 emitted every year in the atmosphere, and to reuse agricultural and industrial solid wastes. Therefore two sets of experiments were investigated by replacing part of Ordinary Portland Cement (OPC) with: 1) RHA and 2) mixture of RHA and ceramic wastes, to produce modified cement bricks, at different curing time, namely7,14 and 28 days. Characterizations of raw materials used for the target preparation were carried out covering: free silica and organic matters, XRD, TGA, and DTA. The cold and boiling water absorption, compressive strength, apparent porosity and bulk density for the prepared modified concrete samples are determined. The experimental results proved that the , modified cement brick contains 5% RHA and 3% ceramic powder as cement replacement shows higher bulk density and compressive strength compared to other brick samples. The bulk density and the compressive strength were 2.33gm/cm^{3}and 295 kg/cm^{2}respectively, which are higher than the allowable standard limits. In addition, preliminary production cost was estimated.

Keyword: ash, rice husk, brick, cement, compressive strength, ceramic waste.

1. INTRODUCTION

Bricks have been a major construction and building material for a long time. The worldwide annual production of bricks in 2015is about 1500 billion units and the annual demand for bricks is expected to be continuously rising by 5-6% [1,2]. Ordinary Portland cement (OPC) is a conventional brick, composed of cement and sand. It is very similar to concrete, except that the aggregate materials used are much finer. It is well known that the production of OPC is highly energy intensive and releases significant amount of greenhouse gases [3]. Production of 1 kg of OPC consumes approximately 1.5 kwh of energy and releases about 1 kg of CO_2 to the atmosphere. Worldwide, production of OPC is responsible for about 7% of all CO_2 generated [4]. For environmental protection and sustainable development, many researchers have studied utilization of waste materials to produce bricks [5-9].On the other hand, over one million acres of rice crops were cultivated in Egypt, where one acre of rice produces 1.6 million tons of husks after the harvest in October and November, which are burned in open field, where uncontrolled combustion contributes to enormous environmental threats lowering theair quality in the involved area [10-14]. In addition, the disposal of large bulk of rice husk ash (RHA) has gain serious concerns due to the importance of preserving a clean environment in the present days. The utilization of this waste reduces the negative effects of its disposal, as well as energy consumption and CO_2 emission. In addition, it would be more profitable to utilize a priceless waste while simultaneously minimizing pollution. For that, the objective of the present work is to study the possibility of reusing RHA in the manufacture of environmentally saved low cost developed cement bricks.

2. MATERIALS AND METHODS

2.1. Raw materials

Four types of raw materials are used in the experimental work:1) OPC obtained from Portland cement company in Cairo, Egypt,2) rice husk (RH) obtained from local paddy mill rice in Egypt, 3) broken ceramic wastes and 4) commercially available stone chips and sand as coarse and fine aggregates.

2.2. Experimental procedureand analyses

Two groups of experiments were investigated by replacement part of cement by: 1) RHA and 2) RHA and ceramic wastes, to form modified cement bricks

2.2.1. Preparation and characterization of cement /RHA bricks

RHA was burnt at different temperatures (400^{o}C to 800^{o}C) to obtain ash via muffle furnace. Itwas used as a partial replacement of cement material in weight percentage starting from 0 % till 20 %, increasing by 5 %.Five mixtures were prepared, each mixture ratio was 1: 2: 4 (cement blend: fine (sand): coarse aggregates (stone chips). The cement blend consists of a pre-determined mixture of cement, RHA, and broken ceramics. The results were compared with a control mixture consisted of the same constituents with the same ratios except the absence of RHA and ceramics. All combinations were mixed together for five minutes before the addition of water to obtain a homogenous mixture. Potable tap water was used for mixing and curing the cement bricks. The blend was then casted into cubic molds of approximate dimensions 50x50x50 mm^3. To minimize segregation, all the mixtures were compacted by hand tamping, compaction wascarried

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out till no rising of air bubbles occur. One day after casting, the specimens were de-molded and cured until the age of tests (7, 14, and 28 days) as shown in Figures 1 and 2.Characterization of raw materials used was covered: free silica and organic matters, XRD, TGA, and DTA [9]. The prepared modified concrete samples were subjected to determine water absorption, compressive strength-by means of a compression test machine with a maximum capacity of 2000 kN-, apparent porosity and bulk density. Each result was the average of three bricks samples.

Figure-1. RHA modified cement brick.

Figure-2.RHA/Ceramic modified cement brick.

2.2.2. Preparation and characterization of cement / RHA/ceramic bricks

Based on the optimum composition and optimum curing time of the modified cement bricks previously prepared in item 2.2.1. another part of OPC is replaced by different percentages of waste ceramics (3,5,7,10%). The prepared samples were characterized by determination of compressive strength and bulk density.

All specifications of testing samples were compared with the Egyptian and ASTM Standard Specifications [15-22].

3. RESULTS AND DISCUSSIONS

3.1. Raw materials characterization

3.1.1. Chemical analysis

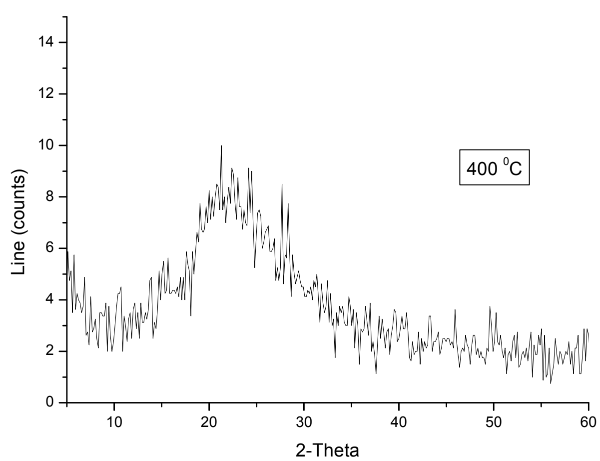
XRF of OPC and RH are presented in Table-1, it is clear that the major chemical compositions of OPC are CaO and SiO_2.

Table-1. Chemical composition of main raw materials.

Main constituents	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	TiO_2	MnO
OPC (wt,%)	21.51	5.07	4.39	64.21	2.00	3.25	0.29	0.23	-	0.15
RH (wt%)	13.28	0.22	0.57	0.77	0.13	0.33	2.22	0.06	0.08	0.06

3.1.2. The XRD pattern of RHA

Figure-3 represents the XRD of RHA at different burning conditions from 400^{o}C to 800^{o}C, to identify amorphous or crystalline silica of RHA. Qualitative assessment of the crystallinity of the sample can be ascertained from the intensity of the narrow reflections, as compared to the broad band around 22^o (2θ),which indicated that at low temperature from 400^{o}Cto600^{o}C, the silica in RHA is amorphous as it is in an active form, while the crystalline form occurs when the temperature rises up to 800^{o}C.



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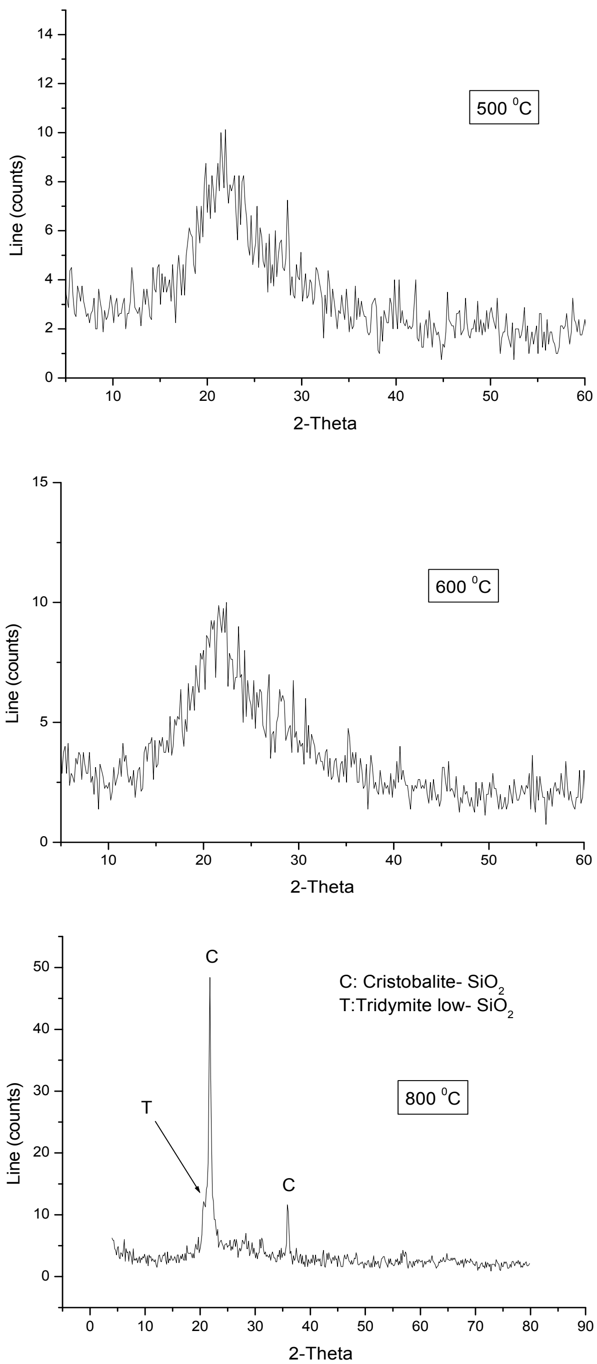

Figure-3. XRD pattern of RHA at 400 - 800^{O}C burning temperature.

3.1.3. The XRD pattern of anhydrate OPC ceramic and sand

Alite (Ca_3SiO_5) and belite (Ca_2SiO_4)are the major mineral phases in OPC as remarkable in Figure-4. At the same time, small peaks of calcite as well as $SiO_2$are also detected in the figure. Moreover, the XRD pattern of sand is shown in Figure-5, where silicon oxide is the main peak of the chart. In addition Figure-6 represents the XRD of the ceramic waste, which contains magnesium calcite phase.

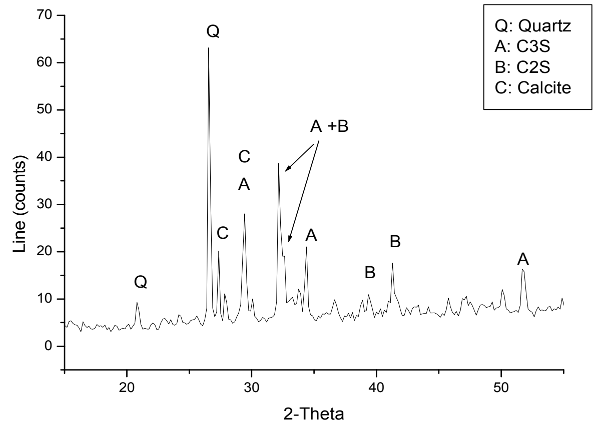

Figure-4. XRD pattern of OPC.

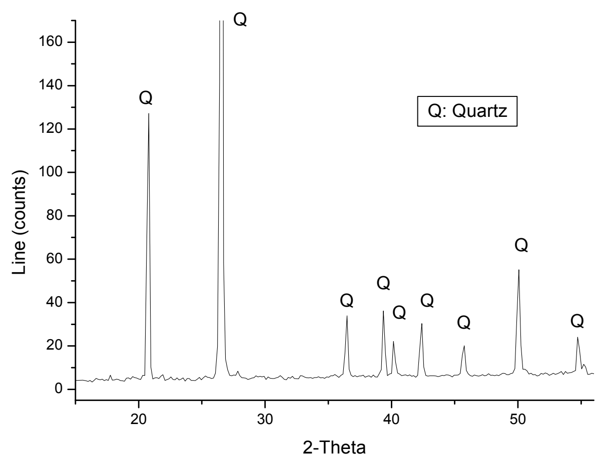

Figure-5. XRD pattern of sand.

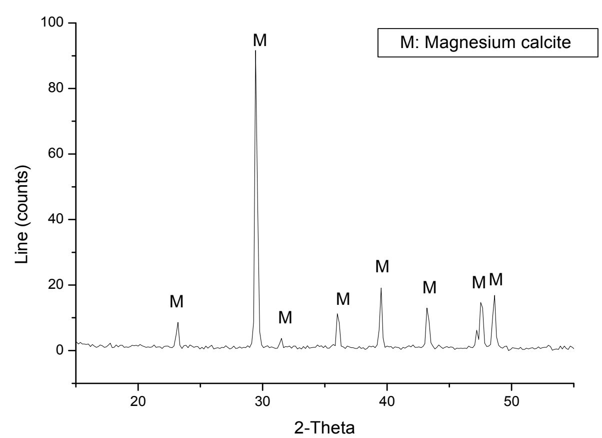

Figure-6. XRD of ceramic waste.

3.2. Testing of prepared cement/RHA bricks at different curing times

3.2.1. Bulk density

The bulk density of hardened brick samples containing different ratios of RHA is graphically represented in Figure-7as function of curing time (7, 14 and 28 days). The bulk density of all brick samples increases as curing time increases for all cement pastes due to the continuous hydration of OPC as well as pozzolanic reaction of RHA which leading to increase the precipitated hydration products which fill some of the open pores of hydrated cement. The formation and accumulation of excessive amounts of more dense hydrated products such as CSH (calcium silicate hydrate), CAH (calcium aluminates hydrate) and CASH (calcium sulfoaluminate hydrate) increase the bulk density [23].On the other hand, it was found that the bulk density has decreased with increasing the RHA content; this is attributed to the low density of RHA and also the CSH decreasing due to the decrease of OPC.

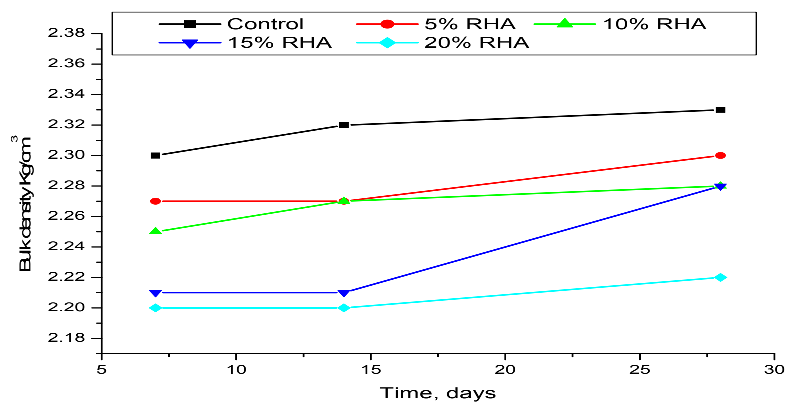

Figure-7. Bulk density of hardened brick samples containing (5, 10, 15, 20% RHA).

3.2.2. Apparent porosity

The apparent porosity of the hydrated cement brick pastes has decreased with curing time for the entire cement pastes as depicted in Figure-8. This is mainly due to the continuous hydration of cement clinker and the accumulation of hydration products in the pores of cement paste. It can be seen as well that the apparent porosity also increases with RHA. RHA reacts with the liberated calcium hydroxide from cement hydration forming calcium silicate hydrate. The increase of porosity with RHA addition may be due to that CSH formed in presence of RS is less effective in pores filling of the matrix. It is also clear that; the values of apparent porosity of 5% wt RS substituted cement is very close to control samples.

3.2.3. Compressive strength

Compressive strength of brick samples with different percentage of RS are shown in Figure-9.Compressive strength is obtained mainly from the reaction of the silicate phases to form calcium silicate hydrate. Tri-calcium silicate is the principal cementing phase, whereas di-calcium reacts at a much slower rate to form similar hydration products [24]. From the figure, it is clear that, the compressive strength increases with curing time for all brick samples. This increasing in the strength is attributed to the progress of cement hydration. By increasing time the amount of hydrated products, in particular calcium silicate hydrate which is the main source of strength increases [25]. The compressive strength also decreases with increasing RS percentage; this is due to the replacement of cement which has high binding properties with RS. The values of compressive strength show that; 5% wt RS substitution is close to the control sample.

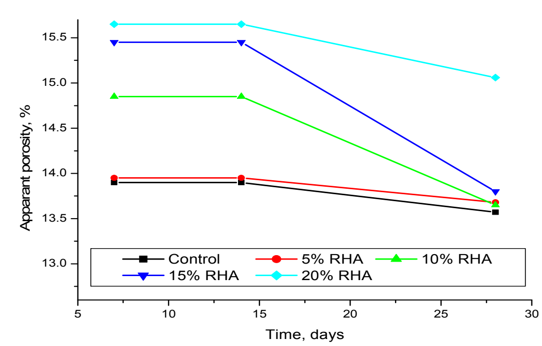

Figure-8. Apparent porosity of brick samples containing (5, 10, 15, 20% RHA).

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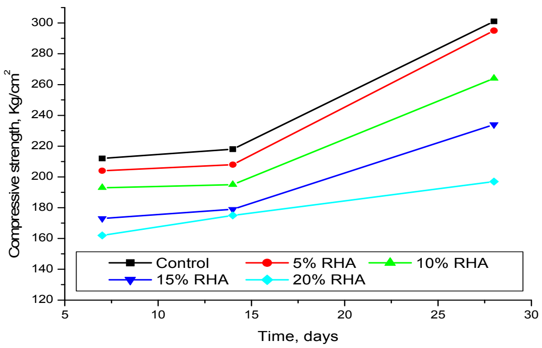

Figure-9. Compressive strength of different brick samples containing (5, 10, 15, 20% RHA).

3.2.4. Water absorption

Figures(10) and (11) showed the water absorption of cement bricks sample hydrated for 7, 14, 28 days. This test can be used as an indication for the samples resistance to immersion. It is related to pore volume connected to the surface of sample; it is a measure to the open porosity [24]. In case of cold as well as hot water immersion; the water absorption decreases with increasing time. This is resulted from the progress of cement hydration and increasing bulk density, in addition to the decreasing of porosity. This decreasing in porosity causes decreases in water absorption. At the same time; water absorption increases with RHA addition; this is due to increasing of porosity and decreasing of bulk density with RHA content as discussed before.

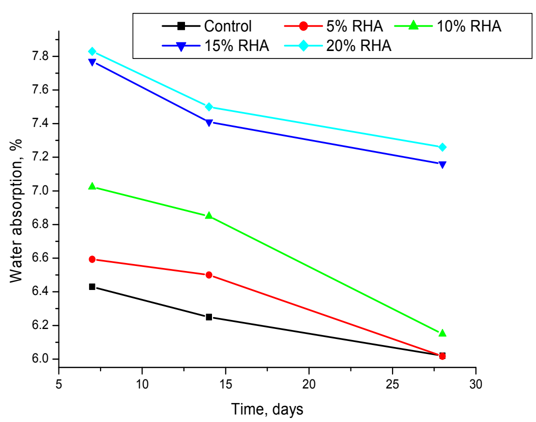

Figure-10. Cold water absorption of different hardened brick samples.

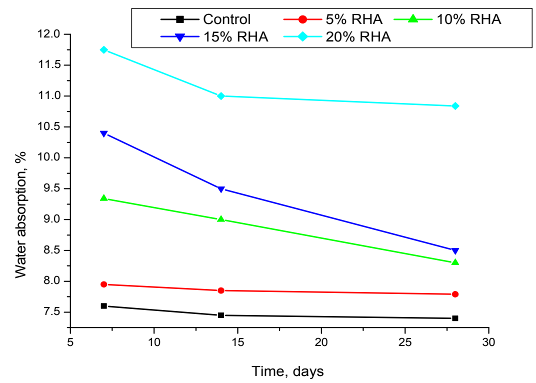

Figure-11. Hot water absorption of different hardened brick samples.

3.3. Testing of prepared cement/RHA/ceramic bricks

3.3.1. Bulk density

The effect of ceramic powder addition on bulk density of control as well as RHA cement brick samples is graphically presented in Figure-12. The bulk density increases with ceramic powder substitution up to 7 % then decreases. 3 % substitution shows high values of bulk density, this may be attributed to enhancement hydration reaction at this low percent and consequently hydration products increases. In hydration reaction; calcium hydroxide liberated from cement reacts with silica present in both RHA and ceramic powder forming calcium silicate hydrates (CSH). At 10% ceramic substitution bulk density decreases; this is attributed to substitution of high percent of cement as an active material with high percentage of ceramic powder.

3.3.2. Compressive strength

Figure-13 illustrates the effect of ceramic powder on control and RHA cement brick samples. It is clear that, the compressive strength has been enhanced by substitution of cement with ceramic powder. Sample contains 3% ceramic powder shows high compressive strength than control and other RHA brick samples. This may be due to that, at this low percent ceramic powder acts as nucleating sites in which hydration products accumulates in it and gives high compressive strength [23]. The compressive strength decreases by increasing ceramic powder contents up to 7% substitution but still higher than control and RHA cement brick samples. On the other hand, substitution cement with 10% ceramic powder shows the lowest value of compressive strength than other samples.

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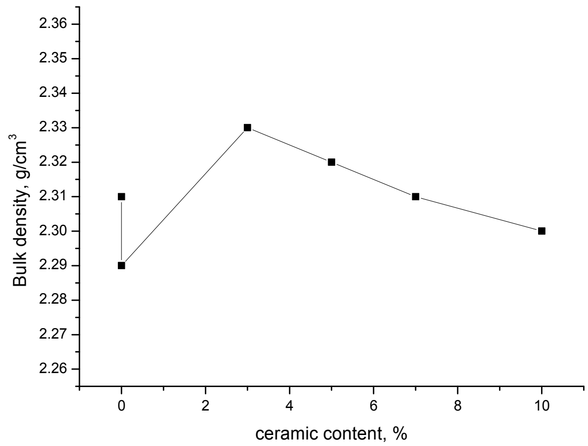

Figure-12. Bulk density of control (C) and RHA cement brick samples with different ceramic%.

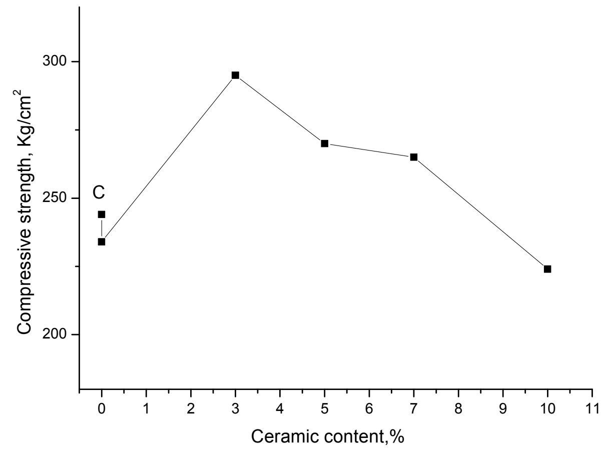

Figure-13. Compressive strength of control (C) and RHA cement brick samples with different ceramic%.

4. PRELIMINARY PRODUCT COST ESTIMATION

This part is dedicated with the process description for Cement/RHA/Ceramic bricks preparation, and accordingly the material balance involved, followed by product cost estimation. The latter was calculated based on the assumption that the cost of raw materials is 50% of the total production cost [26]. Costs of raw materials, locally purchased, are estimated according to current costs as provided by local market.

4.1. Process description

Figure-14represents the process descriptions of modified cement brick contain 5%RHA and 3% ceramic waste as cement replacement.

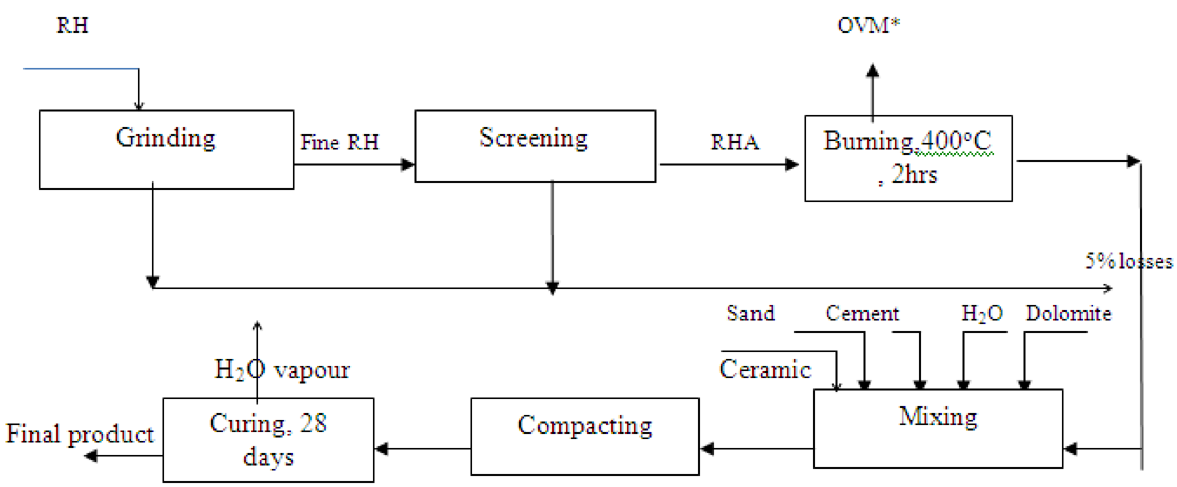

Figure-14. Process block diagram of cement/RHA/ceramic bricks.

4.2. Material balance

According to data obtained from the experimental work, material balance calculations are presented in Figure-14, carried out based on the following operations and assumptions:

a) Initial raw materials calculations/ brick:(bulk density= 2.27 gr/cm^3)

1. Blend ratio: cement mixture: sand: dolomite =1: 2: 4.

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2. Initial blend composition: 13%$_{wt}$ (92% OPC + 5% RHA + 3% ceramic): 26%$_{wt}$ Sand: 52%$_{wt}$ Dolomite: 9%$_{wt}$ Water
3. Final brick composition:14%$_{wt}$ (92% OPC, 5% RHA, 3% ceramic):27%$_{wt}$Sand: 55% Dolomite: 4%$_{wt}$ Water
4. Brick dimensions: 25cm x12cm x 6cm.
5. Final volume: 1800 cm^3.
6. Weight of product brick= 1800 x 2.27= 4086 gm.

Accordingly, the required raw materials per brick are estimated via:

7. Required weight of OPC= [(4086 x 0.14) x 0.95]= 543.5 gm.
8. Required weight of RHA= [(4086 x 0.14) x 0.05]= 28.5 gm.
9. Required weight of sand= [4086 x 0.27]= 1103 gm.
10. Required weight of dolomite= [4086 x 0.55]= 2247gm.

b) Calculations in kg mass: [basis = 5000 bricks/day

The estimated mass balance is demonstrated in Figure-15.

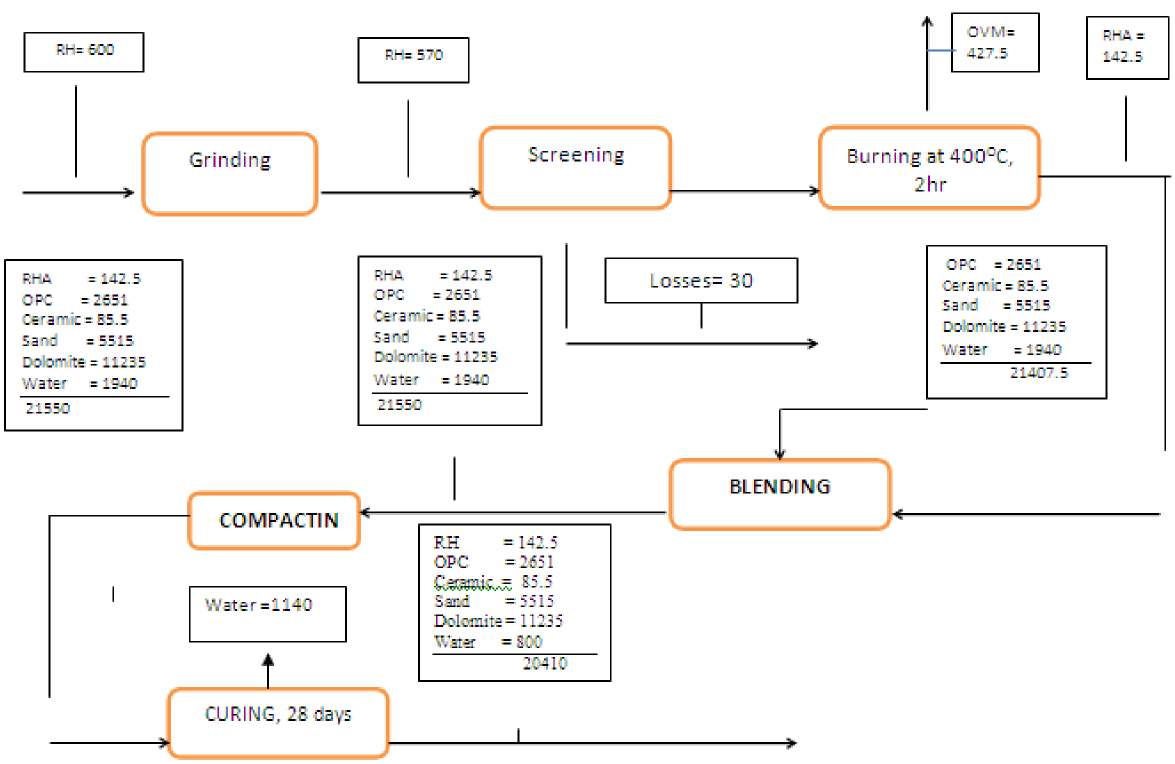

Figure-15. Material balance for production of cement/RHA/ceramic bricks (5000 bricks/day).

Hence, the final composition of one brick is 0.544 kg OPC, 0.029 kg RHA, 1.103 kg Sand, 2.247 kg Dolomite, 0.164 kg Combined water, with a total brick mass of 4.086 kg.

4.3 Total product cost.

Table-2 depicts the annual cost of raw materials required for 1,500,000 bricks/year of modified cement production (based on 300 days/year working time).

Table-2. Production cost of cement/rice husk ash/ceramic bricks.

Raw materials of OPC/RHA bricks	Amount of R.M. needed /year	Price LE/unit	cost LE/year
Cement	815 ton	75/ton	61,125
Rice Husk*	180 ton	Nil	Nil
Ceramic waste	108 ton	Nil	Nil
Sand	1290 m^3	30/m^3	38,700
Dolomite	11235 ton	15/ton	168,525
Water	582 m^3	0.25/m^3	146
Total R.M. cost			268,496
Total Product cost			536,992

* Rice husk and ceramic wastes are solid wastes, and therefore are considered of zero value.

Therefore, the production cost of cement rice husk ash/ceramic bricks per 1000 units product capacity is 360LE/10^3bricks, which, when compared with that of conventional cement bricks (480LE/10^3bricks), is reduced by 25%.

5. CONCLUSIONS

The research results supported the use of 5%RHA and 3% ceramic wastes for partial replacement of OPC to produce modified cement bricks at 28 days curing time. Bulk density and compressive strength of modified cement bricks proved higher values than the Egyptian and ASTM Standards. Preliminary cost estimation of the proposed modified cement brick showed25% less than the regular cement bricks cost. Fore that, using this modified mixture of high compressive strength to serve the purpose of making low-cost and high durable bricks for construction can be promoted because of their quality, economic and environmental benefits.

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