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EXAMINING THE SWELLING POTENTIAL OF EXPANSIVE SOIL CONTAINING WASTE PAPER ASH

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ABSTRACT: Construction on swelling soil can be a critical problem for civil engineers because of its propensity to volume change. Using waste material to enhance this type of soil would be an ideal choice, as it takes into consideration economic factors and environmental protection. This study investigates the effectiveness of using waste paper ash (WPA) to enhance the swelling soil. The expansive soil in the study was first produced by mixing fine soil with bentonite. Different percentages of WPA, ranging from 0% to 12% of the sample's dry weight, were combined with the soil. A direct method using a single oedometer test was conducted to measure the swelling potential and swelling pressure of the samples. The results showed that both the swelling potential and swelling pressure decreased as the paper ash percentage content increased until a level of 9% of WPA was reached, and after that, both the swelling potential and pressure began to show increases of around 50% and 10% respectively, compared to the values for a 9%WPA content. In addition, consistency limits were conducted for the samples, and similar behavior was observed. Microstructure examinations were performed for the swelling soil and the waste paper ash and for the soil with a 9% content of WPA. It was concluded that an optimum paper ash content of 9% of the soil's dry weight was required to enhance the expansive soil's properties. This showed a reduction of 81% and 80% in swelling potential and swelling pressure, respectively.

Keywords: *Waste paper ash, Expansive soil, Swelling pressure, Swelling potential, Environmental protection*

1. INTRODUCTION

Swelling or expansive soil is widely distributed in many areas worldwide and is problematic in its natural state [1, 2]. It exhibits volumetric change when subjected to different environmental conditions, characterized by swell-shrinkage behavior [3]. This behavior can be responsible for subsequent building deterioration, especially with lightweight structures. Therefore, numerous efforts have been made to stabilize swelling soil because, in many cases in the field, it is not an available option for the geotechnical engineer to avoid this kind of soil.

Accordingly, many researchers have tried to enhance swelling soil with additives, mainly lime and cement, for example [4] and [5].

However, producing such additives can negatively affect the environment by producing carbon dioxide, which is regarded as a costly material. In addition, using high percentages of these additives can make the soil structure more brittle. Therefore, care should be taken with the amount of additives to be added. Using an 18% content of limestone powder has provided better enhancement to improve highly expansive soil [6]. In another study, adding 5% of cement or steel fibers or injecting with cement grout showed a better improvement [7].

Considering the limitations of traditional swelling soil stabilizers, in recent decades, using waste or by-product industrial materials as additives to soil has been considered a viable approach that has dual functions; in addition to improving the soil, it contributes to environmental protection. Several researchers have investigated the engineering characteristics of swelling soil mixed with industrial waste such as fly ash [8]. Similarly, waste glass powder has also been utilized to improve the swelling of soil [9].

In addition, marble dust has been tried as an alternative additive; different percentages were added to black cotton soil and tests were carried out including Atterberg limits tests and free swell index, along with tests of compaction characteristics, swelling percentage and unconfined compressive strength. The results indicated that adding marble dust has a significant effect on improving the characteristics of swelling soil [10].

Waste paper can be found in large amounts in any country. Paper recycling is undoubtedly one of the most successful recycling processes for producing new paper in many countries around the world and should be promoted. Many researchers have also investigated the potential use of waste paper in the reinforcement for concrete [11] or as a partial replacement of concrete [12].

However, a few previous studies have been found to explore the effectiveness of using waste paper sludge to enhance soil. Waste paper sludge ash

(WPSA) was used in clayey soil. The results of tests on the admixture showed that an admixture of 10% waste paper ash (WPSA) achieved a better improvement in shear strength. In addition, the California Bearing Ratio (CBR) increased about 1.5 times compared to that of untreated soil and 3.6 times for unsoaked and soaked soil conditions, respectively [13].

Another study was conducted [14] on the effect of adding WPSA to a swelling clay. The unconfined shear strength and the stability of the swelling soil in terms of volumetric change was greater for soil with WPSA added compared to soil with industrial lime added.

Furthermore, using 125 gm was concluded provide a good amount of nanostructured waste paper ash to improve lateritic soil when used for pavement structures [15].

From the above literature review, it is obvious that attempts have been made to exploit the waste paper sludge which is a waste product of paper recycling factories. However, in Iraq and many developing countries, paper recycling facilities are limited to providing paper sludge. Conversely, a large amount of waste paper can instead be found in landfills. Thus, the use of waste paper ash rather than waste paper sludge in soil mixes is more efficient in this case.

In this study, different percentages of waste paper ash are added to swelling soil samples to investigate the influence of this material when used instead of other additives to stabilize swelling soil.

2. RESEARCH SIGNIFICANCE

This study focuses on the use of waste paper to lessen the swelling characteristics of soil by adding different percentages by weight to soil (at 0%, 3%, 6%, 9%, and 12%). Different properties, including swelling potential, swelling pressure, consistency limits, and compaction properties, were investigated. On one hand, using this type of additive can significantly diminish the amount of waste in landfills and reduce the negative impact on the environment which would be produced by traditional alternatives. On the other hand, it would improve swelling soil and lessen problems caused by swelling soils from a civil engineering point of view.

3. MATERIALS and METHODS

A series of experimental tests were conducted to study the ability of WPA to improve swelling soil.

3.1 Materials

3.1.1 Swelling Soil

Bentonite was mixed with fine clay obtained from the south of Baghdad City to create artificially swelling soil. Soil and bentonite were combined in a 2:1 ratio. The properties of the resulting swelling soil were identified and are displayed in Table 1. The soil grain size distribution of the soil used is depicted in Fig. 1. Van der Merwe stated in 1964 that the swelling potential of soil might be regarded as high based on the value of the plasticity index (48%). The soil used in this study contains 80% clay, which qualifies it as highly expansive soil. The expansion potential of soils categorized as clays of high plasticity (CH) is typically high to very high. The soil employed in this study is categorized as very highly expansive soil in terms of its swelling capability based on its consistency limits.

Table 1 Geotechnical properties of the expansive soil sample.

Physical properties	Soil with bentonite	Specification
Specific gravity (Gs)	2.7	ASTM D 854 [16]
% Clay(<0.005mm)	80	-
Liquid limit (L.L), %	74	ASTM D 4318 [17]
Plastic limit (P.L), %	26	ASTM D 4318 [17]
Plasticity index (P.I), %	48	ASTM D 4318 [17]
Optimum moisture content (O.M.C), %	20.0	ASTM D 698 [18]
Maximum dry density, gm/cm^3	1.51	ASTM D 698 [18]
Soil classification (USCS)	CH	ASTM D2487 [19]

(USCS) Unified Soil Classification System.

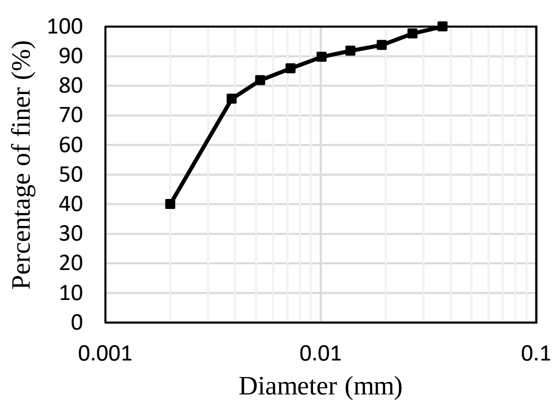

Fig.1 Grain size distribution of the swelling soil.

An energy–dispersive X-ray spectroscopy (EDS) test was conducted for the swelling soil and the results are presented in Table 2. The most dominant elements are silicon and aluminum. In addition, scanning electron microscope (SEM) examination of the swelling soil was conducted, and the results are shown in Fig. 2.

Table 2 Results of EDS for swelling soil.

Element	Atomic %	Atomic % error	Weight %	Weight % error
C	21.6	0.4	14.2	0.2
O	56.2	0.6	49.3	0.5
Na	1.0	0.0	1.3	0.1
Mg	1.9	0.0	2.5	0.0
Al	3.8	0.0	5.6	0.1
Si	11.5	0.1	17.6	0.1
S	0.3	0.0	0.5	0.0
Cl	0.2	0.0	0.4	0.0
K	0.3	0.0	0.6	0.0
Ca	2.5	0.0	5.6	0.0
Ti	0.0	0.0	0.1	0.0
Fe	0.7	0.0	2.2	0.1
Ni	0.0	0.0	0.1	0.0

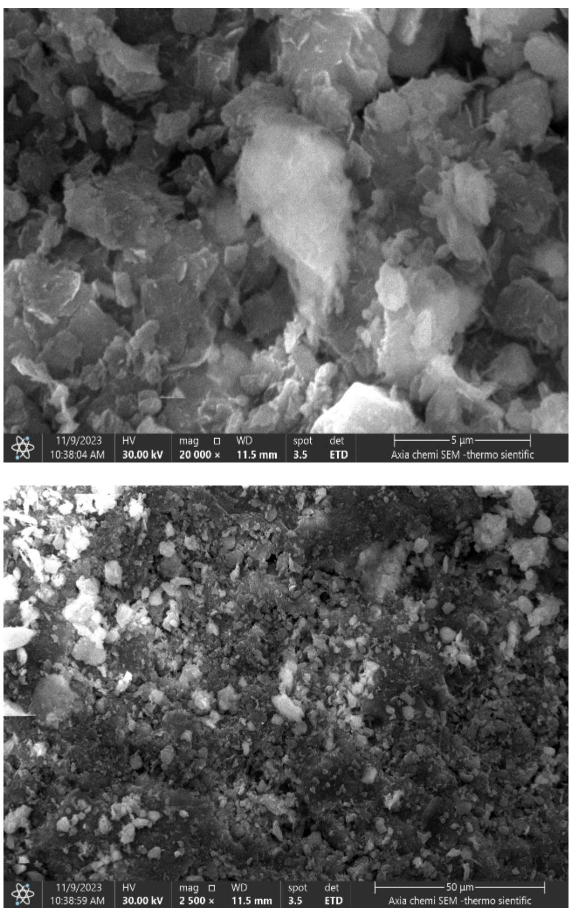

Fig.2 SEM for the swelling soil.

3.1.2 Waste paper ash

Waste paper ash (WPA) refers to the residue left behind after burning paper. When paper is burned, the organic materials combust, leaving behind mainly inorganic mineral components in the ash. The composition of the ash depends on various factors such as the type of paper burned, the temperature of combustion, and presence of additives in the paper.

WPA typically contains a variety of minerals, including calcium carbonate, potassium carbonate, magnesium carbonate, and various trace elements. Its composition makes it suitable for certain applications, such as:

- Soil amendment: WPA can be used to amend soil, especially if it is deficient in certain minerals. It can help neutralize soil acidity and provide essential nutrients to plants.
- Construction material: In some cases, WPA can be used as a partial substitute for cement in concrete production. This not only reduces the environmental impact of concrete production but also utilizes a waste product.
- Fertilizer: Because of its mineral content, WPA can serve as a source of nutrients for plants when added to compost or used directly as a fertilizer.
- Absorbent: Waste paper ash can be used as an absorbent material, for example, to absorb oil spills or as a component in cat litter.

Printed waste paper was collected from locations, in particular schools and universities, and then incinerated in an oven. The waste paper was blasted at 525°C for 60 minutes according to ASTM D 586 [20]. Sieve no. 600 µm was used after the oven incineration to obtain fine ash as shown in Fig.3. In this study, paper ash was used at a range of percentages of 0%, 3%, 6%, 9% and 12% of the dry weight of the swelling soil.

Fig.3 Waste paper ash inside the furnace.

To determine the chemical composition of the paper ash, an EDS test was conducted as shown in Table 3. It can be noted that the most available element in WPA is calcium. The results of the SEM examination of the WPA are shown in Fig. 4.

Table 3 EDS results for waste paper ash.

Element	Atomic %	Atomic % error	Weight %	Weight % error
C	25.1	0.2	16.2	0.1
O	59.7	0.4	51.4	0.3
Mg	0.2	0.0	0.3	0.0
Si	0.4	0.0	0.6	0.0
Ca	14.6	0.1	31.6	0.1

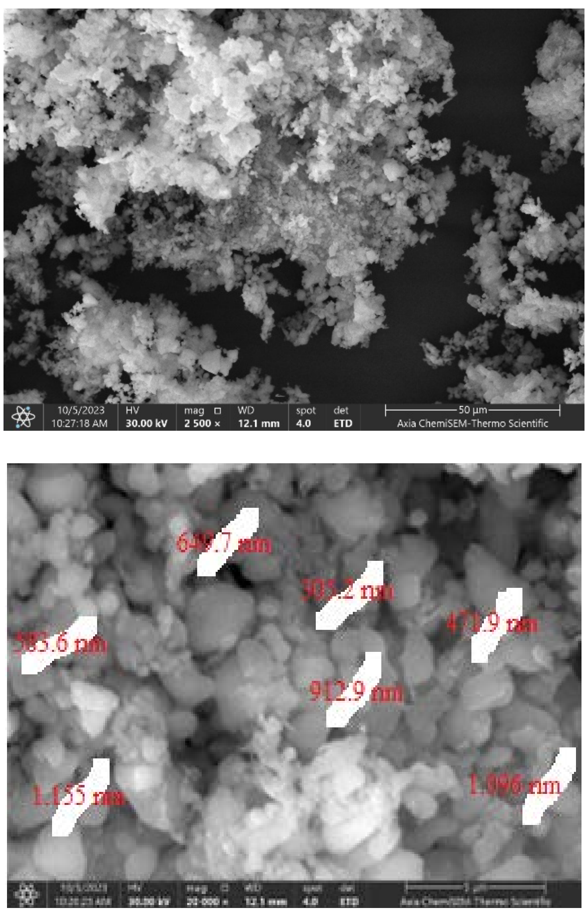

Fig.4 SEM results for waste paper ash.

4. RESULTS AND DISCUSSION

4.1 Effect of WPA on Consistency Limits

The consistency limits of the soil can be understood as an indicator of the soil's swelling susceptibility. Therefore, in this study, consistency limits were determined for the treated and untreated soil samples as shown in Table 4.

The type and quantity of ash supplied, as well as the original characteristics of the soil, all influence how waste paper ash affects the soil's consistency limits. Minerals found in waste paper ash can alter the physical properties of the soil, such as its consistency limits, including the plastic limit (PL), liquid limit (LL), and plasticity index (PI). The liquid limit for soil containing varying percentages of paper ash is depicted in Fig. 5. With a rise in WPA content, it is evident that the liquid limit declines. It decreased from 75% for untreated soil to 47% and 40% for 3% and 6% of WPA content respectively. However, a significant reduction occurred for the mixture with 9% WPA, where the liquid limit reached 35%. However, with the further addition of WPA, the liquid limit increased to 38%. The plastic limit even decreased with increases in the WPA content as shown in Table (4). In a similar vein, Fig. (6) illustrates that the resultant plasticity index reduced. The reduction in the plasticity index started at 50% for the soil with 3% WPA up to 63% for the 9% WPA mixture. This indicates that adding a WPA to the swelling soil can improve the soil by lessening the soil's vulnerability to swelling.

It can be noticed that the sharp reduction in both the liquid limit and plasticity index occurred at a 3% WPA content, whereas it continued with a gradual decrease until a 9% WPA content.

However, when the WPA content was above 9%, a modest increase was shown by both the plasticity index and the liquid limit but still low compared to the initial values.

It is important to highlight that the most striking finding is that the mixture of 9% WPA achieved the lowest values for the plasticity index. Therefore, it can be concluded this is the optimal percentage to improve the swelling soil used in this study.

Mixing WPA with swelling soil can cause complex chemical reactions and mechanical effects. The previous EDS analysis of waste paper ash showed that the most abundant ion within its structure was calcium.

A chemical reaction can occur between the clay particles and the calcium present in WPA. Cations exchange between the sodium ion in the clay and the calcium ion in the WPA will take place. This will reduce the diffuse double layer around the clay particles and consequently reduce the plasticity of the mixture. Moreover, this reaction can result in mechanical effects by making the clay particles more flocculate, which leads to a reduction in the plasticity of the soil.

Table 4 Consistency limits with different percentages of waste paper ash.

Paper ash content %	Liquid limit %	Plastic limit %	Plastic index %
0	75	26	49
3	47	24	23
6	40	21	19
9	35	18	18
12	38	20	18

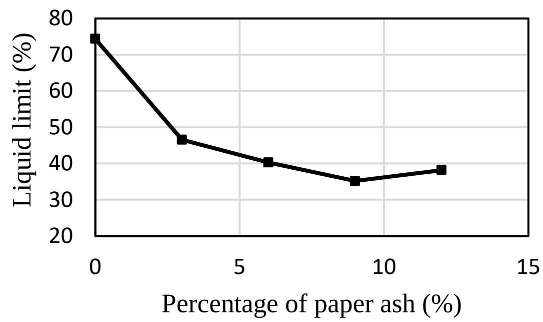

Fig.5 Changes in the liquid limit for different percentages of paper ash.

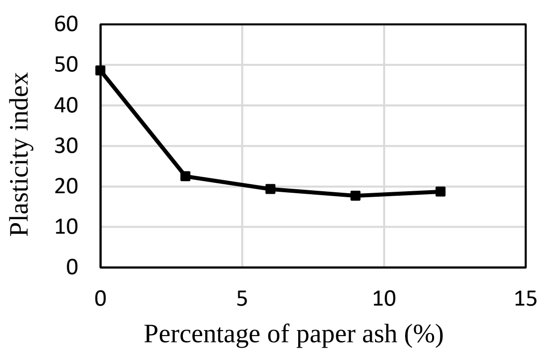

Fig.6 Changes in plasticity index for different percentages of paper ash.

4.2 Effect of WPA on Compaction Characteristics

The effect of WPA on the compaction characteristics of soil can vary depending on several factors, including the type and amount of ash added, the properties of the soil, and the compaction method used.

Fig. 7 depicts the impact of adding waste paper on the ideal water content and dry density of the soil samples. As the ash concentration rose, so did the dry density. The figure shows that the dry density was 1.51 and 1.59g/cm^3 for the untreated sample and the soil with 9% WPA respectively. This increase in dry density can be primarily linked to the fact that the ash may act as a filler material between the soil particles, decreasing the voids within the soil matrix and resulting in increased density of the soil mass.

The ion exchange that occurs between clay particles and WPA, as mentioned in section 4.1, results in the flocculation structure of the soil particles, and under compaction, the particles will rearrange in a denser structure.

However, when the ash content increased beyond 9%, there was no significant change in the soil dry density. This plateau behavior could be attributed to the soil reaching a stable structure by filling all the voids with WPA. In addition, adding more WPA would not be active in a further chemical reaction that bonds the soil particles. This means that the soil is sufficiently stabilized, and no more enhancement will be expected with further increments of WPA. Therefore, for compaction characteristics, 9% can be considered as an optimal percentage to mix with the swelling soil used in this study.

Fig. 7 indicates that with an increasing percentage of ash content, the optimum water content also increased. WPA is characterized by a high surface area, which permits the absorption of more water during compaction to achieve the optimum moisture content. In addition, if pozzolanic reactions occur between the calcium in WPA and the silica in the soil, this reaction consumes water in order to take place. The resultant compounds show cementitious behavior.

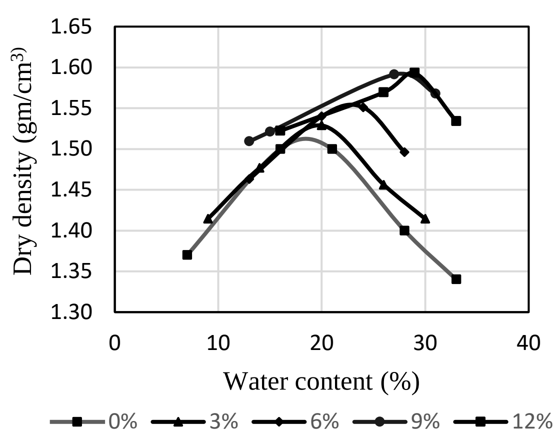

Fig.7 Compaction curves of swelling soil treated with different percentages of paper ash.

However, several variables influence the complex impact of waste paper ash on soil compaction properties. To find the best mix proportions for certain engineering applications and to determine whether waste paper ash is suitable for improving soil compaction, site-specific testing and evaluation are required.

4.3 Effect of WPA on the Swelling Pressure

Swelling potential and swelling pressure are the most significant parameters for swelling soil.
Different techniques can be adopted to measure them. However, in this study, a single oedometer test was conducted according to ASTM 4546 [21]. This test is considered one of the most common and accurate techniques used to measure swelling potential and swelling pressure. The sample was compressed inside the oedometer ring under static load to achieve the optimum dry density. According to this method, the ring was set inside the oedometer cell which was filled with water. The sample was left to swell under a surcharge of 6.9 kPa. The free swell was determined according to Eq (1):

Free swell percentage = $(\Delta h / h)*100$ …………… (1)

where Δh: Change in the height of the specimen, and h: Initial height of the specimen.

Fig. 8 illustrates that adding waste paper ash (WPA) to the swelling soil sample can significantly affect its swelling potential.

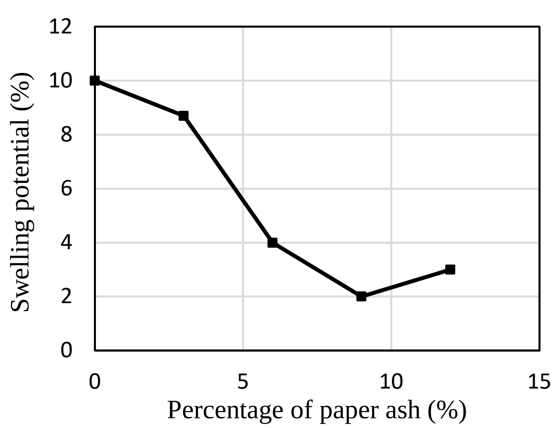

Fig.8 Changes in the swelling potential for different percentages of paper ash.

When adding 9% WPA to the soil, the reduction in swelling potential was determined to be 81%. Following the same trend, the swelling pressure also showed a reduction, and reached 80% when adding 9% WPA, as illustrated in Fig. 9.

The results of the single oedometer test show agreement with the results for the consistency limits. Table 5 illustrates a summary of swelling potential and swelling pressure levels with different WPA contents. The effect of WPA on the swelling pressure of soils can vary depending on several factors, including the type and amount of ash added, the mineralogy of the soil and the environmental conditions.

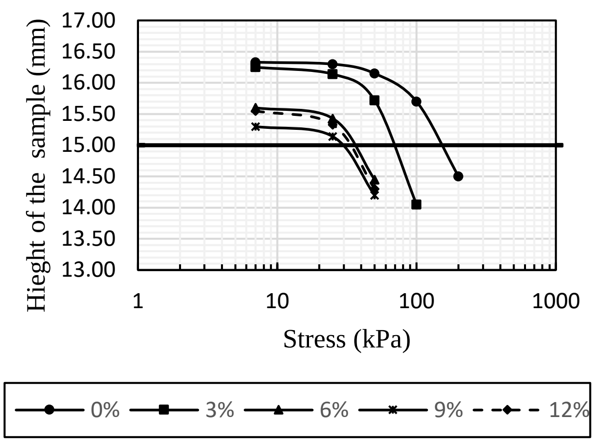

Fig.9 Changes in swelling pressure for different percentages of the paper ash.

Generally speaking, swelling pressure describes the force that soil particles apply when they expand and absorb water, changing their volume in the process. The effect of WPA on swelling pressure can be that the fine particles included in the ash fill in the gaps between these soil particles. WPA can potentially lessen swelling pressure in soils that are prone to swelling, such as expansive clay soils, by reducing the volume available for soil particle expansion.

Table 5 Swelling potential and swelling pressure with different percentages of waste paper ash.

Percentage of paper ash	Swelling potential (%)	Swelling pressure (kPa)
0	10	160
3	8.7	73
6	4	38
9	2	30
12	3	35

The additive's modification of the reference soil's mineralogy through the interacting of the new minerals interacting with the components of cementitious paper ash justifies the decrease in swelling.

However, the specific effect will depend on the unique characteristics of both the ash and the soil, as well as the conditions in which they interact. Site-specific testing and evaluation are essential to assess the suitability of WPA for mitigating swelling pressure in a particular soil.

Soils with a low natural water content, high dry density, poor expansion potential, and fractured state benefit from this treatment. If the soil is ash-reactive, it can be treated with hydrated lime or ash, broken up completely and then compacted to reduce its high tendency for swelling. The pozzolanic reaction of silty soils may be accelerated by ash. Granular soils can have their gradation enhanced.

These findings are consistent with those of [22], who found that adding paper ash to clay soil enhances fluidity, swelling potential, compaction properties, and shear strength parameters.

EDS and SEM tests were also conducted for the soil with the optimal percentage of WPA (9%) as presented in Table 6 and Fig. 10.

The mineral composition of WPA can influence its interaction with soil minerals and water. Some minerals present in WPA, such as calcium carbonate, may have a stabilizing effect on expansive soils by promoting the flocculation of clay particles and reducing their swelling potential. In addition, certain minerals in the ash may react with soil components to form compounds that alter the soil's swelling behavior.

A more thorough examination of the WPA–clay mixes' microstructures reveals the development of a porous matrix with stable connections. Furthermore, different green replacement materials and soils demonstrate that the porosity and strength characteristics of blends show distinct relationships with their porosity and binder concentrations.

Waste paper ash has the potential to absorb water due to its porous nature and high surface area. When incorporated into the soil, the ash may compete with soil particles for water absorption, thereby reducing the availability of water for swelling. This mechanism can contribute to the mitigation of swelling pressure in soils, especially during wetting cycles.

Table 6 EDS of swelling soil with 9% WPA.

Element	Atomic %	Atomic % error	Weight %	Weight % error
C	20.5	0.2	13.4	0.2
O	58.1	0.4	50.6	0.3
Na	0.9	0.0	1.1	0.0
Mg	1.7	0.0	2.2	0.0
Al	3.2	0.0	4.7	0.0
Si	10.7	0.0	16.4	0.1
Cl	0.1	0.0	0.3	0.0
K	0.3	0.0	0.6	0.0
Ca	3.5	0.0	7.7	0.0
Ti	0.1	0.0	0.2	0.0
Fe	0.9	0.0	2.8	0.0

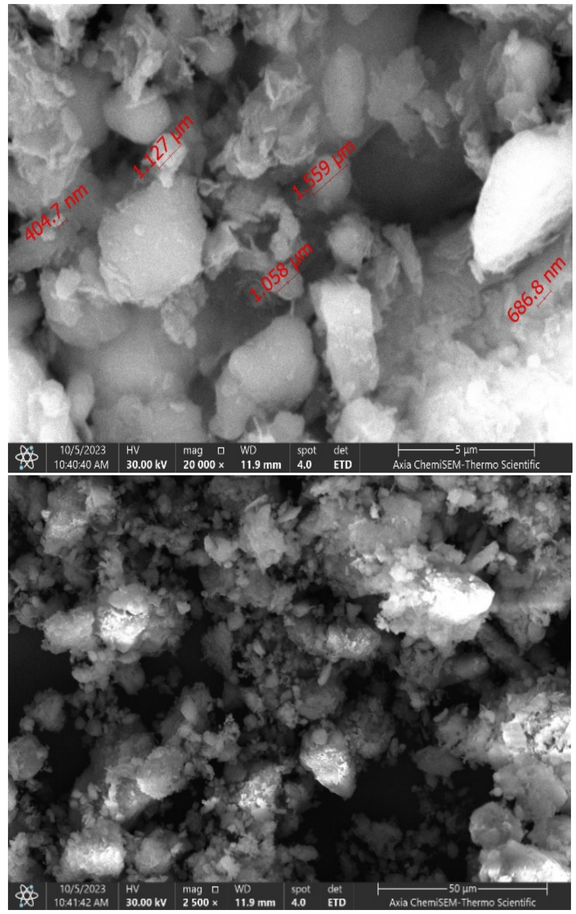

Fig.10 SEM results of swelling soil with 9% of WPA.

This suggests that the WPA responds at a level that maximizes micro-aggregation and inter-particle packing, minimizing inter-particle voids and lowering the water absorption of the resultant composites. The composites' water absorption rises as the WPA content in the clay matrix reaches 9%. This might be because of the clay's many pores, which are caused by the particles' fineness. Furthermore, WPA has a higher hydrophilicity than clay soil and is the most permeable in this instance.

In the same manner, [23] concluded that fiber has a small tendency to absorb water, so as this material occupies a volume within the soil, it decreases the water kept within the soil voids. Also, AlGharbawi et al. [24] concluded that the Magnesium Oxide additive fills the voids and leads to densification of the soil.

When the percentage of WPA exceeds 9%, the voids of the swelling soil are filled with WPA and the mass of the soil increases, so that the specific surface area is changed. In addition, the increase in some mineral content such as Na and Mg leads to an increase in the absorption of water and hence soil swelling.

5. CONCLUSIONS

By investigating the effectiveness of waste paper ash (WPA) in enhancing and enhancing expansive soil, the following conclusions were obtained:

- Using WPA with swelling soil can result in a complex process involving chemical and mechanical effects within the soil matrix.
- Mixing the swelling soil with WPA resulted in a decrease of the liquid limit, the plastic limit, and the resultant plasticity index. The liquid limit was determined to be 75% for untreated soil while it decreased to 35% for the mixture containing 9% WPA; the reduction in the plasticity limit reached 62% for the soil with a 9% WPA content. The reduction in the plasticity of soil indicates an increase in the workability of the soil and a reduction in its swelling characteristics.
- An increase in the ash content of the soil led to an increase in the dry density. The dry density values were measured at 1.51 g/cm^3 for untreated soil and 1.59 g/cm^3 for soil containing 9% WPA. The addition of WPA to swelling soil had a significant impact on its swelling potential. Incorporating 9% WPA resulted in an 81% reduction in swelling potential. Similarly, the swelling pressure decreased by 80% when 9% WPA was added to the soil. This is compatible with the results for the consistency limits.
- *The* optimal percentage of WPA to be used for the swelling soil used in this study was found to be 9%. A further increase in the amount of ash can produce an opposite effect or plateau behavior.

The chemical component of the soil and ash has an important effect on the chemical reaction occurring within the mixture. Therefore, the optimal percentage of the ash can vary depending on the soil type and the chemical components of both the soil and ash. The results of this study offer a sustainable solution for civil engineers to adjust the properties of swelling soil and reduce waste paper in landfills, especially in developing countries.

Moreover, using WPA is preferable to using traditional stabilizers such as lime and cement for many reasons. Firstly, producing such traditional materials causes the emission of carbon dioxide, which has a negative effect on the environment. In addition, their production is considered expensive compared to using available waste paper.

While there are many advantages, as previously mentioned of employing WPA for swelling soil stabilizations, some possible limitations should be considered. Waste paper may be mostly recycled in some countries, so there is no available waste paper to be used as ash to improve the soil. Moreover, properties of the source of waste paper, including the type of paper and the ink used on it, and the burning temperature can affect the chemical compositions of the ash. Therefore, all the mentioned factors should be considered when utilising WPA to stabilize swelling soil in the field.

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