Journal of Cleaner Production 190 (2018) 261–271

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

A practical proposal for utilisation of water hyacinth: Recycling in fired bricks

Gaurav Goel*, Ajay S. Kalamdhad

Department of Civil Engineering, Indian Institute of Technology Guwahati (IITG), 781039, India

ARTICLE INFO

Article history:
Received 25 June 2017
Received in revised form
10 April 2018
Accepted 19 April 2018
Available online 20 April 2018

Keywords:
Water hyacinth
Fired brick
Sustainable development
Additives
Compressive strength

ABSTRACT

Strenuous efforts are being made to make the manufacturing activities sustainable. Consequently, industries are seeking ways not only to reduce energy consumption, waste accumulation and carbon footprint but also to reduce exploitation of precious natural resources. Fertile soil is one such precious resource which is being used for brick manufacturing for centuries. Brick industry needs frugal innovations to accommodate large quantities of waste and to make the production processes sustainable. Numerous studies in the past have tried to recycle waste materials by incorporating them into the brick production cycle. This experimental feasibility study is first to demonstrate the use of aquatic weed (water hyacinth) in brick manufacturing. Using chemical-mineralogical and physical-mechanical characterization, optimal mixing ratio of water hyacinth (WH) and soil was determined for achieving the desirable mechanical properties (compressive strength and water absorption) of a fired clay brick compliant with Indian and ASTM standard codes. XRD results confirmed that addition of WH does not cause compositional changes in the phase and leads merely to an increased porosity in bricks. An optimum mix of 10% WH with soil and a firing temperature of 900 °C were found appropriate for brick production using WH as a partial substitute to the soil. Greenhouse gas (CO_2) emission during firing was ascertained and it was estimated that incorporation of 10% WH leads to 7% net saving in the consumption of external fuel required for firing the bricks.

1. Introduction

Construction industry is an important indicator in defining the economic growth of a nation, especially that of the developing countries. Due to ongoing infrastructure expansion, India produces about 250 billion bricks per annum (Bhushan et al., 2016; Kamyotra, 2016) making it the second major country after China in the world to do so. In view of production method, bricks are categorized into three categories (i) Fired bricks (ii) Cemented bricks and (iii) Geopolymerization brick (Zhang, 2013). Out of these, fired and cemented bricks are available commercially due to being economic. Fired bricks are among the oldest construction material plausibly due to the easy accessibility of the soil. Fired bricks possess reasonable physical, mechanical and thermal properties, particularly compressive strength, that made masonry popular since the ancient times (Dondi et al., 1997; Kadir and Sarani, 2012; Sutas et al., 2012). Around 90% of the bricks in India are produced using hand moulding (Bhushan et al., 2016). However, this process is leading to a crisis problem because much of the soil for brick moulding is obtained by excavating agricultural fields up to a depth of 2 m resulting into land degradation and loss of cultivation. Accordingly, the motivation of this work was to evaluate ways on how can brick masonry be made more sustainable.

Brick work in modern structures is mainly done to make partition walls and hence the load bearing capacity requirements of these bricks is not as stringent as what it used to be in the ancient times when no other material like concrete was available (Goel and Kalamdhad, 2017a; b). In view of this, authors propose that the fired bricks need redesigning to achieve further reduction in weight without significant compromise in performance. One of the viable ways to achieve this at a commercial scale will be to introduce perforations to cause micro-porous sites initiated by pore-making additives. When pore-making additives are used in making fired bricks, the organic parts burn out thus leaving micro pores behind (Goel and Kalamdhad, 2017a; b). There is also an inherent advantage of using these additives i.e. the self-calorific value of these additives reduces the amount of energy associated with firing of

* Corresponding author.
E-mail addresses: gaurav.goel@iitg.ernet.in, goel2001@gmail.com (G. Goel).

https://doi.org/10.1016/j.jclepro.2018.04.179
0959-6526/© 2018 Elsevier Ltd. All rights reserved.

List of abbreviations:

AAS	Atomic absorption spectrometer
CO	Carbon monoxide
CO_2	Carbon dioxide
DSC	Differential scanning calorimetric
EDX	Energy dispersive X-ray analyser
ETE	Estimated total emissions
FESEM	Field emission scanning electron microscope
FTIR	Fourier transform infrared spectroscopy
HHV	Higher heating value
IPCC	Intergovernmental Panel on Climate Change
LOI	Loss on ignition
TGA	Thermogravimetric analysis
WH	Water hyacinth
XRD	X-ray diffraction
XRF	X-ray fluorescence

brick which reduces the expenses of external fuel (Barbieri et al., 2013; Kamyotra, 2016; Mohajerani et al., 2016). Finally, porous bricks acts as good heat insulator – a tremendous property required to reduce the air-conditioning load during peak summers (Morales et al., 2015; Kurovics et al., 2016) in Indian subcontinent. On the other hand, considerable amount of waste material continuously being generated from different industrial and agricultural sources can be recycled. Utilisation of industrial and agricultural waste has been globally recognised as a pathway to solve environmental issues (Madurwar et al., 2013). Due to significant efforts being made to protect the environment, usage of soil for brick making has been restrained, especially in countries like China (Zhang, 2013). Consequently, the use of waste has become evident as a practical technology in brick production. Recent reviews on fired bricks have highlighted that assortment of organic and inorganic solid waste materials can be used by incorporating these into brick making (Dondi et al., 1997; Kadir and Mohajerani, 2011; Raut et al., 2011; Madurwar et al., 2013; Zhang, 2013; Bories et al., 2014; Monteiro and Vieira, 2014; Muñoz Velasco et al., 2014; Cusido et al., 2015). These studies have reported the usage of industrial waste materials such as marble processing waste, glass waste, fly-ash, mining tailings, metallurgical slags, paper mill sludge, and agricultural wastes such as rice husk, sunflower seeds, olive stone, grapes and cherries seeds, sawdust in bricks manufacturing. Water hyacinth (WH) will be a new addition into this list, which is a problematic perennial aquatic weed.

WH (*Eichhornia crassipes*) is a freely floating aquatic weed that has caused havoc across majority of the continents (Malik, 2007; Patel, 2012; Aguiar and Ferreira, 2013; Theuri, 2013; Brundu, 2015; Wang et al., 2016). Originated from Amazon basin, WH has spread across the tropical and subtropical regions and is recognised as one of the worst weeds (top ten) in the world (Gunnarsson and Petersen, 2007; Villamagna and Murphy, 2010; Patel, 2012). WH has caused widespread environmental, ecological, social and economic threats (Abbasi and Nipaney, 1986; Chua, 1998; Aguiar and Ferreira, 2013; Koutika and Rainey, 2015). Dense growth of this weed in water bodies threaten biodiversity, cause eutrophication and result in oxygen depletion, negatively impact fisheries and related commercial activities, harbour pests and vectors, block waterways, affect navigation, hydroelectric programmes, tourism and hinder agriculture and aquaculture yields (Ambrose, 1997; Minakawa et al., 2012; Patel, 2012; Rocha-Ramirez et al., 2014; Kriticos and Brunel, 2016).

After having examined the threats posed by WH, the present work focuses on making a feasibility study to produce eco-friendly, light weight and porous bricks through a binary mix of WH and soil. To the best of author's knowledge, this study is the first to explore the use of WH in manufacturing the fired bricks and to determine the cause-effect of nature and physico-mechanical properties of WH incorporated bricks. The results from this work are expected to help the brick industry to become sustainable across the globe.

2. Materials and methods

2.1. Materials

This laboratory scale study used WH from the Amingaon industrial area near Indian Institute of Technology (IIT) Guwahati, Assam in India. As for the primary raw material, two types of soils were used namely laterite soil and alluvial soil. Laterite soil was collected from IIT Guwahati campus whilst alluvial soil was obtained from a brick kiln located in an area near Guwahati. The rationale to take these two type of soil samples is based on Indian standards (BIS:2117, 1991; BIS:11650, 1991) and other studies (Rahman, 1987; Reddy, 2004; Mueller et al., 2008; Goel and Kalamdhad, 2017a; b). Both types of soils and WH were dried independently and ground to particle size finer than 600 μm prior to brick making.

2.2. Characterization of raw materials

Prior to performing the brick making activity, it was considered necessary to perform the material characterization as this could pave way for a scientific understanding of the process. In particular, of interest to observe were the mineralogical, chemical, thermal and index properties and therefore a comprehensive characterization of the constituent materials, namely, soils and WH was done using several instruments. For instance, particles were screened based on the particle size distribution performed on the laser diffraction particle size analyser (Malvern Mastersizer-2000). Elemental Analysis of chemical elements C, H, N and S was performed by combustion of powdered samples in oxygen atmosphere (Euro Vector, EuroEA3000). Fourier transform infrared (FTIR) spectroscopy (PerkinElmer) was performed on dried powdered samples by producing KBr pellets. Crystalline phases were probed qualitatively using X-ray diffraction (XRD, Rigaku, TTRAX III) with CuK_α radiation ($\lambda = 1.5406$ Å) at 50 kV and 100 mA at a scan rate of 3° per min. XRD patterns were recorded in the 2θ range between 10 and 80°. Thermal analysis (TGA-DSC) (Netzsch STA 449, heating rate 10 °C/min) was performed using alumina crucible in static nitrogen atmosphere (temperature range of 30–1000 °C). Higher heating value (HHV) was ascertained using plain jacket oxygen Bomb Calorimeter (Parr 1341, 6775 digital thermometer). The total concentration of metals was evaluated using atomic absorption spectrometer (AAS, Thermo scientific, iCE 3000) after the digestion of 0.2 g sample with 10 ml of H_2SO_4 and $HClO_4$ (5:1) concoction in block digestion system (Pelican equipments) for 2 h at 300 °C (Singh and Kalamdhad, 2013). Plasticity index and specific gravity were deduced in agreement with BIS: 2720-1985. Finally, chemical analysis was done using the X-ray fluorescence (XRF-sequential spectrometer, PANalytical, AXIOS) whilst field emission scanning electron microscope (FESEM, Zeiss, Sigma) equipped with energy-dispersive X-ray analyser (EDX, Oxford) was employed to examine the burnt residue in the form of ashes obtained after firing the samples at 950 °C.

2.3. Flow diagram of brick production

WH was mixed in both type of soils individually in varied