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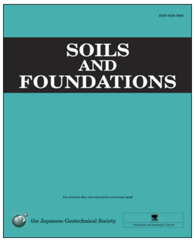

Thermal conductivity of compacted fill with mine tailings and recycled tire particles

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Abstract

With the advantages of a light weight and improved thermal insulation, recycled tire particles have been utilized as engineered fills either alone or mixed with other geomaterials. To better utilize recycled tire particles, the thermal conductivity of their mixtures with mine tailings is studied as affected by the water content, mixing ratio of tailings and tire crumbs, compactive effort, and size of tire crumbs. The results show a clear correlation between the thermal conductivity and bulk density of the mixtures. Furthermore, the horizontal thermal conductivity is slightly higher than the vertical thermal conductivity and the anisotropic effect is more pronounced for the mixtures with lower water contents. The experimental data are processed via an analysis of variance (ANOVA), and the results indicate that the factors included in the simulation are statistically significant at a confidence level of 95%. A multiple linear regression model is proposed to relate the thermal conductivity with the composition of mixtures and compaction conditions. The interpretation methods developed in this study can be extended to enhance the understanding to the thermal characteristics of compacted geomaterials in engineering applications.

Keywords: Tire crumbs; Mine tailings; Thermal conductivity; Compaction; Anisotropy; Statistics

1. Introduction

Geomaterials mostly consist of mineral solids, water and air at various proportions. The study on heat transfer through geomaterials is important in geoengineering applications such as oil and gas pipelines, high-power electric cables, radioactive waste disposal facilities, and ground heat exchangers. Thermal transport takes place through conduction, convection and radiation, in which conduction is most predominant in granular materials and the rate of heat transfer is quantified by the thermal conductivity. The thermal conductivity of a geomaterial is strongly dependent on the volumetric fractions of its constituents. The thermal conductivities of basic geomaterial constituents vary across several orders of magnitude, for example, mineral solids (order of 10 W/mK), water (order of 1 W/mK) and air (order of 0.01 W/mK).

In civil engineering applications, reusing solid wastes can be beneficial to reduce greenhouse gas emissions. The solid wastes that have a potential to be recycled for use as construction materials include scrap tires and mine tailings. Waste rubber tires exhibit low density, high durability, good thermal insulation, high energy absorption and relatively low cost. Edil and Bosscher (1994) assessed the engineering properties of soil-scrap tire mixtures such as compactivity, compressibility, permeability, strength and deformability. They concluded that the behavioral characteristics of scrap tires would be beneficial for practical applications. Scrap tires are grinded to particles of various sizes for

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practical purposes. According to ASTM D 6270 (ASTM, 2008), they classified into three distinct groups in particle size: tire shreds (50–305 mm), tire chip (12–50 mm) and granulated rubber (less than 12 mm), that is commonly known as tire crumbs (Edincliler et al., 2010). Studies on tire crumbs and soil-tire crumbs mixtures have been carried out extensively, including characterization of mechanical properties such as strength, stiffness, compressibility, and swell. Feng and Sutter (2000) performed torsional resonant column tests to investigate the shear modulus and damping ratio of granulated rubber-sand mixtures and presented the maximum shear modulus and minimum damping ratio with the percentage of rubber in the mixtures. Ghazavi (2004) carried out direct shear tests to examine the shear strength characteristics of sand mixed with granular rubber and demonstrated that the addition of 10–20% rubber to sand is optimal to achieve the highest friction angle. Lee et al. (2007) reported the small and large-strain response of sand and fine-grained rubber mixtures using wave propagation and triaxial testing, and identified the transition from a rigid to a soft granular fabric by increasing rubber fraction in the mixtures. Christ and Park (2010) explored the effect of subfreezing temperature on granulated rubber-sand mixtures, and stated that the ultrasonic velocities of compressional and shear waves increase with decreasing temperature. Patil et al. (2011) estimated the odometric swell behaviors of expensive clays mixed independently with silica sand and granulated rubber, and revealed that adding the stiff sand particles results in better swell mitigation than adding flexible rubber particles. Sheikh et al. (2013) investigated the shear and compressibility characteristics of sand-tire crumb mixtures, and addressed that the higher content of tire crumbs in the mixture causes the larger reduction in the shear strength, which is in contract with other studies where tire chips or tire shreds are used. Kaneko et al. (2013) analyzed the seismic response characteristics of tire crumbs and sand-tire crumbs mixtures by using online pseudodynamic response tests and stated that when tire crumbs were mixed with sand or placed as layers, significant damping and seismic isolation effects were achieved. In contrast, there are a few studies on the thermal conductivity of scrap tires and soil-tire mixtures. Shao and Zarling (1995) reported the results of thermal conductivity tests of pure tire chips/crumbs at different compactions. The estimated thermal conductivities ranged between 0.10 and 0.17 W/mK, which are comparable with those reported in Humphery et al. (1997). Humphery et al. (2002) measured temperature profile of an in-situ three-layer (soil-tire chip-soil) system under steady state condition and back-calculated the thermal conductivity of tire chips by using one-dimensional heat flow theory. The calculated thermal conductivity is in the range of 0.29 and 0.42 W/mK. Wappett and Zornberg (2006) monitored the thermal response of a full-scale tire shred-soil embankment over a period of 18 months and evaluated the thermal conductivity of tire shreds and soil-tire shreds mixtures. On the other hand, tailings from mining activities are ground rock particles from which valuable metals and minerals are extracted. Mine tailings are traditionally disposed of on-site in the form of impoundment. Since natural soils are often limiting at mine sites, non-acid-generating tailings are used for civil engineering structures (Sivakugan et al., 2006) and mine reclamation (Larcheveque et al., 2013). Fall et al. (2009) assessed the potential of bentonite-tailings mixtures as engineering barrier material for waste containment facilities. Qian et al. (2011) reported that the tailings-based pavement subbase has relatively high strength and stiffness that could meet the requirements of pavement. In combination, tire crumbs and mine tailings may be utilized in construction as structural fills. Knowledge of the thermal conductivity of tire particles and their mixtures with geomaterials is essential in analyzing the thermal interaction of buried engineered facilities.

This study is concerned with the beneficial use of tire particles as lightweight fill materials with enhanced thermal insulation. Non-acidic tailings from a mine site and tire crumbs were chosen for the study reasons discussed in the previous section. Thermal conductivity measurements were performed on wet mixtures of mine tailings and tire crumbs. Forty specimens were compacted under various water contents, mixing ratios of mine tailings and tire crumbs, compactive efforts and tire crumbs sizes in the laboratory. Experimental results were presented to illustrate the general relations of thermal conductivity with the influencing factors. The thermal conductivity anisotropy of the compacted mixtures was also observed. Statistical data analysis was conducted to identify the significance of these influencing factors. A stepwise multiple linear regression analysis was also carried out to establish an empirical model for predicting the thermal conductivity of the compacted mine tailings and tire crumbs mixtures.

Table 1
Physical properties of mine tailings and tire crumbs.

Properties	Mine tailings	Tire crumbs	
		Small size	Large size
Specific gravity, G_s	3.37	1.19	1.16
Effective size, D_{10} (mm)	0.0028	0.24	1.0
Median size, D_{50} (mm)	0.0256	0.46	2.1
Coefficient of uniformity, C_u	11.4	2.08	2.20
Coefficient of curvature, C_c	1.6	0.96	0.89

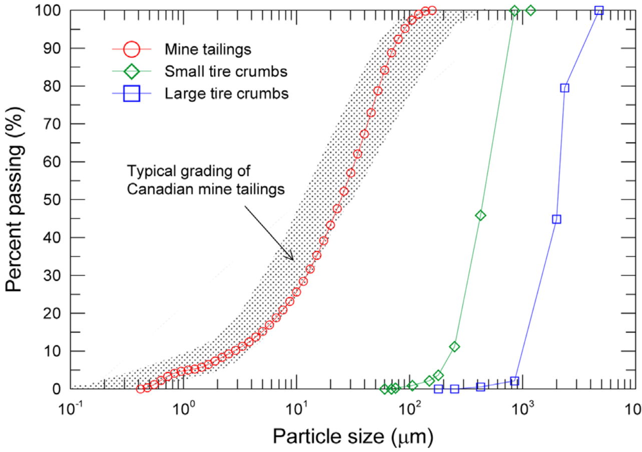

Fig. 1. Particle size distributions of test materials.