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Influence of recycled tyre amendment on the mechanical behaviour of soil-bentonite cut-off walls

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ABSTRACT

Generation of the scarp tyre has increased in recent years, and finding innovative reusing methods is of interest to researchers. This study aims to investigate the hydraulic conductivity and one-dimensional consolidation behaviour of soil-bentonite (SB) backfill amended with powdered recycled tyre (PRT) and crumbed recycled tyre (CRT) by performing a series of oedometer consolidation and rigid-wall hydraulic conductivity tests. Three values of PRT and CRT (i.e., 2%, 5% and 10% by dry weight) were used to prepare the specimens. The investigation on vertical strain-time graphs showed that the addition of PRT and CRT caused an increase in settlement characteristics of the SB backfill. The results also showed that the addition of PRT and CRT caused an increase in the compression index (C_i) and the swelling index (C_s) of the SB specimens. The coefficient of consolidation (c_v) based on the Casagrande and Taylor methods showed a consistent increasing trend by increasing the PRT and CRT. The hydraulic conductivity was computed based on the Terzaghi consolidation theory (k_{theory}), and the results showed that increasing the PRT and CRT caused an increase in hydraulic conductivity of the SB backfill. The hydraulic conductivity (k_f) measured using a rigid-wall permeability compaction mould showed a similar increasing trend by increasing the PRT and CRT contents of the backfills.

1. Introduction

Australia is facing a significant growth in waste production due to increases in population and consumption rates in recent years (Keramatikerman et al., 2017; Plant et al., 2014). The tyre industry is one of the sectors growing the most, with around 52.2 M tyres disposed each year in Australia, only 13% of which are recycled, and the rest is stockpiled in landfills (Chegenizadeh et al., 2017; SUEZ, 2016). Along with this increasing trend of scarp tyre generation emerges serious environmental and health issues for the future, and highlights the importance of innovative reusing methods. The scarp tyre has some natural characteristics that make it useful when applied to drainage, insulation, and lightweight aggregate backfill purposes (Edil et al., 2004). Previous studies investigated the potential reuse of tyres in structural engineering and in particular in improving the strength characteristics of concrete (Kashani et al., 2017; Hesami et al., 2016; Bravo and de Brito, 2012; Pelisser et al., 2011), however many more studies need to be conducted to fully investigate the potential application of scarp tyres in various sectors. This material also has a wide range of usage in environmental studies (Ghazavi, 2004; Rao and Dutta, 2006; Bhalla et al., 2010; Turner and Rice, 2010; Lian et al., 2011, 2013). Since carbon is the main constituent of the scarp tyre, this material has a high potential for the absorption of waste containing volatile organic compounds (VOCs) and can be applied in the waste management industry as well. As an example, Cokca and Yilmaz (2004) investigated effect of rubber and fly ash mixed bentonite as a liner material. They indicated that the mixture of bentonite and fly ash, with up to 10% rubber, provided a satisfactory barrier system with an appropriate hydraulic conductivity required for liner systems. In another example, Park et al. (2003) investigated the suitability of the shredded tyre as a collection medium for landfill leachate in a large scale tank, and concluded that tyre chips are good for the absorption of contamination. Park et al. (1997) also reported on the effectiveness of ground tyre to absorb the VOCs in a series of laboratory scale column tests.

The construction of soil-bentonite (SB) slurry cut–off walls is a

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well-established approach to control the migration of contaminants into an uncontaminated area. This method is a cost-effective and time-saving approach in comparison to the construction of a treatment plant (Hong et al., 2012). The SB barriers have an intrinsic low sorption capacity when exposed to volatile organic compounds (VOCs) and require modification with some amendments that have a high capability for carbon absorption (Malusis et al., 2009; Park et al., 1997). It has been indicated that materials such as activated carbon, flyash, zeolite, and scarp tyre etc. contain a high level of carbon that are effective in increasing the absorption capacity of SB slurry walls (Hong et al., 2012; Malusis et al., 2009; Mott and Weber, 1992), however some of their most crucial engineering characteristics (i.e., hydraulic conductivity and compressibility) are not clear after amendments. For instance, Hong et al. (2012) investigated the effect of zeolite amendment on compressibility and hydraulic conductivity of the SB slurry walls by performing a series of laboratory scale hydraulic conductivity and consolidation tests. It was indicated that the addition of zeolite had little impact on the settlement and permeability characteristics of the SB backfill. In another example, Malusis et al. (2009) investigated the effect of two types of activated carbon (i.e., powdered and granular) amendment on permeability and consolidation characteristics of the SB slurry walls. They indicated that the application of powdered activated carbon marginally reduced the hydraulic conductivity and increased the compressibility of the SB backfill.

In aforementioned literature, it was determined that the generation of the scarp tyre is increasing day to day and finding innovative solutions to reuse this material is of interest to the researchers. Also, it was mentioned that the scarp tyre, like some other materials (i.e., fly ash carbon, and zeolite etc.), has a high level of VOCs absorption that has the potential for application in SB slurry walls, however their effect on engineering characteristics such as hydraulic conductivity and compressibility of the SB slurry walls is unknown. Thus, this study aims to investigate the effect of two types of scarp tyre after recycling, powdered recycled tyre (PRT) and crumbed recycled tyre (CRT), on hydraulic conductivity and compressibility of the SB slurry cut-off wall. This study is part of ongoing research at Curtin University (Keramatikerman et al., 2017).

2. Materials and methods

The materials used to prepare the backfill consist of sand, sodium bentonite, powdered recycled tyre (PRT) and crumbed recycled tyre (CRT) at 0, 2, 5 and 10% by dry weight. The sand used is classified as poorly graded sand (SP) according to the Unified Soil Classification System (USCS) [(ASTM D2487 (ASTM, 2011a)], and was obtained from Baldivis, Western Australia. The bentonite used has a liquid limit (LL) and a plastic limit (PL) of 455 and 387, respectively [ASTM D4318 (ASTM, 2010)], and is classified as a high plasticity (CH) clay according to the USCS. Both the PRT and the CRT have a specific gravity of solids (G_S) of 1.2. They were made from recycled truck tyres using a tyre buffing machine and purified of any other waste materials such as wood, glass, fibre or metal by the supplier. The uniformity coefficient (C_u) was 2.5 and 1.20, and the coefficient of curvature (C_c) was 1.02 and 1.20 for PRT and CRT, respectively. The particle size distribution (PSD) tests were performed for the materials in accordance with ASTM C136 (ASTM, 2014) and ASTM D422 (ASTM, 2011b), and the results are presented in Fig. 1.

A Bentonite-water (BW) slurry was prepared by the addition of 5% bentonite (by dry weight) to tap water. The slurry was then mixed for 30 min in an automated Hobart mixer machine and left to hydrate for 24 h (Hong et al., 2012). The prepared slurry had a density and marsh funnel viscosity of 1035 kg/m^3 and 40 s,

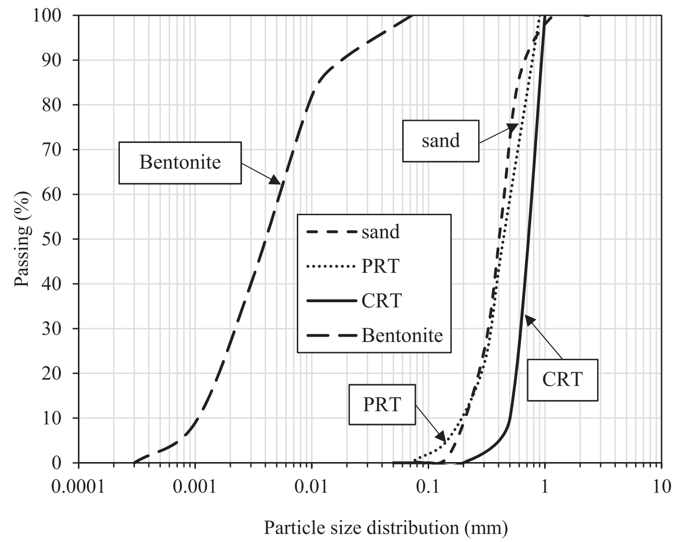

Fig. 1. Particle grading of the used materials.

respectively. Also, the electrical conductivity (EC) and pH of the slurry at 25 °C were equal to 115.5 mS/m and 8.80. The unamended SB backfill was prepared by mixing sand with 4% bentonite (by dry weight) in the automated mixer for 30 min (Malusis et al., 2009; Hong et al., 2012). During preparation, water content equal to 8% of the sand (similar to the original gravimetric water content) was added to the backfill to keep its uniformity (Hong et al., 2012). To prepare the unamended SB backfill, the BW slurry was mixed with the base mixture and blended in the mixer machine until a targeted slump of 125 ± 12.5 mm was obtained [ASTM, 2015a (ASTM C143)]. The total bentonite content of the final SB mixture was 5.8% (by dry weight of the soil). Fig. 2 shows a typical slump test performed for the SB backfill mixture. To prepare the PRT and CRT amended backfills, a greater amount of slurry was required to be added to each mixture due to the difference in nature of the tyre with sand. Also, the amount of added dry bentonite was adjusted to maintain a similar total bentonite content for each PRT and CRT amended mixture. This modification was necessary to maintain a constant bentonite content in each backfill in order to compare the hydraulic conductivity and consolidation characteristics under the same condition. Table 1 shows the characteristics of each backfill

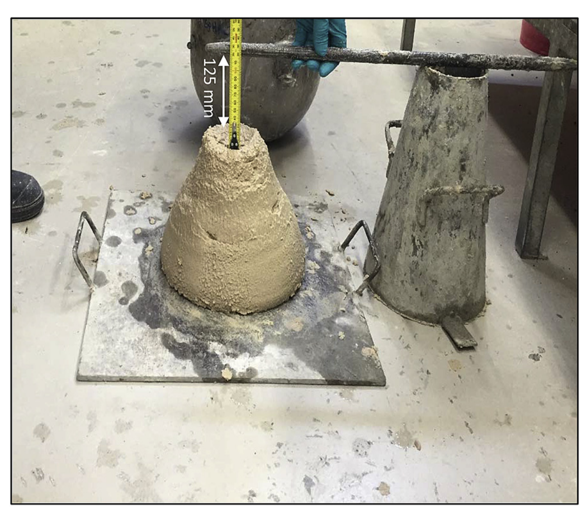

Fig. 2. A typical slump test performed on SB backfill.