Effect of tire-chips on geotechnical properties of clayey soil

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Abstract

Use of tire-chips in construction projects, such as highway embankments, leachate collection systems, landfill cover, backfill material and similar projects is increasing world wide. This paper presents results of compaction, undrained triaxial and one-dimensional consolidation tests on compacted clay-tire chip mixtures, the tests were carried out with different mixing ration of tire-chips and clay. Laboratory investigations showed that by adding tire-chips in clayey soils, the cohesion of mixture is increased and angle friction is decreased. In addition, the results of consolidation tests indicate that when the tire-chip content increases within the mixtures, compression and swelling indices of the specimens decreases and increases, respectively. These experiments discuss the practical applicability of lightweight geomaterials which are made of tire-chips in civil engineering constructions.

Key words: Clay, Consolidation, Pore water pressure, Tire-chips, Undrained triaxial test.

1. Introduction

The value of scrap tires in stockpiles increases every year in the world. These materials cause environmental pollution and pose fire and health hazard. To manage this large volume of waste tires, in the last decade, innovative methods of recycling and reuse of the scrap tires were developed. According to Dickson et al. (2001), there are more than 500 million tires stockpiled across the United States, and 270 million more are generated each year. Official Iranian Statistics estimated that about 20 million tires were produced in Iran in 2005 and about 10 million scrap tires are added to the existing stockpile annually (Iranian Information Centre of Industries and Mines, 2006).

Waste tires have many properties which result in their being of value from a civil or geotechnical engineering perspective: low density, high strength, hydrophobic nature, low thermal conductivity, durability, resilience and high frictional strength. It is due to these properties that the use of tires has been specifically recommended in civil engineering applications such as lightweight material for backfill of retaining structures, drainage layer, landfill cover systems, reinforcement layer and similar projects. Many investigations have been carried out on the engineering properties of pure tire chips and /or sand-tire chip mixtures (Lee et al., 1999; Yang et al., 2002; Youwai and Bergado, 2004).

Ahmed (1993) conducted triaxial tests on tire shred-soil mixtures (tire shred size = 25 mm) with various mixing ratios. A tire shred-soil mixture ratio of approximately 40:60 by dry weight (65:35 by volume) was reported to produce maximum shear strength values at low to medium confining stresses. Results of consolidated-drained and consolidated-undrained triaxial tests showed that the peak strength of the rubber fiber-clay composite is comparable to or greater than that of clay alone when tested at confining stresses below 200–300kPa (Özkul and Baykal, 2007).

Venkatappa and Dutta (2006) showed that the sand tire chip mixtures up to 20% can be used in the construction of highway embankments up to around 10 m height. The friction angle of sand–shred mixtures increases by using optimum shred aspect ratio and depending on shred width and aspect ratio, shred content, and mixture compaction (Ghazavi and Sakhi, 2005).

Sarıca (2001) indicated that inclusion of 10% by weight tire buffings improves the compacted unsaturated strength of the low plasticity clay. Foose et al. (1996) investigated the shear strength of sand and tire shred mixtures and they found that Normal stress, shred content and sand matrix unit weight are quite important in determining the shear strength of such mixtures. Youwai and Bergado (2003) carried out drained triaxial compression tests on shredded rubber tire-sand mixtures. They showed that with an increasing proportion of sand in the mix, the strength and unit weight increased and deformation, due to isotropic compression, decreased.

Cetin et al. (2006) indicated that the shear strengths increase up to 30% for fine and 20% for coarse tire chip mixtures. Cohesion increases as the value of tire-chips increases up to 40% for both fine and coarse mixtures, while the angle of internal friction decreases. After 40%, however, while the cohesion decreases, the angle of internal friction increases.

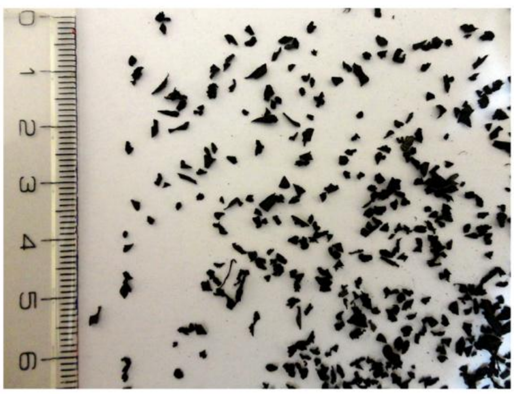
The main goal of this research is to evaluate the geotechnical properties of clay-tire chip mixtures for civil engineering applications. In this study, the compaction, undrain triaxial and consolidation tests were performed on several different clay-tire chip mixtures.

2. Materials and Test Methods

2.1 Material

The soil used in this study has index properties of LL=33%, PI=12% and G_S=2.698. This clay has been classified under the United Soil Classification System (USCS) as CL.

The tire chips which were derived from waste tires for this study is shown in Fig. 1. Average grain size of tire-chips was 1.275 mm (between No. 12 sieve and No. 20 sieve) and their specific gravity was 0.812. The particle size distribution of the soil and tire-chips can be seen in Fig. 2. Samples were prepared and tested at three different percentages of tire-chip content (i.e. 10%, 20% and 30% by weight).



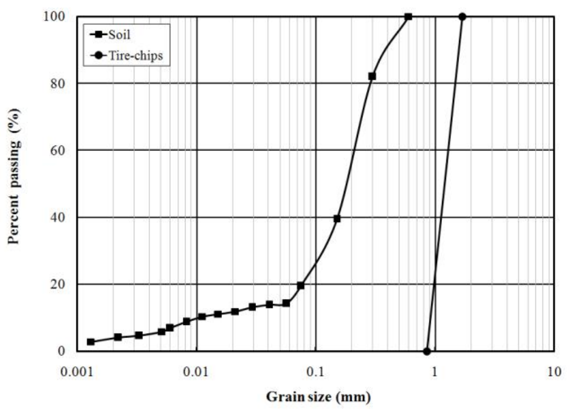


Fig 1: Photograph of tire-chips **Fig 2**: Particle size distribution curves

2.2 Test Methods

Prior to preparing the test specimens, the maximum dry unit weight and optimum water content were obtained. Standard proctor (compaction) tests were performed according to ASTM D698 on pure clay soil and clay-tire chip mixtures specimens.

Soil specimens for strength testing were prepared in the laboratory by a static compaction method. The specimens were compacted in a series of three layers of equal mass. The apparatus consists of an aluminum split mold that is bolted together prior to compaction and a series of aluminum plugs used to compact the different layers. The central layer is the first one to be compacted. Subsequent layers are then compacted on alternating sides of the central layer. The nominal dimensions of the compacted specimens, after all three layers are compacted, are 50 mm in diameter and 100 mm in height. In this research, the standard consolidated undrained triaxial compression tests with pore pressure and volume change measurements were conducted at effective confining stresses ranging from 100 to 300 kPa.

One-Dimensional consolidation tests were conducted in the conventional oedometer of 75 mm diameter and 20 mm thickness. The specimens were statically compacted in the oedometer ring in two layers. Free swelling was allowed under a seating surcharge of 5 kPa by allowing water into the specimen. After final heave was conducted, the sample was compressed under incremented vertical loads till initial void ratio (e) was attained.

3. Discussion of Test Results

The compaction tests' results on pure clay and clay-tire chip mixtures were shown in Table 1. The compaction test data depict two different observations: (1) the maximum dry unit weight systematically decreases with increasing tire-chip content and (2) the optimum water content is not significantly affected by the addition of tire chips to the soil.

No.	Sample Name	ω_{opt} (%)	γ_{dmax} (kN/m^3)
1	soil	19.50	16.35
2	10% tire-chips	19.46	14.84
3	20% tire-chips	19.00	14.31
4	30% tire-chips	18.89	13.59

Table 1. The compaction tests' results.

Triaxial undrained tests were performed to determine the shear strength and excess pore water pressure of the clayey soil and the clay-tire chip mixtures under different effective confining stresses. The triaxial response was examined by looking at the deviator stress and excess pore pressure versus axial strain. For example, the deviator stress and excess pore pressure have been plotted for pure clay specimen under different effective confining stress and samples under effective confining stress, σ'_c=300 kPa in Figs. 3~4, respectively. Variation of peak deviatoric stress and peak pore pressure versus tire-chip content are presented in Fig. 5. This figure shows that at low consolidation stress, maximum pore water pressure increases with an increase in tire content and at high consolidation stress, minimum excess pore water pressure occurs in specimen with tire content of about 10%. The test data showed that shear strength values for clayey soils are low compared to those for clay-tire chip mixture. In terms of variation of peak deviatoric stress versus tire-chip content it has been shown that by adding the tire chips to clayey soils, shear strength of mixture increased.

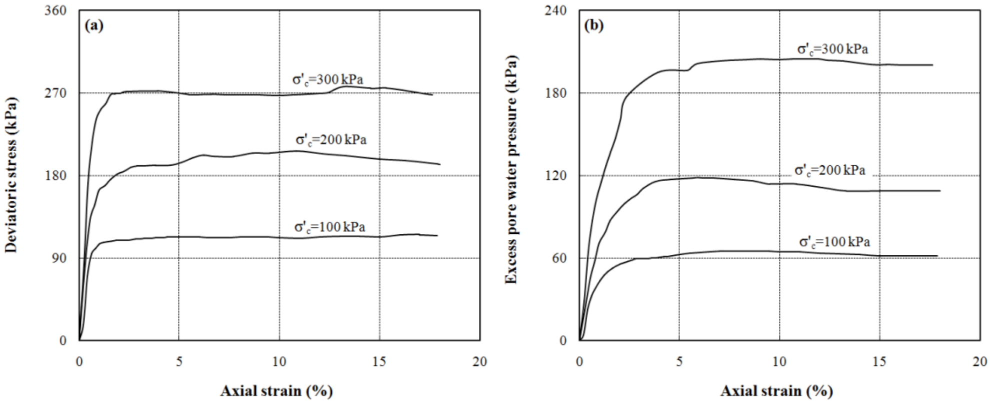


Fig 3: Variations of: a) deviatoric stress and b) excess pore water pressure versus axial strain, for soil specimen under σ'_c=100, 200 and 300 kPa.

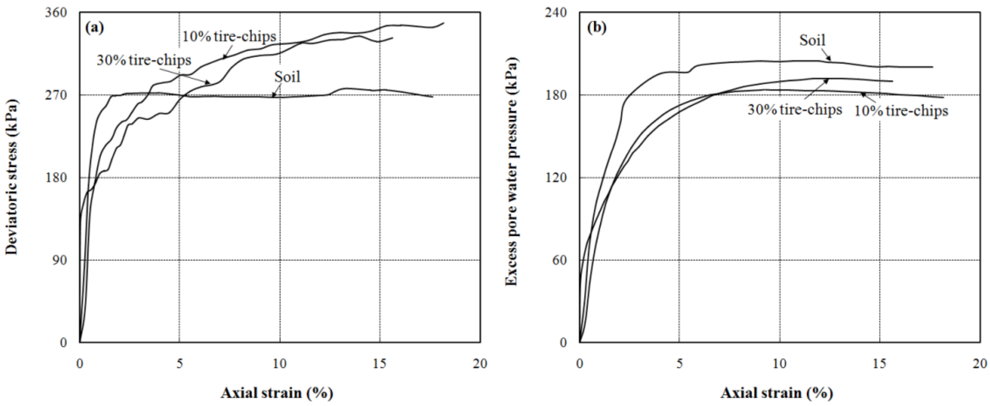


Fig 4: Comparison of test results of specimens under σ'_c=300 kPa:
a) deviatoric stress and b) excess pore water pressure versus axial strain

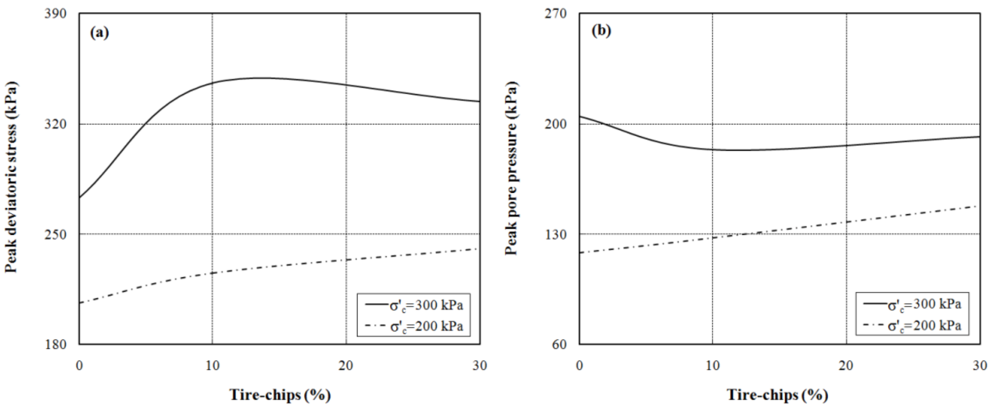


Fig 5: Variation of: a) peak deviatoric stress and b) peak pore pressure versus tire-chip content.

The result of the variation of cohesion and angle of internal friction versus tire-chip content for specimens is shown in Fig. 6. This variation indicated that the angle of internal friction decreased and the cohesion increased with an increase in chips content.

The amounts of the compression index, C_c and swell index, C_s were determined from the appropriate portions of the *e*-log *p* curves. The data of figures showed that as the tire chips increased in the mixtures, the initial void ratio of the samples decreased.
Fig. 7 shows the *e*–log *p* curves for the unreinforced and mixed specimens. Based on the results, the compression and swelling index of specimens were obtained and variations of these parameters with tire-chip content are illustrated in Figure 8. As displayed in Fig. 8 compression index of specimens decreases when the tire-chip content increases. Swelling index increases with increasing in the tire-chip content and increasing rate is negligible when tire-chip content varies from 20% to 30%.

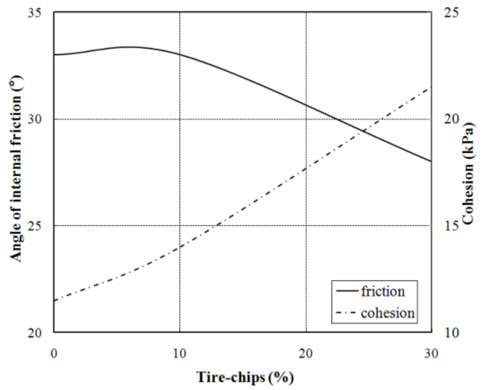


Fig 6: Variation of cohesion and angle of internal friction versus tire-chip content.

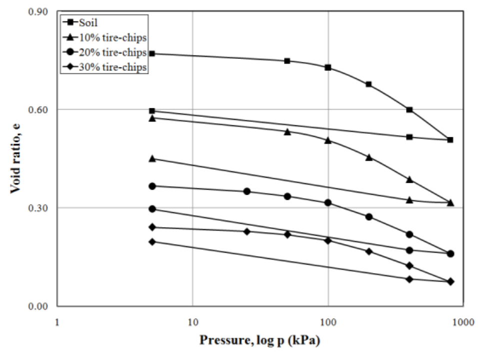


Fig 7: variation of void ratio versus pressure

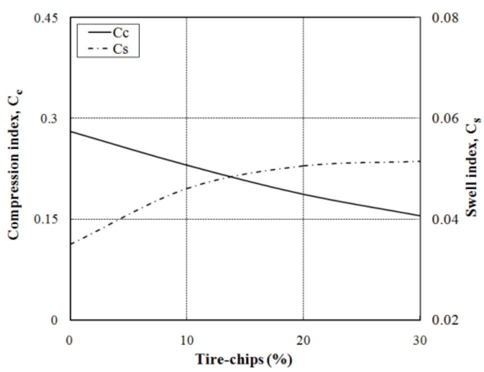


Fig 8: Variations of compression index and swell index versus tire chip content

4. Conclusions

The waste materials such as tire chips, polypropylene, polystyrene and polyethylene fibers can be used to improve the engineering properties of soils. Also this work can be of great value to recycling the waste materials so that environmental and health hazards are reduced in the world. In this study a series of laboratory tests, to evaluate the geotechnical properties, on pure clay and clay-tire chip mixtures were conducted. The results indicate that as the percent of tire-chips increases, the compression index decreases while the swelling index increases.

Özkul and Baykal's (2007) findings showed that the average hydraulic conductivity of clayey soils is around 2×10^{-7} cm/s which does not change significantly due to the inclusion of rubber fibers. According to result of the previous research and this study, because of the increase of shear strength, the decrease of pore water pressure and the lack of significant change in permeability as a result of adding tire-chips to clayey soils, it is found that the mixture of clay and 10% tire-chips can be used as impervious materials in dams. Based on the above findings and observations, the results indicate that the clay-tire chip mixtures up to 10% tire-chips can be used in embankment fill construction.

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