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RESEARCH

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Preparation of insulating firebricks using date seeds

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Abstract

Background The use of combustible vegetable waste in the manufacture of refractory insulating firebricks has a double advantage: making use of vegetable waste and decreasing the production cost of bricks.

Results Ground date seeds were added to kaolin and grog at different ratios and their blend was mixed with water. The wet mixtures were shaped in steel molds, dried overnight at 90 °C and fired at 1200 °C for 2 h. The physical and mechanical properties of the fired bricks were determined and found to be incompatible with standard values. Small amounts of polystyrene beads and perlite were then added to decrease the bulk density and increase the crushing strength. A mixture composed of 6% date seed, 72.5% kaolin, 17.5% grog, 2.5% perlite and 1.5% polystyrene produced bricks that abided by Indian Standards 2042 requirements regarding their bulk density, porosity, crushing strength, percent linear change on reheat and thermal conductivity at 600 °C.

Conclusions Date seeds have been successfully used as pore generating material in the preparation of Class B insulating firebricks, in a mixture with kaolin, grog and small amounts of polystyrene and perlite.

Keywords Insulating, Firebricks, Date seeds, Kaolin, Grog

Background

The world market for insulating fire bricks (IFB) used in the internal lining of industrial furnaces is expected to rise from 1265.2 million USD in 2022 to reach 2142.4 million USD in 2024 (IFB 2024). Among the main challenges faced by that industry is the need to produce bricks with excellent thermal insulation and good chock resistance (Chris 2023). To reach this aim, various attempts were made to research the possibility of using vegetable waste as pore creators to substitute all or part of the more expensive polymers used to that effect, such as polystyrene. Saw dust and straws of different origin were used in that respect. Aramide (2012) used sawdust in the preparation of IFB and concluded that the maximum level of addition should not exceed 15% to prevent mechanical failure. A similar approach was made by Viruthagiri et al. (2013) who recommended limiting the addition to 20%. Their products showed values of thermal conductivity at 1100 °C ranging from 0.0417 to 0.1429 W $m^{-1o}C^{-1}$, depending on the composition of the mix. Different results were obtained by Cultrone et al. (2020) on using a type of clay rich in silica and phyllosilicates. They reached a porosity of 60% on adding 10% sawdust. However, they did not attempt to determine the thermal conductivity of their products, but rather decided about the insulation effectiveness by means of IR images. Bories et al. (2015) mixed a mixture of wheat straw, sunflower seed cake and olive stone flour with clay. They reached a minimum thermal conductivity of 0.2 W m^{-1} K^{-1} at 920 °C corresponding to a cold bending strength of 10 MPa. On the other hand, Hadi and Hussein (2019) used mixtures of raw and burned wheat straw in equal weigh ratios to prepare refractory elements. A minimum thermal conductivity of 0.31 W m^{-1} K^{-1} at

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1300 °C was obtained on using 30% of the wheat straw mix. An attempt to compare the use of different pore-forming agents was made by Hossein and Roy (2019) who used different wastes such as fly ash, rice husk and rice straw ash. A maximum porosity of 57% was reached at 800 °C on using a mix composed of 50% fly ash, 30% rice husk ash and 5% rice husk corresponding to a thermal conductivity of 0.65 W $m^{-1o}C^{-1}$. Rice husk was also recently used by Zharmenov et al. (2022) as a renewable source of silica in the preparation of lightweight refractories. Using up to 50% rice husk, the produced bricks, fired at 1200 °C, exhibited high porosities (> 75%) and reasonable bending strength (> 1.6 MPa). Also, the bricks prepared by Isinkaye et al. (2015) by firing at 1200 °C using rice husk possessed high bulk densities (0.95–1.6 g cm^{-3}). Their claim to reach a crushing strength of 23.5 kN mm^{-2} (23,500 MPa) is, however, illogic.

Other attempts were made using diverse pore generating materials. Muñoz et al. (2016) summarized the efforts deployed in that respect up to 2016 in a comprehensive manner. Later, Hassan et al. (2018) prepared lightweight firebricks using a mixture of bagasse and polystyrene beads and firing at 1200 °C. A mixture of 3% bagasse and 1% beads with kaolin resulted in bricks complying with ASTM C155-97 for C-30-type insulating refractories with a cold crushing strength of 4.08 MPa and a thermal conductivity of 0.37 W m^{-1} K^{-1} at 800 °C.

Also, Rahman et al. (2019) used coal with different particle sizes and showed that the percentage and particle size of coal affected the thermal conductivity and cold crushing strength of the prepared samples fired at 1150–1200°C. On the other hand, Adazabra et al. (2018) prepared lightweight refractories by mixing tea waste for up to 15% with local clay and firing the molded mixes at 1200 °C. They obtained bricks with reasonable crushing strength (> 2.5 MPa), but failed to obtain porosities lower than 60%, the maximum value attained being 45%. Also, the thermal conductivity of the bricks exceeded 0.5 W m^{-1} K^{-1}, which is higher than that specified by international standards (ASTM F1312-19) (2023), IS2042 (2006).

Local spent papyrus fragments were added to clay mud at percentages reaching 40%, dried and fired at a maximum temperature of 1050 °C (Karim 2019). The produced samples exhibited an excellent cold crushing strength (> 12.78 MPa), but failed to secure a reasonable porosity, since its maximum value did not exceed 40%, which is much higher than that required by standards (ASTM F1312-19) (2023).

Using powder of spent mushrooms as pore generating material, Ali et al. (2023) prepared refractory insulating bricks by mixing the powder at weight percentage reaching 15% with ball clay and firing at a maximum temperature of 900 °C. Although they could obtain suitable values for thermal conductivity (029 W m^{-1} K^{-1} at 900 °C), they failed to reach a suitable porosity, since the maximum value reached was 36.6% only, compared to a maximum value of 60%, as required by ASTM F1312-19.

The substitution of conventional insulating refractory bricks by a refractory castable was suggested by Hossain et al. (2021) using rice husk. Their product showed a low bulk density of 0.8 g cm^{-3}, when fired at 1100 °C corresponding to a porosity of 65% and a thermal conductivity of 0.136 W m^{-1} K^{-1} and a cold compressive strength of 6MPa. The same authors later presented a comprehensive review on the matter that reported the use of vegetable waste in the preparation of different ceramic products including insulating refractories (Hossein and Roy 2020). Using gmelina seed shells as porosity promoter, Obidiegwu et al. (2020) prepared insulating refractory samples on firing at temperatures reaching 1050 °C. However, their results were short of producing sound bricks since the minimum bulk density reached was 1.5 g cm^{-3} corresponding to a compressive strength of 0.126 MPa. Also, Lawanwadeekul et al. (2016) used different sizes of crushed corncobs to produce insulating bricks fired at a maximum temperature of 1150 °C. Although they obtained reasonable figures for crushing strength, the porosities of the bricks were too low to produce any reasonable insulating effect. This point was overlooked by the authors since they did not report any values for thermal conductivity. Similar research has been carried out that failed to secure either a reasonably low bulk density or a suitable crushing strength (Obidiegwu et al. 2015; Folurunso et al. 2015; Micheal and Moussa 2022; Paliwal et al. 2018; Mgbemere et al. 2020).

In the present paper, ground date seeds were used primarily as pore generating materials in the preparation of insulting refractory bricks compatible with IS 2042, 2006 (2006). The use of such waste serves a dual purpose, besides ridding the environment from a waste, it also employs cheap available vegetable waste as pore creator, thus decreasing the manufacturing cost of the product.

Methods

Raw materials

Date seeds

Date seeds were obtained from dates purchased from the local market. These were washed in deionized water, dried overnight at 105 °C, then ground and sieved. Grinding was carried out in a laboratory ball mill of 30 L capacity, rotating at about 50 rpm for 4 h. The fraction retained between screens of mesh size 20 (590 µm) and mesh size 30 (840 µm) was selected for this work. This size was chosen to ensure the formation of enough macropores in the fired body.

Kaolin clay
This was obtained from the Esseila region, South of Sinai. It was ground in a laboratory ball mill and the fraction between screens 35 (250 µm) and 60 (500 µm) retained.

Grog
Grog was obtained by grinding down defective fire clay bricks containing 45% alumina and a size range like that of kaolin was selected. The reason for that choice is to avoid having a large difference in particle size between the different components of the mix. This is since such a difference may result in a decreased porosity of the fired brick (Mota et al. 2023).

Perlite
This is an amorphous type of volcanic glass that expands to 20 times its volume when heated to 1000 °C (Samar and Saxena 2016). It was supplied as spheroidal beads of size range 1–4 mm by the Egyptian Company for Manufacturing Perlite.

Polystyrene (PS)
Polystyrene of formula $(C_6H_5{-}CH{=}CH_2)_n$ is a polymer that totally volatilizes at 500 °C generating pores in the fired body. This was imported from the Hangzhou Epsole technologies C° (Zhejiang, China). It was delivered as spherical beads of 1.5 mm size.

Characterization of raw materials
Chemical analysis
Chemical analysis of the raw materials was carried out using X-ray fluorescence (XRF). Table gives the XRF results for date seeds, kaolin, grog and perlite.

Mineralogical analysis
XRD was used to assess the phase composition of the kaolin used. This was performed in a Brukur D8 A computerized X-ray diffractometer apparatus. Figure 1 shows that it is mainly composed of kaolinite $(Al_2Si_2O_5(OH)_4)$, quartz (SiO_2) and illite $((K,H_3O)(Al,Mg,Fe)_2(Si,Al)_4O_{10}[(OH)_2,(H_2O)$.

The XRD pattern of grog showed only two main phases, namely mullite $(Al_6Si_2O_{13})$ and quartz. Calculation of the average crystallite size was performed using the Sherrer equation (Vinila and Isac 2022):

$$D = \frac{0.89\lambda}{\beta \cos\theta} \quad (1)$$

where λ is the wavelength of emitted X-ray (0.154nm), β is the full width at half maximum (FWHM) (rad) and θ is the diffraction angle corresponding to each peak (rad).

The average crystallite size was found to equal 39.8 nm. This average size is typical of clay minerals (Li et al. 2023).

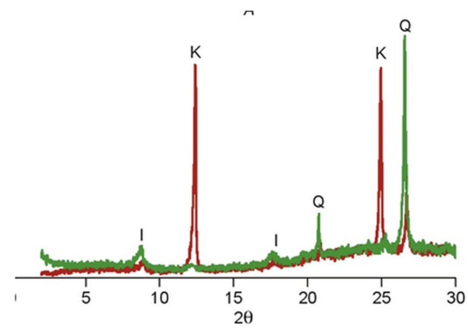

Fig. 1 XRD of kaolin

Thermal analysis
The thermal analysis of date seeds and kaolin was carried out in a Netzsch STA 409 C/CD apparatus. TG–DTG traces of the date seeds (Fig. 2) reveal a major weight loss amounting to 69.5%, associated with a major DTG peak at about 334 °C and a minor one at about 428 °C. These correspond to the devolatilization of organic volatile matter (Raza et al. 2023). The loss in weight at 1000 °C is about 96%, confirming the XRD figure of LOI.

The thermal analysis of kaolin (Fig. 3) produced a small DTG ak at 76 °C, ending at about 155 °C corresponding to the elimination of moisture. The main peak at 518 °C associated with a large weight loss corresponds to the dihydroxylation of kaolin to *m*-kaolin through the reaction:

$$Al_2Si_2O_5(OH)_4 = Al_2Si_2O_7 + 2H_2O$$

The loss in weight at 1000 °C amounts to about 15.3%, including about 2.7% moisture, which checks with the LOI of the dry material in Table 1.

The thermal analysis curve of grog did not produce any appreciable weight loss.

Preparation of samples
Samples were prepared by mixing the ingredients (kaolin, date seeds, grog, etc.) in water using a laboratory kneeder. The resulting mud was molded in $50 \times 50 \times 50$ mm^3 steel molds and left to dry at 90 °C overnight.

After removing the dry specimens from the molds, they were fired to 1200 °C and left at the final temperature for 2 h. The firing schedule was regulated to avoid rapid evolution of water during the dihydroxylation of kaolin by keeping the temperature fixed at 650 °C for 1 h. Figure 4 shows cooled specimens after firing.

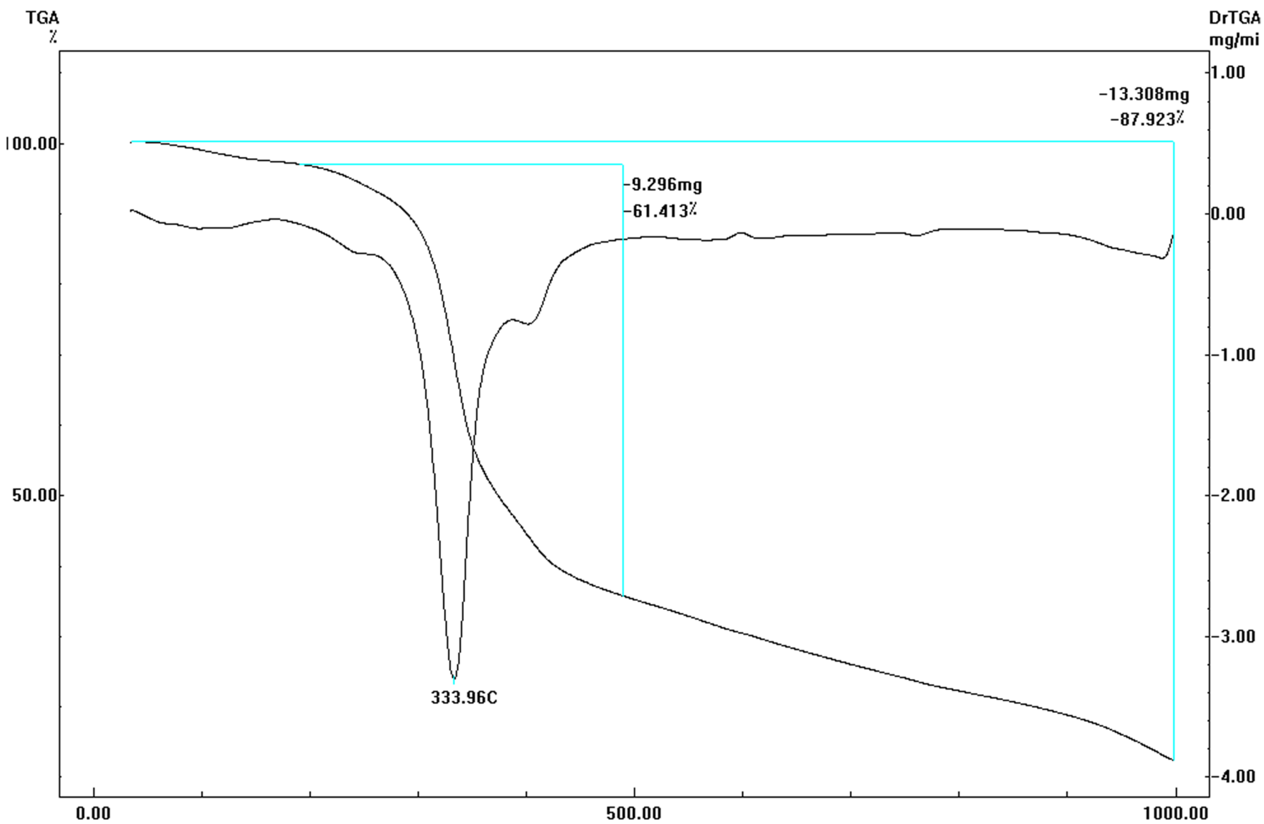

Fig. 2 TG–DTG of date seeds

Testing fired samples

The following tests were then carried out on the fired bodies, taking each time an average of 3 readings.

Apparent porosity, water absorption and bulk density

These tests were performed following ASTM C20-00 (2015). The percent apparent porosity was determined from the expression:

$$\% P = \frac{W - D}{V} \times 100 \tag{1}$$

The percent water absorption, on the other hand, was obtained from:

$$\% A = \frac{W - D}{D} \times 100 \tag{2}$$

Here, D represents the weight of a dry specimen, g. W is the weight of the specimen saturated with water, g. V is the exterior volume of the specimen, cm^3.

The bulk density is calculated from:

$$\rho_B = \frac{D}{V} \tag{3}$$

Following IS 2042, the bulk density of Class-B refractory bricks should not exceed 0.90 g cm^{-3}, whereas the percentage porosity should not be less than 60%.

Permanent linear change on reheating

This test was carried out on the fired samples according to ASTM C113-14 (2019) and should not numerically exceed −1.5% at 850 °C for Class-B insulting refractories following IS 2042. To that aim, special specimens of dimensions $228 \times 114 \times 64$ mm^3 were prepared and fired to 850 °C, following the heating schedule described by ASTM C113-14.

Cold crushing strength (CCS)

This test was performed according to ASTM C133-97 (2021). The minimum acceptable strength, according to IS 2042 is 15 kg_f cm^{-2} (1.47 MPa). This was determined by dividing the breaking load (N) by the cross-sectional area of the specimen (50×50 mm^2).

Thermal conductivity

Thermal conductivity required preparing samples with the same dimensions as for the percent linear change

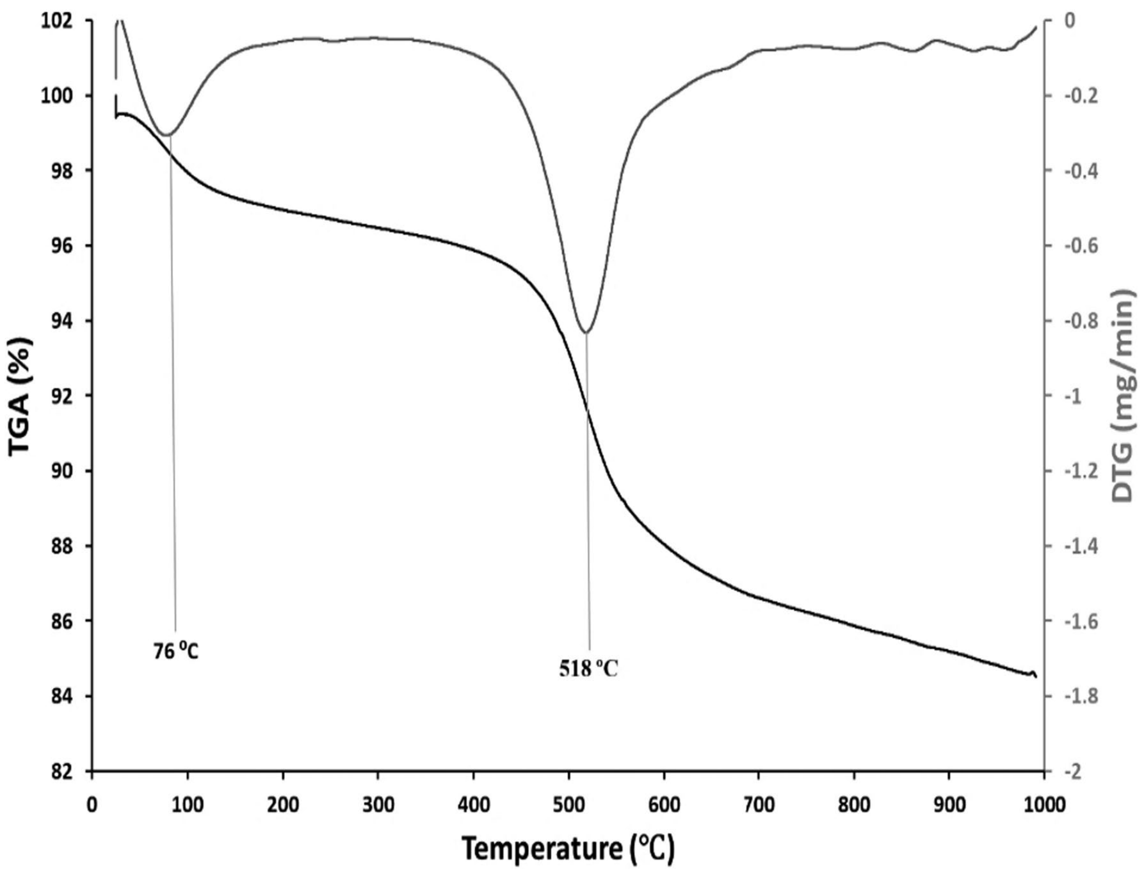

Fig. 3 TG–DTG of kaolin

Table 1 Chemical analysis of raw materials

wt.%	Date seeds	Kaolin	Grog	Perlite
SiO_2	0.86	47.58	55.02	71.50
Al_2O_3	0.08	36.4	44.91	14.21
Fe_2O_3	0.18	0.73	0.09	1.18
CaO	0.62	0.11	–	0.88
MgO	0.32	0.146	–	0.32
Na_2O	0.03	0.036	0.010	3.30
K_2O	0.57	0.22	0.011	3.97
TiO_2	–	1.52	0.010	–
SO_3	0.3	–	–	–
P_2O_5	0.25	–	–	–
Others	0.12	–	–	–
LOI	96.65	13.3	0.011	4.33
Total	99.99	100.04	100.06	99.99

Fig. 4 Fired specimens

on reheating ($228 \times 114 \times 64$ mm^3). The test adopted complied with ASTM C182-19 (2019). Following IS 2042, the thermal conductivity of Class-B insulating

Table 2 Compositions of mixes in the first trial

% date seeds	2.5	5	7.5	10	12.5	15	17.5
% Kaolin	77.5	75	72.5	70	67.5	65	62.5
% Grog	20	20	20	20	20	20	20

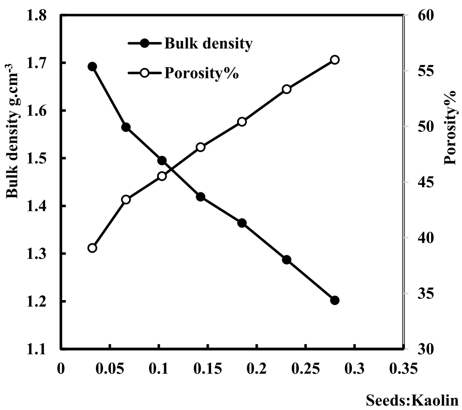

Fig. 5 Effect of seed-to-kaolin ratio on bulk density and porosity (trial 1)

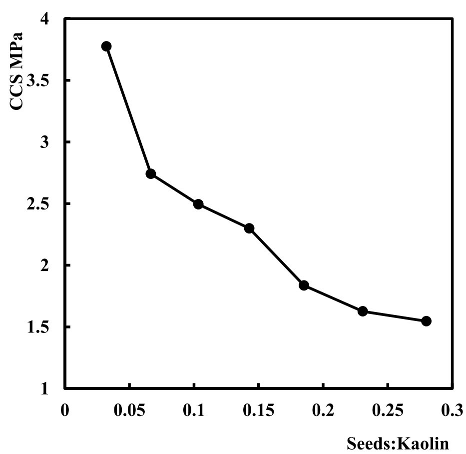

Fig. 6 Effect of seed-to-kaolin ratio on CCS (trial 1)

refractories should not exceed 0.35 W m^{-1} K^{-1} at 600 °C.

Results

Experimental trials

Trial 1

In a first trial, the prepared mixes consisted solely of date seeds powder, kaolin and grog. The percentage grog was kept constant at 20% while the percentages of date seeds and kaolin varied keeping a fixed total of 80% (Table 2).

An increase in the percentage of date seeds powder decreased the bulk density owing to increase in porosity (Fig. 5). Despite obtaining figures for crushing strength exceeding the minimum requisite of 1.47 MPa (Fig. 6), density values did not abide by the maximum allowable bulk density of 0.9 g cm^{-3} required by IS 2042. As expected, the increase in date seed content increased the porosity and decreased the crushing strength.

Trial 2

In that trial, asset of mixes was prepared with fixed grog percentage of 20%. The seed-to-kaolin ratio varied from about 0.05–0.17 and polystyrene beads were added at 1% and 1.5% levels to enhance lower bulk density. Table 3 reveals the composition of the different mixes.

Figures 7 and 8 reveal that, although there was an improvement in bulk density figures, they still fell short of abiding by the maximum standard value of 0.9 g cm^{-3} when 1% PS was added. As the PS level was increased to 1.5%, bulk densities lower than 0.9 g cm^{-3} were obtained. However, such mixes failed to achieve the minimum required strength of 1.47 MPa. In these figures, the dotted line represents maximum and minimum permissible values, respectively.

Table 3 Compositions of mixes in the second trial

	1st set (1% polystyrene)				2nd set (1.5% polystyrene)			
% seeds	4	6.5	9	11.5	3.5	6	8.5	11
% Kaolin	75	72.5	70	67.5	75	72.5	70	67.5
% Grog	20	20	20	20	20	20	20	20
% PS	1	1	1	1	1.5	1.5	1.5	1.5

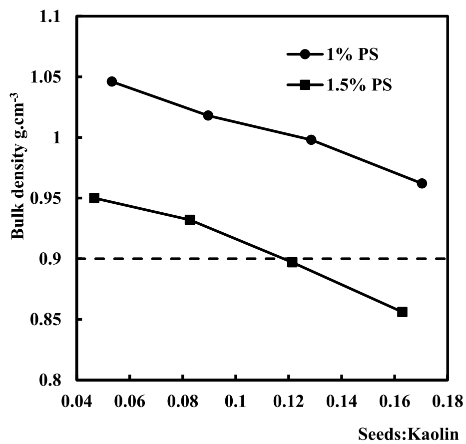

Fig. 7 Effect of seed-to-kaolin ratio on bulk density (trial 2)

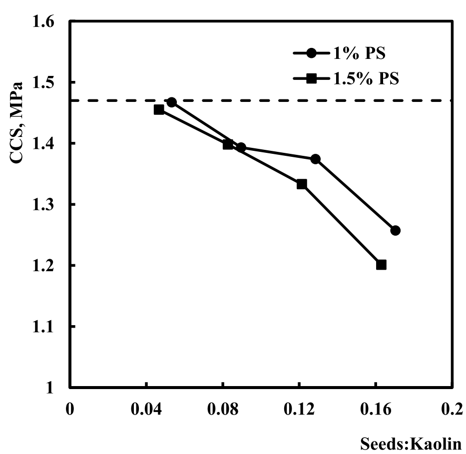

Fig. 8 Effect of seed-to-kaolin ratio on CCS (trial 2)

Table 4 Correlation coefficients between levels of raw materials and final properties

Material	Bulk density	CCS
% Date seeds	−0.482	−0.937
% kaolin	0.558	0.955
% PS	−0.824	−0.524

The results of this trial were subjected to correlation analysis to investigate the relative effect of each component on the final properties. The linear correlation coefficients obtained for the effect of the different materials on the two main properties (bulk density and crushing strength) are reported in Table 2. These were calculated using the "Correlation" function available from the "DATA ANALYSIS" module in EXCEL (Table 4).

Table 5 Compositions of mixes in the third trial (bold column represents the chosen mix)

% date seeds	5	5.5	**6**	6.5	7
% Kaolin	73.5	73	**72.5**	72	71.5
% Grog	17.5	17.5	**17.5**	17.5	17.5
Perlite	2.5	2.5	**2.5**	2.5	2.5
PS	1.5	1.5	**1.5**	1.5	1.5

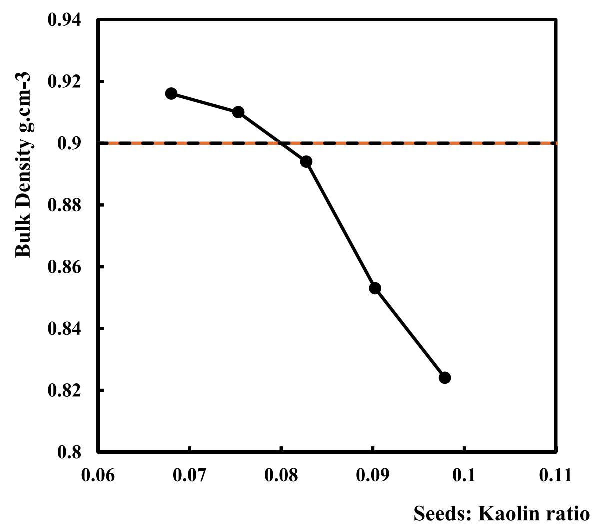

Fig. 9 Effect of seed-to-kaolin ratio on bulk density (trial 3)

This table reveals that the percentage date seeds strongly affect the strength in a negative way, while mildly affecting the density so that it is preferable to use a relatively low fraction of date seeds powder. Also, kaolin, while mildly affecting density, strongly promotes higher strength, suggesting using a relatively high percentage of kaolin. Finally, the effect of variation in PS content on decreasing bulk density exceeds its negative effect on strength.

Trial 3

Perlite was then introduced in the mixes to substitute part of the grog to promote lower density, while keeping the crushing strength at reasonable figures. Table 5 shows the composition of the mixes and the results obtained for bulk density and cold crushing strength. The amount of kaolin was kept relatively elevated, while those of grog, PS and perlite were kept constant.

Figures 9 and 10 present the variation of bulk density and crushing strength with the seed-to-kaolin ratio. The dotted lines represent the standard limits as regulated by IS 2042.

These figures show that the only mix that fulfills the two standard requisites of bulk density (<0.9 g cm^{-3})

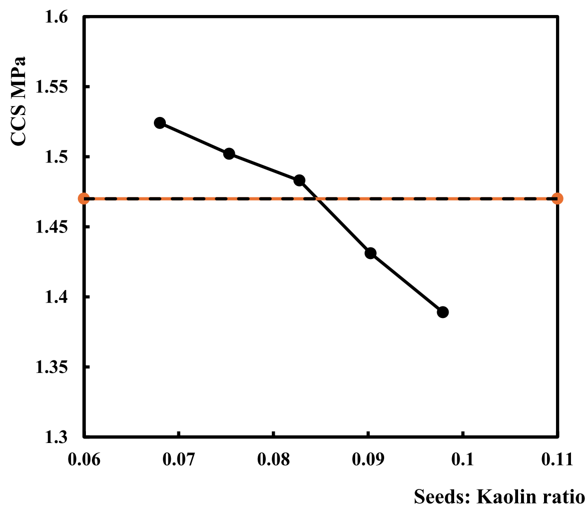

Fig. 10 Effect of seed-to-kaolin ratio on CCS (trial 3)

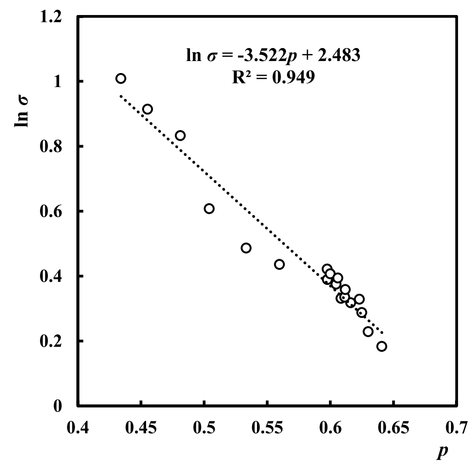

Fig. 11 Plot of ln σ against p

and crushing strength (> 1.47 MPa), for Class-B insulating refractories, is that where the seed-to-kaolin ratio is about 0.0827 (6:72.5). This mix is represented in bold figures in Table 4. It also conforms to the standard in terms of porosity (65.6 > 60%).

Determination of thermal conductivity for the chosen mix

The chosen mix was then tested for thermal conductivity at 600 °C, the temperature mentioned in IS 2042. According to that standard, its value should not exceed 0.52 W m^{-1} K^{-1} for Class-B insulating refractories. Three specimens of dimensions 228 × 114 × 64 mm^3 were consequently tested and the average value of three runs obtained = 0.306 W m^{-1} K^{-1}.

Determination of permanent linear change on reheating

Three specimens of dimensions 228 × 114 × 64 mm^3 prepared from the chosen mix were heated to 850 °C (the temperature specified for Class-B insulating refractories) and maintained at that temperature for 5 h. After cooling, the length was measured and a mean value determined. The average percentage linear change was −0.82%, a value lower than the maximum allowed value for Class-B insulating refractories (−1.5%).

Discussion

Effect of different operating variables on the properties of the prepared bricks

Effect of kaolin percentage

The effect of kaolin percentage on the mechanical strength of the fired bricks was very favorable. Increasing its level produced bricks with increased cold crushing strength. This result is in accordance with the work of Ugehoke et al. (2006) who showed that the use of kaolin in higher proportions increased the strength of insulating firebricks prepared using rice husks as pore generator. A similar trend was also observed by Viruthagiri et al. (2013) on investigating the properties of insulating firebricks produced from saw dust and a mixture of clays.

Effect of grog percentage

Increasing the amount of grog yielded bricks with higher crushing strength, yet with lower porosity. This is since grog, which consists of pre-fired crushed refractory firebricks possesses an elevated mechanical strength. Yet, since it does not decompose with gas evolution and its particles retain their original size. This way, it will not contribute to any increase in porosity. On the contrary, decomposition of kaolinite and perlite may reduce their particle size, driving the smaller particles to fill the voids between grog larger particles, therefore conferring a lower porosity to the body. A similar result has been reported by El Nagar et al. (2009) and recently by Odewale et al. (2021).

Effect of pore generating materials

The effect of adding any combustible material, like saw dust and polystyrene is to increase the porosity and consequently decrease the bulk density and crushing strength. This effect has long been reported by several authors (Viuthagiri et al. 2013; Muñoz et al. 2016; Hassan et al. 2018).

An interesting result was obtained when the values of fractional porosity (p) were correlated with those of strength (σ). In this respect, the following expression was used (Hamad et al. 2018).

$$\sigma = \sigma_0 e^{-kp} \tag{4}$$

Here, k is a constant ($3 < k < 7$) and σ_0 is the strength at zero porosity.

This equation can be rewritten in the form:

$$\ln \sigma = \ln \sigma_0 - k.p$$

This way, a plot of $\ln \sigma$ against p should yield a straight line of slope $-k$ and intercept· Such a plot has been carried out using all the experimental results obtained (Fig. 11). The points fairly align and the values of the parameters k and σ_0 were obtained. Equation (4) takes the form:

$$\sigma = 11.97\mathrm{e}^{-3.522p}\left(R^2 = 0.949\right)$$

Suitability of date seeds to produce insulating firebricks

To compare the use of ground date seeds to the use of other pore-forming materials, several factors must be considered:

Cost of raw material

Date seeds are available all year long in Egypt whether as a waste from fresh or dried dates. One inconvenience is the need to have them ground to a size roughly ranging from 0.5 to 1 mm. However, all other types of waste used in similar studies like sugarcane bagasse (Hassan et al. 2018) or coal (Rahman et al. 2019) or rice husks (Hossein and Roy 2019; Zharmenov et al. 2022; Isinkaye et al. 2015) or other materials (Adazabra et al. 2018; Karim 2019; Ali et al. 2023; Obidiegwu et al. 2020; Lawanwadeekul et al. 2016) require initial treatment involving either grinding or shredding.

Operating costs

The main expenditure in the production of all types of refractory bricks consists of the cost of fuel required for firing at high temperatures. All successful previous attempts to prepare insulating firebricks required a firing temperature of no less than 1200 °C (Zharmenov et al. 2022; Isinkaye et al. 2015; Hassan et al. 2018). Exceptions were found in several works, by firing at lower temperatures. However, the values obtained for porosity were lower than those proper to insulating firebricks (Adazabra et al. 2018; Karim 2019; Ali et al. 2023; Obidiegwu et al. 2020, 2015; Lawanwadeekul et al. 2016).

Compatibility with standard values

The main properties that define the suitability of insulating firebricks for use are its bulk density (which is related to porosity), cold crushing strength and thermal conductivity. The main problem usually encountered in this respect is the need to obtain a low bulk density associated with a reasonable strength to minimize losses on handling, placing and in use, due to mechanical failure of the bricks. Most often than not, researchers succeed in obtaining accepted values for one of these properties at the expense of the other (Adazabra et al. 2018; Karim 2019; Ali et al. 2023; Lawanwadeekul et al. 2016; Obidiegwu et al. 2015; Folurunso et al. 2015; Micheal and Moussa 2022; Paliwal et al. 2018; Mgbemere et al. 2020). Only in some cases, this was possible by suitable choice of raw materials and mix compositions (Zharmenov et al. 2022; Isinkaye et al. 2015; Hassan et al. 2018). In the present case, it was possible to formulate a suitable recipe satisfying these conflicting requirements.

Conclusions

Ground date seeds were used as a pore former in the preparation of refractory insulating samples. The starting recipes consisted of kaolin, grog and ground seeds to different ratios. Water was added to the mixes, which were then shaped in steel molds. After removal from the molds, they were dried and subsequently fired to 1200 °C, maintaining the specimens in the kiln for 2 h at that temperature.

As the previously fired mixes did not abide by the standard IS 2042, small percentages of polystyrene and perlite were added to decrease the bulk density without seriously affecting the crushing strength.

As expected, increasing the percentage of seeds and/or polystyrene results in a decrease in both bulk density and crushing strength, while increasing the porosity of the fired samples. The chosen mix consisted of 6% date seeds powder, 72.5% kaolin, 17.5% grog, 2.5% perlite and 1.5% polystyrene. Its properties abided by the standard IS 2042 for Class-B insulating refractories, as evidenced from Table 6.

With the rise of reclaimed lands for agriculture in Egypt, it is expected that this will be accompanied with a corresponding increase in wastes. These can be used in the production of numerous lightweight building components, such as clay bricks and blocks, face bricks, lightweight cement bricks and concrete, and in the present context refractory insulating bricks. This paves the way

Table 6 Conformity of the properties of the chosen mix to IS 2042

Property	Chosen mix	IS 2042 limits
Bulk density (g cm^{-3})	0.894	< 0.9
Porosity (%)	65.60	> 60
Cold crushing strength (MPa)	1.483	> 1.47
Thermal conductivity W m^{-1} K^{-1}	0.306	< 0.52
Linear change on reheating (%)	− 0.82%	− 1.5% (max.)

for potential research fields aiming at optimizing the use of any of these cheap and available waste in the building and construction field.

Abbreviations

CCS Cold crushing strength
DTG Differential thermogravimetry
IFB Insulating firebricks
IS Indian Standards
PS Polystyrene
TG Thermogravimetry
XRD X-ray diffractometry
XRF X-ray fluorescence

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Author contributions

MA has revised and interpreted the results and written the manuscript. HME has supervised some experiments and ensured the reproducibility of results. OAI has supervised some experiments. NRE has prepared the fired bricks and carried out physical and mechanical testing. All authors have read and approved the final manuscript.

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