Construction and Building Materials 142 (2017) 11–22

Contents lists available at ScienceDirect

Construction and Building Materials

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

Characterisation of fired-clay bricks incorporating biosolids and the effect of heating rate on properties of bricks

Aruna Ukwatta *, Abbas Mohajerani

Civil and Infrastructure Engineering, School of Engineering, RMIT University, 124, La Trobe Street, Melbourne, Victoria, 3000, Australia

HIGHLIGHTS

- Use of biosolids in fired-clay bricks studied with different heating rates.
- The best results are obtained at a heating rate of 1.5 °C min^{-1} for all biosolids bricks.
- Addition of biosolids produced light-weight bricks.
- Properties of biosolids bricks were within standards limits.
- Biosolids can be regarded as a promising raw material in manufacturing bricks.

ARTICLE INFO

Article history:
Received 27 December 2016
Received in revised form 7 March 2017
Accepted 8 March 2017
Available online 19 March 2017

Keywords:
Biosolids
Bricks
Heating rate
Sustainable building materials

ABSTRACT

Biosolids are a major by-product of the wastewater treatment process. In this study, biosolids from Melbourne Water's Western Treatment Plant (WTP) were used as a secondary raw material with brick soil in the production of fired-clay bricks. WTP biosolids and brick soil were characterised in terms of their mineralogical and chemical composition, as well as their geotechnical and thermal properties. Bricks were produced incorporating 5, 10, 15, 20, and 25% WTP biosolids by weight. Green bricks were fired at 1050 °C for 3 h with different heating rates of 0.7, 1.0, 1.5, and 2.0 °C min^{-1}. The influence of incorporating WTP biosolids and the change in heating rate on the physical and mechanical properties of bricks including compressive strength, density, water absorption, and shrinkage were investigated. The brick properties were compared to those of conventional bricks with no additives. The addition of WTP biosolids produced bricks with lower compressive strength compared to the control bricks with no additives; for instance, the compressive strength of the biosolids-amended bricks fired at a heating rate of 0.7 °C min^{-1} ranged from 29.5 MPa to 10.5 MPa, while the compressive strength of the control bricks was found to be 30.5 MPa. The results of the cold water absorption of the control and biosolids-amended bricks showed that the addition of WTP biosolids caused a gradual increase in the cold water absorption for all heating rates. In addition, the results indicated that bricks fired at a heating rate of 1.5 °C min^{-1} improved the water absorption and compressive strength properties for all percentages of biosolids-amended bricks as well as the control bricks. Adopting the heating rate of 1.5 °C min^{-1} reduced the sintering time by 47% compared to 0.7 °C min^{-1}, which is significant in terms of energy savings. Finally, the WTP biosolids-amended bricks fulfilled the standard requirements, particularly in terms of compressive strength, while, at the same time, they offered light weight bricks compared to the control bricks.

1. Introduction

Biosolids are produced in large quantities as a by-product of the wastewater treatment process. Biosolids are treated and stabilised sludge that has undergone different stabilisation processes, such as aerobic and anaerobic digestion, thermal drying, oxidation, disinfection, lime treatment, and thermal hydrolysis [1]. The production of biosolids is increasing annually as a result of the ever increasing water demand and wastewater generation in metropolitan areas throughout the world, which, consequently, is resulting in an urgent need for landfill spaces to dispose of biosolids and other by-products [2].

* Corresponding author.
E-mail addresses: s3442271@student.rmit.edu.au (A. Ukwatta), dr.abbas@rmit.edu.au (A. Mohajerani).

http://dx.doi.org/10.1016/j.conbuildmat.2017.03.047

In 2015, the total production of biosolids in Australia and New Zealand was approximately 310,000 and 77,000 dry tonnes, respectively. In 2015, approximately 89,900 dry tonnes of biosolids were produced in the state of Victoria, which accounts for 29% of the total production of biosolids [3,4]. This is an increase of 3.3% compared to the annual Australian production of biosolids in 2010. In 2015/16 WTP produced 12,439 dry tonnes of biosolids, which brings the total estimated stores at WTP to 1,590,000 dry tonnes of biosolids. It is estimated that the annual biosolids production in the USA and Europe is approximately 10 million and 7.2 million dry tonnes, respectively [1].

The ever-increasing volume of biosolids throughout the world highlights the urgency of finding innovative routes for the recycling of biosolids. Among the various existing recycling options, geotechnical engineering applications and roadwork applications have been proven to be attractive alternative choices for recycling biosolids [5–10]. Interestingly, incorporating biosolids into fired-clay bricks has been found to be a promising alternative approach for the comprehensive utilisation of biosolids [11].

Bricks are presently, and have been one of the most common and widely accepted building materials throughout the world over a long period of time. Global annual brick production is currently about 1391 billion and the demand for bricks is continuously increasing [12,13]. In Australia, clay brick production reached 1.38 billion units in 2013, an increase of 7.8% from 1.28 billion units in 2012. In the first quarter of 2014, clay brick production was 315,810,000 units [14]. Due to a shortage of clay, brick production has been limited in some countries, such as China, in order to protect the environment and clay resources [13]. Therefore, innovative approaches to producing fired-clay bricks that are less dependent on virgin sources are highly encouraged from the perspective of protecting the natural resources and sustainable development.

In recent years, there has been great interest in incorporating different waste materials into building materials, including fired-clay bricks and masonry units [2,11,12,15–39]. These innovative approaches have become a win-win strategy, because, not only do they convert waste into beneficial products but they also alleviate the issues pertaining to their disposal. In addition, substituting leftover materials in manufacturing bricks is a promising solution to the scarcity of natural earth resources.

Therefore, the utilisation of WTP biosolids in the production of fired-clay bricks could be a feasible and promising alternative route for recycling biosolids. The objective of this study is to evaluate the level of influence by incorporating different percentages of WTP in fired-clay bricks, and the effect of the heating rate on the physical and mechanical properties of fired-clay bricks. The selected heating rates ranged between 0.7 and 2 °C min^{-1}, which was selected based on the study conducted by Kadir & Mohajerani [23], who investigated the effect of change in heating rates between 0.7 and 10 °C min^{-1} on the properties of bricks and found that the quality of bricks started to diminish at heating rates greater than 2 °C min^{-1}. Furthermore, the physical and chemical properties of raw materials were characterised and a relationship between the compaction parameters and Atterberg limits of different biosolids-soil mixtures were obtained. In addition, the measured properties of biosolids-amended bricks were compared with the control bricks and the limits stipulated in the Standards.

2. Materials and methods

2.1. Raw materials

Biosolids were collected from stockpile No 10 at the WTP in Melbourne (Fig. 1a) and the collected biosolids sample was labelled as WTP10. The age of the WTP10 stockpile is 5 years and the existing volume is approximately 30,000 m^3. Approximately 1 m^3 of WTP10 was collected as shown Fig. 1(b). The brick soil was provided by Boral bricks Pty Ltd.

2.1.1. Chemical and mineral composition

The chemical composition of the WTP biosolids and brick soil was tested using the X-ray fluorescence (XRF) method. The mineralogy of raw materials was determined based on the X-ray Powder diffraction method (XRD) by means of Nickel filtered CuKα radiation, operating at an intensity of 40 kV and 35 mA. The 2θ range was from 5 to 70° with a step size of 0.001 (2θ).

2.1.2. Thermal analysis

Thermogravimetric analysis (TGA) was performed thereafter using the Pyris 1 TGA thermogravimetric analyser. The biosolids samples were placed in platinum crucibles, and approximately 10 mg of each sample was heated from 30 °C to a maximum temperature of 850 °C at a constant heating rate of 10 °C per minute in a 20 ml per minute flow of air. Both the WTP10 and brick soil were tested under the same conditions, including temperature range, atmosphere, and heating rate.

2.1.3. Geotechnical properties

The particle size distribution of the raw materials was determined according to the standard method of analysis by sieving [40]. The Atterberg limits (liquid limit and plastic limit) were determined according to the Australian Standards [41,42]. The particle density (specific gravity) of the biosolids and brick soil was determined according to AS 1289.3.5.1 [43]. The organic content of WTP10 and brick soil was determined according to BS 1377-3 [44] in which samples were ignited at 440 °C in an electric furnace for 4 h.

2.2. Methods

2.2.1. Preparation of bricks

Bricks were manufactured incorporating five different percentages – 5, 10, 15, 20, and 25 wt% – of WTP10, which were labelled as W5, W10, W15, W20, and W25, respectively. To enable a comparison of the properties, the bricks with no biosolids were also made and labelled as B0.

2.2.2. Forming of bricks

Different percentages of WTP10 biosolids were added to brick soil and the biosolids-soil mixtures were manually mixed while adding the required amount of water. A series of standard Proctor compaction tests were carried out according

Fig. 1. (a) WTP Stockpile No 10; (b) collecting about 1 m^3 of biosolids from WTP stockpile No 10.