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Environmental challenge by geotechnic's method: example of the sandy soils reinforcement by rubber aggregates from used tires.

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Abstract: The objective is to develop new civil engineering applications that will free the environment from a large quantity of used tires. The present work consists of mixing rubber aggregates with sand to improve the mechanical behavior of soils. The study was carried out on Hostun sand mixed with proportions by weight of rubber aggregates between 0 and 30%.The experimental protocol followed consisted in determining the variations of the maximum and minimum void ratios of the mixtures versus the percentage of rubber aggregates. Direct shear tests were carried out on sand-rubber mixtures at relative densities of 55 and 95% and at normal stresses of 100, 200 and 400 kPa. Based on the results of the experimental data, the following conclusions were obtained: the maximum and minimum void ratios decrease with increasing rubber content up to 60% and then increase again. It is also shown that the shear strength of sand increases with increasing rubber content. The shear strength of the mixtures for the two relative densities of 55% and 95% is maximal for a content of 20% of the rubber aggregates. It also increases with the increase of the normal stress applied and with the increase of the relative density.

1 INTRODUCTION

Massive volumes of waste are generated worldwide each year at an increasing rate. Over 1,000,000,000 tires are discarded each year (Thomas, et al., 2014). Tire waste often cause pollution and environmental degradation. Currently, waste tires are managed through various treatment methods including: burning, landfilling, or re-utilization. Their non-biodegradability, incompressibility and flammability generate serious threats to various human ecosystems and other animals. Due to its lightness and appropriate resistance, as well as environmental considerations, the used tire has always been attractive for civil engineering applications (Tortum, et al., 2005; Cao, 2007; Pacheco, et al., 2012; Shu and Huang, 2014). Because of their inherent geotechnical properties, such as durability and low apparent density, scrap tires can be mixed with soil and used in geotechnical projects as fill material, retaining wall backfill, seismic isolation material, and soil reinforcement in seismic zones. Indeed, the addition of rubber to soil can be effective in improving the mechanical properties of soils (Yadav and Tiwari, 2016a ; Akbarimehr and Aflaki, 2018 ; Negadi and Arab, 2018 ; Saberian et al., 2018 ; Akbarimehr et al., 2019a ; Chenari et al., 2019 ; Balaban and Smejda, 2019 ; Enquan and Qiong, 2019 ; Aksoy et al., 2021 ; Rouhanifar et al., 2021). The durability of soil-rubber mixtures is very important and has been the subject of many studies (Li et al., 2020 ; Anvari et al., 2017). The addition of waste tires, to a sandy soil, in various forms as shredded, chipped, crumbled and fibers is conventional and has only been studied to reveal improvements in its properties (Edil and Bosscher, 1994; Foose et al., 1996 ; Tatlisoz et al., 1998 ; Moo-Young et al., 2003 ; Zornberg et al., 2004 ; Attom, 2006 ; Rao and Dutta, 2006 ; Neaz et al., 2013 ; Cabalar and Karabash, 2014).

Shear strength is a notable and essential geotechnical property in practical and experimental terms. Given the attractiveness of sand and waste rubber mixtures for various geotechnical applications, the shear strength of the sand and waste rubber mixture was investigated in this study. The present work used aggregate rubber at different sizes ranging from 2 to 5 mm mixed with sand. Shear tests were conducted to fully understand the effect of rubber aggregates on the sand-rubber mixture mechanical behavior.

2 MATERIALS AND METHODS

The materials used in this work are Hostun sand and rubber aggregate from used tires, their characteristics are summarized below.

2.1 Hostun sand

The sand used in the present study is considered a reference material in many civil engineering laboratories in France. The physical and chemical characteristics of this sand were determined in our laboratory (Tables 1 and 2). The sand belongs to the category of fine sands with an uniform and well graded grain size. The sand has an average grain size D_{50}=0.32 mm, the void ratio can vary between e_{min}=0.752and e_{max}=1.006and the specific density of the grains is 2.625 g/〖cm〗^3determined by the pycnometer method NF P94-054 and NFP94-512-3. The grain size curve of this sand was obtained based on NF P94-056. Figure 1 shows the grain size distribution of the sand. Figure 2a shows a microscopic view (SEM) of the Hostun sand used in this study.

Table 1: Physical characteristics of used Hostun and granulated rubber

Materials under study	Hostun sand	Granulated rubber 2 mm ≤ D_{GR}<5 mm
D_{10} (mm)	0.22	2.55
D_{30} (mm)	0.28	2.95
D_{50} (mm)	0.32	3.35
D_{60} (mm)	0.34	3.55
C_u (/)	1.55	1.39
C_c (/)	1.05	0.96
ρ_s (g/cm^3)	2.625	1.129
ρ_{dmax} (g/cm^3)	1.498	0.59
ρ_{dmin} (g/cm^3)	1.309	0.53
e_{max} (/)	1.006	1.112
e_{max} (/)	0.752	0.908

Table 2: Chemical characteristics of Hostun sand by X-ray fluorescence spectrometry

Chemical composition	%
SiO_2	73.726
TiO_2	0.009
Al_2O_3	0.801
Fe_2O_3	0
MnO	0.009
MgO	0
CaO	0.106
Na_2O	0.194
K_2O	0.134
P_2O_5	0.006

2.2. Aggregate Rubber

The physical characterization of the aggregate rubber samples having different diameters varying from 2 to 5 mm with an average diameter D_{50} = 3.35 mm requires the determination of various parameters such as: the water content, the specific density of the solid grains, the maximum density ρ_{dmax}(or minimum void ratio and the minimum density ρ_{dmin} (or maximum void ratio). To determine the water content of the "aggregate rubber" sample, the drying method in an oven was used, according to the experimental standard NF P94-050. The result obtained for the tested sample showed that the water content is around 0.5%. In addition, the determination of the specific density of the solid grains is carried out using the pycnometer method NF P 94-054 and NF P 94-512-3. The result obtained for the sample tested showed that the specific density $\rho_s$of the solid grains is 1.129 g/cm^3. The determination of the minimum density ρ_{dmin} and maximum density $\rho_{dmax}$of the soils was carried out in accordance with standard NF P 94-059.

The test consists in implementing materials to be studied in a mold successively in a loose state ($\rho_{dmin)}$and in a dense state (ρ_{dmin}). The void ratio is calculated by the following

Equations (1) and (2):

$$e_{max} = \rho_s / \rho_{dmin} - 1 \quad (1)$$

$$e_{min} = \rho_s / \rho_{dmax} - 1 \quad (2)$$

The granulometric analysis carried out according to NF P94-056. The particle size distribution curve of rubber aggregate is shown on Figure 1. Figure 2b shows picture of the rubber aggregates used and which are differentiated by their geometric characteristics.

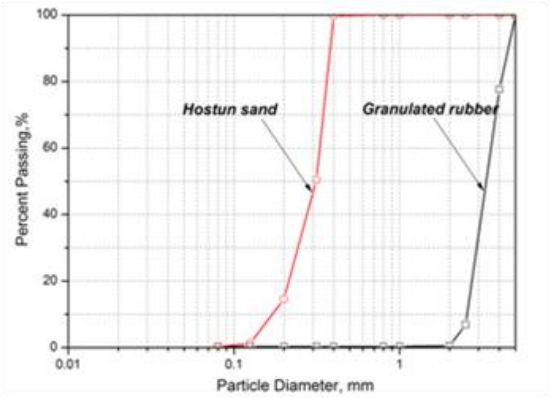


Figure 1. Grain size distribution curves of Hostun sand and rubber grains.

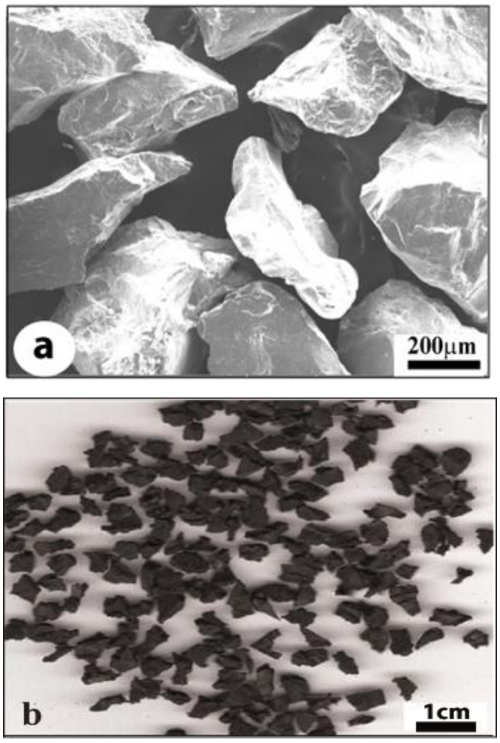


Figure 2.Microscopic view of the Hostun sand (a) and aggregates rubber with 2mm<D_{GR}<5mm (b).

2.3 Standard Direct Shear Test and Sample Preparation

In this study, a shear box was used to perform all standard direct shear tests on samples containing sand/rubber mixtures according to NFP94-071-1. The rectilinear shear tests carried out with the box allow the determination of the effective shear resistance parameters of soils. The test method is to place the Hostun sand-rubber mixture in a dry state in the mold of the direct shearing apparatus having a square section of side 60 mm and height of 30 mm, and then put it under a variable normal stresses of100, 200 and 400 kPa. The horizontal boxes containing the mixture are then separated and a displacement at a constant strain rate of 1 mm/min is imposed on one of the two half-boxes. The vertical and horizontal displacements as well as the generated shear forceare measured during the shearing of the sample. The shear box is equipped with force and displacement sensors. The precision of the servocontrol allows a measurement of the shear load on the sample up to 5000 N with an accuracy of around 50 N. Regarding horizontal and vertical displacements are measured with a 25 mm sensor for the first and 10 mm for the second with a measurement accuracy of around 0.01 mm. The influence of the crushed Rubber Content (RC), vertical normal stress of 100, 200 and 400 kPa on the shear strength ofthe dry sand-rubber mixture was studied. Laboratory sample preparation was performed based on maximum and minimum void ratio and relative density (D_r). The mass of the mixture (m_s) to be placed in the direct shear cell is evaluated as a function of the desired relative density by Equation (4) (the initial volume of the sample is known), the density state of the sample being defined by the relative density D_r::

$$D_r = (e_{max} – e) / (e_{max} - e_{min}) \quad (3)$$

$$m_s = (V_T - \rho_s) / (1 + e_{max}(1 - D_r) + D_r \times e_{min}) \quad (4)$$

Where:ρ_s is the specific density of solid grains, e_{min} and e_{max} are, respectively, the minimum and maximum void ratios, V_T is the volume of the sample, and D_r is the desired relative density.

3. RESULTS AND DISCUSSIONS

Shear strength characteristics of the composite materials were examined with respect to void ratio, the size of granulated rubber, the percentage of rubber and the applied normal stress on the samples in the direct shear test. The influences of granulated rubber and tire chips on the shear properties were analyzed considering varying sizes and contents of rubber. The dilation behaviour of the sand/rubber mixture sample on the increase in rubber content was also analyzed. In this section, the results of the laboratory tests are presented with a discussion highlighting the effects of the various parameters.

The variation of the maximum and the minimum void ratio (e_{max} and e_{min}) with the rubber content is illustrated in Figure 3. It can be observed that these two void ratios decrease with the increase of the rubber content RC in the sand-rubber mixtures until a value of RC near to 60% where the trends is inverted for higher value of RC.

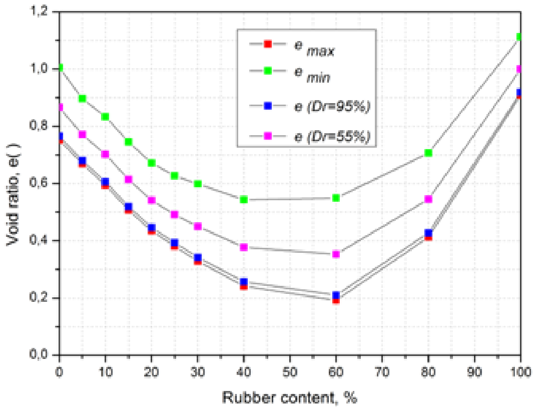
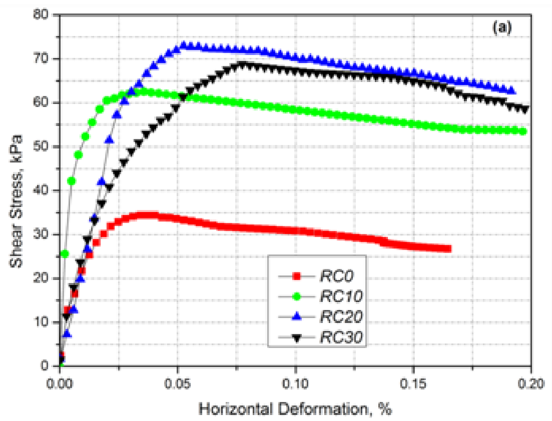


Figure 3.Variation of the maximum and minimum void ratiosversus rubbers content

3.1 Effect of Aggregate Rubber Content on Shear Strength of Sand

Figure 4 shows an example of the response of the material to horizontal deformation, namely Hostun sand mixed with aggregates rubber aggregates. These direct shear tests were performed for different aggregates rubber contents ranging from 0 to 30%, under an applied normal stress of 100 kPa. The results show that the presence of aggregates rubber affects significantly the shear strength of the sand. This shear strength under a vertical normal stress of 100 kPa increased from 34.38 ± 2.89 to 62.5 ± 2.99 for RC = 10% and from 34.38 ± 2.89 to 72.94 ± 3.02 for RC = 20%. Then, it decreased for a rubber content of 30% but it still remains higher than that of pure sand. The mixtures show a typical behavior of a medium state dense of the sand (Dr = 55%), with no decrease in strength after the maximum. This clearly shows that the presence of aggregates rubber leads to a significant improvement in the shear strength of the mixtures. This increase in the shear strength of the mixtures with increasing rubber content can be attributed to the redistribution of sand grains and aggregates rubber in the mixture matrix. Thus, the sand grains are pushed towards the rubber grains which deform and increase the contact area between the two materials. An additional content of RC = 30% rubber increased the shear strength of pure sand, but it decreased compared to the addition of RC = 20%. This is because in the shear zone, the rubber grains surround the sand grains and tend to roll and slide over them to create more voids.



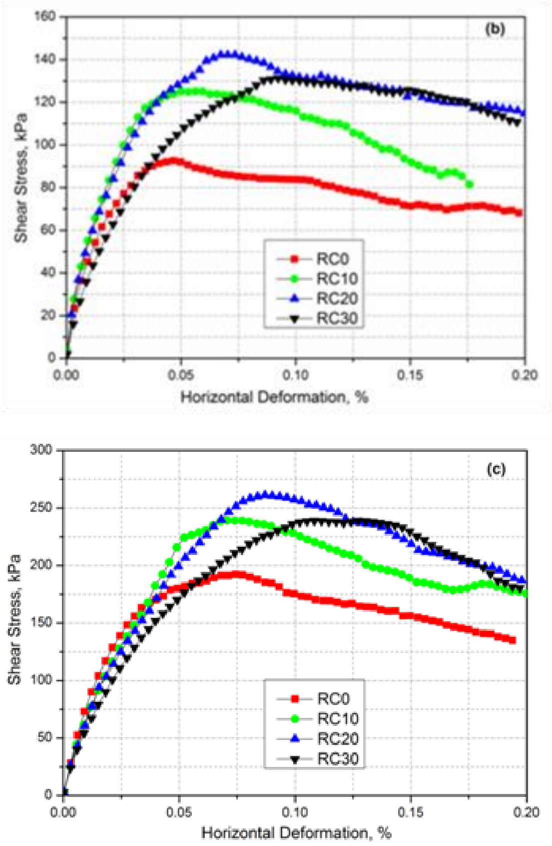
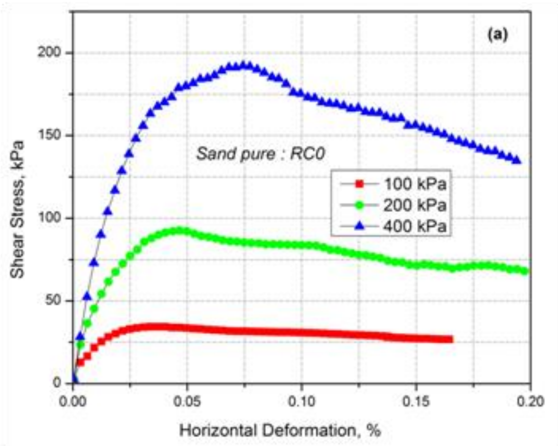


Figure 4.Shear stress variation curves for different rubber contents under a normal stress of: 100kPa (a), 200kPa (b) and 400 kPa (c) (Dr =55 %)

3.2 Effect of Normal Stress on Shear Strength of sand-rubber mixtures

Figure 5 shows that the shear strength of the sand-rubber mixture increases significantly with increasing normal stress. Indeed, for a rubber content of 20% under a normal stress of 100 kPa, the shear stress reaches a value of 73 ± 3.02 kPa, while for a normal stress of 200 kPa and 400 kPa, the shear stress reaches a value of 142 ± 3.25 kPa and 262 ± 3.65 kPa respectively. This increase is due to the change in the microstructure of the mixtures which will generate an improvement of the contacts between the particles as already cited by Zhang et al., 2018. However for 30% rubber content, this shear strength decreases in the three normal stress cases cited above.



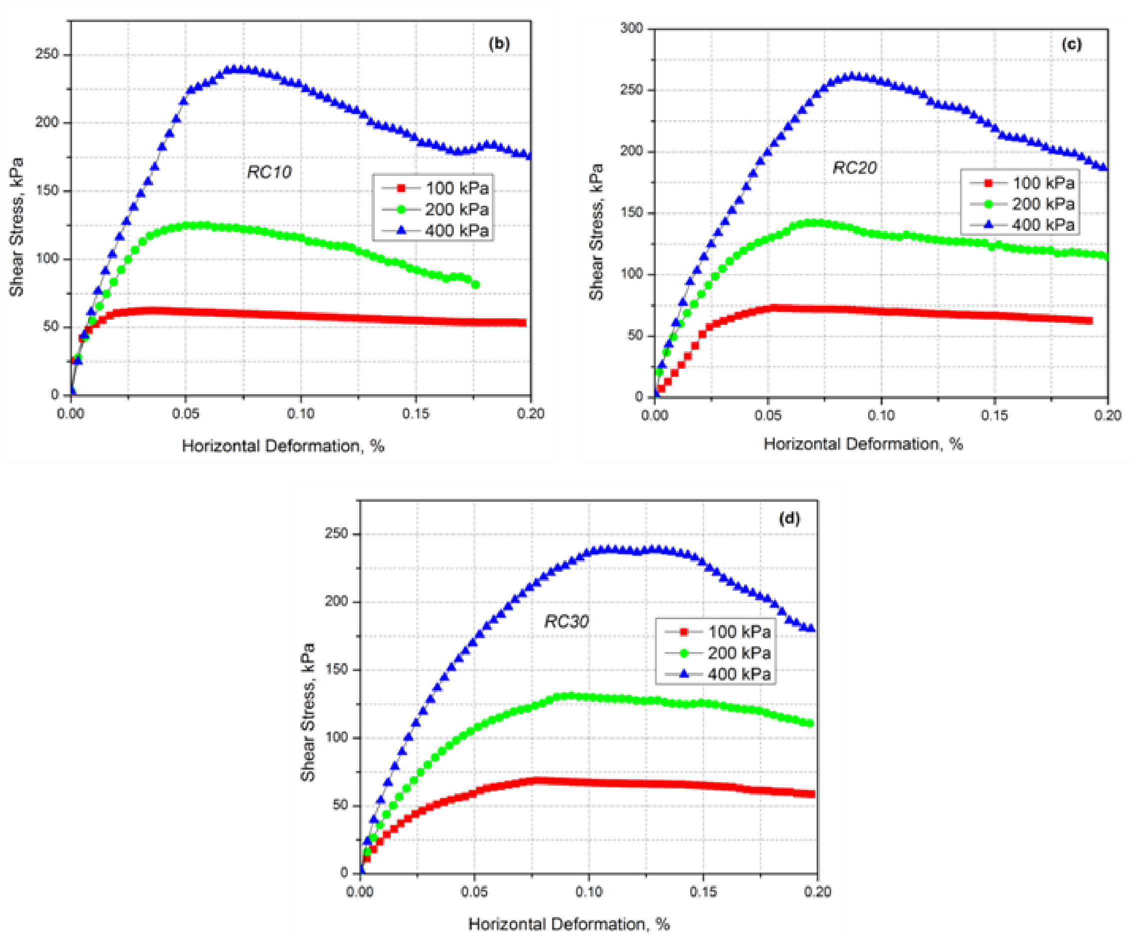
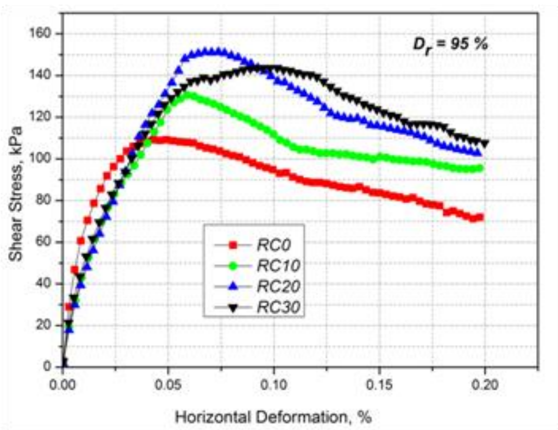


Figure 5.Shear stress variation curves for different normal stress and different rubber contents: RC = 0% (a), RC = 10% (b), RC = 20% (c) and RC = 30% (d), (Dr =55 %)

3.3 Effect of relative density on shear strength of sand-rubber mixture

Figure 6 shows the variation of the shear strength of the mixtures as a function of horizontal strain under a normal stress of 200 kPa in the dense and medium dense state. The addition of the rubber aggregate content to the sand has a significant effect on the behavior of the mixtures in the dense state. For samples with relative density of 55 and 95%, the shear strength of the sand-rubber mixtures reaches a maximum value of 20% and then it decreases beyond that. This clearly shows that the presence of more granulated rubber in the sand leads to an improvement in shear strength in both cases of relative density. This increase can be attributed to the redistribution of the sand and rubber grains in the mixture. In effect, the sand is pushed into the rubber intergranular voids, increasing the contact area between the two types of materials. It is noted that the shear strength increases with increasing relative density.



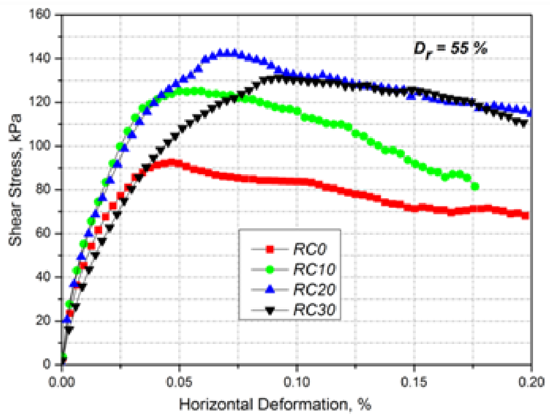


Figure 6.Shear stress variation curves for different relative density: (Dr=95 %)and (Dr=55 %)

4 CONCLUSIONS

This study presents a detailed laboratory investigation about the mechanical properties of sand rubber mixtures. The shear tests were done on samples of the sand-rubber mixture with different rubber aggregate content, under different normal stresses and different relative density, the main results can be summarized as follows:

- The maximum and minimum void ratios decrease with increasing rubber grain contents in mixtures.
- The increase in the aggregate rubber content from 0 to 20% induces an increase in the maximum shear strength of mixture and then it decreases beyond 20% rubber content.
- The shear strength of the mixture increases with increasing normal stress.
- The shear strength of the mixture increases with increasing relative density.

REFERENCES

1. Akbarimehr, D., Aflaki, E., 2018. An experimental study on the effect of tire powder on the geotechnical properties of clay soils. Civil Engineering Journal, 4(3), 594-601. https://doi.org/10.28991/cej-0309118
2. Akbarimehr, D., Aflaki, E., Eslami, A., 2019. Experimental investigation of the densification properties of clay soil mixes with tire waste. Civil Engineering Journal, 5(2), 363-372. https://doi.org/10.28991/cej-2019- 03091251
3. Aksoy, H. S., Taher, N., Awlla, H. A., 2021. Shear strength parameters of sand-tire chips mixtures. Gümüşhane Üniversitesi Fen Bilimleri Enstitüsü Dergisi, 11(3), 713-720.
4. Anvari, S. M., Shooshpasha, I., Kutanaei, S. S., 2017. Effect of granulated rubber on shear strength of fine-grained sand. Journal of Rock Mechanics and Geotechnical Engineering, 9(5), 936-944. https://doi.org/10.1016/j.jrmge.2017.03.008
5. Attom, M. F., 2006. The use of shredded waste tires to improve the geotechnical engineering properties of sands. Environmental geology, 49(4), 497-503.https://doi.org/10.1007/s00254-005-0003-5
6. 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.
7. Cabalar, A. F., Karabash, Z., Mustafa, W. S., 2014. Stabilising a clay using tyre buffings and lime. Road materials and pavement design, 15(4), 872-891.https://doi.org/10.1080/14680629.2014.939697
8. Cao, W., 2007. Study on properties of recycled tire rubber modified asphalt mixtures using dry process. Construction and Building Materials, 21(5), 1011-1015. https://doi.org/10.1016/j.conbuildmat.2006.02.004
9. Chenari, R. J., Alaie, R., Fatahi, B., 2019. Constrained compression models for tire-derived aggregate-sand mixtures using enhanced large scale oedometer testing apparatus. Geotechnical and Geological Engineering, 37(4), 2591-2610.https://doi.org/10.1007/s10706-018-00780
10. Edil, T. B., Bosscher, P. J., 1994. Engineering properties of tire chips and soil mixtures. Geotechnical testing journal, 17(4), 453-464. https://doi.org/10.1520/gtj10306j
11. Enquan, Z., Qiong, W., 2019. Experimental investigation on shear strength and liquefaction potential of rubber-sand mixtures. Advances in Civil Engineering, 2019.
12. Foose, G. J., Benson, C. H., Bosscher, P. J., 1996. Sand reinforced with shredded waste tires. Journal of Geotechnical Engineering, 122(9), 760-767. https://doi.org/10.1061/(asce)0733-9410(1996)122:9
13. Li, W., Kwok, C. Y., Senetakis, K., 2020. Effects of inclusion of granulated rubber tires on the mechanical behaviour of a compressive sand. Canadian Geotechnical Journal, 57(5), 763-769.https://doi.org/10.1139/cgj-2019
14. Moo-Young, H., Sellasie, K., Zeroka, D., Sabnis, G., 2003. Physical and chemical properties of recycled tire shreds for use in construction. Journal of Environmental Engineering, 129(10), 921-929.
15. Neaz Sheikh, M., Mashiri, M. S., Vinod, J. S., Tsang, H. H., 2013. Shear and compressibility behavior of sand–tire crumb mixtures. Journal of Materials in Civil Engineering, 25(10), 1366-1374.https://doi.org/10.1061/(asce)mt.1943-5533.0000696

16. Negadi, K., Arab, A., 2018. A Direct Shear Investigation on the Determination of the Shearing Resistance of Reinforced Soil with Waste Rubber. In Conference of the Arabian Journal of Geosciences (pp. 295-299). Springer, Cham.
17. Norme NF P94-050. Sols: Reconnaissance et Essais Détermination de la Teneur en Eau Pondérale des Sols—Méthode par Etuvage; Editions AFNOR Boutique: Saint-Denis, France, 1991.
18. Norme NF P94-054. Sols: Reconnaissance et Essais—Détermination de la Masse Volumique des Particules Solides des Sols—Méthode du Pycnomètre à Eau; Editions AFNOR Boutique: Saint-Denis, France, 1991.
19. Norme NF P94-056. Sols: Reconnaissances et Essais, Analyse Granulométrique, Méthode de Tamisage à Sec après Lavage; Editions AFNOR Boutique: Saint-Denis, France, 1996.
20. Norme NF P94-059. Sols: Reconnaissance et Essais Détermination des Masses Volumiques Minimale et Maximale des Sols Non Cohérents; Editions AFNOR Boutique: Saint-Denis, France, 2000.
21. Norme NF P94-071-1. Sols: Reconnaissance et Essais—Essai de Cisaillement Rectiligne à la Boîte-Partie 1: Cisaillement Direct; Editions AFNOR Boutique: Saint-Denis, France, 1994.
22. Norme NF P94-512-3. Reconnaissance et Essais Géotechniques. Essai de Sol au Laboratoire. Partie 3: Détermination de la Masse Volumique des Grains Méthode du Pycnomètre; Editions AFNOR Boutique: Saint-Denis, France, 2005.
23. Pacheco-Torgal, F., Ding, Y., Jalali, S., 2012. Properties and durability of concrete containing polymeric wastes (tyre rubber and polyethylene terephthalate bottles): An overview. Construction and Building Materials, 30, 714-724.https://doi.org/10.1016/j.conbuildmat.2011.11.047
24. Rao, G. V., Dutta, R. K., 2006. Compressibility and strength behaviour of sand–tyre chip mixtures. Geotechnical & Geological Engineering, 24(3), 711-724.
25. Rouhanifar, S., Afrazi, M., Fakhimi, A., Yazdani, M., 2021. Strength and deformation behaviour of sand-rubber mixture. International Journal of Geotechnical Engineering, 15(9), 1078-1092.
26. Saberian, M., Mehrinejad Khotbehsara, M., Jahandari, S., Vali, R., Li, J., 2018. Experimental and phenomenological study of the effects of adding shredded tire chips on geotechnical properties of peat. International Journal of Geotechnical Engineering, 12(4), 347-356. https://doi.org/10.1080/19386362.2016.1277829
27. Shu, X., Huang, B., 2014. Recycling of waste tire rubber in asphalt and portland cement concrete: An overview. Construction and Building Materials, 67, 217-224.
28. https://doi.org/10.1016/j.conbuildmat.2013.11.027
29. Tatlisoz, N., Edil, T. B., Benson, C. H., 1998. Interaction between reinforcing geosynthetics and soil-tire chip mixtures. Journal of Geotechnical and Geoenvironmental Engineering, 124(11), 1109-1119.https://doi.org/10.1061/(asce)1090-0241(1998)124:11
30. Thomas, B. S., Gupta, R. C., Kalla, P., Cseteneyi, L., 2014. Strength, abrasion and permeation characteristics of cement concrete containing discarded rubber fine aggregates. Construction and Building Materials, 59, 204-212. https://doi.org/10.1016/j.conbuildmat.2014.01.074
31. Tortum, A., Çelik, C., Aydin, A. C., 2005. Determination of the optimum conditions for tire rubber in asphalt concrete. Building and Environment, 40(11), 1492-1504. https://doi.org/10.1016/j.buildenv.2004.11.013
32. Yadav, J. S., Tiwari, S. K., 2016. Behaviour of cement stabilized treated coir fibre-reinforced clay-pond ash mixtures. Journal of Building Engineering, 8, 131-140. https://doi.org/10.1016/j.jobe.2016.10.006
33. Zhang, T., Cai, G., Duan, W., 2018. Strength and microstructure characteristics of the recycled rubber tire-sand mixtures as lightweight backfill. Environmental Science and Pollution Research, 25(4), 3872-3883.
34. Zornberg, J. G., Cabral, A. R., Viratjandr, C., 2004. Behaviour of tire shred sand mixtures. Canadian geotechnical journal, 41(2), 227-241. https://doi.org/10.1139/t03-086