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Evaluating the Impact of Rubber Particles on the Swelling Potential and Pressure of Tizi Soil in an Area Located in North Western Algeria

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Abstract

Major climatic changes and heavy truck traffic are causing several problems in road base layers, leading to cracking and destruction. This work is part of a general framework aimed at characterizing and evaluating local materials (Tizi) from the Mascara area to valorize them in road and sidewalk construction. In addition to rubber's remarkable technical properties, its reuse as an additive in Tizi soil mixes can be effective in geotechnical projects while reducing its negative environmental impacts. A low mixing ratio experimental program was implemented to study the effect of rubber particles on the swelling of the Tizi. Grain size, specific gravity, Atterberg limit analysis, swelling consistency, and loading and unloading tests were carried out on Tizi soils and their mixtures with varying rubber particle percentages (3, 6, 9, and 12%). The results showed that liquid limits, swelling time, and swelling probability progressively decreased with increasing rubber particle contents in the samples. This reduction is significant for Tizi soil with medium swelling potential, due to the high compressibility of rubber particles, indicating that compaction and decompression indices increase significantly with rubber particle contents. The results highlighted the beneficial effect of particles and rubber powder, as it was found that Tizi soil samples, reinforced with rubber particles, are more ductile than unreinforced samples. This effect is highly desirable in many backfill applications.

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Keywords: *Tizi soil, Rubber particles, Consistency limits, Swelling potential, Compressibility*

1. Introduction

The infrastructure of developing and developed countries consists of a group of basic elements, including roads, bridges, railways, and airports. Roads are an important part of all the elements, as the cost of construction and maintenance are extremely high. Hence, understanding and improving performance are essential to using resources in the best possible way. In some areas, classic materials (good quality of grave) are rare or even not present, so engineers and experts have to build roads at a low cost by adapting local materials (Xiaobing et al., 2022; Amakye et al., 2022). Lots of materials have proven to be very interesting in road design, such as tuff, quarry waste, dam sediments, and desert sand (Pan et al., 2020; Odari et al., 2021; López-Lara et al., 2017). Improving local materials for road engineering is an objective solution (Mlhem, 2023); the goal is to better support their physical and mechanical reactions under various climatic conditions, implement them, and achieve a description that enhances their ease of classification and use by experts. In Algeria, the area covered with tuff soil is about 300,000 square kilometers. It is used in roads, sidewalks, and the foundation layers of infrastructure airports according to Loualbia et al. (2016). Tuffs are non-homogeneous, porous, friable, and light rocks, often powdery, either of calcareous origin, derived from springs or "petrifying" gullies. tThe presence of rich vegetation in tuffs accelerates limestone deposition or volcanic deposits' aggregates found in coarse strata, often under a thin layer of earth soil. Tuffs appear in a wide variety of colors, depending on their constituent elements.

Numerous studies have shown that tuffs are formed bya certain amount of excessive pressure and wet drying and continue to lose their consistency over time. This was well confirmed by their mechanical behavior under static and dynamic loading (Goual et al., 2011; Al Dwairi et al., 2018). This cohesion completely disappears after saturation, affecting the mechanical behavior of the tuff (Goual., et al 2008). Most previous technologies have not achieved the desired objective, and this research is a new window in the field of tuff improvement (Sarireh et al., 2021).

Several studies show that rubber waste improves geotechnical properties when mixed with soils (Anvari et al., 2017; Akbarimehr et al., 2020). The study, conducted by Ekincia et al. (2022), stated that weaved geotextile networks have been effectively employed to increase the longevity of roads by limiting soil slide, expansion, and ground pressures and sustained by increasing the capacity of these structures. Akbarimehr and Hosseini (2022), mixed pure clay samples with different rubber contents (from 2% to 30% by weight)

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and found that the elastic plastic and accumulated plastic could change over different cycles and for two sizes of granular rubber. They concluded that it is well-recommended to use a maximum of 10% rubber in mixtures to obtain a homogeneous, resistant blend.

Jaramillo et al. (2022) used rubber tire granules in clay soils with different contents (5, 10 and 15% of the dry weight of the soil). The addition of 5% rubber led to similar maximum dry density values, while the optimum moisture content was affected by the selected surface. In addition to its use in improving the mechanical behavior of clay soils, the incorporation of recycled tire rubber is more effective in low-stress situations.

According to some relevant studies on fiber-reinforced soils, the percentage of polypropylene is generally 0.05, 0.015, and 0.025 % of the weight of the mother soil (Akbulut et al., 2007). For the rubber particles, the studied proportions were 1, 2, 3, 4, and 5% of the total weight of the knitting samples (Akbulut et al., 2007). For chemical additives, lime or cement was mixed with the soil in all the mentioned studies as suggested by Akbulut et al. (2007). The mixtures prepared with the sediment were studied with 10, 20, 25, and 50% of the purified tire (Sellaf et al., 2014).

This research mainly focused on the contribution of rubber particles to the swelling behavior of Tizi soil in comparison to tuff soil. It proposes a method for improving locally produced materials, including Tizi soil, by adding rubber particles for use in road engineering. In this study, Atterberg limit tests, swelling consolidation, and load discharge tests were combined to investigate the causes of strength changes in Tizi soil mixed with rubber particles.

2. Materials and Methods

2.1 The Tizi soil

The Tizi soil sample was obtained from the quarry, located in Tizi, northwest of Algeria (Figure 1). Samples are collected from quarries in the form of stones or gravel. After that, they are transported to the laboratory and placed in a microbial unit for grinding, then, passed through a 2 mm sieve. This soil underwent several laboratory tests (Consistency limits, Specific weight, Grains sizes analysis, Compaction, and Volume of blue) to determine its identity using standard procedures approved by AFNOR and ISO standards (NFP94-051, NFP94-054, NFP94-056, NFP94-057, and NFP 94-068).

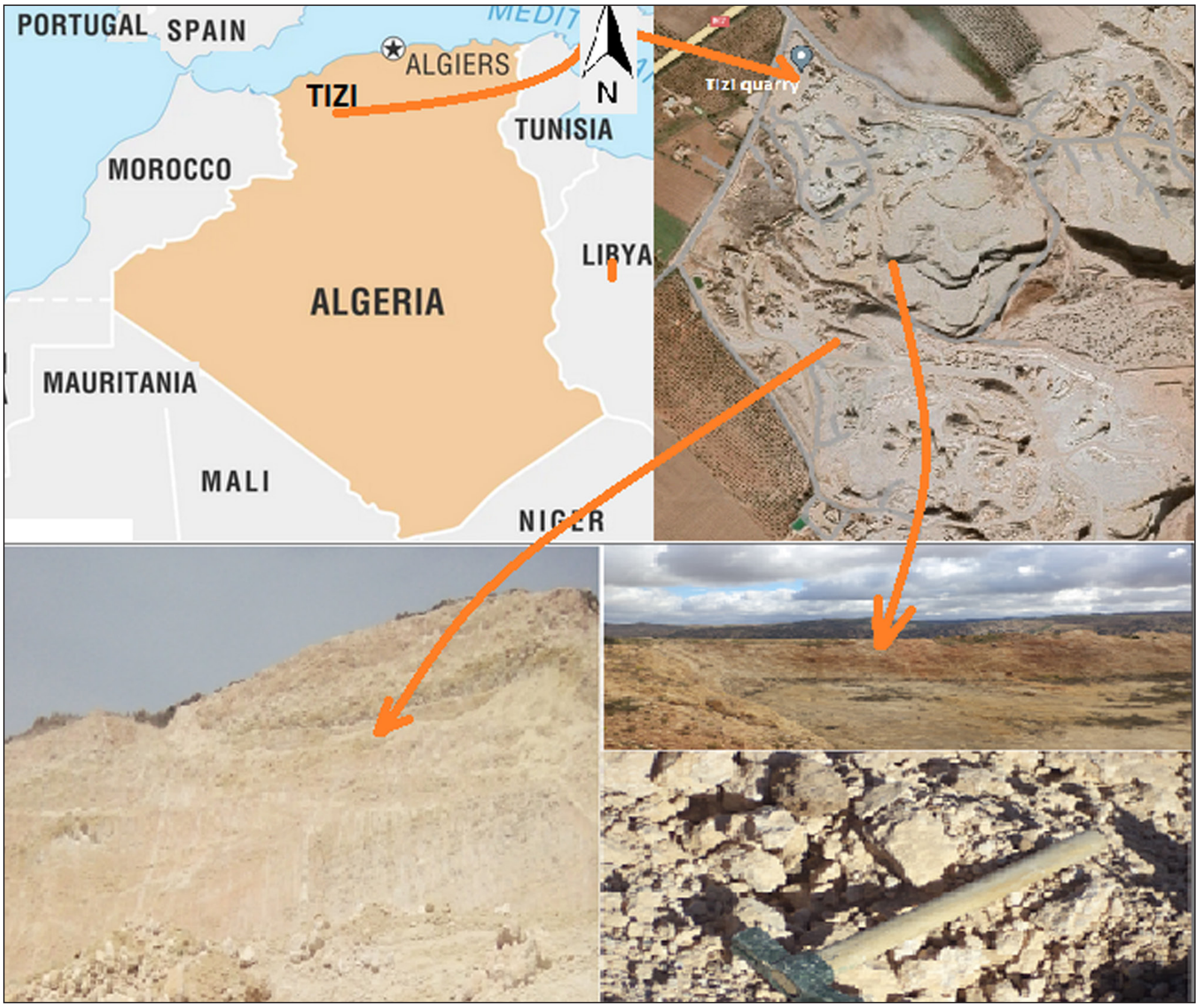

Figure 1. Localization of site.

The results are explained in Table (1). The specific gravity (dimensionless) of the Tizi soil is 1.95, and the distribution of the grain size of the Tizi soil is determined. Table (2) displays the chemical analysis of the Tizi soil according to NF EN 1774.

Mineralogical analysis by X-ray Diffraction (Figure 2) reveals that Tizi soil is mainly composed of calcite (CaCO3), with the presence of traces of quartz (SiO_2) and dolomite (CaMg(CO3)2). This high CaCO3 content is favorable for the hardening and cementation of these compacted materials.

According to the results of Table 1, which is the study of consistency limits, specific weight, grain sizes analysis, compaction, and volume of blue, the Tizi soil is classified as highly plastic clay (CH) according to the Unified Soil Classification System (USCS).

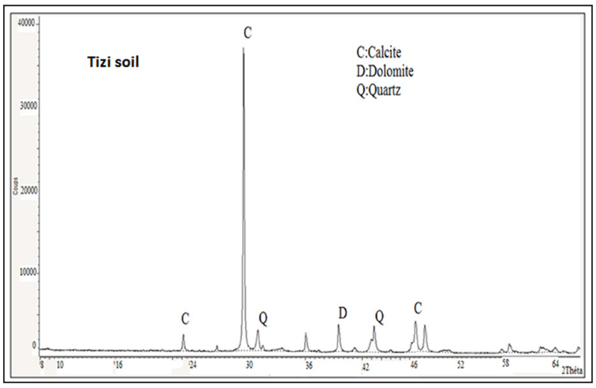

Figure 2. X-ray diffraction of the Tizi soil.

Table 1. Physical properties of Tizi soil

	Properties	Tizi soils
Consistencylimits: NF:P94-051	Liquid limit, [%]	38.28
	Plastic limit,[%]	23
	Plastic ityindex,[%]	16
Specific gravity NF:P94-054	Specific gravity (dimensionless)	1.95
Grains sizes analysis NF:P94-057	Sand, [%]	18
	Silt, [%]	33.33
	Clay, [%]	48.67
Compaction NFP94-093	Maximum dry density:γopm	1.92
Volume of blue NFP94-068	Volume of blue VB(cm^3)	7.52

Table 2. Chemical compositions of Tizi soil

Property	Tizi soil
SiO_2,[%]	9.56
Al_2O_3,[%]	2.65
Fe_2O_3,[%]	0.58
CaO,[%]	70.25
MgO,[%]	2.61
Na_2O, [%]	4.90
Cl,[%]	0.25
SO_3,[%]	1.2
Loss on ignition,[%]	7.73

2.2 Rubber Particles

Rubber particles are obtained through two main processes: (1) the surrounding environment, which is a mechanical method, where scrap tires are ground and (2) the coolant, a process that uses liquid nitrogen to freeze rubber tires and, then, uses a mill to destroy the frozen rubber and convert it into a soft powder. Rubber particles consist of a compound mixture of citric acid (1.2 %), extension oil (1.9 %), carbon lions (31.0 %), zinc oxide (1.9%), and other materials (elastomers, polyisoprene and styrene-butadiene), that is, all the important ingredients for rubber (Balegh and Sellaf, 2022).

Rubber granules, used from five used car tires, are produced by mechanical cutting at the ocean temperature. After that, we separate the granules with a 2 mm dimension from the remainder of the powder, as the powder ratio was more than 41% of the total weight, and the powder tends to clump together (Figure 3). The scrap rubber frame is characterized by a qualitative specific weight of 0.83 g/cm^3 and the absorption of little water.

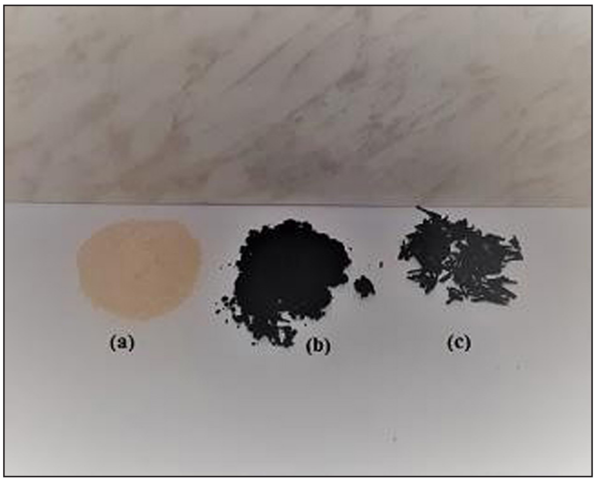

Figure 3. Tizi soil **(a)**, and rubber particles (rubber powder **(b)**, and rubber granules. **(c)**.

2.3 Mix design preparation of Tizi soil-rubber mixtures

Because rubber is affected by temperature, the water content of samples was determined by drying at 35°C, and samples were considered completely dry when the difference did not exceed 2/1000 of the kidney weight in 24 hours.

In this study, the Tizi soil was mixed with rubber granules, and the granule content was chosen as 3, 6, 9, and 12 % of the total weight of the composite samples as illustrated in (Figure 4). The particles frequently clump together, so much care and time have been taken to obtain a homogeneous distribution of particles in mixtures. The materials used as T, P, and G were called Tizi soil T, rubber powder P, and rubber granules G. In the preparation of composite soil, samples are prepared in an optimal protector or in water content that corresponds to liquid reduction.

This study demonstated that the specific gravity of the rubber is less than half of the soil, the mixing rates used are considered up to 12% of the rubber tires and 15% of the water content. The samples were constantly pressed in the standard Proctor in three layers. To ensure a uniform dry density, samples are allowed to be absorbed in an additional cost of one Kilopascal, and this additional cost of the seat is caused by the great difference in the qualitative gravity of the components. After pressing the tuff and its mixtures, uninterrupted cylindrical samples were confirmed in the mold using a hydraulic crane. Samples are wrapped with plastic to prevent water from leaking into gout.

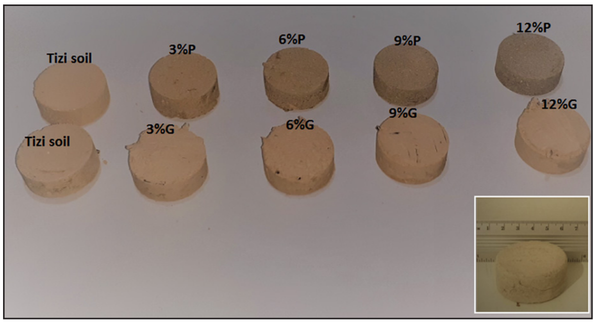

Figure 4. Tizi soil samples with different rubber content (granules or powder).

3. Results and Discussion

3.1 Consistency limits

To determine the consistency values of Tizi soil and mixtures, Atterberg limit tests were conducted in accordance with NF P94-051.

3.1.1 The liquid limit

Figure (5) illustrates the effect of rubber particles (granules and powder) on the boundaries of the consistency of the Tizi soil and its mixtures. The liquid limits are expected to decrease gradually when the content of the rubber particles increases. However, the liquid limit for the Tizi soil, reinforced with rubber granules, exceeds the liquid limit for the Tizi soil, reinforced with rubber powder. This is demonstrated by Akbarimehr and Aflaki (2018).

3.1.1 The plastic limit

As presented in Figure (5), for Tizi soil reinforced by rubber granules, the sample's plastic limit decreases by 3% of the granules, then gradually decreases under 15 % and 28 % of the plastic limit of Tizi, and this also applies for the granules' samples by 6 and 9 %. For Tizi soil, reinforced by rubber powder, the plastic limit of the sample decreases by 3% and 6% of the rubber powder, gradually increases, and, then, reaches the level of plastic of the Tizi soil (9 and 12% of the rubber powder). The results of the Atterberg limits indicate that the Tizi soil reinforced by rubber powder has a higher indicator than the Tizi soil reinforced by rubber grains (Sellaf et al., 2014). Changes in consistency limits of mixtures may be due to the mixture type, the cation exchange capacity, and the relative amount of clay mineral in the mixtures (Al-Mukhtar et al., 2010).

According to Kang et al. (2007) and Akbarimehr and Aflaki. (2018), it is interesting that the plastic limits that were studied for cohesive clay soils initially retain their form, then, undergo a certain degree of modification before returning to their original form. These results are comparable to those of a typical coherent soil with fine grains and medium plasticity.

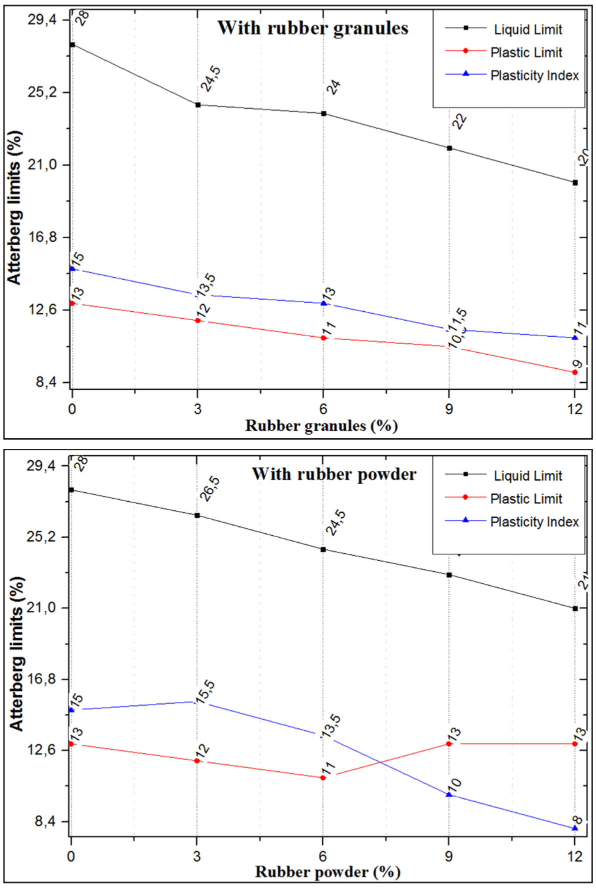

Figure 5. Effect of rubber particles on the consistency limits of Tizi soils.

3.2 Swell-consolidation Tests

Swell-consolidation experiments were carried out on all compacted specimens for the series of tests in accordance with AFNOR XP 94-91 (1995). These tests are conducted on an odometer (diameter 50 mm and thickness 20 mm). Considering how difficult the samples were to prepare, the initial vacuum ratio (e) varies with the contents of the rubber particles and their types. Samples are constantly pressed at a distance in four layers, each with a thickness of 4 mm to ensure a uniform dry density.

For homogeneous dry density, the specimens are statically compressed in the odometer into five layers, each 4 mm thick. Heave was permitted under a sitting surcharge based simply on the odometer for the sample (about 5 kPa) by continually allowing water into the soil specimen. After achieving the final heave (ΔH), the sample is compressed using increasing vertical loads until the original void ratio (e) is reached. For soils and their mixtures, swelling potential (S) and swelling pressure (PS) are measured. The swell potential is calculated as the ratio of the sample's original thickness (H) to its rise in thickness after submersion (ΔH). The pressure (PS) that corresponds to the initial void ratio (e), which is calculated from the e-log p curve, is identified as the swelling pressure (Akbarimehr et al., 2020).

3.2.1 Swell potential

Figure (6) shows the variation of swell potential (S) versus time for the Tizi soil sample compared to samples mixed with 3, 6, 9, and 12% rubber granule contents and samples mixed with 3, 6, 9, and 12% rubber powder contents. Test results indicate that Tizi soil, reinforced with rubber granules, gives a potential of 3.88% in 21 days, whereas Tizi soil supported with rubber powder gives a 4.52% earned in 24 days.

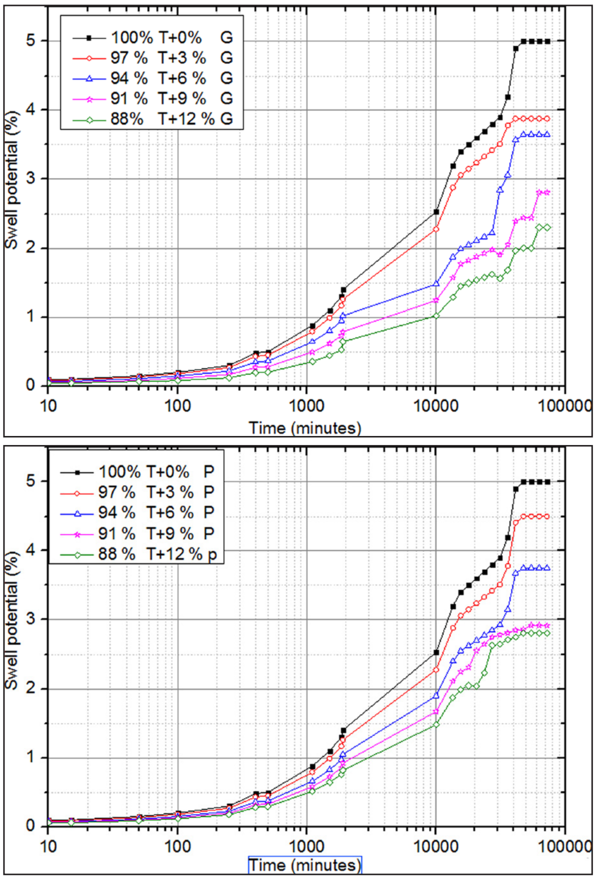

Figure 6. Effect of the rubber particles (granulated or powder) content on the swell potential of Tizi soil.

The final swelling of the compound samples is decreased, and, in practice, it reaches the same period for the compound samples with 3% of the rubber particles (granules or powder) and in less time for the compound samples with 6, 9, and 12% of the rubber particles.

Figure (6) indicates that rubber particles (granulated or powder) are very effective in reducing the swelling potential of Tizi. For the two rubber particles (Seda et al., 2007), the reduction of swell potential increases gradually with particle content. For Tizi soil reinforced with rubber granules, the reduction of swell potential is about 28.50% for a mixture with 3% of the granule content. It then ranges from 38.6% to 66.8% for respectively 9 and 12% of fiber content. Since all samples were prepared at 15% water content and rubber absorbs at most 4% of its weight, the water/Tizi soil rates at the beginning of the test were about 0.15, 0.18, 0.21, 0.24, and 0.28 for the mixture that contains 0, 3, 6, 9, and 12 % of the rubber particles (granules or powder), respectively, and these can be the reasons for reducing time. For Tizi soil reinforced with 3% rubber powder, the reduction of swell potential is about 11.5%, whereas with 6% of rubber powder, the reduction of the swell potential of the composite increases about 28.6%. A further reduction in the well potential of Tizi soil in corporate with rubber powder is obtained by an increase in duration. The swell potential of 88% Tizi soil and 12% rubber decreases to 85% in 13 days (28 days for Tizi soil alone). This reduction in the reach time is undoubtedly due to the initial water: Tizi soil ratios, which were about 0.15 and 0.28 for samples with 0 and 12% of rubber particles. Their suction in the swell potential of the swell potential of Tizi soil increases gradually from 9 to 85% when powder content increases from 3 to 12%.

3.2.2 Swell pressure

Figure (7) illustrates the values of the swelling pressures of studied specimens. Swelling pressure (PS) decreases with particle content (Mistry et al., 2021). For Tizi soil reinforced with rubber granules, the swelling pressure was 6.40 kPa for Tizi soil samples, where as the values of swelling pressure for composite samples at 3, 6, 9, and 12% are 6 kPa, 5.71 kPa, 5.42 kPa, and 5.12 kPa, respectively. The swelling pressure of Tizi soil and its mixtures decrease with rubber powder content. The swelling pressure was 4.35 kPa for Tizi soil samples, where as the values of swelling pressure for powder-composite samples at 3,6,9,and 12% are 4.31 kPa, 4.28 kPa, 4.21 kPa, and 4.15 kPa, respectively.

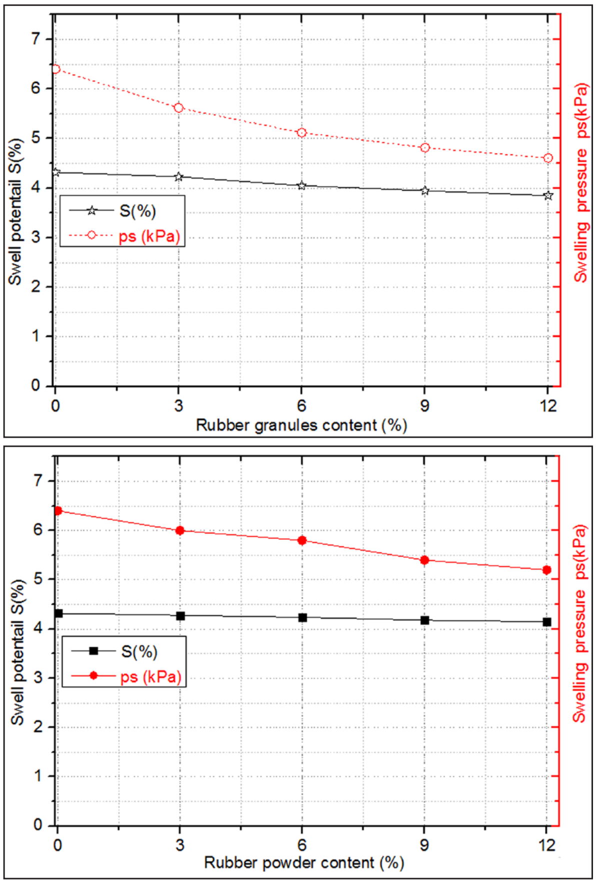

Figure 7. Effect of the rubber particles (granulated or powder) content on swell potential and swelling pressure of Tizi soil.

The swelling pressure values of Tizi soil reinforced with rubber granules were less than half those of Tizi soil reinforced with rubber powder (Ho et al., 2010). The reduction of swelling pressure for a composite sample with 12% rubber particles was about 8.5% and 13% for Tizi soil reinforced with granules and powder, respectively.

3.3 Loading–unloading tests

Due to the compressibility of the rubber particles to a greater degree and their qualitative weight being significantly lower than the specific weight of the Tizi soil (Nassim et al., 2019), a supplementary test program was performed under odometer conditions to obtain additional information on the mechanical behavior of Tizi soil and mixtures.

According to the method (AFNOR XP 94-090-1, 1997), the compression index (Cc) and the recompression Index(Cr) is determined for Tizi soil and composite samples.

3.3.1 Compression index

Figure (8) shows the compressibility indices of the Tizi soil and the mixtures reinforced with rubber granules of both types. It is known that the pressure index (Cc) is the slope of the linear part of the void pressure curve on a semi-logarithmic plot (Ming-Zhi et al., 2017; Ayeldeen and Kitazume, 2017). The Cc values are relatively small because the reshaped Cc has always been smaller than the non-isolated Cc.

The values vary from 0.22 to 0.28 for the Tizi soil that has been reinforced with rubber granules and its mixture and from 0.231 to 0.25 for Tizi soil reinforced with rubber powder and its mixtures. For the Tizi soil, Cc gradually increases with rubber particle content. This is what was found in the references (Soltani-Jigheh, 2016; Dang and Khabbaz, 2019).

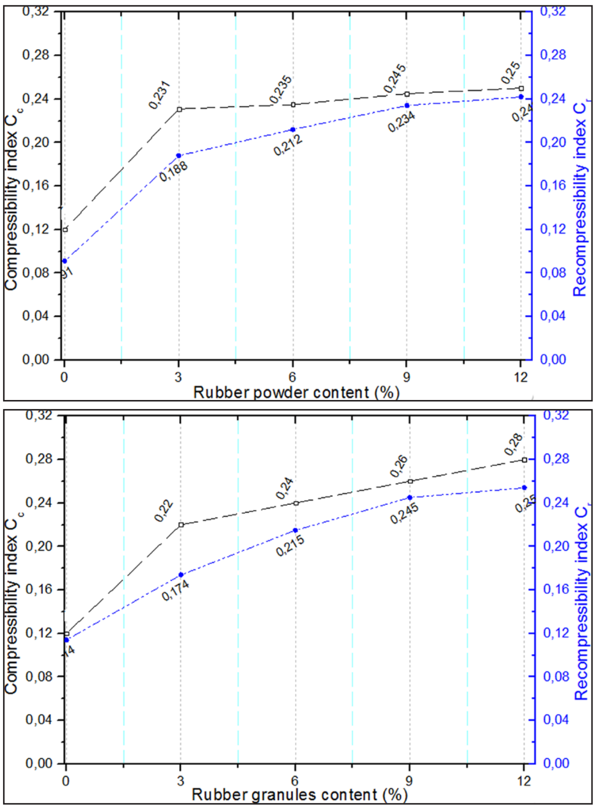

Figure 8. Effect of the rubber particles (granulated or powder) content on compression and recompression index of Tizi soils.

3.3.2 Recompression index

The Swell recompression has been calculated in this work as the decompression index Cr. The values of the swell recompression are generally about five times smaller than the compressibility (Prabakar and Sridhar, 2002; Liu et al., 2019). For all examined samples, Cr is approximately three to four times smaller than Cc, and it rises with rubber particle content.

As it is shown in Figure (8), the values of Cr range from 0.0912 to 0.245 for the Tizi soil reinforced with rubber powder and its mixtures and from 0.0912 to 0.255 for the Tizi soil reinforced with rubber granules and its mixtures. The results of the present study also match the findings of the research conducted by Wu et al., (2022).

4. Conclusion

This investigation leads to the following findings:

- Mixing expansive Tizi soil samples with rubber particles (granules or powder) reduces heave and swelling pressure.
- Adding rubber particles (granules or powder) to swelling Tizi soil increases resistance to swelling due to contact fibers with the soil.
- The reduction in swelling potential at 3% rubber content is approximately 3.88% and 4.52% for low plasticity Tizi soil compared to high plasticity Tizi. For rubber particle contents of 6, 9, and 12%, the reduction is approximately the same for both rubber particles (granules and powder).
- As the rubber absorbs around 4% of the water as a percentage of its weight, the composite samples reach the final height in less time than the Tizi soil samples alone.
- Compression and decompression indices increase progressively with the rubber particle content of both particles (granules and powder). They exceed twice as much as 12% of the rubber particle content.
- Rubber particles, whether in granular or powder form, significantly reduce the probability of swelling and blistering of the tuff soil.
- The use of rubber waste, either powder or granules, as a stabilizing material result in a low-cost stabilization method and considerably reduces the problem of disposing of used tires.
- The current study focuses on the use of rubber waste as an additive to improve soil properties. The recycling of used tires would reduce the volume of solid waste redirected into a material that is useful for preserving the environment.

Data availability statement

The data that support the findings of this study are not available but can be provided upon reasonable request.

Conflicts of interest

The authors declare no conflict of interest.

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References

Akbarimehr, D., Hosseini, S.M. (2022). Elasto-plastic characteristics of the clay soil mixed with rubber waste using cyclic triaxial test results. Arabian Journal of Geosciences 15, 1280.

Akbarimehr, D., Eslami, A., Aflaki, E. (2020). Geotechnical behavior of clay soil mixed with rubber waste.Journal of Cleaner Production 271: 122632.

Akbarimehr, D., Aflaki, E. (2018). An experimental study on the effectof tire powder on the geotechnical properties of clay soils. Civil Engineering Journal 4(3): 594- 601, DOI: 10.28991/cej-0309118.

Anvari, S.M., Shooshpasha, I., Kutanaei, S.S. (2017). Effect of granulated rubber on shear 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.

Ayeldeen, M., Kitazume, M. (2017). Using fiber and liquid polymer to improve the behavior of cement-stabilizeds of clay. Geotextiles and Geo-membranes 45(6): 592–602.

Amakye, S.Y.O., Abbey,S.J., Booth,C.A., Oti,J. (2022). Road pavement thickness and construction depth optimization using treated and untreated artificially-synthesized expansive road subgrade materials with varying plasticity index. Materials 15: 2773.

Akbulut, S., Arasan, S., Kalkan, E. (2007). Modification of clayey soils using scrap tire rubber and synthetic fibers. Applied Clay Science 38(2): 23–32.

Al-Mukhtar, M., Lasledj, A., Alcover, J.F. (2010). Behavior and mineralogy changes in lime-treated expansive soilat20°C. Applied Clay Science 50(2): 191-198.

Al Dwairi, RA., Al Saqarat, B., Shaqour, F., Sarireh, M. (2018). Characterization of Jordanian Volcanic Tuff and its Potential Use as Lightweight Aggregate. Jordan Journal of Earth and Environmental Sciences 9(2): 127 – 133.

Ayala, S., Castaño, V. (2017). Expansion reduction of clayey soils through surcharge application and lime treatment. Case Studies in Construction Materials 7: 102-109.

Balegh, B., Sellaf, H. (2022). Treatment of leachate of landfills using filters of ceramic waste and scrap rubber waste. Water, Air, & Soil Pollution 233 (12).

Dang, L.C., Khabbaz, H. (2019). Experimental Investigation on the Compaction and Compressible Properties of Expansive Soil Reinforced with Bagasse Fiber and Lime. In: McCartney, J., Hoyos, L.(eds) Recent Advancements on Expansive Soils. GeoMEast 2018. Sustainable Civil Infrastructures. Springer, Cham. https://doi.org/10.1007/978-3-030-01914-36

Ekincia, A., Vaz Ferreira, P. M., Rezaeianc, M. (2022). The mechanical behavior of compactedLambeth-group clays without fiber reinforcement. Geotextiles and Geomembranes 50: 1-19.

Goual, I., Goual, M.S., Gueddouda, M.K., & Ferhat, A. (2008). Effect of treatment with lime and cement on the mechanical behavior of calcareous tuffs: For use in pavement layers in the region of Laghouat – Algeria. International Conference on Construction and Building Technology-A- (10), 101–112.

Goual, I., Goual, M.S., Taibi, S., & Abou-Bekr, N. (2011). The behavior of unsaturated tuff- limestones and mixture on drying–wetting and triaxial paths. Geo-mechanics and Engineering, 3,267–284.

Ho, M.H., Chan, C.M., Bakar, I. (2010). One Dimensional Compressibility Characteristics of Clay Stabilised with Cement-Rubber Chips. International Journal of Sustainable Construction Engineering & Technology 1(2): 91-104.

Jaramillo, N.A.D., Dos Santos Ferreira, J.W., Malko, J.A.C. et al. (2022). Mechanical behavior of clayey soil reinforced with recycled tire rubber using chips and fibers. Geotechnical and Geological Engineering 40, 3365–3378. https://doi.org/10.1007/s10706-022-02101-0.

Kang, G., Tsuchida, T., Tang, T.X., Kalim, T.P. (2017). Consistency measurements of cement-treated marine clay using fall conetes tand Casagrande liquid limit test. Soils and Foundations 57: 802-814.

López-Lara, T., Hernández-Zaragoza, J., Horta-Rangel, J., Rojas-González, E., López- Liu, Y., Chang, CW., Namdar, A., She, Y., Lin, CH., Yuan, X., Yang, Q. (2019). Stabilization of expansive soil using cementing material from ricehuskashand calcium carbide residue. Construction and building materials 221: 1-11, https://doi.org/10.1016/j.conbuildmat.2019.05.157.

Loualbia, H., Sebaibi, Y., Duc, M. Goual, I. (2016). Effect of different drying methods on the mechanical behavior and the microstructure of an Algerian compacted limestone crust. Journal of Adhesion Science and Technology 3: 1045-1060.
Mistry, MK., Shukla, SJ., Solanki, C.H. (2021). Environmental Science and Pollution. Reuse of waste tyre products as a soil reinforcing material: a critical review. Environmental Science and Pollution Research 28: 24940–24971, https://doi.org/10.1007/s11356-021-13522-4.

Ming-Zhi, Z., Qiang, L., Ming, W. (2017). Evaluation for intrinsic compressibility of reconstituted clay using liquid limit,initial water content and plasticity index. European Journal of Environmental and Civil Engineering 1: 1-19.

Mlhem, M. (2023). Chemical Effect on Soil Strength by adding Lime and Natural Pozzolana. Jordan Journal of Earth & Environmental Sciences 14 (1): 70-74.

Nassim, A., Mumtaz, W.,Fazal-e-Jalal., De Backer, H. (2019). Stabilization of expansive soil using tire rubber powder and cement kiln dust. Soil Mechanics and Foundation Engineering 56: 54–58.

NF P 94-051, Sols: Reconnaissance et Essais – Détermination des limites d'Atterberg – Limite de liquidité à la coupelle – limite de plasticité au rouleau. Association Française de Normalisation.

NF P 94-054, Sols: Reconnaissances et essais, Détermination de la masse volumique des particules solides des sols, Méthode du pycnomètre à eau. Association Française de Normalisation.

NF P 94-056, Sols: Reconnaissances et essais, Analyse granulométrique, Méthode de tamisage à sec après lavage. Association Française de Normalisation.

NF P 94-057, Sols: Reconnaissances et essais, Analyse granulométrique des sols, Méthode par sédimentation. Association Française de Normalisation.

NF P 94-068, Sols : Reconnaissance et essais, Mesure de la capacité d'adsorption de bleu de méthylène d'un sol ou d'un matériau rocheux, Détermination de la valeur de bleu de méthylène d'un sol ou d'un matériau rocheux par l'essai à la tache. Association Française de Normalisation.

NF EN 1744, Essais visant à déterminer les propriétés chimiques des granulats. Association Française de Normalisation.

NF P94-093: Soils: recognition and tests – Determination of the compaction references of a material

Normal Proctor test – Modified Proctor test. October 2014.

Odari, N., Crispino, M., Toraldo, E. (2021). Laboratory investigation on using recycled materials in bituminous mixtures for dense-graded wearing course Claudia. Case Studies in Construction Materials 15.

Pan, Q., Zheng, J. (2020). Mechanical calculation method and analysis of asphalt pavement considering different modulus in tension and compression. China Civil Engineering Journal 53 (1): 111-117.

Prabakar, J., Sridhar, R.S. (2002). Effect of random inclusion of sisal fiber on strength behavior of soil. Construction and Building Materials 16: 123–131.

Sarireh, M., Ghrair, A.M., Alsaqoor, S., Alahmer, A. (2021). Evaluation of the Use of Volcanic Tuff in concrete block production. Jordan Journal of Earth & Environmental Sciences, 12 (4): 275-284.

Seda, J.H., Lee, J.C., Carraro, J.A.H. (2007). Beneficial Use of Waste Tire Rubber for Swelling

Potential Mitigation in Expansive Soils. Publication: Soil Improvement, https://doi.org/10.1061/40916(235)5.

Sellaf, H., Trouzine, H., Hamhami, M., Asron, (2014). Geotechnical properties of rubber tires and sediments mixtures. Engineering, Technology & Applied Science Research 4(2): 618–624.

Soltani-Jigheh, H. (2016). Compressibility and shearing behavior of clayey soil reinforced by plastic waste. International Journal of Civil Engineering 14: 479–489.

Wu, M., Liu, F., Li, Z., Bu, G. (2022). Micromechanics of granulated rubber–soil mixtures as a cost- effective substitute for geotechnical fillings. Mechanics of Advanced Materials and Structures 30(13): 2701-2717, DOI: 10.1080/15376494.2022.2062628.

Xiaobing , G., Zumei , Z., Mengyan , Z. (2022). A multi-sphere DE-FE method for traveling analysis of an off-road pneumatic tire on irregular gravel terrain. Engineering Analysis with Boundary Elements 139: 293-312. AFNOR. (1995). XP P 94-091, Sols: Reconnaissances et essais, Essai de gonflement à l'odomètre. Détermination des déformations par chargement de plusieurs éprouvettes. Association Française de Normalisation.

AFNOR. (1997). XP P 94-090-1, Sols: reconnaissance et essais. Essai œdométrique, Partie 1 : Essai de compressibilité sur matériaux fins quasi saturés avec chargement par

paliers: 23p.