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Original article

Enhancing The Engineering Characteristics of Clayey Soil with Recycled Tire Rubber Particles

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Abstract
This research examined how adding rubber granulate affected the properties of expansive soil from Shahat City, Libya. The study tested different drying techniques, curing times, and rubber concentrations (0% to 15%). For preparing samples to determine Atterberg limits and for compaction testing, air drying was deemed more suitable than oven drying. The soil's unconfined compressive strength was enhanced by the inclusion of rubber. A 2% rubber mixture produced the highest strength after a 3-day cure, while a 4% mixture was most effective after 7 and 14 days. This addition also transformed the soil's behaviour from brittle to ductile. Microscopic analysis revealed stronger cohesion between particles at the 4% rubber level. The liquid limit rose with smaller rubber amounts but fell with larger ones. The optimum moisture content increased up to 8% rubber before declining, whereas dry density consistently dropped. A numerical Plaxis analysis showed some variance from the experimental findings. Furthermore, the soil's bearing capacity was enhanced and settlement reduced as additional reinforcement layers were added, provided the vertical spacing between them was adequately small to prevent potential collapse.
Keywords. Rubber Granulate, Unconfined Compressive Strength, Scanning Electron Microscopy, Numerical Model.

Introduction

Expansive soils, commonly referred to as swelling clays, are foundation materials that undergo significant volume changes in response to fluctuations in their moisture content. These volumetric shifts pose a serious risk to structures built upon them, often leading to substantial cracking and potential structural failure. In regions like the UK, the annual cost of repairing damage caused by the shrinkage and swelling cycles of such soils is estimated to average £400 million [1]. Consequently, identifying an optimal foundation solution is a critical engineering challenge. While one potential remedy is the complete excavation and replacement of problematic soil, this approach is often prohibitively expensive and impractical. A more viable and economical alternative is soil stabilization, which involves amending the soil with non-swelling materials to improve its engineering parameters, including reducing permeability and swelling potential while enhancing shear strength [2]. Numerous stabilization techniques exist, such as chemical additives, stone columns, and controlled compaction; however, many are costly, ineffective, or require specialized resources [3]; [4]. This has driven the search for cost-effective and sustainable alternatives.

A promising solution aligns with the need to address another significant environmental issue: the global accumulation of waste rubber tires. Millions of scrap tires are discarded in landfills annually, where their low density and resistance to decomposition create substantial disposal challenges. Repurposing this waste material for geotechnical applications presents a dual opportunity to mitigate an environmental problem and enhance soil properties. Research has demonstrated that rubber granulates can effectively improve the mechanical behavior of soils [5]; [6]; [7]. This study investigates the potential of utilizing waste rubber as a cost-effective additive to stabilize weak clay soils in Libya, aiming to improve their suitability for construction.

Methodology

SOIL

The base soil material was a clay obtained from Shahat in eastern Libya. Its geotechnical properties were characterized through standard laboratory testing and are summarized in Section 3.1 (Table 1).

TABLE 1 THE PROPERTIES OF SOIL

Parameters	Value	Method
Field density(g/cm^3)	1.58	ASTM D-1556
Natural moist content (WC)%	34.75	ASTM D-2216
Liquid limit (LL)%	49.04	ASTMD-4318
Plastic limit (PL)%	21.89	ASTMD-4318
Specific gravity (G.s) %	2.87	ASTM D-854
Optimum moisture content (O.W.C) %	20.04	ASTM D-698
Max dry density (MDD)g/cm^3	1.65	ASTM D-698
USCS	CL	ASTM D-2487
Swelling index	70%	Free swell test

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RUBBER GRANULATES

The additive consisted of granulated rubber from recycled tires, which was introduced to the soil in three distinct particle sizes: 0.6 mm, 1.18 mm, and 2 mm (see Section 3.2, Figure 1).

FIGURE 1. THE SIZE OF THE RUBBER EFFECT OF RUBBER GRANULATE ON LIQUID LIMIT

Results and Discussions

Test results reveal that the liquid limit of the clay-rubber mixtures is influenced by the additive percentage. Low concentrations of rubber granulate (2%, 4%, 6%, 8%) resulted in a slight increase in the liquid limit compared to the untreated soil. A decisive reduction, however, was recorded at higher concentrations of 10% and 15%, which decreased the limit by 56.59% and 55.15%, respectively. This reduction is likely due to the non-absorbent rubber particles breaking up the soil's structure into smaller clusters that need less water to become liquid. These findings align with previous work by [8]; [9], who documented that rubber tire content lowers the liquid limit by improving soil particle bonding and decreasing water absorption.

EFFECT OF RUBBER GRANULATES ON COMPACTION CHARACTERISTICS

Figure 2 illustrates how the dry unit weight and optimum moisture content (OMC) of the soil sample were influenced by the inclusion of granulated rubber (GR) at concentrations of 0%, 2%, 4%, 6%, 8%, 10%, and 15% by weight. A consistent reduction in dry density occurred across all soil-rubber blends; mixtures with a greater proportion of rubber exhibited a lower density. This trend is a direct result of the low specific gravity and lightweight nature of the rubber granules.

The OMC was found to rise alongside the rubber content, reaching a maximum of 28.82% at an 8% GR inclusion, compared to 20.04% for the untreated soil. According to [10], this initial increase is likely caused by base exchange and coagulation reactions, which generate additional voids that require more water to fill. Beyond 8% GR, the OMC declined to 23.50% and 22.76% for the 10% and 15% mixtures, respectively. This subsequent reduction occurs because the rubber particles themselves do not absorb water, leaving only a diminishing fraction of the soil matrix to hold moisture.

EFFECT OF RUBBER GRANULATION ON UNCONFINED COMPRESSIVE STRENGTH

This segment of the research analyzed the impact of recycled tire rubber on the unconfined compressive strength (UCS) of clay soil. The investigation considered multiple curing periods (3, 7, and 14 days) and assessed the samples under both dry and saturated (wet) conditions.

Figure 2. Compaction of all samples

UCS IN 3 DAYS (DRY CASE)

The stress-strain behavior from UCS testing after a 3-day cure under dry conditions is presented in Figure 3a. The unreinforced soil achieved a peak strength (q_u) of 568.29 kN/m^2. The incorporation of 2%, 8%, and 10% rubber resulted in strengths of 783.95 kN/m^2, 664.85 kN/m^2, and 727.20 kN/m^2, respectively, with the 2% mixture showing the highest strength among the tested blends. The axial strain at failure, an indicator of ductility, was greater in the rubber-amended samples, suggesting enhanced material flexibility [11]; [7].

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UCS IN 3DAYS (WET CASE)

As shown in Figure 3b, saturated specimens displayed improved strength with a 2% GR addition, recording a value of 77.05 kN/m^2. Fluctuations in moisture content are considered the primary factor for the observed strength variations in these specimens, as higher water content typically correlates with a decrease in strength.

UCS IN 7 DAYS (DRY CASE)

The research evaluated the 7-day UCS of clay amended with granulated tire rubber under dry curing. The composite with 4% rubber content demonstrated the highest strength, followed by the 2% mixture. This finding—that peak strength is attained with 2-4% crumb rubber—aligns with earlier research [12]. Furthermore, every rubberized sample exhibited increased strain at failure compared to the pure soil, a characteristic attributed to the flexible properties of the rubber particles (see Figure 4a).

UCS IN 7 DAYS (WET CASE)

Figure 4b presents the 7-day UCS results for samples tested under saturated conditions. In this wet state, all rubber-additive blends developed lower strength than the natural soil, which had a strength of 187.35 kN/m^2. The data further indicates that samples prepared with a lower initial moisture content yielded higher strength values than those with a higher moisture content.

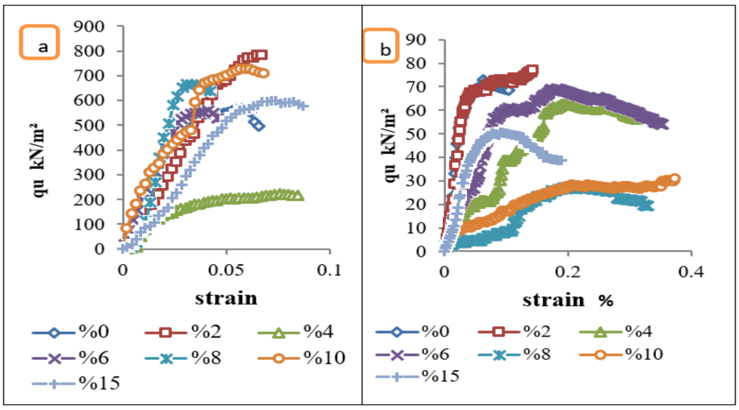

Figure 3. (a) the dry sample (b) the wet sample in 3 days

UCS IN 14 DAYS (DRY CASE)

As presented in Figure (5)(a), the addition of granulated scrap tire rubber affects the Unconfined Compressive Strength (UCS) of clay soil cured for 14 days under dry conditions. The highest strength recorded was 1137.24 kN/m^2 with a 4% rubber mix. The lowest strength resulted from **the 8% rubber mixture,** which also induced increased strain.

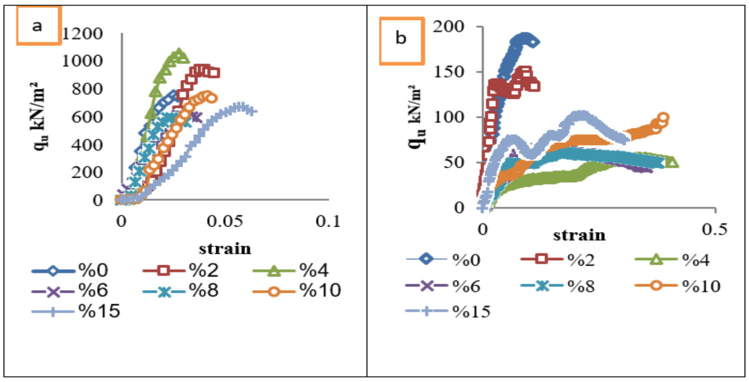

Figure 4. (a) the dry sample (b) the wet sample in 7 days

UCS IN 14 DAYS (WET CASE)

A comparison of natural soil and several soil-rubber composites is shown in (Figure 5b). The unmodified soil sample achieved the peak UCS value of 354.16 kN/m^2. Samples with lower water content (2%, 4%, 10%, and 15% rubber) all showed solid strength, with values descending from 289.50 kN/m^2 to 212.34 kN/m^2. However, composites with high water content, specifically 6% and 8%, resulted in a drastic loss of strength, yielding only 35.33 kN/m^2 and 24.08 kN/m^2.

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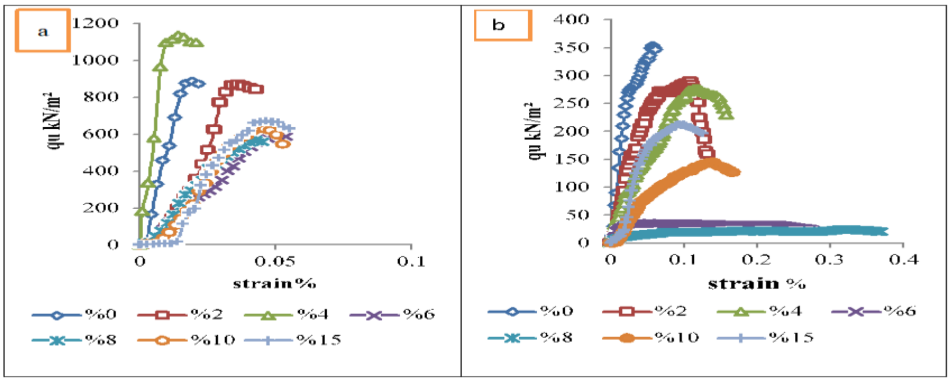

Figure 5. (a) the dry sample (b) the wet sample in 14 days

Influence Of Granulated Rubber on Mixture Failure Modes

Unconfined compression testing revealed distinct failure mechanisms between pure clay and Granulated Rubber (GR) mixtures. Specimens of pure clay experienced rapid crack initiation at low vertical strain values, culminating in complete structural failure as these fractures propagated. The incorporation of GR, however, significantly inhibited crack development. This behavior is attributed to the interfacial bond stress at the rubber-soil boundary, which impedes crack propagation. The inherent elasticity of the rubber particles is a critical factor, as they act to bridge gaps between soil particles, thereby altering and improving the overall failure mode of the composite material (see Figure 6).

Scanning Electron Microscopy (SEM) Analysis SEM micrographs of the native clay and the clay-rubber composite specimens, cured for 14 days, are presented in Figures 7a-b and 7c-d, respectively. The microstructure of the natural clay (Figures 7a-b) displayed a substantial number of inter-aggregate and intra-aggregate pores existing between and within its clay assemblages. In contrast, the micrograph of the mixture with a 4% GR inclusion (Figures 7c-d) demonstrates a notably improved interface connection between the discrete rubber particles and the surrounding clay matrix.

Figure 6. The shape of the failure of the samples

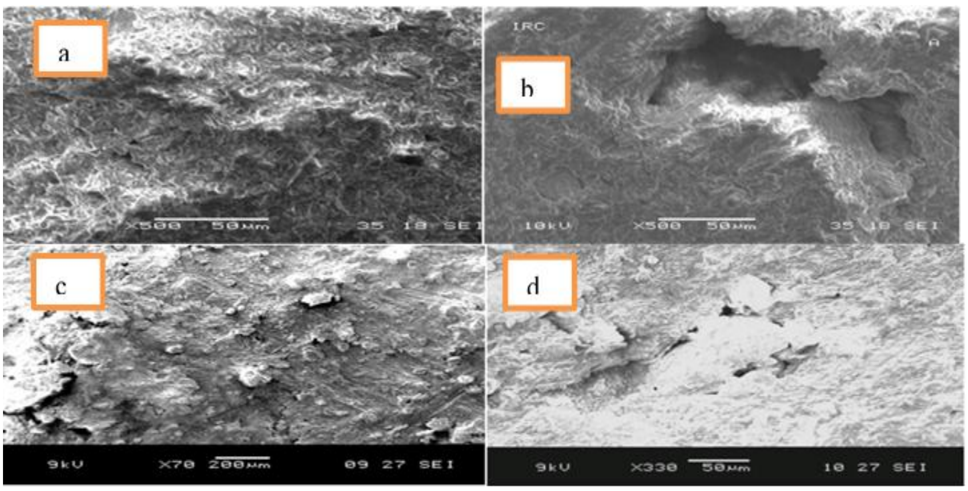

Figure 7. SEM of soil and soil with 4%GR

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Comparison of Laboratory and Numerical (2D PLAXIS) Test Results

(Figure 8 a, b) illustrates the deformation mesh for both unreinforced soil and soil reinforced with 4% rubber granules. The unreinforced soil exhibited a deformation of 2.40×10^{-3} m, while the inclusion of 4% reinforcement reduced this value to 1.90×10^{-3} m, demonstrating a clear improvement in stability.

Following the PLAXIS simulations, stress-strain curves were generated to facilitate a direct comparison between the numerical and experimental results. These curves, presented in Figure 9(a, b), compare the behavior of unreinforced soil and soil with 4% reinforcement.

A comparison of the ultimate stress values, based on the 14-day cured specimens, reveals a close alignment between the two methods. For the unreinforced soil, the laboratory test recorded a stress of 866.37 kN/m^2, compared to the PLAXIS result of 754.66 kN/m^2. For the soil with 4% reinforcement, the laboratory test value was 1090.18 kN/m^2, while the numerical analysis yielded a slightly higher value of 1204.20 kN/m^2. The minor discrepancies between the experimental and numerical results confirm that the PLAXIS model provides a reliable representation of the physical tests.

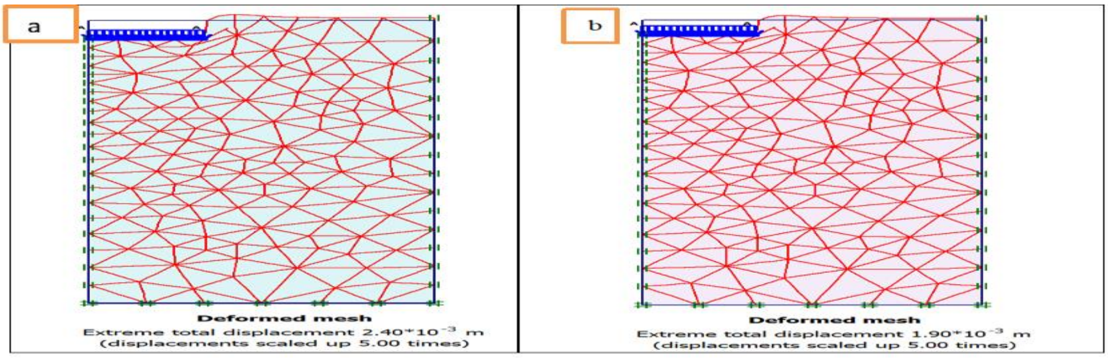

Figure 8 (a) deformation mesh of soil (b) deformation mesh of soil w. 4% GR.

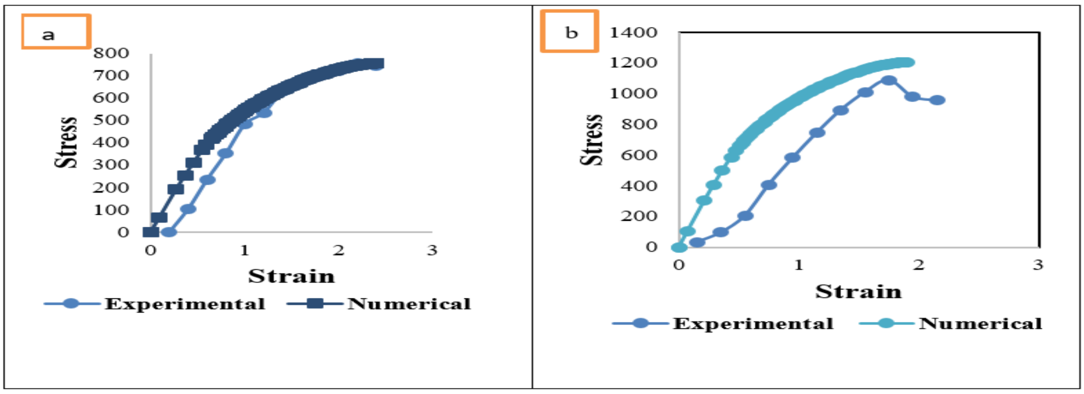

Figure 9. Compare between the experimental and numerical(a) of soil (b) of soil and 4% GR

Conclusion

This investigation confirms that amending clay soil with 4% rubber granulate significantly enhances its geotechnical properties. Improvements were observed in the Atterberg limits, compaction characteristics, and unconfined compressive strength. Scanning Electron Microscopy (SEM) revealed enhanced soil-rubber interactions, and numerical modelling confirmed a reduction in deformation. These findings collectively support the use of rubber granulate as a sustainable and economical method for soil stabilization [7].

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