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COMBINED STABILIZATION OF CLAY USING LIME AND PVC FIBERS

ABSTRACT

Reinforcing soil for foundations or embankments is crucial for ensuring structural stability and longevity. Many methods are used in Geotechnics to reinforce soils, which can be broadly categorized into chemical processes and mechanical approaches. Furthermore, reinforcing soils with fibres is an effective technique in geotechnical engineering to enhance the mechanical properties of soils, such as their strength, stiffness, and resistance to deformation. Despite significant research in this area, the stabilization of clay soils remains a dynamic and evolving field, with ongoing efforts to explore innovative materials, advanced techniques, and sustainable practices to address the challenges associated with problematic soils in construction and infrastructure development. This research aims to improve the geotechnical characteristics of very plastic clay by a combined stabilization: lime treatment at a minimum dosage and reinforcement with PVC (polyvinyl chloride)-type plastic fibres of different sizes from industrial waste. The study involves a comprehensive approach to soil stabilization by first characterizing the reference clay material, then enhancing its properties through lime pre-treatment and reinforcement with plastic waste, followed by assessing the geotechnical properties through various tests: bearing capacity, compressibility and direct shear tests. As a result, Californian Bearing Ratio (CBR) immersion tests revealed that mixtures of treated clay and PVC fibres achieve acceptable bearing capacity under low and medium compaction energies without requiring intense compaction. Furthermore, Unconsolidated undrained shear tests highlighted the short-term behavioural improvements from combining lime treatment with PVC fibres, while œdometric tests demonstrated their positive impact on the swelling and compression of plastic clays. Through this experimental study, it can be concluded that the treatment of clay with lime at minimum dosage and the reinforcement of its structure with the addition of PVC waste is an interesting technical solution for the improvement of clay soil behaviour.

Keywords: *clay, stabilization, plastic waste, lime, geotechnical properties*

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1. INTRODUCTION

Swelling soils, also known as expansive soils, present significant challenges for construction and infrastructure due to their tendency to undergo significant volume changes with moisture variations [1], [2]. These soils swell when they absorb water and shrink when they dry out, leading to substantial ground movements that can damage structures built on or within them [3], [4]. The structural damage, as well as instability and settlement problems from swelling soils, can severely impact both the integrity and functionality of buildings and infrastructure [5]. Addressing the problems associated with unstable soils requires a comprehensive understanding of soil behaviour and the implementation of appropriate stabilization and reinforcement techniques. Several stabilization techniques can be used to mitigate the effects of swelling soils and ensure the stability and durability of structures built on them. These techniques can be broadly categorized into chemical, mechanical, and structural methods, each offering unique advantages depending on the specific site conditions and project requirements [6]. By using these technical methods, engineers can significantly improve the stability and performance of soils, ensuring the safety and durability of construction projects. Stabilization techniques, while crucial for ensuring the stability and longevity of structures built on problematic soils, are not environmentally sustainable and can indeed generate additional costs [7], [5]. These costs can vary significantly depending on the type of stabilization method used, the scale of the project, and the specific site conditions. Seeking an economical stabilization solution involves a careful balance of costs and benefits, thorough planning, and strategic implementation. By leveraging locally available materials, employing efficient design and construction practices, and exploring natural and sustainable solutions, it is possible to achieve effective soil stabilization without incurring excessive costs. Tailoring the stabilization approach to the specific conditions of the site and the needs of the project ensures both economic efficiency and structural stability. Combining additives for soil stabilization is a practical approach when a single stabilizer does not achieve the desired strength improvement [8]. By leveraging the synergistic effects of different stabilizers, it is possible to enhance the geotechnical properties of clay soils economically and effectively. The study by Cai et al. [9] on clay soil treated with lime and polypropylene fibres demonstrated that the lime and fibre content, along with the curing time, significantly influence the geotechnical properties of the treated material. Recently, Yang et al. [10] investigated the treatment of silty soil using cement and polypropylene fibres, finding that the geotechnical properties of the treated soil were influenced not only by cement dosage and fibre content but also by the length of the fibres. There are very few studies in the literature examining this technique, with most existing research focusing on polypropylene fibres rather than the use of plastic waste as a reinforcing material. On the other hand, every year, the world generates approximately 330 million metric tons of plastics, with only 9% recycled and 79% ending up in landfills, which poses significant environmental and health challenges [11]. A substantial portion of plastic waste enters the ocean, creating massive pollution problems. This includes visible debris and microplastics [12], [13]. Therefore, marine life is severely affected by plastic pollution, with many species ingesting plastic or becoming entangled in it. Furthermore, Plastics in the ocean break down into microplastics, which are ingested by marine organisms [14], [15]. These organisms are then consumed by humans, introducing microplastics into the human food chain. Besides that, plastics contain harmful chemicals that can leach into food and water, posing health risks to humans. Recycling plastic waste in construction projects presents a viable solution to the growing problem of plastic pollution [16], [17]. By incorporating recycled plastic into building materials and infrastructure, we can reduce environmental impact, enhance the durability and performance of construction materials, and promote sustainable development. This approach not only addresses the urgent issue of plastic waste but also provides economic and environmental benefits [17], contributing to a more sustainable future. Given the lack of published research on the combined effects of the chemical treatment of clays and the reinforcement with plastic fibres from waste, exploring this technical solution is both necessary and promising. This study aims to valorize PVC (polyvinyl chloride) carpentry waste by using it to reinforce the structure of clay by applying a minimal dosage of lime, addressing technical, environmental, and economic considerations.

2. MATERIALS AND METHODS

2.1. MATERIALS

In this work, three essential materials were used, namely clay, PVC waste and lime.

The clay material was brought back from Guerttoufa, located in Tiaret province, Algeria (figure 1a). Its main characteristics are summarized in Table 1. According to the technical guide for road earthworks [18], the soil is classified in the category of clay and marl clay, as well as very plastic silts.

The second material was collected from PVC carpentry and then sieved to form four classes: PVC1 (1/1.6mm), PVC2 (2/2.5mm), PVC3 (2.5/3.15mm) and PVC4 (3.15/4mm). A sample of PVC2 is shown in the figure 1b.

The quicklime (figure 1c) is brought back from the Lime-Saida Factory (Saida province, Algeria).

The PVC fibres were used as reinforcement elements of clay material, while quicklime was used as a treatment agent of clay.

Figure 1. Materials used: (a) clay; (b) PVC waste 2/2,5mm; (c) quick lime (Photo by Feriel Berrahou)

Table 1. Main characteristics of Clay

Symbol	Parameter	Value
Gs (g/cm3)	Specific Gravity	2.7
% Fines	Sieve percentage at 80µm	94
WL (%)	Liquid limit	62.3
WP (%)	Plastic limit	32.9
VB	Methylene Blue Value	4.3
% CaCO3	Carbonate content	22

2.2. METHODS

In this work, two categories of tests were used: bearing capacity tests and mechanical tests. The mixtures were prepared by adding quicklime at a percentage of 1% and PVC fibres at different percentages (10, 20 and 30%). The different percentages are reported to the global mass of the sample. The addition of quicklime at a small percentage is to cut down the swelling potential of the clay while reducing the cost of treatment.

As the soil is intended to be used as a fill material, Proctor and CBR (Californian Bearing Ratio) tests [19], [20] have been carried out on the reference material (Clay) and the different mixtures containing clay, lime and PVC fibres at different percentages. Oedometric and Direct shear tests [21], [22] were also carried out on the various mixtures.

The standard Proctor test was performed to determine the Optimal Water Content (OWC) and Maximum Dry Density (MDD) of various mixtures. Samples were prepared, mixed with varying water contents, and compacted in three layers using a manual rammer. After compaction, specimens were weighed, oven-dried to remove moisture, and reweighed to calculate dry density. This process was repeated for all specimens, and the results were used to plot the compaction curve.

CBR tests were performed on each mixture under varying compaction energy levels by applying 10, 25, and 56 blows per layer. After compaction, specimens were soaked in water for 96 ± 2 hours to simulate extreme conditions and achieve saturation. The resistance to penetration was measured using a CBR press, and the corresponding CBR values were calculated to evaluate the material's strength under load.

The œdometric test evaluates soil compressibility under one-dimensional loading. A cylindrical soil specimen is placed in a rigid mould within an œdometric cell, with porous stones on top and bottom for drainage. The sample is saturated before testing. Vertical loads are applied incrementally, with each load maintained until deformation stabilizes. Vertical displacements are recorded during loading and unloading to assess soil behaviour. The results are analyzed to determine key parameters such as compression index and swelling index, providing insights into the soil's compressibility and consolidation characteristics.

The direct shear test evaluates the shear strength of soil by placing a prepared specimen in a split shear box, which allows horizontal displacement. A normal load is applied vertically to simulate overburden pressure, and a horizontal shear force is gradually applied at a controlled rate to the upper half of the box. Displacements and shear forces are recorded throughout the test, continuing until the soil fails or reaches a specified displacement. Under unconsolidated undrained test conditions, the direct shear test enables the determination of undrained cohesion (Cu), a critical parameter for assessing the short-term behaviour of soil.

3. RESULTS AND DISCUSSION

The method of Eads and Grim [23] can be used to determine the amount of lime needed to stabilize clay by identifying the point of fixation, which allows for determining the lime content that raises the pH to 12.4. This pH level indicates that enough lime has been added to stabilize the clay by ensuring the completion of pozzolanic reactions. The results are shown in Figure 2, which indicate that the lime demand for material clay is about 3%.

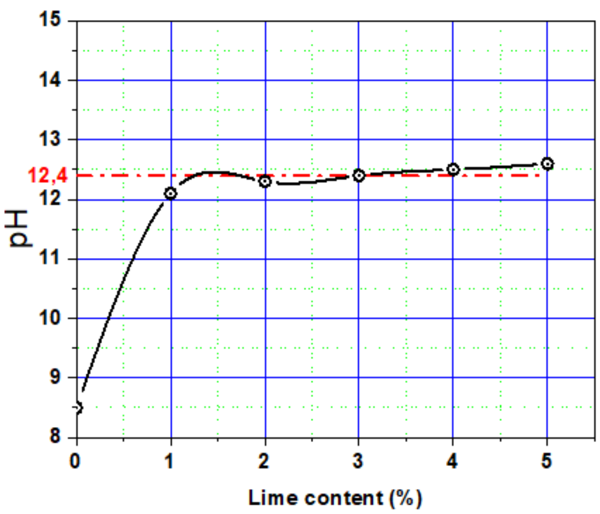

Figure 2. pH measurements for different clay and lime mixtures

Figure 3 shows the Proctor curves for natural clay and different mixtures containing 3 % lime and various PVC fibre contents. It is noted that the lime treatment and the addition of PVC waste both influence the optimal water content and the maximum dry density. Indeed, lime has a tendency to absorb water, which is why when lime is added to a mixture, the optimal water content (the amount of water needed to achieve the best compaction) increases. PVC waste, especially in the form of plastic fibres, does not absorb water. However, the presence of PVC waste still affects the mixture’s handling and compaction. The optimal water content may vary depending on the size and amount of PVC fibres added. In fact, the amount of water increases by increasing the size of PVC fibres.

On the other hand, the decrease in dry density when lime and PVC waste are added is primarily due to the increase in the mixture’s volume. The addition of lime causes flocculation and an increase in void spaces, while larger PVC fibres further contribute to this effect by adding more voids and disrupting the compactness of the mixture.

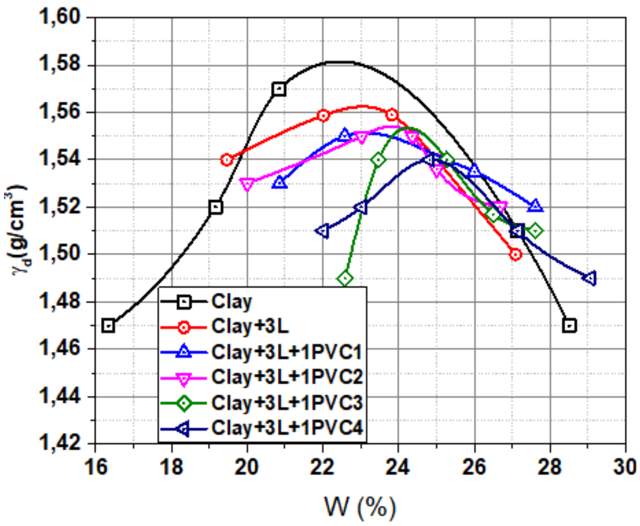

Figure 3. Proctor curves for natural clay and different mixtures

Figure 4 presents the results of soaking California Bearing Ratio (CBR) tests, which were conducted on different mixtures under varying compaction energies. These mixtures include natural clay, clay treated only with 3% lime and clay treated with 3% lime and reinforced with 1% PVC fibres of various dimensions. At low compaction energy (10 Blows/Layer), the smallest PVC fibres (1.0/1.6 mm) give the highest CBR index. These fibres likely integrate well within the clay matrix, effectively reinforcing the structure without creating excessive voids. At medium compaction energy, both the smallest (1.0/1.6 mm) and slightly larger (2.0/2.5 mm) PVC fibres produce the best CBR values. The increased compaction energy likely helps in better aligning and integrating the fibres into the clay matrix, reducing voids and enhancing the overall structural strength [24]. When the clay is treated with 3% lime and compacted at a high energy level of 56 C/C, the mixture achieves a well-organized and dense structure. Lime treatment improves the clay's strength by inducing chemical reactions that reduce plasticity and increase cohesion. This well-compacted, lime-treated clay achieves the best CBR values, indicating superior load-bearing capacity even after immersion. However, when PVC fibres are added, the high compaction energy leads to overcompaction, disorganizing the mixture and reducing its effectiveness, as evidenced by lower CBR values. It is important to note that applying moderate compaction energy can be sufficient to achieve high CBR values for clay treated with lime and reinforced with PVC fibre. This leads to the conclusion that the best combination of clay stabilization is 3% lime and 1% PVC1.

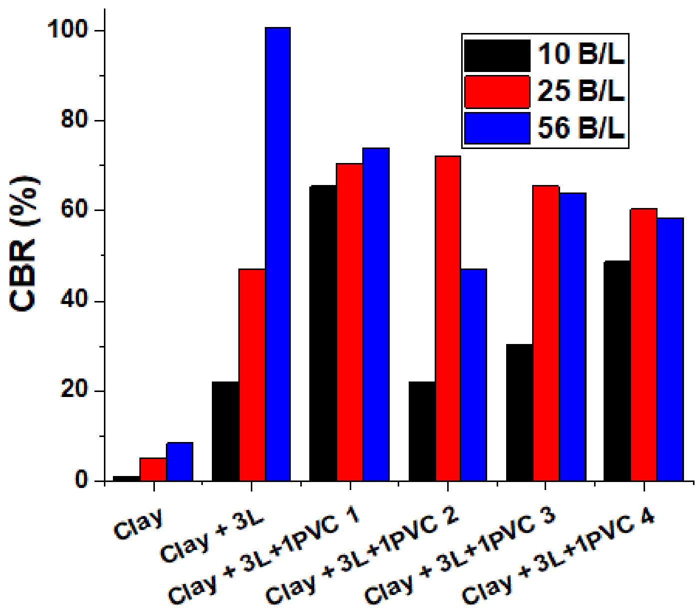

Figure 4. CBR results for the different mixtures

The results of the direct shear test in Unconsolidated Undrained (UU) conditions for clay, lime-stabilized clay, and the mixture containing PVC fibres of class 1.00/1.60 mm are presented in Figure 5. It can be noted that the addition of PVC fibres to lime-treated clay significantly strengthens the structure by providing additional tensile strength [25] and consequently increases the undrained cohesion; such improvement leads to enhanced short-term resistance, making the material more supporting higher loads or resisting shear failure shortly after treatment. This conclusion suggests that the combination of lime treatment with PVC fibre reinforcement is highly effective for applications requiring immediate strength and stability. In fact, the incorporation of plastic fibres into the soil enhances the reinforced soil's performance by introducing interfacial shear stress between the soil particles and the fibres, as well as the tensile stress contributed by the fibres. Figure 6 shows the two interfaces of the specimen after failure, indicating the shear strength of the treated material [10].

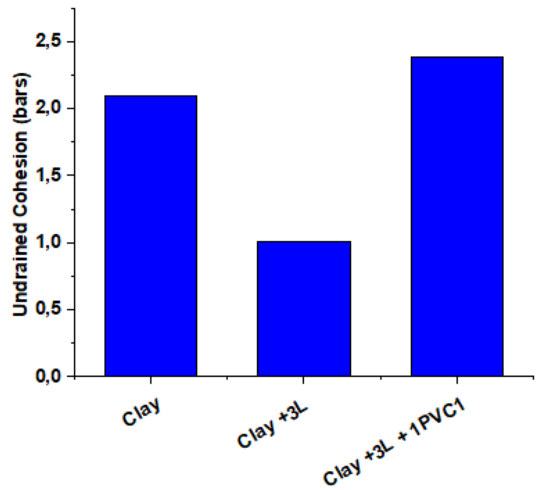

Figure 5. UU direct shear results

Figure 6. Specimen of treated soil after failure

Oedometer compressibility tests applied to lime-treated clay reinforced with PVC waste provide insights into how these treatments affect the soil's compressibility and swelling potential. As we can see in Figure 7, the treatment of clay with 3% lime alters the shape of the compressibility curve, which typically represents the relationship between void ratio and applied pressure during an oedometer test. This change in shape indicates that lime treatment fundamentally modifies the clay's behaviour under load. Indeed, the observed decrease in the slopes corresponding to both the swelling index (Cs) and the compression index (Cc) on the compressibility curve suggests that lime treatment significantly reduces the soil's tendency to swell and compress under load. This reduction can be attributed to the chemical reactions induced by lime, which transform the clay minerals into more stable compounds that are less prone to water absorption and deformation. However, when PVC fibres are added to the mixture, there is a slight re-increase in both the compression index (Cc) and the swelling index (Cs), likely due to structural changes, but these indices remain much lower than in natural clay.

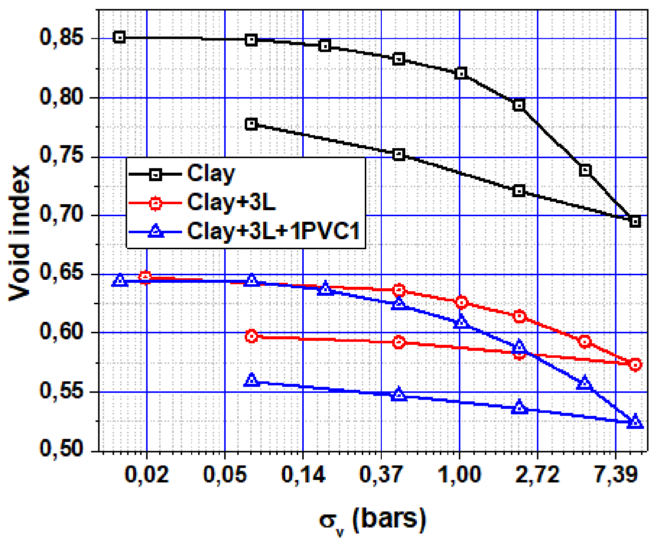

Figure 7. Compressibility curves of the different mixtures

4. CONCLUSIONS

The work focused on an approach to improve the properties of clay by combining lime treatment and PVC fibre reinforcement to create a more stable material that is less sensitive to water. The outcomes of the study can be summarized as follows:

- The Proctor tests revealed that the optimum water content increases with the addition of lime and PVC waste, and this depends on the size of the plastic fibres added. The curves corresponding to mixtures containing plastic fibres with dimensions smaller than 2 mm tend to flatten out, which indicates that the material becomes less sensitive to variations in water content.
- From the CBR immersion tests, it was noted that the mixtures containing lime-treated clay reinforced with PVC fibres exhibit promising results under low and medium compaction energies. These mixtures are easily compactable, which allows for achieving an acceptable bearing capacity without the need for intense compaction. However, when intense compaction energy is applied, the combination of lime treatment and PVC fibre reinforcement (with 1% fibre content and dimensions between 1 and 4 mm) appears to be less effective, which is probably due to the overcompaction leading to disorganising the soil matrix, resulting in a reduction in bearing capacity rather than an improvement.

- According to the direct shear tests, it was observed that the introduction of PVC fibres into the lime-treated clay leads to an increase in undrained cohesion, which is a key parameter for short-term stability in UU conditions. The fibres likely contribute by providing additional tensile strength and reducing the potential for sudden shear failure. Oedometer tests have also demonstrated the positive impact of the combined treatment process on the swelling and compression behaviour of plastic clays.
- The findings from this experimental study clearly indicate that treating clay with lime and reinforcing its structure with PVC waste offers a promising technical solution for enhancing the behaviour of clayey soils. This combination improves the soil's stability, reduces its sensitivity to water, and increases its overall performance in construction applications, making it a valuable approach in geotechnical engineering.

  Further evaluation through field trials and long-term monitoring is essential to provide a more comprehensive understanding of how clay stabilized with lime and PVC fibres performs in real-world conditions over time, ultimately increasing confidence in its use for geotechnical applications.

Acknowledgement

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Born in Tiaret, Algeria, he completed his primary, middle, and secondary education locally. He earned an engineering degree in mining geology in 2003 from Badj Mokhtar University in Annaba, Algeria. In 2016, he pursued further studies in hydrogeology and the environment at Ibn Khaldoun University in Tiaret, obtaining a master's degree. Currently, he serves as a geological engineer in charge of studies at the Western Public Works Laboratory (LTPO) in Algeria.

СТАБИЛИЗАЦИЈА ГЛИНЕ КОРИШТЕЊЕМ КОМБИНАЦИЈЕ КРЕЧА И ПВЦ ВЛАКАНА

Сажетак: Ојачавање тла за темеље или насипе кључно је за обезбјеђивање конструктивне стабилности и дуготрајности. У геотехници се користи много метода за ојачавање тла, које се могу широко категоризовати на хемијске процесе и механичке приступе. Поред тога, ојачавање тла влакнима представља ефикасну технику у геотехничком инжењерству за побољшање механичких својстава тла, као што су чврстоћа, крутост и отпорност на деформације. Упркос значајним истраживањима у овој области, стабилизација глиновитих тала остаје динамично поље у сталном развоју, са сталним напорима да се истраже иновативни материјали, напредне технике и одрживе праксе за рјешавање изазова повезаних са проблематичним тлима у грађевинарству и инфраструктурном развоју. Ово истраживање има за циљ побољшање геотехничких карактеристика високо пластичне глине кроз комбиновану стабилизацију: третман кречом у минималној дози и ојачавање типа ПВЦ (поливинил хлорид) пластиком различитих димензија из индустријског отпада. Студија укључује свеобухватан приступ стабилизацији тла, почевши од карактеризације референтног глиновитог материјала, затим побољшања његових својстава помоћу претходног третмана кречом и ојачања пластичним отпадом, након чега слиједи процјена геотехничких карактеристика кроз различите тестове: носивости, сабијања и директног смицања. Као резултат, тестови калифорнијског индекса носивости (CBR) у условима потапања показали су да мјешавине третиране глине и ПВЦ влакана постижу прихватљиву носивост при ниским и средњим притисцима компактирања без потребе за интензивним компактирањем. Поред тога, неконсолидовани недренирани тестови смицања (брзи тестови смицања) истакнули су краткорочна побољшања понашања комбиновањем третмана кречом и ПВЦ влакнима, док су едометарски тестови показали њихов позитиван утицај на бубрење и сабијање пластичних глина. Овом експерименталном студијом може се закључити да третман глине минималном дозом креча и ојачавање њене структуре додатком ПВЦ отпада представља занимљиво техничко решење за побољшање понашања глиновитог тла.

Кључне ријечи: глина, стабилизација, пластични отпад, креч, геотехничка својства