Influence of waste tire chips on steady state behavior of sand

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Abstract

Materials such as waste tire chips were widely used to improve the strength of soil. The objective of this study is to discuss the residual strength or steady-state behavior of sand-waste tire chip mixtures. A series of undrained monotonic triaxial compression tests were conducted on reconstituted saturated specimens of sand and sand-tire chip mixtures with variation in the tire-chip contents from 0 to 4 percentages by dry weight of soil. The specimens are prepared using dry deposition method of preparation. The influence on residual resistance of varying confining pressure (100, 200, and 300 kPa) and sand mixture relative density (40, 65, and 80%) were evaluated. Tests results showed that by increasing the tire chip contents, the residual strength increased and steady-state lines move to the right of log S_{us}-e diagram. Also, the residual resistance improvement induced by tire chip inclusions was found to be sensitive to the relative density of samples and applied confining pressure.

Keywords: Steady-state strength, Waste tire chips, triaxial test, Sand, Relative density, Confining pressure.

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Introduction

One way of improving the shear strength of soils is to reuse waste tire chips, which not only improves the shear strength of the soil, but also address growing environmental and economic concerns. Research in recent years showed that the use of waste tire chips is a promising new ground improvement method in civil engineering applications. Edil and Bosscher [1] presented the characteristics of shredded scrap tires and their engineering properties and behavior alone or when mixed with soils. Based on their test results, tire-chip-soil mixtures exhibit a significant initial plastic compression under load and improve the frictional response of sand in mixtures. An investigation on sand reinforced with shredded waste tires of different size was conducted by Foose *et al*. [2]. They found that the normal stress, shred contents and matrix unit weight affecting shear strength of mixtures of sand and tire shreds. Adding shred tires increased the shear strength of sand. Tatlisoz *et al*. [3] conducted large-scale direct shear tests with tire chip mixtures of sand. The results showed that the shear strength of the sand-tire chip mixtures increased with increasing tire chip contents up to 30% by volume and the fiction angle of the sandy silt-chip mixtures was nearly independent of tire chip contents. Youwai and Bergado [4] carried out triaxial tests on compacted shredded rubber tire-sand mixtures. It has been found that with an increasing proportion of sand in the mixture, the density, unit weight, and shear strength of mixture increased, but the compressibility decreased. The large scale direct shear tests with tire buffing, sand and sand-tire buffing mixtures with 10% tire buffing by weight was reported by

Edincliler *et al*. [5] and Edincliler [6]. The results of their experiment showed that the addition of 10% by weight of tire buffing to sand alters the deformation behavior of mixture by stiffening the material at low strains, and softening it at large strains. An experimental testing program was undertaken by Zornberg [7] using a large-scale triaxial apparatus to evaluate the optimum dosage and aspect ratio of tire shreds within granular fills. The tire shred contents and tire shred aspect ratio were found to increase the stress-strain and volumetric strain behavior of the mixture. Ghazavi and Sakhi [8] investigated the effects of optimizing the size of waste tire shreds on shear strength parameters of sand reinforced with shredded waste tires. The results showed that the normal stress matrix unit weight, shred content, shred width and aspect ratio of tire shreds influencing shear strength of sand-shred mixtures. Rao and Dutta [9] carried out compressibility and triaxial tests by varying chip size and chip contents to assess the behavior of the admixtures. The results reveal that the tire chip-sand admixtures up to 20% chip contents behave like gravel-sand mixtures and the strength have a significant improvement.

Atom [10] carried out direct shear tests to discuss the shear strength of mixtures of sand and shredded tires. The results demonstrated that the addition of shredded waste tire increased both the angle of internal fiction and the shear strength of sand. In a research by Kawata *et al*. [11], undrained and drained triaxial tests were performed on tire chip-sand mixtures in order to examine their monotonic shear characteristics. The specimen made of pure tire chips showed linear stress-strain relation and the volumetric strain showed compressive behavior. As the volume of tire chips in the sand mixtures increased, the secant friction angle showed large decrease with increase in confining pressure. Cabalar [12] investigated the sand shear strength improvement by mixing fine and coarse sand with rubber wastes at four percentages (5,10, 20 and 50%). The results expressed that sand containing rubber particles less than 10% indicated a reduction in maximum shear strength values. An experimental study was conducted by Baleshwar and Valliapan [13] to investigate the influence of tire chips on the strength characteristics of a cohesive clayey silt soil and a cohesionless fine sand soil. The standard proctor, unconfined compression and California bearing ratio tests was carried out on samples of the cohesive soil-tire mixtures. The result showed that stress-strain behavior of the soil is markedly affected due to the addition of tire chips. The initial stiffness of reinforced soil is decreased and a greater peak compressive strength is obtained at higher axial strains. Neaz Sheikh *et al*. [14] introduced shear and compressibility behavior of sand-tire crumb mixtures. They observed that the peak shear strength and corresponding axial strain of sand are affected by the presence of tire crumbs and confining pressure. The axial strain corresponding to peak deviator stress has been increased. Anvari and Shooshpasha [15] investigated effects of granulated tire chips size (4 to 9 mm) on the bearing capacity of sand. Sand at relative density 55% was reinforced with different tire chip contents (5, 6, 7, 8, 10 and 15%) by weight. The research results showed that, by using tire chips the settlement of footing decreased and the lowest settlement was happened in optimum percentage of tire chips. The

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shear strength and dilatancy behavior of sand-tire chip mixtures have been investigated by Mashiri *et al*. [16]. They carried out a series of monotonic triaxial tests on sand mixed with various proportions of tire chips. It has been found that tire-chips significantly influence the shear strength and the dilatancy behavior of sand-tire chip mixtures. Takano *et al*. [17] investigated the shear behavior of tire chips and mixed sand with tire chips. The direct shear test was conducted. The results indicated that the shear stress of the sand tire chip mixtures under direct shearing are small and increased monotonically compared with that of sand. Ersizade *et al*. [18] performed drained monotonic triaxial tests on pure clay and tire chips-clay mixture with 10, 20 and 30% contents by weight. They found that shear strength and created pore water pressure is affected by tire chip contents. Anbazhagan *et al.* [19] conducted a large direct shear test to assess the influence of granulated rubber and tire chips size and composition on the strength behavior of sand-rubber mixtures. The result determined that the peak strength was significantly increased with increasing granulated rubber size of 9.5-12.5 mm at 30% granulated rubber content. Qafouri Amirbande *et al*. [20] investigated the influence of worn tire crumb size on shear strength parameters of sandy soil and force-displacement-load curve in large-scale direct shear test (30*30 cm). The results at different normal stress and tire crumb contents showed improvement in ductility capacity, internal friction and shear strength. Tajdini *et al.* [21] conducted undrained and drained triaxial and California bearing ratio test on Kaolinite clay as base material with tire chips as reinforcement. Result showed improvement of shear strength parameters and ductility of clay reinforced with tire chips.

It is noted that only a limited number of studies have been conducted on the use of sand-tire chip mixtures for steady state strength behavior of mixed sand-tire chips, as reviewed in the previous studies. Hence, the main objective of this study is to investigate the waste tire chip contents, consolidation pressure, and relative density on steady state strength of sand. Undrained triaxial compression tests have been carried out for three confining pressure, four waste tire chip contents, and three relative densities.

Test Materials

Soil

Firozkuh sand which is clean, relatively uniformly graded sand, classified as SP according to the Unified soil classification system were used in this study. Individual particles are sub-rounded and predominant minerals are feldspar and quarts. Physical properties of tested material and the grain size distribution of sand are shown in Table 1 and Figure 1.

Table1.Physical properties of sand

Properties	value
Average particle size(mm)	0.19
Coefficient of curvature	1.11
Coefficient of uniformity	1.49
Specific gravity	2.62

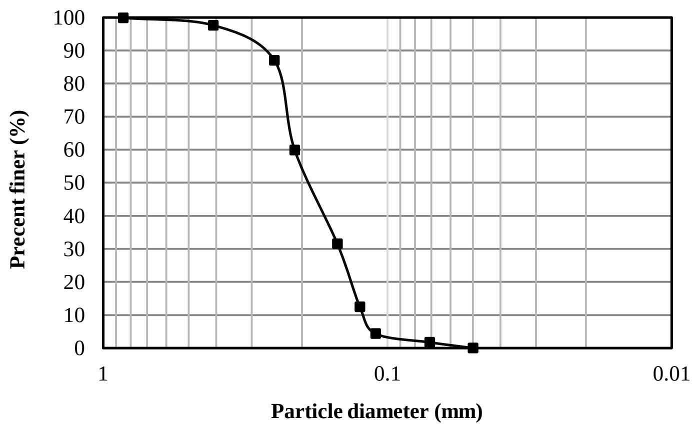

Figure 1. Grain size distribution of sand

Tire chips

The waste tire chips used in this study was provided of shredded waste car tires. Use of tire shreds without steel belts was considered in the testing program to facilitate cutting the shreds into controlled size and avoid punching the membranes of triaxial specimens during testing. The thickness of tire shreds used is not uniform. The length used in the tests was 10 mm with a constant width of 2 mm. The specific gravity and water absorption value of the tire chips used in this study was determined and found 1.12 and 3.24 which compares well with results reported by Bosscher *et al*. [22] for tire shreds without steel belts. Figure 2 shows tested materials for sand, waste tire chips and sand-tire chip mixture.

The maximum and minimum void ratios of sand and sand tire chip mixtures are shown in Figure 3. It can be observed that the maximum and minimum void ratio of matrix decrease with the increase in tire chip contents. This behavior explained by Lee *et al*. [23] and Kim and Santamoria [24].

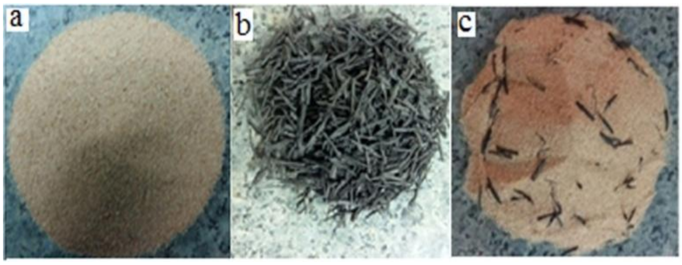

Figure 2. Test materials for a) sand, b) waste tire chips, c) sand-tire chip mixture

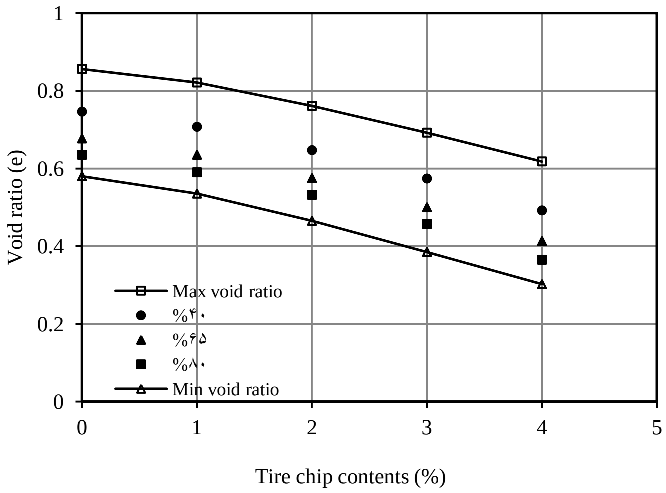

Figure 3. Maximum and minimum void ratios of sand and sand tire chip mixtures

Sample preparation and testing procedure.

For the purpose of observing the steady state behavior of sand and sand waste tire chip mixtures, undrained triaxial compression test were conducted on reconstituted saturated samples of Firozkuh sand with variation in waste tire chips from 0-4%. The specimens were

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50.8 mm (2 inches) in diameter and 101.6 mm (4 inches) in height. The dried tire chips and Firozkuh sand were mixed at the prescribed mix ratio by weight. The mixtures were prepared ensuring that the tire chips were disturbed randomly and uniformly in the mixtures. The specimens prepared by a dry deposition technique with gentle tamping to obtain the volume of the mold for the required densities (40, 65, and 80%) without any segregation. One of the factors that may influence the results of the experiments is segregation. Edil and Bosscher [1] subjected that when the ration of sand to tire chips is high, segregation does not happen. In this study the amount of sand in samples is high and also the length of tire chips (10 mm) is not long. Therefore, segregation will not occur. However, to avoid segregation, the necessary care was taken during mixing and preparing the samples. After the specimen was formed, the specimen cap is placed and sealed with O-rings, and a partial vacuum of 35 kPa is applied to the specimen to reduce the disturbances. The saturation process was performed by percolating carbon dioxide and then deaired water from the base of specimen. The saturation of the samples was ensured by making sure that the pore-pressure parameter “B” values were above 0.95 at a back pressure of 200 kPa. The specimens were consolidated isotropically at mean effective pressures of 100, 200 and 300 kPa and then subjected to undrained monotonic triaxial loading with a constant strain rate of 1% per minute (ASTM D4767-02) [25] to investigate the influence of waste tire chip contents, relative density and confining pressure on steady-state behavior of sand.

Result and discussion

In this study, the results from the undrained monotonic triaxial tests were used to determine the effect of waste tire chips on the steady-state behavior by comparing the residual strength of sand and sand-tire chip mixtures before and after inclusion. The present of all figures in this paper is cumbersome and makes the paper lengthy, so only a limited number of them are presented here.

Effect of tire chip contents on residual strength

Typical trends of the deviatoric stress-strain , effective stress path and pore water pressure curves obtained from tests for confining pressure of 300 kPa presented in Figure 4 to indicate the influence of percentage of tire chips on residual strength of sand. It is evident that the amount of tire chips has significant influence on the residual behavior of the mixtures. It can be seen that the deviator stress and pore water pressure increase with the increase in the percentage of tire chips in the mixture and the corresponding axial strain also increases, so sand-tire chip mixtures deform more than sand. Also, the stress-strain curves show an increase in stiffness with the addition of tire chips to the mixture.

c) pore water pressure

Figure 5 presents the influence of the percentage of tire chips on the residual stress at different confining pressure for relative density of

40%. At all confining pressure, the residual stress increased with increasing percentage of tire chips in the mixtures.

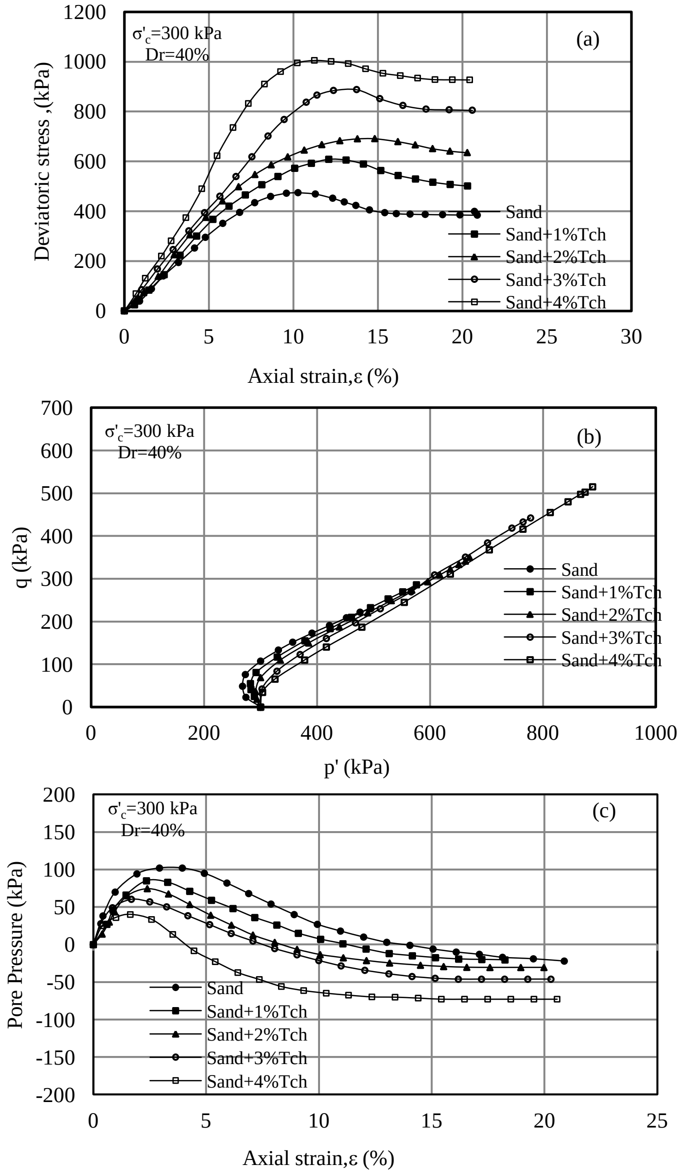

Figure 4. Effect of percentage of tire chips on a) residual stress, b) effective stress path and

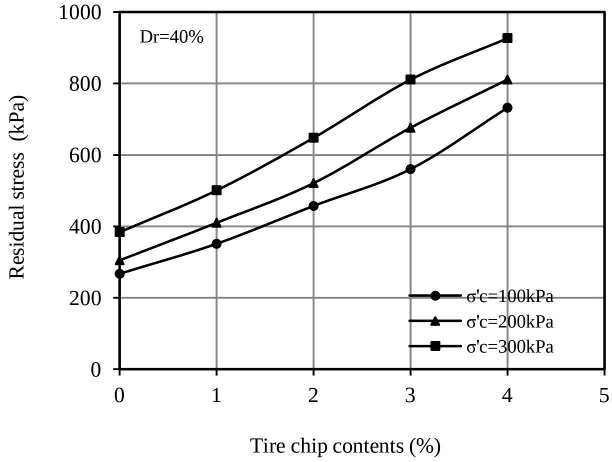

Figure 5. Effect of percentage of tire chips on residual stress

Effect of confining pressure on residual strength.

The behavior of sand and sand with 2% tire chip mixtures at a relative density of 40% in terms of deviator stress-strain curves, effective stress path and pore water pressure curves are shown in Figure 6. It is evident that the behavior of sand tire chip mixtures is significantly influenced by the confining pressure. The stiffness measured from the slop of stress-strain curve, residual strength, pore water pressure and the corresponding axial strain increase with the increase in confining pressure. It can be observed that, for all the confining pressures considered in this study (100, 200, and 300 kPa), the residual strength of sand tire chip mixtures are upper than that of sand.

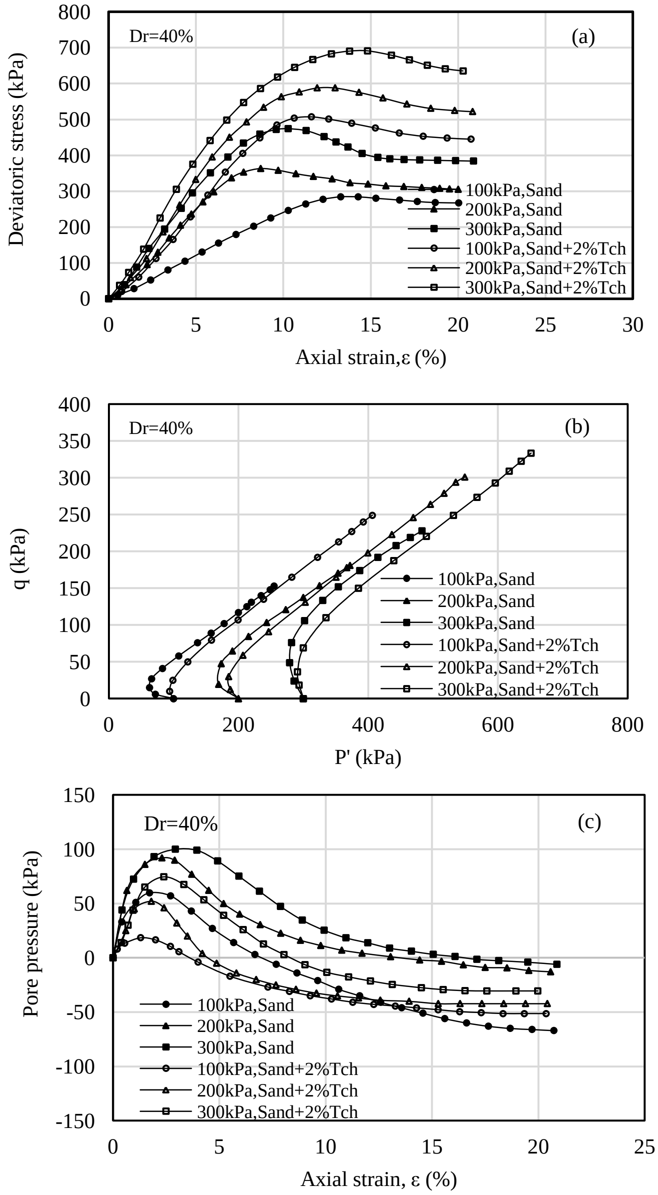

Figure 6. Effect of confining pressure on a) residual stress, b) effective stress path and c) pore water pressure **for sand with 2% tire chip contents**

Figure 7 summarized the effects of confining pressure and amount of tire chips on the residual stress for 40% relative density. The residual strength shows a linear relationship with the confining pressure. The slopes of the residual stress-confining pressure curve are almost the same with the increase in the amount of tire chips. However, the rate of increase of residual strength decreases with increase of tire chips amount (Figure 7).

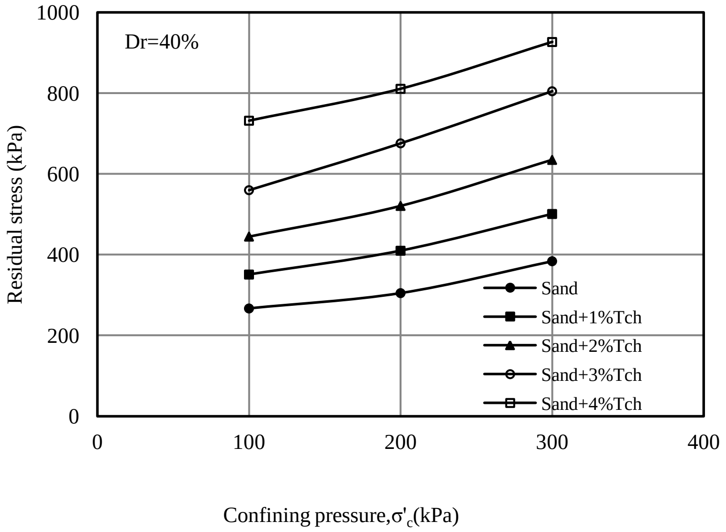

Figure 7.Effect of confining pressure on residual stress for different tire chip contents

Effect of relative density on residual strength

Figure 8shows comparisons of deviatoric stress versus strain, effective stress path and pore water pressure behavior of sand and tire chip mixtures, having tire chip content of 4%. Tests have been conducted on mixtures with initial relative densities of 40%, 65%, and 85% at a constant effective confining pressure of 200 kPa. It is

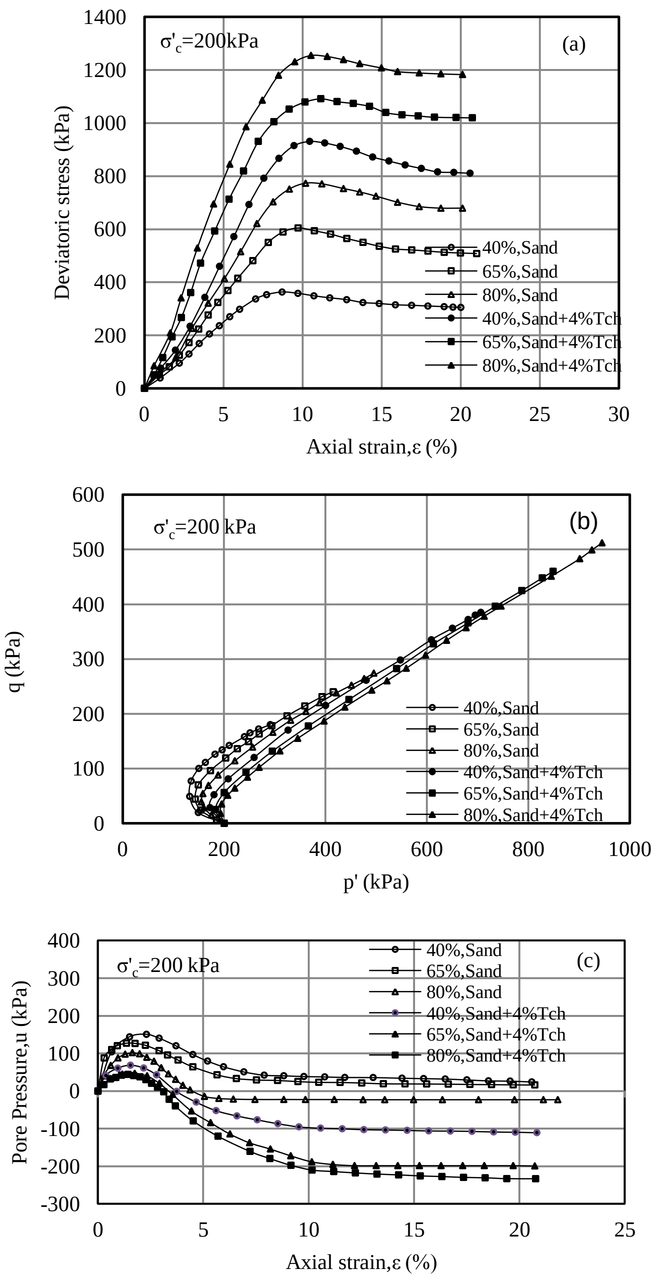

Figure 8. Effect of relative density on a) residual stress, b) effective stress path and c) pore water pressure

evident from Figure 8 that the relative density affects the residual strength and dilative behavior of soil as expected. As shown in Figure 9, for all three densities, the tire chip contents, the residual strength and pore water pressure increases with increasing at all relative densities. The sand with 4% tire chip inclusion shows a greater improvement in residual strength.

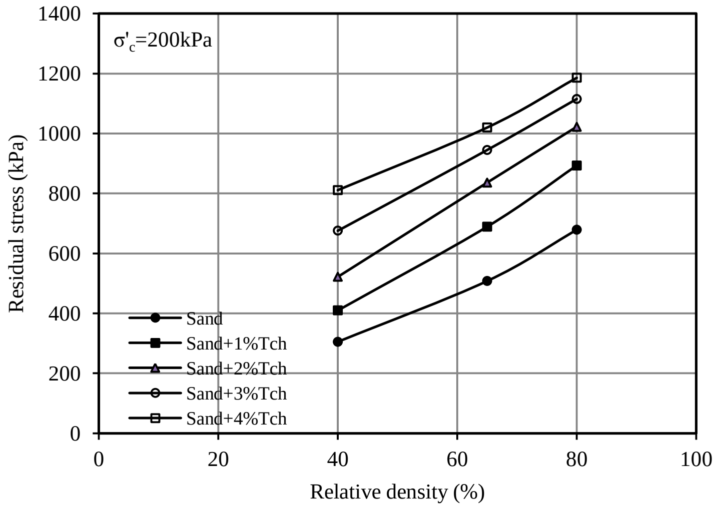

Figure 9. Effect of relative densities for different tire chip contents

Effective stress strength parameter

The effective stress strength parameters φ' and C' computed from the residual strength values are presented in Table 2. It is shown that the value of φ' decrease marginally with percentage inclusion at least for the range of specimens tested. Forinstance, the value of φ' of sand with 2% of tire chip inclusion decrease from 23.5° for sand to 17.5°, so there is effect of tire chips on the magnitude of φ'. The variation of the residual friction angle in relation to the amount of tire chips and relative densities is shown in Figure 10, as expected, residual friction angle increases with increasing relative density. The value of cohesion intercept C' increase with increasing tire chip contents. The value of C' is zero for sand and it continues to increase with tire chip contents (Figure 10). At 4% tire chip contents, the apparent cohesion is found to be the maximum compared to that of the sand, due to significant interlocking effects. Appreciable cohesion intercept is thus created in sand tire chip mixtures.

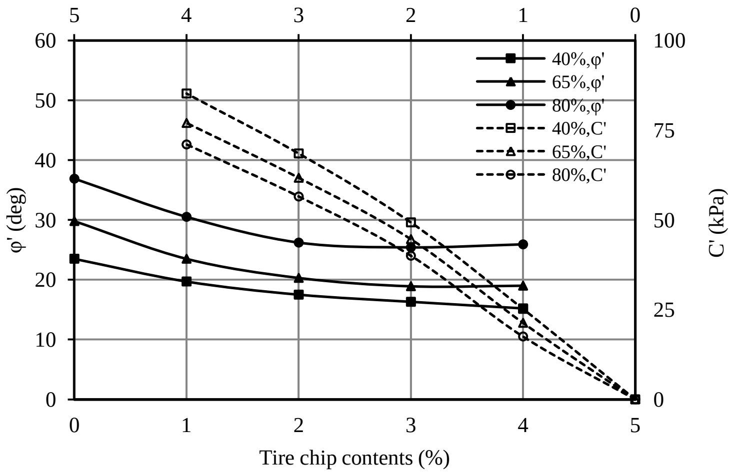

Figure 10.Variation of φ' and C' with tire chip contents and relative density

Table 2.Strength parameters for sand tire chip mixtures

Relative density	Strength parameter	Percentage of tire chips				
		0	1	2	3	4
40	φ'(deg)	23.5	19.7	17.5	16.3	15.2
	C'(kPa)	0	25.2	49.3	68.5	85.2
65	φ'(deg)	29.8	23.5	20.3	18.9	19.0
	C'(kPa)	0	21.3	44.6	61.7	77.0
80	φ'(deg)	36.9	30.5	26.2	25.4	25.9
	C'(kPa)	0	17.5	40.0	56.5	71.0

Steady state lines

The steady state lines for monotonic triaxial tests on sand and sand with different tire chip contents (0-4%) presented in Figure 11. This Figure shows that as the tire chip contents increase, the steady state line moves to the right in the log S_{us}-e diagram. In fact, by adding tire chips, residual strength and liquefaction resistance significantly increases. As expected, the increasing trend of the SSL in the log S_{us}-e plane confirms that sand behavior varies from contractive state to dilation due to the increase in tire chip contents.

The normalized residual shear strength in terms of waste tire chip contents for the relative density of 40 percentages at effective overburden pressure of 100kPa presented in Figure 12, indicate that for the range of 0-4 percentage tire chip contents, the residual strength steadily increases.

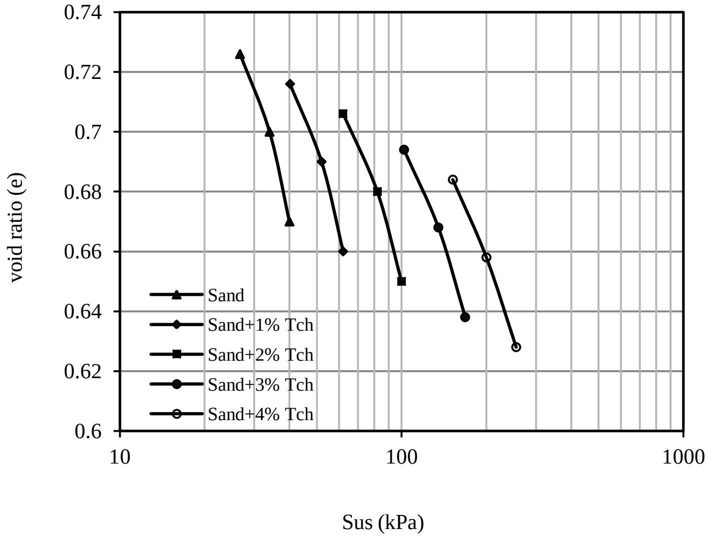

Figure 11. Steady state lines

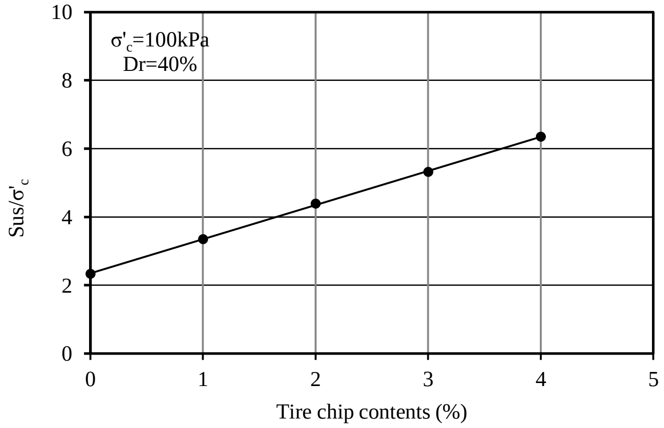

Figure 12. Normalized residual shear strength versus tire chip contents

Conclusion

This study presents the result of undrained compression triaxial test carried out on sand-waste tire chip mixtures. The results show that:

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- When the content of tire chips varies from 0 to 4 percentages by dry weight; the residual shear strength and the corresponding axial strain of sand affected by the presence of tire chips. The residual shear strength and corresponding axial strain of the mixtures increase with increase in the waste tire chips.
- As expected, the residual shear strength has been found to increase with increase in the effective confining pressure and initial relative density. On the other hand, the dilatancy has been found to decrease with increase in the effective confining pressure, but increase with the increase in the initial relative density of the mixtures. In all case, sand with tire chip contents of 4% shows maximum improved residual shear strength with a significant reduction in dilatancy.
- An apparent cohesion is obtained in samples containing tire chips. This cohesion increase in samples containing more percentage of tire chips. This parameter also is greater in more computed specimens.
- As expected, residual friction angle increases with increasing relative density. For a particular relative density, residual friction angle decreases with the increase in the tire chip contents.
- An increased sand matrix relative density does significantly improve the residual strength of sand-waste tire chip mixtures for different range of tire chip contents.

- The position of the steady state is influenced by the tire chip contents. As the tire chip contents increased up to 4%, the steady state line moves to the right in the log S_{us}-e diagram and the contractiveness is decreased.
- Normalized residual shear strength is reasonably constant and increased with increasing tire chip contents up to 4 percentages.

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