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The impact of waste plastic on the durability evaluation of cementitious materials for stabilizing weak soils

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***Abstract* –** Stabilizing problematic and weak soils is a common practice in geotechnical and pavement engineering. It involves adding a small quantity of cementitious materials to the soil to enhance its mechanical characteristics. Numerous studies have shown that lime and cement treatment can significantly alter the physical and mechanical properties of compacted soils, including reduced settlement potential, higher shear strength, increased modulus of elasticity, and changes to compaction parameters. Furthermore, the reusability of plastic waste is a promising solution for reducing atmospheric pollution. In this investigation, a laboratory experiment on stabilizing weak soil with different additions of cementitious materials and plastic waste was carried out by a series of tests, including Proctor compaction tests, optimal dry density, CBR tests, and unconfined compressive strength tests (UCS). The aim was to evaluate the effectiveness of the cementitious materials treatment of soil with waste plastic and find the optimal amount for practical design. The conclusion drawn was that adding waste plastic and a modest amount of lime and cement to the soil is a suitable method for stabilizing road construction's sub-base layer, with significant practical implications for the field. This research provides valuable insights for engineers, researchers, and students in geotechnical and environmental engineering, informing them about effective soil stabilization techniques and their environmental benefits.

Keywords – Stabilization, Weak soil, Waste plastic, Lime, Cement

I. INTRODUCTION

Most countries have expansive soil, a type of soil that undergoes significant volume changes with variations in moisture content. The volume of expansive soil increases during the rainy season and decreases during the dry season. The situation of shrinking and expanding expansive soils results in bearing capacity failure and excessive settlement, which can cause significant damage to infrastructure. In recent years, expanding soils have become the cause of destruction for numerous projects. According to studies, expansive soils should be addressed before any structures are built on them. Some techniques for dealing with expansive soils include Stabilization, mixing, soil fortification, and replacing the soil with coarse material. Stabilization, a process that improves the engineering qualities of weak soil, is not only crucial for construction but also economically viable. It increases soil strength while considerably reducing swelling qualities, thereby reducing the significant cost of replacing unstable soil. Stabilization can be mechanical or chemical, including cement, lime, thermal, bituminous, grouting, and electrical stabilization [1].

This emphasis on the economic benefits of Stabilization should reassure the audience about the feasibility of the process. Every year, more than 100 million tons of plastic are produced, and 200 billion pounds of fresh plastic material are foamed worldwide. Furthermore, more than one million plastic bottles are purchased per minute, and over five trillion plastic bags are purchased per year [2]. Because society was unaware of the negative consequences of plastics, people discarded them in public places and bodies of water after usage. Plastic waste is thus rated third in terms of environmental pollution, trailing only food and paper waste. Plastic waste's complex behavior is characterized by its durability, as it takes a long time to degrade [3].

Soil stabilization using waste materials such as demolished construction materials, bricks, fly ash, and manufacturing wastes is gaining popularity. Plastic garbage is the most damaging to the environment because it decomposes so slowly. There is a need to create new strategies for waste plastic disposal. Using trash as a road layer material is the most cost-effective, lowers pollution, and improves the unpredictable qualities of weak soil [4] when stabilized according to established processes, which include compaction, addition of stabilizing agents, and curing. Many researchers discovered that using plastic fibers considerably enhances soil engineering qualities. According to studies, adding waste plastic strips to cement kilns [5], waste plastic strips with lime [6], waste plastic strips with brick powder, waste brick powder mixed with lime [7], and randomly distributing fiber as reinforcement increased the strength properties, swelling potential and frictional resistance of fine-grained soil.

According to research on how plastic trash affects certain types of soil, building flexible pavement with chips made from used plastic bottles is an alternate way to improve the subgrade soil for pavement. Some researchers have discovered that the CBR and UCS values of black cotton soil are enhanced by plastic garbage. Research on broken waste glass polyethylene, bottles, and shopping bags combined with lime and rice husk ash [8], and other reinforcement materials revealed a small improvement in the unconfined compressive strength and CBR values. The study demonstrates that the engineering qualities of samples, such as plastic index, compaction characteristics, and strength properties, are improved by combining waste plastic High-density Polyethylene with waste crushed glass as reinforcement for subgrade strength improvement [8].

This potential of plastic waste to improve soil properties should pique the audience's interest in the research. The purpose of this study was to investigate the addition of plastic waste strips to the lime and cement stabilization to improve the properties of silty soil using experimental methods. The investigation was conducted by laboratory experiments on soil samples that included 0%, 2%, 4%, and 6% lime, and 2% cement, as well as 0%, 5%, and 10% plastic waste strips. The results obtained from CBR, compaction, and unconfined compressive strength with curing period of 28 days on dry and wet states demonstrate the relevance of using plastic waste with lime and cement to stabilize the weak soil, revealing that the stabilized soil can be used as subgrade materials in roadway foundation layer construction.

II. Materials and Method

A. *Materials*

- *Soil.* The soil is utilized to support the road connecting the dry port in the commune of TIXTER, Bordj Bou Arreridj. Which is around 40 kilometers from the city of BBAc, Algeria (Figure 1. a). Several laboratory experiments were performed to characterize the soil. the geotechnical parameters of the soil describe it as silty sand with poor plasticity.
- *Lime.* The lime used in this study is a quicklime produced by the company BMSD-SARL located in the city of Saïda, Algeria (southwest of the national territory) (Figure 1. b).

- *Plastic waste bottles.* This study makes use of widely available plastic waste (a high-density polypropylene water bottle). It is a type of plastic waste that has been examined because of its availability, low cost, and chemically inert nature, as well as because it does not absorb water and has no reaction with soil. Daily laborers collect plastic water bottles and physically cut them into strips of a specific size for use, as depicted in (Figure 1. c).
- *Cement.* The hydraulic binder used in our study is MATINE cement (Figure 1. d). CPJ-CEM II / B 42.5 N (NA 442); gray cement for high-performance concrete intended for the construction of civil engineering structures, infrastructure and superstructures for buildings.

B. *Sample Preparation*

Initially, the needed quantity of air-dried soil samples is prepared. The amount of lime, cement, and plastic waste strips added to the soil was determined as a proportion of its dry weight. For compaction, CBR, and UCS, the specimens were compressed to achieve maximum dry density at the optimum moisture content determined by the compaction test.

The method of mixing soil, lime, cement, and plastic waste strips follows precise protocols. Firstly, the lime and cement are thoroughly mixed into the soil at the appropriate moisture level. then, the plastic strips were physically mixed with the soil.

A homogeneous distribution of plastic strips is visible when the stabilizers are mixed with the soil As a result, the study investigated how varied quantities of lime (0%, 2%, 4%, and 6%), plastic waste (0, 5%, and 10%), and cement (2%) percentage variation influenced the soil plasticity and strength.

Several experiments in the laboratory are performed to establish the optimal percentages of plastic waste strips with lime and cement needed to stabilize the silty weak soil. As a result, strength parameters and CBR. Table 1 summarizes the laboratory test findings for soil stabilized with lime, cement, and plastic waste strips.

Fig. 1 Materials: a/ silty soil, b/ lime, c/ plastic waste, d/ cement

Table 1. The laboratory test findings for soil stabilized with lime, cement and plastic waste strips.

N	*Notation*	*Mixtures*
1	**S0**	Soil + 0%plastic waste + 0% lime
2	**S3**	Soil + 5%plastic waste + 2% lime
3	**S4**	Soil + 5%plastic waste + 4% lime
4	**S5**	Soil + 5%plastic waste + 6% lime
5	**S6**	Soil + 10%plastic waste + 2% lime
6	**S7**	Soil + 10%plastic waste + 4% lime

7	**S8**	Soil + 10%plastic waste + 6% lime
8	**S9**	Soil + 5%plastic waste + 2% lime+2% cement
9	**S10**	Soil + 10%plastic waste + 2% lime+2% cement

III. Results

A. *Variation of Optimum Dry Density with lime, cement, and plastic waste proportions.*

The result indicated a significant effect was observed with increased plastic waste strips, lime, and cement proportions.

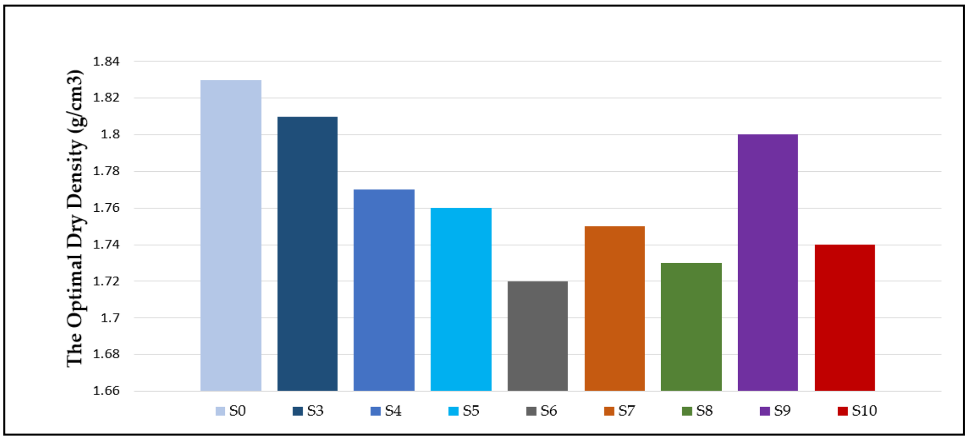

Fig. 2 Materials: a/ silty soil, b/ lime, c/ plastic waste, d/ cement

Figure 2 shows the effect of the addition of lime, cement, and plastic waste strips with different proportions on the optimal dry density of soil. The addition of 5% waste plastic with a low rate of lime induces a decrease in the dry density of the soil for rates varying from 1.63% to 3.96%. The addition of 10% waste plastic with a low rate of lime induces a significant decrease in the dry density of the soil, with rates varying from 4.89% to 6.52%. These rates of change are considered substantial in the context of soil density management. The addition of 5% and 10% of waste plastic with a low rate of lime and cement induces a decrease in the dry density of the soil for rates varying from 2.17% to 5.12%.

The addition of waste plastic, lime, and cement does lead to a slight reduction in dry density, primarily due to the time-dependent nature of the hydration of cement and lime. However, the addition of waste plastic strips to the soil can reduce the dry density by about 6%, a significant finding given the relatively low weight of the plastic. These findings are impressive and underscore the potential of these additives in soil density management, a fact that we can all appreciate.

B. *Variation of CBR values with lime, cement, and plastic waste strips proportions.*

The result indicated that an increase in the proportion of plastic waste, lime, and cement results in significant improvement.

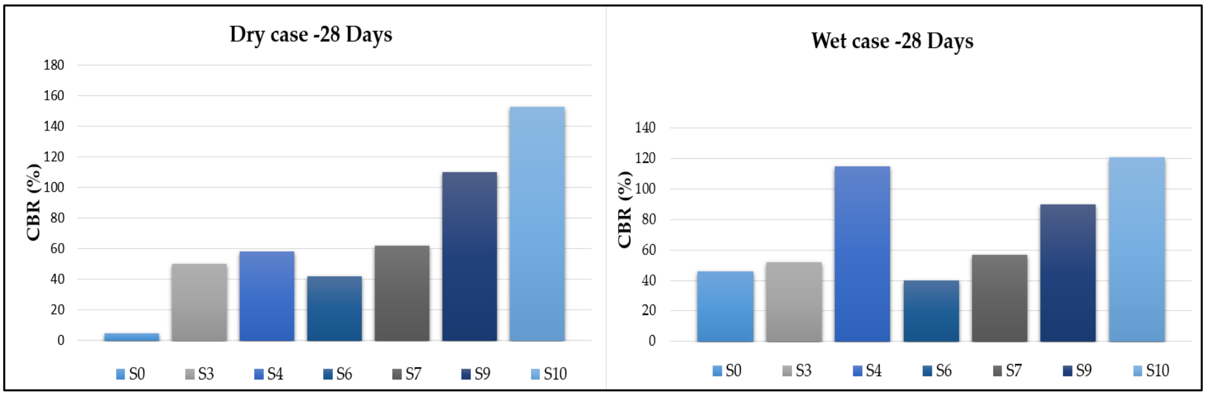

Fig. 3 Effect of lime, waste plastic, and cement on the CBR values of silty soil in Dry and Wet cases for 28 days.

We can observe from the figure 3 that the addition of Plastic waste, lime, and cement in the soil increases the bearing capacity in the dry and submerged state. The mixtures with cement give the highest CBR values, which allows us to conclude that the efficiency of cement hydration in a short time is greater than that of lime, instilling confidence in the results.

The addition of plastic waste strips rates between 5% and 10% to the dry samples of the soil induces a significant increase in the bearing capacity of the soil, especially the addition of 4% lime and mixtures with cement, where the increase amounts to an impressive >150% compared to S0.

The same effects were observed for mixtures kept in a wet case (submerged) >120%. We observe that the CBR in 28 days in the mixture of 10% PT plastic waste and 4% lime is 58.2% in the wet state and 61.6% in the dry state, and the mixture of 10% PT plastic waste and 4% cement is 152.5% in the dry state. In addition, 120% in the submerged state. Therefore, we conclude that the cement gives a good result compared to lime because of the hydration of the cement in a short time more than lime. In comparison, it was noted that the cement dosage rate improves the cohesion, which provides the mixture with a new granular matrix characterized by a very high bearing capacity compared to S0. However, for reasons of economy and preservation of nature, it is desirable to mix in situ soil with 10% PT plastic waste, 2% lime, and 2% cement. This practical application of our research findings empowers civil engineers and environmental scientists to make informed decisions in their projects.

C. *Variation of Unconfined Compressive Strength UCS with lime, cement, and plastic waste proportions.*

The result indicated that a significant improvement is observed with an increase in the proportion of plastic waste, lime and cement.

It's promising to note that the UCS increases in the wet state for the mixture of 10% waste plastic strips and 4% lime, underscoring the potential of waste plastic in soil stabilization. Conversely, the other lime mixtures show less effectiveness in stabilizing this soil. The addition of 2% cement to the mixtures with 5 or 10% waste plastic and 2% lime results in a significant increase in UCS values, a testament to the potential of this research. On the other hand, the immersion mixtures yield positive results compared to the UCS of the natural soil. The addition of waste plastic, lime, and cement significantly modifies the mechanical characteristics of the stabilized soil, particularly the undrained cohesion. This cohesion sees a notable increase between 50.05 kPa and 305.03 kPa, reassuring us of the effectiveness of this approach. It's clear that the addition of waste plastic, lime, and cement enhances the UCS of the treated soil.

According to the results, we observe that the UCS in 28 days in the mixture of 10% waste plastic and 4% lime is 850 kPa in the wet state. And the mixture of 10% waste plastic, 2% lime and 2% cement is 1400 kPa in the wet state. Therefore, we notice the UCS of the soil has increased by about 2 times in the wet state. We conclude that the cement gives a good result compared to lime because of the rapid ‘’ hydration of the cement ‘’, a chemical process where water reacts with the cement, leading to faster and stronger binding, more than lime.

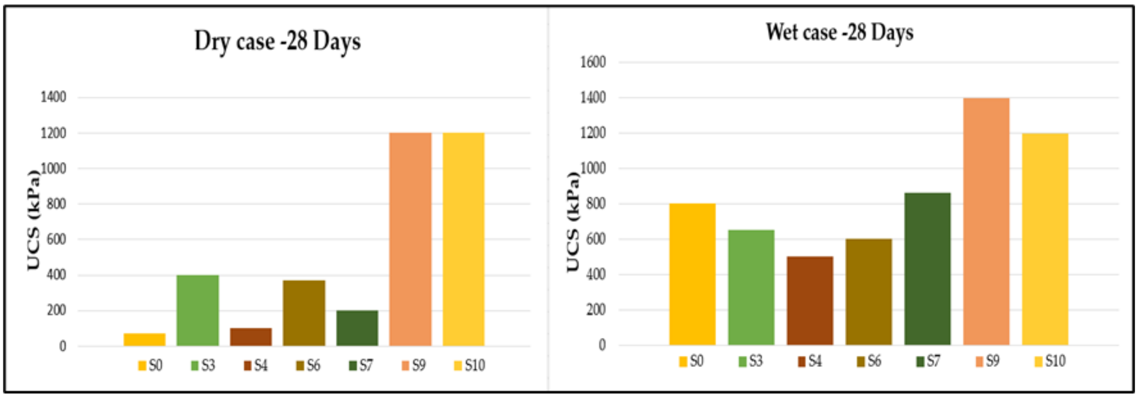

Fig. 3 Effect of lime, waste plastic, and cement on the CBR values of silty soil in Dry and Wet cases for 28 days.

D. *Durability result.*

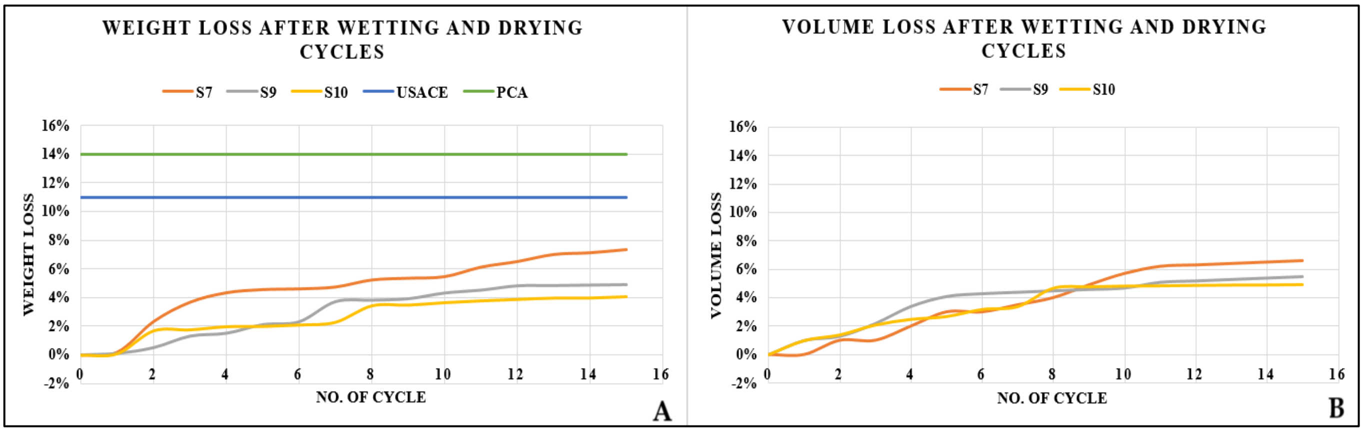

Fig. 2 Materials: a/ silty soil, b/ lime, c/ plastic waste, d/ cement

Three selected samples (S7, S9, and S10) were subjected to a durability test. The test assesses the treated soil's durability during long-term exposure to severe environmental conditions. The weight and volume loss are meticulously and rigorously recorded after 15 cycles of wetting and drying with brushing access. The results, presented in Figs. 4-A, and 4-B, are a testament to the thoroughness of our testing process. It was revealed that after 15 cycles, the weight loss was equal to 7.33%, 4.88% and 4.09% for S7, S9 and S10, respectively. The volume loss after 15 cycles equals 6.92%, 5.45% and 4.95% for S7, S9 and S10, respectively.

According to the Portland Cement Association (PCA) and the USA Corps of Engineers (USACE), the maximum permissible weight loss is 14% and 11%, respectively. The recorded weight and volume loss for the selected samples not only meets but also comfortably stays within the allowable limits, providing a strong foundation for further research and application.

IV. CONCLUSION

The goal of this study is to enhance the strength of weak soils and reduce pollution by utilizing waste plastic strips in the subgrade layer of road pavements. An experimental investigation was conducted, leading to the following conclusions:

- The addition of lime, cement, and plastic waste strips significantly enhances and stabilizes weak soils, resulting in notable improvements. .
- Incorporating waste plastic strips increases the durability of the cementitious materials used in the stabilization technique.
- Significant improvements in California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) values were observed in both dry and submerged conditions.
- The addition of lime, cement, and plastic waste strips improved the strength characteristics of the weak soil, indicating that the stabilized soil can be used as subgrade material in flexible pavement construction.
- This study proposes a more effective method for disposing of waste plastic than recycling, landfilling, or dumping them outdoors.

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