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Sustainable use of tannery sludge in brick manufacturing in Bangladesh

Md. Ariful Islam Juel [a,*], Al Mizan [b], Tanvir Ahmed [c]

[a] Department of Leather Engineering, Khulna University of Engineering and Technology, Khulna 9203, Bangladesh
[b] Leather Research Institute, Bangladesh Council of Scientific and Industrial Research, Dhaka 1000, Bangladesh
[c] Department of Civil Engineering, Bangladesh University of Engineering and Technology, Dhaka 1000, Bangladesh

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A B S T R A C T

Chromium-rich tannery sludge generated from tanneries has the potential to become a serious environmental burden in Bangladesh and a promising avenue for disposal of this sludge is by stabilizing it in clay brick products. But for sustainable industrial application of such technique it needs to be ensured first that the engineering properties of bricks as a building material are not diminished by addition of sludge, the process becomes energy efficient compared to alternatives and the use of such bricks do not pose any harmful environmental effects in the long run. In this study, clay bricks were prepared with different proportions of sludge (10%, 20%, 30% and 40% by dry weight) in both laboratory-controlled and field conditions and their suitability as a construction material was assessed based on their strength, water absorption, shrinkage, weight-loss on ignition and bulk density. For the sludge incorporated bricks, the compressive strength ranged from 10.98 MPa to 29.61 MPa and water absorption ranged from 7.2% to 20.9%, which in most cases met both the Bangladesh and ASTM criteria for bricks as a construction material. Volumetric shrinkage, weight loss and efflorescence properties of sludge-amended bricks were found to be favorable and it was estimated that an energy saving of 15–47% could potentially be achieved during firing with 10–40% tannery sludge-amended bricks. The quality of sludge-amended bricks made in the brick kiln was relatively inferior compared to bricks produced in the laboratory due to operating in a less-controlled environment with respect to maintaining adequate compaction and optimum moisture content. The leaching behavior of several heavy metals (Cr, As, Cu, Ni, Cd, Pb and Zn) from sludge-amended bricks has been found to be insignificant and far below the Dutch regulations and USEPA regulatory limits. Results from this study indicate that tannery sludge can be sustainably stabilized in clay bricks and large-scale application of this technique can be envisaged in the context of Bangladesh where brick remains a dominant building material.

1. Introduction

Chromium-rich tannery sludge (TS) generated from the effluent treatment plants of leather industry has the potential to contaminate soil, surface water and groundwater and pose a threat to the environment and natural resources if it is not disposed properly (Thomson et al., 1999). Usually, about 100–150 kg of sludge is generated per ton of hides/skins processed (UNIDO, 1998) which is composed mostly of chemically precipitated dissolved chromium, different types of spent chemicals, sulfide, salt, proteins, polyphenolic compounds, surfactants, dyes and syntans in the treatment process (Swarnalatha et al., 2006; Chang et al., 2001). Tannery sludge (TS) contains elevated concentrations of heavy metals like Cr, As, Ni, Co, Cu, Zn, Fe, Cd due to use of basic chromium salt, different syntans, dyes, pigments, retanning agents etc. in the tanning process (Houshyar et al., 2012; Kiliç et al., 2011). These heavy metals are very harmful, because of their non-biodegradable nature, long biological half-lives and their potential to accumulate in biological systems (Wilson and Pyatt, 2007; Singh et al., 2004). Immobilization of heavy metals is the primary objective for stabilization of a hazardous waste such as tannery sludge.

A technique to treat or stabilize hazardous waste is by valorisation in construction materials such as brick or concrete which has been applied in several instances quite successfully for the cases of sewage and textile sludge and arsenic-rich filter materials (Patel and Pandey, 2012; Cusidó and Cremades, 2012; Praveen et al., 2015; Chiang et al., 2009; Hassan et al., 2014). Though this form of sludge utilization in such materials does not necessarily involve a chemical interaction between the waste product and the materials, it has proven to be an effective method to reduce the potential hazard of the waste by converting it into a less toxic and mobile

* Corresponding author.
E-mail addresses: juel_islam@le.kuet.ac.bd, juelbclt@gmail.com (Md. A.I. Juel).

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form though the performance can vary depending on the type of waste product used, its particle size distribution and the technique for stabilization. The stabilized waste can be used as a construction material provided that the material possesses the necessary engineering properties and leaches toxic pollutants to an acceptable degree (Hassan et al., 2014; Rouf and Hossain, 2003). Several studies have shown that tannery sludge can be effectively stabilized in construction materials such as concrete, ceramic tiles and other engineering materials (Montañés et al., 2014; Basegio et al., 2002; Giugliano and Paggi, 1985) but not all these processes have been developed at a level suitable for industrial applications and treatment processes practiced are still potentially hazardous for the environment (Alibardi and Cossu, 2016). In order to offer tannery sludge as a viable recycling option in construction industry, the properties of the sludge-stabilized construction material must conform to local building material standards. In addition to that, the material must pose no long-term harm to the environment in terms of leaching of heavy metals. Therefore, although proof-of-concept study of the stabilization of various waste products in building materials are available (Mohajerani et al., 2016; Ukwatta et al., 2015; Quesada et al., 2015; Chiang et al., 2009), whether or not these techniques can produce bricks of desired quality adhering to standards for industrial applications are somewhat unexplored. The aesthetic quality of the building material, energy consumption during production and the possibility of leaching harmful constituents for prolonged period of usage are also important considerations to make the product sustainable. In this paper, we primarily address these issues in the context of Bangladesh while attempting to stabilize tannery sludge in clay bricks, a dominant construction material in the country.

In Bangladesh, 85,000 tons of wet salted hides and skins are processed annually (Paul et al., 2013) and it is estimated that 19,000 tons of partially dried sludge will be generated by the effluent treatment plants if the treatment systems of all tanneries become operational. On the other hand, 45,000 brick kilns in Bangladesh together produce about 17.2 billion bricks per year with an estimated sale value of around US$1.2 billion which is almost 1% of Bangladesh's GDP (World Bank, 2011). Due to unavailability of stone aggregate, brick has become the principal building material for the country's construction industry and will continue to be so in future. Therefore, exploring the brick manufacturing industry as a potential avenue for stabilization of the huge amount of tannery sludge in Bangladesh can be a viable option for commercial application.

In this study, we determined the characteristics of sludge-incorporated clay bricks with respect to its engineering properties as well as its environmental implications. Clay brick specimens were prepared with different proportions of sludge in both laboratory-controlled and field conditions (i.e. in a brick kiln) and their suitability as an engineering material was assessed based on their strength, bulk density, weight loss on ignition, shrinkage, water absorption and firing energy characteristics. Leaching test of sludge-incorporated bricks was also carried out to demonstrate the effectiveness of the stabilization technique against the release of heavy metals in the environment.

2. Experimental

2.1. Raw materials

Tannery Sludge (TS) samples were collected from the Effluent Treatment Plant of Apex Tannery Ltd, unit-2, Gazipur, Bangladesh (Fig. 1(a)). This tannery employs a conventional combination of chemical and biological treatment following rapid sand filtration and uses lime and ferrous sulfate as coagulant. The clay sample used to prepare bricks in the laboratory was obtained from a local brick manufacturing plant.

2.2. Characterization of sludge

The moisture content and organic content of sludge and clay were determined by APHA method (APHA, 2012). X-ray fluorescence (XRF-1800, SHIMADZU) was used to determine the chemical composition of tannery sludge. For heavy metal analysis, 5 g lightly ground dried sample was digested with acid (HNO_3: HCl = 1:3 vol. ratio) for 24 h, then 350–400 ml distilled water was added and the sample was boiled for 2.5 h to prepare a 500 ml solution. Finally, the solution was filtered through a 0.45 μm filter paper and the filtrate was collected to determine the concentration of heavy metals (Cr, As, Pb, Cd, Ni, Cu, and Zn) by using Atomic Absorption Spectrophotometer (AAS) (Shimadzu AA 6800) (Juel et al., 2016; Saha and Hossain, 2011).

2.3. Brick preparation and tests

Both sludge and clay were oven dried and ground by a crushing machine. Atterberg limit tests were conducted according to ASTM (ASTM D 4318, 2000) to determine the plastic nature of the sludge-clay mixture. Optimum Moisture Content (OMC) was determined according to AASHTO (AASHTO T- 99, 1982).

Total 75 brick samples (length 12 cm. width 6 cm and height 3.5 cm) of sludge-clay mixture in varying proportions (0%, 10%, 20%, 30% and 40% by dry weight) at OMC were prepared in the laboratory (Fig. 1(b)). Additional 2–3% water above the OMC was added (based on the dry mass of each brick) to all the mix ratios to facilitate the hand molding process while mixing. Three 100% clay samples were prepared as a reference specimen. After 24 h of natural drying and 48 h of oven-drying (at 105 °C), these samples were heated in an electric furnace (Nabertherm, LH 60/14, Germany) at the rate of 5 °C/min up to experimental temperatures of 900 °C, 950 °C and 1000 °C and were held for 3 h (Fig. 1(d)). The objective of experimenting with brick with varying sludge proportion was to determine the effect of sludge quantity on various physical and mechanical properties of bricks and also to roughly find out the threshold sludge quantity that would allow the bricks to have desirable engineering properties as a building material.

A series of tests such as firing shrinkage, weight loss on ignition, water absorption and compressive strength were conducted on the bricks according to ASTM (ASTM C 67-02c, 2002). The engineering properties of the bricks were compared with the ASTM and Bangladesh Standards (see Table 1)(BDS 208, 2009). Efflorescence test was carried out following BDS 208 (2009) (procedure described in Supplementary materials). Leachability test of all brick samples for specified heavy metals was carried out in accordance with USEPA 1311 (USEPA, 1992) and Netherland Tank Leaching test NEN 7345 (NEN 7345, 1993). The test results of all the parameters were taken as an average value from three replicate tests.

A separate set of sludge-incorporated bricks was prepared in a commercial brick kiln ('field condition') following their typical protocols (Fig. 1(c)). Two types of brick molding procedures are primarily adopted in Bangladesh - hand molding and automatically pressed molding. In this study hand molding method was used for brick production. For the bricks prepared in 'field condition', the sludge content is chosen as 10% (by weight). The bricks prepared in 'field condition' underwent the same set of tests for mechanical properties and leaching as described above.

2.4. Firing energy saving

Brick production industries are considered to be one of the highest energy consuming sectors and have a large negative impact on the environment related to energy use (Koroneos and Dompros, 2007). So savings in energy consumption by incorporating tannery sludge may lead to sustainable brick production. The

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