



Improving geotechnical properties using paper ash and olive pomace

Berdi Inas, Messast Salah, Benzaid Riad, Idoui Imane

University of Jijel, Algeria
Faculty of Natural and Life Sciences, Geological Engineering Laboratory
e-mail: inas.berdi@univ-jijel.dz

Abstract

Soil stabilization techniques play a crucial role in improving soil quality, reducing construction costs, and addressing environmental and mechanical challenges encountered in civil engineering. Faced with low-quality soils, several researchers have explored innovative solutions by using natural waste materials. New approaches are being developed to recover local waste and reuse it in civil engineering applications, particularly in earthworks. In this study, the goal is to experimentally compare the impact of two types of waste on the stabilization of clay soils, by testing different percentages (2%, 4%, 6%, 8%) through various laboratory tests, such as compressive strength, shear strength, and oedometer compression test. The results obtained are analyzed to evaluate the effectiveness of these wastes in soil treatment. The preliminary study conducted on the clay soil showed a significant improvement in its mechanical properties, which could enhance its stability and bearing capacity.

Keywords: recovery, industrial waste, stabilization, agricultural waste

1 Introduction

Materials recovery is a key approach to sustainable resource management, as it enables waste to be recycled to extract materials that can be reused in various sectors. The choice of waste materials to be recycled depends mainly on their abundance, availability, and potential for use in specific applications, particularly in civil engineering.

Through an in-depth literature review, we have identified the effectiveness of various additives on the geotechnical properties of soils. Agricultural or industrial waste can be converted into soil reinforcement additives [1]. This type of modification is particularly beneficial in civil engineering applications, where soil workability and stability are essential for infrastructure projects.

The work in [2] used ash from burnt olive waste as a material to stabilize bentonite clay, with proportions ranging from 1% to 10% by weight. Test results showed a decrease in the plasticity index, reducing the deformability of the soils, making them less plastic and therefore easier to

handle. Similar results were obtained by the authors in [3], who demonstrated that 3% olive pomace ash was sufficient to stabilize expansive soil.

The authors in [4] studied the use of olive waste in the form of burnt ash to improve the geotechnical properties of soils. Their research showed that the addition of 2.5% by weight of this ash significantly increased the unconfined compressive strength and maximum dry density of the soil. This improvement translates into better soil compactness, meaning that particles are more densely agglomerated, reducing voids in the soil structure. The increase in compactness also leads to an improvement in compressive strength, an essential parameter for the stability and durability of infrastructure built on this type of soil.

The authors [5] conducted an experiment on soft sandy-clay soil to examine the effect of ash from waste paper sludge on the mechanical behavior and microstructure of the soil. The tests were carried out with mixtures containing between 2% and 16% ash by weight. The results showed that the best mechanical performance, particularly in terms of shear strength and compressive strength, was obtained with the addition of 10% ash. At this proportion, significant changes in the soil microstructure were observed, including the formation of new cementitious agents acting as binders. These agents strengthen the interactions between soil particles, improving the overall stability of the mixture.

For their part, the authors [6] explored a combination of calcined paper sludge and cement as a soil stabilizing material. Their study revealed that this mixture considerably improves the bearing capacity of the soil, making it better able to support heavy loads.

In the study by [7], it was highlighted that the use of calcined paper sludge as an additive offers an alternative and effective solution for improving the geotechnical properties of soils, even surpassing commonly used materials such as lime and cement. This finding is particularly important in the context of soil stabilization for construction or infrastructure projects.

In addition, the improvement in soil densification, measured by the increase in the CBR (California Bearing Ratio) value, is a key indicator of the effectiveness of the additives. The authors [8, 9] used paper ash to treat soils with different percentages. They employed nanostructured waste paper ash as an additive to improve the geotechnical properties of lateritic soil, conducting a series of standardized tests. A significant increase in the CBR value was observed, and the compressive strength increased with a 28-day curing time, ensuring durability. They concluded that paper ash is an excellent soil strength enhancer, particularly for sub-base materials used in pavement construction.

The authors [10] found that the use of paper ash to reduce soil swelling produced promising results, demonstrating the effectiveness of this addition in soil stabilization. In fact, an 80% reduction in swelling is a crucial factor in improving the mechanical properties and stability of soils.

Integrating these materials into the stabilization process is an innovative approach that not only improves the geotechnical properties of clay soils but also promotes more sustainable management of local waste.

2 Materials

2.1. Clay soil: The soil used in this study consists of 80% treated Kaolin extracted from the Soalka company and 20% Bentonite, marketed by the Bental company. From an experimental

point of view, the use of this soil offers the advantage of providing a swelling reference soil with uniform geotechnical properties for all the tests.

Table 1: physico-mechanical properties of soil [10]

Parameters	Values
Optimum content moisture (%)	20,20
Maximum dry density (t/m^3)	1,55
Cohesion(Bar)	0,2
Angle of friction ($^{\circ}$)	4.57
Compression index (%)	31.5
Swelling index(%)	11
Compressive strength (Mpa)	0.259

Mineralogical analysis was carried out at the emerging materials research unit in Sétif. The reference soil components show that mostaganem bentonite contains montmorillonite as an abundant phase, followed by illite. Quartz and calcite, while Tamazert kaolin contains an intense peak of kaolinite, quartz and muscovite. For the reference soil, the appearance of an intense peak corresponding to quartz, kaolinite, muscovite, also the appearance of illite.

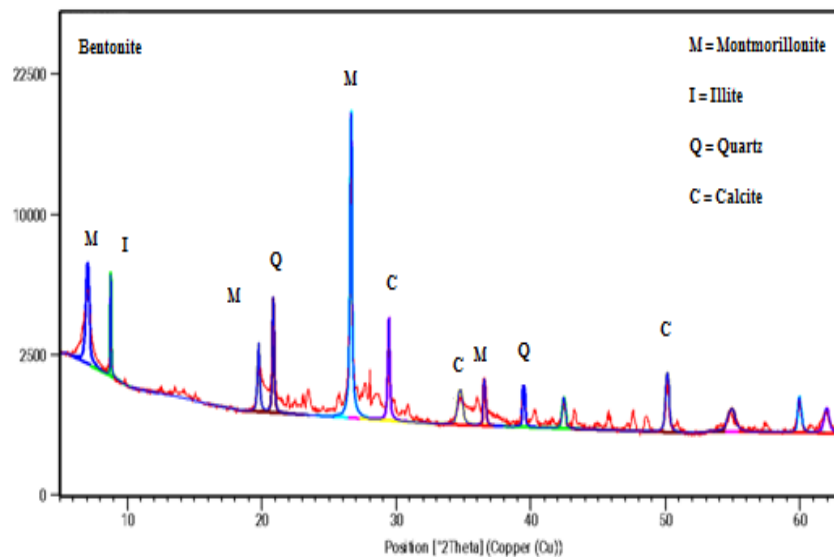


Figure 1: Mineralogical analysis of Mostaganem Bentonite

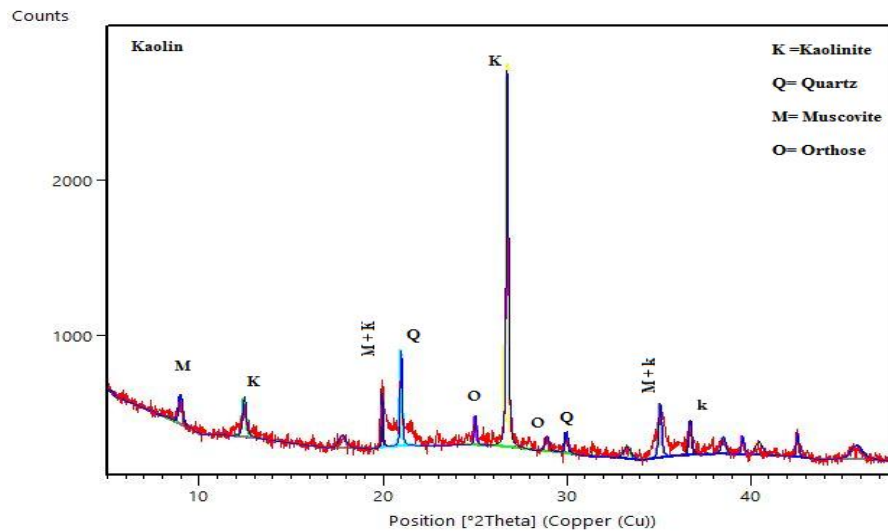


Figure 2: Mineralogical analysis of processed kaolin 2

Microstructural analysis of the reference soil using scanning electron microscopy (SEM) revealed a characteristic organisation of the clays present. The observations reveal the presence of dispersed sheets, typical of clays with a lamellar structure, distributed randomly. The sheets have a scaly structure, which is mainly due to the presence of kaolinite, the main clay mineral in the mixture. This scaly structure is due to the specific morphology of kaolinite, characterised by fine, flattened platelets, [11].

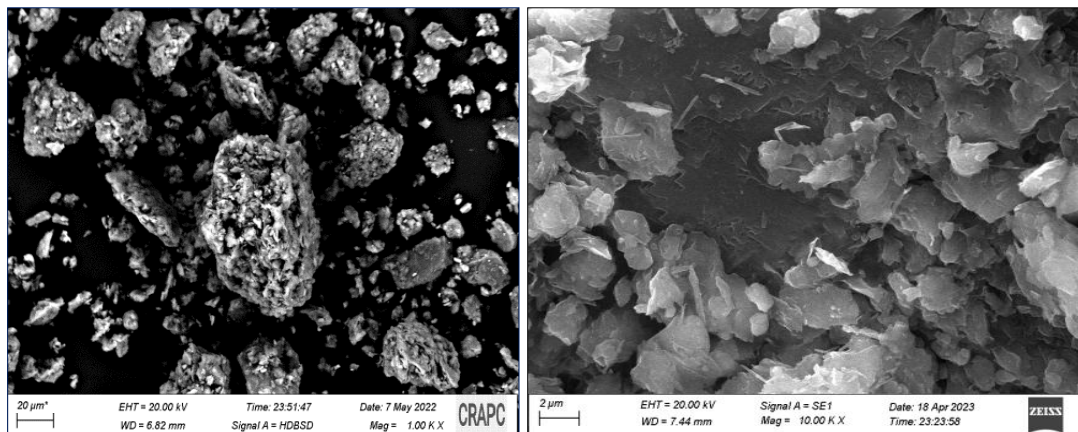


Figure 3: SEM analysis of the reconstructed soil at different magnifications

2.2 Wastes: Our work consists of selecting several types of waste in different forms (powders, grains) to determine which form offers the best performance for soil stabilization. The choice of wastes was based on their local availability, low cost, and ecological potential. Among these wastes, paper ash and olive pomace were selected because of their specific properties and their compatibility with improving the physical and chemical properties of soils. The chemical and mineralogical analyses carried out on these materials support the use of these wastes in soil stabilization for the following reasons: the rigidity provided by olive pomace and the high calcium content in paper ash, which favors the formation of bonds between the addition

and the components of the soil. The incorporation percentages of these wastes were determined based on laboratory tests and the analysis of existing works.

2.2.1. Paper ash:

Paper ash is obtained by incinerating waste paper. The process involves collecting the waste and then burning it at high temperatures, reducing the paper to ash. The temperature and duration of combustion can influence the chemical and mineralogical composition of the ash. In our work, we used office paper subjected to an average temperature of 600°C. Once combustion is complete, the ash is cooled, sieved to remove impurities, and sometimes ground to obtain a fine, homogeneous powder ready for use in soil stabilization tests.

The mineralogical and chemical composition of the ash varies according to the type of paper used, the combustion process, and the temperature applied.

Chemical analysis shows that paper ash is rich in lime (CaO), with a content of 86.3%, a key component in soil stabilization processes. This reacts with clay particles and water to form cementitious compounds such as hydrated calcium silicate (C-S-H) and hydrated calcium aluminate (C-A-H), which improve the geotechnical properties of soils.

Table 2: Chemical analysis of soils used by XRF (x-ray fluorescence) [10]

Oxydes	SiO ₂	Al ₂ O ₃	CaO	Fe ₂ O ₃	MgO	TiO ₂	Na ₂ O	SO ₃
Pourcentages	4.58	1.74	86.3	2.07	0.977	0.16	1,14	4.58

XRD analysis of paper ash powder enabled us to determine the different crystalline phases. Lime (CaO) represents the major phase of the ash, followed by Gehlenite (Ca₂Al₂SiO₇), Mayenite (Ca₁₂Al₁₀O₄₀) and Calcite (CaCO₃) with traces of Portlandite (Ca(OH)₂) and Hatrurite (Ca₄Al₃O₁₂). The results of this XRD analysis corroborate those obtained in a previous study conducted by [7], he reported the appearance of Belite (Ca₂SiO₄) and Quartz (SiO₂), suggesting a possible variation in mineralogical composition depending on combustion conditions or paper sources.

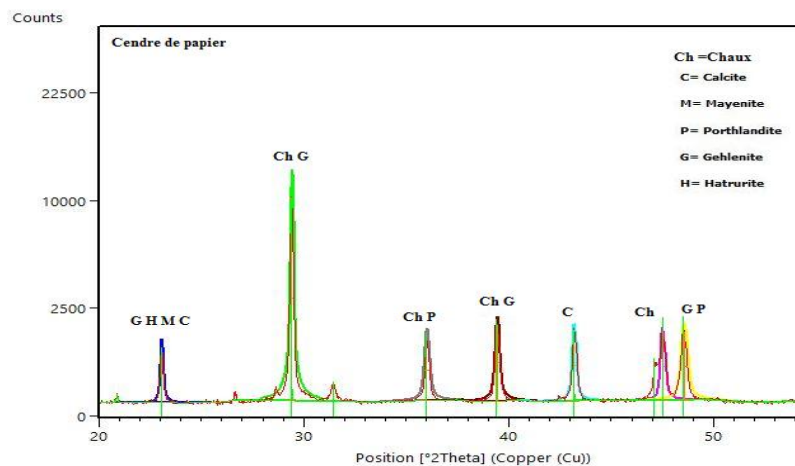


Figure 4:DRX of paper ash

SEM scanning electron microscopy shows a fibrous structure, suggesting that paper ash consists mainly of fibers. These fibers may originate from the cellulose present in the paper. Furthermore, the presence of particles between the fibers suggests that there are elements other than the fibers themselves in the composition of the ash. These particles could be additives present in the paper, or elements derived from paper combustion.

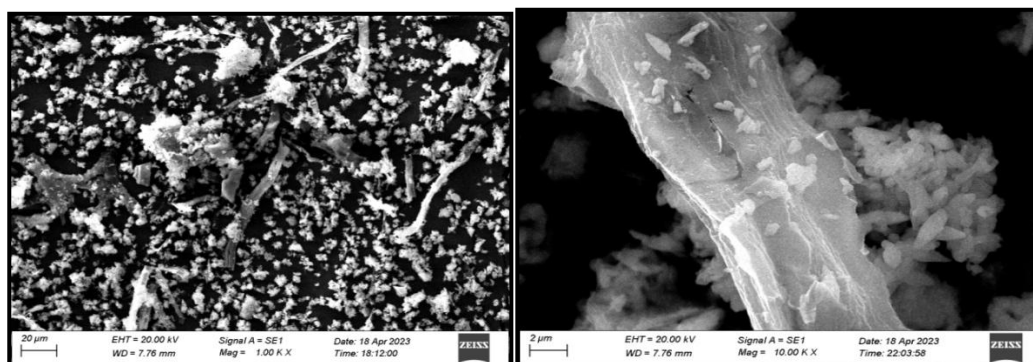


Figure 5: Microstructural analysis of paper ash at different magnifications

2.2.2. Olive pomace: It is a by-product of the olive oil extraction process, consisting of skins, pulp residues, and stone fragments. The olive pomace used in this study comes from oil mills in the commune of Sidi Abdelaziz, in the wilaya of Jijel, before being used as an additive for soil stabilization. The pomace must be dried to reduce its moisture content. Since pomace is rich in organic matter, drying is essential to prevent undesirable effects such as excessive biological degradation (composting) [12].

This preparation ensures better preservation of the pomace and improves its performance as an additive for soil stabilization



Olive trees

Olive pomace

Table 3: EDX results on olive pomace

Chemical elements	Si	Al	Ca	Fe	K	Mg	O	C	Cu
% by mass	7.48	5.21	2.88	2.26	1.05	0.51	40.04	39.69	0.87

The EDX results showed the most important chemical elements by mass to be carbon (C) and oxygen (O). These results agree with those obtained [13] which showed the appearance of two

peaks. Olive pomace, rich in organic carbon, can have a beneficial effect on soil structure, increasing tensile strength and stability.

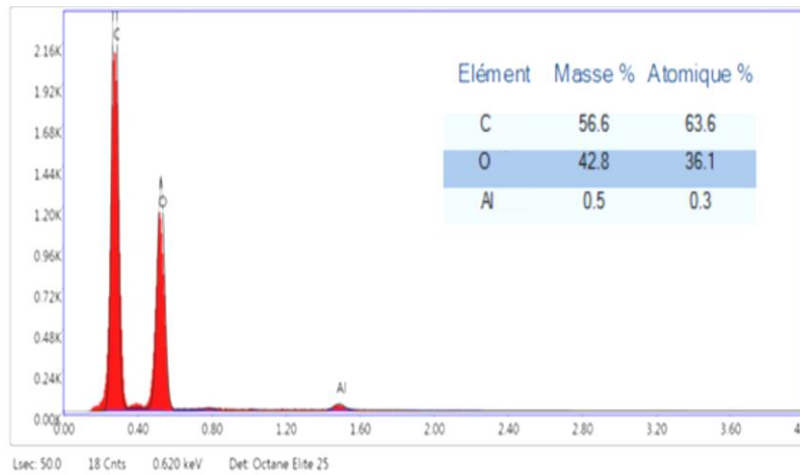


Figure 6: Energy of dispersion by x-rays of olive pomace (EDX)

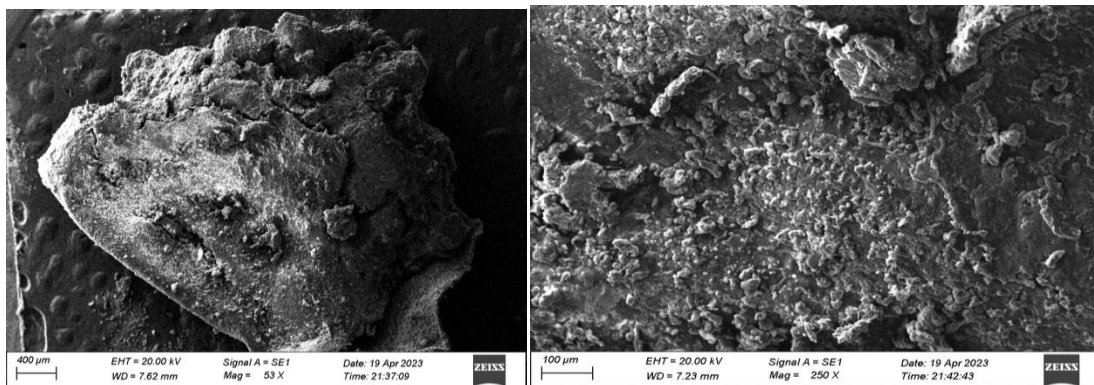


Figure 7: SEM of olive pomace

Microstructural analysis of olive pomace has revealed a complex and heterogeneous morphology. This structural diversity testifies to the rich characteristics of the pomace, which presents a varied range of structures and compositions visible at different scales, from the microscopic to the macroscopic.

Observations also revealed the presence of hollow cavities, which could be attributed to natural voids formed during processing or drying. These cavities, combined with a rough surface, are the direct result of the presence of plant fibres. These fibres, made up mainly of cellulose (32.7%), hemicellulose (16.2%) and lignin (30.6%) [14] contribute to the irregular texture and give the pomace its specific mechanical properties.

This unique microstructure could influence the functional properties of olive pomace, such as its adsorption capacity, its mechanical characteristics or its potential for soil reinforcement applications.

3 Methods

In order to study the effectiveness of olive pomace and paper ash in stabilising clay soils, we launched an experimental programme based on a series of standard tests. Firstly, a mixture of soil and additions was prepared with different percentages of 2%, 4%, 6% and 8% by weight of soil (Figure 8 and Figure 9).

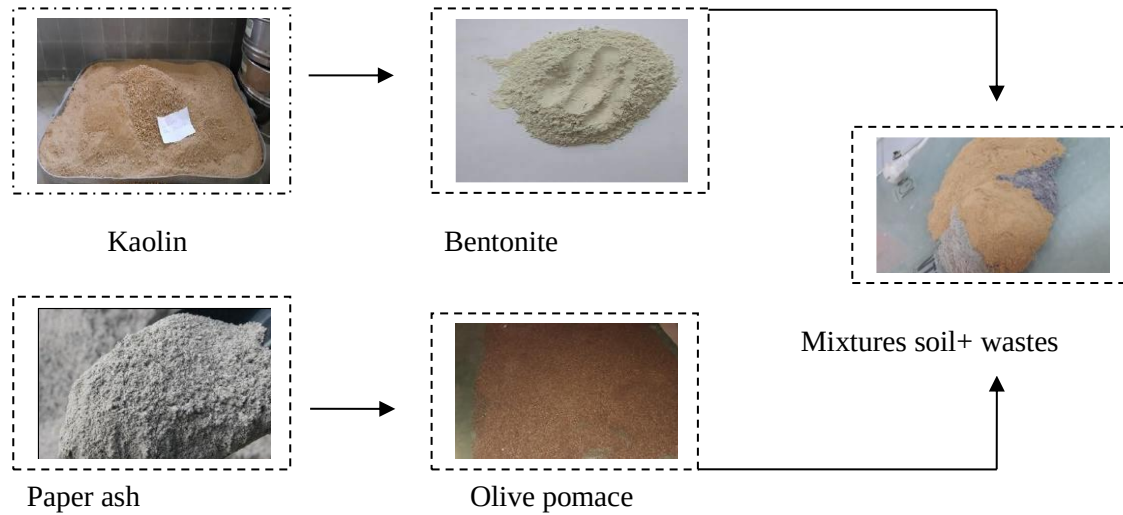
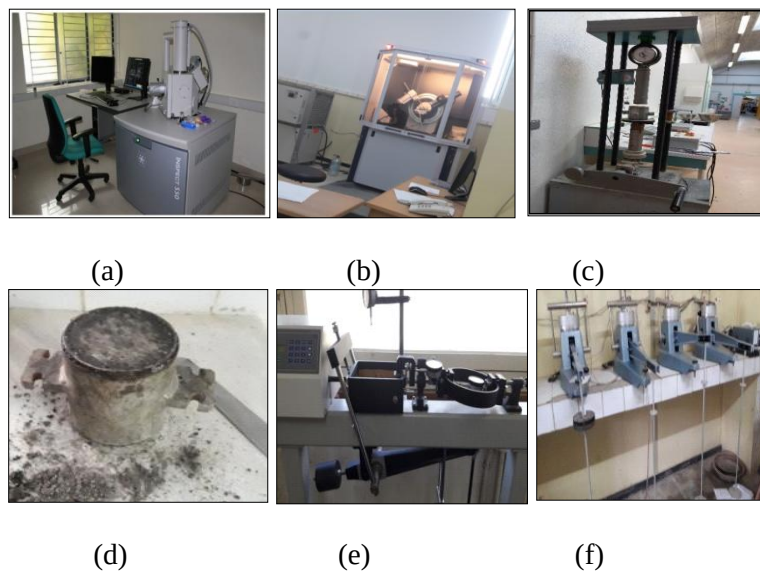


Figure 8: Materials used



- (a) SEM microstructural analysis
- (b) Mineralogical analysis by DRX
- (c) Compressive strength test according to the NF P 94-093 standard.
- (d) Compaction test according to the NF P 94-093 standard.
- (e) Direct shear test according to the NF P 94-071-1 standard.
- (f) Compressibility test according to the standard (XP P 94-090--1).

Figure 9: Geotechnical tests performed in this study

4 Results and discussion

4.1. Behaviour of paper ash and olive pomace on soil microstructure:

The SEM results show a significant change in the morphology of the reconstituted soil particles treated with ash, compared with the reference soil. This change is characterised by a rearrangement of the soil particles, indicating the influence of the ash on the overall structure of the soil. As the ash penetrates the soil matrix, it begins to fill the pores between the grains, resulting in the formation of chemical or physical bonds that act as binders. These binders improve the cohesion between soil particles, resulting in a reduction in the number of pores.

Reducing the number of pores is particularly important because it increases the density of the soil and reduces its porosity. This gives the soil greater mechanical stability, which is essential for many geotechnical applications, particularly in the construction of foundations and infrastructure. In addition, the positive effect of ash on soil microstructure is reflected in an increase in soil strength, as the ash acts in a similar way to a cement binder, consolidating the soil structure while improving its load-bearing capacity.

SEM analysis also reveals that the addition of ash imparts a porous appearance to the surface of the treated soil, suggesting that the ash may play a role in water absorption. However, this aspect requires further investigation in future studies.

Regarding the impact of olive pomace, the SEM results indicate a distinct mechanical effect. Olive pomace, as an organic material, appears to enhance the ductility of the soil, making it more flexible and less prone to fracture under mechanical loads. This improvement in ductility is particularly beneficial in geotechnical applications, as it allows the soil to deform without breaking, which is essential in environments subject to variable movements or pressures.

In addition to improving ductility, the incorporation of olive pomace modifies the surface of soil grains, facilitating the formation of bonds between particles. This surface modification may also influence water retention and circulation within the soil, which could have significant implications for agricultural or environmental applications.

Moreover, olive pomace seems to increase the coarseness of the soil, impacting its texture. A coarser soil, characterized by larger particles and improved aeration, can enhance permeability and drainage. This is particularly advantageous for preventing waterlogging in overly compacted soils. Such changes in texture are valuable for agricultural soil management or soil improvement in civil engineering projects, especially in contexts where erosion resistance and effective rainwater management are critical concerns.

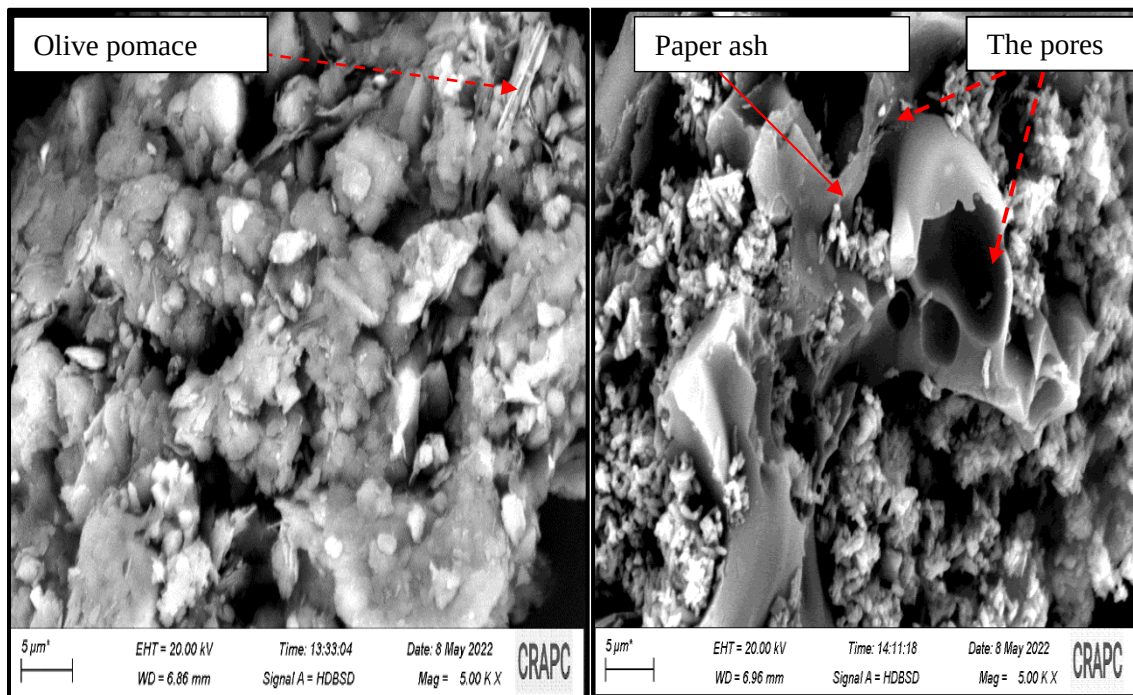


Figure 10: Effect of paper ash on the microstructure of reconstituted soil

4.2. Effect of paper ash and olive pomace on soil mechanical parameters:

We examine the results of incorporating olive pomace and paper ash on soil behaviour. All the results are shown in the following table:

Table 4: Results of paper ash on mechanical parameters

%	Compressive strength	Angle of friction	Cohesion	Swelling index	Compression index
0%	259	4.57	20	11	31
2%	270	7	8	9.4	30.2
4%	300	13	64	7.4	21.2
6%	363	11	39	7	19.8
8%	376	15	50	5.5	19.9

Table 5: Results of olive pomace on mechanical parameters

%	Compressive strength	Angle of friction	Cohesion	Swelling index	Compression index
0%	259	4.57	20	11	31
2%	270	5.2	62	11.9	33
4%	280	6.27	79	10.5	29.8
6%	300	14	90	8.1	28.1
8%	340	21	55	5.1	18.1

4.2.1. Compressive strength

The compressive strength of the natural soil is initially measured at around 0.259 MPa. However, after treatment, a significant increase in compressive strength is observed. In fact, the compressive strength of soil treated with paper ash increases by around 40% compared with untreated soil, rising from 0.259 MPa to 0.376 MPa, and from 0.259 MPa to 0,340 MPa for soil treated with olive pomace. This significant improvement in compressive strength testifies to the effectiveness of the treatment applied to the soil, making it better able to support higher loads and resist deformation under stress.

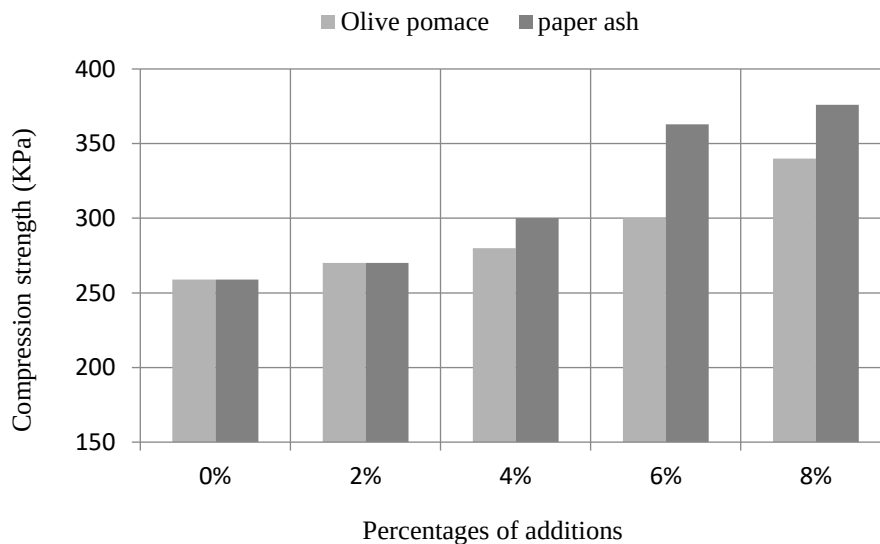


Figure 11: The effect of additions on compression resistance

4.2.2. Shear strength

The Cohesion increases as the percentage of paper ash increases, rising from 20 kPa to 64 kPa for 4% addition, after which it falls to 39 kPa and then rises to 54 kPa. The angle of friction gradually increases from 4.5° to 11°. The improvement in mechanical properties is due to the filling of the pores by the paper ash.

The Cohesion treated with olive pomace showed a significant increase, from 20 kPa for the untreated soil to 90 kPa for the reconstituted soil treated with an addition of 6%. Thereafter, cohesion decreased slightly to 55 kPa. In general, a trend of gradual and continuous increase was observed for the angle of friction, rising from 4.57° to 21°. This increase testifies to a significant improvement in the soil's ability to resist shear stresses.

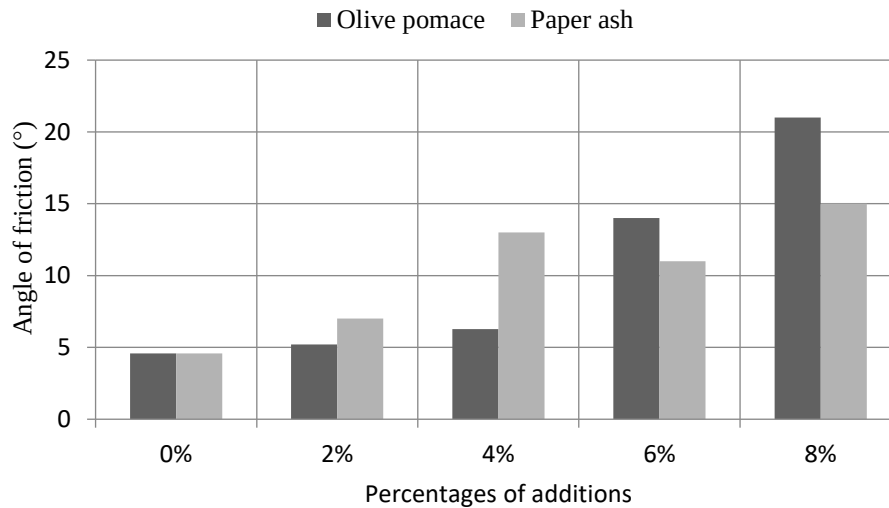


Figure 12: The Effect of additions on the angle of friction of the soil

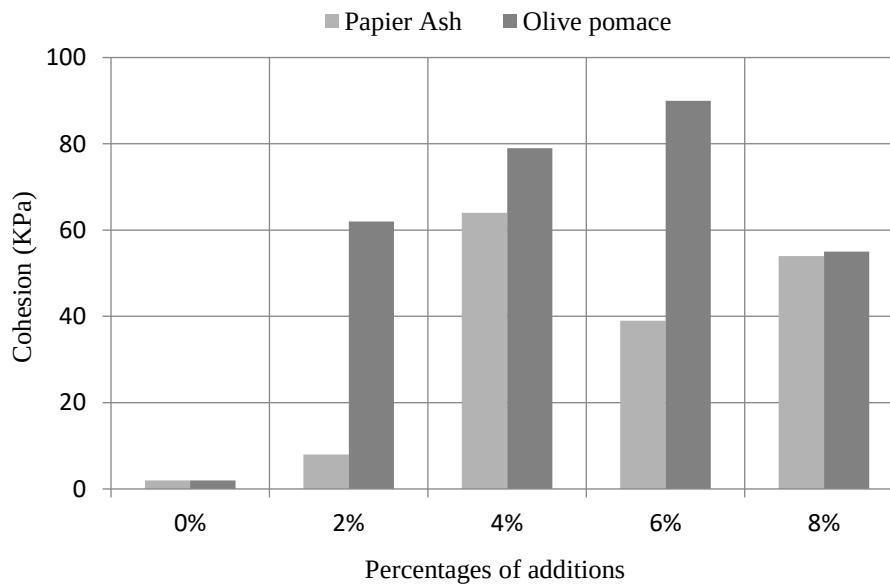


Figure 13: The effect of additions on soil cohesion

4.2.3. Oedometer compression

As the percentage of paper ash increases, the swelling and compression indices of the soil progressively decrease. Increasing the addition of paper ash leads to a progressive decrease in the swelling index, from 11% for the reference soil to just 5.5% for an addition of 8% paper ash. The compression index falls from 31% for the untreated soil to just 19% for the addition of 8% paper ash. This reduction indicates a decrease in the soil's susceptibility to expansion in the presence of water and means that the treated soil is less likely to undergo excessive settlement under load, which may help to improve its stability and load-bearing capacity.

With the initial addition of 2% olive pomace, a slight increase in the compression and swelling indices was observed, but these values then gradually decreased until they were reduced by around half.

Olive pomace significantly reduced the swelling index from 11% to 5.5%. Similarly, the compression index also fell, from 31% to 18%. These results indicate a significant improvement in the geotechnical properties of the soil following the addition of olive pomace. This reduction in the compression and swelling indices suggests a reduction in the soil's susceptibility to excessive deformation under load or in the presence of water.

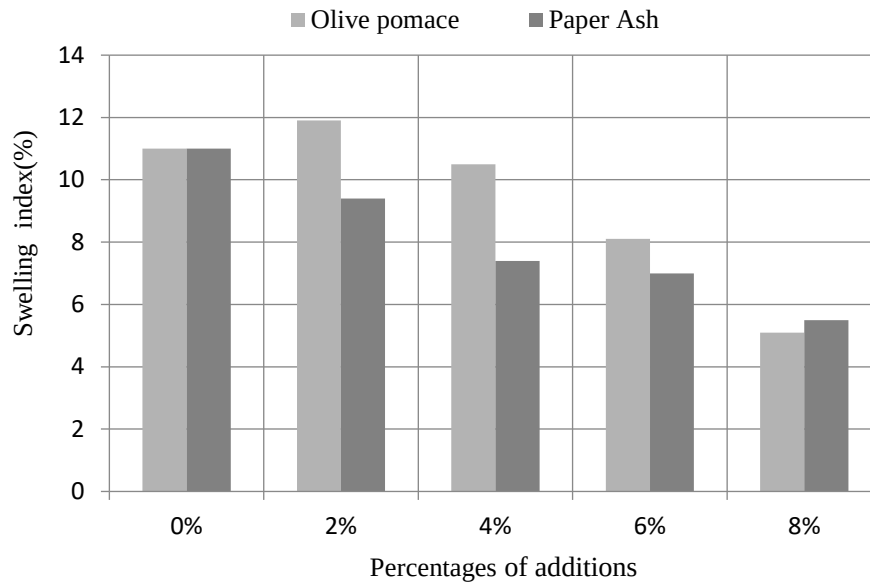


Figure 14: The effect of additions on the swelling index

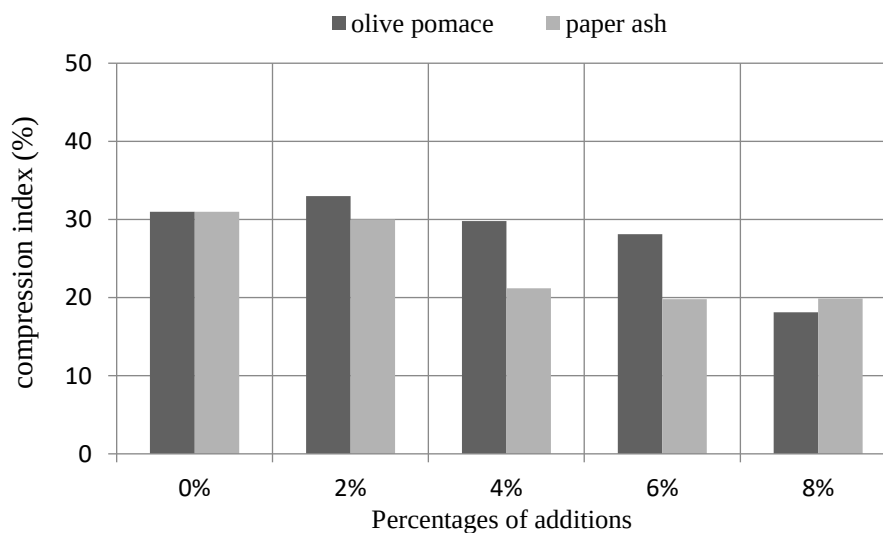


Figure 15: The effect of additions on the compression index

5 Conclusion

Incorporating paper ash into soils is an effective method for improving their geotechnical properties. The ash acts as a stabilizing material, enhancing the soil's resistance to vertical loads (compression) and horizontal forces (shear). Clay soils, which are particularly prone to swelling when absorbing water, benefit significantly from this addition. Paper ash reduces the ability of soil particles to retain water, thereby decreasing their swelling potential.

On a microstructural level, the chemical interaction between paper ash and soil components results in the formation of binders, such as cementitious compounds. These binders reduce the size and quantity of pores in the soil, enhancing overall cohesion and minimizing deformation caused by moisture

This approach is an innovative solution for stabilizing soils and improving their mechanical performance, while mitigating the risks associated with their sensitivity to water

The incorporation of olive pomace into soils is an innovative approach to improving their physico-chemical and mechanical properties, thereby enhancing their stability and performance under different conditions. The addition of olive pomace helps to reduce susceptibility to swelling by limiting the expansion of clay particles.

By altering the internal structure of the soil, olive pomace enhances the shear and compression parameters, thereby strengthening the soil's resistance. This modification improves cohesion between soil particles, increasing overall strength. Furthermore, by modifying the microstructure, olive pomace reduces pore size and increases the apparent density of the soil

These additions are currently regarded as a short-term solution for specific applications, such as stabilizing construction site runways or facilitating the temporary passage of heavy machinery.

Future research will focus on:

- **Studying long-term behavior:** This includes evaluating the resistance of stabilized soils to freeze-thaw cycles, prolonged humidity, and repeated mechanical stress.
- **Durability:** It is essential to determine whether these temporary solutions can be made durable, particularly for applications in sustainable infrastructure.

This work paves the way for the increased use of alternative and recycled materials in soil engineering, fostering a more sustainable and cost-effective approach

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