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Original Research Article

STABILIZATION OF EXPANSIVE SOIL MIXTURE USING HUMAN HAIR FIBRE (BIOPOLYMER)

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Abstract

Expansive soils sensitivity to volumetric change is one of the well-known challenges in the field of geotechnical engineering. Various attempts have been made by researchers to solve this problem. Current research presents the effect of human hair fibers on the behavior of expensive soils. A reconstituted soil of 80% kaolin as raw material and 20% bentonite with different percentages of human hair (0%, 0.5%, 1%, 1.5% and 2%) was used.

The microstructure of the formulations was characterized by studying the interactions between soil and human hair using scanning electron microscopy (SEM). The microstructure of the formulations was characterized by studying the interactions between soil and human hair using scanning electron microscopy (SEM). Atterberg limits, compaction characteristics, swelling parameters, compressibility and shear strength were also examined. The results of this study indicate that the inclusion of human hair fibers significantly improves the properties of the expansive soil mixture. These results open up new prospects for the stabilization of expansive soils.

Keywords: expansive soil, stabilization, human hair, SEM, compressibility

1. INTRODUCTION

Expansive soils are those with excessive swelling clay minerals such as montmorillonite. The presence of expansive clay minerals in soils can cause excessive swelling when the soil comes into contact with water and is a problem [1]. Their swelling and shrinkage behavior demand special attention during foundation and pavement construction projects [2]. To tackle these challenges, soil stabilization is extensively researched to enhance its geotechnical properties such as compressibility, permeability, and strength [3,4]. Common stabilization techniques comprise mechanical stabilization, cement, lime, bituminous, and chemical stabilization [5].

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however, an innovative approach has recently emerged, which involves using waste materials for soil stabilization, including human hair fiber. In the literature, several investigations have shown significant results on the use of human hair fiber (HHF) as a reinforcing material to improve the strength and shear characteristics of clay soils [6,7,8] and [9]. However, there are still gaps in the use of human hair fiber to reduce swelling potential and improve shear characteristics in expansive soils.

The principal objective of this work is to investigate the potential of human hair fiber as a stabilizing agent in a reconstituted expansive soil, composed of 80% kaolin from Milia-Jijel and 20% bentonite from Mostaganem. while monitoring the effect the human hair has on soil properties, such as compaction, swelling and consistency characteristics.

2. MATERIALS AND METHODS

2.1. Kaolin

The kaolin used in this study is of the KT2 type, a commercial product treated kaolin, obtained by hydrocycling and washing, and generally used in the ceramics industry. It comes from the Tamazert deposit, located in the El Milia region, in the Wilaya of Jijel. This deposit is currently exploited by the company Soalka SPA. Geologically, the clay deposits at the origin of this kaolin as well as the showings are associated with alterations of the Precambrian gneissic basement, as well as veins of granitic intrusions [10].

The most important soil parameters are summarized in Table 1. According to the Classification of fine soils by the Casagrande diagram, kaolin is not very plastic clay and admits a medium swelling.

Table 1. Properties of kaolin components

Liquid limit LL (%)	Plastic limit LP (%)	Plasticity Index PI (%)	Free swelling index (%)
37	15	22	7

2.2. Bentonite

The bentonite used for this study is a commercial bentonite from the M'zila Sidi Ali region (wilaya of Mostaganem). This bentonite was kindly supplied by Enof BENTAL. It is an untreated, grey material in the form of a finely ground powder (Fig. 1.).

With regard to geology, the bentonite comes from the M'zila quarry. This quarry is characterized by Upper Miocene sedimentary deposits. These deposits can be described as consisting of a sequence of bentonite clay layers, interbedded with biotitic sandstones, all overlain by a clayey marl. More than ten layers of bentonite clay have been mined [11].

Table 2 shows the chemical composition of bentonite. The SiO_2/Al_2O_3 ratio is 4.53 [12], confirming the presence of montmorillonite [13].

This bentonite is classified as a calcic bentonite, due to the preponderance of the percentage of calcium over sodium [14].

2.3. Reconstituted soil

We reconstituted a KB-type soil using a mixture composed of 80% kaolin and 20% bentonite to enhance its swelling potential (see Fig. 1). The KB reconstituted soil gives us swelling characteristics comparable to those of many soils found in different parts of the world [3]. This mixture also offers stable and reproducible characteristics for several samples and tests [15].

Table 2 presents the detailed mineralogical composition obtained from the reference soil. The main constituents of KB soil are oxides of silica (SiO_2) at 56.2% and aluminum (Al_2O_3) at 27.3%, followed by Fe_2O_3 at 7.19% and K_2O at 4.23%. Traces of MgO, TiO_2, Na_2O, SO_3, and P_2O_5 are also present. This composition confirms the significant presence of silica and aluminum in the soil.

The basic properties of the reconstituted soil sample, obtained from various laboratory tests, are summarized in Table 3. According to the classification of the Road Techniques Guide [16] and the results found (Table 3), KB soil is identified as a very plastic class A3 clay. This type of soil is characterized by high plasticity, which makes it very cohesive at average water content, but it becomes sticky or slippery when wet. additionally, these materials are difficult to handle in the laboratory and to implement on-site.

It is important to note that the KB soil has a swelling index greater than 4%, classifying it as a very expansive soil. When the swelling index (Cs) is greater than or equal to 4%, the swelling of the material must be taken into account [17].

Fig. 1. Soil used: a) kaolin, b) bentonite, c) soil KB

Table 2. Chemical composition of bentonite and kaolin. X-Ray Fluorescence results [12,18]

Oxides	**SiO_2**	**Al_2O_3**	**CaO**	**Fe_2O_3**	**Na_2O**	**MgO**	**K_2O**	**SO_3**	**TiO**	**P_2O_5**
Bentonite	65.8	14.5	6.36	3.5	3.04	2.87	2.65	0.47	0.34	/
Kaolin	54.3	29.2	0.86	7.83	0.15	0.63	4.56	0.35	0.29	0.42
Soil KB	56.2	27.3	1.51	7.19	0.46	0.87	4.23	0.33	0.29	0.38

2.4. Human Hair fibre

Human hair fiber (HHF) is a natural biopolymer composed of keratin, which is a natural protein [8]. According to the work of [19], normal hair consists of 45.68% carbon, 27.9% oxygen, 6.6% hydrogen, 15.72% nitrogen, and 5.03% sulfur. This specific composition and the inherent properties of hair make it an attractive candidate for soil stabilization and reinforcement [20]. Unfortunately, hair is often

considered worthless solid waste, leading to its disposal in landfills and thereby creating environmental problems [6].
In this study human hair was collected in a hair salon in the Jijel province, before using it in the treatment, the hair was subjected to an initial pretreatment: first, it was cleaned with distilled water and dried to remove moisture, then were cut to the same length (see Fig. 2).

Fig. 2. Human hair fibre

Table 2. Geotechnical properties of soil KB

Physical and chemical characteristics	**Values**
Liquid limit (WL)	73.97 %
Plastic limit (WP)	37.36 %
Plasticity Index (IP)	36.61 %
Optimum water content (W opt)	21.16 %
Maximum dry density (γd max)	1.501 t/m3
Cohesion (C)	2 kPa
Internal friction angle (φ)	4.5°
Methylene blue value	6.66 cm^3
Compressibility Coefficient (Cc)	6.20%
Swelling Coefficient (Cs)	20.40%

Table 3. Properties of human hair fibre (HHF)

Property	**Specifications**
Cross-section	Circular
Chemical reaction	Depends on Hair surface porosity. About 80 % of human hair fibre is formed by a protein known as keratin
Absorption	Depends on physical process of surface tension
Friction	Depends on the cuticle geometry and on the physical–chemical status of the hair

3. TEST PROCEDURE

To answer our problem of improving the geotechnical properties of the KB soil, we adopted an experimental approach. This approach consists of integrating different proportions of human hair fibers into the soil, while observing the evolution of its characteristics compared to our reference values. To this end, we carried out an experimental laboratory study on reconstituted soil, both untreated and treated with different percentages of human hair fibers. These tests included determination of the Atterberg limit, compaction test, shear test, oedometer compressibility tests and microstructure analysis.
Regarding the amount of human fibers added to the KB soil for its stabilization, we opted for the proportions mentioned in the work of [6]: 0%, 0.5%, 1%, 1.5% and 2%. This standard seemed relevant to us for our study and will enable us to obtain comparable and significant results, thus opening up new perspectives in the field of soil stabilization.

- Atterberg limits: in order to determine the parameters of consistency such as the limit of plasticity (PL), limit of liquidity (LL) and the index of plasticity (PI) we have followed the standard NF P 94-051.
- Compaction test: the determination of the compaction parameters of the soil by the normal proctor test, such as the maximum dry density and the optimum moisture content were carried out according to the standard NF P 94-093.
- Direct shear test: the shear test consists of determining the intrinsic characteristics of the soil cohesion and angle of friction. The test was conducted according to al standard NF P 94-071-1.
- Compressibility test: to determine the behavior of soil subjected to an increase in vertical stress, an odometer test is carried out. The main parameters that can be deduced from the odometric compressibility test are preconsolidation pressure, compressibility index and swelling index. This test was carried out in accordance with the following standard: XP P 94-090-1
- Free swelling index: this method is a test to determine the free swelling index of soil. Free swelling refers to the increase in volume of soil without any external stress when immersed in water [21]. This test was performed according to IS 2720 (Part - 40- 1977).
- Microstructural Characterization (Scanning Electron Microscopy): We carried out microstructural analyzes of untreated and human hair-treated soils at the PTAPC - Ouargla research laboratory. The scanning electron microscope (SEM) allows the surface of a solid to be analyzed using a focused beam of high-energy electrons [22]. SEM gives magnified images of the size, shape, composition, crystallography, and other physical and chemical properties of a specimen [23]. There should be an 18-point space before and a 6-point space after the title, capital letters and numbers (12 points) in bold should be used, beginning with the left margin.

4. RESULTS AND DISCUSSION

4.1. Influence of human hair fibre on Atterberg limits

Fig. 3 shows the histogram of the variation of the Atterberg limits for untreated and treated soil with different pile contents (0%; 1%; 3%; 6% and 9%).
Initially, the liquid limit of KB soil increases slightly with the addition of 0.5% fiber. This increase is due to the fact that human hair fiber absorbs the moisture contained in the soil [6]. It then decreases with the addition of 1% and finally increases with the addition of 1.5% hair. On the other hand, the plasticity limit had the same behavior as the liquidity limit, but above 1% the value gradually increases and exceeds the value of the plastic limit of the reference soil. The plasticity limit of the soil increased from

37.36% to 44.24%, and the liquidity limit from 37.36% to 44.24%, when the percentage of human hair fiber increased from 0% to 2%. The variation in these Atterberg limits indicates that human hair fibers reduce the difference between the liquid and plastic states of the soil, indicating an improvement in soil consistency and strength.

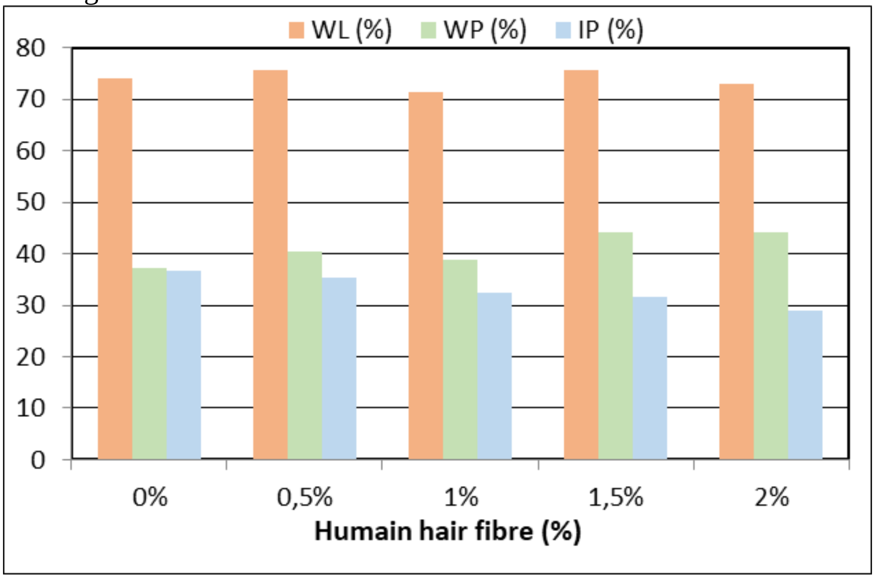

Fig. 3. Histogram of Atterberg limit results of KB soil treated with human hair

The plasticity index varies from 36.61 to 28.33%, decreasing progressively with increasing HHF content. It can be concluded that the addition of hair to KB soil has an effect on its Atterberg limits, modifying its plasticity and consistency properties.

4.2. Influence of human hair fibre on compaction parameters

Fig. 4 presents the compaction test curve showing the variation of optimum water content (OMC) and maximum dry density (MDD) of KB soil treated with different percentages of human hair.
These results show a slight variation in dry density from 1.501 to 1.477 g/cm3 for 0% to 2%, and a decrease in optimum soil moisture from 21.16% to 20% for an addition of 0.5 %, then an increase that exceeds the benchmark. The water content of the soil from 20% to 24.53% for an addition of 0.5% to 2% respectively. According to our results and the work already done by [6]; [24] et [8]. hair causes the maximum dry density (MDD) to decrease and the optimum water content (OMC) to increase.
We found a flattening of the curve of the treated soil becoming more flattened compared to the reference soil and this is due to the fact that the hair also reduces the water sensitivity of the soil [25].
It can be concluded, the use of human hair fibre in KB soil leads to significant changes in its compaction properties, influencing both the dry density and the optimum water content.
The decrease in dry density can be explained by the fact that a mass of soil has been replaced by a lighter material (HHF). The increase in water content is due to the adsorption capacity of capillary fibers, which results in water retention on their surface.

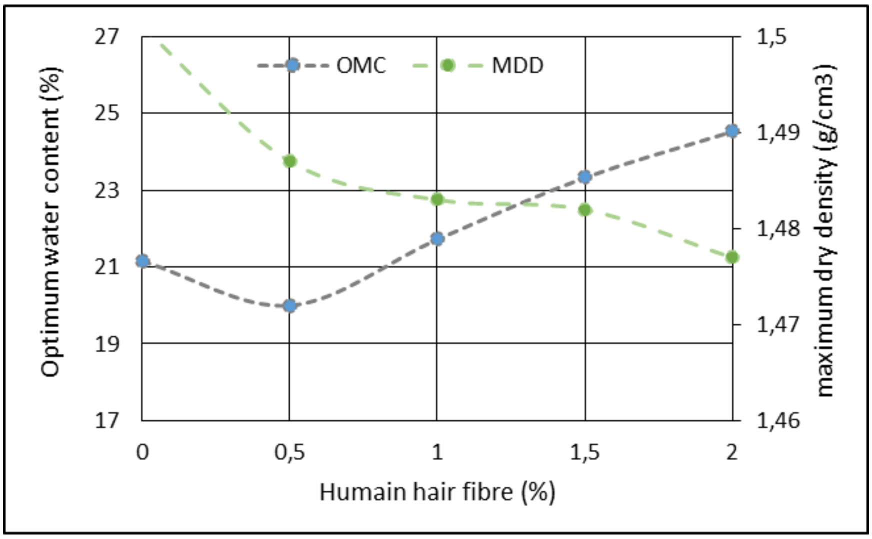

Fig. 4. Curves of the KB soil compaction test with different percentages of human hair fibre (HHF)

4.3. Influence of human hair fibre on shear strength parameters

Fig. 5 shows the effect of human hair fibre on the shear parameters cohesion (C) and angle of friction (φ). Show that when human hair fibre is added to soil with a percentage of 0; 0.5; 1; 1.5 and 2% the values of cohesion (C) and angle of friction (φ) reach (2; 28.7; 53.7; 60.1 and 67.5 kPa) and (4.5; 12.4; 13.27; 15.48 and 16.17°) respectively.

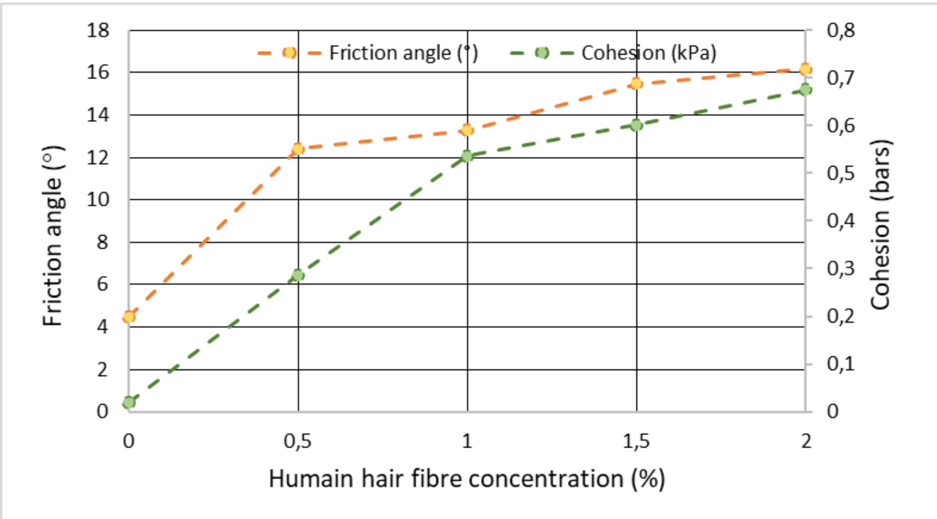

Fig. 5. Effect of human hair fibre on shear strength parameters

It can be seen that increasing the concentration of human hair fibers leads to an increase in the angle of friction and cohesion. Human hair fibers increase the shear strength of the treated soil and confer tensile strength by creating bonds between particles, thanks to their fibrous nature and tensile strength, making the soil more cohesive.

4.4. Influence of human hair fibre on soil compressibility

Fig.6 shows the variation of compressibility characteristics (compressibility index and swelling index) of KB soil as a function of human hair. It is well known that the compressibility index Cc is the slope of the tangent to the loading curve, and the swelling index Cg is the slope of the unloading curve.
The results of the compressibility tests indicate that the Cs values vary from 9.8 to 4% and the Cc values vary from 31 to 20% for hair percentages ranging from 0% to 2%. It is observed that the compressibility index and the swelling index decrease with the increase in the percentage of human hair.
According to the classification of the soil according to the swelling index, the results indicate that the treated soil changed from a very high swelling soil to a low swelling soil [27].
The compressibility index decreased as soil stiffness increased with the addition of hair. The addition of human hair fibers to KB soil induces significant changes in soil compressibility characteristics. Adding human hair fibre to KB soil induces significant changes in the compressibility characteristics of the soil.

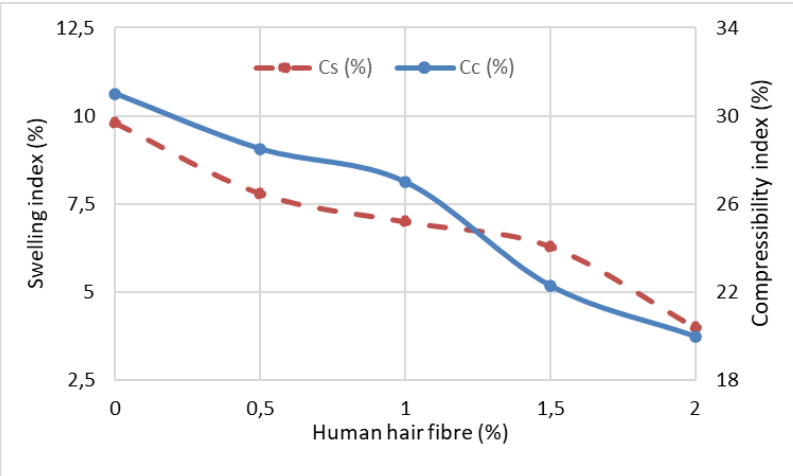

Fig. 6. Evolution of the compressibility index of the soil swelling index as a function of the percentage of human hair fibre

4.5. Influence of human hair fibre on the free swelling index test

The influence of human hair fibre on the free swelling index (FSI) is represented by the curve in Fig. 7. The values of the free swelling index of the treated KB soil reached 61.5; 53.84; 38.48; 13.33 and 7.14% for 0; 0.5; 1; 1.5 and 2% human hair fibre respectively.

A remarkable decrease in the free swelling index with the increase in the percentages of human hair fibre which represents an improvement in the behaviour of the soil vis-à-vis the swelling phenomenon. According to the classification of soils based on the free swelling index [28], the value of the free swelling index of the treated soil is reduced from a very high degree of swelling to a low swelling. we can conclude that human hair fiber reduces the rate of soil swelling, indicating that human hair fiber may be a solution to soil swelling problems.

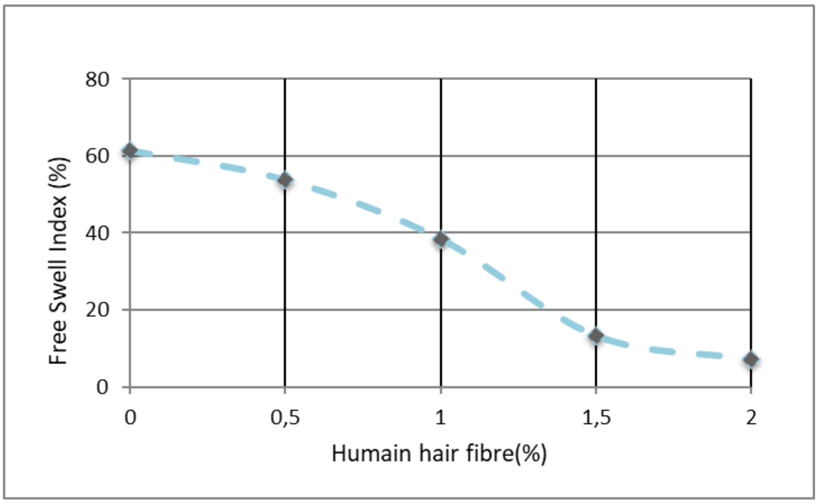

Fig. 7. Effect of human hair fibre on free swelling index

4.6. Effect of treatment on soil microstructure (SEM)

A microstructural study using scanning electron microscopy (SEM) was carried out to verify and understand the changes that occur in the microstructure of the KB soil after adding human hair. SEM images of human hair; the reference soil and the KB sol mixture + human hair fibre are shown with different magnifications in the Fig. 8.; Fig. 9. and Fig. 10. respectively.

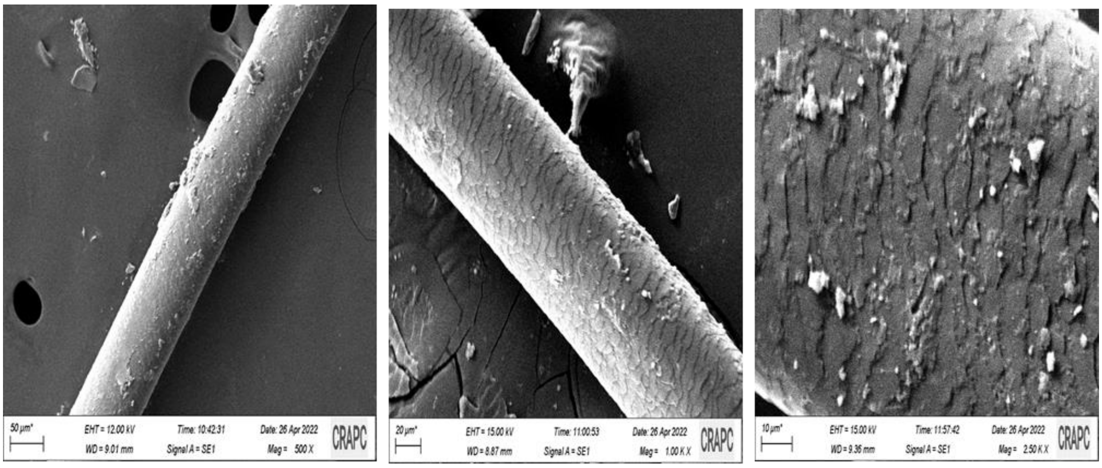

Fig. 8. SEM images of human hair fibre with magnification (50 µm; 20 µm and 10 µm)

Fig. 9. shows the microstructure of KB sol at a magnification of 20 µm; 10 µm and 5 µm. KB ground surface images allow the visualization of scale structure with several small pores, this scale appearance is due to the presence of kaolinite [29], its presence was confirmed by XRD analysis.

Fig. 8. shows the microstructure of a human capillary fiber at 50 µm, 20 µm and 10 µm magnification, which has a rough surface. In terms of particle shape and surface characteristics, human capillary fiber is completely different from KB soil.

Fig. 10. shows the microstructure of human hair-treated KB sol at 50 µm magnification; 5µm and 2µm. Comparing the surface morphology of KB soil with that of KB soil + human hair, the latter had changed after the human hair fibre treatment. The treated soil shows a change in particle orientation, with fewer pores observed. On

the other hand, the addition was not accurately detected in the SEM image of the soil stabilized with human hair fiber.

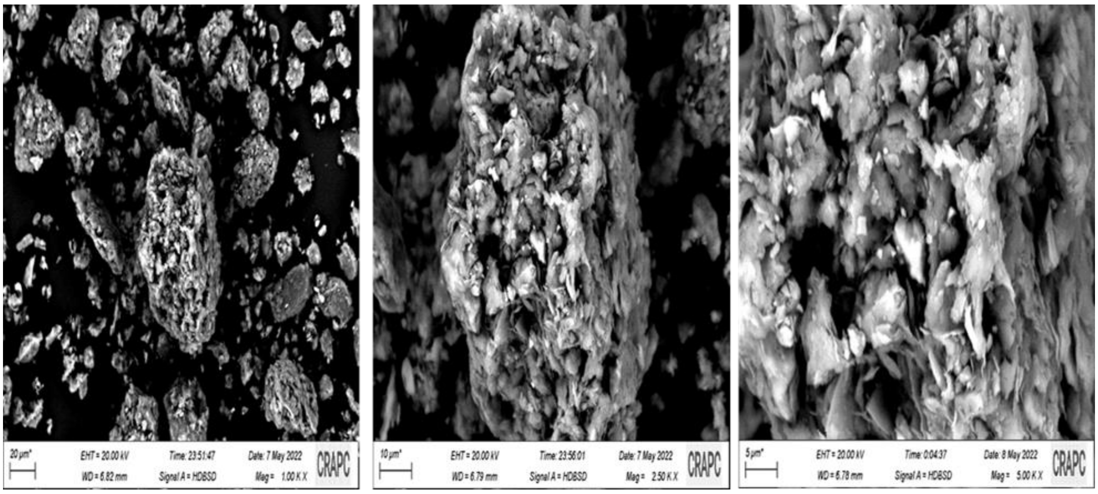

Fig. 9. SEM images of soil KB with magnification (20 μm; 10 μm and 5 μm)

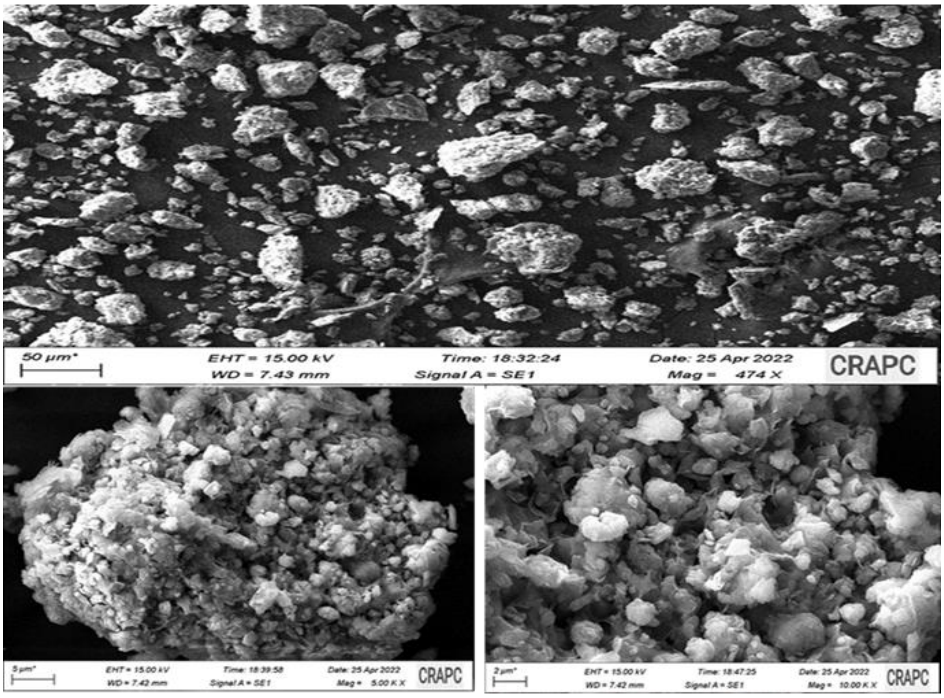

Fig. 10. SEM images of soil treated by human hair fibre with magnification (50 μm; 5 μm and 2 μm)

5. CONCLUSION

This study was carried out to evaluate the effect of the random addition of human hair fibre by different percentages (0; 0.5; 1; 1.5 and 2%) on the physico-mechanical behavior of a soil reconstituted from a mixture of 80% kaolin and 20% bentonite.

In this study, a series of analyses were carried out for treated and untreated soils, such as the Proctor test, Atterberg limits, compressibility test, shear test and free swelling index.
The main objective of this work is to propose an innovative solution to stabilize swelling soil using human hair, an often-neglected natural waste. The main objectives of this study are as follows:

- soil stabilization, while protecting the environment by disposing of this waste in the natural environment.
- The recovery of large quantities of this non-recovered waste
- Reduce the cost of soil stabilization works with conventional materials such as hydraulic binders.

Based on the results of this study of a soil sample,
the following conclusions can be drawn from this study:
From the Atterberg limit test, we observed a slight decrease in plasticity index with increasing hair content. The plasticity index fell from 36.61 to 28.83% with the addition of 2% human hair.
The following conclusions can be drawn from the results of this study:

- From the Atterberg limit test, we observed a slight decrease in the plasticity index with increasing hair content. The plasticity index decreased from 36.61 to 28.83% with the addition of 2% human hair.
- From the Proctor compaction test, it is observed that the maximum dry density (MDD) increases, and the optimum moisture content (OMC) decreases with the addition of 2% human hair.
- From the results of the shear test, it can be seen that the increase in the concentration of human hair fibre leads to an increase in the angle of friction and cohesion.
- According to the compressibility characteristics, it is found that the compressibility index and the swelling index decrease with the increase in the percentage of human hair.
- The Free Swell Index (FSI) of KB soil decreases with increasing percentage of hu-man hair.
- These results show the significant impact of human capillary fiber on the geotechnical properties of KB soil, making this approach effective for stabilizing expansive soils. This approach not only improves soil characteristics, but also enables waste to be recycled and contributes to environmental preservation.

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