Geotextiles and Geomembranes 44 (2016) 623–640

Contents lists available at ScienceDirect

Geotextiles and Geomembranes

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

Feasibility study of copper slag as a structural fill in reinforced soil structures

P.S. Prasad [a, *], G.V. Ramana [b, 1]

[a] Geotechnical Engineering Division, CSIR – Central Road Research Institute, Mathura Road, CRRI (PO), New Delhi 110025, India
[b] Civil Engineering Department, Indian Institute of Technology Delhi, Hauz Khas, New Delhi 110016, India

ARTICLE INFO

Article history:
Received 26 January 2015
Received in revised form
18 March 2016
Accepted 29 March 2016
Available online 22 April 2016

Keywords:
Geosynthetics
Copper slag
Structural fill
Pullout resistance
Stick – slip behaviour
Reinforced soil structures

ABSTRACT

Copper slag (CS) is a granulated cohesionless glassy material with the appearance of dark black coloured sandy size material. Copper slag is classified as poorly graded sand (SP) as per the Unified Classification System (USCS) and has a specific gravity of 3.6. Copper slag contains iron silicates, calcium oxide, and alumina, with small amounts of copper, lead, zinc, and other metals. The evaluated gradation, physical, shear strength characteristics and electrochemical properties of copper slag met the standard specifications for a structural fill material recommended for use in mechanically stabilized earth (MSE) walls and reinforced soil slopes (RSS). The angle of shearing resistance of copper slag varied between 35° and 49° for loose and dense states, respectively. Thereafter pullout tests were conducted to determine interface apparent coefficient of friction ($\mu_{S/GSY}$) between the geogrid and copper slag at normal stresses of 7.3 kPa, 12.5 kPa, 25 kPa and 50 kPa and obtained results are then compared with those of geogrid in reference fill material, Yamuna sand (YS). The pullout tests were carried out as per ASTM Standard D 6706–01(2013) on an apparatus that was fabricated indigenously. This paper addresses the geogrid – copper slag interaction and geogrid – Yamuna sand interaction from pullout tests and demonstrates that copper slag can be effectively used as a structural fill for reinforced soil structures.

1. Introduction

Copper slag (CS) is a waste generated during processing of copper. The waste-to-product ratio is 2.2 i.e. 2.2 metric tons of slag is produced for each metric ton of copper. Every year, approximately 24.6 million ton of slag is generated from world copper production (Gorai et al., 2003; Chew and Bharati, 2009) and India has around 1.63 million ton of slag at different sites of the three copper producers viz. Sterlite, Birla Copper and Hindustan Copper Ltd. These slags can be used for different Geotechnical applications considering the fact that physico - mechanical characteristics are similar to that of sand.

The use of CS for construction of: (i) building blocks dates back to 1785, (ii) embankments and reclaiming low-lying areas to 1812 and (iii) as an aggregate for the construction of roads by the end of 18th century (Ferguson, 1996). Madany et al. (1991) studied the possibility of copper blasting grit waste as a construction material. Das et al. (1983) studied geotechnical properties of CS and concluded that CS can be used as engineering fill and its characteristics are similar to that of medium sand. Public Works Research Institute (2005), Japan specifies that CS can be used as aggregate in concrete and road-bed material.

Several investigators have studied the utilization of the CS in diversified ways such as: raw material in cement production (Gorai et al., 2003; Alp et al., 2008), as Portland cement replacement (Mobasher et al., 1996; Arino and Mobasher, 1999; Boakye et al., 2013; Chockalingam et al., 2013), fine aggregates (Hosokawa et al., 2004; Resende et al., 2008; Wu et al., 2010; Pazhani and Jeyaraj, 2010; Al-Jabri et al., 2011; Alnuaimi, 2012; Gupta et al., 2012; Boakye et al., 2013; Nazer et al., 2013: Chockalingam et al., 2013; Chavan and Kulkarni, 2013) and coarse aggregates (Khanzadi and Behnood, 2009) in concrete and asphalt pavements (Al-sayed and Madany, 1992; Pundhir et al., 2005; Nikolov et al., 2007), base course of flexible pavements (Emery, 1982; Collins and Ciesielski, 1994; Shahu et al., 2013), fill and ballast (Emery, 1982), abrasive (Peart and Fultz, 1990; Potana, 2005; Lim and Chu, 2006), aggregates (FHWA-RD-97-148, 1998; Kamon et al.,

* Corresponding author. Tel.: +91 9013471432; fax: +91 11 26845943, +91 11 26830480.
E-mail addresses: pulikanti@gmail.com (P.S. Prasad), gvramanaiitdelhi@gmail.com, ramana@civil.iitd.ac.in (G.V. Ramana).
[1] Tel.: +91 9868818674; fax: +91 11 26581117.

http://dx.doi.org/10.1016/j.geotexmem.2016.03.007

2000; HD 35/04,2004), glass, tiles and bricks (Gorai et al., 2003; Fang et al., 2011; Zhang, 2013) etc. Nikolov et al. (2007) stated that CS has a good cohesion with bitumen. Yusof (2005) reported that in Canada approximately 45% of available CS was used in base construction, rail road ballast and engineered fills. Chun et al. (2005) reported that CS is widely used in harbour revetment and offshore structure construction works etc.

Reuter et al. (2004) identified that CS has good environmental stability due to its amorphous vitreous phase in which heavy metals are locked up and restrained. Alter (2005) conducted leachate studies on CS from Chile, USA as well as Canada and reported an insignificant presence of heavy metal content and concluded that their leachates will remain in the non-hazardous range. The metals removed through laboratory tests are within acceptable limits of US regulatory levels based on drinking water quality. Shanmuganathan et al. (2008) investigated the toxicity characteristics and long-term stability under extreme environmental and weather conditions of the CS generated from M/S Sterilite Copper in India and concluded that these slag samples are non-toxic and pose no environmental hazard and also suggested that CS is safe to be considered for various applications such as Portland cement, tiles and bituminous pavement constructions. Brindha et al. (2010) studied the leaching of heavy metal from CS (M/S Sterilite Industries Ltd.) by using ICP technique and concluded that the leaching of heavy metals (Pb, Zn, Cr, Ni, Mo etc.) was well below the toxicity limits even under belligerent environmental conditions. Harish et al. (2011) reported that the CS was excluded from the list of hazardous waste category by United States Environmental Protection Agency (USEPA) and also does not appear in the hazardous waste category of the hazardous waste management rules of the Ministry of Environment and Forests (MoEF), India.

Limited research has been reported on the utilisation of CS for geotechnical earth work applications like embankments (Havanagi et al., 2007; Patel et al., 2007), land reclamation (Chu et al., 2003; Lim and Chu, 2006), and as a substitute for sand in sand compaction piles (Chun et al., 2005; Kitazume et al., 1998; Nawagamuwa et al., 2013).

It should be noted that no literature exists on the use of CS as a structural fill material behind retaining walls and mechanically stabilised earth (MSE) walls/reinforced soil slopes (RSS). The present study therefore aims at investigating the significance of CS as a structural fill for the above applications.

Experimental work reported in the current paper is carried out in a newly fabricated large scale pullout test apparatus. At the time of drawing specifications for the design of this equipment, an equipment of similar size in India was only available at Indian Institute of Technology (IIT) Madras. Before drawing up the specifications, an extensive literature review (Chang et al., 1977; Ingold, 1982; Palmeria and Milligan, 1989; Berg and Swan, 1990; Bergado et al., 1992; Yasuda et al., 1992; Farrag et al., 1993; Mallick and Zhai, 1995; Lopes and Ladeira, 1996; Moraci et al., 2002; Wilson – Fahmy et al., 1994; Duszynska and Bolt, 2004; Alfaro and Pathak, 2005; Kakuda et al., 2006; Moraci and Recalcati, 2006; Siriwardane et al., 2008; Yin et al., 2008; Nayeri and Fakharian, 2009; Nguyen et al., 2009; Liao et al., 2009; Abdelouhab et al., 2010; Balunani and Prezzi, 2010; Abdi and Arjomand, 2011; Esfandiari and Selamat, 2012; Lawson et al., 2013; Shi and Wang, 2013; Ezzein and Bathurst, 2014) was undertaken under three major headings namely: (i) Pullout box dimensions with strain rates existing at universities in various countries, (ii) Clamping arrangements adopted by different researchers and (iii) Factors that influence the pullout behaviour. Based on literature, specifications for this equipment were prepared and was then fabricated at CSIR – Central Road Research Institute, New Delhi. Significant data on pullout characteristics of geogrids embedded in conventional fill material is not available in India. The purpose of the current laboratory pullout test program was to provide the industry, with data related to interaction coefficient values of geogrids embedded in CS and encourages the use of CS as structural fill for MSE wall and reinforced earth slopes.

2. Materials used for the present study

2.1. Structural fill material

For the present study, the Copper slag (CS) (Fig. 1) produced at Sterlite Industries India Limited, Tuticorin, Tamil Nadu, India, was used as structural fill and a locally available fluvial sand known as Yamuna sand (YS), collected from river Yamuna at Delhi, India is used as reference material.

2.2. Reinforcing material

An extruded HDPE geogrid (TT060 SAMP) was chosen as a reinforcing material for this study (Fig. 2). The summary of geogrid properties as provided by the manufacturer is shown in Table 1.

3. Characterization of CS

3.1. Chemical properties

Chemical composition of CS varies with the types of furnace or process of treatment (Gorai et al., 2003; Shi et al., 2008) and composition of copper (Cu) concentrates used (Harish et al., 2011). Table 2 presents the chemical composition of CS and YS used in this study. It can be observed that both the materials have similar CaO content, whereas YS has high concentration of SiO_2, Al_2O_3 and low Fe_2O_3 as compared to CS. CS contains copper, zinc and lead metal contents which are absent in YS.

3.2. pH

pH of structural fill material is one of the most important criteria for durability of reinforcing material for mechanically stabilized earth wall/reinforced slopes. The leachability of copper (Cu) is more at lower pH i.e. less than 5 (Quina et al., 2009). pH is regarded as the vital variable that regulates the leachability and mobility of metals in the environment (Lim and Chu, 2006). pH of structural fill materials were measured as per ASTM G51 – 95 (2012). Table 3 presents the pH of CS and YS used in present study as well as other

Fig. 1. Typical appearance of the CS used in the present study.