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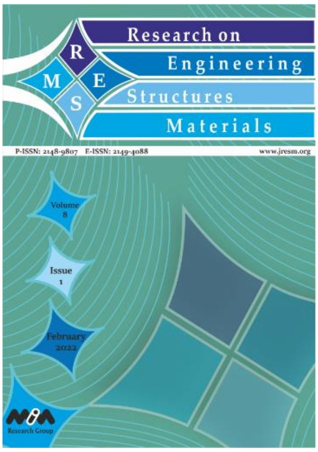

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Online Publication Date: 10 Sep 2021
URL: http://www.jresm.org/archive/resm2021.313st615tn.html
DOI: http://dx.doi.org/10.17515/resm2021.313st615tn

Journal Abbreviation: *Res. Eng. Struct. Mater.*

To cite this article
Mehta PK, Kumarswamy A, Saraswat VK, Shekhar H. Manufacturing brick using waste rocket propellant: thermal insulation improvement through eco-friendly disposal. *Res. Eng. Struct. Mater.*, 2022; 8(1): 91-99.

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Technical Note

Manufacturing brick using waste rocket propellant: thermal insulation improvement through eco-friendly disposal

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Article Info

Article history:
Received 15 Jun 2021
Revised 16 Aug 2021
Accepted 17 Aug 2021

Keywords:

Brick;
Composite Propellants;
Porous Materials;
Thermal Properties;
Building;
Temperature sweep

Abstract

Waste propellant impregnated fire clay brick is investigated for variation in thermal conductivity, thermal diffusivity and specific heat of sample, for different propellant percentage, temperature sweep and propellant percentage. Propellant quantities of 0.0%, 2.5%, 5.0% and 7.5% by weight is added to the green mix of brick and baking in horizontal and vertical direction is carried out for samples made to the size of diameter 12.6+0.1 mm and thickness 2-3 mm. Temperature sweep from 30oC to 100oC is carried out for characterization of brick for thermal diffusivity and specific heat, by using laser flash technique. Higher propellant impregnation by weight results in lowering of thermal diffusivity, enhanced specific heat and reduction in thermal conductivity. Vertical baking results in better thermal insulation properties than horizontal insulation for the same 7.5% propellant impregnated bricks. The thermal conductivity from an average value of 0.7 W/mK for reference brick is observed. 7.5% propellant impregnation by weight in brick may result in thermal conductivity of less than 0.5 W/mK during vertical baking. This substantial reduction definitely leads to an insulating solution to construction, with an eco-friendly disposal solution.

1. Introduction

Brick is an essential construction material for buildings and the thermal properties of brick can have far reaching consequences in terms of reduction in air-conditioning load, thermal insulation requirements and comfort conditions. The properties of Bricks can be altered by adding different additive, which is a better disposal action than dumping or open burning, in terms of environmental concerns. Many attempts are made to incorporate organic agro-waste and household throwaways [1-9], sludge [10-13] and others materials [14-16] as disposal means and also as reduction to the raw material for brick manufacture. into the With this in mind an attempt is made to understand the behaviour of non-homogenous porous brick samples for variation of their thermo-physical properties like thermal diffusivity and specific heat. In literature on Brick the specific heat is mentioned as around 850 J/kg.K and thermal conductivity is of the order of 0.7 W/mK [17]. Additionally, baking orientation and temperature sweeps are also introduced as viable parameters, affecting brick properties. The study illustrates utilization of waste propellant in brick manufacture to alter their thermo-physical properties, as a viable and feasible alternative from sustenance, disposal and environmental concerns.

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DOI: http://dx.doi.org/10.17515/resm2021.313st0615tn

2. Thermo-Physical Characterization of Bricks

The main ingredient of reference brick is clay, which is hydrated alumina-silicate refractory material, suitable for withstanding high temperature. Many attempts are made to alter the thermal properties of bricks and in one such attempt, 9 types of clay were investigated from thermal insulation point of view to finalize the ingredient of brick [18]. It is worth mention that thermal insulation desire lower thermal conductivity of building materials and attention is focused on these aspects Thermo-physical Characterization of bricks, in open literature is limited to reporting values, due to addition of various percentages of additional combustible ingredients [19,20].

The attempt in this paper for inclusion of waste rocket propellants is towards utilization of waste materials and at the same time, deriving long term benefits of enhanced thermal insulation of buildings for reduction in heat loads on air-conditioning systems and protection against hot and cold climatic conditions with smaller wall thicknesses. The waste rocket propellants are generally disposed by open burning and its utilization in brick-manufacture is an eco-friendly disposal alternative. The waste propellant is obtained from one of the propellant processing facilities in India and the indicative composition is 65-68% oxidizer, 16-18% Aluminium powder and rest hydrocarbon binder cured by isocyanate curative using urethane formation reaction. As waste propellant is not central theme of the paper, the information is restricted. Additionally, the small percentage of aluminium powder (16-18 %) in composite propellant results in formation of alumina in finished brick. The formation of additional pores by addition of composite propellant and formation of alumina, both enhances insulation properties. The effect of pores orientation can pave way for better thermal insulation characteristics without any change in resources, materials, cost, process or time. It is only stacking of raw molded brick in the kiln, which is affected and enhanced properties can be incorporated in the brick. This requires higher value of thermal diffusivity and specific heat, both. However, the effects which are responsible for reduction in thermal diffusivity can in fact enhance specific heat. Under such circumstances of contradictory, complementary and competing nature of parameters, it is worth exploration to find an optimum percentage of propellant in brick for better results.

To explore this, at first 2.5% by weight waste rocket propellant is added in the Brick and various properties like water absorption, compressive strength, SEM and XRD are explored. As marginal changes are observed in these properties, thermal insulation properties are also explored for bricks impregnated with 2.5% propellant. In fact the processing of impregnated bricks with various particle sizes of rocket propellant waste is conducted. Larger size of propellants was resulting in breakage of Bricks. So size of propellant for addition to the green mix of brick is optimized to 300 micron for better and favorable results. Attempt is made to assess the efficacy of mixing and addition. After finding them favorable, propellant percentage is increased to 5.0% and 7.5% by weight in the brick formulation and thermal insulation properties are assessed for impregnated brick. For adding one more parameter, the baking of brick is conducted in two orientations and thermal conductivity is also assessed with temperature sweep spanning from 30oC to 100oC. This paper explores, effect of percentage addition of propellant, baking orientation, and temperature on thermal conductivity of rocket propellant impregnated bricks.

3. Materials and Method

Green mix of the Brick is prepared using waste powdered rocket propellants, in weight percentages of 2.5%, 5.0% and 7.5%. The samples are position in the oven for baking according to a pre-set temperature cycle with peak temperature exceeding 100oC in two orientations – flat surface and on edges. Um-impregnated sample is also kept for kilning as reference sample. Normal cuboidal brick samples are prepared for water absorption, compressive strength testing (Figure 1). After baking, they are subjected to water absorption test by immersion in water for 24 hour after heating in oven at 110oC. Weight gain in water immersion is calculated in percentage to give percentage weight gain, indication water absorption capacity of brick. The compressive test is carried out on universal testing machine. Consistent, uniform mix is molded in the button sample, having dimension of 12.6+0.1 mm diameter and 2-3 mm thickness (Figure 1). After baking the obtained samples are subjected to thermo-physical characterization using laser flash method as per ASTM E 1461. Each test is conducted with minimum 5 samples and reported values are average of the 5 test results.

Fig. 1 Rocket Propellant Impregnated Brick Samples

The soil used in the manufacturing of bricks was taken from brick kilns, Nasik, India. The characterization of clay is given in this reference under soils developed on interfluves under sub-humid zone in Nasik [21]. The mix proportion of various materials in the bricks is soil ~ 60 %, flyash ~26%, HEP waste ~4 % and water ~10 %. The mix proportion of various materials in the bricks is soil ~ 60 %, flyash ~26%, waste propellant ~1.5 % and water ~10 %. Waste composite propellant, containing 65-80% Ammonium Perchlorate oxidizer (200-300 micron), 16-18% Aluminium powder (15-20 micron) and 14-20% Hydroxyl terminated polybutadiene (HTPB) as binder, is taken in powder form of 300 micron major dimension, for incorporation in the green mix of brick. The waste composite propellant has a density of 1750 kg/m3 and calorific value of 1200 cal/g. The propellant is added to the tune of 2.5%, 5.0% and 7.5% by weight in the raw material for brick, before baking the same.

Sigma blade mixer with single blade is used for homogeneous mixing of the propellant, soil and fly ash. The duration of mixing is 80 min and speed is 60 rpm. The mixing process was carried out initially with soil, flyash and water for 20 min and subsequently after weathering, waste propellant is added and mixing was carried out for 60 min. The soil dough with fly ash was blended with propellant dust (1.5 wt %) and distilled water (20 to 25 %) to obtain desired level of plasticity. Homogeneity of mix is ensured with the milling cycle to avoid localization of propellant dust powder. The achieved level of water plasticity obtained in this soil dough is in the range of 22 to 24 and the same is obtained through Atterberg plastic limit. The brick samples were oven dried for 48 h at 100˚C to remove excess moisture and avoid cracks during firing. The propellant composition decomposes at around 350 to 400 ˚C. The dried samples were then heated slowly in electric furnace at 1100-1150 ˚C and dwelled for 6 hours and cooled down to ambient temperature.

Thermal Characterization is based on laser pulse method. This technique is one of the most popular methods for the determination of thermal properties of materials because of ease to use at high temperatures, non-contact sensing, very fast measurement, absolute thermal diffusivity measurement etc. In this method, a pulsating flash/ laser energy is made incident onto one side of button shaped (12.5-12.7 mm diameter and 2-3 mm thickness) sample which is placed into the sample holder. Sample holder is kept inside the furnace. An IR detector / thermocouple detector is used at other side of the sample. An schematic of measurement set-up is shown as figure 2.

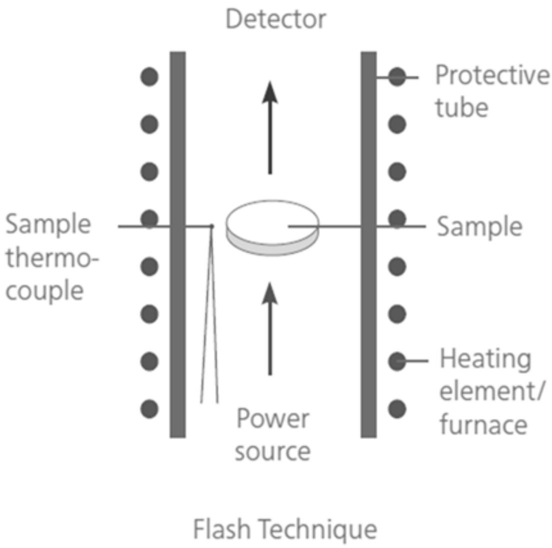


Fig. 2 Schematic of Laser Flash Method for Thermal Properties Assessment

This detector record the thermal disturbances/ temperature rise generated on other side of the sample, due to incident laser on first side. This signal is recorded with time. The signal received from the detector is further amplified, conditioned, denoised and further passed to data acquisition unit. For a given sample thickness (L in mm), the value of Thermal diffusivity is given by α=(1.38 L^2)/(π^2 t_(1/2)), where t1/2 is the time required for the back surface to reach half of the maximum temperature rise. After that heat loss, contact resistance, finite pulse width of laser flash and other corrections are applied. The calibration and validation of test equipment and method is carried out using standard Graphite coated VESPEL material which is Dow Corning make polyimide with good thermal stability. Specific heat is measured by comparison with standard. The equipment used in the study is Antemark Flashline 3000, which has provision to hold sample on a trolley. The trolley moves inside a furnace and required thermal flash is applied on one side of standard and test sample, simultaneously and measurements are made (Figure 3).

The main reason for concentrating on thermo-physical characterization is to observe the effect of incorporating composite propellant in bricks. During preliminary studies, it was observed that incorporation of composite propellant enhances porosity but water absorption, density and compressive strength is not affected significantly. So, in this study an effort is made to exhaustively study the thermo-physical properties for different percentages of composite propellant incorporation. Such thermo-physical characterization studies are used for polymeric, metallic and refractory materials, but are rarely reported for bricks. The reliability of measurement is stated to be around 0.01% and testing at least 5 samples of each type with consistent result is implemented. The values reported are average of these repeated test results.

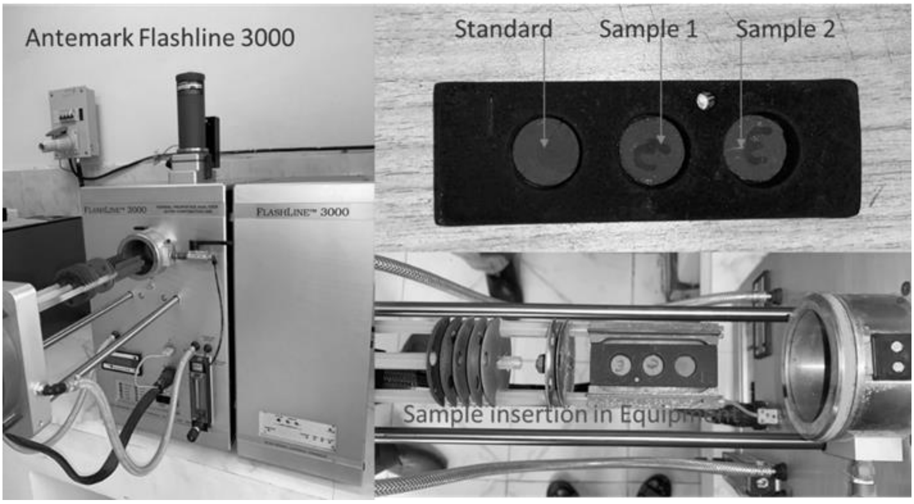
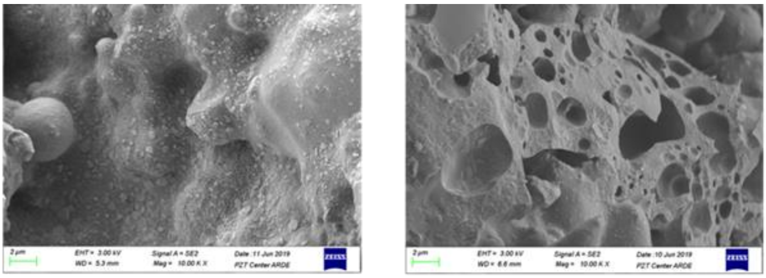


Fig. 3 Thermal Characterization Equipment and Samples

4. Results and Discussion

Initially, a feasibility study was undertaken to understand the effect of adding waste propellant in the manufacture of brick. Waste rocket propellant in range of 0.5% upto 4.0% by weight is added in brick formulation and initial studies were conducted. The variation of compressive strength, water absorption, XRD studies and SEM results were presented elsewhere [22]. Once results were found satisfactory, the study is extended to have thermo-physical characterization and understand the changes in thermal conductivity due to waste propellant addition and baking in different orientation. It is observed that propellant gets consumed during baking of bricks and combustion gases form micro-risers in the bricks. These micro-risers are elongated micro-pores, which are formed by moving upward combustion gases in the bricks. They are blind holes, but can impart directional effects to the thermal conductivity of bricks.

Addition of 2.5% waste rocket propellant in Brick formulation was analyzed first and properties are assessed with reference to the reference sample or non-impregnated brick. Scanning Electron Microscope (SEM) micrograph is used for understanding the variation in internal micro-structure due to impregnation of waste rocket propellant. Addition of waste propellant resulted in formation of micro-pores, as depicted in the Figure 4. Propellant definitely acts as pores-forming agent and the micro-structure in regions other than pores are dense. So, addition of waste rocket propellants has two effects – one is pores formation and local hardening of zones around pores.



a. Reference Sample without propellant Impregnation

b. 2.5% by weight Propellant Impregnated Sample

Fig. 4 SEM Micrograph of Bricks

Percentage gain after immersion in water is carried out for 5 samples of each type and the average values are obtained. Reference sample gave a weight gain of 29±3 %, while the impregnated sample gave around 20±2 % weight gain. This clearly indicated that although samples might have become porous due to propellant addition, but the pores are not assessable to water. This may be attributed to local hardening around pores, which makes water ingress difficult and makes the pores impervious to water. In fact less water absorption is an advantage for the bricks. Compressive strength of the reference brick is found to be 4.25±0.5MPa, while that for impregnated brick is 4.0±0.5 MPa. Compressive strength is not adversely affected by propellant addition. The thermal conductivity increased from 0.72 W/mK at ambient condition to around 0.88 W/mK for the 2.5% by weight impregnated brick sample. Although much gain in thermal insulation properties were not ascertained but reduction in water absorption and marginally change in compressive strength, encouraged to impregnate higher weight percentage of waste propellant in brick and characterize for thermal properties. Additionally, effect of orienting brick sample horizontally (on flat surface) and vertically (on edges) is attempted to find any effect on the thermal properties. Temperature sweep from 30°C and 100°C is also carried out to get thermo-physical properties of Bricks in entire operational range.

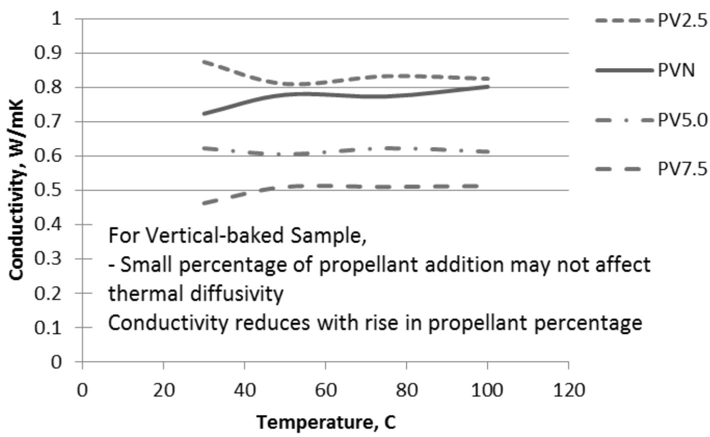


Fig. 5 Thermal Conductivity of Vertically Baked Impregnated Brick

For the vertically baked brick, temperature sweep data for different weight percentages of waste rocket propellant, in respect of thermal conductivity is presented in Figure 5. In the figure, the curves has followed a definite nomenclature. 'P' indicated propellant impregnation, 'V' indicates vertical curing, 'N' indicates reference non-impregnated sample and numerical values are indicating weight percentage of waste propellant. For examples PV2.5 indicates propellant impregnation, vertically cured, 2.5% waster rocket propellant impregnation. It is clear from the curve that over the specified temperature range, the value of thermal conductivity is more or less constant. At room temperature, reference have a thermal conductivity of 0.72 W/mK and the values for 2.5%, 5.0% and 7.5% propellant addition by weight changed the thermal conductivity at room temperature to around 0.89 W/mK, 0.61 W/mK and 0.48 W/mK, respectively. For 7.5%, waste propellant addition, the thermal conductivity at room temperature displayed reduction by 33.3% in numerical value. So, propellant addition improved thermal insulation properties of the brick. the same trend is present for all other temperature ranges also.

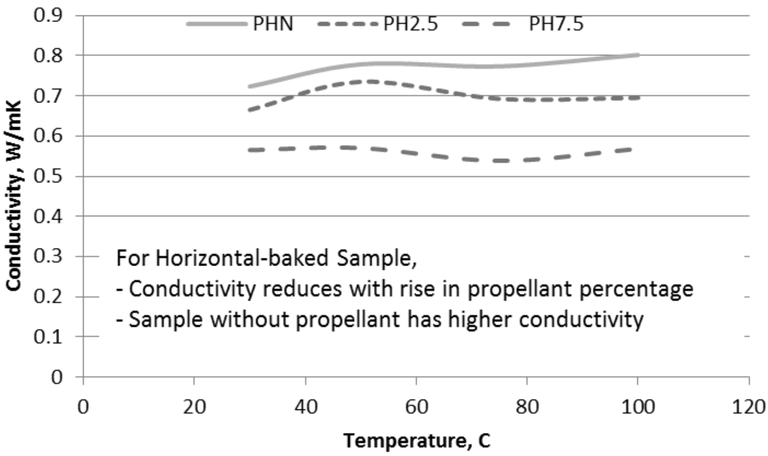


Fig. 6 Temperature Sweep For Thermal Conductivity of Horizontally Baked Impregnated Brick

The exercise is repeated for the horizontally baked sample too and the results are plotted as figure 6. In the figure the curve nomenclature has 'H' indicating horizontal baking condition of the samples. It is observed that for horizontal baking the reduction in thermal conductivity is visible even ay 2.5% waste propellant impregnation. At ambient condition, 0.0% (reference), 2.5% and 7.5% propellant impregnation gave thermal conductivity of 0.72 W/mK, 0.68 W/mK and 0.58 W/mK, respectively. The reduction at 7.5% waste propellant impregnation is around 19%. Although the reduction, in case of 7.5% propellant impregnation for thermal conductivity at room temperature is lower for horizontal baked sample than vertically baked sample, but the reduction even at 2.5% propellant impregnation is the advantage of horizontal baking.

Overall, if practical applications are also considered, it is clear that for vertically baked propellant impregnated brick sample, lower additives quantity lead to enhancement in thermal conductivity, thus defeating the main attempt of enhancing thermal insulation properties. Although such bricks with higher thermal conductivity may be suitable as lining for furnace and boilers. Higher propellant quantity in vertical baking of brick may result in reduction in thermal conductivity, but the structural integrity of bricks is compromised due to large amount of porosity and reduced compressive strength. Contrary to this, horizontal baking results in reduction of thermal conductivity even for the small quantity of composite propellant as additives. So, for thermal insulation application, such bricks are practically useful.

5. Conclusion

Waste rocket propellant is added to brick to understand any change in water absorption, compressive strength or microstructure. Addition of waste rocket propellant in brick makes it porous but water absorption is reduced, due to local hardening around pores by heat generation from propellant during baking of bricks. Orientation, temperature and percentage propellant impregnation, all three affects the thermo-physical characterization of brick sample. The orientation of brick during baking orients pores created by rising combustion gases from combustion of propellants. Thermal conductivity for reference non-impregnated sample of brick is around 0.72 W/mK at ambient condition. For horizontal baking the value reduces to 0.48 W/mK for 7.5% propellant impregnated brick. However, for vertical baking, the value for 7.5% propellant impregnation is 0.58 W/mK. So, higher propellant impregnation and vertical orientation of baking is capable to give bricks with lower thermal conductivity, imparting higher thermal insulation properties. Horizontal baking with 2.5% waste propellant has thermal conductivity value of 0.67 W/m.K and this method of baking is suitable for smaller percentage of waste propellant addition, for enhanced thermal insulation capacity of bricks.

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