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Possible use of biosolids in fired-clay bricks

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HIGHLIGHTS

- Use of biosolids (B) in fired-clay bricks (FCB) studied with promising results.
- Compressive strengths of FCB with 25% of three different B were over 16 MPa.
- Properties of FCB with B samples used in this study were within acceptable limits.
- FCB with biosolids showed lower firing shrinkage depending on organic content.
- S.E. microscopy was used to study the effect of adding B on microstructure of FCB.

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ABSTRACT

In Australia, thousands of tonnes of biosolids are produced annually and millions of dollars expended on their management. Biosolids are derived from wastewater sludge, which is the major solid component collected from the wastewater treatment process. This paper presents some of the results from a study concerning the use of biosolids in fired-clay bricks. The geotechnical characteristics of three biosolids samples from the stockpiles of the Eastern Treatment Plant (ETP) in Melbourne were investigated to assess their suitability as a partial replacement material for the clay in fired-clay bricks. The results of classification tests including liquid limit, plastic limit and sieve analysis indicated that the three biosolids samples were clayey sand and poorly graded silty sand. The linear shrinkage of the biosolids samples varied from 10% to 15% and the organic content varied from 6% to 14%. Control clay bricks with 0% biosolids and clay–biosolids bricks with 25% by weight of biosolids were made and the properties including the compressive strength, shrinkage, density, Initial Rate of Absorption (IRA), and water absorption were determined whereas thermal conductivity was estimated from an empirical model. Furthermore, the effect of adding biosolids on the microstructure of the fired-clay bricks was evaluated by scanning electron microscopy (SEM). The results showed that the compressive strength of clay–biosolids bricks were 25.9, 17.4 and 16.2 MPa for the bricks with the three different biosolids samples used in the study. This was mainly because of the addition of biosolids samples with different organic content, which resulted in fired-bricks with higher apparent porosity and thus lower density and compressive strength. The compressive strength of the control fired-clay bricks was 36.1 MPa.

1. Introduction

Biosolids are primarily the nutrient-rich materials remaining after the wastewater sludge treatment process. Sludge refers to a liquid, which, generally contains up to around 8% of dry solids and is produced by the wastewater treatment process, and which has not undergone further treatment. In contrast, biosolids have under gone a treatment process, which includes aerobic digestion, anaerobic digestion, alkaline stabilization, thermal drying, acid oxidation/disinfection, composting, etc. Consequently, biosolids may have different physical and chemical properties compared to sludge, according to the type of treatment process they have received. Melbourne water biosolids contain between 50% and up to 96% dry solids and are a product of the wastewater sludge once it has undergone further treatment to significantly reduce disease causing pathogens and volatile organic matter, thereby producing a stabilised product suitable for beneficial uses [2].

The amount of biosolids produced annually in the world has increased dramatically because of the growth of new treatment plants and continuous upgrading of existing facilities [42]. Australia currently produces approximately 300,000 dry tonnes

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of biosolids annually from which 55% is applied to agricultural land, 30% goes to land fill or stockpiled and the 15% balance is used for composting, forestry and land rehabilitation [12]. Furthermore, three million cubic metres of biosolids are presently stock piled at the ETP and Western Treatment Plant in Melbourne, which are suitable for forestry, farming, producing energy and structural fill [38]. It is notable that, in Australia alone, approximately A$90 million is spent on the management of biosolids every year.

At present, some biosolids are used as an agricultural land application due to its inherent organic matter and nutrient values [49]. Attempts have been made to recover energy from biosolids, for example, methane production through aqueous anaerobic digestion, and electricity production from microbial fuel cells [42,26]. In addition, multi reuse strategies have been developed worldwide in respect of the management of biosolids. For instance, the use of biosolids in engineering applications is of great interest and has become an innovative approach to the management of biosolids, which undeniably reduces the demand for virgin natural resources [21,42,4].

Arulrajah et al. [3] conducted a study on evaluating the geotechnical properties of wastewater biosolids to ascertain their suitability as a fill material in road embankments. After a comprehensive laboratory study, they found that the geotechnical properties of biosolids could be enhanced by either stabilizing biosolids with an additive or blended with high-quality material to enable biosolids to be used as an engineering fill material in road embankment applications. Moreover, Disfani et al. [22] studied the settlement characteristics of aged biosolids for possible application as a fill material in road construction. They used an analytical method to analyse the biodegradation settlement of a road embankment built with aged biosolids.

Interestingly, the biosolids tested have similar properties to soil, such as moisture content, cation exchange capacity, and moisture retention, and have parallel geotechnical engineering properties to soil [4]; for instance, plastic behaviour, acceptable shear strength parameters and compaction ability. Furthermore, the geotechnical properties of biosolids are enhanced remarkably when blended or stabilized with binding additives [33,36]. The focus of this study is to investigate the possibility of using biosolids from Melbourne Eastern Water Treatment Plant in fired-clay bricks. Incorporating biosolids in fired-clay bricks could provide another alternative and sustainable method for the recycling of biosolids.

Bricks are one of the oldest and major manufactured building materials that have been used over a long period of time. Dried-clay bricks and fired-clay bricks have been used from as early as 8000 BC and 4500 BC, respectively [52]. Due to their strength, reliability, weather resistance, simplicity and durability, bricks have been extensively used and given a leading place in history in conjunction with stone [14]. In recent decades, there has been great interest in reusing different leftover materials in manufacturing construction materials such as masonry units [27]. Moreover, alternative approaches have been investigated to assess the suitability of different materials as a replacement material for the clay in fired-clay bricks; for instance, sludge [51,32], sawdust [18], paper [45], cigarette butts [30], fly ash [35], sugar waste [25], polystyrene [48], and silica fume [13].

The main objective of this study was to investigate the possibility of using aged biosolids from Melbourne Eastern Water Treatment Plant into fired-clay bricks. The ETP biosolids stockpiles have unique and different physical and chemical properties with different organic content. Therefore, in this stage of the study, the effect of the addition of 25% by weight of three different biosolids samples from the ETP to the brick-clay on some physical and mechanical properties of bricks was investigated.

2. Materials and methods

The three biosolids samples used in this study were collected from existing stockpiles at the ETP in Melbourne (Fig. 1). Moreover, Boral Bricks Pty Ltd provided the brick soil for this investigation. The samples from these stockpiles were more than 12 years old. All samples were collected in airtight containers to maintain their in situ moisture contents.

The chemical composition of the brick soil and biosolids samples were performed by means of X-ray fluorescence (XRF), using a Bruker AXS S4 Pioneer spectrometer, and a Bruker X-ray Diffractometer was used to characterise the major crystalline phases of the brick soil and biosolids samples.

Geotechnical laboratory tests – specific gravity, liquid limit, plastic limit, particle size distribution, linear shrinkage – were conducted on the biosolids samples according to the Australian Standards [5], while the organic content test was conducted as per the British Standards [15]. The geotechnical properties of the biosolids samples and the brick soil were tested in triplicate and the average values of the results are reported.

Control clay bricks with 0% biosolids and clay–biosolids bricks with 25% by weight of biosolids were manufactured. All biosolids samples were oven dried at a temperature of 105 °C for 24 h before adding to the brick soil. The moisture contents used for the control bricks and bricks incorporating 25% of B1, B2, and B3 were 17%, 18%, 18.5%, and 22.5%, respectively, which were the optimum moisture contents obtained from Standard Proctor Compaction test [9]. The mixtures were prepared by means of a Hobart Mechanical Mixer with a 10 L capacity for 5 min. Each brick sample was compacted with the same compactive effort in a mould of 100 mm diameter and 50 mm height, with a compaction pressure of 240 kPa. The prepared green bricks were kept in the air for 24 h for air-drying followed by an oven drying period at 105 °C for 24 h; the dried bricks were fired in a muffle furnace at 1100 °C for 3 h. The fired brick samples were then cooled to room temperature in the furnace itself. The manufactured bricks were tested for compressive strength, density, water absorption, IRA, weight loss on ignition, and shrinkage. All the tests on fired-clay bricks were performed according to the Australian Standards [10].

The development of pores and the texture of the samples was evaluated by means of a Philips XL30 scanning electron microscope. Brick samples were mounted on a 25 mm pin stub and gently tied using carbon tape. Then samples were coated with gold using the SPI – Module sputter coater before analysis [24].

3. Results and discussions

3.1. Characterisation of brick soil and biosolids samples

The chemical composition of the brick soil and the three biosolids samples were determined by XRF, the results are shown in Table 1. The brick soil presents a typical composition and mainly consists

Biosolids Sample 1 - B1 Biosolids Sample 2 - B2 Biosolids Sample 3 - B3

Fig. 1. Three biosolids samples used in the study.