Nano World Journal

https://doi.org/10.17756/nwj.2023-s2-052

Research Article

Open Access

Saturation, Rubber Content and Level Loading Effects on the Sand Mechanical Behavior (Direct Shear Tests) Mixture with Rubber Granulates to Morocco

Mohamed Benjelloun[1*], Rachid Bouferra[1], Hassan Ibouh[1], Frederic Jamin[2], Mohamed Essaleh[1] and Abdeltif Bouchehma[3]

[1]*Georessources, Geoenvironement and Civil Engineering Laboratory (L3G), Cadi Ayyad University, Marrakech, Morocco*

[2]*LMGC, Université de Montpellier, CNRS, Montpellier, France*

[3]*Team of Applied Physics and New Technologies, Sultan Moulay Slimane University, Béni Mellal, Morocco*

[*]Correspondence to:
Mohamed Benjelloun
Georessources, Geoenvironement and Civil Engineering Laboratory (L3G), Cadi Ayyad University, Marrakech, Morocco.
E-mail: mohamed.benjelloun@ced.uca.ma

Received: July 25, 2023
Accepted: September 26, 2023
Published: September 28, 2023

Citation: Benjelloun M, Bouferra R, Ibouh H, Jamin F, Essaleh M, et al. 2023. Saturation, Rubber Content and Level Loading Effects on the Sand Mechanical Behavior (Direct Shear Tests) Mixture with Rubber Granulates to Morocco. *NanoWorld J* 9(S2): S305-S310.

Copyright: : © 2023 Benjelloun et al. This is an Open Access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CCBY) (http://creativecommons.org/licenses/by/4.0/) which permits commercial use, including reproduction, adaptation, and distribution of the article provided the original author and source are credited.

Published by United Scientific Group

Abstract

This work consists in highlighting the influence of granulates rubber on the shear strength of sand. It deals with the study of sand-rubber mixtures and in particular saturation and mechanical properties. In order to study the influence of granulate rubber content on the mechanical properties of sand, direct shear tests were performed. The shear results show that the strength of the sand in the dry or saturated state increases with increasing rubber content. A rubber granulate content of 20% is the optimum value for improving the mechanical behavior of sand in dry and saturated conditions. This work also compares the shear results obtained for a dry and saturated sample under various normal stresses (100, 200, and 400 kPa). Increasing the normal stress improves the shear strength of pure sand in both dry and saturated states. A reduction in the maximum shear strength is observed in the saturated condition compared to the dry condition for the same relative density (D_r = 55%).

Keywords

Used tires, Sand-granulated rubber mixtures, Direct shear test, Mechanical behavior, Saturated

Introduction

The Moroccan location is at risk of earthquakes due to its position between two zones with significant geodynamic activity. The convergence of the African and Eurasian plates to the north and the divergence of the African and American plates to the west increases this risk. The city of Agadir, situated on the Moroccan Atlantic coast at an altitude of 75 m above sea level, experienced one of the most destructive earthquakes in the country's history on February 29th, at 23 h 40 min 1960, with a magnitude of 5.8, about 5 km north of the center of the city of Agadir. It corresponds geographically exactly to the point of coordinates 30° 27′ north and 9° 37′ west [1]. Evidence of ground failure in Agadir and other areas resulted in significant property damage and loss of life. Indeed, ground failure was significant in several areas, particularly in the city of Agadir, where sandy soils were ejected to the ground surface during the 1960 earthquakes. Consequently, a geotechnical study of the sandy soils in the region is necessary. The utilization of used tires for reinforcing soil stability in the contemporary era has been a notable development. This approach has proven to be a viable and effective solution for enhancing the mechanical properties of soil, while also being beneficial to the environment and cost-effective. Consequently, numerous scholars have concentrated on exploring the effectiveness of using added or crushed used tires for soil reinforcement [2, 3]. Several studies have indicated that the addition of rubber granulates to soil can enhance its strength. Researchers Anbazhagan et al.

[4] and Tiwari et al. [5] conducted direct shear tests on sand samples reinforced with rubber granulate and found that the shear strength behavior of sandy soil was influenced by the volumetric or mass content in used tires for medium and high densities on the shear strength behavior of sandy soil, particularly for dry samples. They also discovered that an optimal value of 20% or 25% of rubber granulate content in the mixture improved the mechanical characteristics of soils. Furthermore, the properties of the rubber granulate used, such as type, content, dimension, and orientation, also affect the effectiveness of the reinforcement.

The performance of soil reinforced with rubber granulate is dependent on various soil characteristics, including particle size, shape, saturation, and density. Research suggests that the behavior of sand is primarily influenced by the content of rubber granulates and saturation. Indeed, the presence of rubber granulates in low content can create high stability and incompressibility of the soil structure [6]. Enquan and Qiong [7] conducted direct strain-controlled shear tests on Fujian sand-rubber mixtures (1 - 5 mm) with rubber granulate content of 5%, 10%, and 15% by weight, and relative density of 50%, under normal stresses of 100, 200, 300, and 400 kPa. They found that the elasticity of the rubber granulates improves the deformability of the rubber-sand mixture. Moreover, increasing the rubber content led to higher shear strength of the saturated samples, which also increased with higher normal stress levels. In this paper, we discuss the results of an experimental investigation that seeks to explore how the addition of rubber granulate and saturation affect the shear behavior of sand-rubber mixtures. Our research covers a rubber content range of 0 - 40%. This work was conducted on 120 direct shear tests on both unreinforced and reinforced sand-rubber granulate samples, applying various normal stresses (100, 200, and 400 kPa) and testing them in both dry and saturated conditions.

Materials and Method

Below is a summary of the characteristics of the materials used in this study, which include Issen sand and rubber granulates obtained from used tires. All used materials are nanoscale materials.

Issen sand

The sand is collected from the alluvium of Oued Issen, in the region of Aït Baha in Morocco. It is classified as a fine sand (0.063 - 5 mm) with a uniform and well-graded grain size. Its average grain size is D_{50} = 0.48 mm, and its void ratio can vary between e_{min} = 0.612 and e_{max} = 0.835. The sand's specific density is ρ_s = 2.64 g/cm^3, determined by the pycnometer method NF P 94-054 and NF P 94-512-3 [8, 9]. The grain size distribution was determined using the NF P 94-056 method [10] (Figure 1). The sand's geochemical composition was analyzed using X-ray fluorescence spectrometry (Epsilon 4 Benchtop XRF-EDS) and is mainly composed of SiO_2 (60.972%) and Al_2O_3 (14.207%). CaO, Na_2O, and K_2O were present in relatively weak proportions (about 2%), while Fe_2O_3 had proportions exceeding 4%. TiO_2, MnO, and P_2O_5 were present in trace amounts, with proportions below 1%. The mineral composition of the sand is determined by an X-ray diffractometer (Rigaku-Smart Lab diffractometer). The geochemical results are in agreement with the mineralogical composition. It includes high proportions of quartz which testify to the presence of SiO_2, with a small content of plagioclase which is also supported by the presence of Al_2O_3 and finally includes Calcite and Hematite which are respectively carbonate and ferric minerals confirming the observed contents of CaO and Fe_2O_3. Finally, the scanning electron microscope (Vega3 Tescan) showed that the Issen sand is composed of sub-rounded to rounded particles (Figure 2).

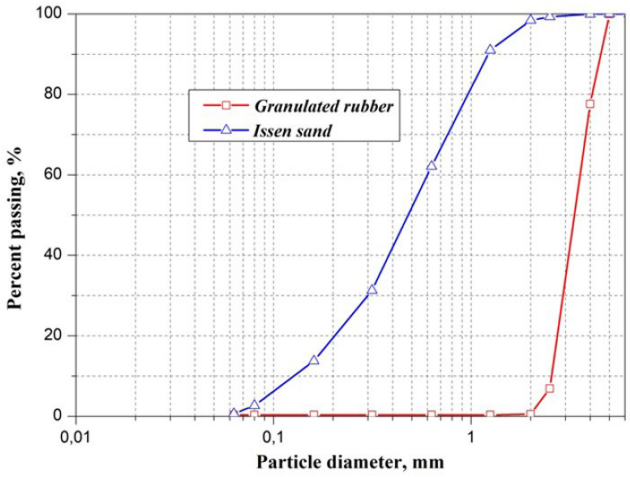


Figure 1: The particle size distribution of the materials studied.

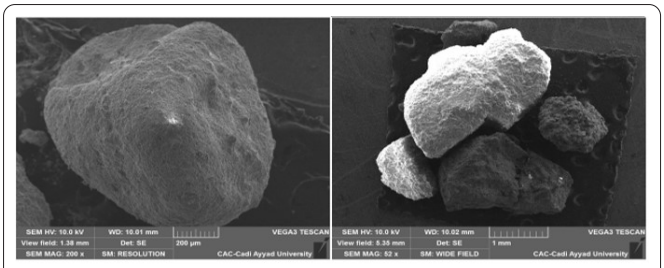


Figure 2: Microscopic image of Issen sand with SEM at different scale.

Granulate rubber

To physically characterize crushed rubber samples of varying diameters (ranging from 2 to 5 mm with an average diameter of D_{50} = *3.35 mm*, several parameters must be determined, including the specific density of the solid grains, the maximum density (ρ_{dmax}) (or minimum void index), and the minimum density (ρ_{dmin}) (or maximum void index). The specific density of the solid grains was determined using the same method as mentioned before for Issen sand. After testing, the specific density of the solid grains was determined to be 1.129 g/cm^3. To determine the minimum and maximum density of the soils, the standard NF P 94-059 [11] was followed, which involves placing the soil sample into a mold successively in a loose state (ρ_{dmin}) and a dense state (ρ_{dmax}).

After determining the densities, the void ratio is then calculated using the equations (1) and (2):

$$e_{max} = \frac{\tilde{n}_s}{\tilde{n}_{dmin}} - 1 \quad (1)$$

$$e_{min} = \frac{\tilde{n}_s}{\tilde{n}_{dmax}} - 1 \quad (2)$$

The range of the void ratio can fluctuate between e_{min} = 0.908 and e_{max} = 1.112. The particle size distribution curve of granulate rubber is presented in figure 1. Additionally, figure 3 displays the various geometric characteristics of the rubber granulates used.

Figure 4 depicts the variation of the minimum and the maximum void ratio (e_{min}, e_{max}) with the rubber content in the sand-rubber mixtures. The graph shows that as the rubber content (RC) increases, these two void ratios decrease, until RC reaches around 30 %. Beyond this point, the trend reverses for higher RC values.

Shear box

In this study, direct shear tests were performed on sand-rubber mixtures in accordance with NF P 94-071-1 [12]. The tests were carried out using a direct shear device manufactured by IGM (Ingénierie Générale de Mesures), equipped with a computer controlled by an acquisition unit. A data processing software (IGM) allowed for the visualization of the various measurements taken during the experiments, as well as their subsequent recording. The test method was conducted by placing the Issen sand-rubber mixture in a dry state in the mold of the direct shear equipment with a square section of 60 mm side (L) and 30 mm height (H), followed by the consolidation phase. At this stage of consolidation, two cases were taken under consideration: the first case, the dry samples were directly subjected to normal stresses, and the second case, the dry samples were saturated and subjected to normal stresses. To investigate the effect of rubber, granulate (RC) content and vertical normal stresses (100, 200, and 400 kPa) on the shear strength of a dry sand-rubber mixture, a laboratory study was conducted. The mixture was placed in horizontal boxes, which were then separated. One of the half boxes was subjected to a constant strain rate of 1 mm/min, and the resulting vertical and horizontal displacements (ΔH and ΔL, respectively) and shear force (T) were measured using force and displacement sensors installed on the shear box. To prepare the laboratory samples, the relative density $\left(D_r = \frac{e_{max} - e}{e_{max} - e_{min}}\right)$ of the sand was used, based on the maximum and minimum void ratio. The density state of the sample was defined by the relative density (D_r). Saturation was also considered as a factor in the study. The mass of the mixture (m_s) was estimated using equation 3.

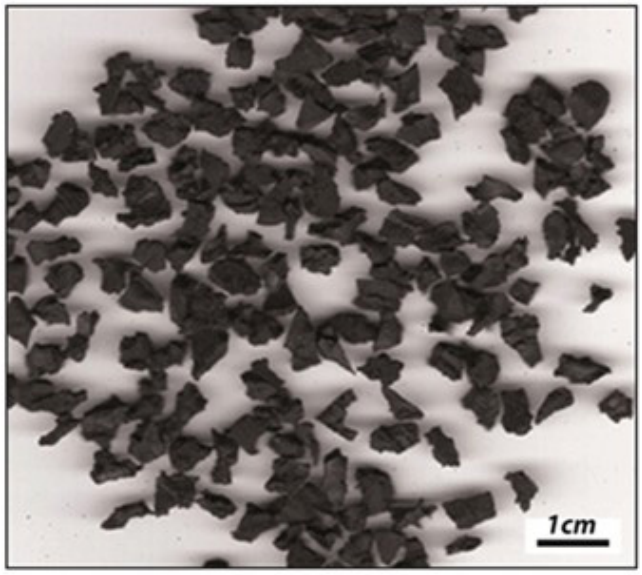


Figure 3: Picture of granulate rubber with 2 mm < DGR < 5 mm.

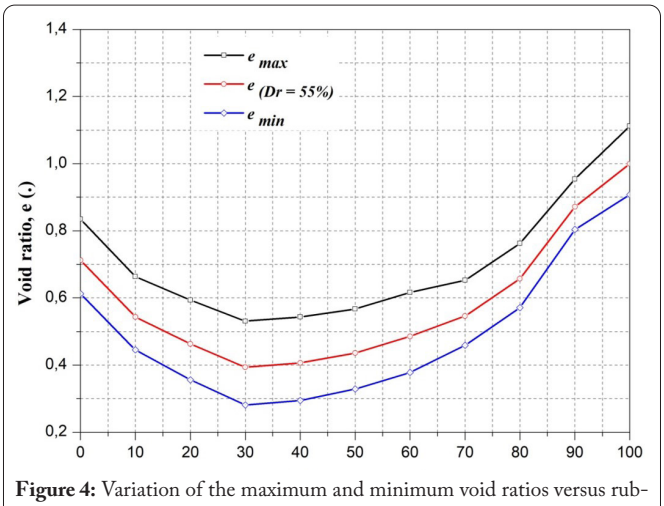


Figure 4: Variation of the maximum and minimum void ratios versus rubber proportion.

$$m_s = \frac{V_t \, x \, _s}{1 + e_{max}\left(1 - D_r\right) + D_r \, x \, e_{min}} \quad (3)$$

Where, ρ_s is the specific density of solid grains, e_{min} and e_{max} are respectively the ratios of the minimum and maximum voids, V_t is the volume of the direct shear cell, D_r is the desired relative density.

To ensure the homogeneity of the mixture, several preventive actions were taken while filling the mold shear box. Firstly, segregation was prevented by carefully pouring the mixture (m_s) in three layers using a funnel. Secondly, the material was mixed thoroughly after each layer until the box was completely filled. Once filled, normal stresses were applied, and the samples were sheared. To investigate the impact of rubber granulates on the shear strength of sands, direct shear tests were carried out on Issen sand. The experimental program involved using varying weight percentages of granulated rubber, ranging from 0% to 40%. Table 1 displays the results of the tests.

Results and Discussion

The addition of rubber granulates has been proven effective in reinforcing soils due to the friction generated between

Table 1: Designations for the different mixtures; Sand-Rubber.

Designations	Sand-Rubber
RC 0	100% Sand + 0% Rubber
RC 10	90% Sand + 10% Rubber
RC 20	80% Sand + 20% Rubber
RC 30	70% Sand + 30% Rubber
RC 40	60% Sand + 40% Rubber

the sand grains and rubber granulates. This study aims to investigate the impact of rubber granulate content by weight ranging from 0 to 40% on the mechanical behavior of sand in a medium-dense state (D_r = 55%), using direct shear tests. It will also examine the influence of both the saturation level and rubber granulate content on the mechanical behavior of reinforced and unreinforced sand at varying normal stress levels.

Figure 5a and 5b demonstrate the impact of saturation on the mechanical characteristics of sand samples with and without reinforcement (RC = 0% and RC = 10%, 20%, 30%, and 40%) at an average relative density of 55% and a normal stress of 200 kPa. The outcomes indicate that the samples reinforced with rubber granulates exhibit superior shear strength ($\frac{T}{S}$, with S: sample surface) performance in both dry and saturated conditions in comparison to pure unreinforced sand. The most satisfactory outcomes are achieved when the rubber granulate content is 20% in both cases. Comparatively, reinforced sand has approximately 15% higher maximum shear strength than unreinforced sand in dry and saturated conditions. However, samples containing rubber granulate exceeding 20% exhibit lower maximum shear strengths, but these strengths are still higher than those of pure unreinforced sand. Figure 6a and 6b show the variation in vertical deformation $\left(\frac{\Delta H}{H}\right)$ as a function of horizontal deformation $\left(\frac{\Delta L}{L}\right)$ for different rubber contents under a normal stress of 200 kPa for both case (Dry and saturated). They validate the trends observed for the shear strength. The contracting phase seen in unreinforced sand is reduced with the incorporation of rubber granulates, resulting in a slightly dilatant behavior. Furthermore, it was observed that the vertical deformations decrease with increasing rubber granulate content. The tests carried out in this section can effectively highlight the real behavior of the soil reinforced with rubber granulates. Thus, the rubber granulates rotate around the sand grains and occupy the intergranular void, generating friction between the sand grains and the rubber granulates.

Figure 7 presents an analysis of the relationship between the crushed rubber granulate content of used tires and the maximum shear stress under different normal stresses. The results show that adding rubber granulate to pure sand significantly increases the maximum shear strength in both dry and saturated states. For instance, under a normal stress of 100 kPa, the maximum shear strength of sand increases from 68.31 ± 3.01 kPa to 83.17 ± 3.06 kPa in a dry state and 55.44 ± 2.96 kPa to 61.89 ± 2.98 kPa in a saturated state, with a 20% rubber granulate content. This increase in strength is attributed to the rubber granulates filling the voids between the sand grains, which prevents their displacement and slippage. However, if the rubber content exceeds 20%, the maximum shear strength decreases due to the deformation of the rubber

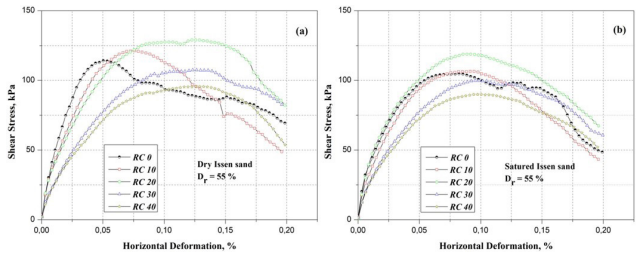


Figure 5: Shear stress variation curves for different rubber contents under normal stress of 200 kPa. **(a)** Dry sand and **(b)** saturated sand.

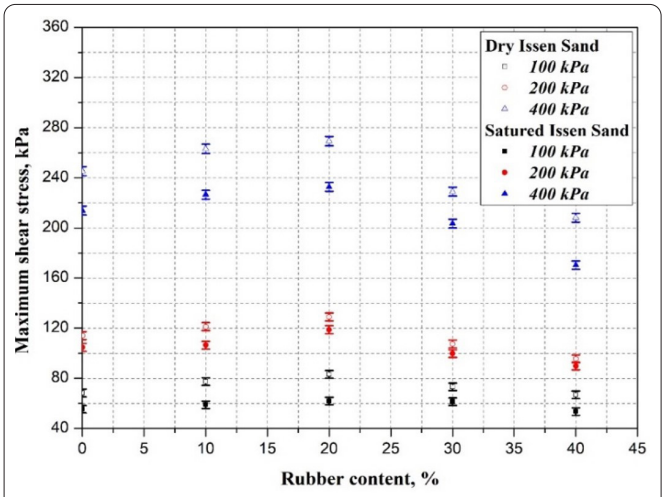


Figure 7: The relationship between rubber proportion and peak shear stress variation.

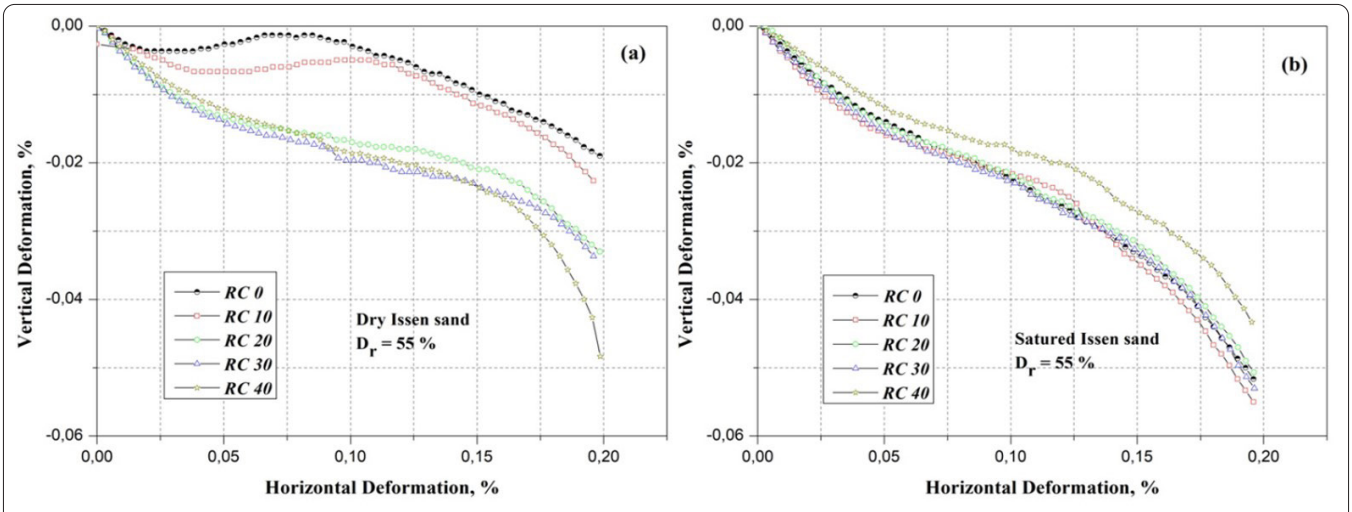


Figure 6: Correlation between horizontal and vertical deformation for varied rubber contents under 200 kPa normal stress: **(a)** Dry sand and **(b)** saturated sand.

material under normal applied stress. Moreover, mixtures with high rubber content exhibit lower shear strength values since their particles can move and slip easily during the shear test. This variation in maximum shear strength can be explained by the change in the void ratio in sand/rubber mixtures.

As the normal stress on samples rises, their shear strength also increases. This occurs due to the grains becoming more tightly packed and the reduction of voids. The increased interlocking, frictional, and cohesive forces between the sand grains counteract the horizontal shear force and prevent motion.

In figure 8, the friction angle is plotted as a function of rubber content for a medium relative density (D_r = 55%). The results indicate that adding up to 20% granulated rubber can increase the initial friction angle of dry sand from 30.9° ± 0.68 to 32.3° ± 0.6, and that of saturated sand from 27.9° ± 0.76 to 29.7° ± 0.7. However, if the rubber content exceeds 20% in either dry or saturated conditions, the friction angle decreases. This can be attributed to the rubber particles surrounding the sand grains in the shear zone, creating more voids that cannot be filled with sand. As a result, the friction between particles is mainly controlled by the rubber granules.

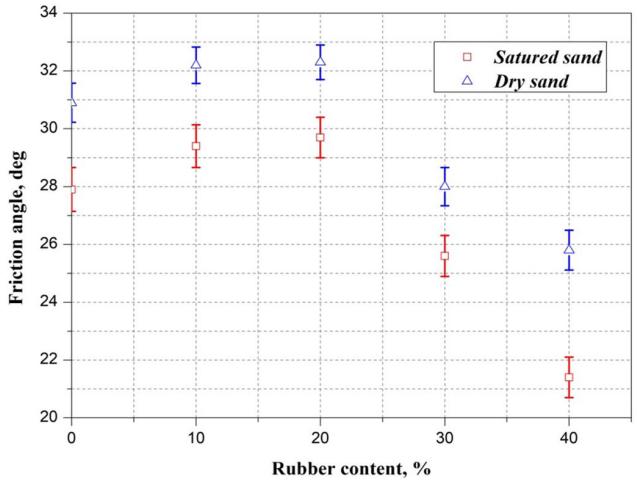


Figure 8: The friction angle of dry and saturated sand as a function of rubber content.

Conclusions

This paper consists of studying the behavior of dry and saturated Issen sand reinforced by rubber granulate from used tires. The experimental direct shear results have led to the following conclusions:

- The shear strength of sand is impacted by various factors such as normal stress, saturation, and the content of rubber granulate.
- An increase in normal stress has a notable effect on enhancing the shear strength of sand in both dry and saturated conditions.
- The maximum shear strength under saturated conditions is lower than under dry conditions for medium relative density (D_r = 55%).
- The mechanical behavior of sand-rubber mixtures can be improved by adding rubber granulate, with an optimal content of 20%. Such addition can enhance the shear strength and prevent soil contraction.

Based on the aforementioned results, the use of granulate rubber as reinforcement appears to be a promising approach for addressing soil instability and deformability. Further investigation is necessary to fully explore this technique, including conducting monotonic and cyclic undrained triaxial tests as well as dynamic triaxial tests on sand samples containing rubber granulate. This will allow for a deeper understanding of soil liquefaction in seismic zones, which is particularly relevant for the Agadir sand as it is susceptible to liquefaction during earthquakes and even under static loads in certain cases. This issue carries significant importance for the region.

Acknowledgements

The authors express their gratitude to several institutions for their contributions to this work, including L3E in Marrakech, Morocco, and LMGC in Montpellier, France. They also thank the company ALIAPUR and its manager, Mr. JEAN Philippe Faure, for providing rubber granulates, as well as the CNRST of Morocco for providing a student scholarship.

Conflict of Interest

None.

References

1. Cherkaoui TE, Medina F, Hatzfeld D. 1991. The Agadir earthquake of February, 29, 1960. Examination of some of the parameters. Symp. on the seismicity, the seismotectonics and seismic risk of the Ibero-Maghrebian region, Madrid. *Publ Inst Geogr Natl Monogr* 130-146.
2. Aksoy HS, Taher N, Awlla H. 2021. Shear strength parameters of sand-tire chips mixtures. *Gümüşhane Üniversitesi Fen Bilimleri Dergisi* 11(3): 713-720. https://doi.org/10.17714/gumusfenbil.865490
3. Rouhanifar S, Afrazi M, Fakhimi A, Yazdani M. 2021. Strength and deformation behaviour of sand-rubber mixture. *Int J Geotech Eng* 15(9): 1078-1092. https://doi.org/10.1080/19386362.2020.1812193
4. Tiwari SK, Sharma JP, Yadav JS. 2017. Geotechnical properties of dune sand-waste tires composite. *Mater Today Proc* 4(9): 9851-9855. https://doi.org/10.1016/j.matpr.2017.06.280
5. Anbazhagan P, Manohar DR, Rohit D. 2017. Influence of size of granulated rubber and tyre chips on the shear strength characteristics of sand-rubber mix. *Geomech Geoeng* 12(4): 266-278. https://doi.org/10.1080/17486025.2016.1222454
6. Benessalah I, Arab A, Villard P, Sadek M, Kadri A. 2016. Laboratory study on shear strength behaviour of reinforced sandy soil: effect of glass-fibre content and other parameters. *Arab J Sci Eng* 41: 1343-1353. https://doi.org/10.1007/s13369-015-1912-6
7. Enquan Z, Qiong W. 2019. Experimental investigation on shear strength and liquefaction potential of rubber-sand mixtures. *Adv Civ Eng* 2019: 5934961. https://doi.org/10.1155/2019/5934961
8. NF P94-054. Soils: Reconnaissance and Tests - Determination of the Density of Solid Soil Particles - Water Pycnometer Method. [https://www.boutique.afnor.org/en-gb/standard/nf-p94054/soils-investigation-and-testing-determination-of-particle-density-pycnometer/fa020767/11077] [Accessed September 28, 2023]
9. ISO 17892-3. Geotechnical Reconnaissance and Testing - Laboratory Tests on Soils - Part 3: Determination of the Density of

Solid Particles. [https://www.boutique.afnor.org/fr-fr/norme/nf-en-iso-178923/reconnaissance-et-essais-geotechniques-essais-de-laboratoire-sur-les-sols-p/fa166641/82913] [Accessed September 28, 2023]

10. NF P94-056. Soils: Recognition and Tests - Particle Size Analysis - Dry Sieving Method After Washing. [https://www.boutique.afnor.org/fr-fr/norme/nf-p94056/sols-reconnaissance-et-essais-analyse-granulometrique-methode-par-tamisage-/fa026936/11075] [Accessed September 28, 2023]
11. NF P94-059. Soils: Recognition and Tests - Determination of the Minimum and Maximum Density of Non-cohesive Soils. [https://www.boutique.afnor.org/fr-fr/norme/nf-p94059/sols-reconnaissance-et-essais-determination-des-masses-volumiques-minimale-/fa106659/17780] [Accessed September 28, 2023]
12. NF P94-071-1. Soils: Reconnaissance and Tests - Rectilinear Box Shear Test - Part 1: Direct Shear. [https://www.boutique.afnor.org/fr-fr/norme/nf-p940711/sols-reconnaissance-et-essais-essai-de-cisaillement-rectiligne-a-la-boite-p/fa029769/11060] [Accessed September 28, 2023]