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Shear strength parameters of sand-tire chips mixtures

Kum-öğütülmüş araç lastiği karışımlarının kayma mukavemeti parametreleri

Hüseyin Suha AKSOY*[1,a], Nichirvan Ramadhan TAHER[2,b], Halmat Ahmed AWLLA[3,c]
[1,2] Firat University, Faculty of Engineering, Department of Civil Engineering, 23119, Elazığ, Turkey
[3] Erbil Polytechnic University, Choman Technical Institute, Department of Information Technology, 44010, Choman

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Abstract
Used tires are unwanted wastes especially in urban areas and their extent is growing every year. With the development of human societies and the increasing use of automobiles, every year millions of used tires are collected as garbage around the world and leave the consumption cycle. However, they can be used by mixing with soil, one of the basic building materials, to improve their mechanical properties. This article discusses the effect of adding tire chips on the shear strength properties of high-friction sand. Different mixing ratios of the sand-tire chips mixture by weight (100: 0, 97.5: 2.5, 95: 5, 92.5: 7.5 and 90:10) were used. The Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) of sand and different sand-tire chip mixtures were determined by the standard Proctor test. Samples were prepared under OMC and MDD conditions and direct shear box test was performed on sand and sand-tire chip mixtures under three different axial stresses. The results showed that when the percentage of tire chips reaches 5%, the internal friction angle was increased by 13.8% and cohesion was decreased by 66.4%. After this point internal friction angle was decreased and cohesion increased slightly.

Keywords: High friction sand, Proctor compaction test, Shear strength parameters, Shear box test, Tire chips

Öz
Kullanılmış lastikler, özellikle kentsel alanlarda istenmeyen ve miktarı her yıl artan atıklardır. İnsan toplumlarının gelişmesi ve artan otomobil kullanımıyla birlikte dünya genelinde her yıl milyonlarca kullanılmış lastik, tüketim döngüsünden çıkarak atık olarak toplanmaktadır. Oysaki bu atıkların, temel yapı malzemelerinden biri olan zeminle karıştırılarak zeminin mekanik özelliklerini iyileştirmek için kullanılması mümkündür. Bu makalede, yüksek sürtünmeli bir kumun kayma mukavemeti parametrelerine, öğütülmüş araç lastiği eklenmesinin etkisi incelenmiştir. Kum- öğütülmüş araç lastiği karışımı için ağırlıkça (100: 0, 97.5: 2.5, 95: 5, 92.5: 7.5 ve 90:10) oranları kullanılmıştır. Katkısız kumun ve kum-öğütülmüş araç lastiği karışımlarının maksimum kuru birim hacim ağırlıkları (MDD) ve optimum su muhtevası (OMC) değerleri standart Proktor deneyi ile belirlenmiştir. Proktor sıkılığında hazırlanan numuneler, üç farklı eksenel gerilme altında kesme kutusu deneyine tabi tutulmuştur. Sonuçlar, içsel sürtünme açısının öğütülmüş araç lastiği yüzdesi %5'e ulaştığında %13.8 artış gösterdiğini ve kohezyonun ise öğütülmüş araç lastiği yüzdesi % 5'e ulaştığında %66.4 azaldığını göstermiştir. Bu noktadan sonra içsel sürtünme açışı azalmış ve kohezyon ise düşük bir oranda artmıştır.

***Anahtar kelimeler**: Yüksek sürtünmeli kum, Proktor deneyi, Kayma mukavemeti parametreleri, Kesme kutusu deneyi, Öğütülmüş araç lastiği*

*[a] Hüseyin Suha AKSOY; saksoy@firat.edu.tr, Tel: (0532) 296 34 40, orcid.org/ 0000-0003-0564-457X
[b] orcid.org/ 0000-0002-1295-080X [c] orcid.org/ 0000-0002-0545-0962

1. Introduction

Due to the development of communities and the excessive use of vehicles, millions of used tires become a problem every year and need appropriate treatment (Rahgozar and Saberian, 2016). The storage of used tires is highly undesirable due to the occurrence and fire risks and the cost of hygienic disposal. Avoiding of used tires is a difficult mission because they have a long life and are not biodegradable. There are some traditional methods for managing unwanted tires such as illegally dumping, landfilling, and stockpiling, but the problem is that all of these methods are short-term solutions. Therefore, recycling used tires is an essential task to be done to avoid excess-storing that huge amount of used tires worldwide (Akbulut et al., 2007; Marto et al., 2013)

Many researchers have devoted great effort to examine the influence of the inclusion of waste tire shreds and tire chips on the engineering properties of different types of soils such as shear strength, permeability, compressibility, compaction properties, poison's ratio and modulus of elasticity. They reported that tire chips are good material for backfilling retaining walls and embankments because of their lightweight (Ahmed and Lovell, 1993; Lee et al., 1999; Tweedie et al., 1998; Youwai and Bergado, 2003; Cabalar, 2011; Edincliler et al., 2010; Rahgozar and Saberian, 2016). On the other hand, some researchers have argued and demonstrated that the aforementioned parameters have a great influence on the serviceability behavior under normal loads and dynamic loads, and reduce vibrations in structures due to the high damping behavior of rubber. (Tsang et al., 2010; Edincliler et al., 2013; Boominathan et al., 2015; Chenari et al., 2017; Edincliler and Toksoy, 2017; Edincliler et al., 2018; Awlla et al., 2020). Ahmed (1992) investigated the properties of sand-tire chips by performing triaxial test. He reported that the percentage of tire chips and confining pressure have a considerable impact on shear resistance parameters of the mixture of sand-tire chips. Rao and Dutta (2006) studied the effect of rectangular tire chips on the shear strength parameters of sand. They suggested that when the length/width ratio of the tire chips is 2 and 20% tire chips is used by weight, the maximum shear strength of sand-tire chips mixture obtained. Tire chips are considered to have good engineering properties due to their flexibility, high durability and low specific gravity. Tire chips have many different geotechnical engineering applications, they can be used for backfilling materials behind retaining walls, soil reinforcement, and construction of highways (Cabalar et al., 2014). In order to analyze the shear resistance properties of the mixture of sand-tire chips, Ghazavi et al., (2011) applied large scale shear box test. For this purpose, different percentages of tire chips were mixed with the sand (15%, 25%, 30% and 35%) by volume. The results revealed that as the tire chips content increased by up to 30 percent, the value of the internal friction angle (ϕ) of the sand increased and then decreased. Naval et al., (2013) examined the effect of the inclusion of used tire fibers on the shear strength properties of sand using the drained triaxial test. To do this, various percentages of tire chips (0.25%, 0.50%, 0.75% and 1.0%) were used and prepared samples with different relative densities (60%, 70%, 80% and 90%). According to the experimental results, it was observed that by adding fibers from used tires to sand, the value of the (ϕ) gets increased. The best improvement was found at a relative density of 60% with a fiber content of 0.75%. Marto et al., (2013) applied several shear box tests on sand-tire chips mixture, it was stated that the (ϕ) of sand reinforced with tire chips is greater than unreinforced sand. It was also found that the optimum percentage of rubber chips to increase the shear strength properties of the sand is 20% by weight. They reported that the percentage of tire chips, unit weight of sand and the value of the axial stress have a considerable influence on the shear resistance properties of the mixture of sand-tire chips. Annadurai and KannanRajkumar (2014) reported that the MDD of the soil determined from the standard Proctor test decreased with increasing percentage of tire chips. This may be due to the lightness of the tire chips. Tiwari et al., (2017) investigated the effect of tire chips on shear strength parameters of dune sand using a shear box test. For this purpose, they used various percentages of tire chips (25%, 50% and 75%) by dry weight of the sand. Based on their experimental results, they concluded that addition tire chips improve the (ϕ) of the dune sand. Anvari et al., (2017) investigated the relationship between (ϕ) of the sand-tire chips mixture and the relative density. The results showed that at high relative densities, the value of (ϕ) decreases with increasing tire chips content. However, at low relative densities, it rises with increasing tire chips content. The optimum granular rubber content was found to be 5% by weight. Li et al., (2020) conducted a series of triaxial tests to investigate the effect of tire chips content on the (ϕ) and material stiffness. Based on the test results, they said that with the same tire chips content, the presence of bigger tire chips particles improves the stiffness of the material. Rouhanifar et al., (2020) studied the deformation and shear strength properties of the sand-tire chips mixture at relative density 30%, they stated that the (ϕ) was increased until tire chip content reached 20 %, until this point cohesion intercept (c) was decreased. After this point (ϕ) was started to decrease and (c) was started to decrease.

Most previous studies have explored the effect of tire chips on the shear strength characteristics of loose or dense dry soil. However, in most cases, there is water with soil, which means it is not dry completely. Also in most cases, the soil must be compacted to a good extent to withstand the incoming loads from the superstructure. For this reason, Proctor density soils with optimum moisture content have been used in this research. This study intends to investigate the shear strength parameters of the sand and sand-tire chips mixture with various mixing ratios (100: 0, 97.5: 2.5, 95: 5, 92.5: 7.5 and 90:10) by weight of the sand. For this purpose, a series of shear box tests were conducted on sand-tire chips mixtures. Specimens were prepared and arranged under the conditions of MDD and OMC.

2. Material and method

The sand used in the study was taken from the Murat River in Elazig in Turkey. The tire chips were provided by the geotechnical staff of Firat University. In Figure 1 the sand, tire chips and their mixture can be seen after adding water with OMC. The angle of repose of the sand was found to be 35° measured in accordance with ASTM- C1444-00, as shown in Figure. A sieve analysis test based on ASTM D422-63 was performed to obtain a gradation of sand and tire chips as shown in Figure 3. According to the sieve analysis results, the percentage of fines is 4.7%, sand fraction 89.6% and gravel fraction 5.7%. Standard Proctor test was applied as reported by ASTM D-698 to find MDD and OMC of sand and sand-tire chips mixture with different percentages introduced previously. The minimum dry density for sand was measured by experiment in agreement with ASTM D4254. The specific gravity of sand was measured conforming to ASTM D854-14. The measured index parameters of the sand are listed in Table 1. The sandy soil used in this study was grouped as well-graded sand (SW) in accordance with the unified soil classification system (USCS). The tire chips were angular surface and its maximum dry density was 0.634 gr/cm^3 and has an OMC of 4.6% by conducting Proctor test. Physical and chemical properties of tire chips are listed in Table 2.
The shear box test according to ASTM D-3080 was performed on the samples of sand and sand-tire chips mixture to determine their shear strength parameters. Specimens for the shear box test with dimensions 6.0 x 6.0 x 2.0 cm were prepared under conditions of MDD and OMC. All tests were performed with strain-controlled shear box test machine with constant shearing rate of 1 mm/min. The shear stress and horizontal displacement were recorded.

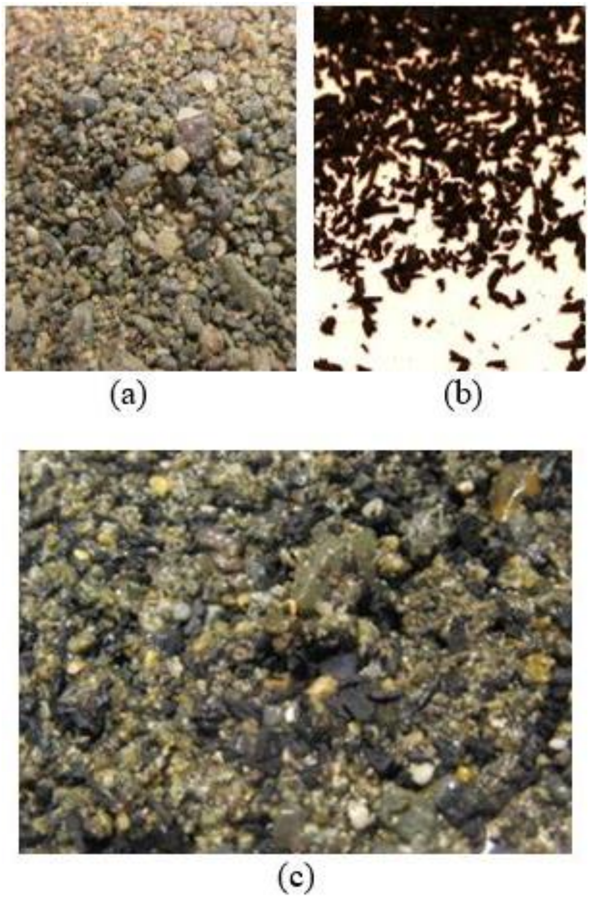

Figure 1. (a) Sandy soil, (b) Tire chip, (c) Sand-tire chips mixture

Figure 2. The angle of repose of the sand

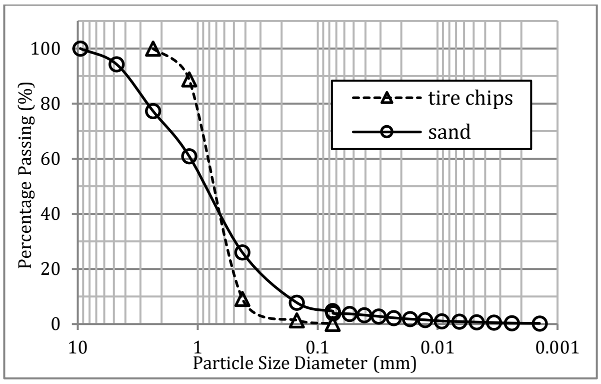

Figure 3. The particle size distribution of sand and tire chips

Table 1. Index properties of the sand.

Property	Value
Effective size, D_{50} (mm)	0.9
Uniformity Coefficient (C_u)	6.315
Curvature Coefficient (C_c)	1.096
(USCS)	SW
Specific Gravity (G_s)	2.74
MDD(gr/cm^3)	2.03
Minimum dry density (gr/cm^3)	1.49
Maximum void ratio (e_{max})	0.839
Minimum void ratio (e_{min})	0.350

Table 2. Physical and chemical properties of tire chips (Celik, 1996).

Property	Value
Gs	1.153-1.198
Elastic modulus, (MPa)	22.96
Tensile strength, (MPa)	28.1
Softening temperature, (°C)	175
Component Sryrene butadienecopolymer, (%)	62
Carbon block, (%)	31
Extender oil, (%)	1.9
Zinc oxide, (%)	1.9
Stearic acid, (%)	1.2
Sulphur, (%)	1.1
Accelerator, (%)	0.7

3. Results and discussion

From the Proctor compaction tests, the OMC and MDD of sand and various sand-tire chips mixtures were measured and are listed in Table 3. With increasing the content of the tire chips, it was noticed that the MDD decreased while the OMC increased. Figure 4 shows the change of void ratio versus various tire chips content. It is clear that by adding 2.5% tire chip content, the void ratio of the sand-tire chips mixture is reduced to a minimum value, but by adding more tire chips, it starts to increase. This phenomenon is due to the fact that the addition of low tire chips content makes it possible to rearrange the particle size distribution of the sand to a denser state. Anvari et al., (2017) found a similar relationship between tire chip percentage and void ratio. However, the minimum void ratio was achieved for 5% tire chips, but the size of the tire chips used by them is much larger than the sand particle's sizes. Therefore, the percentage of tire chips obtained is different from this study.

Table 3. OMC and MDD corresponding to the tire chips percentage.

Tire chip percentage (%)	MDD (gr/cm^3)	OMC (%)
0	2.033	11
2.5	1.99	11.1
5.0	1.905	11.4
7.5	1.84	11.8
10	1.78	12

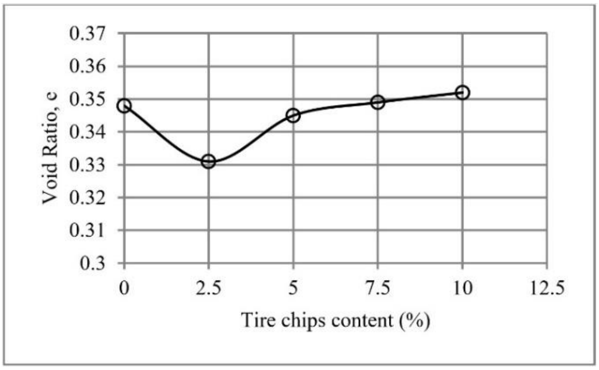

Figure 4. Variation of void ratio corresponding to the tire chips content

Relationships between the shear stress-horizontal displacement for three different axial stresses for sand and sand-tire chips mixtures obtained from shear box tests are given in Figure 5 through Figure 7. It can be seen that by adding more tire chips, the ductility of the sand-tire chips mixture increases. In addition, the variation of the peak shear stress corresponding to the different axial stresses for different tire chips content is presented in Figure 8. It can be concluded that by adding the tire chips, the slope between shear stress and axial stress becomes steeper until the percentage of tire chips reaches between 2.5% and 5.0%. Thus, the value of the (ϕ) of sand-tire chips mixture increases while the (c) decreases. Moreover, when the percentage of tire chips rises above 5%, the slope of shear stress and axial stress changes to gentle. Consequently, the value of the (ϕ) of sand-tire chips mixture gets lower while the (c) increases slightly.

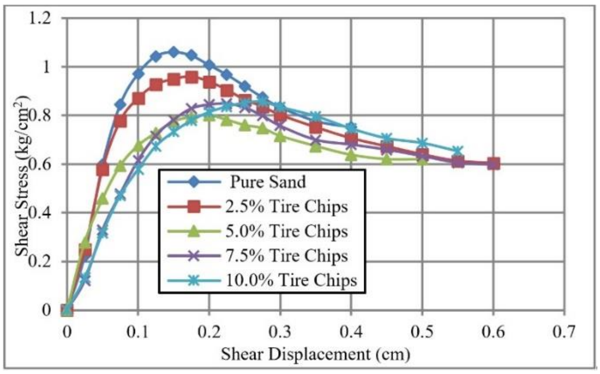

Figure 5. Shear stress-horizontal displacement for sand and different ratios of sand-tire chips mixture to the normal stress of (0.556 kg/cm^2)

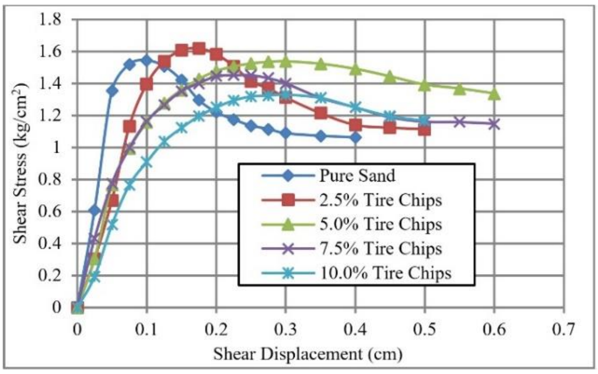

Figure 6. Shear stress-horizontal displacement for sand and different ratios of sand-tire chips mixture to the normal stress of (1.111 kg/cm^2)

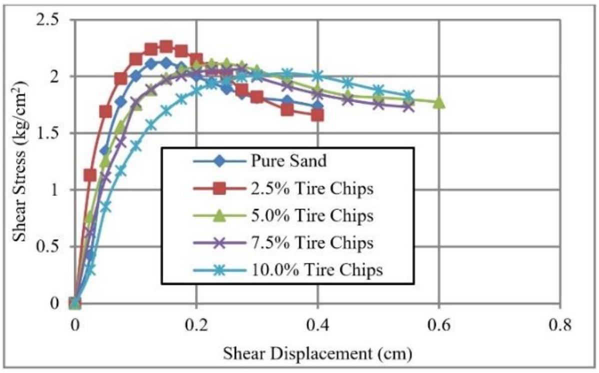

Figure 7. Shear stress-horizontal displacement for sand and different ratios of sand-tire chips mixture to the normal stress of (1.667 kg/cm^2)

Figure displays the change of the (ϕ) of the sand with various tire chips content. The (c) values are also changed with increasing tire chips content as shown in Figur. It was observed that when the tire chips ratio reaches up to 5%, there is a maximum value of (ϕ) and minimum value of (c), but after this percentage the (ϕ) decreases and (c) increases. These properties of the sand-tire chip mixture were also noticed by Rouhanifar et al., (2020), but the difference is that they found the optimum percentage of tire chips to be 20%. This difference is possible because they used loose sand-tire chips mixture while in this study shear box test samples of sand-tire chips mixture were prepared by MDD and OMC. The (c) value in the mentioned study is lower compared to this study, this is due to the fact that the particle size of sand and tire chips is different and the percentage of fines in the sand used in this study is higher compared to the sand used by them.

The reason for the increase in friction angle of the mixture at low values of tire chips content cannot be easily explained. The numerical study by Valdes and Evans (2008) indicates that the tire chips content in a sand-tire chips mixture have a strong influence on the microstructure of force transmission between the particles. On the other hand, higher flexibility of the sand specimens with small values of tire chips content, might provide a greater chance for the particles to move relative to each other to finally reach more stable and stronger critical state situation compared to that for pure sand specimens.

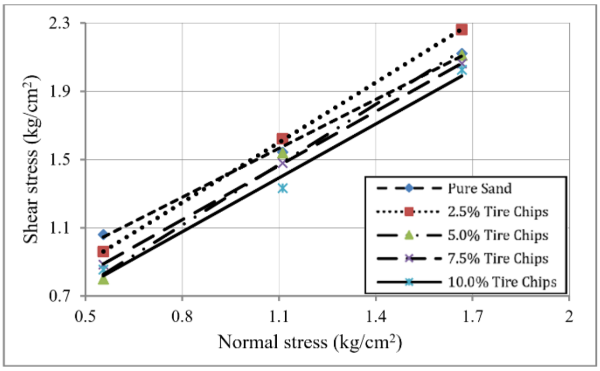

Figure 8. Peak shear stress versus normal stress for different tire chips content

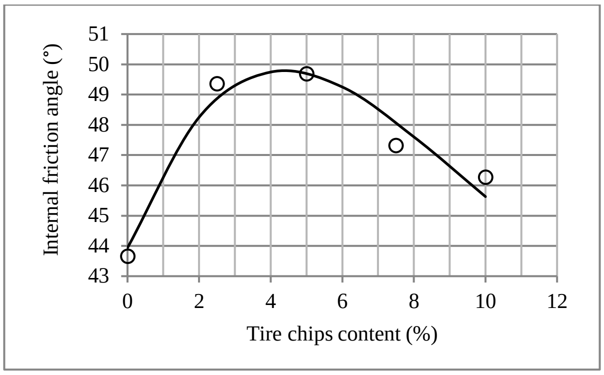

Figure 9. Change of (ϕ) of sand versus different tire chips content

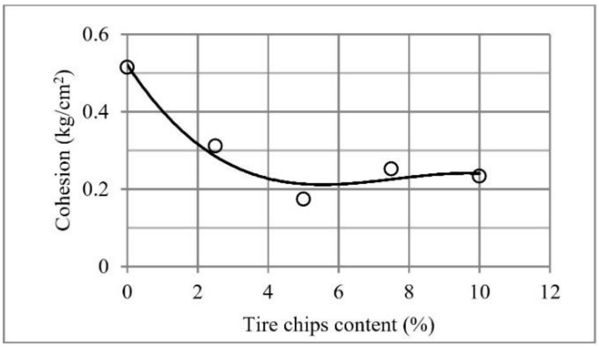

Figure 10. Change of (c) of sand versus different tire chips content.

Many researchers have worked on the shear strength characteristic of the sand-tire chips mixture to study how the tire chips content influence the shear strength parameters of the sand. For this purpose, most of them used the shear box test like this study. Table 4 shows the optimum percentage of the tire chips that causes the increase of the (ϕ) of the sand-tire chips mixture found in literature. From Table 4, It is evident that the results found by the researchers are different as there is a difference in the particle size of the sand and tire chips used by each of them, as well as different relative densities (D_r). Edincliler et al., (2010) used triaxial test sytem to research tire chips effect on sand. They found that increasing tire chips content caused decrease in internal friction angle.

It can be seen clearly from the table that optimum percentage of tire chips is varying from 5% to 25% by weight. It can be said that the optimum percentage of tire chips which results in an increase in the (ϕ) of the sand-tire chip mixture depends on the tire chip content, the relative density of the mixture, normal stress and the grain size of sand and tire chips. In this study, optimum tire chips percentage also found as 5% by weight. It is clear that the results of this study are compatible with the results found by Anvari et al., (2017).

Table 4. The optimum percentage of tire chips for increasing the (ϕ) of sand found by some researchers.

Reference	**The particle size of the Sand (mm)**	**The particle size of the Tire chips (mm)**	**The optimum percentage of tire chips (%)**	**Relative density of soil (D_r)**	**(ϕ) of sand alone (°)**	**(ϕ) of sand-tire chips mixture (°)**
Edincliler et al., (2010)	0.07-2	0.07-5	5% by weight	D_r ≅70%	41.5	38.2
Ghazavi et al., (2011)	0.07-1.2	0.07-10.5	30% by volume	Loose	39.7	43
Marto et al., (2013)	0.06-5	1-4	20% by weight	D_r =70%	32.8	34.2
Tiwari et al., (2017)	0.07-1.3	0.07-5	25% by weight	Loose	30	35
Tiwari et al., (2017)	0.07-1.3	0.07-5	25% by weight	Dense	37	39
Anvari et al., (2017)	0.08-1	1-5	5% by weight	D_r =50%	35.1	39.2
Rouhanifar et al., (2020)	0.3-1.25	0.075-0.3 0.3-1 1.2-5	20% by volume	D_r = 30%	30.7 30.7 30.7	31.8 35 33.8
This study	0.0015-9.5	0.075-2.5	5% by weight	Proctor density	43.6	49.7

4. Conclusion

A series of standard Proctor compaction tests and shear box tests were applied to study the effect of inclusion of tire chips on shear strength properties of dense and high friction sand, the following conclusion can be drawn:

- The MDD of sand-tire chips mixture decreased with increasing tire chips content, due to lightweight of the tire chips.
- The OMC of the sand tire chips mixtures remains nearly same with increasing tire chips content because the particle size of the sand and tire chips almost the same.
- When the content of tire chips reaches 5% by weight, the value of the (ϕ) of sand-tire chips mixture increased by 13.8%, after that it starts to decrease.
- The (c) of sand-tire chips mixtures decreases by 66.4% at the 5% of tire chips, and then increases slightly with increasing tire chips content, but it is still lower than that of unreinforced sandy soil. It appears that tire chips cannot improve the (c) of the sand, which may be due to the use of dense sand in the experiments. However, the (c) is not important when sandy soil concern.
- From the experimental results, it is possible to improve the (ϕ) of the sand by adding a low percentage of tire chips, this improvement can be used in geotechnical engineering applications such as backfill material behind the retaining wall, construction of embankment, etc.

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