Experimental Determination of Waste Tire Chip-Sand-Geogrid Interface Parameters Using Large Direct Shear Tests

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Abstract
The interest in effectively designing tire chips and tire chips-sand fills creates the need for the development of testing procedures to evaluate the interaction properties of tire chips and tire chips-sand with geosynthetics through pullout testing and direct shear testing. This paper determines the interface shear strength parameters of tire chip-sand-geogrid using large direct shear test apparatus. For this purpose, tire chip–sand mixtures with mixing ratios of 0:100, 15:85, 25:75, 30:70, 35:65 and 100:0 by volume were used as fill materials. The mixture alone has been tested at a specified relative density and its shear strength parameters have been obtained as references to which shear strength parameters of tire chip-sand-geogrid interface will be compared at the same compaction degree. In all tests, the mixture has been poured in a half shear test apparatus box and the geogrid layer has been located on it and then the rest of the half box has been filled with mixture. The normal stress has then been applied and the test has been carried out to the terminating stage. In all tests, the shearing velocity has been kept the same. Four normal stresses have been applied in all tests. The angle of friction and cohesion for each mixture are presented. Also, the influence of the different parameters is discussed.

Key words: shear strength, geogrid, waste tires, direct shear test, tire chip-sand-geogrid mixtures

1. Introduction

The use of tire waste in civil engineering applications can reduce the tire disposal problem in an economically and environmentally beneficial way. In addition to these, tire wastes have unique properties for many geotechnical applications. Tire wastes can be used in highway and earthwork construction as lightweight fill material for retaining wall backfills and embankments, or in landfill applications as drainage material, leachate treatment medium, and thermal insulator. By using different processing techniques different sized and shaped tire waste can be obtained, like granular or fiber-shaped tire wastes. Properties of tire wastes such as durability, strength, resiliency, and high frictional resistance are of significant value for the design of highway embankments. The mixture of processed tires with soil for embankment construction may not only provide alternative means of reusing tires to address economic and environmental concerns, but also help solve geotechnical problems associated with low soil shear strength (Edincliler et al., 2010). Previous studies (Ahmed and Lovell, 1993; Edil and Bosscher, 1994; humphrey et al., 1998; Lee et al., 1999) showed that scrap-tire can be used as a lightweight backfill material for embankments and retaining walls. Certain field and laboratory studies also indicated that the use of tire chip-soil mixture, which is defined as a blend of scrap tire chips and soil mixed in various proportional, can potentially enhanced the stability of foundation and reduce settlements in problematic areas.

Edil and Bosscher (1994) concluded that addition of 25% chips (size 20–80 mm) to sand results in shear strength (obtained by direct shear test) slightly greater than that of dense sand at low normal stresses. At higher normal stresses (76 kPa), the result was not as pronounced. Edincliler et al. (2004) conducted large-scale direct shear tests on specimens composed of sand and various percentages of tire buffings. It is reported that addition of tire buffings to sand increased the strength at low confinement pressures.

Gotteland et al. (2005) carried out 9 series of consolidated drained (CD) triaxial compression tests of which the specimens were composed of mixing sand and tire chips by varying the tire content and the orientation of chips. The results indicated that the strength increases with the increase in tire content up to an optimum percentage mass of 34%, after which the shear strength decreases. Venkatappa Rao et al. (2006) performed a drained triaxial compression tests to investigate the behavior of sand with and without tire chips. The varying test parameters in triaxial tests were confining pressure, percentage of tire chips, and size of tire chips. The results of drained triaxial tests revealed that the tire chip–sand admixtures up to 20% chip content behave like gravel–sand mixtures, the strength showing a marginal improvement. Ahmed (1993) used triaxial testing apparatus to study the shear strength properties of waste tire particles in various size and shapes. He reported that adding tire chips increases the shear strength of sand, with angle of friction up to 65 obtained for dense sand with 30% tire chips. Zornberg and Cabral (2004) concluded that an optimum percentage of tire shreds, where a maximum shear strength was attained, occurred at approximately 35% by mass of tires. The volume variations observed were similar to the results reported by Youwai and Bergado (2003).

Edil and Bosscher (1992) conducted direct shear tests on sand reinforced with tire shreds. They found that a random addition of 10% shreds by volume to outwash sand gives greater shear strength than of the sand tested alone. Foose et al. (1996) conducted comprehensive large direct shear tests on sand reinforced with tire shreds. They found that normal stress, shred orientation, compaction degree of sand–tire mixtures, shred contents, and shred length had influence on shear strength parameters of the mixtures. Among them, vertical stress, shred contents, and mixture compaction had greater effects. Foose et al. (1996) obtained an

initial angle of friction of 67° for sand reinforced with shreds, whereas the sand alone had a friction angle of 34° at the same sand matrix unit weight.
To use tire chips or tire chip-sand mixtures as backfill behind geosynthetic-reinforced walls and embankments, interaction properties between the backfill and geosynthetics are required. Bernal et al. (1996, 1997) performed pull out tests on geogrids using tire chips as backfill and obtained interaction coefficients lower than common interaction coefficients for geogrids with soils. They suggest that lower interaction coefficients may occur because the shearing areas above and below the geogrids are not fully developed, and thus the maximum shear stress is not mobilized along the geogrid layer.
The Objective of the present study is to investigate the shear strength and geosynthetic interaction of tire chips or soil-tire chip mixtures that might be used for geosynthetic reinforced retaining walls or embankments on soft ground. Tests were conducted to characterize the interaction of soil-tire chip mixtures with geogrid during direct shear, as well as the shear strength of soil-tire chip mixtures. For this purpose, a series of large direct shear tests have been carried out on mixtures of sand and tire chips with six different percentages of tire chip: 0, 15, 25, 30, 35 and 100% by volume.

2. Testing Program

2.1. Test Equipment

A large direct shear apparatus with dimensions of 300 mm×300 mm was used to carry out the tests. Three actuators controlled by computer facilitate the equipment movements. The horizontal actuator has a maximum load capacity of 50 kN and is connected to a 50 kN tension/compression load cell. Horizontal and vertical displacements are controlled by an internal displacement transducer.

2.2. Materials Tested

A relatively uniform sand with angular shape of particles was used as soil in the experimental program. The grain size distribution of the sand is shown in Fig 1. Dry sand has a coefficient of uniformity of 1.62, a coefficient of curvature of 1.38, and a specific gravity of 2.67. Using these values and the Unified Soil Classification System (USCS), the sand can be classified as SP, uniform graded sand. Also, a peak friction angle of the sand for density of 1400 kg/m^3 is 30.2°.
Tire chips used in this study is a granular material obtained by processing scrap tires. Fig. 1 shows the grain size distribution of the tire chips. The specific gravity of the free-steel tire chips was measured 1.20.
One type of geogrid was used for interface tests. Fig. 2 shows the geogrid specimen that has been used in tests. Also, Table 1 presents the properties of the geogrid provided by the manufacturer.

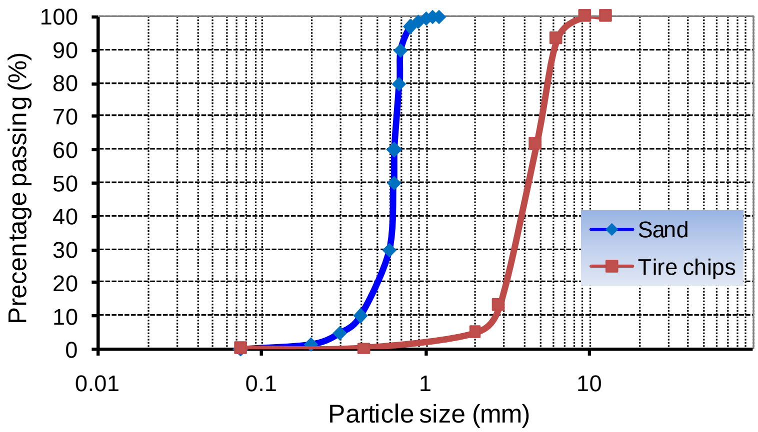

Fig 1: Grain size distribution of sand and tire chips

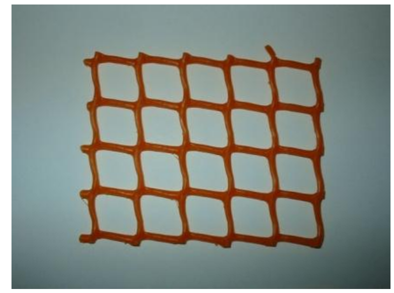

Fig 2: Geogrid specimen

Geogrid	Aperture size (mm)	Thickness (mm)	Mass per unit area (gr/m2)	Tensile strength (kN/m)
A	12	3	340	4.68

Table 1. Properties of geogrid

2.3. Test procedure

In the test program, six tire chip contents of 0, 15, 25, 30, 35 and 100% by volume have been used. For preparation of sand-tire chip mixtures and to determine tire chip contents in each mixture volumetric basis was used instead of gravimetric basis. A volumetric specification would be more easily implemented in the field, for example, by courting the relative number of truck loads of soil and chips (Foose et al., 1996).

As a unified criterion for similarly compacted mixtures, matrix unit weight for the sand was used. This is defined as the weight of the sand divided by the volume of sand matrix (Foose et al., 1996; Ghazavi and Amel Sakhi, 2005b). In current tests, this unit weight was $\gamma_m = 14\ \mathrm{kN/m^3}$.

For various mixtures, the weights of sand and tire chips were calculated and mixed uniformly. In the present experiments, care was taken to distribute the tire chips randomly in the mixtures as much as possible. This was controlled by eye observation.

In all tests, the tire chip-sand mixtures has been poured in a half shear test apparatus box and the geogrid layer has been located on it and then the rest of the half box has been filled with tire chip-sand mixtures. The normal stress has then been applied and the test has been carried out to the terminating stage (shear displacement 25 mm).

The unit weight of samples with various mix ratios is presented in table 2. The normal stresses applied to the samples were 2 kPa, 30 kPa, 60 kPa, and 90 kPa. The shear rate selected for all the tests was 1 mm / min. All samples were tested under strain controlled condition.

Tire chip content (%)	0	15	25	30	35	100
Unit weight (kN/m^3)	14	13.7	13.5	13.4	13.3	7.5

Table 2. Unit weight of samples

3. Test Results

The direct shear tests were conducted on tire chip-sand mixtures to evaluate the mixture shear strength parameters (cohesion “c” and friction angle “φ ”), and on geogrid reinforced samples to evaluate the interface parameters between geogrid and tire chip-sand mixtures (adhesion “ca” and interface friction angle “δ”). The results of direct shear tests include the determination of shear stress–shear displacement variation for tire chip-sand-geogrid interface at different normal stress.

As two examples, Figs 3 and 4 present the shear stress–shear displacement and vertical displacement-shear displacement variation for tire chip-sand mixtures at normal stress of 90 kpa, respectively. Increasing the percentage of the tire chips content increased the shear stress.

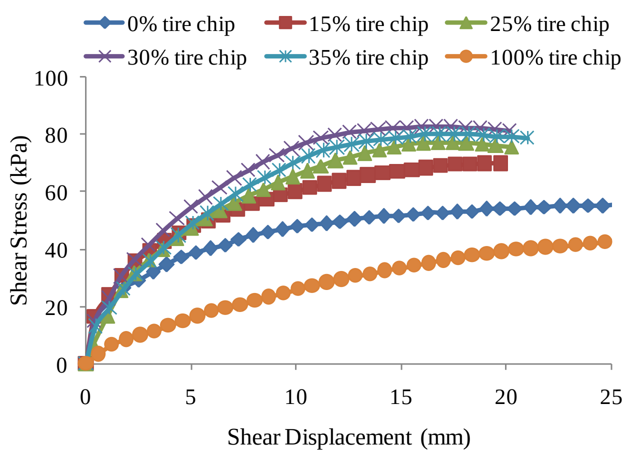

Fig 3: Variation of shear stress versus shear displacement for tire chip-sand mixtures at normal stress of 90 kPa

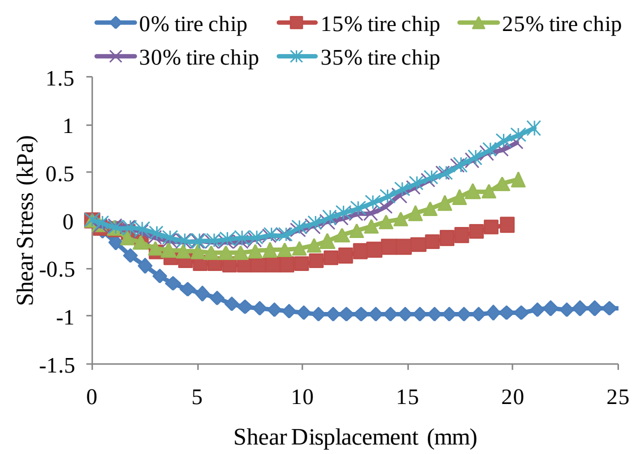

Fig 4: Variation of vertical displacement versus shear displacement for tire chip-sand mixtures at normal stress of 90 kPa

As an overall view, Fig 5 shows the variation of maximum shear stress with tire chips content. It is observed in the Fig 5 that the shear strength increases with the increase in tire content up to an optimum percentage volume of 30%, after which the shear strength decreases, specially at high normal stress.

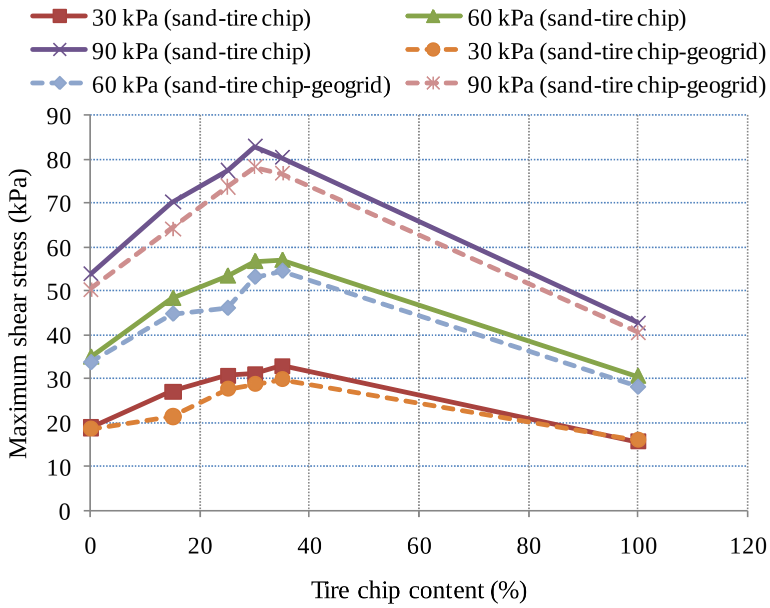

Fig 5: Variation of maximum shear stress with tire chip content at different normal stress

The shear stress-normal stress variation for tire chip-sand mixtures and tire chip-sand-geogrid interface is presented in Figure 6 and 7, respectively.

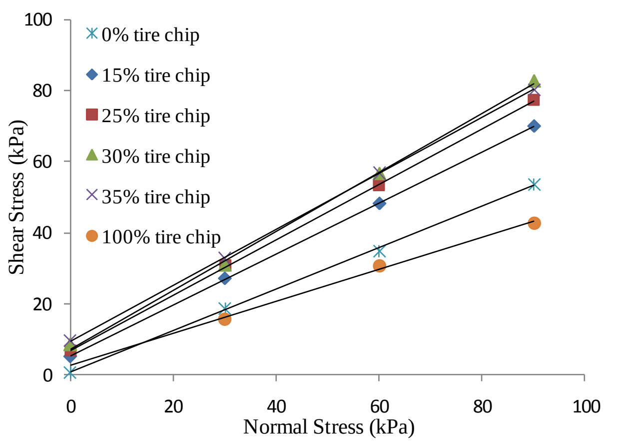

Fig 6: Shear stress-normal stress variation for sand-tire chip mixtures with various mix ratios

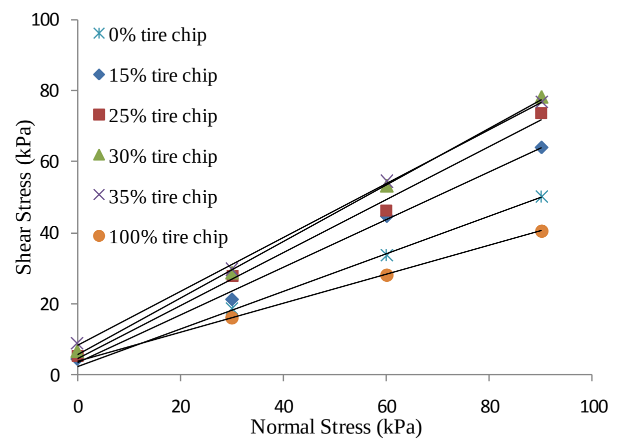

Fig 7: Shear stress-normal stress variation for sand-tire chip-geogrid interface with various mix ratios

The variation of the internal friction angle with tire chip contents is shown in Fig 8. As can be seen from the Fig. 8, the internal friction angle increases with increasing tire chip content and reaches a maximum for a tire chip content value around 30% and then decrease for tire chip contents beyond this value.

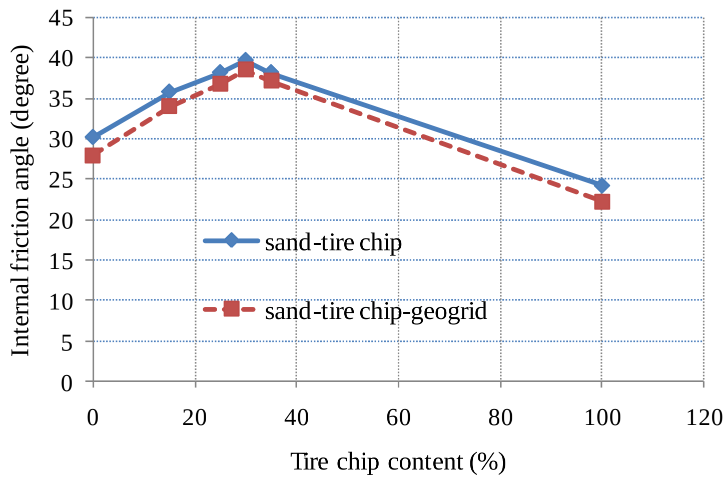

Fig 8: Variation of internal friction angle with tire chip content

Angle of friction (φ, δ) and cohesion (c) were calculated after plotting Mohr envelope. An equivalent angle of friction (φ_{eq}, δ_{eq}) was also calculated considering the cohesion as being zero. This data can be used in order to simplify the comparison between the different mix ratios. Table 3 depicts the internal friction angle of tire chip-sand mixtures and tire chip-sand-geogrid interface.

Material	Parameter	Percentage of tire chips (% by volume)					
		0	15	25	30	35	100
Sand-tire chip	c (kPa)	0.8	5.1	6.8	7.3	9.4	2.5
	φ (deg.)	30.2	35.8	38.2	39.7	38.2	24.2
	φ_{eq} (deg.)	30.7	38.4	41.3	43	42.6	25.9
Sand-tire chip-geogrid	c (kPa)	2.3	3.3	4.5	5.8	8.3	3.7
	δ (deg.)	27.9	34	36.7	38.5	37.2	22.2
	δ_{eq} (deg.)	29.2	35.8	39	41.4	41.4	24.7
-	$\tan\delta_{eq}/\tan\varphi_{eq}$	0.94	0.9	0.92	0.94	0.96	0.94

Table 3. Shear strength parameters of sand-tire chip mixtures and sand-tire chip-geogrid interface

Based on the test results, at a same normal stress, the shear strength of tire chip-sand mixtures is greater than that of the sand alone. Also, the shear strength increases with the increase in tire content up to an optimum percentage volume of 30%, after which the shear strength decreases, specially at high normal stress. This trend is similar to findings of Humphrey et al. (1993), Foose et al. (1996), and Bernal et al. (1996). Foose (1993) shows, however, that the strength decreases when the tire chip content increases beyond 30% because the sand-tire chip mixture behaves less like reinforced soil and more like a tire chip mass with sand inclusions. The direct shear stresses of the sand-tire chip mixtures, at the same normal stresses were higher than those with geogrid reinforcements because there were no reinforcements blocking the contact area of the mixtures at the shear plane. Therefore, the direct shear stresses were mobilized fully at the shear plane.

4. Conclusions

The interaction between geogrid reinforcement and sand-waste tire chip mixtures were studied by large-scale direct shear tests. For this purpose, tire chip–sand mixtures with mixing ratios of 0:100, 15:85, 25:75, 30:70, 35:65 and 100:0 by volume were used as fill materials. The tests were performed under four values of normal stress. Samples were sheared at constant rate of 1 mm / min. It has been found that tire chip contents and normal stress are influencing factors on shear strength of the mixtures. From the test results the following conclusions are drawn:

- The shear strength and friction angle increase with increasing tire chip content and reach a maximum for a tire chip content value around 30% and then decrease for tire chip contents beyond this value.
- Dilation characteristics were observed in sand-tire chip mixtures and sand-tire chip-geogrid mixtures, especially in samples having greater tire chip content.
- Adding tire chip increases the shear strength of sand and sand-geogrid interface, with angle of friction up to 39.7 and 38.5 obtained for sand with 30% tire chips, respectively.
- The ratio of interface friction angle to the angle of internal friction of sand-tire chip mixtures ($\tan\delta/\tan\varphi$) increases with increasing of tire chip content.

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