

Treatment and improvement of clay soils by adding waste rubber in arid regions

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Abstract:

Introduction/purpose: This study examines the effect of waste rubber granules on the geotechnical properties of clay soils in arid regions. The

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findings are of practical relevance to construction, foundation engineering, and environmental sustainability, as the incorporation of recycled rubber can enhance soil performance while mitigating ecological impacts.

Methods: To evaluate this potential, a series of laboratory experiments was conducted on clay samples blended with varying proportions of waste rubber granules (0%, 5%, 10%, 15%, 20%, and 25%). The mixture samples were prepared in arid area conditions. To ensure a more uniform distribution of particles in the mixtures, the selected samples with varying compositions were subjected to a hydraulic device.

Results: The results demonstrate a clear trend of decreasing liquid limit, swell potential, and swelling pressure as the rubber granules content increases. The cohesion improves with the incorporation of rubber granules. The stress–strain curves obtained from unconfined compressive strength (UCS) tests indicated that the addition of rubber granules enhanced the UCS of the soil.

Conclusion: These results emphasize the positive impact of waste rubber granules in enhancing the mechanical properties of the specimens. The incorporation of rubber granules significantly alters the physical structure of clay soil and helps mitigate both swelling potential and compaction. The pressure, recompression indices, and unconfined compressive strength (UCS) of the samples rise proportionally with the increase in rubber content, contrary to the fact that cohesion decreases as the proportion of waste tire rubber increases.

Key words: clay, waste rubber, swelling behavior, compressibility, compressive strength, arid region.

Introduction

In Algeria, arid zones account for almost 95% of the national territory, with around 80% classified as hyper-arid (Halitim, 1988). Many regions have reported problems associated with soil swelling, prompting extensive research on this phenomenon (Hadji et al., 2014). Several stabilization techniques have been investigated and applied, leading to a notable reduction in the swelling potential of problematic soils. The swelling–shrinkage phenomenon generally occurs in arid regions, where extended droughts are interrupted by short periods of rainfall, and it is also prevalent in Mediterranean climates.

In most cases, buildings cannot withstand these soil movements without sustaining damage, leading to the formation of cracks that may reach several centimeters in width, distorting doors and windows, detaching adjacent buildings from each other, and even breaking buried pipes. These disorders can also affect exterior landscaping (Xu et al., 2022).



Additionally, used tyres are inconvenient and harmful. By size, age, wear, and face shape, they comprise a diverse population. The primary materials of the waste tires are steel, silicon, carbon dioxide, and synthetic rubber. Every year, Algeria produces more than 26,000 tons of trash tires (Trouzine et al., 2012). Landfills are the places where used tires can be disposed of. In the field of civil engineering, various methods exist for recycling tires for use as decorative features and retaining walls (Sellaf et al., 2018; Hajoui et al., 2024; Raj et al., 2024; Shukla et al., 2024).

Balegh et al. (2024) investigated the mixing of two types of tire shavings with compressive soil. Their findings showed that the fluidity limit, swelling time, and swelling potential gradually decreased as the proportion of rubber particles in the samples increased. This reduction is particularly notable in soils with medium swelling potential, as the high compressibility of rubber particles leads to a marked increase in both compaction and decompression indices with rising rubber particle content. Moreover, investigating the effect of waste rubber on geotechnical and mechanical performance of clay can play a significant role in geotechnical projects (Akbarimehr et al., 2021).

This research focused on the effect of rubber granules on the behavior of clay soil in the regions. It proposes a method for improving these local materials, including clay soil, by adding rubber granules for use in building projects. In this study, Atterberg limit, swelling consolidation, load discharge, Compression and recompression index, direct shear, and unconfined compression strength tests were combined to investigate the behavior of clay soils mixed with waste rubber granules.

Experimental study

The soil and rubber granules

The physical characteristics of a clay soil from the desert area of the south-western Algerian province of Adrar were examined. In accordance with AFNOR-approved standard procedures, this soil underwent several laboratory tests to ascertain its physical characteristics (NF P 94-068; NF P 94-057; NF 94-056; NF P 94-054; and NF P 94-051). The clay soil utilized in the experiment is depicted in Figure 1.

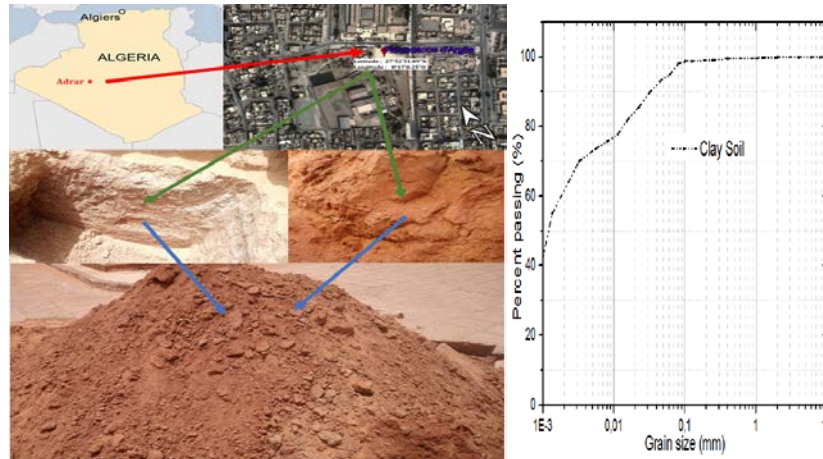


Figure 1 – Grainsize distributions for clay soil

Table 1 summarizes the geotechnical properties of the clay soil, providing a detailed description of its main characteristics. The soil is distinguished by a relatively high liquid limit (40%) and a plasticity index of 20%, with a specific gravity (G_s) of 2.45. Based on the Unified Soil Classification System (USCS), the soil is categorized as high-plasticity clay (CH). Additionally, the chemical composition of the clay was determined using wavelength-dispersive X-ray spectroscopy, in accordance with the NF EN 1744-1 standard, and the results are presented in Table 2.

Table 1 – Properties of the clay soil

Properties	Properties	Units	Clay soil
Consistency limits : NF: 94051	Liquid limit,	[%]	40
	Plastic limit,	[%]	20
	Plasticity index,	[%]	20
Specific weight NF: P 94-054	Specific weight		2.45
Grains sizes analysis NF: P 94-057	Sand,	[%]	10
	Silt,	[%]	31.33
	Clay,	[%]	58.67
	Maximum dry density	g/cm ³	1.92
Compaction NF P 94-093	Volume of blue VB	(cm ³)	20.5
	Specific surface SST	(m ² /g)	430.5

Table 2 – Chemical composition of clay

Component	Clay
SiO ₂ ,[%]	60.65
Al ₂ O ₃ ,[%]	19.35
Fe ₂ O ₃ ,[%]	0.95
CaO ,[%]	5.05
MgO ,[%]	0.30
NaOH ,[%]	0.30
Cl ,[%]	1.40
SiO ₃ ,[%]	1.5
P.F2 ,[%]	9.5

Rubber fibers can be obtained from used tires through the process of grinding the rubber with a friction machine. Then the rubber crumbs resulting from the process are collected and sifted through a two-mm sieve. Tire rubber is composed of a complex mixture of elastomers, mainly styrene-butadiene, polyisoprene, and polybutadiene. In addition to these polymers, tires contain several key additives, including stearic acid (1.2%), zinc oxide (1.9%), and extension oil (1.9%), as well as a significant proportion of carbon black (31.0%) (Balegh et al., 2023; Sellaf et al., 2022). In Figure 2, a rubber granules sample from a used tire is illustrated.



Figure 2 – Clay soil and rubber granules

Mixture design

Preparation of clay soil-rubber content mixtures

Because temperature can influence the properties of rubber, the water content of the samples was measured after they were dried at 35 ± 5 °C. Based on relevant studies on rubber-reinforced clays, the proportions of rubber commonly investigated are 1%, 2%, 3%, 4%, and 5% of the total weight of the reinforced samples (Akbulut et al., 2007). In all the referenced studies, fibres and either lime or cement were mixed with soils. Bekhiti et al. (2020) investigated mixtures made with dune sand, in which rubber powder and lime were used as partial replacements. To examine the effect of these additives, rubber content was incorporated at proportions ranging from 8% to 20% in increments of 4%, while lime was added at levels between 2% and 5% in increments of 1%. All percentages were calculated relative to the dry weight of the mixture. Since the fibers tended to clump together, considerable effort and time were required to achieve a uniform distribution within the mixtures.

The rubber mixture, composed of 0, 5, 10, 15, 20, and 25% rubber granules of the sample weight, was prepared after the clay and arid area samples have been prepared and oven-dried at 105 degrees Celsius.

To ensure a more uniform distribution of particles in the mixtures, selected samples with varying compositions were subjected to a hydraulic device that applied an additional load of approximately 1 kPa. The samples were then covered with plastic sheets to reduce water loss.

Experimental results and discussion

Consistency limits

Atterberg limit tests were carried out in accordance with the AFNOR NF P 94-051 standard to determine the consistency limits of the clay soils and their mixtures.

Liquid limit

Figure 3 presents the influence of rubber content on the consistency limits of clay and its mixtures. The results indicate a steady decline in the liquid limit as the proportion of rubber increases. However, the rate of reduction remains relatively consistent across all mixtures, varying between 3% and 5%.

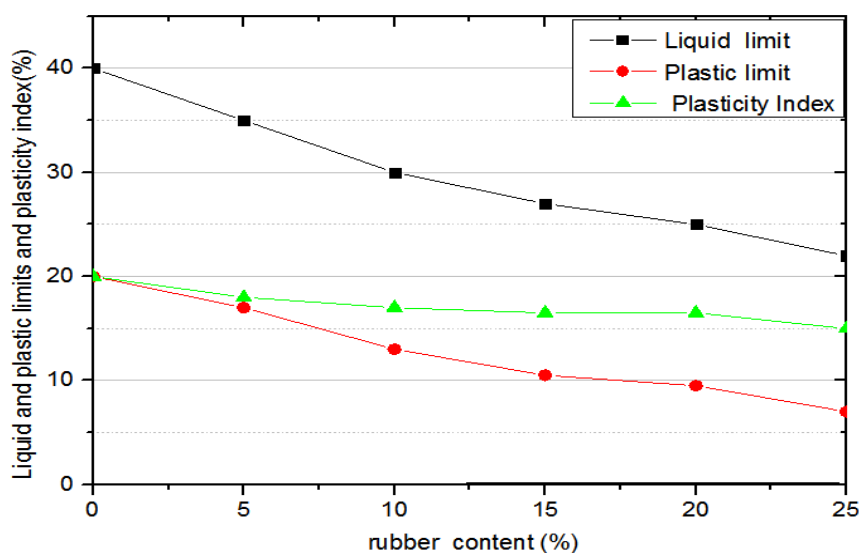


Figure 3 – Effect of rubber content on the consistency limits of clay soil

Plastic limit

For clay soils, the plasticity limit of samples incorporating 5% rubber granules shows an initial decrease, followed by a gradual increase, with only minor reductions ranging from 1% to 2%. The variations observed in the consistency limits of these mixtures can be explained by factors such as the type of mixture (Bell, 1993), cation exchange capacity, and the relative proportion of clay minerals present (Schmitz et al., 2004). Notably, Cetin et al. (2006) found that in clay soils with superficial cohesion, the plasticity limit initially remains nearly constant, then decreases slightly, before stabilizing once more. These trends align with the behavior typically observed in fine-grained cohesive soils of medium plasticity (Cetin et al., 2006).

Swell-consolidation tests

Consolidation and swelling tests were performed on all compacted samples in accordance with the AFNOR XP 94-91 standard. The composite specimens, prepared following the specified procedure, were evaluated using a standard oedometer. The initial void ratio (E) differed from one sample to another. Each specimen was assembled in five layers, each 4 mm thick, and carefully compacted within the oedometer cell.

For the second sample, the additional cost was set at 0.2 times lower than that of the first sample. After reaching the final height (ΔH), the specimen was subjected to further vertical loading until the initial void ratio (e) was restored. The swelling potential ($S\%$) and swelling pressure (P_s) were then determined for both the natural soil and its mixtures. The swelling potential is defined as the ratio of the increase in sample thickness during immersion (ΔH) to its original thickness (H).

Swell potential

Figure 4 illustrates the evolution of swelling potential ($S\%$) over time for clay soil samples stabilized with varying proportions of waste rubber granules (0, 5, 10, 15, 20, and 25% by weight). The results indicate that untreated clay soil reaches a swelling potential of 4.25% after 26 days, whereas soil reinforced with 5% rubber exhibits a swelling potential of 4.05% after 28 days. For the reinforced samples, the ultimate swelling potential decreases progressively with increasing rubber content, with stabilization occurring over a similar period for the 5% mixture and within shorter durations for mixtures containing 10%, 15%, and 25% rubber.

All samples were prepared with a water content of 20%, while the rubber itself is capable of absorbing up to 4% of its weight. Consequently, the initial water-to-clay ratios were approximately 0.12, 0.25, 0.37, 0.50, and 0.62 for mixtures containing 0%, 5%, 10%, 15%, and 25% scrap tire rubber, respectively. These variations in water-to-clay ratio may explain the reduced time required to reach maximum heave.

Swelling pressure

Figures 4 and 5 present the swelling pressure values of the studied specimens. The swelling pressure (p_s) decreases with increasing waste rubber granules content. For soil A, the swelling pressure of the untreated soil was 75 kPa. For the composite samples containing 10%, 15%, 20%, and 25% rubber, the values decreased to 71 kPa, 65 kPa, 48 kPa, and 38 kPa, respectively.

Several researchers, including Du et al. (2020), Hu et al. (2019), and Odriozola and Aguilar (2005), have concluded that the physicochemical nature of expansive soils is highly complex, controlling the swelling process, swelling behavior, and soil-water interaction mechanisms.

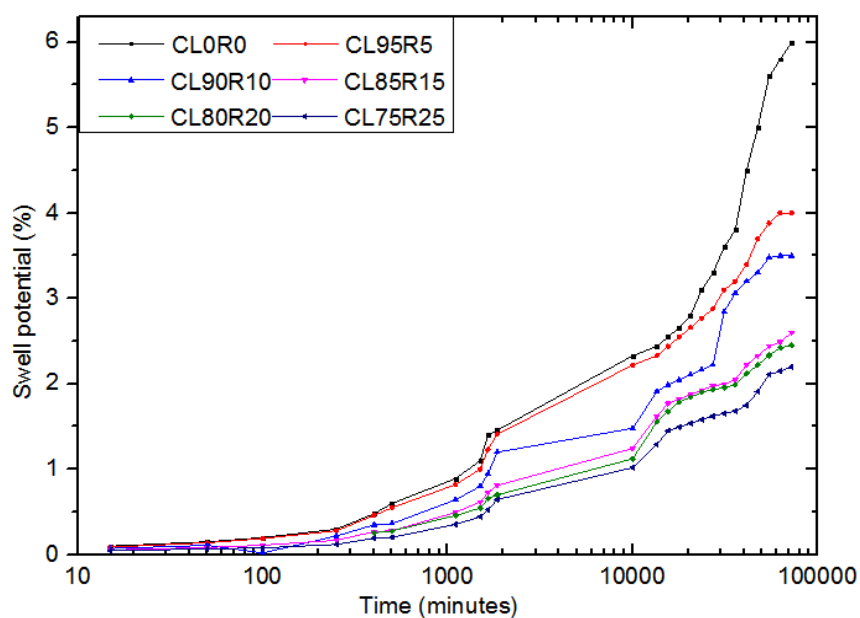


Figure 4 – Effect of the rubber content on the swell potential of clay soil

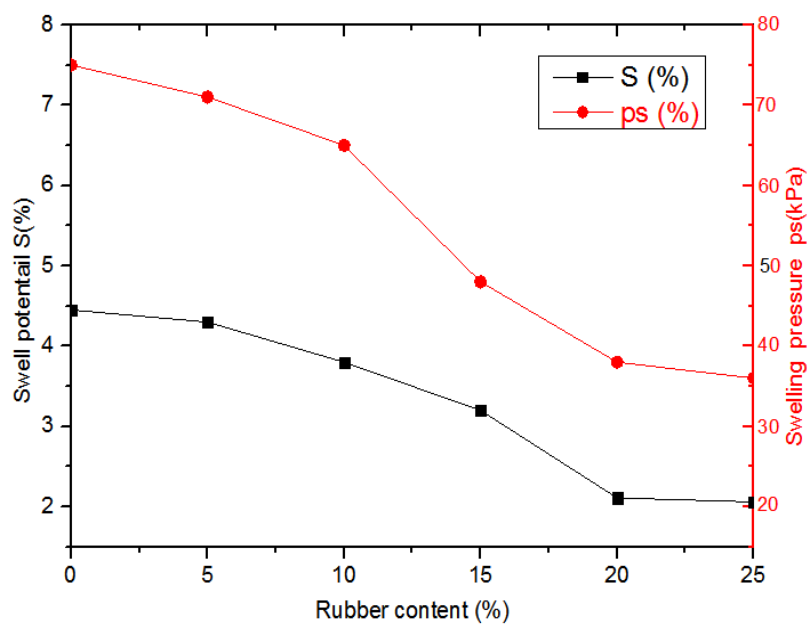


Figure 5 – Effect of the rubber content on swell potential and swelling pressure of clay soil

Loading–unloading tests

The mechanical behavior of clay soils was assessed by analyzing the compression index (C_c) and the recompression index (C_r) for mixtures containing different proportions of waste rubber granules, in accordance with the AFNOR XP P 94-090-1 standard.

Compression index

The pressure coefficient " C_c " is the slope of the linear portion of the pressure void ratio curve. Figure 6 shows the difference in compressive modulus as a function of the rubber content.

The minimum value of the coefficient of compression " C_c " varies from 0.22 for the sample clay soil composed of 0% rubber content, in contrast to the maximum value of 0.44 for the sample clay soil composed of 25% rubber content. The values of the compression coefficient " C_c " of the samples increase with the increase in the rubber content from 20 to 35%, as this gave results for coefficients of " C_c " ranging from 0.24 to 0.31, 0.38, 0.42 to 0.44.

Recompression index

The recompression index (swelling) is the indicator resulting from the release of loads or the removal of pressure. It is a measure used to study the compression and recompression of soils, particularly those with exceptionally high compressibility. In this study, we refer to it as the C_r factor.

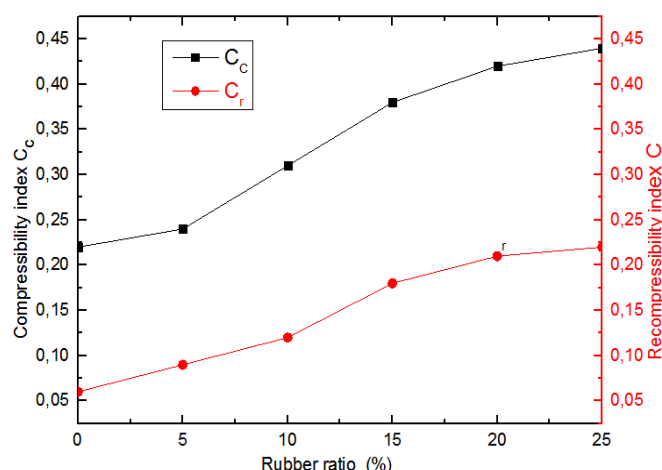


Figure 6 – Effect of the rubber content on compression and recompression indices of clay soil

The curves shown in Figure 6 illustrate the relationship between the C_r factor of compression and the rubber content. In general, C_r factor values are around five times lower than the C_c factor (Bardet, 1997). For all samples tested, C_r factor values are around 3 or 3.5 times lower than the C_c modulus values, and increase with increasing rubber content. C_r factor values range from 0.06 to 0.22. C_r factor values for samples supported with rubber increased from 30% to 42%. Previous studies have shown a relationship between the physical properties of expansive soil (liquid limit and initial void ratio) and the C_r recompression factor (Kordnaei et al., 2015).

Direct Shear Tests (DST)

To assess the soil's shear properties, direct shear tests (DST) were conducted in the laboratory, including the determination of the point of elasticity and cohesion (C), as well as the soil's angle of internal friction (ϕ). These properties were examined under various soil humidity and dry bulk density conditions, in accordance with French standard NF P 94-071-1.

All soil samples containing varying proportions of rubber were subjected to these tests. The specimens were prepared in accordance with the procedure outlined in paragraph two to ensure homogeneous mixing. The shear test results are illustrated in Figures 7 and 8.

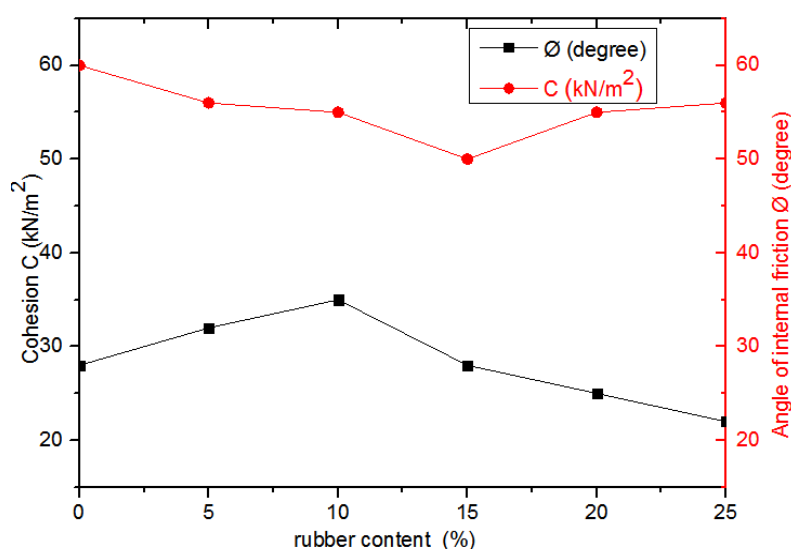


Figure 7 – Effect of rubber content on cohesion and angle of internal friction of the clay soil

The data show that cohesion improves with the incorporation of rubber granules, reaching maximum value in samples containing 10% rubber with 90% clay, after which it decreased as the rubber content increased. This indicates an optimal mixture composition of the mixture (90% clay and 10% rubber). The influence of material shape on elastic modulus and shear strength is well documented. Due to the variable contact surface of rubber grains depending on the shape of the material, elastic modulus and shear strength, like other factors, are naturally influenced by shape. Similar observations regarding the influence of shape on the modulus of elasticity and shear strength have been reported in previous studies, notably by Islami et al. (2024) and Haq et al. (2024). The internal friction angle exhibits irregular variations depending on the amount of tire rubber granules (TRP) added.

These observations from Figure 7 indicate that the cohesion values and friction angle do not exhibit direct proportionality to the quantity of clay soil added to the mixtures. This lack of direct proportionality suggests that there is an anomaly or non-linear behavior in the relationship between rubber content and these shear properties.

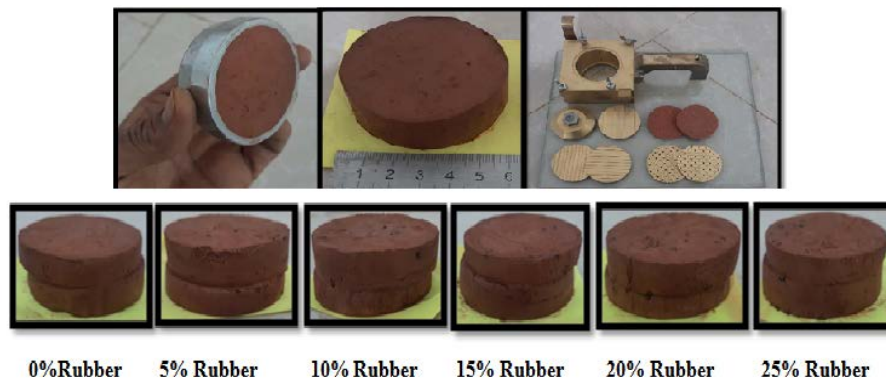


Figure 8 – Clay samples with different rubber content

Unconfined compression strength

Compressive strength tests were conducted in an open environment on soil samples containing varying amounts of rubber. Each test was performed on three cylindrical specimens with dimensions of 80 mm in diameter and 160 mm in height. After their initial weight was recorded, the specimens were placed in sealed bags and stored in the laboratory at a controlled temperature of 22 ± 2 °C for 28 days. They were then subjected to static loading in the OPM using a double press at a constant speed of 1.14 mm/min.

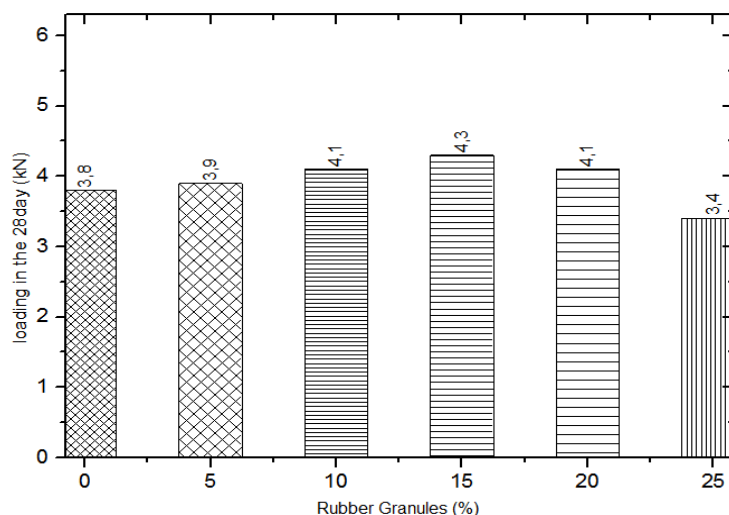


Figure 9 – Effect of rubber content on the UCS of mixtures

The results presented in Figures 9 and 10 illustrate the effect of rubber content on unconfined compressive strength (UCS) after 28 days. A distinct upward trend is observed, with UCS values increasing as the proportion of rubber granules rises. In particular, incorporating 5% to 15% rubber into clay soil samples enhances UCS by approximately 4% to 5%. These outcomes are in good agreement with the findings by Rouaiguia et al. (2020).

After adding 20 to 25 percent rubber content, the compressive strength index decreases by approximately 4 to 5 percent, which can be attributed to the inconsistent composition or mixture of the samples, as well as the lack of interaction and harmony between the rubber particles and the clay soil particles.

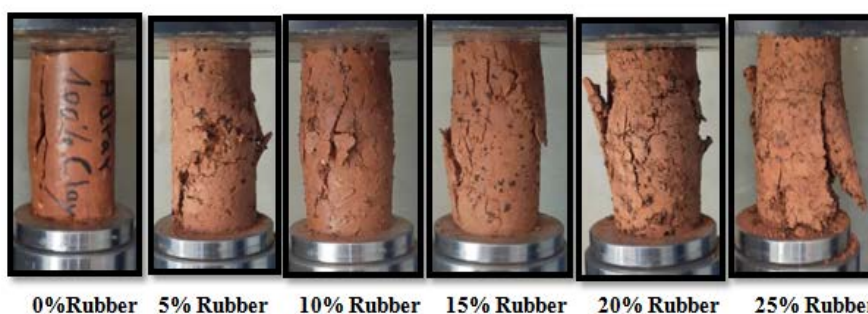


Figure 10 – Compression test on cylindrical specimens (50x100 mm²) of mixtures of clay and rubber content after 28 days

Conclusion

In this work, we conducted an experimental study to stabilize clay soils by adding waste rubber granules in varying percentages. The primary objective of this research was to qualitatively assess the reduction of swelling potential in clay soils with distinct swelling characteristics through the addition of waste rubber granules, using a controlled laboratory experimental setup. Waste rubber granules are a non-biodegradable material; however, when blended with soil and buried, they become shielded from major degrading factors such as light and heat. Based on this study, the following conclusions and recommendations can be drawn:

- The incorporation of rubber granules significantly alters the physical structure of clay soil, as reflected in the notable changes observed in its liquid limit and plastic limit.
- Incorporating rubber granules into expansive clay samples helps mitigate both swelling potential and compaction.
- This behavior can be explained by the substitution of expansive clay with rubber granules, combined with the resistance of rubber particles to swelling when in contact with clay minerals.
- The pressure and recompression indices rise proportionally with the increase in rubber content.

Shear test results indicate that cohesion decreases as the proportion of waste tire rubber increases, whereas the internal friction angle shows a fluctuating trend.

- The unconfined compressive strength (UCS) of the samples increased progressively with higher rubber granules content.
- The deformation values also rose with increasing rubber granules content, which can be attributed to the non-homogeneous nature of the mixture.

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Tretiranje i poboljšavanje glinovitih tla dodavanjem otpadne gume u sušnim područjima

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OBLAST: materijali, građevinarstvo

KATEGORIJA (TIP) ČLANKA: originalni naučni rad

Sažetak:

Uvod/cilj: Ovaj rad ispituje uticaj otpadnih gumenih granula na geotehnička svojstva glinovitog tla u sušnim područjima. Rezultati su od praktičnog značaja za građevinarstvo, geotehničko inženjerstvo i održivost životne sredine, budući da dodavanje reciklirane gume može poboljšati svojstva zemljišta i istovremeno ublažiti uticaj na životnu sredinu.

Metode: U cilju procene ovog potencijala sproveden je niz laboratorijskih ispitivanja na uzorcima gline sa različitim udelima otpadnih gumenih granula (0%, 5%, 10%, 15%, 20% i 25%). Mešani uzorci pripremljeni su u uslovima sušnog područja. Kako bi čestice u smešama bile ravnomernije raspoređene, odabrani uzorci različitog sastava podvrgnuti su delovanju hidrauličkog uređaja.

Rezultati: Rezultati pokazuju jasan trend smanjenja granice tečenja, potencijala bubrenja i pritiska bubrenja sa povećanjem sadržaja gumenih granula. Kohezija se povećava dodatkom gumenih granula. Krive napon–deformacija dobijene ispitivanjima jednoaksijalne čvrstoće pri pritisku pokazale su da dodavanje gumenih granula povećava jednoaksijalnu čvrstoću tla pri pritisku.

Zaključak: Ovi rezultati naglašavaju pozitivan uticaj otpadnih gumenih granula na poboljšanje mehaničkih svojstava uzoraka. Ugradnja gumenih granula značajno menja fizičku strukturu glinovitog zemljišta i doprinosi smanjenju potencijala bubrenja i zbijanja. Pritisak, indeksi rekompresije i jednoaksijalna čvrstoća pri pritisku uzoraka povećavaju se proporcionalno sa povećanjem sadržaja gume, nasuprot činjenici da se kohezija smanjuje povećavanjem udela otpadne gume iz pneumatika.

Ključne reči: glina, otpadna guma, ponašanje pri bubrenju, stišljivost, čvrstoća pri pritisku, sušno područje.

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