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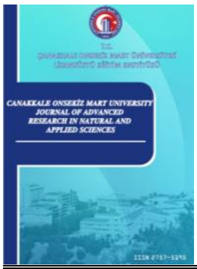

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# Using Granular Waste Tire as a Factor to Increase Shear Strength of Cohesionless Soils

Koray Aktürk[1], Öznur Karaca[1,*]

[1]Department of Geological Engineering, Faculty of Engineering, Çanakkale Onsekiz Mart University, Çanakkale, Turkey

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***Research Article***

**Abstract** − Soils used as foundation or structural materials in construction are considered to be weaker than rocks and problems such as bearing capacity, erosion, sliding, collapse, and liquefaction can be encountered. In such cases, since most soil problems are site specific, the soil properties should also be improved by appropriate techniques. Improvement methods applied to strengthen soils often cause financial burden. Recently, there are studies about the use of waste rubber tires, which pose an environmental risk during storage, as a reinforcement material for soils. The main purpose of this study is to examine the effect of poorly graded sand (SP) mixed with granular waste tires in different proportions (10%, 20%, 30%, 40% and 50%) on the shear strength of the sand. For this purpose, the physical (water content, specific weight, unit volume weight) and mechanical (shear strength) parameters of the mixtures were determined. According to the results of the research, the material with 100% sand content contributes to the shear strength by a certain proportion when compared to the mixed materials containing granular-sized waste rubber. According to the results of this research, the highest shear resistance value was observed in material with 20% tire content in waste rubber sand mixtures, while higher rates of tire addition provided lower results than 100% sand material. In addition, considering the issue in terms of environmental impact, a column test was carried out on the mixture containing 20% rubber-80% sand and no adverse effects of the pollutants were observed.

***Keywords –*** *Sand, scrap tire, shear strength, soil, soil improvement*

## 1. Introduction

Soil is the name given to material comprising rock fragments formed as a result of weathering and degradation with a variety of environmental factors, containing organic matter, voids and which may hold water. Therefore, they are considered more problematic compared to rocks (Huat, 2010). Depending on the soil properties and environmental conditions, problems such as liquefaction, sliding, collapse, subsidence, bearing capacity, erosion may occur. In such cases, since most soil problems are site specific, the soil properties should also be improved by appropriate techniques.

When improvement methods are investigated, in addition to improving methods aiming to compact and strengthen soils from depth, like dynamic compaction, injection and vibroflotation, there are surface improvement methods aiming to strengthen the soils by adding supplementary material like lime, volatile clay, cement, etc. to improve strength at the level close to the foundation surface (Şengezer, 2010). Additionally, the use of lightweight materials like volatile ash, glass fragments, slag, plastic waste and especially waste rubber tires have been investigated by many researchers in recent years with the aim of ameliorating soft and compressible fill soils.

Waste tires have become a global environmental problem due to difficulties with storage and separation processes (Chang, 2008). These tires are flammable and fires tend to release toxic gases. This situation affects the health of organisms and at the same time causes aesthetic discomfort (Attom, 2006; Reddy and Marella, 2001).

[1] koraybahce17@gmail.com

[2] oznurkaraca@comu.edu.tr

*Corresponding Author

Waste tires, when useful life finished and inappropriate for repeated use, are one of the materials with most successful results in terms of regain through recycling, at present. When research is examined, the regain rates for recycled waste tires are 95% in Europe and 84% around the world (url1). When European Tyre & Rubber Manufacturers' Association (ERTMA) data are examined, 292.000 tons of waste tires were produced in Turkey in 2014, with this number reaching 314.000 in 2015 and 251.000 in 2016 (Çataklı and Ergüder, 2019). According to data from the Ministry of Environment and Urbanization in Turkey for "regulation and applications for the control of end-of-life tires" in 2018, 184.313 tons of waste tires were collected in 2017 (Eryılmaz and Demirarslan, 2011). Nearly 59% of the collected waste tires can be recycled in facilities (url1).

The use of waste tires in construction engineering applications may be beneficial not just with the aim of strengthening soils but from an environmental aspect (Keskin and Laman, 2012). The use of waste tires in construction engineering projects has many benefits like reducing the pressure on natural fill, lowering material costs, improving the geotechnical properties of soil, and ensuring effective recycling. In the recent past, many studies were performed about the properties of waste tires, including in potential engineering applications (Edil and Bosscher, 1994; Foose et al., 1996; Zornberg et al., 2004; Cetin et al., 2006; Hataf and Rahimi, 2006; Vinod et al., 2015). Studies using tires from scrap vehicles, especially as light weight material, commonly choose sand (Marto et al., 2013; Umu et al., 2014; Erenson, 2015; Vinod et al., 2015; Göztepe, 2016; Ordu et al., 2017; Bayat et al., 2019; Ghaffari, 2020) and rarely silty sand (Benavente-Huaman et al., 2019) and clay materials (Cetin et al., 2006; Balaban et al., 2019) as soils. Though waste tires are mostly used in granular (Göztepe, 2016; Balaban et al., 2019; Bayat et al., 2019; Ghaffari, 2020) and sliced (Marto et al., 2013; Benavente-Huaman et al., 2019) forms, there is rare research where they are used in powder form (Umu et al., 2014; Ordu et al., 2017) and even whole (Erenson, 2015).

Among the important properties of waste tires, beginning to come to the forefront for construction engineering applications, are the low unit weight in addition to insulating features, resistance, and high drainage capacity (Youwai and Bergado, 2003). However, when tire particles are used alone, high deformation and compression problems may be encountered, just as they may be sensitive to exothermic reactions. For this reason, research in recent years has used sand-waste tire mixtures which are not sensitive to exothermic reactions (Youwai and Bergado, 2003; Zornberg et al., 2004). Thus, adding waste tires to soil materials does not just solve the exothermic reaction problem, at the same time it improves deformation features and increases the strength of the fill. Here, the topic that requires special attention is the proportions in the mixture, because increased proportions of soil material within the mixture increases total weight and this may cause settlement of foundations resting on loose soils (Youwai and Bergado, 2003).

Among the current uses for waste tires, uses as reinforcement material for road construction, for control of erosion, stabilization of sloped areas, thermal insulation, fill for retaining walls and bridge feet, edge drainage and construction of storage areas and use in building foundations may be listed.

Shear strength is a basic mechanical property used in stability analysis. Previous studies observed that optimum shear strength values were reached with a certain proportion between waste tires and soil materials.

A study researching the effect of waste tires on groundwater quality (Humphrey et al., 1997) investigated the possible polluting effects of waste tire chips placed above groundwater level. As a result of tests completed with regular checks within a long time period of nearly five years, there was no evidence that the primary standards for drinking water of barium (Ba), cadmium (Cd), chrome (Cr), lead (Pb) and selenium (Se) and secondary standards for drinking water of aluminum (Al), zinc (Zn), chlorine (Cl) or sulfate ($SO_4$) levels were increased (Humphrey and Katz, 2000). Additionally, research in field conditions in 7 different regions of the USA investigated the possible pollutant effects on groundwater of aggregate produced from tires and rubber-modified asphalt material (Humphrey and Sweet, 2006). The results of this research did not encounter any pollutant value exceeding primary and secondary drinking water standards.

The aim of this study is to investigate the usability of granular waste tires for improving problematic soils to overcome a range of difficulties experienced with problematic soils during geotechnical applications and to effectively reuse this waste. Within this scope, the ability to increase the strength of sandy soils with granular waste tire rubber supplementation was considered by using natural material instead of industrial sand and the optimum mixing rates were determined. The raw material of rubber tires is formed by the combination of oils and a variety of chemical materials. For this reason, it is very important to research the effect on the environment of tires in a variety of areas of use when mixed with soils. Within the scope of this study related to the topic, column leach tests were performed for waste tire-sand mixtures and the leaching of harmful elements from tires to the environment was researched.

## 2. Materials and Methods

The sand used in the study was obtained from an active landslide region in Çanakkale province along the coast of Güzelyalı village in September 2015. The waste tire samples used in laboratory studies were obtained from a workshop located in Bursa Organized Industrial Zone with steel wire bands removed, particle sizes 2-4 mm and obtained in granular form (Figure 1).

Figure 1. Waste tire particles at granular size

The natural water content (ω) and specific gravity ($G_s$) of the sandy sample obtained from the study area were determined. With the aim of determining the grain size distributions of tire fragments and sand samples, sieve analyses (ASTM D 422) were performed.

In this study, compaction tests were performed on samples of waste tires mixed with soil. Samples prepared with combinations of sand and tire fragments were placed in a compaction mold in layers. Each layer was hit with a hammer 25 times for compression and then the mold and compacted sample were weighed. To determine water content, a sample was left in an oven for 24 hours at 105 °C. With the addition of water to the soil, the other steps were repeated in the same way and compaction tests were performed. Finally, the values for water content as a result of the obtained data were plotted on a graph of equivalent dry unit weight and optimum water content was found.

Standard proctor tests determined the maximum and minimum dry unit weight per unit volume ($\gamma_{kmax}$-$\gamma_{kmin}$) for waste tire and sand and the optimum water content ($\omega_{opt}$). Additionally, the maximum and minimum void ratio reflecting the loosest and most compressed situation for sand were identified. Using the calculated void ratios, the relative compaction values were obtained (Equation 2.1).

$$D_r = \frac{e_{max} - e}{e_{max} - e_{min}} \quad (2.1)$$

In this study, with the aim of determining the shear strength of mixtures prepared with sand and tire grains at granular size with 10%, 20%, 30%, 40% and 50% proportion by weight, a range of direct shear box tests (ASTM D 3080) were performed. A direct shear device of 6 cm x 6 cm x 3.5 cm sized was used during these tests. A total of six direct shear tests were carried out, one of which was sand. Prepared samples were tested three times with the normal stress of 50, 100, and 200 kN/m$^2$.

Furthermore, a column test was conducted to investigate the environmental impact of the optimum waste tire-sand mixture obtained in this study. This test was conducted using a glass column with 2.5 cm inside diameter and 30 cm length. Known mass of sample was placed in the column, and porosity and pore volume were calculated. Deionized (DI) water was flushed through it from the top at a constant flow rate. The effluent was collected for each pore volume separately. Analyses were carried out using Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES) for the elements considered to be harmful.

## 3. Results and Discussion

### 3.1. Index Properties

Laboratory tests were performed with the aim of determining the physical parameters of the sand and waste tire mixtures used as soil material in the study. In this context, sand was found to have natural water content ($\omega_n$) of 15.46% as a result of water content experiments. The specific gravity of pure sand was determined as 2.62 with pycnometer method. The unit weight values determined with experiments on the mixtures are shown in Table 1. In addition, sieve analysis was carried out to determine the grain size of both the sand and the granular size tire used in this study (Figure 2, 3). As a result of the sieve analysis, uniformity coefficient ($C_u$) and coefficient of gradation ($C_c$) values of sand were found from the grain size distribution curve (Equations 3.1, 3.2). $C_u$ and $C_c$ values were computed as 2.235 and 0.819, respectively, and are shown in Figure 2. Based on these results, soil class for sand samples was determined as SP (poorly graded sand).

$$C_u = \frac{D_{60}}{D_{10}} \quad (3.1)$$

$$C_c = \frac{(D_{30})^2}{(D_{10})(D_{60})} \quad (3.2)$$

Table 1
Unit weight data for tire-sand mixture

| Mixing rate | | Unit weight (kN/m$^3$) |
|---|---|---|
| Sand | Tire | |
| 90% | 10% | 16.975 |
| 80% | 20% | 16.769 |
| 70% | 30% | 16.063 |
| 60% | 40% | 16.337 |
| 50% | 50% | 16.337 |

### 3.2. Standard Proctor Test

The standard Proctor test was used to obtain the maximum dry unit weight of soil and the corresponding optimum water content. Repeatedly performed standard Proctor experiments observed the dry unit weight ($\gamma_k$) values reached up to 19.90 kN/m$^3$ with a reduction after this point. For this reason, for the maximum dry unit weight ($\gamma_{kmax}$), value of the material of 19.90 kN/m$^3$, the optimum water content was calculated as 19.50%. In this context, the variation in water content linked to dry unit weight values is shown in Figure 4.

The maximum and minimum void ratios ($e_{max}$ and $e_{min}$) were calculated for full sand and waste tire-sand mixtures. For 100% sand, the $e_{max}$ and $e_{min}$ values were 0.77 and 0.29, respectively. Additionally, the maximum void ratio ($e_{max}$) reached lowest values for the mixture containing 20% tires (0.370), while the minimum void ratio ($e_{min}$) reached highest values (0.180) for the mixture with 30% tire content. Both values form the peak values in terms of the experimental sets.

As a result of experiments, the relative density of sand ($D_r$) was determined as 58%, while the sand used in the study is qualified as 'medium dense' according to the relative density table (Table 2).

### 3.3. Shear Box Tests

The type of material examined within the scope of this study may be used in construction engineering applications such as road fill and fill behind retaining walls on weak or compressible soils and it is necessary to know the strength and deformation properties of materials used in these types of applications. As a result, with the aim of determining the shear strength characteristics of the mixtures, shear box tests were performed with soil alone and later with the mixtures. During the tests, shear force versus horizontal displacement of the samples were measured and plotted. From the plot, the maximum shear stress was determined and shear stress graphs corresponding to the normal stress are plotted. From the plot, a straight-line approximation of the failure envelope curves was drawn. In the graph the cohesion is the y-intercept, and the angle of internal friction is the slope of the line.

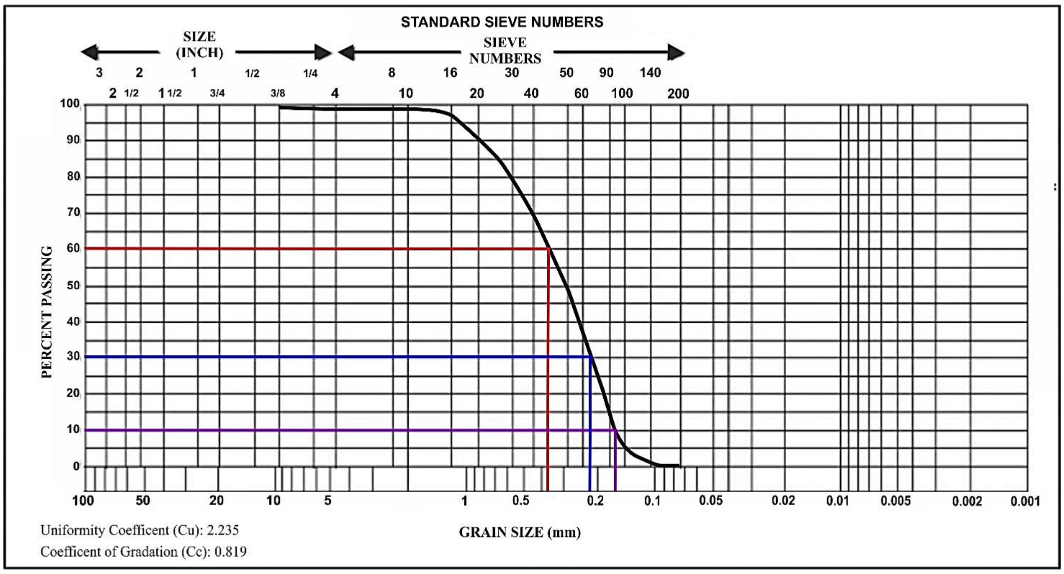


Figure 2. Grain size distribution of sand

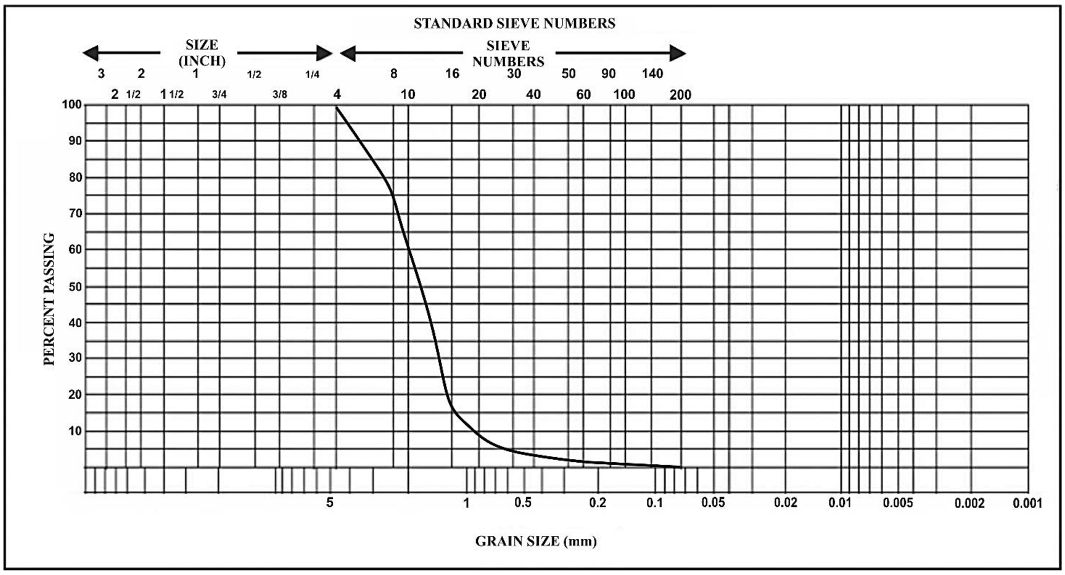


Figure 3. Grain size distribution of waste tires

Considering the shear box experiment data, the angle of internal friction value reached highest values for the mixture containing 20% waste tires (48.82°). As the tire content continued to increase, a reduction was observed in these values (Figure 5).

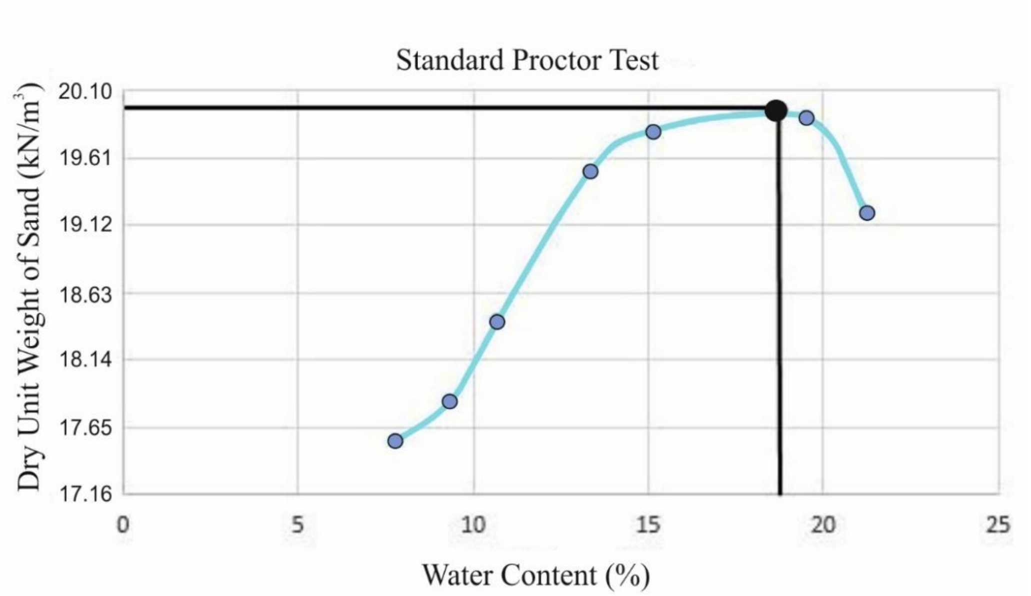


Figure 4. Water content versus dry unit weight relationships

Table 2

Soil classification based on relative density (Lambe and Whitman, 1969)

| Relative density ($D_r$) | Soil compactness |
|---|---|
| 0 – 15% | Very loose |
| 15 – 35% | Loose |
| 35 – 65% | Medium dense |
| 65 – 85% | Dense |
| 85 – 100% | Very dense |

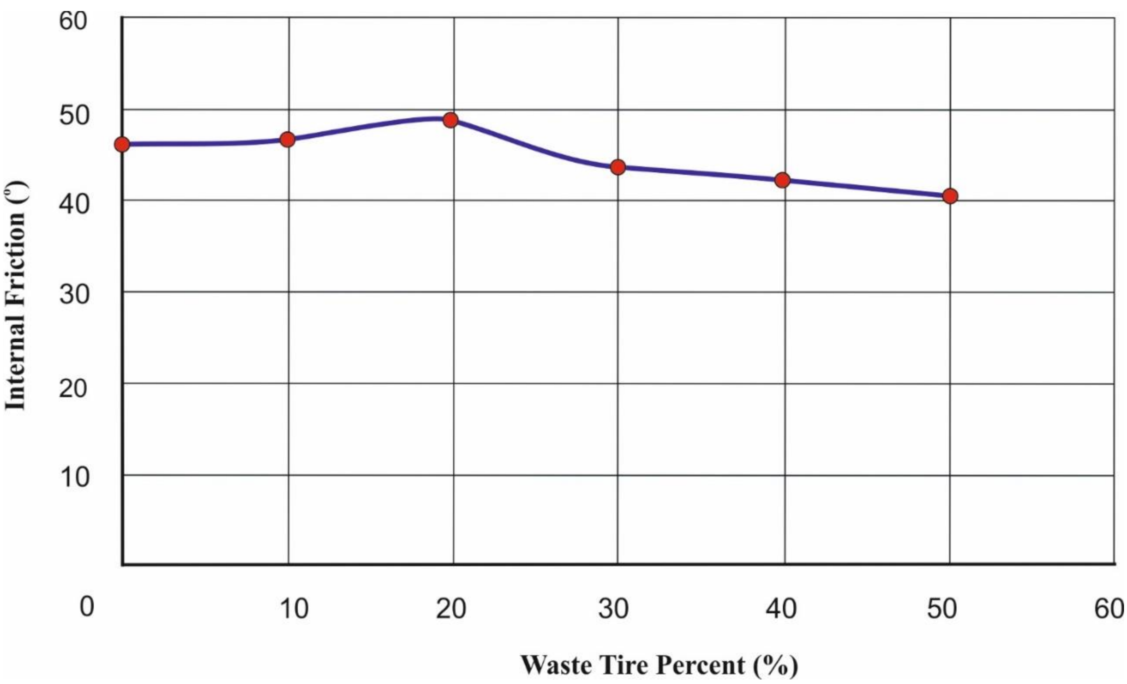

Figure 5. Variation in internal friction angle linked to tire content

There was a linear increase in cohesion values with highest value for the mixture containing 30% waste tires (52.465 kN/m$^2$). However, when the tire content was above 30%, a reducing tendency was observed (Figure 6).

When the shear strength values obtained as a result of the shear box tests are examined, these values linearly increased in proportion to the waste tire content of the mixtures, in parallel to the internal friction angle values. Again, highest shear stress values were reached for the mixture containing 20% waste tires.

The failure envelopes obtained from all samples are shown in Figure 7. As seen on the figure, the soil containing only sand (0% tire) had 118 kN/m$^2$ shear strength under 100 kN/m$^2$ normal stress, while this value increased to 152.30 kN/m$^2$ for the 20% (waste tire) mixture (Aktürk, 2018).

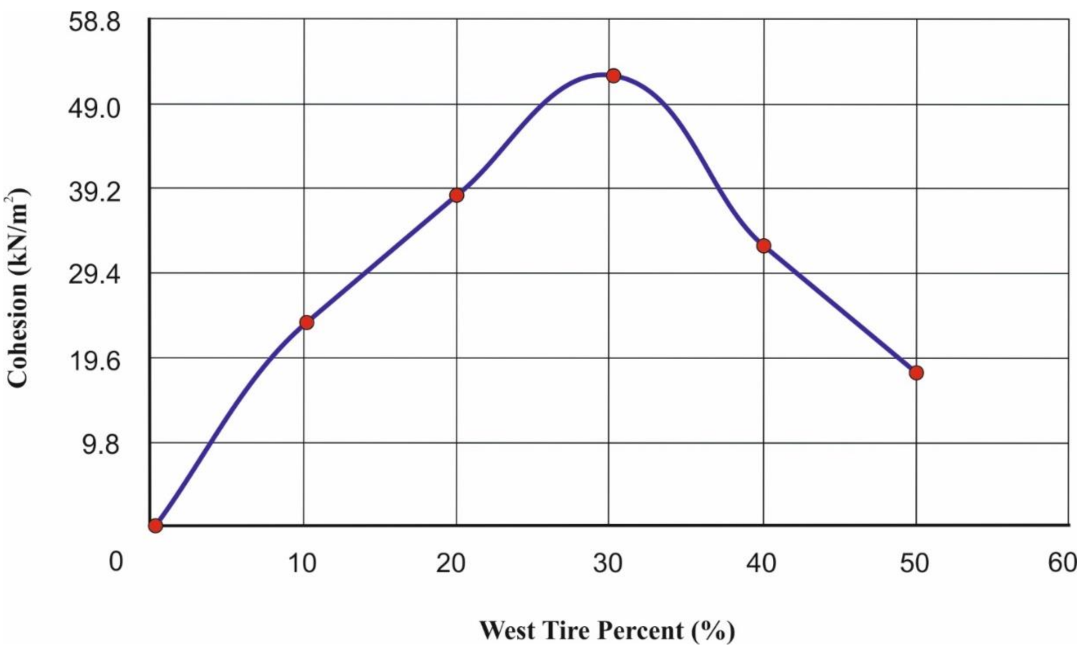

Figure 6. Variation in cohesion linked to tire content

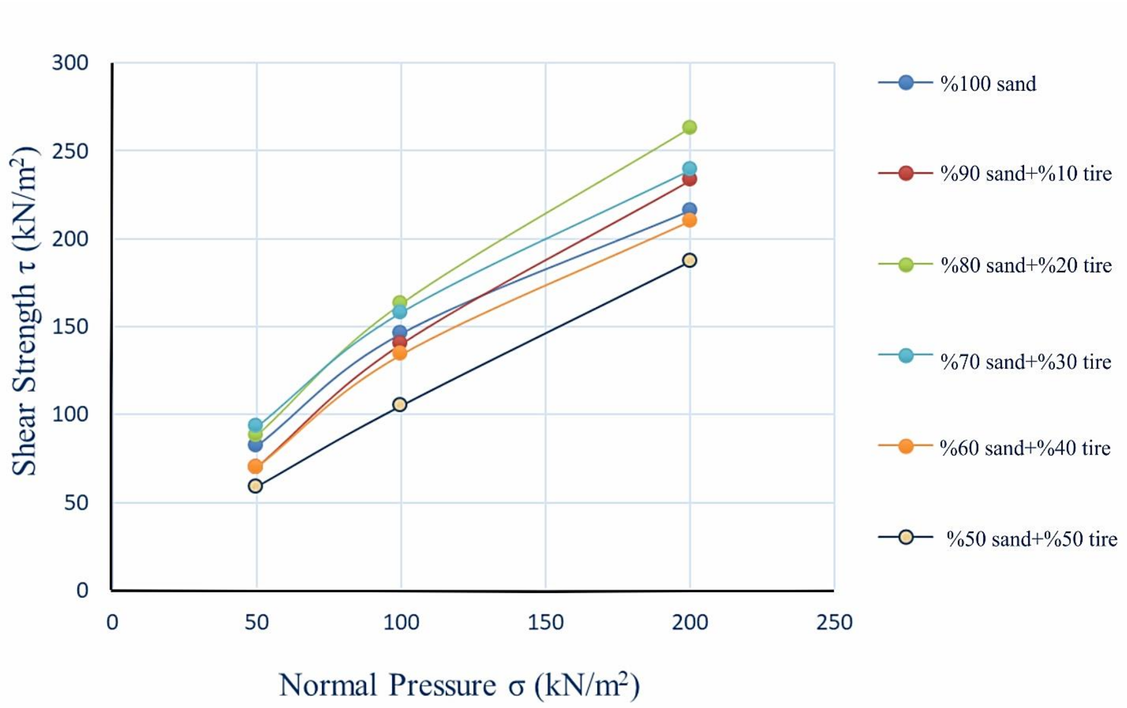


Figure 7. Normal stress vs. shear stress plot for the mixtures

In addition, column test was carried out to investigate the environmental impact of the 20% tire and 80% sand mixture obtained at the end of this study. Laboratory analyses were performed on the leachate from the mixture and the values for elements that may have a polluting role were investigated (hydrocarbon, arsenic, iron, chrome, chlorine, fluorine, nitrate, sulfate, aluminum, antimony, barium, beryllium, boron, cadmium, calcium, cobalt, copper, lead, lithium, magnesium, manganese, molybdenum, nickel, phosphorus, potassium, selenium, silver, sodium, vanadium, zinc, thallium). While the hydrocarbon amount remained below 50 µg, there was no major cation encountered. For this reason, it was concluded that the leachate did not have any polluting effect.

## 4. Conclusion

In this study the effect of waste tire contributions to sandy soils were investigated. Laboratory tests were carried out to determine the engineering properties of the soil sample collected from Güzelyalı. For this purpose, water content, sieve analysis, pycnometer and standard Proctor tests were performed. Soil was classified as SP-poorly graded sand. Then direct shear box tests were performed to determine the shear strength parameters of both soils alone and the waste tire-sand mixture. The increase in tire content caused an increase in strength to a certain value; however, continued increase then caused a reduction in strength parameters. Hence, the increase in tire amount after the optimum value provided shear strength values that were lower even then the situation where only sand material was used. Large-scale shear box tests and slope stability analysis are needed to determine the role of mixtures created with waste tire particles and sand material in different projects to be used in practice. This study also focused on identifying potential environmental problems of waste tires, which are considered to be used in practice. For this purpose, the leachability of the 20% tire and 80% sand mixture were investigated. Thus, column test was performed by using mixture and DI water. When the effluent was analysed, no contaminants were found. For this reason, the use of waste tires in this way gains importance in the sense of improvement and carries great importance for reuse of tires with no storage areas and with hundreds of tons discarded in the environment every year.

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**Author Contributions**

Koray AKTÜRK: Performed sampling studies in the field, completed experiments in the study and contributed to writing the article.

Öznur KARACA: Ensured the study was completed according to plan, performed sampling studies in the field, checked the completion of experiments in the study and contributed to writing the article.

**Conflicts of Interest**

The authors report no conflict of interest.

**References**

Aktürk, K. (2018). *Effect of granular waste tires on the shear strength of sandy soil (In Turkish)* (Unpublished master's thesis). Çanakkale Onsekiz Mart University, Çanakkale, Turkey. Retrieved from: https://tez.yok.gov.tr/UlusalTezMerkezi

ASTM-D422 (2003). Standard test method for particle-size analysis of soils. *Annual Book of ASTM Standards*, pp. 10–17, Vol. 04.08. American Society For Testing and Materials, West Conshohocken, PA.

ASTM-D3080 (2003). Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions. *Annual Book of ASTM Standards*, pp. 347–352, Sect. 4, Vol. 04.08. American Society for Testing and Materials, West Conshohocken, PA.

Attom, M. F. (2006). The use of shredded waste tires to improve the geotechnical engineering properties of sands. *Environmental Geology*, 49(4), 497-503. Retrieved from: https://www.researchgate.net/publication/227314487_The_use_of_shredded_waste_tires_to_improve_the_geotechnical_engineering_properties_of_sands

Balaban, E., Smejda, A. & Onur, M. I. (2019). Influence of tire crumbs on mechanical properties of sand-fine soil mixtures. *Geomechanics and Geoengineering*, 1-16. Retrieved from: https://doi.org/10.1080/17486025.2019.1688870

Bayat, O., Askarani, K. K. & Hajiannia, A. (2019). Effects of waste tire on the shear strength of sand. *International Journal of Structural and Civil Engineering Research*. Retrieved from: https://www.researchgate.net/publication/335797966_Effects_of_Waste_Tire_on_the_Shear_Strength_of_Sand

Benavente-Huaman, E., Navarro-Cardenas, M. ve Duran-Ramirez, G. (2019). Strength behaviour of shredded rubber silty sand mixtures. *In 2019 7th International Engineering, Sciences and Technology*. Retrieved from: https://ieeexplore.ieee.org/document/8943600

Cetin, H., Fener, M. & Gunaydin, O. (2006). Geotechnical properties of tire-cohesive clayey soil mixtures as a fill material. *Engineering Geology*, *88*(1-2), 110-120. Retrieved from: https://doi.org/10.1016/j.enggeo.2006.09.002

Chang, N. B. (2008). Economic and policy instrument analyses in support of the scrap tire recycling program in Taiwan. *Journal of Environmental Management*, 86, 435–450. Retrieved from: https://www.sciencedirect.com/science/article/pii/S0301479706004294

Çataklı, T. & Ergüder, T. H. (2019). Biyo-devulkanizasyon: Atık lastik yönetiminde çevre dostu bir yaklaşım. *Ulusal Çevre Bilimleri Araştırma Dergisi*, 2(1), 20-34. Erişim tarihi: https://dergipark.org.tr/tr/pub/ucbad/issue/44367/548695

Edil, T. B. & Bosscher, P. J. (1994). Engineering properties of tire chips and soil mixtures. *Geotechnical testing journal*, 17(4), 453-464. Retrieved from: https://www.researchgate.net/publication/245403336_Engineering_Properties_of_Tire_Chips_and_Soil_Mixtures

Erenson, C. (2015). *Atık lastiklerin taş/kum kolon uygulamalarında kullanılmasının deneysel olarak incelenmesi*. Yüksek Lisans Tezi. Retrieved from: https://tez.yok.gov.tr/UlusalTezMerkezi

Eryılmaz, H. & Demirarslan, K. O. (2019). Ömrünü tamamlamış lastiklerin (ötl) sıvılaştırılarak geri dönüşümünün araştırılması. *Sürdürülebilir Mühendislik Uygulamaları ve Teknolojik Gelişmeler Dergisi*, 2(1), 50-56. Retrieved from: https://dergipark.org.tr/tr/pub/smutgd/issue/45823/523437

Foose, G. J., Benson, C. H. & Bosscher, P. J. (1996). Sand reinforced with shredded waste tires. *Journal of Geotechnical Engineering*, 122(9), 760-767. Retrieved from: https://ascelibrary.org/doi/abs/10.1061/(ASCE)0733-9410(1996)122:9(760)

Ghaffari, J. (2020). Triaxial determination of shear strength of tire chips-sand-geotextile mixtures. *AUT Journal of Civil Engineering*. Retrieved from: https://ajce.aut.ac.ir/article_3898.html

Göztepe B. (2016). *Experimental study on mitigation of earthquake hazards using rubber-soil mixture*.Yüksek Lisans Tezi. Retrieved from: https://tez.yok.gov.tr/UlusalTezMerkezi

Hataf, N. & Rahimi, M. M. (2006). Experimental investigation of bearing capacity of sand reinforced with randomly distributed tire shreds. *Construction and Building Materials*, 20(10), 910-916. Retrieved from: https://www.researchgate.net/publication/229113150_Experimental_investigation_of_bearing_capacity_of_sand_reinforced_with_randomly_distributed_tire_shreds

Huat, B. B. K. (2010). Problematic soil in search for solution. Biography, Universiti Putra Malaysia Press Serdang p. 131. Retrieved from: http://psasir.upm.edu.my/id/eprint/18250/2/INAUGURAL%20PROF.%20BUJANG.pdf

Humphrey, D. N., Katz, L. E.& Blumenthal, M. (1997). Water quality effects of tire chip fills placed above the ground water table. *Testing soil mixed with waste or recycled materials*. ASTM International. Retrieved from: https://www.astm.org/DIGITAL_LIBRARY/STP/PAGES/STP15659S.htm

Humphrey, D. N. & Katz, L. E. (2000). Water-quality effects of tire shreds placed above the water table: Five-year field study. *Transportation research record*, 1714(1), 18-24. Retrieved from: https://doi.org/10.3141/1714-03

Humphrey, D. N. & Swett, M. (2006). Literature review of the water quality effects of tire derive daggregate and rubber modified asphalt pavement. *Report for US EPA*. Retrieved from: https://archive.epa.gov/epawaste/conserve/materials/tires/web/pdf/tdastudy.pdf

Keskin, M. S. & Laman, M. (2012). Atık lastik-kum karışımlarının kayma mukavemetinin laboratuar deneyleriyle incelenmesi. *Çukurova Üniversitesi Mühendislik-Mimarlık Fakültesi Dergisi*, 27 (2): 27-36. Retrieved from: https://dergipark.org.tr/tr/pub/cukurovaummfd/issue/22761/242943

Lambe, T. W. & Whitman, R. V. (1969). *Soil Mechanics*. John Wiley & Sons, New York.

Marto, A., Latifi, N., Moradi, R., Oghabi, M. & Zolfeghari, S. Y. (2013). Shear properties of sand-tire chips mixtures. Electronic Journal of Geotechnical Engineering, 18: 325-334. Retrieved from: https://www.researchgate.net/publication/260390260_Shear_Properties_of_Sand_-_Tire_Chips_ Mixtures

Ordu, E., Biçer, P., Ordu, S. & Abanozoğlu, E. G. (2017). An investigation on the soil stabilization with waste tyres materials in granular soils. *Aksaray University Journal of Science and Engineering*, 1(1), 51-61. Retrieved from: https://www.researchgate.net/publication/320646165_An_investigation_on_the_soil_ stabilization_with_waste_tyres_materials_in_granular_soils

Reddy, K. R. & Marella, A. (2001). Properties of different size scrap tire shreds: implications on using as drainage material ın landfıll cover systems. Retrieved from: http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.513.6637

Seed, H. B. &Idriss, I. M. (1971). Simplified procedure for evaluating soil liquefaction potential. *Journal of Soil Mechanicsand Foundations Division.* Retrieved from: https://trid.trb.org/view/127844

Şengezer, L. (2010). *Granüler zeminlerde dinamik kompaksiyon uygulaması*. Doktora Tezi. Retrieved from: https://tez.yok.gov.tr/UlusalTezMerkezi

Umu, S. U., Okur, D. V., Yılmaz, G. & Fırat, S., (2014). Dinamik yükleme şartlarında kum/lastik karışımlarının rijitlik ve sönüm özelliklerinin incelenmesi. *Politeknik Dergisi*, 17 (1):13-21. Retrieved from: https://pdfs.semanticscholar.org/d578/8e17cbddb7fde13498ee23f47fedf6dd6271.pdf

Vinod, J. S., Tsang, M. N., Mastello, D., Indraratna, B. & Mashiri, M. S. (2015). The direct shear strength of sand-tyre shred mixtures. *Proceedings of the International Conference on Geotechnical Engineering*, (pp. 193-196). Retrieved from: https://ro.uow.edu.au/eispapers/4475/

Youwai, S. &Bergado, D. T. (2003). Strength and deformation characteristics of shredded rubber tire sand mixtures. *Canadian Geotechnical Journal*, 40(2), 254-264. Retrieved from: https://www.nrcresearchpress.com/doi/abs/10.1139/t02-104

Zornberg, J. G., Cabral, A. R. & Viratjandr, C. (2004). Behaviour of tire shred sand mixtures. *CanadianGeotechnicalJournal*, 41 (2): 227-241. Retrieved from: https://www.nrcresearchpress.com/doi/abs/10.1139/t03-086 url1: https://atiksahasi.com/Omrunu-Tamamlamis-Lastikler, Retrieved date: 15.11.2020