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Degraded municipal solid waste as partial substitute for manufacturing fired bricks

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HIGHLIGHTS

- Fired bricks containing degraded municipal solid waste (degraded MSW) were produced.
- Mechanical and durability properties of bricks incorporating degraded MSW were studied.
- Saving in energy consumption for firing of degraded MSW incorporated bricks.
- Substitution of degraded MSW in brick manufacturing can lead towards sustainable and economical construction.

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ABSTRACT

As a potential pathway to sustainable construction, this novel study demonstrates the feasibility of incorporating degraded municipal solid waste (MSW) as one of the constituents for production of fired bricks. The raw materials, degraded MSW and two different soils, i.e. laterite soil and alluvial soil, were mixed together in different proportions ranging from 5 to 20%. Specimens of these mixtures were then fired at 850 and 900 °C respectively. Various properties such as bulk density, linear shrinkage, loss on ignition, water absorption, compressive strength, and modulus of elasticity on light of the respective Indian and ASTM standard codes were studied and compared. An optimum constituent mix of 20% degraded MSW with (laterite or alluvial) soil fired at temperature of 900 °C was found to be most appropriate for brick production. The ultimate uptake of this study is 8% net saving in the energy consumption of external fuel by mixing 20% degraded MSW.

1. Introduction

Fired brick is one of the oldest building construction materials being used for millenniums in the world. Brickmaking is preferred for construction activity due to ease of manufacturing from the readily available raw material i.e. soil and due to mechanical properties such as specific strength, fire resistance, chemical and corrosion resistance, durability and long term life performance [1–3]. Moreover, bricks also possess moderate insulation properties providing some level of control on the heat transfer in adverse weather conditions [4]. One of the key ingredients required by brick making is cultivable soil, especially which is useful for agriculture [5]. Over the last few years, it has been realised by China and India that the continuous manufacturing of bricks has put enormous strain on virgin natural resources [6–8] thereby threatening the future of agriculture. This couples further by the fact that heavy foundations consumes lot of brick masonry thereby increasing the volume of soil consumption even further. Therefore, brick making business is open to innovation to develop sustainable, light weight and low cost bricks with potential possible improvements in thermal and mechanical performance.

One of the ways of weight reduction of bulky bricks and at the same time to harness improved performance is to introduce voids by incorporating organic particles into the clay mixture [9,10]. During the last few decades, a lot of research has been done to incorporate various type of waste materials into the production of bricks including sludge [11–14], pulp and paper mill residue [15], processed waste tea [16], olive industry waste [17–20], biomass ash [21,22], boron waste [23,24], spent coffee grounds [25,26], and cigarette butt [27]. Researchers have tried to also use waste materials such as blast furnace slag [28], iron tailings [29,30], sludge waste [31] in making of autoclaved bricks and calcium silicate bricks and it only proves how fertile this area of research is. Recycling of wastes by incorporating them into brick making is one of the best approaches to develop sustainable and

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green manufacturing thereby potentially providing a way forward towards circular economy. In addition, the bricks incorporated with various types of organic wastes have shown promising potential improvements in the physical and functional properties of bricks such as lightweightness, improved porosity, water absorption, thermal conductivity, and reduction of energy used during firing.

Generation of municipal solid waste (MSW) is linked to population, family size, lifestyle, urbanization, geographic features, local climate and policies [32–34]. The worldwide MSW production is expected to increase to approximately 2.2 billion tonnes per year by 2025 [35,36]. While countries in Europe and North America have matured systems for comprehensively handling the MSW with segregation of recyclable and non-recyclable wastes; developing countries especially in Asia such as India and China are still lacking ways to efficiently handle the MSW [35,37,38]. Present practices are not healthy and open landfill dumping release significant amounts of methane gas (a greenhouse gas) into the atmosphere, pollute land and water resources nearby and encourage the proliferation of rats and disease-carrying organisms. Due to increasing urbanisation, land availability for dumpsites and pest/rodent control has become increasingly challenging. Existing landfill sites have exhausted their capacities. In this scenario, it becomes imperative to make use of degraded MSW (about ~2 months old) to accommodate fresh dumping. With time, the organic matter in the degraded MSW undergoes a process of biodegradation, making it free from foul smell. Therefore, the 2 months old degraded MSW becomes a suited replacement to the soil for brick making purposes.

These thoughts motivated the development of this work and this study propose to make use of the degraded MSW as one of the constituent for making of fired bricks. The strategy here is two pronged (a) use of waste material to minimise the disposal problem (b) saving the precious fertile soil which is essentially useful for the agricultural purposes. Degraded MSW is selected due to its easy and abundant availability and due to its properties being similar to soil. This work seeks to determine the resulting effect on the performance of fired clay bricks due to nature and the amount (% wt) of degraded MSW.

2. Experimental procedure

The raw materials used in this work were laterite soil and alluvial soil which are by and large the major constituents for brick making in a typical kiln in India, and degraded MSW (about ~2 months old), containing 19 wt% of water, collected from Boragaon landfill site, Guwahati, Assam, India. The samples of collected soil and degraded MSW were dried and grinded to particle size finer than 1 mm before proceeding to brick making. The samples of pristine laterite and alluvial soil were chemically and mineralogically characterized by X-ray fluorescence (XRF) and X-ray diffraction (XRD), the details of which are available elsewhere [15]. Both alluvial soil and laterite soil are kaolinitic, non-calcareous and low refractory. Thermal differential (DSC) and thermogravimetric (TG/DTG) analyses of degraded MSW was performed in a model Netzsch STA 449 Instrument from 30 to 1000 °C, with heating rate of 10 °C/min in static nitrogen atmosphere. Higher heating value (HHV) was determined using plain jacket oxygen Bomb Calorimeter (Parr 1341, 6775 digital thermometer).

An experiment was designed for varying the mixture of degraded MSW in different mix ratios (5%, 10%, 15% and 20%) in both type of soils, as shown in Table 1.The brick samples were designated as M for the bricks made with laterite soil and X for bricks made with alluvial soil. Benchmarking of results was achieved by manufacturing the control bricks without degraded MSW (label M and label X shown in Table 1). 20–25% water was added and mixed to obtain plastic condition of binary mix. Prismatic bricks with dimensions of 61 mm × 29 mm × 19 mm were formed using hand moulding. The brick specimens were air-dried at room temperature for 24 h and then oven dried at 105 ± 5 °C for another 24 h to remove the water content. Firing was done in electrically operated muffle furnace at two temperatures (850 and 900 °C). Brick manufacturing process has been presented in Fig. 1. Six samples for each series were prepared and tested for representative results. Changes in linear shrinkage values were measured using a digital vernier calliper (Mitutoyo) after drying and firing steps as per [39] with a precision of 0.01 mm. Water absorption (5 h boiling test), apparent porosity, and bulk density were determined in accordance with [40]. Compressive strength of bricks were determined with universal testing machine (UTM, BISS, Median-250) [41,42]. Modulus of elasticity was determined in accordance with ASTM code [43]. Fourier transform infrared (FTIR) spectroscopy (PerkinElmer) was conducted on dried powdered samples by making KBr pellets. The standard toxicity characteristic leaching procedure (TCLP) method was applied according to EPA Method 1311 in order to investigate the presence of harmful elements to the environment, such as As, Cd, Cr, Pb, Zn, Mn, Ni, and Co with limits determined by the EPA [44,45]. Solid sample weighing 5 g (size less than 4.75 mm) mixed with 100 mL of acetic acid (pH 4.93 ± 0.05) was taken in reagent bottle (125 mL) and kept at room temperature for 18 h in a shaker at 30 ± 2 rpm. The suspensions were centrifuged at 10,000 rpm for 5 min and filtered through Whatman® No. 42 filter paper. Filtrate was stored in reagent bottle at 4 °C for analysis of selected heavy metals. The concentration of metals was measured using atomic absorption spectrometer (AAS, Thermo scientific, iCE 3000).

Table 1
Composition of prepared brick samples.

Brick labels	Ingredients by wt%		
	Laterite soil	Degraded MSW	Alluvial soil
M	100	0	0
M 5	95	5	0
M 10	90	10	0
M 15	85	15	0
M 20	80	20	0
X	0	0	100
X 5	0	5	95
X 10	0	10	90
X 15	0	15	85
X 20	0	20	80

3. Results and discussion

3.1. MSW characterization

Typical composition of MSW in Guwahati city was determined in an earlier study [46] following the ASTM [47]. The data is reproduced below in Table 2. Since MSW is very heterogeneous material and has lot of spatial and temporal variations, the data given in Table 2 may roughly be considered representative. Proximate analysis of degraded MSW is reported in Table 3. The higher heating value of the degraded MSW sample was obtained as 1054 kJ/kg. The thermogravimetric (TGA) and differential scanning calorimetric (DSC) curves of degraded MSW up to 1000 °C are shown in Fig. 2.

Regardless of the sample of degraded MSW collected from Guwahati based landfill sites, the general trend of mass loss studied by the thermal analysis revealed four distinct mass loss regions. Mass loss in phase I is due to its high water content up to 200 °C.