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Study of Thermal Conductivity and Mechanical Property of Insulating Firebrick Produced by Local Clay and Petroleum Coal Dust As Raw Materials

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Abstract

Thermal insulation is one of the major requirements for various industrial applications. In this study the evaluation of thermal conductivity and mechanical property of an insulating refractory was carried out at elevated temperature. As additive, coal dust and 4-5wt% water were mixed with local clay. After forming the bricks by conventional uniaxial pressing method, the samples were first air dried for 2 hours at ambient temperature of 30°C, then oven dried for 8-10 hours at 110°C and finally fired in furnace for 6 hours at 1050°C. The combustion of fully combustible coal incorporated extra porosity in the final products resulting in enhanced thermal insulation. As experimental variables, three different sets of coal particle size range (coarse: 100-500 µm, medium 20-100 µm, fine: less than 20µm) and four different coal percentages were used. The results thus obtained showed that increased fineness of coal dust for a fixed coal percentage improved crushing strength and porosity and decreased thermal conductivity. In contrast, for a fixed coal particle size range, crushing strength and thermal conductivity decrease and the percentage of porosity increases with the increase of coal percentage.

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1. Introduction

The industrial application of insulating fire bricks is increasing day by day. Thermal resistance and crushing strength

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are most important properties from their application point of view. Like all the other cases, the structure property relationship plays very vital role in achieving and modifying the desired properties in refractory bricks. For example, how much heat flux will flow through the section of refractory body will be determined by the conductivity of the individual phases present, the nature of their interfaces, their distribution etc. The main challenge in producing insulating fire brick is the desired balance between mechanical and thermal properties. For example, incorporation of increased amount of pores may improve thermal resistance but at the same time deteriorate strength. For that reason, optimization of the properties by varying manufacturing parameters can be very significant area of investigation. Among many methods available for manufacturing the insulating bricks, burnout process is most common. In this method, normally an easily combustible bio material is incorporated in the slurry which during firing burns out producing a pore similar to its size. Rice husk, saw dust, coal dust etc. have been tried as combustible additives. Different types of additives create their characteristic pores. For example, rice husk gives d-shaped or longitudinal pores, saw dust gives pores of irregular size and coal dust gives spherical size pores [1, 2].
In this present study, coal was first collected and ball milled, then a sieve analysis was carried out to segregate particles of different size range. Chemical analysis of locally collected clay was made and then several batches of specimens (bricks) were made varying the coal particle size and percentage of coal incorporated. The specimens were fired in a furnace after required periods of drying cycle.

Percentage of porosity for each sample was calculated from their apparent and true densities. Then cold crushing test was carried out in a universal testing machine. The thermal conductivity of each sample was obtained using Lee's apparatus. Then the experimental results were represented graphically.

2. Experimental

2.1 Raw materials processing & analysis

The raw materials used for the manufacturing of insulating refractory brick were clay and coal dust. The composition of clay was found out by wet analysis method. Result of analysis is given in table 1.

Table 1. Chemical analysis of clay.

Components	Percentage(wt.%)
Iron(III) oxide, Fe_2O_3	5.99
Alumina, Al_2O_3	27.01
Silica, SiO_2	63.81

Hard coal pieces was first ball milled to achieve fine coal powder. Then sieve analysis was carried out in a sieve anlyser to separate the powders of different sizes. The hard coal, sieve analyzer and coal powders collected in separate containers are shown in figure 1.

a b c

Fig. 1. (a) Hard coal pieces, (b) sieve analyzer , (c) Coarse, medium and fine coal powders collected after ball milling and sieve analysis.

Particles of three different ranges of particle sizes were collected under three different names. The type of powder and particle size range in micrometer (μm) is given in table 2.

Table 2. Particle size range of different types of coal powder

Type of coal powder	Particle size range(μm)
Coarse	100-500
Medium	20-100
Fine	Less than 20

The analysis of coal powder is then carried out. The analysis of coal is given in table 3 .

Table 3 Chemical analysis of coal.

Components	Percentage(wt.%)
Ash	5.04
Moisture	2.72
Volatile matter	28.61
Fixed carbon	63.63

2.2 Mould preparation

The function of mould is to give the shape and a dense packing to achieve the sufficient green strength for handling of the green bricks. Mould size, shape, consisting parts, material can be changed depending upon requirement. In present case, the mould was made of mild steel which consisted of three parts: (a) base part (b) ring shaped mould body and (c) ramming press or load. Different parts of mould and mould assembly is shown in figure 2.

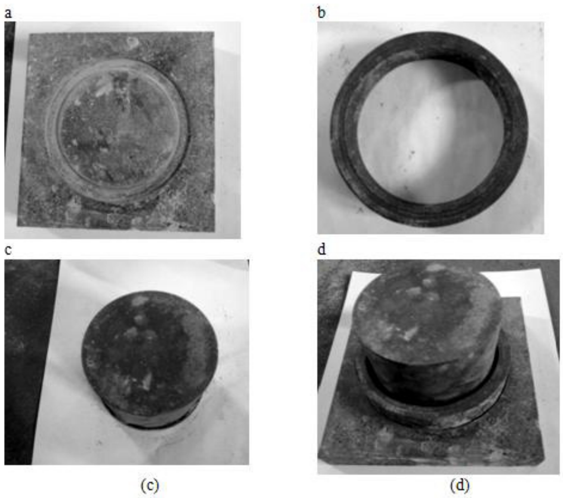

Fig. 2. (a) Base part, (b) mould body , (c) ramming press , (d) mould assembly .

2.3 Specimen preparation

Coal powder of particular size range was weighed and added to a mixing bowl. Clay was also weighed and then mixed thoroughly with coal powder in the bowl. However, water was added insufficiently each time, mixing it into the slurry by hand. Care was taken so that the water gets absorbed into the mixture instead of setting down the bowl. After preparing the slurry, the mould was filled and pressed hard so that the mixture reaches to all the corners and sides. Finally, the brick was ejected from the mould. Then, the green bricks were at first dried for several hours at the room temperature followed by oven drying at 110°C for 8-10 hours. After drying they were taken into the furnace and arranged separately to get sufficient amount of oxygen for proper burning of the combustible material (coal) in the brick. They were heated slowly up to 400°C and then rapidly to 1050°C. Total firing time was about 6 hours. The assembly of the bricks inside the box type muffle furnace used in this investigation is shown in fig.3.

Fig. 3. Circular bricks placed in oven.

2.4 Measurement of apparent and true density

At first the specimen was weighed and by measuring radius and thickness of the circular brick volume was calculated. Dividing the mass by volume, apparent density was measured. For measuring true density, the circular block was crushed first and then a known amount of this powder was taken into a pycnometer bottle full of water . The weight of water lost from pycnomoter gives the volume of the water which is equal to the volume of the powder. Dividing the previously known weight by this volume gives true density which excludes the presence of all types of pores (both internal and external) . From true and apparent density, percentage of porosity was calculated from the following formula,

$$\%\text{Porosity} = [1 - (\frac{Apparent \quad density}{True \quad density})] \times 100 \ \%$$

Using this method, apparent density and percent porosity were measured for all speciments. Then two graphs were plotted showing change of apparent density and percent porosity with increasing percentages of coal and varying coal particle size (Fig.7b).

2.5 Measurement of crushing strength

At first, a square shaped block was prepared from the circular brick. Then it was polished for getting accurate dimension of one inch by one inch. After preparing the block, it was set into the crushing machine and load was applied on the block. The block was broken at a certain load and this load was noted for measuring the crushing strength. Dividing the load by area (load bearing surface), Crushing strength was calculated.

Crushing strengths for all specimens were determined by this process and then a graph was plotted showing change of crushing strength with increasing percentage of coaland varying coal particle size(fig. 8b).

Fig. 4. The cold crushing test assembly of a universal testing machine.

2.6 Measurement of thermal conductivity

Lee's apparatus [3] was used for measuring the thermal conductivity of the specimens which is shown in figure 1. The apparatus consists of a hollow cylinder C with two tubes attached to it, known as steam chamber, two brass discs A & B with radial holes.

Weight of the disc A was measured first and the thickness and diameter of the specimen were measured. Then the specimen was polished for good contact with the brass discs and placed over the disc A. Disc B and hollow cylinder was placed over

the specimen S respectively. Steam was passed into the steam chamber. Two thermometers were set and waited for taking the steady temperature T_1 & T_2. At this steady state, the heat conducted through the refractory specimen (which is a bad conductor) will be eual to the heat radiated from the lower exposed portion of the metallic disc.Then to find the heat radiated from the lower disc, the steam supply was stopped and steam chamber with disc B was removed. Specimen S with disc A was placed upon by a concentric insulator disc and heated by burner for increasing the temperature up to (T_1 +10°C).Then the disc A was cooled and cooling time was noted for every 1°C decrease in temperature. By plotting cooling time and temperature values, a cooling curve was drawn. A tangent was drawn to the curve at or near temperature T_2 and dT/dt was calculated. The thermal conductivity was measured by using the following formula,

$$K = \left[ms \frac{\left(\frac{dT}{dt}\right)\left(\frac{d}{D}\right)}{(T_1 - T_2)} \right] cal.cm^{-1}.{}^{\circ}c^{-1}.\sec^{-1}$$

Where, m=Weight of Disc A;

S=Specific heat of A (specific heat of brass);

d=Thickness of A;

D=Cross sectional area of A;

T_1= steady temperature of disc B;

T_2= steady temperature of disc A.

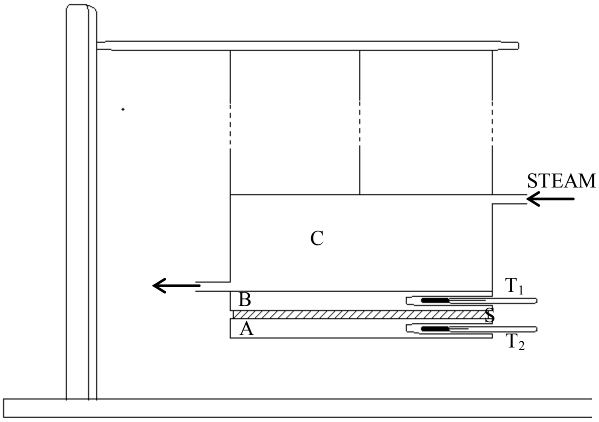

Fig. 5. Schemetic image of Lee's apparatus.

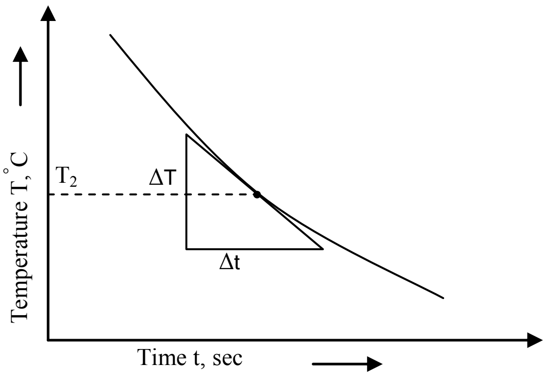

Fig. 6. Cooling Curve.

3. Results and discussions

As seen from figure 7(a), as the percentage of the coal increases, apparent density decreases. Density has been decreased from 1.48 to 1.1 for fine coal particle, from 1.56 to 1.20 for medium coal particle, from 1.62 to 1.3 for coarse coal particle with increasing the percentage of coal from 5% to 20 % which is shown in figure 7(a). From figure 7(b), we can see that porosity has been increased from 46.50% to 58.48% for fine coal, from 42.03% to 56.60% for medium coal, from 38.36% to 53.65% for coarse coal with increasing the coal amount from 5% to 20 %.

The coal is of lower density than clay. This coal almost burned out during firing leaving minute amount of ash and spherical pores created against pressure of carbon-di-oxide and vapour which are product of combustion. This means incorporation of higher coal percentages, increases the overall points which areoccupied by light weight coal rather than clay, in other words, increasing coal percentage decreases weight in a fixed volume. The apparent density calculates weight per unit volume. That's why apparent density decreases with increasing coal percentage, whereas true density almost remains same. Porosity in a sense, is a measure of how low the value of apparent density is from true density. Percentage of porosity increases as apparent density decreases. For that reason increasing coal percentage increases percentage porosity.

From figure 7(a), it is obvious that apparent density values are little affected by particle size. Although specimens with finer particles possess higher surface area with the furnace environment once combustion is started (surface coal particles burnt out leaving smaller size pores) so effective combustion throughout the bulk volume is preferred here and possibility of remaining unburnt coal particles is reduced.

Figure 7(b) shows that size effect is more obvious in case of percentage porosity; for example, at 15 wt% coal it s around 58% for fine coal but 45% for specimens containing coarse coal particles. So, it can be concluded that as fineness increases, percentage of porosity also increases. This can be attributed to the favorable complete combustion condition existing in fine coal samples explained above.

a b

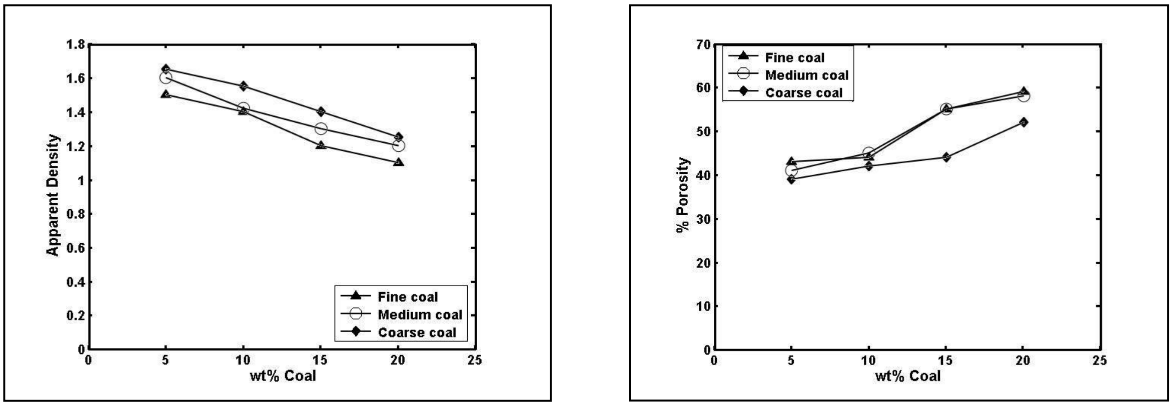

Fig.7. Relationship of (a) apparent density and (b) percentage of porosity of insulating fire bricks with coal weight percentage and particle size.

Figure 8(a) shows the effect of coal addition on thermal conductivity. It shows that thermal conductivity decreases from 4.1×10^{-4} cal·cm^{-1}·°C^{-1}·sec^{-1} to 2.37×10^{-4} cal·cm^{-1}·°C^{-1}·sec^{-1} for fine coal, from 4.18×10^{-4} cal·cm^{-1}·°C^{-1}·sec^{-1} to 2.38×10^{-4} cal·cm^{-1}·°C^{-1}·sec^{-1} for medium coal, from 4.24×10^{-4} cal·cm^{-1}·°C^{-1}·sec^{-1} to 2.85×10^{-4} cal·cm^{-1}·°C^{-1}·sec^{-1} for coarse coal with increase of coal amount from 5% to 20%. Thermal conductivity depends not only on the clay but also on the size, shape, and amount of the organic particles. With the increase of coal addition, the porosity increases. This porosity acts as a barrier to the flow of heat and as a result of which thermal conductivity decreases. From figure 7(a), it can be concluded that thermal conductivity of the brick using fine coal is relatively less than the medium and coarser coal of same composition. Fine coal gives smaller pore size. Which means heat flux needs to face a higher area of low conductivity in its way across the brick. That's may be the reason for slightly decreasing thermal conductivity with decreasing coal particle size.

From figure 8(b), we can see that cold crushing strength decreases from 22.79MPa to 5.5MPa for fine coal particle, from 20 MPa to 5MPa for medium coal, from 18.6MPa to 6.1Mpa for coarse coal with increase of coal content from 5% to 20%. Coal is a non plastic material. With the addition of coal, binding action decreases. Moreover during firing, this coal particles burn out and leaves the pores and decreases the density. This results in decrease of crushing strength. From figure 8(b), it can be seen that cold crushing strength of the brick using fine coal is relatively high than the medium and coarser coal of same composition. This can be attributed to the fact that, specimens with finer coal powders possess finer pores and consequently offers higher load carrying area during test.

a b

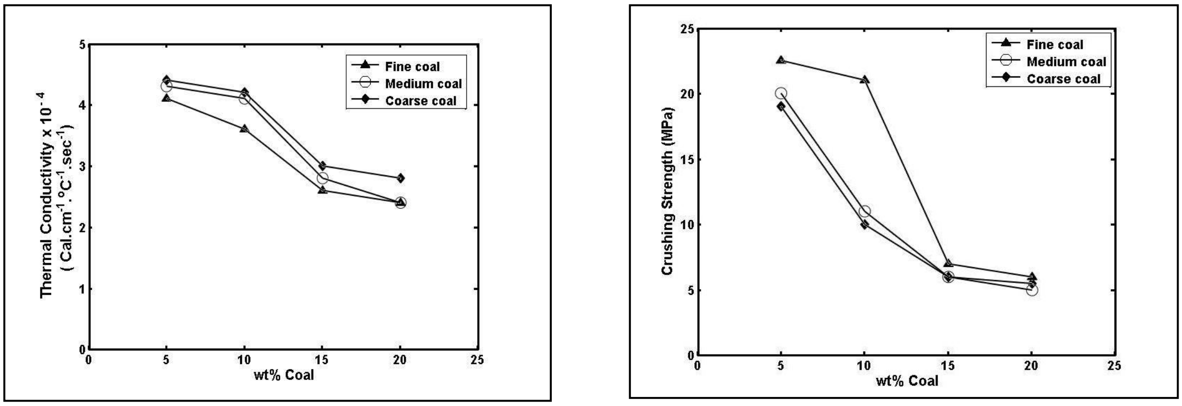

Fig.8. Relationship of (a) thermal conductivity and (b) crushing strength of insulating fire bricks with coal weight percentage and particle size.

Stress is calculated from force per unit area, so these specimens will undergo less stress for same applied load. Also any internal crack will face more obstacles in its way of propagation in specimens with finer coal powder. That's why specimens of fine coal powder shows higher crushing strength than coarse ones.

4. Conclusion

The relationship between thermal and mechanical properties of insulating bricks with the particle size and percentage of coal was investigated. The investigation revealed that apparent density, thermal conductivity and cold crushing strength decreases and percentage porosity increases as the coal percentage increases in the specimens. On the other hand, apparent density and thermal conductivity decreases but percentage porosity and cold crushing strength increases as the fineness of the coal particles increases.

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