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Review

Towards sustainable bricks production: An overview

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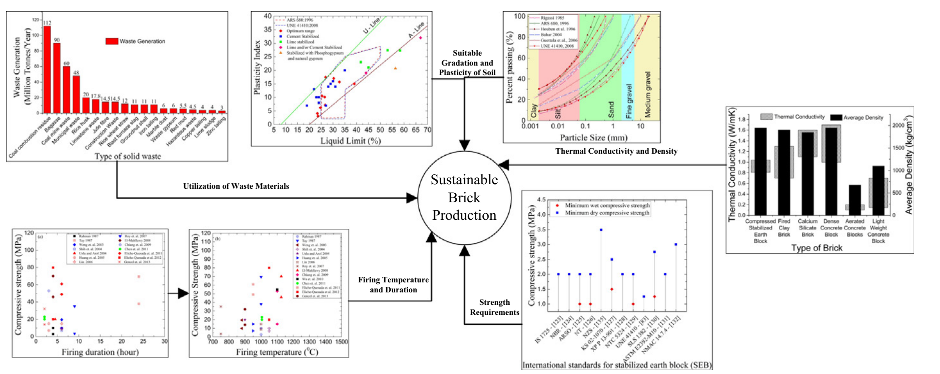
HIGHLIGHTS

- Different methods of unfired brick production have been presented.
- Effect of different parameters on strength properties has been investigated.
- Use of industrial, municipal and agricultural wastes for brick production is studied.
- Durability and Strength requirements of various international standards are reviewed.

GRAPHICAL ABSTRACT



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ABSTRACT

The history of bricks making dates back to 7000 BCE, when the bricks used to be in the form of sun-dried mud blocks. Since then, a lot of modifications have been done in the composition of bricks and in brick making procedures. As a result, in today's world, brick is considered as one of the most sought after materials used in the construction of various civil engineering structures. Now-a-days, bricks are mostly made of clay and sand mixed in suitable proportion, to which binder is added. Many-a-time, the bricks are also made up earth blocks stabilized with different materials. The stabilized block is then pressed to a suitable shape and size that can be either fired or sun-dried. However, much variation is observed in the properties of bricks and especially in its compressive strength, depending upon the composition of bricks and the manufacturing procedures (viz., moulding, pressing, firing, autoclaving, cementing, geo-polymerization etc.). Moreover, the bricks are specified and classified differently in various international standard codes, depending upon the importance of structures and the severity of environmental conditions. Hence, a thorough review of the composition and properties of bricks and the various factors related to its manufacturing process is highly required for better standardization of bricks. The same has been done in the present study. A better understanding of different wastes as the brick composing material is supposed to act as a catalyst in the utilization of various mining, industrial as well as solid municipal wastes in brick industry, which will help in achieving the goal of sustainable development.

Abbreviations: AC, Alumina Cement; ARSO, African Organization for Standardization; CCR, coal combustion residues; CSSB, Cement Stabilized Soil Brick; ESS, Egyptian Standard Specification; GBFS, granulated blast furnace slag; GHG, green house gas; GSCC, Grounded Silicate Cement Clinker; HAC, High Alumina Cement; HD, High Draught; IS, Indian Standard; KS, Kenyan Bureau of Standard; LL, Liquid Limit; LOI, loss on ignition; LPW, Limestone Powder Waste; MJ, Mega Joule; NBR, National Brazilian Regulations; ND, Natural Draught; NMAC, New Mexico Administrative Code; NZS, New Zealand Standard; OMC, optimum moisture content; OPC, ordinary Portland cement; PI, plasticity index; RH, Relative Humidity; SBA, Sugarcane Bagasse Ash; SC, Slag Cement; SCEB, Stabilized Compressed Earth Block; SEB, Stabilized Earth Block; SLS, Sri Lanka Standards; UFB, unfired brick; WSW, Wood Sawdust Waste.

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Contents

1. Introduction

Population explosion and migration of people to urban area has created a huge gap between demand and supply of affordable shelter. This difference between the demand and supply is further widened by the high priced construction materials (viz., brick, steel, cement etc.). Construction materials cost about 60% of the total cost of a building [1]. On the other hand, production process of these materials is highly energy intensive, non-eco-friendly and acts as a source of waste generator. Unsustainable development in construction industry is considered as a major threat to the environment in many countries. For example, it is reported that the Indian construction industry alone is responsible for 22% of the total greenhouse gases (GHG) emitted into the atmosphere [2,3]. Similarly, cement production emits about 2070 million tonnes of carbon dioxide (CO_2) globally, out of which 148 million tonnes is contributed by India alone [4].

Manufacturing of bricks being an essential part of construction industry, contributes heavily to environmental degradation. A brick kiln emits about 70–282 g of carbon dioxide, 0.001–0.29 g of black carbon, 0.29–5.78 g of carbon monoxide (CO) and 0.15–1.56 g of particulate matter per kilogram of brick fired, depending on the type of kiln and fuel used for the firing [5,6]. Further, it consumes about 0.54–3.14 MJ of specific energy per kilogram of brick produced, depending on the type of brick kiln and fuel. This data seems to be very important with the fact that, China produces about 700–800 billion bricks per year and India, Pakistan, Bangladesh and Vietnam together produce more than 260 billion bricks per year, catering about 75% of the global demand for fired bricks [7]. Based on the information gathered from literature, a map was developed, showing different types of brick kilns in India as shown in Fig. 1. It can be observed from the map that the majority of brick kilns are of clamp and fixed chimney types, which consume higher specific energy (1.2–4.5 MJ/kg of fired product) as compared to other brick kilns like zig-zag HD and ND kilns, vertical shaft brick kilns and hybrid Hoffman kilns that consume less specific energy (0.7–1.1 MJ/kg of fired products). As per the survey, further, it is found that the process of firing bricks results in generation of ash and an average of 20% of sub-standard bricks, which pose a problem for disposal.

One of the reasons behind consumption of large amount of energy is that the conventional brick manufacturing process requires firing of wet mix of clay and sand in the kilns. This makes it energy intensive and non-eco-friendly. Therefore, bricks manufactures and researchers around the globe are facing with multi-faceted challenge of producing an alternate brick-like material which would be affordable, eco-friendly, durable and sustainable in nature. This growing demand for the environmental-friendly and sustainable material has forced the investigators to probe into alternate methods and materials for the production of bricks. Earth being abundantly available in nature has been an obvious choice of investigators for the production of unfired bricks by adopting a suitable stabilization technique [8–36]. However, it may lead to depletion of natural resources like soil. In order to conserve natural resources, utilization of industrial wastes seems to be a viable option. Extraction and processing of industrial products generates about 12 billion tonnes of solid waste globally [37]. In view of this fact, many investigators have probed into the possibility of producing unfired bricks using municipal waste as well as waste from industries, agriculture and mining as raw material [38–63]. Moreover, efforts have been made to convert the wastes into useful materials and thereby solving the problem of waste disposal as well. At the same time, efforts have been made to improve the flexural strength of unfired masonry blocks with incorporation of natural as well as artificial fibres [64–70]. Thermal properties of these bricks have also been investigated by researchers [67,71–79].

As per the literature survey, much variation was found in the properties of fired and unfired bricks, depending upon its composition and the manufacturing procedures. Moreover, the bricks are specified and classified differently in various international standard codes, depending upon the importance of structures and the severity of environmental conditions. Hence, a thorough review of the composition and properties of bricks and various factors related to its manufacturing process is highly required for better standardization of bricks. The same has been done in the present study. This paper presents a detailed review of the various approaches made and the materials adopted by different investigators for the production of bricks. It also includes an insight into the different parameters affecting physico-mechanical and thermal properties of bricks.

2. Production of earth blocks by stabilization

Using earth as a construction material has an inherent advantage of being eco-friendly, having low thermal conductivity and is abundantly available in nature. However, at the same time, it suffers from the disadvantage of being vulnerable to water. It tends to lose its strength and dimensional stability, when coming in contact with water for a long time. In some cases, it may lead to complete disintegration of earth blocks as well. However, strength and stability properties of earth blocks mainly depend upon its composition and the stabilization process. In this section, various aspects of Stabilized Compressed Earth Block (SCEB) have been discussed.

The type of earth (i.e. soil gradation and its plasticity) is one of the important factors that decide the properties of stabilized compressed earth block. Fig. 2 presents the upper and lower limits of the particle size distribution curves of some soils used by previous researchers and also as proposed in some codes for the production of stabilized compressed earth block [20,25,80–83]. It was observed that the sand, silt and clay contents of different soils are generally in the range of 36–82%, 12–34% and 6–30%, respec-