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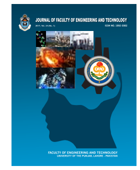

MANUFACTURING OF LIGHT-WEIGHT REFRACTORY BRICKS USING LOCAL RAW MATERIAL

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Abstract

Refractory with low thermal conductivity, high porosity and good mechanical strength are desirable to control the heat losses during high temperature processing. Locally produced insulating firebricks cannot be used at high temperatures due to poor refractoriness and low hot strength. In the present experimental work, locally available cheap raw materials, namely, clay, rice husk and saw dust were used to manufacture light-weight refractory bricks using different ratios of raw materials. Various process parameters were investigated and the bricks with optimized properties were produced which can be used upto 1200 °C. Moreover, the bricks produced will be lower in price and also beneficial from energy conservation point of view due to low heat losses.

Keywords: Energy Conservation, Porosity, Insulating Firebricks, Rice Husk, Dust

1. Introduction

The demand of the high quality refractories to reduce the heat losses for the high temperature processes is increasing. This is due to the fact, that a considerable amount of energy is required in high temperature processes; but a part of that energy is used for the actual process and ~30-40 % energy is wasted through the walls into the surroundings. To prevent this heat escape into the ambience, use of special type of refractory materials i.e. insulating refractory firebricks (IRFBs) is recommended. The important parameters for these refractories are; high porosity and low thermal conductivity in order to reduce heat flow and improve heat conservation [1, 2]. Furthermore, other desirable characteristics of insulating bricks are low-weight and low thermal conductivity, which is mainly due to high degree of porosity. There are large numbers of small pores filled with air present in the structure of insulating material. As air is second best insulator, therefore, these pores also have low thermal conductivity. The air spaces inside the pores of a brick reduce the heat conduction whereas particles of brick conduct the heat. For the better insulating properties, there should be a balance between air spaces and solid particles. Good insulating properties are achieved, when uniformly distributed small sized pores are present in the whole body of brick [3, 4]. Some of the drawbacks of insulating refractory bricks (IRBs) are poor chemical resistance; e.g. slag, molten glass, gases, fumes, liquids etc. can easily penetrate into porous bricks at high temperatures and poor mechanical strength. IRBs often undergo thermal spallation due to sudden changes in the temperature [6, 7].

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Many researchers have produced IRBs using different raw materials and examined various physical properties. Ugheoke et al. [11] used kaolin, rice husk and plastic clay to develop IRBs and experimentally examined the appropriateness and the ideal ratio of these ingredients. They showed that the samples prepared with a ratio of 4:1:2 (kaolin, rice husk and plastic clay, respectively) offered the optimal performance in service life. After firing at 1200 °C, the bulk density was 1.04 - 1.41g/cm3, apparent density was 2.56-5.77 g/cm3and thermal conductivity was 0.005-0.134 W/mK. Olasupo et al. [12] prepared insulating refractory ramming mass after mixing several ratios of clay, silica, mica, bentonite and calcium aluminate cement, and then sintered the samples at 1100 °C. They showed that eight ramming cycles were sufficient for the production of the ramming masses. Al-Taieet al. [14] studied the feasibility of producing light-weight ceramic thermal insulating bodies using finely distributed saw dust, AlF3 (0-40 wt.%) and clay (Kaolinite). The samples were fired in range of 900-1100 °C. They achieved light-weight thermal insulators with bulk density (0.7-1.3 g/cm3), compressive strength (25 kgf/cm2) and thermal conductivity between (0.23 and 0.46 W/mK). Sutcu et al. [15] produced an orthite based porous lightweight refractory bricks from the mixtures of paper processing remains (PPR) and three different clays like enriched clay, commercial clay and fireclay. Samples with 30–40 wt% PPR were sintered at1200–1400 °C. Compressive strength of compacted and fired samples consisting of anorthite ranged from 81-438 kgf/cm2. Olokodeet al. [17] utilized cow dung and clay in different ratios to produce insulating refractory bricks. The prepared bricks were sintered at 1200 °C. They obtained following range of results: bulk density (1.97–2.35 g/cm3), cold crushing strength (64-152.5 kgf/cm2), apparent porosity (22.54–30.62 %) and thermal conductivity (0.156–0.21 W/mK). These results showed that all the bricks samples had good insulating characteristics, suggesting that cow dung can be used as additive in production of insulating fire- bricks. Oncheet al. [18], investigated the influence of rice husk and diatomite on the insulating properties of fireclay bricks. The samples having different compositions were fired in range of 900-1200 °C. Highly porous structures of insulating specimens were obtained which made them appropriate for backup insulation. The mixing ratio of 3:2:4:1(kaoline, plastic clay, rice husk and diatomite, respectively) provided the optimal performance values of all the properties. At 1200 °C, 1.11 g/cm3 for bulk density, 98.25 % for apparent porosity and 0.038 W/mK for thermal conductivity were obtained. Aramide et al. [19] studied the effect of compositions of saw dust admixture on the thermal conductivity of IRBs. The raw clay and sawdust were processed to very fine particles, and then the prepared bricks were fired in the furnace at 1000 °C. The results showed that the amount of sawdust admixture variably affected the properties such as: porosity increased with percentage increase in sawdust admixture while the thermal conductivity and other properties of the sample reduced with percentage increase in sawdust admixture. It was concluded that for structural insulating bricks where compressive strength is important the sawdust admixture should not exceed 10 to 15 percent. Christian et al. [21] investigated the production high fired kiln insulating bricks using local clays and various soft wood dusts.

The insulating refractory bricks (IRBs) produced in Pakistan cannot be used at a temperature upto 1200 °C, and possess low mechanical strength. These bricks crumble during handling. This research work is focused to develop light-weight thermally insulating refractory bricks (IRBs) using low cost locally available raw materials. Two pore forming materials saw dust and rice husk have been used in this work to mix with a fireclay composition to investigate their effects on the properties of the resulting IRBs. It has been tried to produce bricks with low bulk density, high porosity, and high cold crushing strength for the use at cold face of the furnaces. The effect of pore former on the properties of the insulating refractory has also been studied.

2. Experimental

2.1.Raw Materials

The raw materials used for preparation of insulating refractory specimens were clay, sawdust and rice husks. The compositions of the clay, saw dust (SD) and rice husk (RH) used in this work are given in Tables 1 and 2, respectively.

2.2.Processing

Three different batches on the basis of various mixing ratios of SD, RH, clay and plastic clay were prepared, i.e. Batch I, Batch II and Batch III. The compositions of these three batches are given in Table 3. These raw materials were processed in different stages to form the brick specimens.

Constituents	Content (wt. %)
Organic material & moisture	73.87
Al_2O_3	1.23
Fe_2O_3	1.28
CaO	1.24
MgO	0.21
SiO_2	22.12
MnO_2	0.074

Table 1. Chemical composition of the clay.

Constituents	Rice husk (wt. %)	Sawdust (wt. %)
Volatile matter	64.7	85
Fixed carbon	15.7	13
Ash	19.6	2
Carbon	38.7	48
Hydrogen	5	6.5
Oxygen	36	43
Nitrogen	0.5	0.5
Sulphur	0.1	NA

Table 2. Chemical composition of the saw dust and rice husk.

All the raw materials including SD, RH and clays were ground to fine particles before further processing. Mortar and Pestle were used for the purpose of grinding. After grinding, the raw materials were sieved through a screen of mesh 30 to get the desired particle size. Rice husks were examined carefully to make sure that these do not contain any grains of rice. Then the raw materials were weighted according to Table 3. Each composition was mixed for 10 minutes in dry state then water was added slowly in the dry mixture and continued mixing for a period of 20 minutes until an acceptable flush distribution of each aggregate was attained. In this process 3-4 wt.% of water was added to get a uniform mixture.

For moulding, steel mould having dimensions 9 x 5 x 2.5 inches was used. The mould walls were cleaned and lubricated with oil. The mould was filled with wet-mixture and allowed to set for few minutes. Afterwards, the specimens were removed from the mould and dried in open air for 24 hours, then dried in electric dryer for 24 hours at 110 °C.
The dried specimens were fired in two steps in a gas fired kiln. In the first step, specimens were heated up to 450 °C for 24 hours to burn out the combustible materials which developed porosity. In second step, the specimens were fired at 1200 °C for 2 days. In overall sintering process low heating rate was selected.

2.3. Testing and Characterization
Fired specimens were visually inspected for defects such as cracks and surface deformation etc. so that defect free samples could be separated.

2.3.1. Apparent Porosity
It is measure of the open pore space in refractory and expressed as average pore space in volume of porous refractory. To find out the apparent porosity, the specimens were dried for 24 hours at 110 °C and dry weight (D) was measured. Then specimen was boiled in water for 2 hours, and kept in water at room temperature for 24 hours. The soaked weight (W) was measured while suspended in air. Finally, samples were suspended in water and suspended weight (S) was recorded. The apparent porosity was calculated using following formula:

$$A.P=(W-D)/(W-S)*100 \qquad (1)$$

Batch I				Batch II				Batch III			
20% Plastic Clay (wt. %)				30% Plastic Clay (wt. %)				40% Plastic Clay (wt. %)			
Sawdust		Rice Husks		Sawdust		Rice Husks		Sawdust		Rice Husks	
SD	**Clay**	**RH**	**Clay**	**SD**	**Clay**	**RH**	**Clay**	**SD**	**Clay**	**RH**	**Clay**
0	80	0	80	0	70	0	70	0	60	0	60
10	70	10	70	10	60	10	60	10	50	10	50
20	60	20	60	20	50	20	50	20	40	20	40
30	50	30	50	30	40	30	40	30	30	30	30
40	40	40	40	40	30	40	30	40	20	40	20
50	30	50	30	50	20	50	20	50	10	50	10

Table 3. Mixing ratios of SD and RH with clay and plastic clay for three batches for making insulating refractory bricks.

2.3.2. Bulk Density

Bulk and apparent densities were calculated in conjunction with apparent porosity using following formulae:

$$\text{Bulk Density}=D/(W-S) \quad g/cc \qquad (2)$$
$$\text{Apparent Density}=D/(D-S) \quad g/cc \qquad (3)$$

2.3.3. Cold Compression Strength (CCS)

It indicates the failure probability under load in service life. The maximum load at which cracks appeared in the specimen was used for the calculation of CCS according to following formula:

$$CCS=(\text{Failure Load})/(\text{Cross section Area}) \quad kgf/〖cm〗^2 \quad (4)$$

3. Results and Discussion

3.1. Effect of Sawdust (SD) contents on the Properties of IRBs

The effect of sawdust (SD) contents on bulk density, cold crushing strength, apparent density and apparent porosity of the sintered IRBs has been studied here, and plotted as function of plastic clay content (20, 30 and 40%). These plots are shown in Figure 1(a-d).

It is revealed from the plots shown in Figure 1 (a and b) that the bulk density and CCS of the sintered IRBs is decreasing by increasing the sawdust contents due to increase in the number of pores. The similar trend was observed in the specimens having different amount of plastic clay which is shown by downward drop in the curves of Figure 1 (a and b). Whereas, apparent density and apparent porosity showed an increasing trend with the increase in SD content as can be seen in Fig. 1 (c and d) due to increase in number of small pores produced by the combustion of sawdust. The increase in content of plastic clay also showed the similar trend (see Figure 1, c and d).

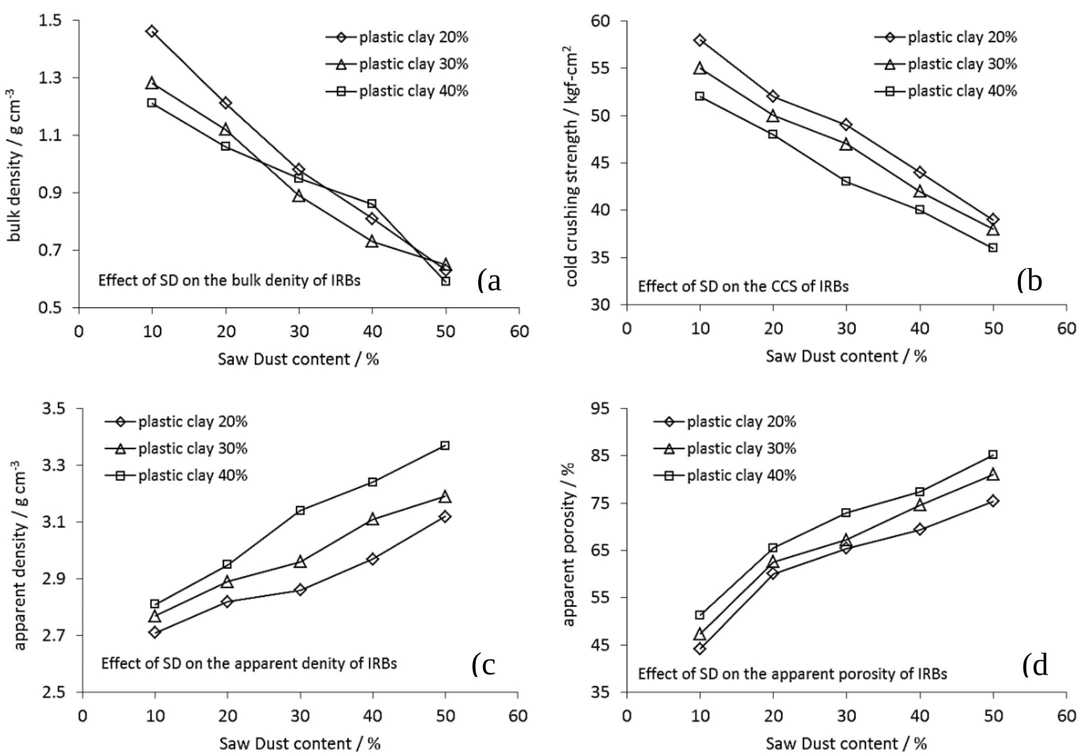


Figure 1. (a) Effect of Saw Dust on the bulk density of insulating refractory bricks (IRBs), (b) effect of SD on the CCS of IRBs, (c) effect of SD on the apparent density of IRBs, (d) effect of SD on the apparent porosity of IRBs

3.2. Effect of Rice Husk (RH) contents on the Properties of IRBs

The effect of rice husk (RH) contents on the bulk density, cold crushing strength, apparent density and apparent porosity of the sintered IRBs has also been studied here and plotted as function of plastic clay content (20, 30 and 40 %; Figure 2, a-d).

It is revealed from the plots shown in Figure 2(a-d) that RH is playing the same role as played by SD. It is acting as a combustible material during sintering and responsible for the development of fine pores. The number of fine pores is increased with the increase in RH contents which ultimately reduces the bulk density and CCS of the sintered IRBs (see Figure 2, a and b). The plastic clay is also playing a similar role i.e. decrease in bulk density and CCS with the increase in the contents of plastic clay (see downward drop in the curves of Figure 2, a and b).

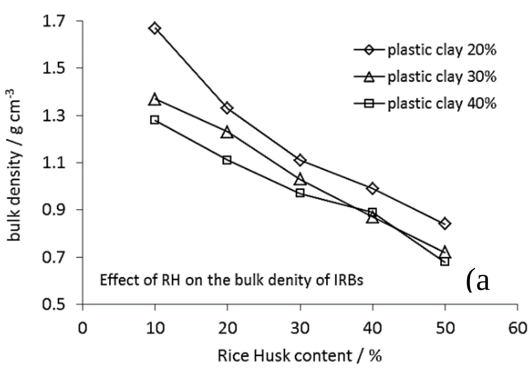
As the number of pores is increasing with the increase in RH contents, therefore, the properties like apparent density and apparent porosity are showing an increasing trend with RH as can be seen in Figure 2(c and d) The increase in the %age of plastic clay also showed the similar trend (see Figure 2, c and d)..

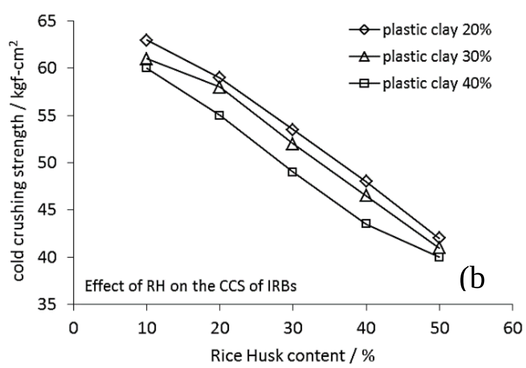
3.3. Comparison of Saw Dust and Rice Husk as Combustible Materials (CM)

Here, a comparison of the effects of combustible materials (rice husk and saw dust) as pore former on the properties of insulating refractory bricks has been given.

3.3.1. Bulk Density

Figure 3 shows a comparison of the effects of SD and RH on the bulk density of IRBs with 20, 30 and 40% plastic clay. The overall comparison (see Figure 3, a, b and c) shows that IRBs containing RH as combustible material have higher values of bulk densities compared to those having saw dust. The higher values of bulk densities show that RH is producing less number of pores in IRBs during firing stage compared to SD. The maximum bulk density obtained in case of RH is ~1.7 g/cm3 at 2:1:7 (plastic clay, RH and clay) which is reduced to 0.7 g/cm3 at 4:5:1 (plastic clay, RH and clay). In case of bricks having SD as pore former, the maximum bulk density is ~1.5 g/cm3at 2:1:7 (plastic clay, SD and clay) that is reduced to ~0.6 g/cm3 at 4:5:1 (plastic clay, SD and clay). These values of bulk densities are lying in good applicable range [11,14,18].





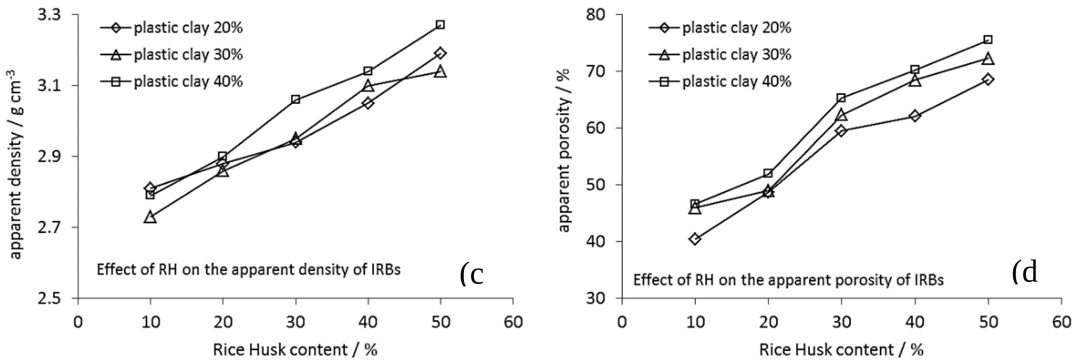


Figure 2. (a) Effect of Rice Husk (RH) on the bulk density of insulating refractory bricks (IRBs), (b) effect of RH on the CCS of IRBs, (c) effect of RH on the apparent density of IRBs, (d) effect of RHon the apparent porosity of IRBs.

3.3.1. Cold Crushing Strength (CCS)

The comparison of the effects of SD and RH on CCS of IRBs is shown in Fig. 4. It is clear from overall comparison at 20, 30 and 40 % plastic clay (see Figure 4, a, b and c) contents that cold crushing strength (CCS) is higher in case of bricks having RH as pore former compared to the refractory bricks containing SD. The reason is again the less pore formation in case of RH which resulted in higher CCS. The maximum CCS of the bricks with RH is ~63 kgf/cm2 at 2:1:7 (plastic clay, RH and clay) and it is reduced to ~41 kgf/cm2at 4:5:1 (plastic clay, RH and clay). Whereas the highest value of CCS in case of SD is ~58 kgf/cm2 at 2:1:7 (plastic clay, SD and clay) and the minimum value is ~36 kgf/cm2at 4:5:1 (plastic clay, SD and clay). The results show that the cold crushing strength of the bricks is present within reasonable use range [14,17].

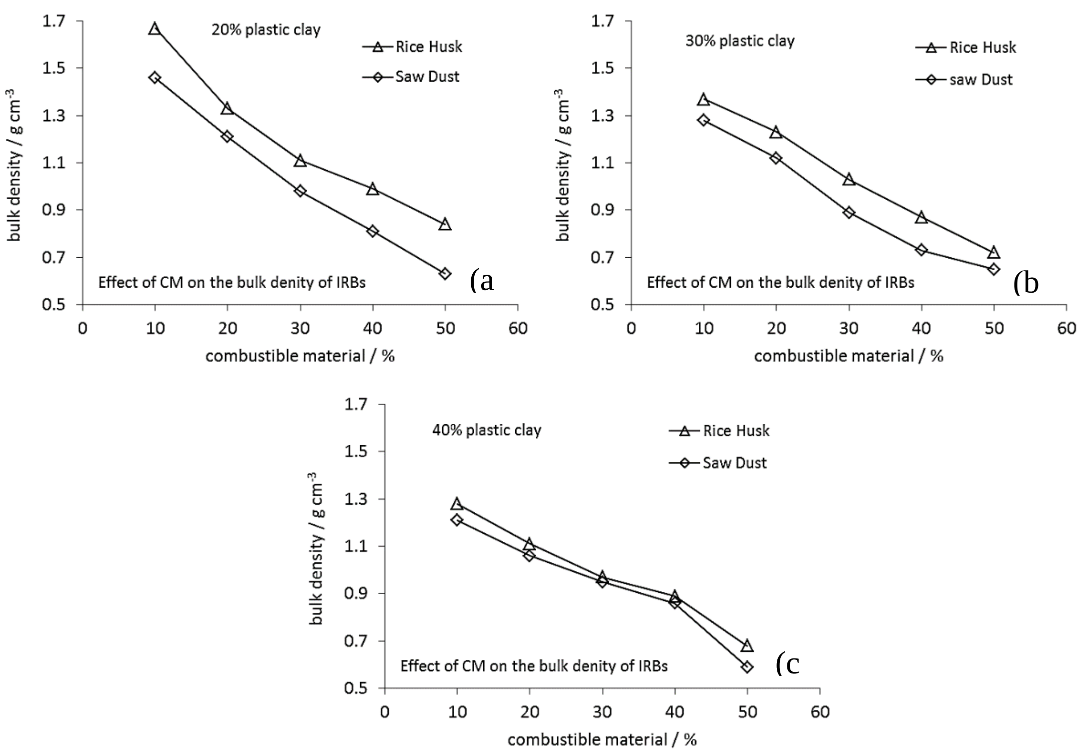


Figure 3. Effect of RH and SD as combustible materials on the bulk density of IRBs at 20, 30 and 40% plastic clay contents, respectively.

3.3.3. Apparent Density

The comparison of the effects of SD and RH on apparent density of IRBs can be seen in Figure 5 at 20, 30 and 40% plastic clay. It is clear from overall comparison (see Figure 5, a, b and c) that apparent density is higher in case of bricks having SD as pore former compared to the IRBs containing RH. This is obviously due to higher pore formation in case of SD. The maximum apparent density of IRBs with SD as pore former is ~3.4 g/cm3 at 4:5:1 (plastic clay, SD and clay) and it is reduced to ~2.7g/cm3at 2:1:7 (plastic clay, SD and clay). While in case of IRBs with RH as pore former, the highest value of apparent density is ~3.2 g/cm3 at 4:5:1 (plastic clay, RH and clay) and the minimum value is ~2.8g/cm3at 2:7:1 (plastic clay, RH and clay). The results show that the apparent density of the bricks also has a reasonable applicable range [11, 18].

3.3.4. Apparent Porosity

Figure 6 presents the comparison of the effects of SD and RH on the apparent porosity of IRBs with 20, 30 and 40 % plastic clay contents, respectively. This again shows that the saw dust is capable to produce higher number of pores in refractory bricks to make them light weight. The maximum apparent porosity of IRBs with SD as pore former is ~85 % at 4:5:1 (plastic clay, SD and clay) and it is reduced to ~44 %at 2:1:7 (plastic clay, SD and clay). While in case of IRBs with RH as pore former, the highest value of apparent porosity is ~75 % at 4:5:1 (plastic clay, RH and clay) and the minimum value is ~40 %at 2:7:1 (plastic clay, RH and clay). The results show that the values of apparent porosityof IRBsare in good applicable range [17, 18].

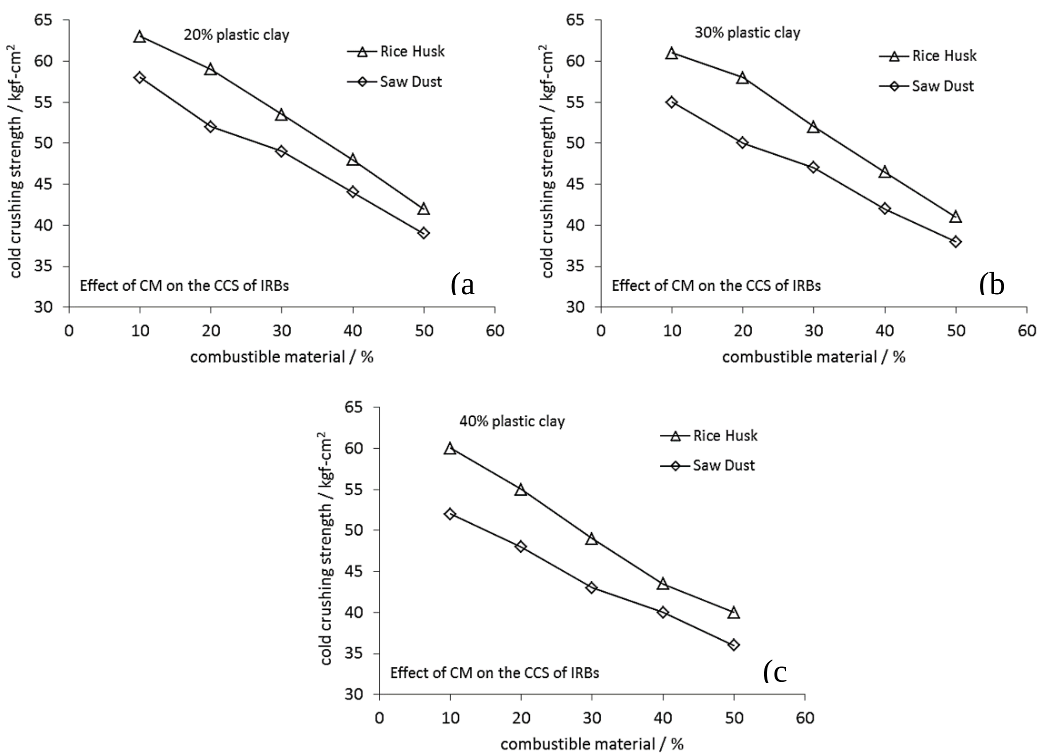


Figure 4. Effect of RH and SD as combustible materials on the cold crushing strength of IRBs at 20, 30 and 40 % plastic clay contents, respectively.

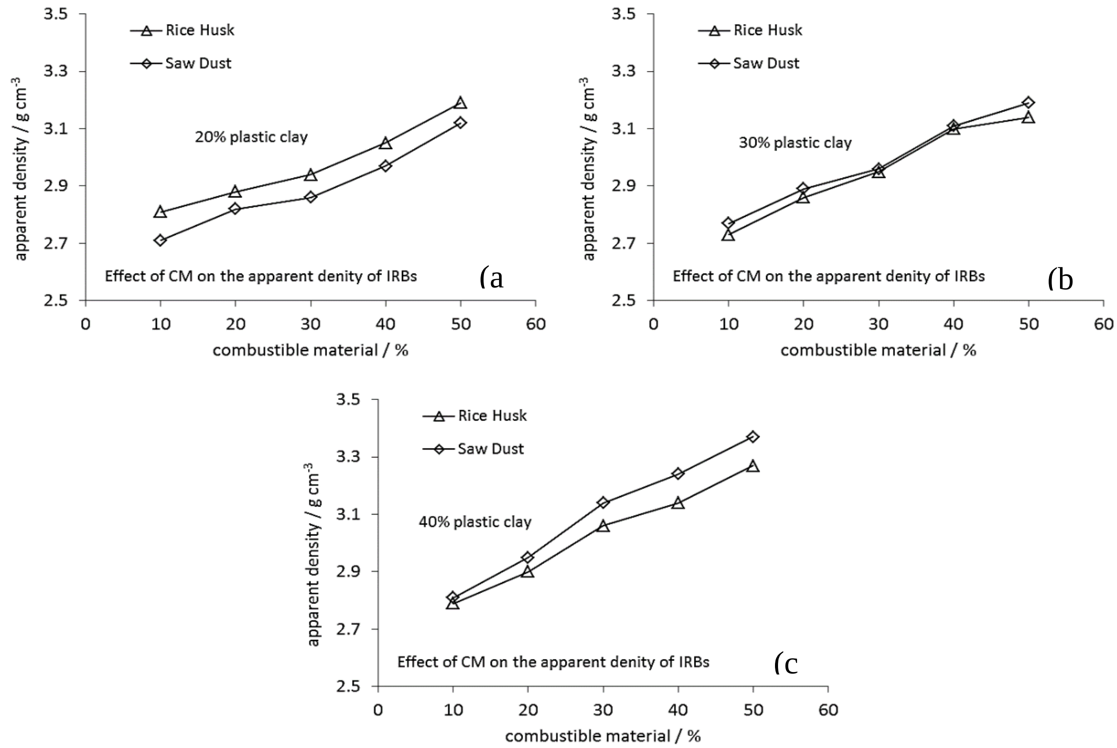


Figure 5. Effect of RH and SD as combustible materials on the apparent density of IRBs at 20, 30 and 40 % plastic clay content.

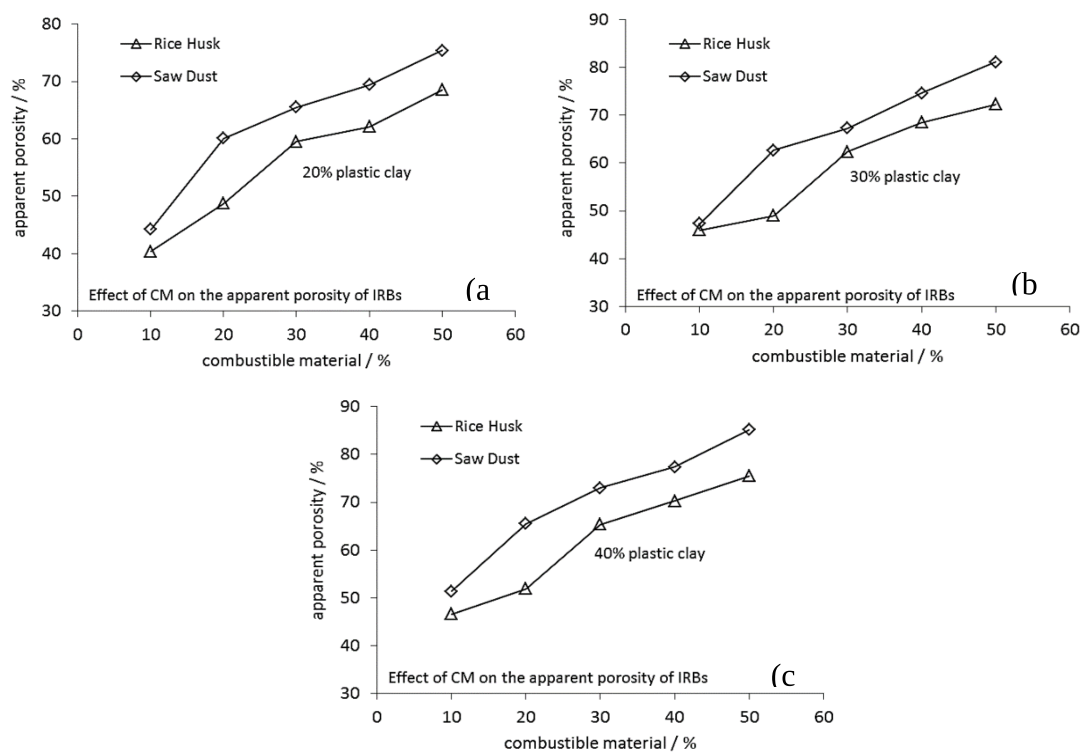


Figure 6. Effect of RH and SD as combustible materials on the apparent porosity of IRBs at 20, 30 and 40 % plastic clay content.

4. Conclusions

On the basis of the results of the present experimentations, the following conclusions can be withdrawn:

1. The bulk density and CCS decrease with increase in amount of combustible material while apparent porosity and apparent density increase.
2. With increase in plastic clay contents the bulk density and CCS of IRB samples decrease while apparent porosity and apparent density increase.
3. The apparent porosity creates due to burning of sawdust particles is in range of (44-85%) while in case of rice husks apparent porosity is (40-75 %) which is an indication that sawdust is a better pore forming combustible material as compare to rice husks.
4. The IRBs specimens develop in this project have enough CCS to withstand structural load in service life. The CCS value in case of sawdust is (3.58-5.71 MPa) and in case of rice husks the value is (3.95-6.21 MPa).
5. The specimens having 40 % sawdust, 10 % plastic clay and balance fireclay were excellent in properties. This composition is recommended for IRBs.

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