DOI: 10.2478/sspjce-2021-0013

Treatment of clay soil with paper ash

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Abstract

The mineralogy of fine soils such as clays has always posed problems and remains an uncontrollable phenomenon in the presence of water and causes destructible damage throughout the world. In order to minimize the cost of implementation, it is necessary to find practical and less expensive solutions to ensure the stabilization of these soils by the valorisation of local waste available in nature. This article concerns an experimental study on the treatment of reconstituted soil by the addition of paper ash of different proportions on a set of standardized tests, the preliminary results show that the paper ash to the clay soil improves its swelling potential, its plasticity, its compaction characteristics, and its shear strength parameters.

Key words: recovery, industrial waste, stabilization, paper waste ash

1 Introduction

Paper ash is an inorganic waste product from the burning of paper and has a cementitious and pozzolanic appearance due to the presence of lime (CaO). The increasing accumulation of waste in nature requires rapid action to minimise the high cost of implementation on the one hand and to protect the environment on the other. The use of waste paper as an additive in the stabilisation of clay soils has shown satisfactory values. Following the results obtained by [1] used Nanostructured Waste-Paper Ash (NWPA) as adjuvants to improve the geotechnical properties of lateritic soil with different percentages from 3% to 15% by weight on a set of standardized tests. The best results are obtained at 12% a decrease in the plasticity index, good compactness, an increase in the CBR index. The compressive strength increases with the 28 day cure time.
The work [2] determined the optimum percentage concentration of Waste-Paper Sludge Ash (WPSA) as an additive for best performance of clay soil with variants from 2% to 14% by total weight with a curing time of 14 to 28 days. A proportional increase between the addition and the compressive strength and CBR value up to 12% and then it starts to decrease. The durability of the addition is ensured by the curing time of 28 days.

The authors [3] repeated the experiment on soft sandy clay soil to show the effect of wastepaper sludge ash (WPSA) on the mechanical behaviour and microstructures of the soil.
A mixture of soil and additions from 2% to 16% by weight. The highest values of shear strength, compression are obtained at 10% of the addition. Without forgetting the change of the microstructure due to the appearance of new minerals.
The authors in [4] presented two investigations which were carried out to stabilize the soil, the first in the laboratory by compression testing and the second in situ by compaction testing using percentages ranging from 3% to 6% by weight. The mixture of calcined paper sludge and cement promotes an improvement in the bearing capacity of the soil.
The authors in [5] used paper ash as an alternative lime stabilizer. The experimental study showed the effectiveness of the addition on soil behavior and this was proved by improving soil workability and increasing compressive strength with curing periods of 7-14 days.
The same authors [6] have succeeded in showing that ash sludge is a good additive and modifies the geotechnical properties of soil better than lime and cement.
Other authors [7] treated clay soil with sludge from paper ash with a percentage of 2% to 10% by weight over a set of geotechnical tests. The results show a decrease in maximum dry density from 18.2% to 24.2% and an increase in water content from 16.71 (kN/m^3) to 14.97 (kN/m^3) and an increase in compressive strength up to optimum mixing. The saturation threshold is found at 6% of the addition.
The results are similar to the work [8], which confirmed the adhesion between paper ash and clay soil and that the best values are obtained with 5% of the addition.
Because of the enormous amount of paper used for waste in the various departments of the faculties of our university, we wanted to conduct an experiment to exploit and reuse it in the context of soil stabilization and to know its impact in the long- and short-term impact.

2 Materials used

2.1 Reference soil

- **The kaolin** of the Tamazert deposit is extracted by the Soalka company, it is located 17 km north of El-Milia in Jijel City (North-East of Algeria), it contains only the clay fraction. It is a treated kaolin 2 (KT2).
- **Bentonite** originates from the clay deposits of M'Zila (City of Mostaganem). It is a commercial clay. The proprieties of components are in Tables 1 and 2.



Kaolin KT2 Bentonite Reference soil (80%k+ 20%B)

Figure 1: The reference soil components

Table 1: Properties of the reference soil components

Proprieties	Bentonite	Kaolin
pH	7.86	4.94
Water content(%)	9.20	20.00
Gravity specific	2.60	1.87
Free swelling index (%)	83.33	7
Particle size analysis (≤0,08mm)	73	80
Methylene blue	19	2.66
Specific surface area (m^2/g)	399	55.86
liquidity Limite (%)	123	37
Plasticity Limite (%)	40	15
Plasticity Index (%)	83	22

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

Oxides	Kaolin	Bentonite
SiO_2	54.3	65.8
Al_2O_3	29.2	14.5
CaO	0.863	6.39
Fe_2O_3	7.83	3.50
K_2O	4.56	2.65
MgO	0.630	2.87
TiO_2	0.294	0.349
Na_2O	0.156	3.04
SO_3	0.356	0.479
P_2O_5	0.421	0.0818

2.2 Industrial waste

Paper is considered an industrial waste available in all Algerian administrations. The first phase is focused on the collection of paper and then combustion to obtain ash prepared for use as a stabilizing addition. The proprieties of the paper ash are in Tables 3 and 4.



ollect paper Combustion Paper ash

Figure 2: The stages of preparation of industrial waste

Table 3: Physical properties of paper ash

Proprieties	paper ash
pH	12.33
Gravity specific	3.42

Table 4: Chemical analysis of paper ash by XRF

Oxides	SiO_2	Al_2O_3	CaO	Fe_2O_3	K_2O	MgO	TiO_2	Na_2O	SO_3	Cl
Paper ash	4.58	1.74	86.3	2.07	0.256	0.977	0.162	1,14	4.58	0.592

3 Properties of reference soil

We used it as feedstock for the preparation of reconstituted soil which is composed of 80% Kaolin KT2 and 20% Bentonite. This option of using reconstituted soil allows us experimentally to have a swelling reference soil with the identical properties for the different test samples.

3.1 Physical-mechanical properties

The identification is based on the physical-mechanical parameters during the preliminary tests. The characteristics are in Table 5.

Table 5: Geotechnical Properties of reference soil

		Properties	Values
Physical Properties		pH	9.81
		Specific gravity	1.78
		Free swelling index (%)	61.5
		Liquidity limits (%)	70
		Plasticity limits (%)	35
		Plasticity index (%)	35
		Methylene blue	6.66
		Specific surface area (m^2/g)	138
Mechanical proprieties	Compaction	Optimum water content (%)	20.20
		Maximum dry density (t/m^2)	1.55
	Shear test	Cohesion (Bar)	0.02
		Internal friction angle (°)	3
	Compressibility	Compression index (%)	19.4
		Swelling index (%)	9.8

Atterberg limits allows to know the type of soil and the state of soil from the index of plasticity according to [9], it is a plastic clayey soil. According to the same classification, the results show that the soil is swelling, medium compressibility. The cohesion value found shows the weak liaison between the particles and also the shape of the narrow Proctor curve shows the sensitivity of the soil, all these properties favour the swelling of the soil.

3.2. Chemical analysis of soil mixture

The chemical analyses performed at the University of Farhat Abbas 1's Unit of Research on Emerging Materials are summarized in the Table 6.

The results of chemical studies indicate that the major constituents of the studied soil are oxides SiO_2 (56.2%), Al_2O_3 (27.3%), and Fe_2O_3 (7.19%), with K_2O (4.23%) coming in second, followed by traces of MgO, TiO_2, Na_2O, SO3 and P_2O_5. The sol is relatively rich in silica, aluminium. The presence of silica with aluminium favours the appearance of kaolinite. The presence of potassium is attributed to the existence of illite and muscovite.

Table 6: Chemical analysis of soils used by XRF (x-ray fluorescence)

Oxides	**SiO_2**	**Al_2O_3**	**CaO**	**Fe_2O_3**	**K_2O**	**MgO**	**TiO_2**	**Na_2O**	**SO_3**	**P_2O_5**
80%K+20%B	56.2	27.3	1.51	7.19	4.23	0.872	0.299	0.465	0.339	0.381

The information in Table 3 shows that the CaO content is very high and the most abundant (85%). Due to the nature of the waste, which contains only celluloses, the triangular table SiO_2- CaO- Al_2O_3 allowed us to classify this waste in class C according to the American Society for Testing and Materials (ASTM) standards, which favours the chemical reaction between the paper ash and the soil components and the growth of the cementitious products C-S-H, C-A-S-H, which play a role in soil improvement.

3.3 Mineralogical analysis of soil mixture

Mineralogical analysis of the natural soil is performed by X-ray diffraction (XRD) on a sample < 63 µm air-dried sample. The objective was to determine the main mineralogical phases. The appearance of an intense peak corresponding to Quartz (SiO_2) (2θ = 26.26, d = 3.34) then kaolin ($Al_2Si_2O_5(OH)_4$) (2θ = 12.3, d= 7.16), muscovite (2θ = 8.2, d = 9.9), Biotite, also the appearance of illite $(KH_3O)Al_2Si_3AlO_{10}(OH)$ (2θ = 26.26, d = 9.99) (Figure 3).

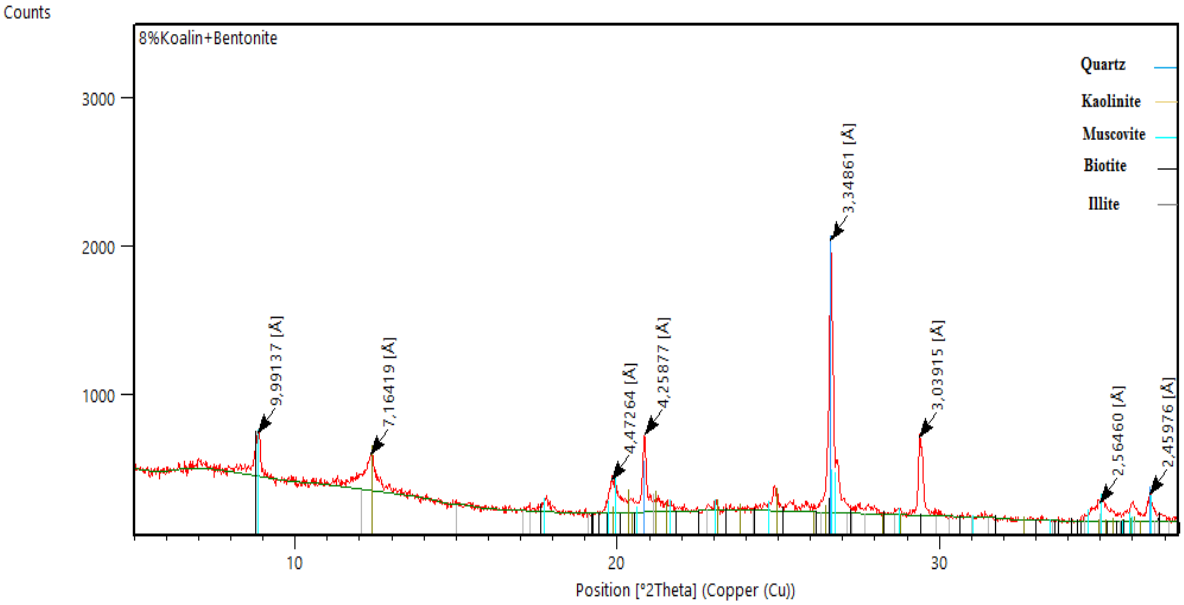


Figure 3: X-ray diffraction of reference soil

4 Methods

In order to ensure the stability of reference soil, paper ash was used as an additive to improve the geotechnical properties of this soil, several percentages have been proposed 2 %by weight, 4%, 6%, 8% on a series of standardized tests:

a) pH according to standard NF ISO 10390:1994 [10]

The determination of the pH is necessary to quantify the contribution of acidity, the alkalinity of a solution can be expressed by the concentration of H+. The reading is made directly on a pH meter.

b) Specific gravity according to standard NF P 94-054

The standard (NF P 94-054) [11] applies to any sample of intact or reworked soil whose largest elements are smaller than 2 mm. The purpose of the test is to determine the average density of a sample composed of particles.

c) Free swelling index according to standard IS-2720-PART-40-1970 [12]

Soil passing through a 425-micron sieve is used in this test. 10 g are soaked in two test tubes for 24 hours (one with distilled water and the other with kerosene)

Percent = ((*Vd*-*Vk*) / *Vk*) * 100

Or:

Vd = The volume of the soil sample read in the graduated cylinder containing distilled water.

Vk = The volume of the soil sample read in the graduated cylinder containing kerosene.

d) Atterberg limits According to standard NF P 94-051 [13]

It is a property characterizing a coherent soil, resulting in a variation of the mechanical behaviour of this soil according to its water content. The three distinguished limits (W_L,W_p, I_p) make it possible to classify the soil (very plastic, plastic, less plastic).

e) Compaction test according to standard NF P94-093 [14]

The test consists in damming a soil sample in a defined and repetitive way by varying its water content. The regular measurement of the water content and the dry density of the material once plotted on a graph, gives a bell-shaped curve. The optimum is then determined by the maximum point of the curve which gives the optimum water content for a maximum density.

f) Direct shear test. According to standard NF P 94-071-1 [15]

The test comprises the shearing of three specimens of the same dimensions prepared under conditions sheared at the same speed but subjected to different vertical forces. The principle of the test consists in determining the intrinsic characteristics of soil C and φ.

g) Compressibility test according to the standard (XP P 94-090-1) [16]

The compressibility test according to the standard XP P 94-090-1 is a fundamental and slow test because it is necessary to wait for the end of the consolidation for each stage on fine soils and fine coherent materials. The oedometer compressibility curve can be characterized by several parameters: the swelling index and the compressibility index.

5 Results and discussions

The results of the effect of paper ash on soil behaviour are summarized in the following figures:

5.1 Effect of paper ash on the pH

Figure 4 shows that the treated soil has a higher pH than the untreated one and this is for all the proportions of addition used. It is a basic medium, which is reflected by a better dissolution of silicates and aluminates of the clayey proportion of the soil stabilized by the paper ash and improved mobility of ions during ionic interactions.

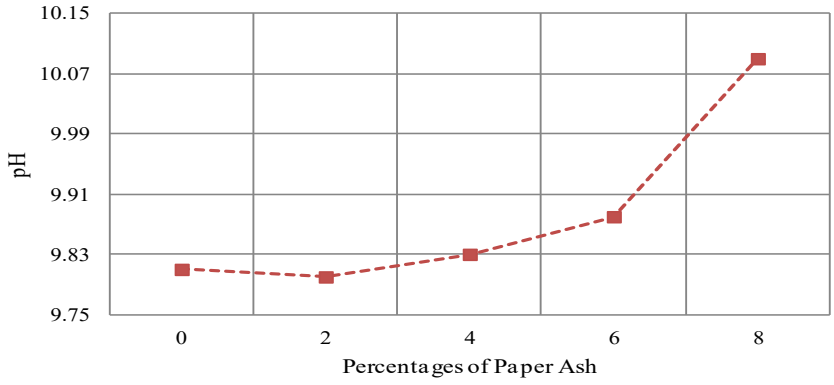


Figure 4: Effect of paper ash on the pH

5.2 Effect of paper ash on specific gravity

Figure 5 shows the change in specific gravity of the soil mixed with a varying percentage of the paper ash. The addition of the admixture increases the specific gravity of the soil.
This increase may be due to the higher value of the ash (3.42) than that of reference soil (1.78) which makes the soil denser.

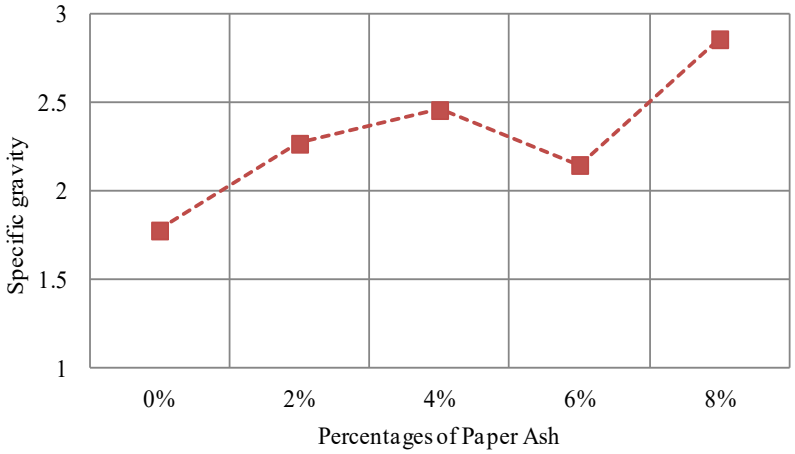


Figure 5: Effect of paper ash on specific gravity

5.3 Effect of paper ash on the free swelling index

Figure 6 shows a noticeable decrease of the free swelling index with the increase of the percentage of paper ash. It decreases to 2%, then it increases to 4% and then it starts to decrease progressively until it reaches the value of 11%.The improvement exceeds almost 80% of the reference soil.

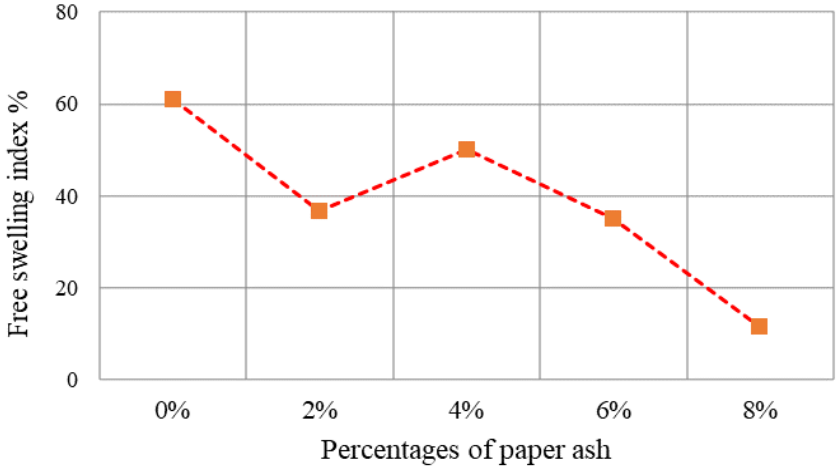


Figure 6: Effect of paper ash on the free swelling index

5.4 Effect of paper ash on the Atterberg limits

The Atterberg limit is considered as an indicator qualifying the plasticity. The results obtained from reference soil show that the plasticity index is 35%, the liquidity limit is 70% and a plastic limit of 35%, which indicates that the clay is of high plasticity.
A considerable increase in the plasticity limit of the soil compared to the liquidity limit which increases slightly with the increase of the percentage of ash. So, the effect of paper ash is approved when the plasticity index gradually decreases from 35% for untreated soil to 28% for treated soil with 8% addition, which makes the soil less plastic with better soil workability (Figure 7).

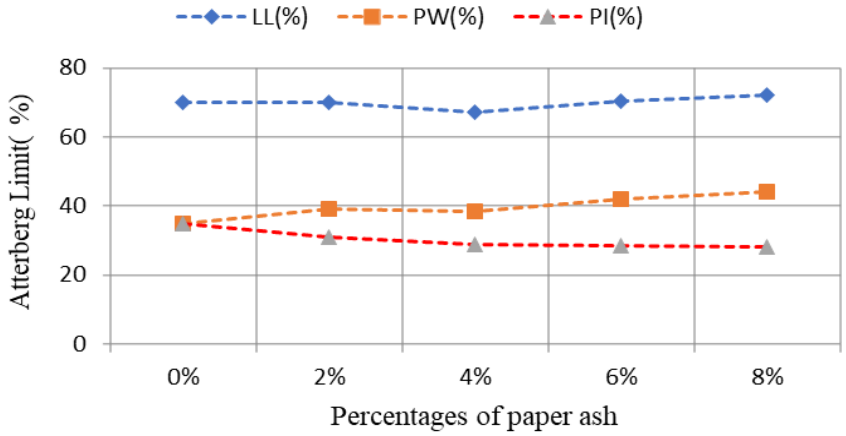


Figure 7: Effect of paper ash on the Atterberg limits

5.5 Effect of paper ash on compaction

Figure 8 demonstrated the effect of paper ash on soil compaction. A notable decrease in the dry density compared to the reference soil. After the percentage of 2% the density remains almost constant (1.42-1.40-1.39) is justified by the need for low compaction energy. The same figure shows that the optimum water content decreases linearly with the evolution of the ash up to 6%, this is due to the cementitious effect of paper and necessitates water for its hydration.

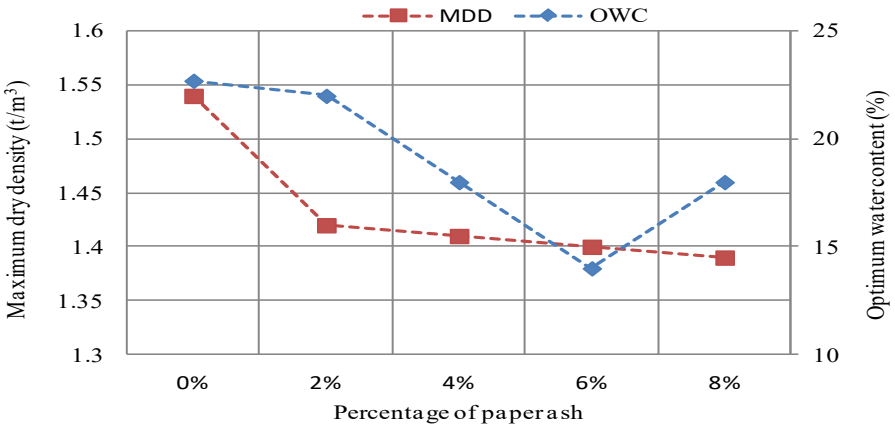


Figure 8: Effect of paper ash on compaction

5.6 Effect of paper ash on shear strength

Shear strength is one of the most significant soil properties and is required whenever a structure depends on the shear strength of the soil. The mechanical characteristics determined in direct shear (Figure 9) show that the reconstituted soil has varying angles of friction. A well-developed cohesion is comparable to the reference soil. The increase in cohesion from 0.02bar to 0.64 bar, after the percentage of 4% the curve begins to decrease until 0.39 bar then it increases by 0.54 bar. While the angle of friction increases gradually from 4.5° for 0% to 13° for 4%. Then it increases from 11°for the percentage of 6% to 15° for the percentage of 8%. Cohesion and friction angle promote the increase in shear strength. The best results are provided by the combination of cohesion = 0.5 bar and friction angle = 15°.

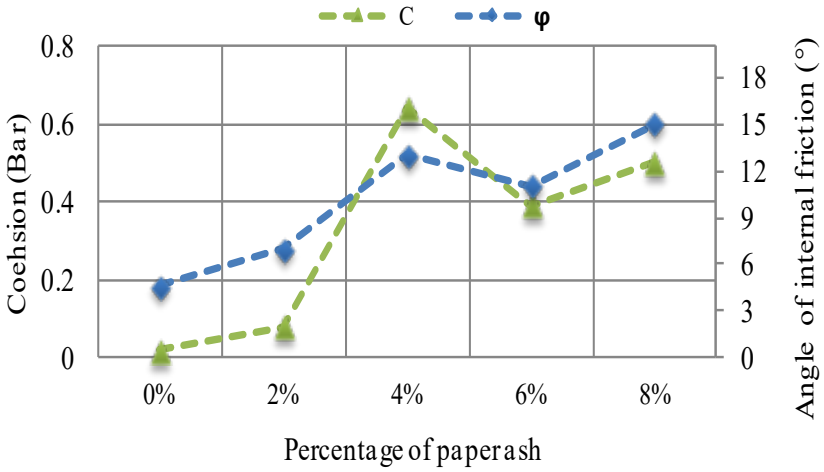


Figure 9: Effect of paper ash on shear strength

5.7 Effect of paper ash on the oedometer compressibility test

The effect of paper ash on compressibility is shown in Figure 10. The increase in addition gradually decreases the swelling index from 9.8% =10% for a reference soil to 5.5% for 8% paper ash, and also a reduction in compression index from 31% for the untreated soil to 5% for 8% addition, so there is a decreasing linear variation for the soil to go from swelling to less swelling and from less compressible to non-compressible soil. The reason for the decrease in swelling is justified by the additive which has modified the mineralogy of the reference soil by the formation of new minerals interacting with the cementitious-looking paper ash components.

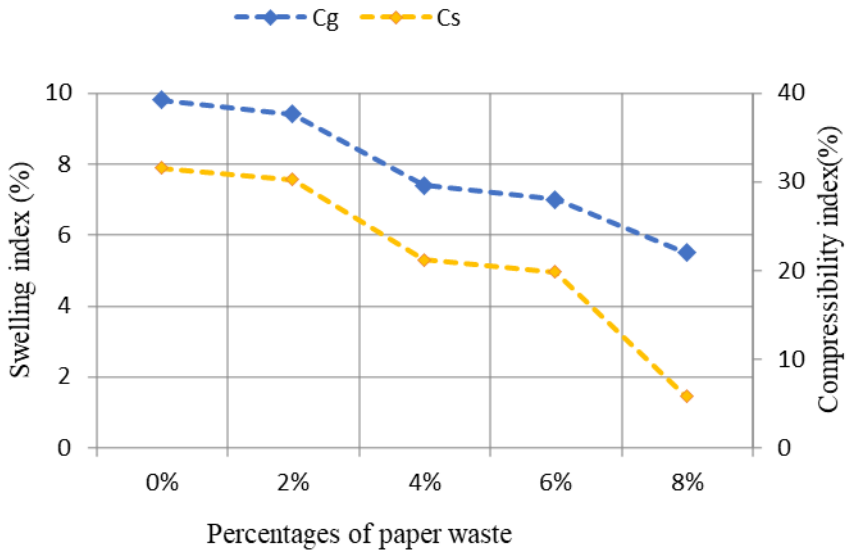


Figure 10: Effect of paper ash on soil compressibility

6 Conclusion

Soil treatment is a technique that has developed very rapidly in recent years and is still set to undergo significant development. Easy to implement, economical and efficient, soil stabilization by paper ash promotes the improvement of geotechnical properties in the short term on the various tests carried out:

- An improvement in soil plasticity decreases by almost 20% compared to the reference soil.
- A decrease of 80% in the free swelling index compared to the untreated soil.
- An increase of 43% in the angle of friction and 60% in the cohesion compared to the reference soil.
- A decrease of 81% in the swelling index and 40% in the compressibility index compared to the reference soil.

Our objective is also to choose the right percentage that gives us the best improvement results and confirms the saturation threshold.
For future work it is also necessary to know the microstructure of the soil by SEM to confirm the observed macrostructure, also to confirm the durability of this addition in the long term.

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