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Triaxial Determination of Shear Strength of Tire Chips-Sand-Geotextile Mixtures

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ABSTRACT: Waste tires are widely used for geotechnical applications as backfill material that is either a substitute for natural soils or combined with them. This paper determines the shear strength parameters of tire chip-sand-geotextile mixtures using a triaxial test apparatus. For this purpose, tire chip–sand mixtures with mixing ratios of 0:100, 15:85, 25:75, 35:65, and 100:0 by volume were used as fill materials. Also, for the reinforcement of these mixtures, the layer of geotextile is used. In all tests, the strain rate has been kept the same. Three confining pressures have been applied in all experiments. The influences of the tire chip content, number of geotextile layers, and confining pressure at the strain levels of 3%, 6%, 9%, 12%, 15%, and 18% on the sample were studied and described. This paper focuses on the stress-strain behavior of different mixtures. The results show that the imposed strain level on the samples plays an essential role to increase the strength of the tire chip-sand mixtures compared with sand alone. It implies that the beneficial effect of tire chip content to enhance the strength of samples appears in high strain, especially for reinforced samples with geotextile, while in low strain, tire chip does not have a beneficial effect. Hence, it is necessary to consider the strength of tire chip-sand mixtures compared with sand alone at the imposed strain level.

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1- Introduction

Nowadays, the waste tire is widely used in civil works, especially in geotechnical applications. In the building of highways and earthworks, waste tires can be used as lightweight fill material for retaining wall backfills and embankments. These materials can also be prepared in different sizes and shapes, like fiber or granular waste tires. Scrap-tire properties such as strength, high frictional resistance, and durability are of important value in the construction of highway embankments [1]. Mixing recycled tires with soil for embankment building can not only offer alternative means of reusing tires to resolve economic and environmental issues but also help to solve geotechnical problems related to low soil shear strength [2]. Previous researches [3-6] have shown that waste tire may be used as a light-weight backfill material for retaining walls and embankments. Specific field and experimental research also have suggested that the use of the combination of soil-tire chip, described as a mixture of scrap tire chips and soil mixed in different proportions, may conceivably improve the strength of the foundation and decrease settlements in problem zones.

Several laboratory models have been developed by Jalali Moghadam et al. [7], in which the effect of crumb rubber as filler material on the stability of the reinforced wall is investigated. They found that the backfill with 10% (by weight) crumb rubber provides the wall with the maximum bearing capacity. A drained triaxial compression test was conducted by Venkatappa Rao et al. [8] to investigate sand behavior with and without tire chips. Content of tire chips, size of tire chips, and confining pressure were variable parameters of triaxial experiments. The findings of drained triaxial tests showed that the tire chip–sand admixtures up to 20 percent chip content act such as gravel-sand combination, a slight increase in strength. Foose et al. [9] conducted extensive large direct shear tests on sand-tire shreds mixture. They observed that shred orientation, shred contents, shred length, compaction degree of sand-tire combination, and normal stress affected mixture strength parameters. Among them, there were more significant effects on mixture compaction, shred content, and vertical stress. Also, the friction angle was 67° for sand- tire shreds mixture, while the sand itself had a friction angle of 34°. Noorzad and Raveshi [10] conducted drained triaxial tests on dry sand rubber mixtures of rubber content ranging from 0 to 30% by weight at a relative density of 70%. They concluded that increasing the rubber content results in a decrease in peak shear strength, stiffness, and dilatancy of the mixture. Reddy et al. [11] determined the optimum mixing ratio of sand, and tire chips considering void ratio, dry unit weight and shear strength of the mixture. Researchers concluded that the optimum ratio for considered properties

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in this study can be between 30 and 40%. Madhusudhan et al. [12].performed static and cyclic consolidated-undrained triaxial tests on saturated sand rubber mixture. The sand had an average grain size of 0.6 mm and the rubber had an average grain size of 1 mm. Increasing the rubber content resulted in a decrease in shear strength and shear modulus, and an increase in damping ratio. For large strain applications, Lee et al. [13] conducted a set of direct shear tests under effective stress of 40 kPa, they concluded that friction angle decreased at higher rubber contents, ductile behavior became dominant at high rubber inclusions with contractive behavior at shearing. Anbazhagan et al. [14] conducted research to investigate the effect of sand gradation and a tire chip size on the shear strength characteristics of sand–rubber mix. It was observed that higher shear strength is assessed when more uniform sand is reinforced with tire chip. The shear stress increased up to tire chip content of 30% by volume, after which no increase was observed. This finding is valid for all rubber granulates except for 12–20 mm tire chip cases. The shear behavior of mixtures of fine-grained sand and granulated rubber is investigated by Anvari et al. [15]. The obtained results show that the granulated rubber improves the shear strength of fine-grained sand at medium relative density and low normal stress. Isotropically consolidated drained triaxial and one-dimensional odometer tests have been conducted to investigate the mechanical properties of sand-rubber mixtures by AbdelRazek et al. [16]. They concluded that the unit weight, shear strength, and stiffness of sand-rubber mixtures decreased whereas deformability increased at increased rubber content. A non-linear stress-strain response was observed, that changed from brittle to ductile behavior at increased rubber content. Balaban et al. [17] investigated the effect of tire crumbs on the mechanical properties of sand-fine soil mixtures. It is found that tire crumbs decrease the unit weight of soil, increases the angle of friction of soil. The optimum amount of tire crumb is found in 20% of the soil.

The goal of this study is to investigate the effects of the content of tire chips and the variety of geotextile layers on the shear strength of the sand–geotextile-tire waste combination for geosynthetic reinforced retaining walls or embankments. A series of compression triaxial tests on combinations of sand and tire chips with five different percentages of tire chips: 0, 15, 25, 35, and 100% by volume were conducted for this purpose.

2- Testing Program

2.1. Testing devices

The standard triaxial system was used for evaluating unreinforced and reinforced dry samples, which were cylinders with a 50 mm diameter and a height of 100 mm. This machine contains a maximum load of 50 kN and a working pressure ceiling of 1700 kPa. The device components are load frame, specimen base adapter, triaxial cell, de-aired water device, universal pump, bladder type air/water pressure system, and pressure indicator screen, transducers, volume-changing unit, Autonomous Data Acquisition Unit, and a computer with DataSystem 6.

2.2. Materials

The soil used in the tests was relatively uniform grading sand with the angular shape of particles. Fig. 1 indicates the sand distribution of grain size. Uniformity and curvature coefficients and a specific gravity of dry sand are 1.62, 1.38, and 2.67, respectively. The sand can be categorized as SP, According to the Unified Soil Classification System (USCS). A peak sand friction angle for 1400 kg/m^3 density is also 31.5°.

Tire chips used in this experiment is a granular material provided by the processing of scrap tires. The distribution of the grain size of the tire chips is shown in Fig. 1. An apparent cohesion and a peak angle of friction of the tire chip for a maximum density of 750 kg/m^3 are 23.5 kPa and 24°, respectively.

For reinforced samples, one type of geotextile was used. The material used for research is shown in Fig. 2. Also, Table 1 presents the properties of the manufacturer's geotextile.

2.3. Test procedure

In three layers, the samples were compacted by tamping with a tamper consisting of a circular disc attached to a steel rod. The disk had a slightly lower diameter than the mold. The reinforcement was placed horizontally within the specimen after compacting and leveling each layer of sand. The reinforcement diameter was slightly less than the sample diameter. Depending on the geotextile arrangement, the number of layers to prepare the specimen was selected between zero and two (Fig. 3).

Five tire chip contents of 0, 15, 25, 35, and 100 percent by volume were also used in the test program. A volumetric basis rather than a gravimetric basis was used to prepare sand-tire chip mixtures and determine tire chip contents in each combination. It would be easier to implement a volumetric specification in the field, for example by counting the relative number of soil and chip truckloads [1, 9].

Matrix unit weight for the sand was used as a unified criterion for similarly compacted mixtures. This is known as the sand weight divided by the sand matrix volume [1, 9, 18]. This unit weight was γ_m=14kN/m^3 in current tests.

The weights of sand and tire chips were measured and combined uniformly for various mixtures. In the current experiments, care has been taken to uniformly disperse the tire chips as much as possible in the mixtures. This was checked by eye observation. Table 2 displays the unit weight of samples with various mix ratios. The confining pressures were 50 kPa, 100 kPa, and 200 kPa. For all the tests, the strain rate selected was 1 mm/min. All samples were tested under strain-controlled conditions.

3- Results and Discussions

3.1. Stress-strain behavior

The triaxial compression tests were carried out on tire chip-sand-geotextile mixtures to determine the parameters of the shear strength of the combination (c and φ). The findings of triaxial tests provide the assessment of deviatoric stress–axial strain variability for tire chip-sand-geotextile at various

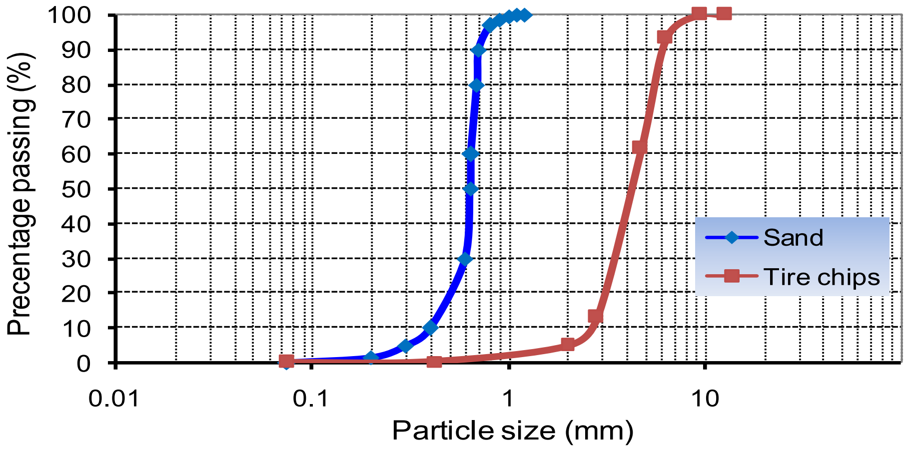


Fig. 1. Grain size distribution of sand and tire chip

(a) **(b)** **(c)**

Fig. 2. Materials: a) sand, b) tire chips, and c) geotextile specimen

Table 1. Properties of geotextile

Product name	Polymer type	Mass per unit area (g/m^2)	Thickness (mm)	Tensile strength (kN/m)	Grab elongation (%)
GTN.20	Polypropylene	200	1.80	14.1	>50

Table 2. Unit weight of samples

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

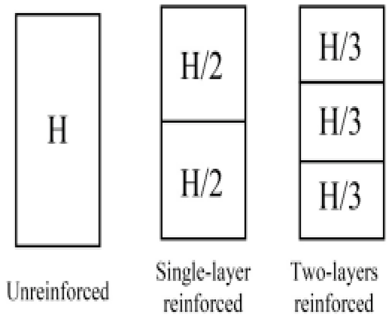


Fig. 3. Geotextile arrangements for triaxial tests

(a) (b)

Fig. 4. Sample of the sand-tire chips mixture with two layers of geotextile: a) before testing and b) after testing

confining pressures. Fig. 4 displays the view of the sample from a mixture of sand and tire chips reinforced with two layers of geotextile.

The deviatoric stress–axial strain variation for the unreinforced and reinforced samples with different numbers of geotextile layers and tire chip contents under confining pressure of 50, 100, and 200 kPa have been shown in Figs. 5-8. Figs. 5a-c shows that, compared to unreinforced samples, the geotextile layer significantly increases the shear strength of the samples. This issue is mainly due to the increase in confinement; geotextile layers cause internal confinement in reinforced specimens, which has been explained by an increased confinement concept by Yang [19]. It can be found that in stress-strain behavior there were no apparent points of failure, as the number of reinforcements increased, the samples became more flexible as clogging developed in a shear band within specimens. Stress–axial strain curves obtained at different confining pressure for unreinforced sand with different tire chip contents are presented in Figs. 6a-c. These figures show that the peak stress increases significantly with an increase in the content of the tire chip and the corresponding axial strain increases. Also, the stress-axial strain behavior of various tire chip contents in reinforced sand with one and two layers of geotextile has been shown in Figs. 7a-c and Figs. 8a-c, respectively.

Figs. 5-8 also show that the tire chip content and geotextile layer significantly increases the strength of reinforced samples in high strain, while in low strain; tire chip and geotextile layers do not have a beneficial effect. It means that high levels of strain should be imposed to show the effect of tire chips and geotextile layers to increase sample strength. These comparisons demonstrate that the level of strain imposed on the samples plays an essential role in increasing the strength of the reinforced samples relative to the unreinforced sample.

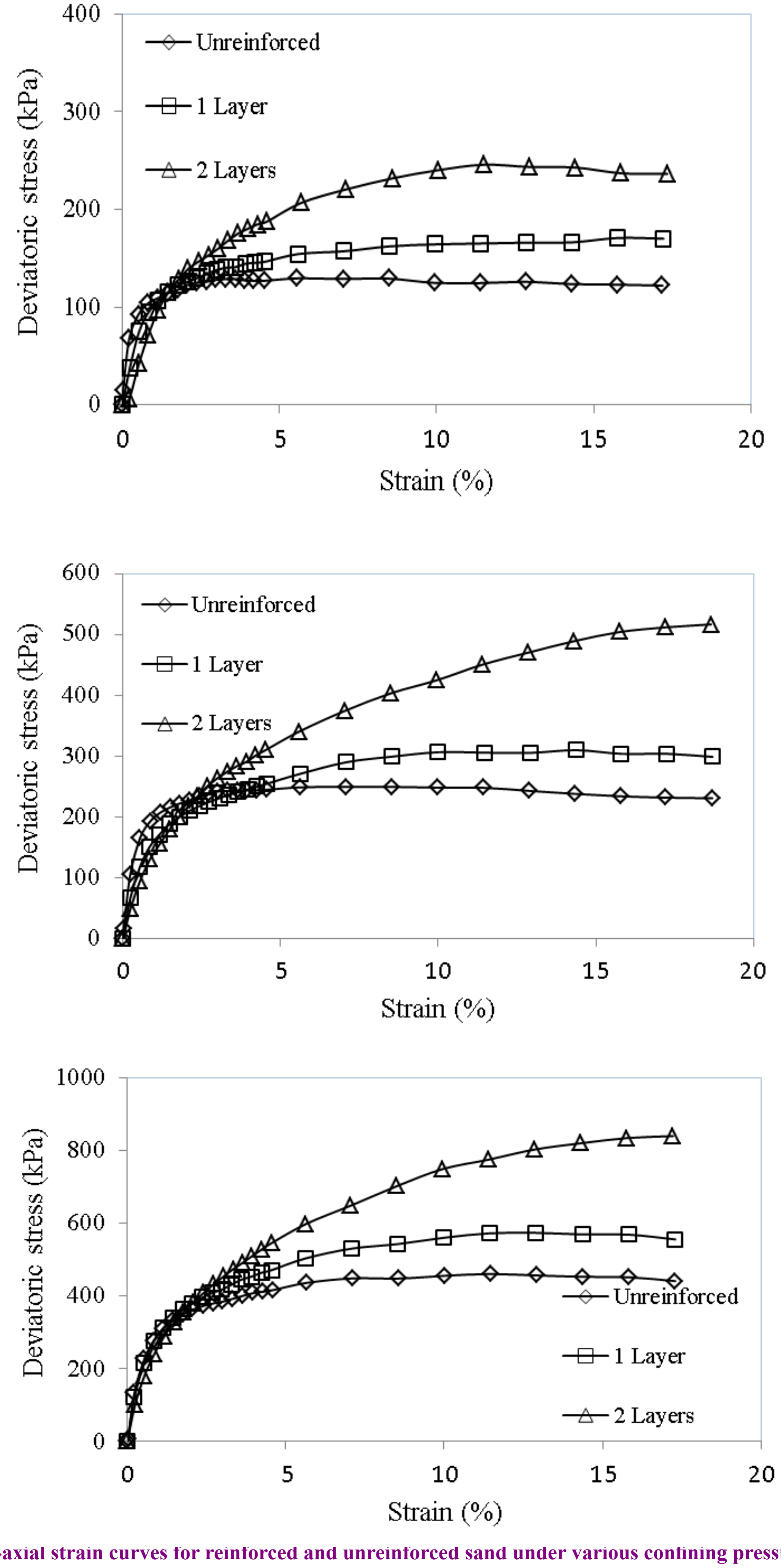


Fig. 5. Stress-axial strain curves for reinforced and unreinforced sand under various confining pressure (a) 50 kPa; (b) 100 kPa; and (c) 200 kPa

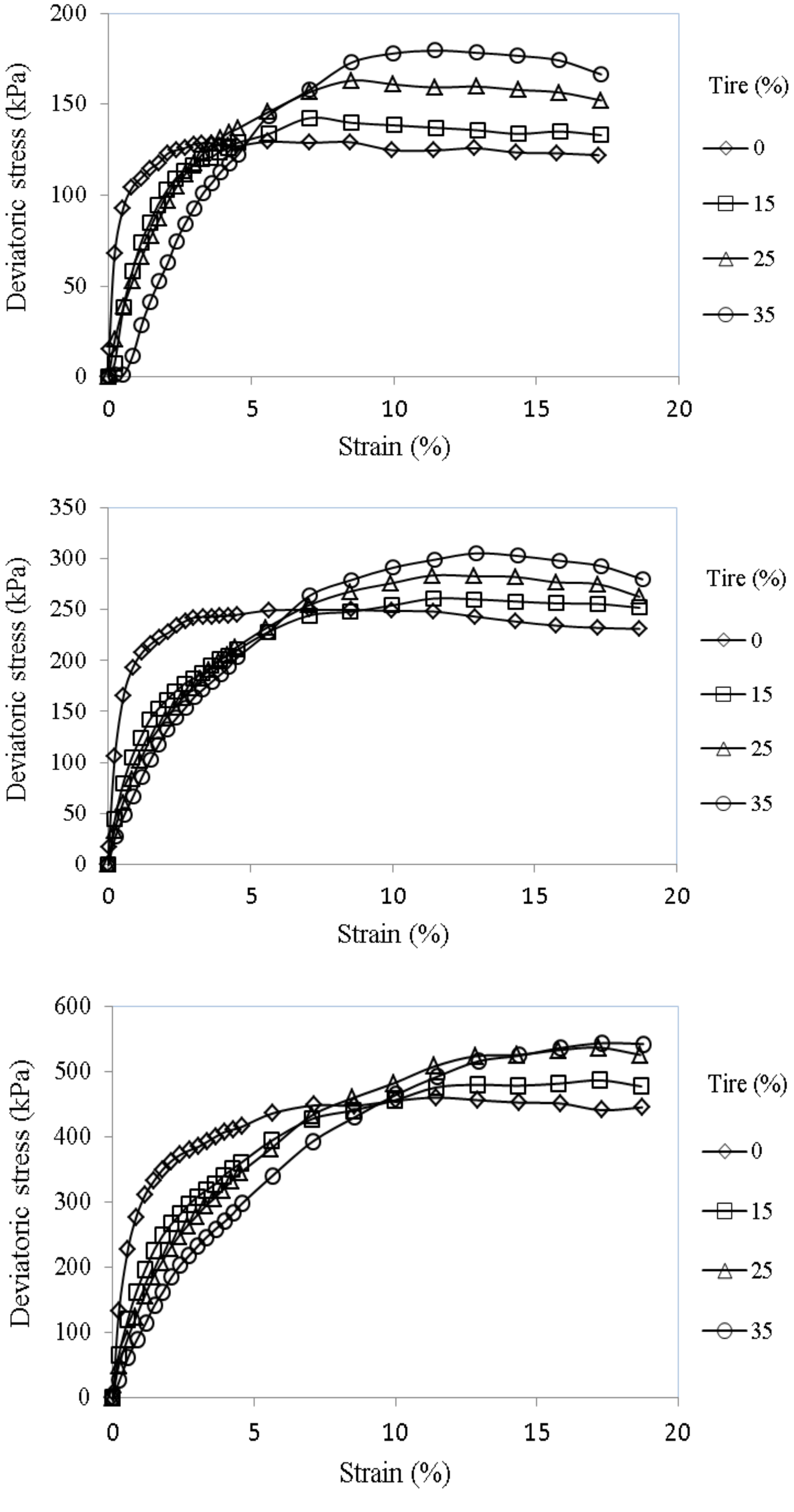
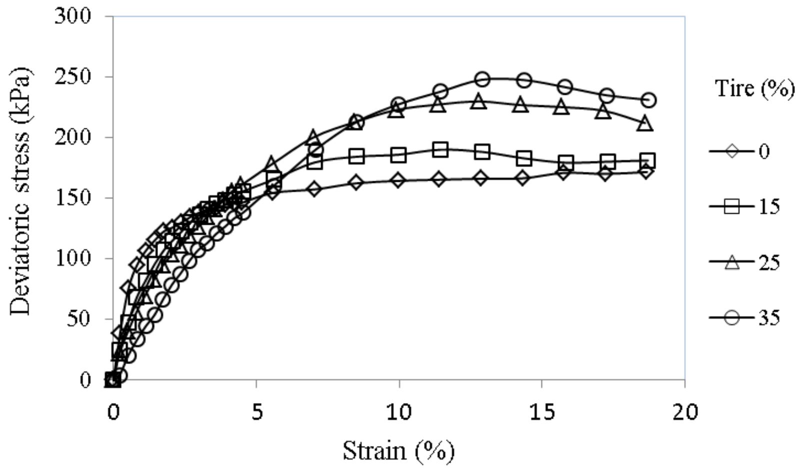
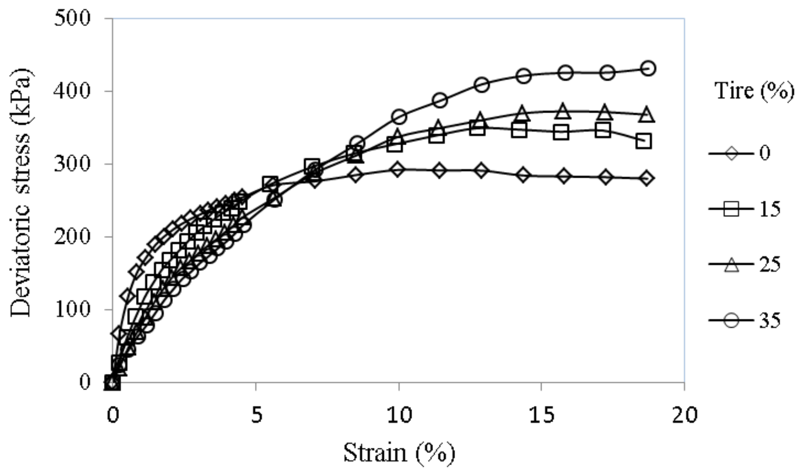


Fig. 6. Stress-axial strain curves for tire chip-unreinforced sand mixtures under various confining pressure (a) 50 kPa; (b) 100 kPa; and (c) 200 kPa



(a)



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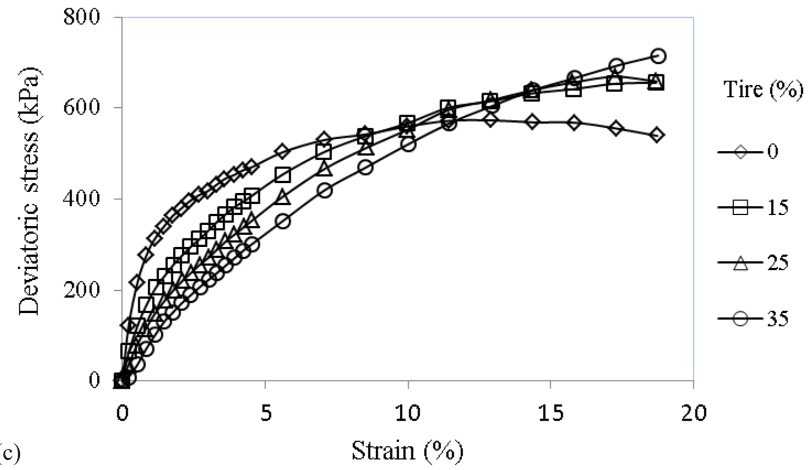
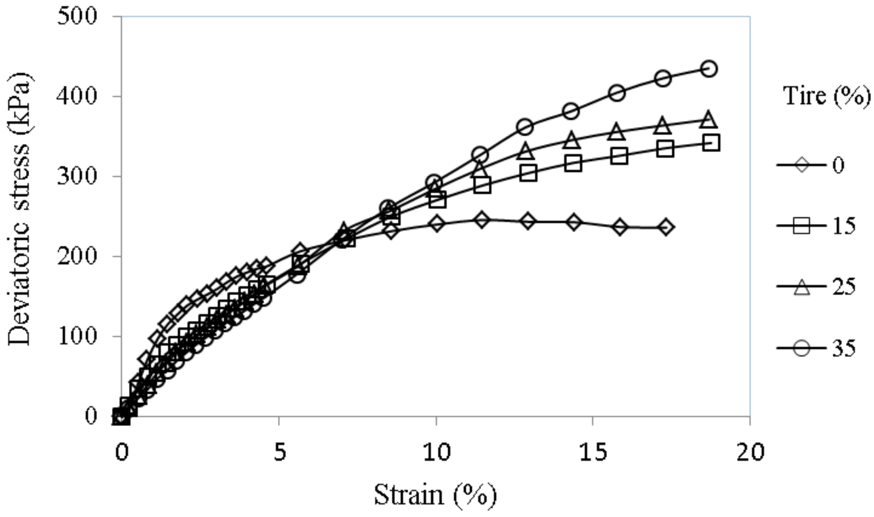
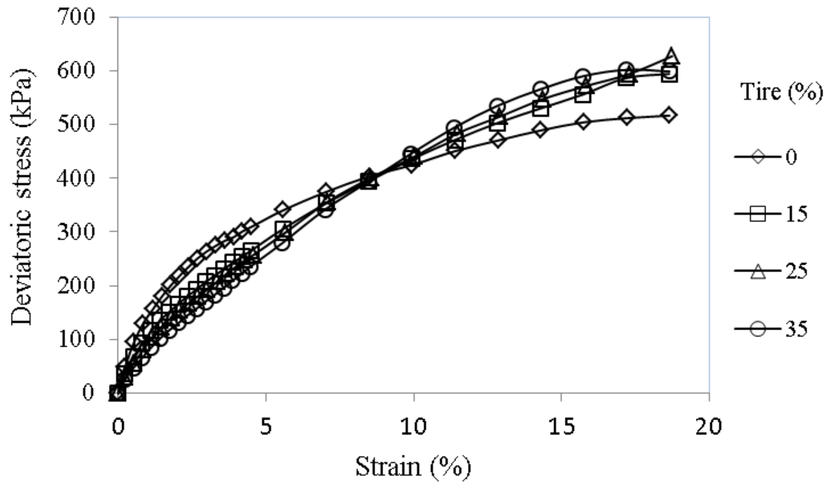


(c)

Fig. 7. Stress-axial strain curves for tire chip-reinforced sand with one layer of geotextile under various confining pressure (a) 50 kPa; (b) 100 kPa; and (c) 200 kPa



(a)



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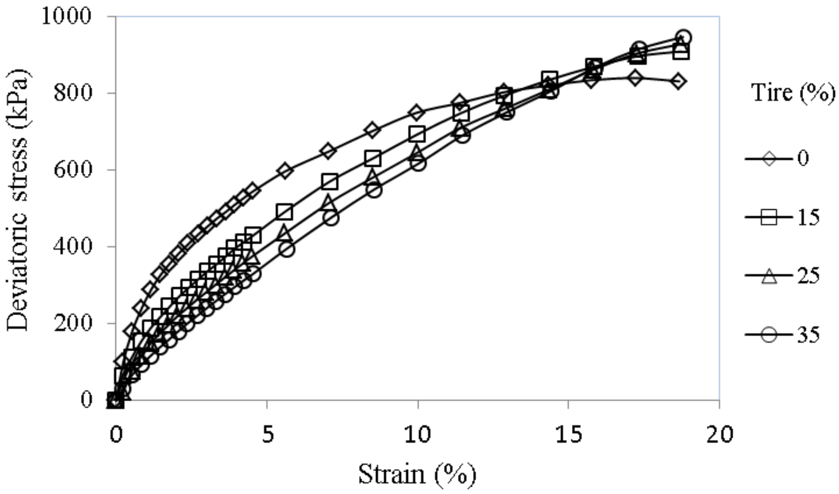


(c)

Fig. 8. Stress-axial strain curves for tire chip-reinforced sand with two layers of geotextile under various confining pressure (a) 50 kPa; (b) 100 kPa; and (c) 200 kPa

3.2. The effect of the number of geotextile layers on strength at different strain levels

Figs. 9a-c shows the variations of deviatoric stress values versus a number of geotextile layers, under confining pressure of 50, 100, and 200 kPa at different strain levels of 3%, 6%, 9%, 12%, 15%, and 18% for sand alone. It reveals that deviatoric stress (σ_d) increases with increasing the number of geotextile layers. As seen from Figs. 9a-c, the rate of increase of deviatoric stress with an increase of geotextile layer is not very significant at lower strain levels (e.g., the strain of 3%), while in higher strain levels, the geotextile layer increases the deviatoric stress, significantly. It means that the geotextile layers cause internal confinement. Also, by focusing on Figs. 9(a) to (c), it is clear that by increasing the strain from 3% to 18%, the deviatoric stress does not increase in all cases. For example, in Fig. 9(c), the deviatoric stress in the strain=18% is lower than the strain=12% and 15%. It can be justified that in stress-axial strain curves for sand (Fig. 5), there is a little post-peak loss of strength. But such behavior is not observed with increasing geotextile layer. Therefore, for unreinforced sand, the deviatoric stress in the strain=18% is lower than the strain=12% and 15%. Geotextile inclusion enhances peak strength, axial strain at failure and reduces post-peak loss of strength. The progress is more effective with a higher number of geotextile layers. In fact, increasing the number of geotextile layers resulted in more ductility of the samples as clogging developed in the shear band within the specimens. Further, the presence of geotextile reinforcement improves the soil strength and changes the strain-softening stress-strain behavior of sand samples into strain-hardening. The results observed are in agreement with those reported recently by Haeri et al. [20].

To evaluate the effects of the strain level on the strength of the reinforced soil, a parameter of the strength ratio is introduced in specific strains defined as:

$$\text{Strength Ratio} = \frac{(\sigma_d)_{\varepsilon_i}^{rein.}}{(\sigma_d)_{\varepsilon_i}^{unr.}} \tag{1}$$

Where $(\sigma_d)_{\varepsilon_i}^{rein.}$ and $(\sigma_d)_{\varepsilon_i}^{unr.}$ are the deviatoric stress for reinforced (with geotextile layer or mixed with tire) and unreinforced (sand) samples at any strain level, respectively. Figs. 10a-c shows the variations of strength ratio versus a number of geotextile layers, under confining pressure of 50, 100, and 200 kPa at the different strain levels. The graphs illustrate that strength ratio increases with increasing the number of reinforcement layers significantly, under low confining pressures.

Also, the percent increase is more clearl for the high strain level. For example, in two layers of reinforcement under confining pressure of 50 kPa, the strength ratio increase about 118% (strength ratio =2.18) for strain-level 15%, whereas there is only 64% (strength ratio =1.64) increase under strain-level 6%. Hence, the strength ratio (or strength) of reinforced soil compared with unreinforced soil should be considered at the specific level of strain.

3.3. The effect of the tire chip contents on the strength of sand at different strain levels

Figs. 11a-c show the variation of strength ratio versus strain level of unreinforced samples, at different tire chip content of 0%, 15%, 25%, and 35%, and for different confining pressure values of 50, 100, and 200 kPa. The graphs show that the percentage of the content of the tire chip improves deviatoric stress after a specific strain level, considering confining pressure values. For example, tire chip increases the strength of samples after strain levels of 4%, 8%, and 10% under confining pressures of 50, 100, and 200 kPa, respectively. This trend can be seen in Figs. 12a-c and 13a-c were carried out on reinforced samples of one and two geotextile layers respectively.

Figs. 11-13 indicate that the beneficial effect of the content of the tire chip to improve the strength of the samples occurs in high strain, especially for reinforced samples with geotextile, while in low strain, tire chip does not have a beneficial effect. This suggests that high levels of strain should be applied to improve the strength of samples by tire chips. In other words, the axial strain at failure was also found to increase, especially at a higher percentage of tire chips. The results of this study are in agreement with the findings of the earlier investigators (e.g. [14-17]). To justify this mater can say that the secant/elastic modulus decreases with increasing granulated tire chips content (Fig. 6). This result was predictable by comparing the stiffnesses of granulated tire chips and sand grains. Also, by replacement of the sand grains with granulated tire chips, the sample becomes softer and its shear stiffness decreases. Also, it can be observed that the adding of the tire chips into the sand matrix makes the mixture more ductile. Therefore, increasing tire chips has an adverse effect on the strength ratio in low strain levels. The results observed are in agreement with those reported recently by Anvari et al. [15]. These observations show that the level of imposed strain on the samples plays an essential role in increasing the strength of the tire chip-sand mixtures compared with sand alone.

It can be observed that the adding of the tire chips into the sand matrix makes the mixture more ductile. This characteristic is favorable for the use of mixtures in seismic isolation applications [21]. Also, mixtures tire chips and sand may be useful as soil reinforcement in embankment construction, allowing the embankment to resist larger strains without failure under static loads than for sand alone.

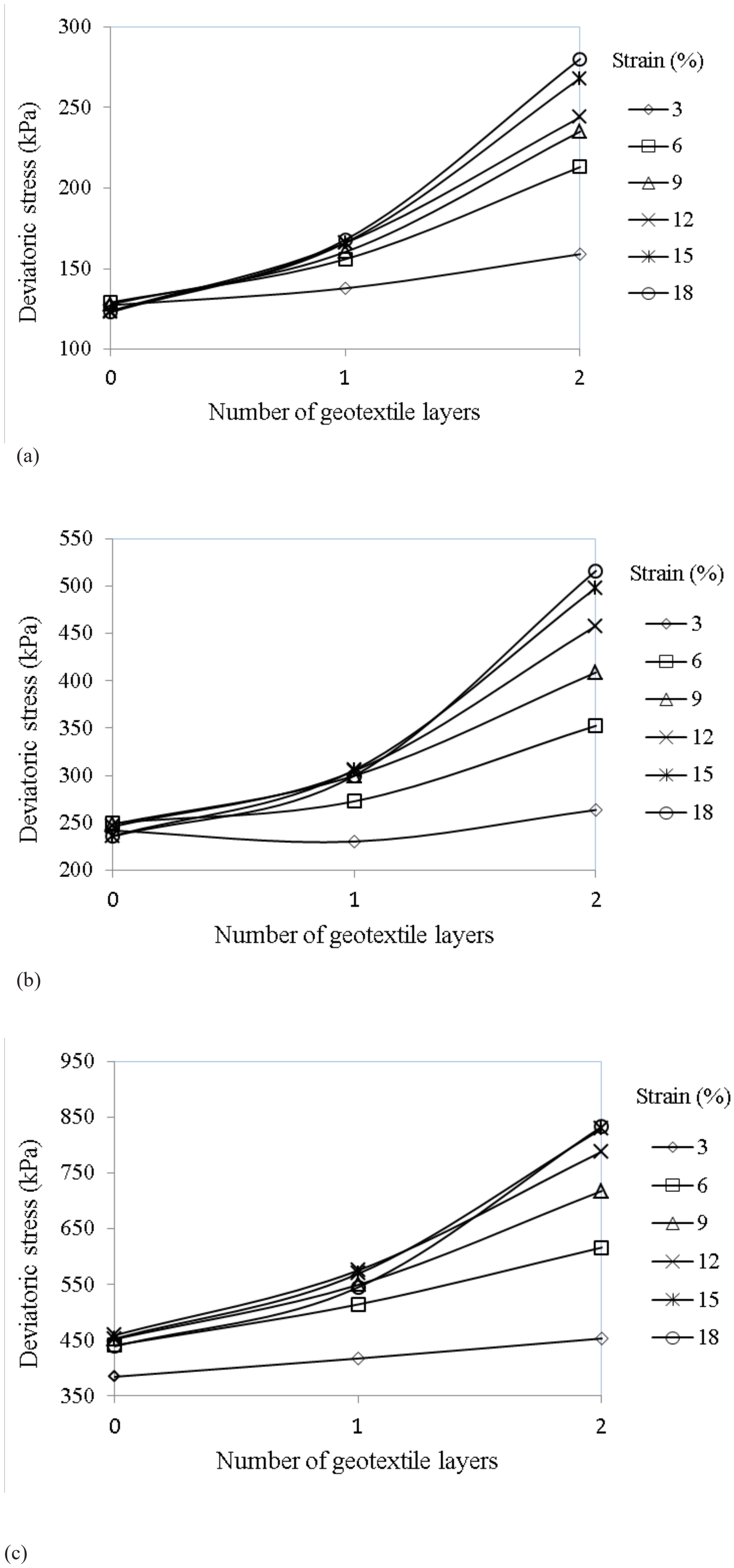


Fig. 9. Deviatoric stress values versus number of reinforcement at different strain levels under various confining pressure (a) 50 kPa; (b) 100 kPa and (c) 200 kPa

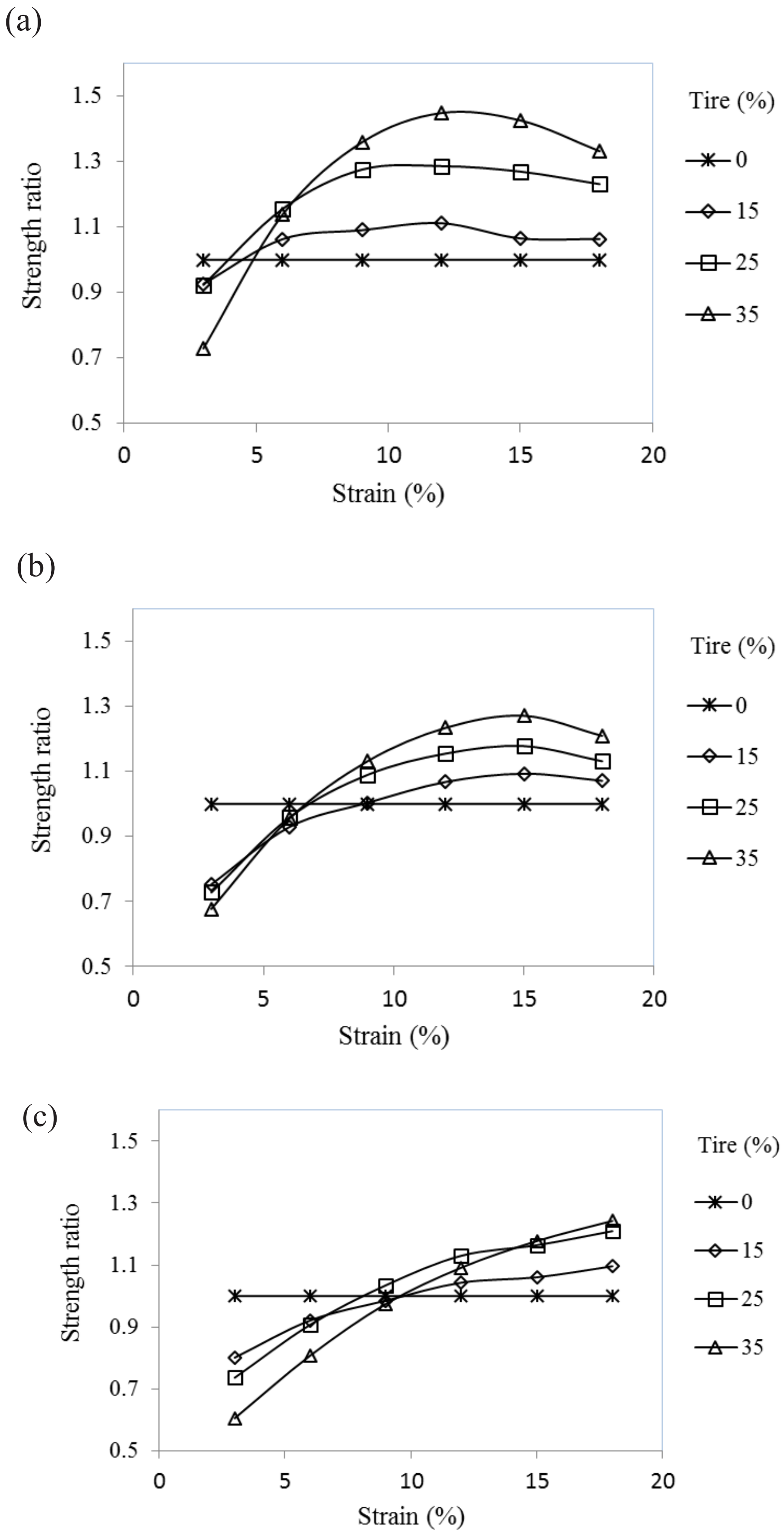


Fig. 10. Strength ratio values versus number of reinforcement at different strain levels under various confining pressure (a) 50 kPa; (b) 100 kPa and (c) 200 kPa

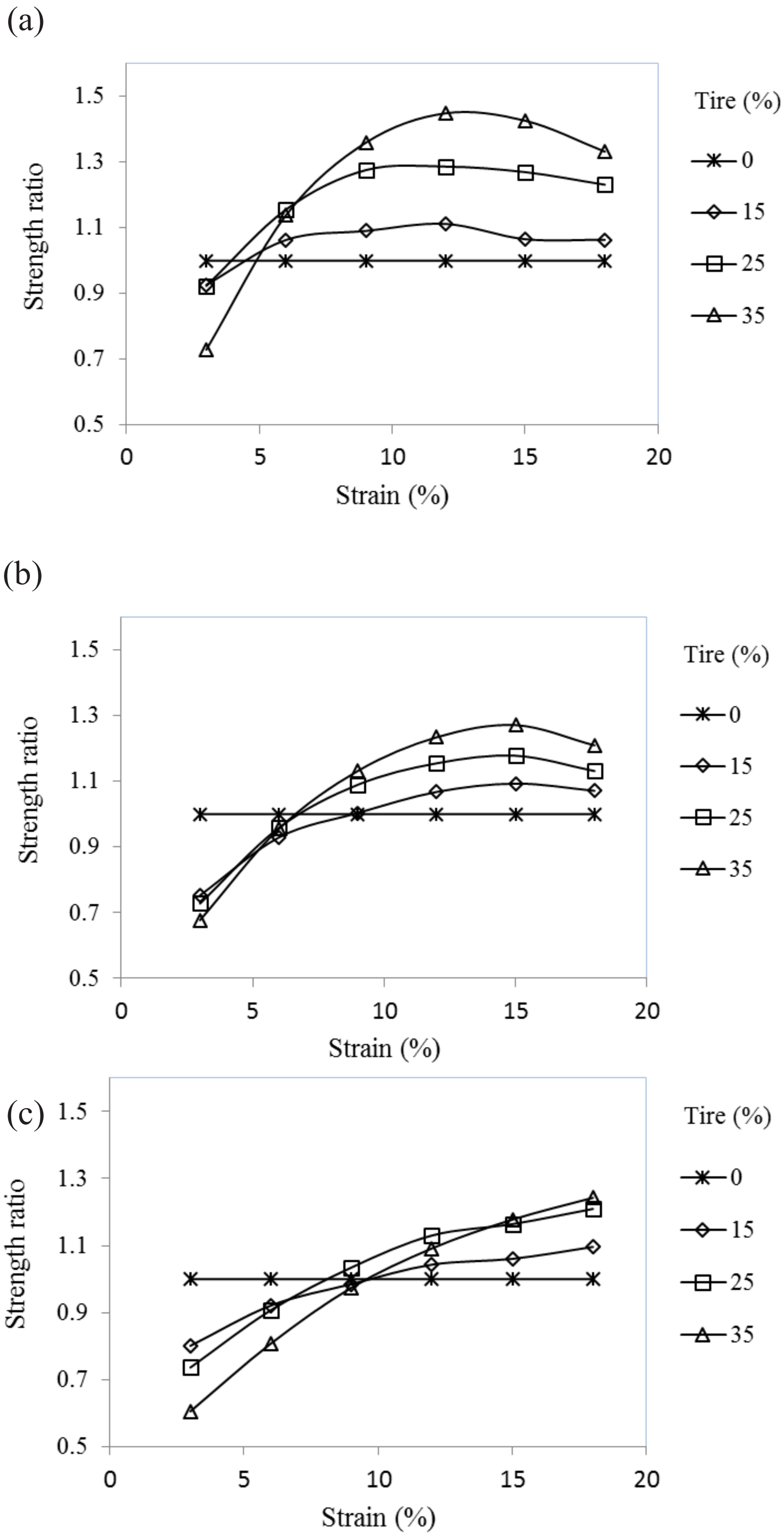


Fig. 11. Strength ratio values versus axial strain for tire chip-unreinforced sand mixtures under various confining pressure (a) 50 kPa; (b) 100 kPa; and (c) 200 kPa

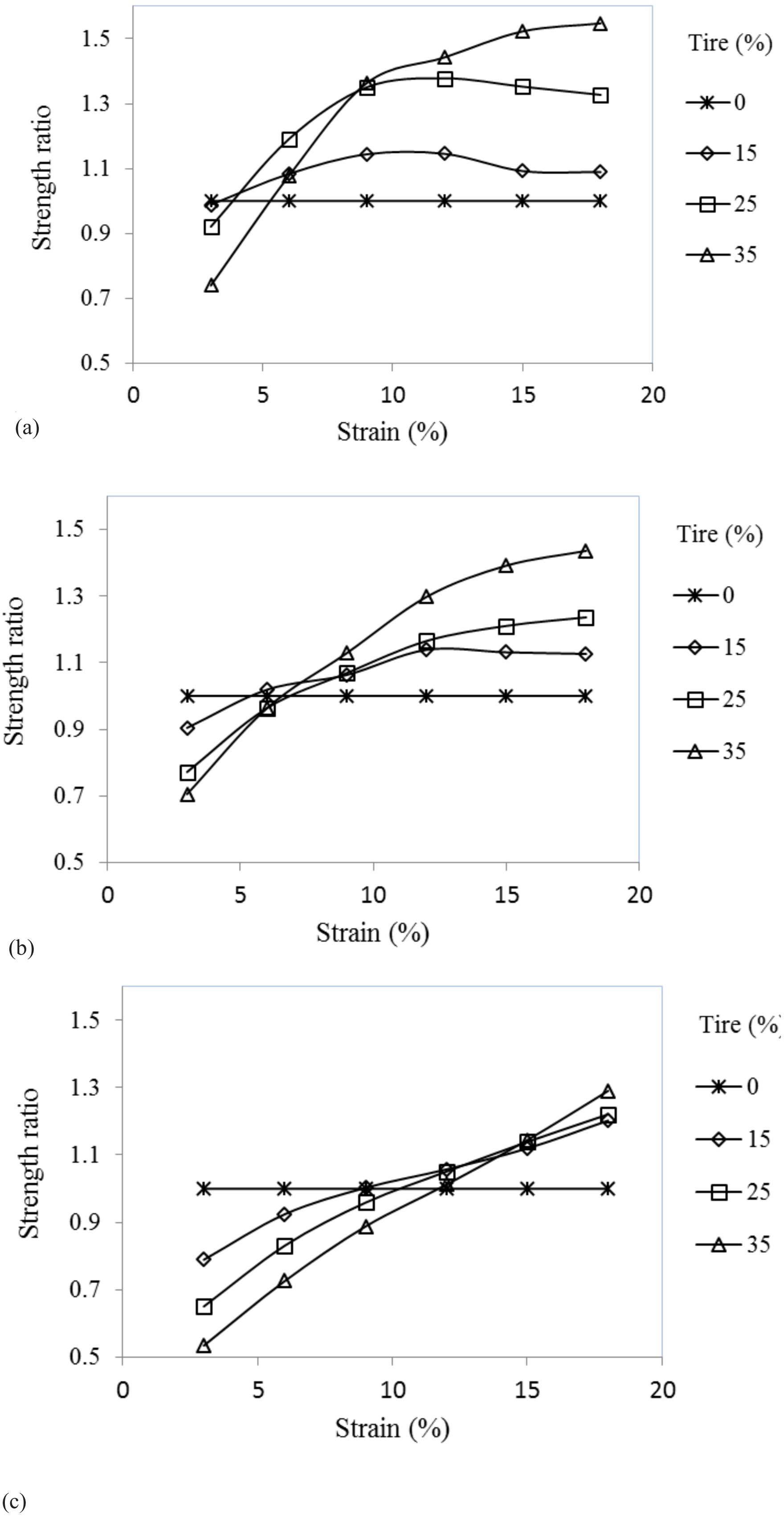
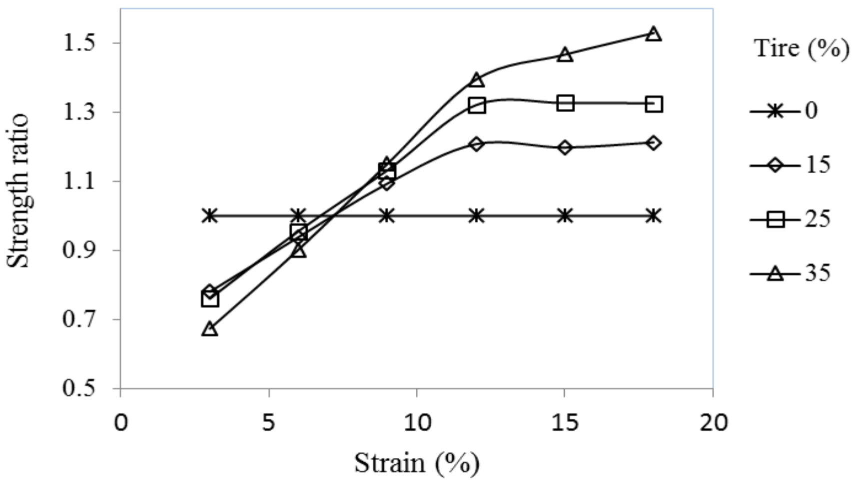
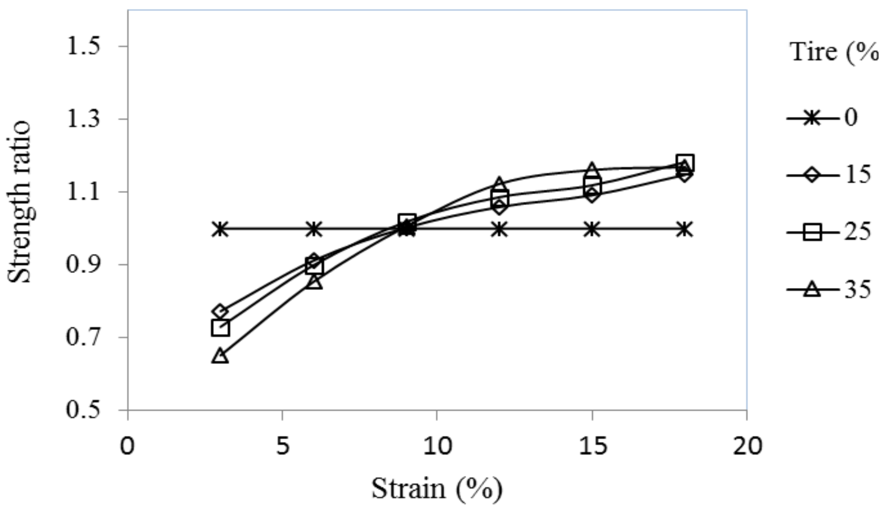


Fig 12. Strength ratio values versus axial strain for tire chip-reinforced sand with one layer of geotextile under various confining pressure (a) 50 kPa; (b) 100 kPa; and (c) 200 kPa



(a)



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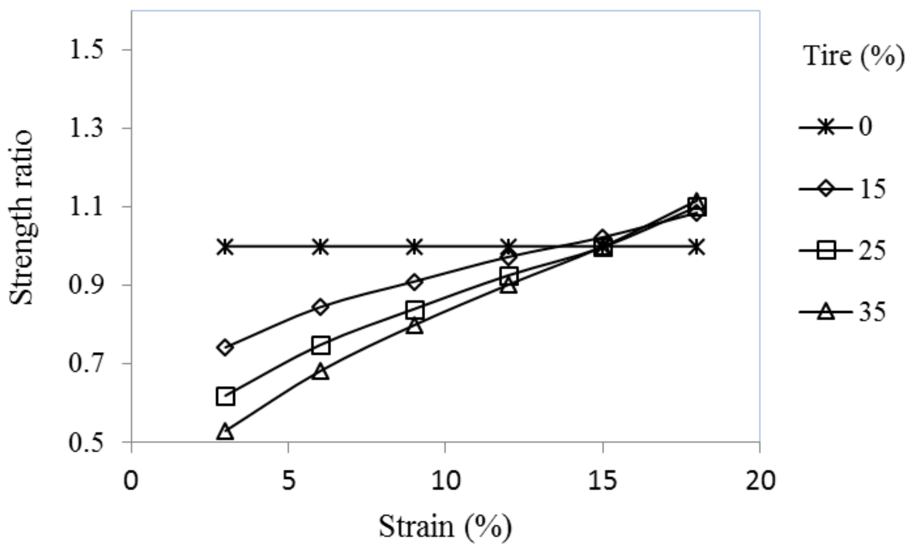


(c)

Fig. 13. Strength ratio values versus axial strain for tire chip-reinforced sand with two geotextile layers under various confining pressure (a) 50 kPa; (b) 100 kPa; and (c) 200 kPa

3.4. The effect of confining pressure on strength at different strain levels

Figs. 14a-b shows the variation of strength ratio versus confining pressure for different values of strain and without reinforced layers. It illustrates that, for strain levels higher than 3%, the strength ratio decreases with an increase in confining pressure. Consider, for example, in 35% tire chip-sand mixture and 15% strain level, the strength ratio increase about 43% (strength ratio =1.43) under confining pressure of 50 kPa, whereas there is only a 17% (strength ratio =1.17) increase under confining pressure of 200 kPa. The explanation may be the decrease in interaction between the tire chip and sand associated with increased confining stress. On the other hand, it indicates that the tire chip at high confining pressure (at the high depth below the ground surface) is not very effective. These results are in agreement with those obtained by Anvari et al. [15].

A similar trend is observed for reinforced samples with geotextile layers. On the other hand, in reinforced samples with geotextile layers, the strength ratio decreases with an increase in confining pressure. Figs. 15a-b show the variation of strength ratio versus tire chip content for various number of reinforcement at strain level 15% under confining pressures of 50 and 200 kPa. As seen from Figs. 15a-b, there is an increase in strength ratio due to an increase of tire chip content at confining pressure of 50 kPa, irrespective of the number of reinforcement layers (Fig. 15a). But at confining pressure of 200 kPa, the strength ratio improves with increasing tire chip content and achieves a maximum for a tire chip content value of about 25% for unreinforced sand and around 15% for one layer reinforced sand and then constantly continues for tire chip contents beyond this values (Fig. 15b). For reinforced samples with two geotextile layers, the strength ratio does not change with increasing tire chip content under the confining pressure of 200 kPa.

Figs. 16-17 show the contours of strength ratio at strain level 18% under confining pressures of 50 Pa and 200 kPa, respectively. Also, these figures illustrate that, for all samples, the strength ratio increases with increasing tire chip content under low confining pressures.

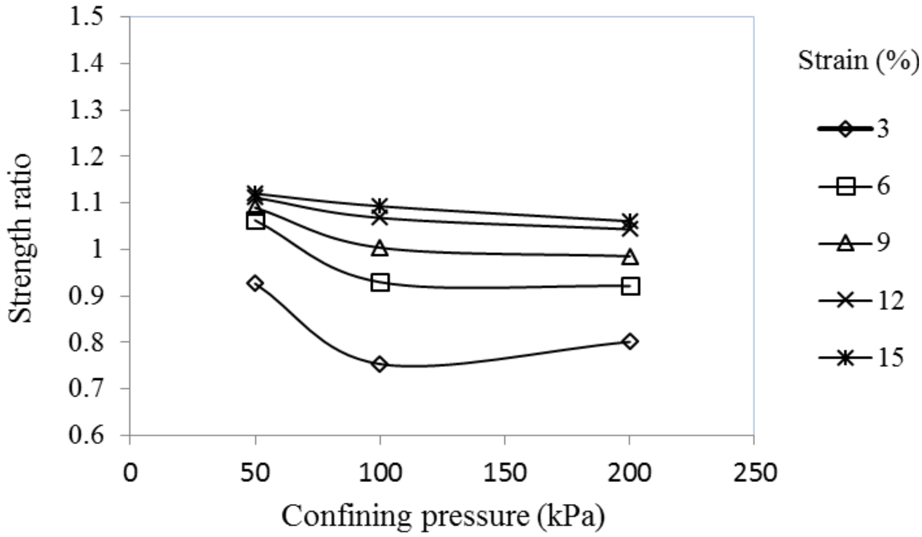
It is stated that the use of a peak-point failure strength or strength equivalent to the axial-strain approximately 15% ([22]) to evaluate the effect of reinforcement on strength (or strength ratio) without considering the imposed strain level on the soil can be caused hazard and uncertainty in Realistic design. Therefore, the strength (strength ratio) should be considered exactly at the applied strain level.

4- Conclusions

Compression triaxial tests studied the effects of tire chip content on shear strength of sand and reinforced sand with geotextile layers. For this reason, 0:100, 15:85, 25:75, 35:65, and 100:0 volume mixtures with mixing ratios were used as filling materials. The tests were conducted under 50, 100, and 200 kPa confining pressure. It has been found that the numbers of layers of reinforcement, tire chips content, confining pressure, and strain level are influencing factors on the shear strength of the samples.

For strain higher than 3%, the strength ratio decreases with an increase in confining pressure. This value decreases from 250% to 10%. It indicates that the tire chip and reinforcement at high confining pressure (at the high depth below the ground surface) are not very effective. Findings show that the imposed strain level on the samples plays an essential role in increasing the strength of the tire chip-sand mixtures compared with sand alone. Tire chip increases the strength of samples after strain levels of 4%, 8%, and 10% under confining pressures of 50, 100, and 200 kPa, respectively. Therefore, the beneficial effect of tire chip content to improve the strength of samples occurs in high strain, especially for reinforced samples with geotextile, while in low strain; tire chip does not have a beneficial effect. The variation of strength ratio due to the increase in tire chip content depends on the number of geotextile layers and confining pressure. For reinforced samples with two geotextile layers at high confining pressures, the strength ratio does not change with increasing tire chip content.

The findings above show that the trend and value of the strength ratio for different levels of strain can be changed. It implies that the use of a peak-point failure strength or strength equivalent to the axial-strain of approximately 15% to evaluate the strength ratio due to tire chips and reinforcement without considering the imposed strain level on the soil may cause hazard and uncertainty in realistic design. Consequently, the strength ratio at the applied level of strain should be considered.



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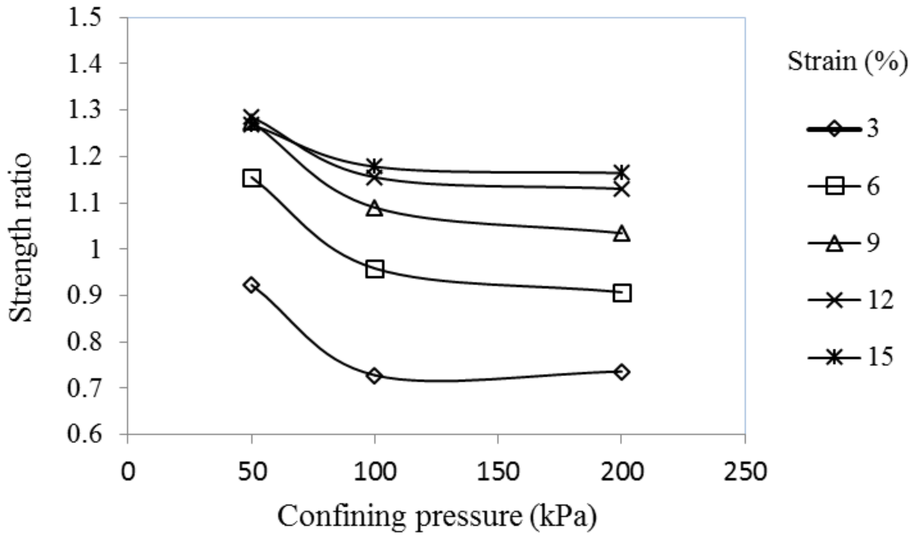

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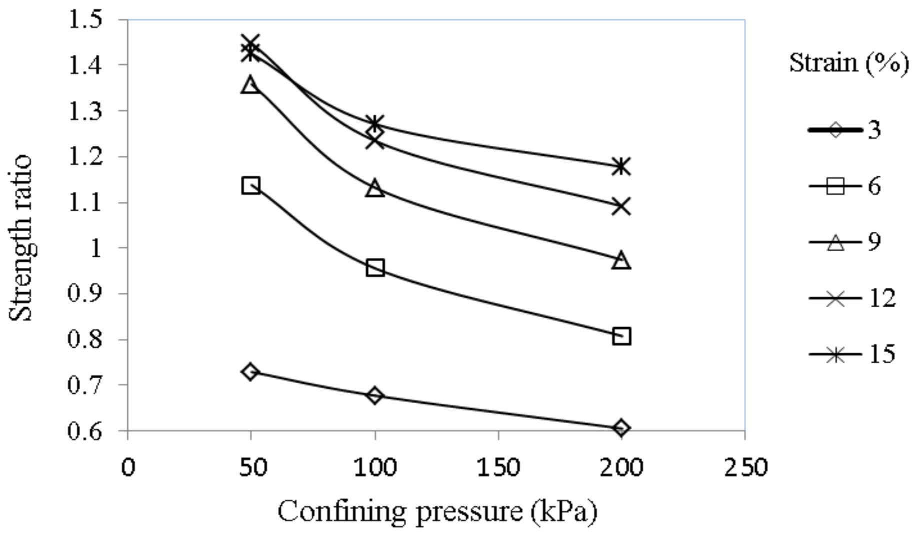
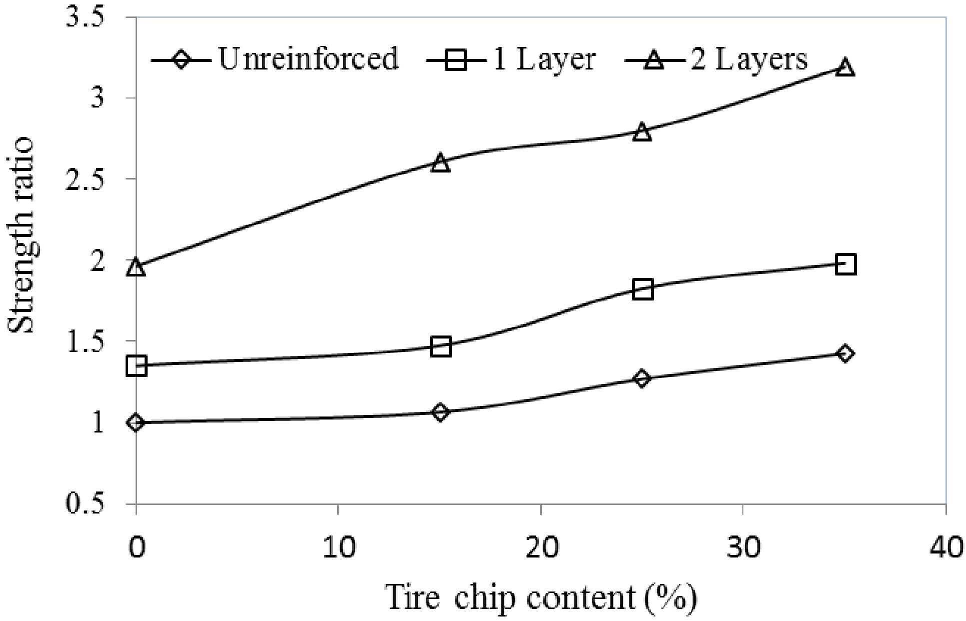
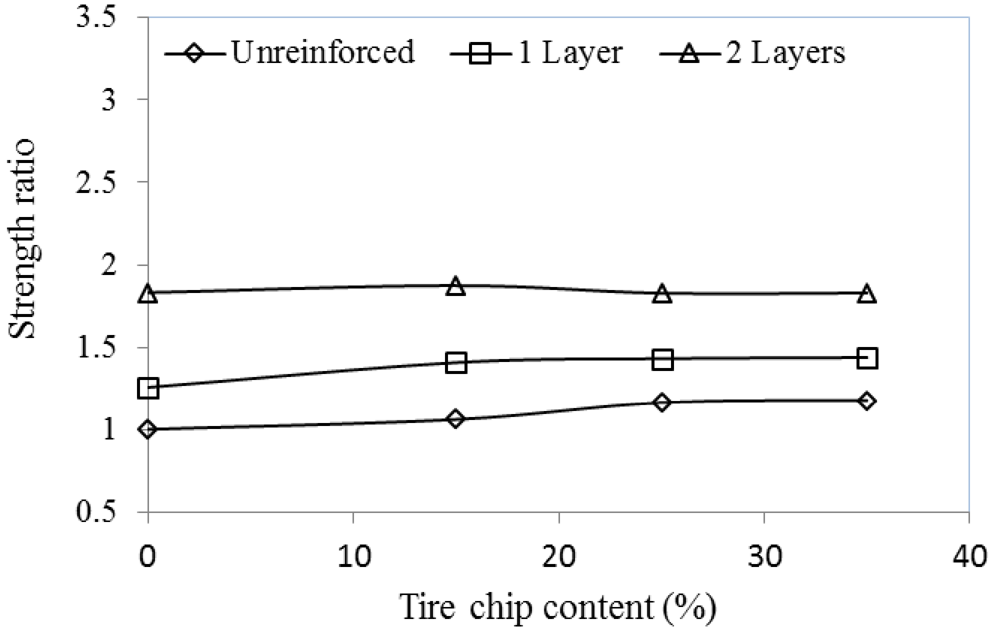


(c)

Fig. 14. Strength ratio values versus confining pressure at different strain levels and for various tire chip contents: (a) 15%; (b) 25% and (c) 35%



(a)



(b)

Fig. 15. Strength ratio values versus tire chip content for various number of reinforcement at strain level 15% under confining pressure of: (a) 50 kPa and (b) 200 kPa

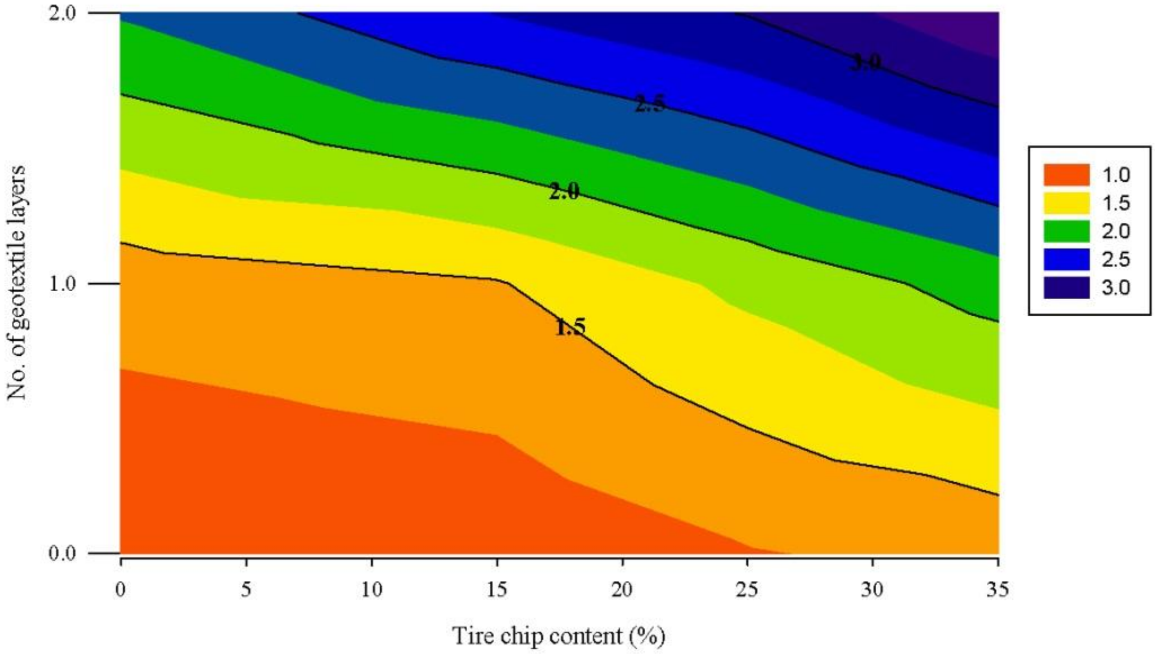


Fig. 16. Strength ratio contours at strain level 18% under confining pressure of 50 Pa

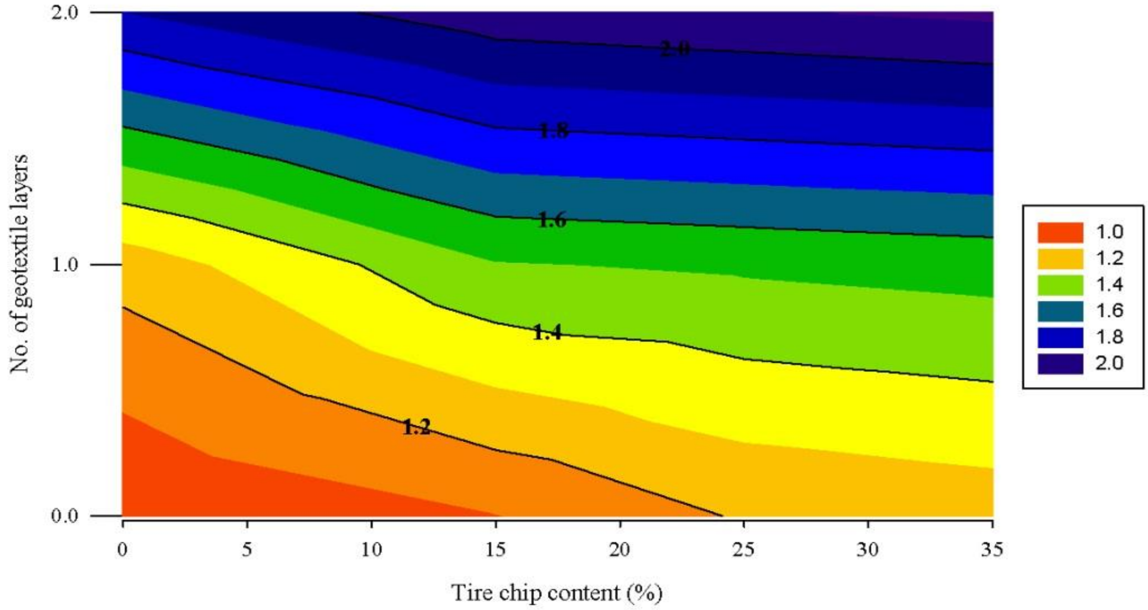


Fig. 17. Strength ratio contours at strain level 18% under confining pressure of 200 Pa

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