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Shear behavior of waster tire chip-sand mixtures using direct shear tests

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ABSTRACT: In this paper, waste tire chips in various contents have been added to sand to investigate changes in shear strength parameters of the sand. The chip-sand mixtures are composed of two types of relatively uniform sand and tire chips in two grain size distribution. The sand is granular shaped. Four chip contents of 15, 30, 50, and 100% by volume have been chosen and mixed with the sand to obtain uniformly distributed mixtures. Two moisture contents and two compaction states have been considered. The results show that the influencing parameters on shear strength characteristics of sand-chip mixtures are normal stress, sand matrix unit weight, chip content, and moisture content. Moreover, the initial friction angle is mostly affected by compaction and moisture content. From environmental viewpoint and based on findings in this paper, it appears that if mixtures of tire chips and sand are mixed and properly confined, they can be used as lightweight materials for backfilling in highway applications.

1 INSTRUCTION

Typically waste tires are disposed in huge open piles, causing the environmental problems. Thus, finding appropriate applications for them are necessary. Nowadays, waste tires are used for reinforcing soft soil in road construction (Bosscher et al., 1997), to control ground erosion (Poh and Broms, 1995), for stabilizing slopes (O'Shaughnessy and Garga, 2000a), as lightweight material for backfilling in retaining structures (Bosscher et al., 1997; Tatlisoz et al., 1997; Allman and Simundic, 1998; O'Shaughnessy and Garga, 2000a), as aggregates in leach beds of landfills (Hall, 1991; Ahmed and Lovell, 1993), as an additive material to asphalt (Foose et al., 1996; Heimdhal and Druscher, 1999), as sound barriers (Hall, 1991), as limiting for freezing depth (Humphrey et al., 1997), as a source for creating heat (Lee et al., 1999), as a fuel supplement in coal-fired boilers (Ahmed and Lovell, 1992), for vibration isolation (Eldin and Senouci, 1993), as cushioning foams (Ahmed and Lovell, 1992), for low strength but ductile concrete (Eldin and Senouci, 1003), for varying shear strength parameters of soils (Foose et al, 1996; Lee et al., 1999; Ghazavi, 2004, Ghazavi and Amel Sakhi, 2005a), and for CBR improvement (Ghazavi and Amel Sakhi, 2005b).

In the present study, large direct shear tests were carried out on rubber particles mixed with sands. The main goal of the tests was to investigate the influence of the waste tire particles on shear strength parameters of tire chip-sand mixtures as lightweight materials.

2 MATERIALS

Two types of relatively, uniform and rounded sand (S_1, S_2) and two types of waste tire chips (R_1, R_2) were chosen for present experiments. Various contents of waste tire chips have been mixed with sand at two loose and slightly dense states in two dry and saturated conditions. The sand alone was tested in direct shear tests. The grain size distribution was obtained based on ASTM D854-63 (1995). Figure 1 shows the grain size distribution of sands and tire chips.

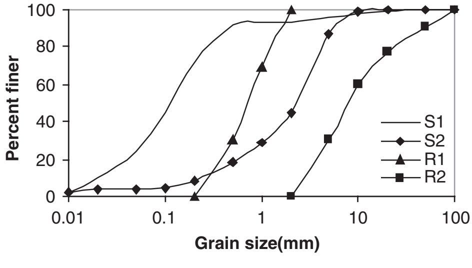

Figure 1. Particle size distribution of sands and chips.

Table 1. Properties of two types of sand.

Description	Value		
Sand type		S_1	S_2
Effective size, D_{10}		0.02	0.35
D_{30}		0.08	1.1
Mean size, D_{50}		0.11	2.71
D_{60}		0.15	3.2
Uniformity coefficient		7.5	9.14
Curvature coefficient		2.13	1.1
Unit weight at lower compaction (kN/m^3)		14.8	15.9
Unit weight at higher compaction (kN/m^3)		19	2.88
Friction angle at lower compaction (degree)	Dry	40	41
	Saturated	18	35
Friction angle at higher compaction (degree)	Dry	42	51
	Saturated	26	43
Specific gravity		2.64	2.67
Sand classification	Sandy silt		SW

Table 2. Unit weight of various sand-chip mixtures.

Mixture unit weight (kN/m^3)				
	Sand			
	S_1		S_2	
Chip content (%)	Loose	Dense	Loose	Dense
0	14.8	19	15.6	20.2
15	13.9	17.9	15.4	19.1
30	13.93	17.2	14.5	17.8
50	13.43	16	14.5	17.2
100	5.2	6.1	5.2	6.1

A value of 2.64 and 2.67 were measured for the specific gravity of S_1, and S_2 according to ASTM D92-854 (1995). The minimum and maximum values of unit weights of S_1 were 14.8 kN/m^3 and 19 kN/m^3, and for S_2 were 15.9 kN/m^3 and 20.2 kN/m^3, respectively using the procedure described in loose and dense case by ASTM D4254, and ASTM D4253 (2003). Other details of the sands are presented in Table 1.

A special simple machine was developed by local industries to produce chip from waste tires. The produced chip grains were granular and angular. An average value for the specific gravity of the chip grains was found to be about 1.1 as tested several times based on ASTM D854-92 (1992).

3 TESTING PROCEDURE

Small direct shear test apparatus with square mold having a width of 63 mm was used to perform shear tests on sand-chip samples. The thickness of samples depended on tire chip content. The tests were carried out based on the procedure described by ASTM D 3080-99. In all tests, three normal stresses of 49.05, 98.1, and 147.15 kN/m^2 were used. Samples consisting of sands alone, tire chip alone, and various mixtures of sand-chip were tested. A matrix unit weight for the sand is used, as defined and used by others (Foose et al., 1996; Ghazavi and Amel Sakhi, 2005a; Ghazavi and Amel Sakhi, 2005b).

Numerical calculations were made to determine the amount of the sand and the chip grains for each mixture and after that poured in a container. The materials were then carefully mixed with a blade. The mixed materials were poured steadily into the shear box with a circular motion using the blade. At each stage, the materials in the container were mixed by means of the blade and then poured in the shear box. Segregation did not occur during sample preparation and transferring into the shear box. This was controlled carefully by a continuous mixing the materials in the container and with careful observation.

To obtain loose mixtures, the mixtures were poured in the shear box from a very low height. For preparing slightly more compacted samples, a square steel plate was located at the top of the sample. Then a weight with a mass of 0.5 kg was dropped from a height of 15 cm on the plate five times. Table 2 shows unit weights of loose and slightly compacted samples. For saturated case, the procedure was repeated to a situation when the shear box became full of water for 8-12 hours each time, depending on the grain size of tire chip and sand.

When a certain chip-sand mixture was prepared at a prescribed sand matrix unit weight, the normal stress was applied and then the sample was sheared. The procedure was identically repeated for another normal stress. All shear tests were conducted using a controlled-displacement procedure. The shear rate in standard direct shear test instrument is normally controlled by an electric motor and a multi-speed drive unit, typically providing 240 speeds ranging from 5 mm/min to about 0.0003 mm/min (Head, 1982). In the present experiments, the shear rate was 0.5 mm/min and this was kept constant for all tests. This speed was suitable for shearing mixtures containing sand S_1. According to ASTM D3080 (1999), all tests were continued until the shear stress becomes essentially constant or until a maximum shear deformation of 7 mm has been reached. The maximum shear stress, in almost all samples, was achieved at deformation less than 7 mm (Figures 6 and 7). The inclusion of all figures in this paper makes the paper lengthy. Only a limited number of them are presented here.

Figures 2 and 3 illustrate the variation of shear stress versus normal stress for S_1 mixed with R_1 in two moisture contents for various chip contents of the loose

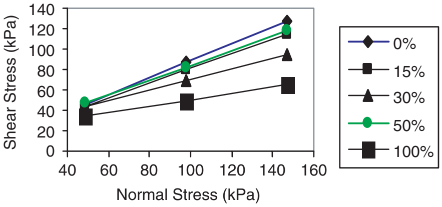

Figure 2. Variation of shear stress with normal stress for loose dry samples containing $S_1 + R_1$.

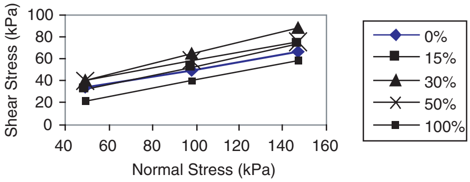

Figure 3. Variation of shear stress with normal stress for loose saturated samples containing $S_1 + R_1$.

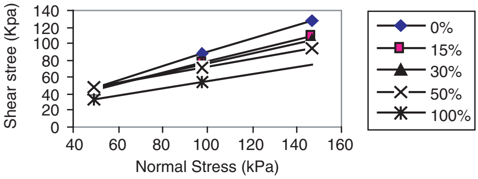

Figure 4. Variation of shear stress with normal stress for loose dry samples containing $S_1 + R_2$.

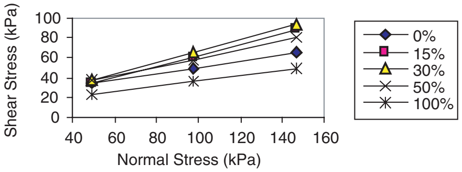

Figure 5. Variation of shear stress with normal stress for loose saturated samples containing $S_1 + R_2$.

mixtures. Figures 4 and 5 illustrate the variation of shear stress versus normal stress for S_1 mixed with R_2 in two moisture contents for various chip content of the loose mixtures. Similar trends were observed for mixture in slightly compacted and sand S_2 at the same condition (Alimohammadi, 2005).

4 RESULTS FOR SAND-CHIP TIRE LOOSE MIXTURES

Figures 6 and 7 show the variation of shear stress versus horizontal displacement for various chip grain content of the loose mixtures having S_1 with R_1 in dry and saturated conditions, respectively. The normal stress was 98.1 kPa. As seen, for all chip grain contents in the mixtures, except 100%, a peak shear stress is observed, explaining shear strength of the mixtures.

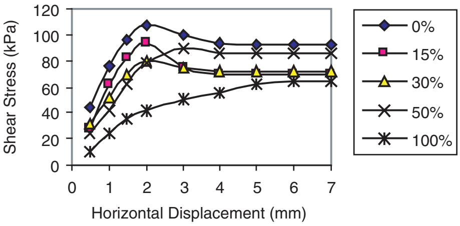

Figure 6. Variation of shear stress with horizontal displacement for slightly compacted $S_1 + R_1$ mixtures and at normal stress of 98.1 kPa in dry state.

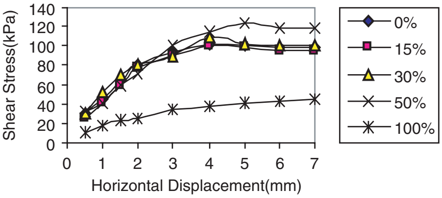

Figure 7. Variation of shear stress with horizontal displacement for loose with $S_2 + R_2$ mixtures and at normal stress of 147 kPa in saturated state.

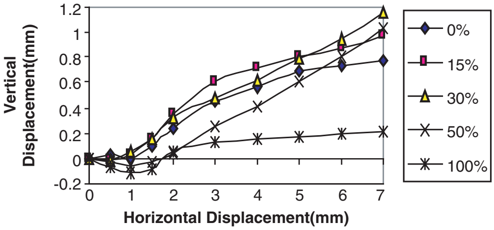

Figure 8. Variation of vertical displacement whit horizontal displacement for slightly compacted whit $S_1 + R_1$ mixtures under 98.1 kPa in dry states.

Figures 8 and 9 show the variation of vertical displacement versus horizontal displacement for slightly compacted $S_1 + R_1$ mixtures under 98.1 kPa in dry and saturated conditions, respectively.

Figure 10 illustrates the variation of initial friction angle versus chip content for $S_1 + R_1$ mixtures in dry and saturated state with loose and slightly compacted samples.

Some remarks may be extracted from Figures 2–11 as follow:

1) For a given normal stress applied on specimens, the shear resistance of the sand-chip mixtures is

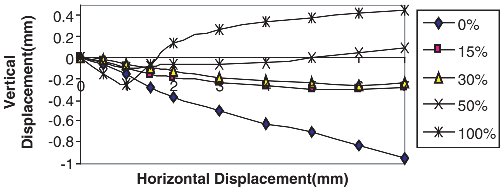

Figure 9. Variation of vertical displacement whit horizontal displacement for slightly compacted whit $S_1 + R_1$ mixtures under 98.1 kPa in saturated states.

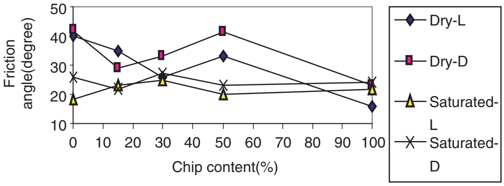

Figure 10. Variation of initial friction angle versus chip content for $S_1 + R_1$ mixtures in dry and saturated state with loose and slightly compacted samples (L = Loose ; D = Dense).

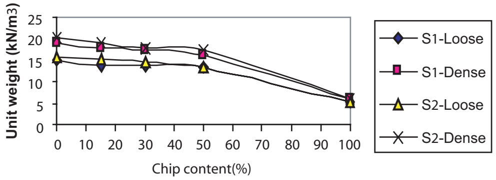

Figure 11. Variation of mass density of different mixtures versus chip contents at two compaction states for $S_1 + R_2$ mixtures.

greater than that of the sand alone at the same compaction state, especially in saturated samples containing 30% chips. However, this phenomenon for dry condition is revered and shear resistance in mixtures is smaller than that of the sand alone.

2) A relatively clear peak can be observed in shear resistance of almost all mixed samples, regardless of compaction level and chip contents, except for pure chips for which the shear stress still increases slightly with increasing the horizontal deformation in dry state. For saturated samples, the shear stress peak is not reached and it still increases slightly with increasing the horizontal deformation (Figures 6 and 7).
3) The inclusion of chip grains decreases the shear resistance of the mixtures in dry state whereas it tends to increase in saturated cases.
4) The shear resistance of the mixtures does not increase in a regular manner with increasing chip.
5) An apparent cohesion is obtained in samples containing chips.
6) The Mohr-Coulomb envelope is almost linear. The linear envelope obtained in the present paper is similar to that found by Tatlisoz et al. (1997) who mixed sandy silt with tire chips with dimensions of 11–33 mm and tested in large direct shear test apparatus. In the present experiments, the same trend was observed for saturated mixtures. It should be noted that the use of larger reinforcing tire shreds mixed with sands may result in nonlinear envelopes (Foose et al., 1996; Ghazavi and Amel-Sakhi, 2006). Nonlinear envelopes were also reported by Gray and Ohashi (1983) for fiber-reinforced dense sand. It seems that small grain sizes of chip mixed with sand and distributed randomly in sand-chip mixtures make a continuum material and have a granular behavior. Thus, it is likely to have a linear behavior in Mohr-Coulomb envelope similar to pure sand (Ghazavi, 2004). In contrast, randomly distributed discontinuous long inclusions such as shreds, strips, and fibers in the mixtures can cause nonlinearity in Mohr-Coulomb envelopes.
7) When a normal stress of 98.1 kPa is used, slightly compacted mixtures containing chip grains in all content of chip in mixture, at first until a little displacement condensed and then dilated under shear stress. The dilation of mixtures increases with increasing chip volume. It is significant in dense state with high content of chip. The sand alone dilates after a small compressing. These findings are I agreement with those reported by Lee et al. (1999), who found that rubber-sand mixtures tend to contract initially and then begin to expand. This is a typical behavior of sands, but the range of strains for which there is contraction is wider than that for sands, and dilation much less in saturated condition and in slightly compacted state for S_1+R_1 mixtures. All mixtures present smooth variations in vertical displacements upon shear displacements, except mixtures containing 100% chips. In such mixtures, the samples show clearly dilation characteristics.
8) The initial friction angle (ϕ) of dry mixtures containing up to 15% chips by volume initially decreases. By the use of chip contents in excess of 15%, ϕ increases and then decreases. For saturated loose mixtures, ϕ first increases slightly with increasing chip contents up to 30% and then decreases smoothly toward the friction angle of the sand alone. In compacted mixtures, there is no significant change in the friction angle values in terms of chip content variation in the mixtures.

The values of initial friction angle for different sand-chip mixtures at two compaction conditions and at two moisture contents are shown in Figure 10. The results for sand and tire chips alone are also shown at the same compacted effort and saturated conditions to demonstrate the effectiveness of chip inclusion. Figure 10 clearly shows that the addition of chip to sands cannot increase the friction angle effectively.

5 CONCLUSIONS

In the present research, shear strength behavior of sand-tire chip grain mixtures have been investigated in order to assess their use as a lightweight backfill material. Small direct shear apparatus has been used to determine the influence on shear response of waste tire chips mixed with two types of sand. Tire chips alone, sand alone, and sand-tire chip mixtures having 15%, 30,% and 50% waste tire chip by volume have been used. Two different compaction degrees, two size of gradation for chips and sand and two dry and saturated conditions have been considered. An apparent cohesion is obtained in samples containing chip grains. Moreover, adding tire chips to sand decreases the friction angle in both cases of moisture contents. Within the materials used and regardless of moisture contents and compaction degrees, it has been generally shown that an addition of tire chips to sand the friction angle does not vary significantly, but light mixtures are obtained which can be used as lightweight material for back-filling. Also the mixtures of tire chips and sand can be used as a free draining material in construction of subgrade where water table level is close to the ground. Dilation characteristics have been observed in sand-chip mixtures, especially in samples having greater tire chip content and more compaction. For dry and saturated mixtures, dilation has delay versus dry state.

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