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Granular Lightweight Fill Composed of Sand and Tire Scrap

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ABSTRACT: A granular lightweight fill was proposed by blending sands with tire scrap in proportions. To research its deformation behavior helps understand its mechanical properties and determine the ground settlement in the fields. A laboratory investigation was conducted to disclose the materials' compression and shear deformation behaviors. Three tests were implemented, i.e., 1-D compression tests, direct shear tests and consolidated drained triaxial compression tests. A compression strain-load model was proposed to describe its compression behavior. Rebound-reload tests revealed that materials' plastic deformation was associated with the mixing ratios. The materials' shear stress-shear displacement curves were simulated using a hyperbolic model. Deviatoric stress-axial strain-volumetric strain curves were observed. Lightweight fills underwent contraction during shearing process, which is different from the shear dilation behavior of compact sands. Effects of mixing ratios and stress conditions on shear deformation behaviors were also discussed. The efforts described in the paper not only provide technical data usable for deformation analyses, but also prompt the reuse of disposed tires to engineering domains.

INTRODUCTION

Along with the escalating development of global auto industry, disposable tires are becoming one of overwhelming solid byproducts. According to the statistics (CRIA 2006), over 100 million tires are manufactured in China annually, close to the generations of the U.S. and Japan; around 50 million tires are disposable in a year. Disposals of such vast volume byproducts not only occupy large-scale stack yards or landfills; improper or unsafe handling (e.g. irrational combustion) may pose adverse impact to the environments. To beneficially reuse disposable tires is thought the ultimate solution to this concern. Such efforts have initiated worldwide, for instance, as substantial energy sources via safe combustion, to be used into embankments and vibration isolation or mitigation facilities (CRIA 2006, Humphrey 1999). With the rapid advance of chipping and grinding techniques, more and more researchers have focused on the reuses of tires in the form of scraps, particularly as construction granular materials owning special properties. For instance, the tire scraps can be proportioned into asphalt concrete to mitigate vibration and noise, and thermal variations (Huang and Zhang 2006, 2007, Cao and Ren 2007). The tire scraps can be concreted into pavement bricks, providing walk-comfortable effect. The scraps are also technically suitable for the uses of absorbing pollutants and preventing soil piping in filter systems (Waritha and Rao 2006). Recently, tire scraps were mixed with soils and pozzolanic materials to make structural geomaterials (Pierce and Blackwell 2003, Tweedie et al. 1998, Edil and Bosscher 1994, Foose et al. 1996). There are few publicly accessible sources focusing on the nonstructural geomaterials without addition of pozzolanic materials.

In this paper, tire scraps and construction sands were mixed into geomaterials at certain mass ratios. Such formed geomaterials, known as sand-tire lightweight fills, are advantages over general fills by being lightweight. The property of low unit weight makes the lightweight fills suitable for various infrastructure works, e.g., embankments over soft grounds or for widen projects, slope and retaining structures, and utilities trench backfilling works. To research the mechanical behavior, especially deformation characteristics of sand-tire lightweight fills, helps predict the settlement and deformation of the field applications. A laboratory study was conducted to discover the compression and shear deformation behaviors through 1-D compression tests, direct shear tests and triaxial compression tests. Factors affecting the deformation behaviors were analyzed. The work can be regarded as an initiative for further addressing the constitutive laws of such granular lightweight geomaterials.

EXPERIMENTAL PROGRAM

Materials and Specimens

Materials include construction sands and tire scraps. The water content of sands is around 5%. Sand specific gravity is 2.62. Figure 1 shows the sand gradation curve. Sand is well graded. Tires are made of rubber, a polymer with a bit elastic and frictional property. The tires were chipped into even scraps by the manufacturers, as shown in Figure 2. The size of scraps falls within 4-5 mm. The specific gravity of tire scraps is 1.33, a half of typical soils, contributive to reducing the unit weight of mixtures.

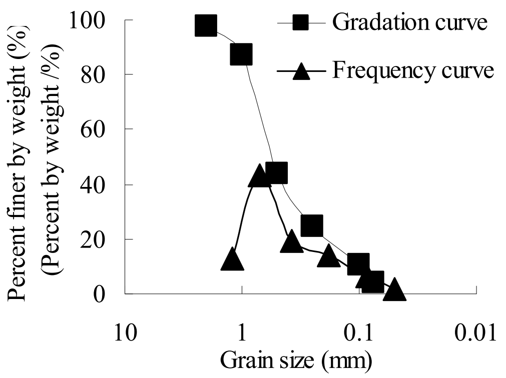


FIG. 1. Gradation curves of sands.

FIG. 2. Scrap tire beads.

The sands and tire scraps were mixed together according to the mass ratio of sand versus tire, known as sand-tire ratio η. The ratios were selected as following: 10:0, 9:1, 8:2, 7:3, 6:4 and 0:10. Scaled materials were mixed homogenously via air-mixing methods. The mixing ratios and unit weights of mixtures are presented in Table 1. It is seen that one tenth increase of tire leads to 10% decrease in unit weight of mixtures.

Table 1. Mixing Ratios and Densities of Specimens.

Sand-Tire Scrap Ratio η	**Relative Densities, D_r**	**Densities, ρ (g/cm^3)**
10:0	0.7	1.784
9:1	0.7	1.617
8:2	0.7	1.466
7:3	0.7	1.325
6:4	0.7	1.257
0:10	0.7	0.701

Test Methods

Test methods include 1-D compression tests, direct shear tests and consolidation-drained triaxial compression tests. The test procedures were implemented in accordance with Standard for Soil Test Method (GB/T50123-1999). In 1-D compression test, the loads P were 12.5, 25, 50, 100, 200, 400, 800, 1600 and 3200 kPa. The normal stresses σ in direct shear tests included 100, 200, 300 and 400 kPa. The confining pressures σ_3 in triaxial compression tests included 100, 200, 300 and 400 kPa. The compression velocity in triaxial tests was 015mm/min.

RESULTS AND DISCUSSION

Compression Characteristics

Terzaghi's 1-D consolidation model assumes that the volumetric compression of soil particles and pore water are neglectable. In sand-tire mixtures, however, tire is relatively less rigid compared to the sand. Under 1-D loading, tire scraps prone to exhibiting volumetric strain. As such, the void ratio e is better to be replaced with alternative parameters to predict the settlement or deformation of the mixture mass. To quantify the compression deformation, compression strain ε_c (representing vertical deformation divided by the specimen initial thickness), was used to take into account both the void and tire scrap compression. The relationship between ε_c and vertical loads P may reflect the compression characteristics of lightweight fills under 1-D loading conditions, and used to calculate the compression modulus E_s.

Figure 3 presents the ε_c - $\lg P$ curves of specimens at varied ratios. It is shown that the curves develop hyperbolically without clear yield or jump points, which is thought ascribed to the elastic and frictional property of tire scraps. The curve directions are clearly associated with the sand-tire ratios. With ratio η transiting from 10:0 to 0:10, component sand decreases and component tire scrap increases; the specimen's compression deformation intensifies. When the mixture is solely tire scraps (η =0:10), ε_c - lg P curve is distinctive from the other curves, presenting significant deformation. It is inferred that sand particles efficiently fill the voids of tire scraps and thus offset partial compressions.

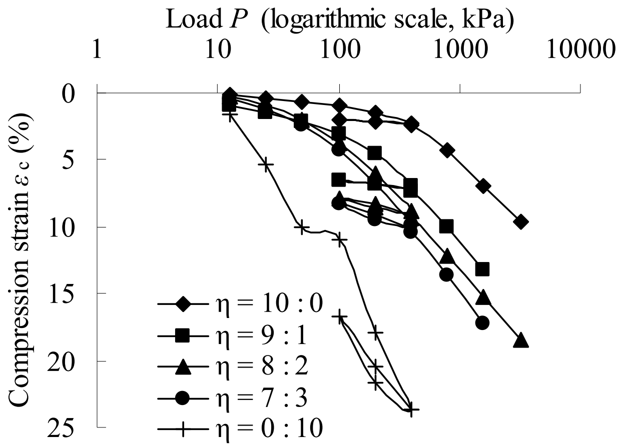


FIG. 3. ε_c - lg P **curves of sand-scrap tire fills.**

Rebound-reloading procedures were also conducted in the 1-D compression tests. The loading P followed the path of 400-100-400 kPa. Leaned from the resilient modulus in general *e-P* curves, resilient index C_{s1-4} was defined as the slope of the rebound curves shown in Figure 3. A high C_{s1-4} value indicates a high elasticity and low plasticity of mixtures. It is shown that C_{s1-4} increases with the increase of tire scrap (decrease of η), which means that tire scrap is able to convert the mixture into an elastic body. It is also seen that the compression of sand-tire scrap is composed of two parts, i.e., plastic deformation and elastic deformation. Both of them increases with decrease of η .

To simulate the ε_c - lg P curves results in a quantified estimation of deformation or settlements of practical works using the sand-tire scrap lightweight fills. The curves may be simulated using Eq. 1, where, a_1, b_1 representing parameters (see Table 2).

$$\lg(P) = \varepsilon_c / (a_1 + b_1 \varepsilon_c) \tag{1}$$

Table 2. Parameters for ε_c - lg P **Hyperbolic Simulations.**

η	a_1	b_1	R^2
10 : 0	0.21	0.27	0.99
9 : 1	0.71	0.27	0.99
8 : 2	0.63	0.27	0.97
7 : 3	0.67	0.29	0.98
0 : 10	1.77	0.33	0.95

Direct Shear Deformation Characteristics

Figs. 4 and 5 depict the shear stress-shear displacement curves of specimens under normal stresses σ of 100 and 300 kPa. The curves present hyperbolical shapes. It is seen that there is a clear difference between curve of pure sand and curves of mixed materials. The curves are basically divided into two groups. For pure sand specimens, the stress is constant after the peak value is reached, being a strain-soften style of compact sand; for sand-tire scrap mixtures, the curves are strain-hardening styles, similar loose sands. It is interpreted that not only elastic tire scraps decrease the rigidity of whole mixtures, but also the flexibility of the scraps yield volume for sand dilation, similar to the shear deformation of loose sands.

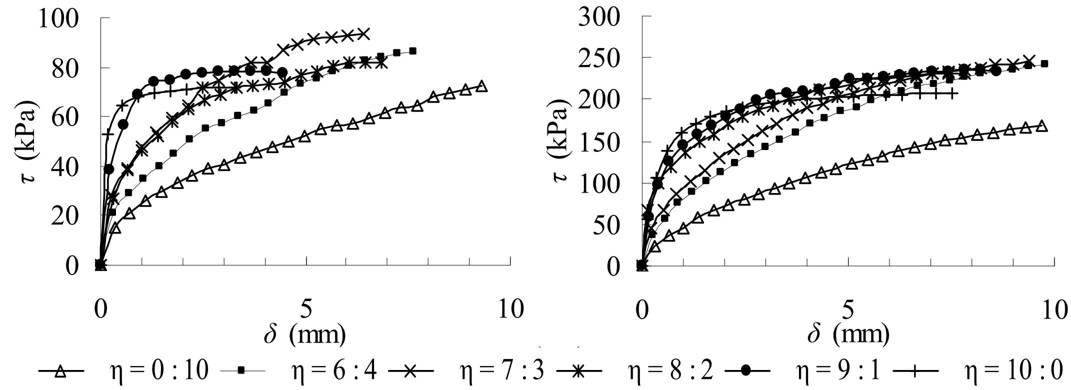


FIG. 4. τ **-** δ **curves (**σ **=100kPa)** **FIG. 5.** τ **-** δ **curves (**σ **=300kPa)**

It is also shown in Figs. 4 and 5 that shear resistances decrease with the increase of tire scraps (decrease of η). With the increase of tire scrap contents, the stress-harden level intensifies. This can be interpreted in terms of the shear strength mechanism (Qu 1987, Lu et al. 2006). It is pointed out that internal friction angle φ of granular materials is related to three components, as shown in Eq. 2.

$$\varphi = \varphi_\mu + \varphi_d + \varphi_b \tag{2}$$

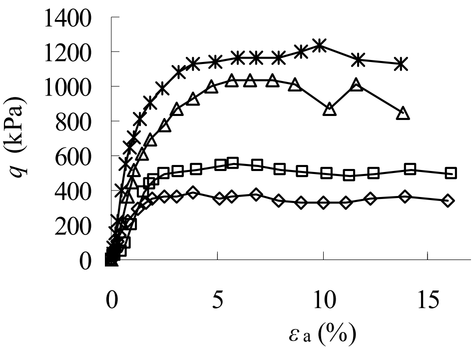
Where, φ representing internal friction angle of granular soils, φ_μ representing component of sliding friction, φ_d representing component of dilation, φ_b representing component of breakage and rearrangement.

In the case of sand-tire scrap mixtures, flexible tire scraps yield space for the shear dilation. The mixture is lagged in particle breakage and rearrangement compared to pure sands (leading to decreased φ_b). Furthermore, the interlock force is offset (leading to decreased φ_d). While tire scraps are able to increase a bit skin friction, such resultant increase of φ_μ is less than the decrease of φ_b and φ_d . As a result, the shear resistance is reduced on the whole.

Triaxial Shear Deformation Characteristics

Figs. 6-9 depict the deviatoric stress-volumetric strain-axial strain curves of specimens at sand-tire scrap ratios of 10:0, 9:1 and 7:3, respectively. Under the conditions of same mixing ratio and different confining pressure σ_3, hardening levels of deviatoric stress-axial strain curves increase with σ_3. With the increase of σ_3, relative densities of mixtures increase. The interlock force and shear resistance increase. As a result, the higher the σ_3, the higher shear resistance and elastic modulus.

Distinct from the shear dilation of compact sand, all mixtures underwent shear contract. Under the same axial strain ε_a, the higher the σ_3, the more the volumetric strain ε_v. If the portion of tire scrap increases (Fig. 9), the influence of confining pressures on volumetric strain is clearer. It is thought that high σ_3 effectively "consolidates" the scrape before shearing. The major volumetric strain of tire scraps was accomplished in the consolidation processes. On the other size, such highly "consolidated" scraps yield relatively less volumetric strain.



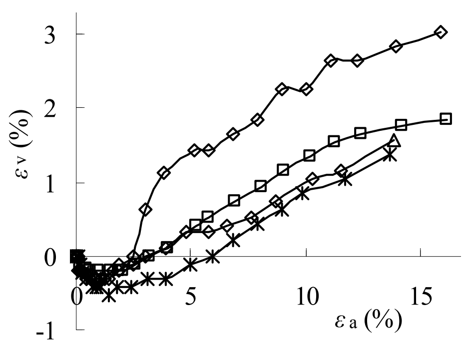
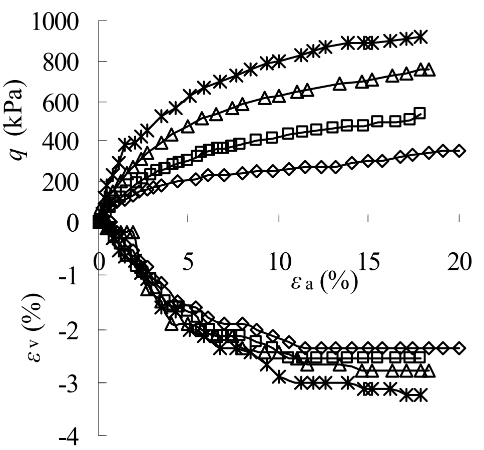


FIG. 6. q - ε_a **curves (**η **=10:0)**

FIG. 7. ε_v - ε_a **curves (**η **=10:0)**



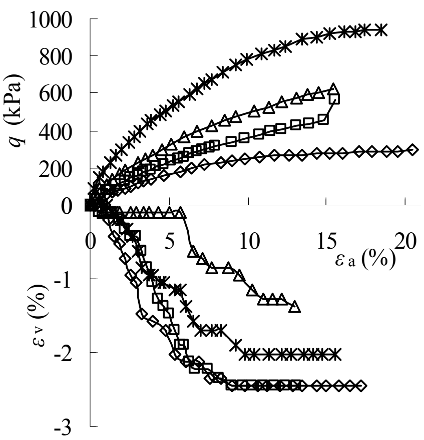


FIG. 8. q - ε_v - ε_a **curves (**η **=9:1)**

FIG. 9. q - ε_v - ε_a **curves (**η **=7:3)**

CONCLUSIONS

This work was conducted to research the compression and shear deformation characteristics of granular sand-tire scrap lightweight fills. It was found that the relationship between compression and load develops hyperbolically. The compression include two parts, e.g., elastic and plastic deformation, which increase with decrease of η. The compression summation can be used for predicting the settlement of practical works. Mixtures underwent shear contraction in triaxial tests. Hardening levels of stress-strain curves increased with confining pressures. The contents of tire scraps were able to influence the relationship between confining pressures and volumetric strains.

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