



Journal of Materials and Engineering Structures

Research Paper

Improving properties of modified clay with cement containing random chicken feather fibers

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ARTICLE INFO

Article history :

Received : 14 October 2021

Revised : 9 March 2022

Accepted : 30 May 2022

Keywords:

Clay

Cement

Chicken feather fiber

Compressive / Shear strength

ABSTRACT

Over the past decades, the poultry meat processing industry's growth has generated a huge amount of feather "waste". This waste has given rise to a number of environmental concerns and had a low value-being when used in many industrial applications. Promoting the use of sustainable materials is now a pole of interest in engineering construction. Aiming to recover this waste in enhancing the properties of problematic soils, an experimental study is conducted using these materials. An earth material named Zebabdja clay is treated by the cement to improve its properties. The inclusion of waste byproducts such as chicken feather fibers would improve the characteristics of the soil with low load bearing capacity. The present work attempts to valorize this kind of natural fiber in the field of building and solve an environmental problem using local materials. The control parameters evaluated herein include cement content (6%, 8%, 10% et 12%) and chicken feather fibers contents (1%, 2% et 3%). The unconfined compressive and direct shear tests were measured at different curing times. The results found show that 10% is the needed amount of cement to be used in order to stabilize the clayey soil treated. An increase in chicken feather fibers up to 2% indicates an improvement of the mechanical performances of the clayey soil, which may constitute a very interesting engineering solution for the weak soil.

1 Introduction

Construction world is now faced with a need to change its practices and methods in order to respond to the challenges of sustainable development, which can be summed up in the preservation of natural resources, the reduction of energy consumption and greenhouse gas emissions. This development involves the use of materials with a low environmental impact [1]. In civil engineering, earthen construction materials (soil), whose use is ancestral, meet the environmental requirements and a renewed interest related to their insulation properties and their low environmental impact (use of local materials, non-use of conventional binders, easy recycling at the end of life) [2].

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Inadequate mechanical characteristics, such as low strength and brittle behavior, are probably the main problems related to the structural use of materials, especially for buildings and civil works likely to be subjected to natural hazards that have a decisive impact on their lifespan. For these reasons, these soils can be improved by chemical and / or cement additives and by the inclusion of fibers. The effectiveness of these additives and their content depend on the nature of the soil to be treated and the characteristics of the addition materials. In old earthen constructions, commonly used additives are lime and more recently cement and other by-products considered as artificial pozzolana. Numerous experimental studies have been carried out on the stabilization potential of the mineral additions and their effect on the physical and mechanical properties of the clay soils. These properties depend on the type of soil, the combination of the amount of stabilizers and even the curing time.

The addition of cement to coherent soils has widened the stabilization zone. Many studies on the effect of cement on Atterberg boundaries conducted by Osula [3] and others, agree that a soil treated with cement showed a significant decrease in the plasticity index. Sasanian [4] also noted that the shear characteristics, internal friction angle and cohesion of unstable soils to which cement was added, improved remarkably during different curing times. This is attributed to the calcium ions present in the cement which causes a decrease in the plasticity, thus making the soil more friable and easier to handle. Even for swelling clays, Afès and Didier [5] deduced the same conclusion. Bozbey and Garaisayev [6] examined the efficiency of adding cement on improving the compaction characteristics of problematic soils. They found a decrease in the maximum dry density and an increase in the optimum moisture content. In the same trend, other investigators, Mellal and Lamri [7] used cement to improve shear strength. The test results revealed an increase in shear strength compared to control soils. Mahantesh and Keshavaraj [8] conducted an experimental study to evaluate the compressive and shear strength of cement stabilized rammed Earth material in both dry and wet state. They show that the wet compressive strength of the rammed earth specimen is less than that of the dry one.

To create from a soil an innovative construction material, the addition of fibres plays a key role in the reinforcement of earthen matrix, giving them not only a greater tensile strength, but also the ductility essential for their structural use. Currently, the use of natural fibres as reinforcements continues to spread over the world because of the strengthening of environmental legislation and the growing pressure on high-performance materials. The development of composite materials based on natural fibres or eco-friendly composites with high specific properties is a very promising research area. The improvement of problematic soil resistance with the addition of randomly distributed fibres has been reported by many researchers [9, 10]. Chicken feathers are among all natural keratin-rich reinforcing fibres. Millions of metric tons of waste feathers are generated each year by commercial poultry processing plants creating a tremendous volume of solid waste problem all over the world [11, 12]. These by-products generated in large quantities by the poultry processing industry and considered as the least studied and unexploited protein waste. They are in abundance, with good properties, durability and resistance to degradation. In Algeria, poultry droppings are the only waste that is really valued. Feather chicken waste is not valued; they are incinerated or thrown into the public landfill [13]. Many researchers use them either alone or sometimes in combination with other materials to make profitable commercial applications such as to manufacture composites for construction or textile products (yarns and fabric) [14]. It was observed that the incorporation of feather fibres into the cement plaster resulted in crack-free mortar surfaces, reduced acoustic echo and contributed to increased roughness, porosity, compressive strength and durability [15]. It also improves the thermal conductivity and the adhesion to the surface of the hardened mortar coating. In geotechnical engineering, several researchers have randomly incorporated lime-stabilized ground feathers to improve their resistance. They concluded that this is an interesting alternative for the stabilization of an expansive soil [16].

This study is an additional contribution in the field of soil stabilization to enrich the range of soil improvement methods that has continued to expand. The main objective of this work is to assess the viability and impact of including chicken feathers on the consistent soil reinforcement used as an earth building material and to study its relevance as a replacement for commercial materials a bit expensive. It will also contribute to find a solution for the disposal of such waste in bulk which is a global environmental problem responsible for the pollution of soils and groundwater sources. The mechanical properties of the clayey soil including unconfined compressive and direct shear tests are studied to show the influence of the main variables considered in this investigation, which were the amount of cement and the percentage of the chicken feather fibres.

2 Materials

The soil samples used in this study comes from the clay quarry of the brickyard located in Chlef (western Algeria). In the laboratory, the crushing and grinding of soil samples were carried out using a disk mill to obtain a 0/5 mm grind (see Figure 1).

Table 1 – Chemical and geotechnical characteristics of the treated soil

Basic Characteristics	
CaO	12.04
MgO	1.53
Fe ₂ O ₃	6.40
Al ₂ O ₃	14.48
SiO ₂	29.10
SO ₃	0.03
Color	Dark Grey
Depth (m)	Quarry
Natural water content (%)	21.92
Specific Density	2.6
Fineness (cm ² /g)	803900
Elements passing by sieve 80 µm (g)	318.73 (79.68%)
Liquid Limit (%)	39.48 < 50
Plastic Limit (%)	20.86 > 20
Plasticity Index (%)	18.62 > 7
Optimum water content (%)	20
Maximum dry density (kg/m ³)	1550
Cohesion (kPa)	18.07
Friction angle (°)	21.29



Fig. 1 – Zebabdja clay after crushing and grinding

The grading and the particles fractions for the clayey soil from natural source are illustrated on the Figure 2. The Engineering properties of the collected clay soil used as well as its classification were determined according to American ASTM D2487-98 standards [17] and showed in Table 1.

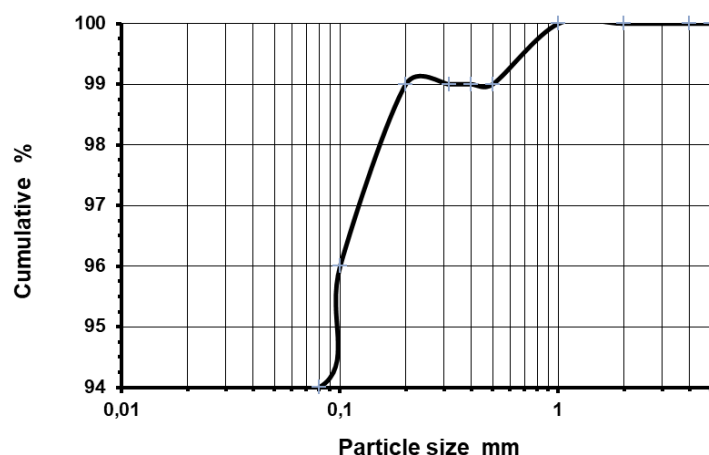


Fig. 2 – Grain size distribution of the clayey soil (Zebabdja clay)

2.1 Cement

The cement used in this study was supplied by the cement factory of Chlef located in west of Algeria. The physical and chemical properties of the product are presented in Table 2.

Table 2 – Physical and chemical properties of cement

Name	Cement CEM II/A 42.5
Physical appearance	Grey powder
CaO	64.76
MgO	0.47
Fe ₂ O ₃	3.78
Al ₂ O ₃	5.13
SiO ₂	21.34
SO ₃	2.28
Na ₂ O	0.04
LOI	1.00
K ₂ O	1.18
Specific Density	3.14
Fineness (cm ² /g)	2950
C ₃ S	66
C ₂ S	14
C ₃ A	7
C ₄ AF	12

2.2 Chicken Feather fibres

Chicken feather fiber used in this investigation was provided by a slaughtering facility (see Figure 3). Chicken feathers contain crude lipid (0.83%), crude fiber (2.15%), crude protein (82.36%), ash (1.49%), nitrogen-free extracts (1.02%) and moisture content (12.33%) whereas the ultimate analyses showed: carbon (64.47%), nitrogen (10.41%), oxygen (22.34%), and sulphur (2.64%) [14]. The mean density of whole chicken feathers is 0.97 g/cm³ [14]. Before mixing the chicken feather, they were cut to reduce their length.



Fig. 3 – Chicken Feather Fibers

3 Experimental procedure

In this experimental program, the clay used herein was mixed with cement (C) as stabilizer and reinforced with solid inclusions of chicken feather fibers (CFF). The obtained soil sample with varying content of additives will be subjected to unconfined compressive test and direct shear test. After finding the optimum moisture content for the control soil (CS), cement is added by different percentages to the control soil, then after, chicken feather fibers are introduced.

3.1 Sample preparation

The dry components of the samples were hand mixed, thoroughly in a tray before water was added. A determined percentage of water should be added and then the soil can be mixed thoroughly again. The percentage of cement used as clay replacement was 6, 8, 10 and 12%, while the chicken feather content was 1, 2 and 3%. The mix compositions of the different mixtures and the applied tests were selected as shown in Table 3. All the samples were compacted at the optimum water content deduced from the compaction test according to the standard ASTM D 698-91 [18].

Table 3 – Mix design of the different mixtures and the different tests applied

Designation test	Mixture of CS with different % cement	Mixture of CS with different % of chicken feather	Mixture of CS+10%C with different % of CFF	Water added
Unconfined compressive strength	CS+ 0%C	CS+0% CFF	CS+10%C+	20% of each mixture
	CS+ 6%C	CS+1%CFF	CS+10%C+1%CFF	
	CS+ 8%C	CS+2%CFF	CS+10%C+2%CFF	
	CS+ 10%C	CS+3%CFF	CS+10%C+3%CFF	
	CS+ 12%C			
Normal stress applied on the different mixtures				
	100 kPa	200 kPa	300 kPa	
Direct shear strength	CS	CS	CS	20% of each mixture
	CS+10%C	CS+10%C	CS+10%C	
	CS+10%C+1%CFF	CS+10%C+1%CFF	CS+10%C+1%CFF	
	CS+10%C+2%CFF	CS+10%C+2%CFF	CS+10%C+2%CFF	
	CS+10%C+3%CFF	CS+10%C+3%CFF	CS+10%C+3%CFF	
CS :Control Soil		C: Cement	CFF: Chicken Feather Fibres	

3.2 Testing procedure

For compression test, the mixtures were cast in cylinder specimens of 70 mm diameter and 140 mm height. After demolding, the samples were stored in a plastic bag for different periods before testing (7, 14 and 28 days). The unconfined compression was performed according to ASTM D 2166-06 standards [19]. A minimum of three samples are used to determine the compression strength.

For direct shear test, the specimens were cast in square with the size 60 mm × 60 mm × 25 mm. Normal stress applied were 100 kN/m², 200 kN/m² and 300 kN/m². The speed of the movement of the half-box was fixed at 1 mm/min. The test was carried out according to ASTM D 3080-04 [20].

4 Results and discussion

4.1 Proctor results

The Proctor curve results for Zebabdja clay mixed with and without the cement are presented in Figure 4. An increase in the optimum water content value from approximately 20% to 22.5% is observed when adding cement to the control soil from 6% to 12%, which corresponds to an enhancement in the maximum dry density ranged from 1550 to 1750 kg/m³ respectively. As expected, the soil with cement needs more water than the soil without cement. This resulted in an increase of the dry density of the soil of 13%. It is deduced that the introduction of 10% of cement in the clayey soil, improves the physical characteristics of the soil. This performance may be due to the fine particles of the cement added to the clayey soil which has minimized the voids in the combined soil [21].

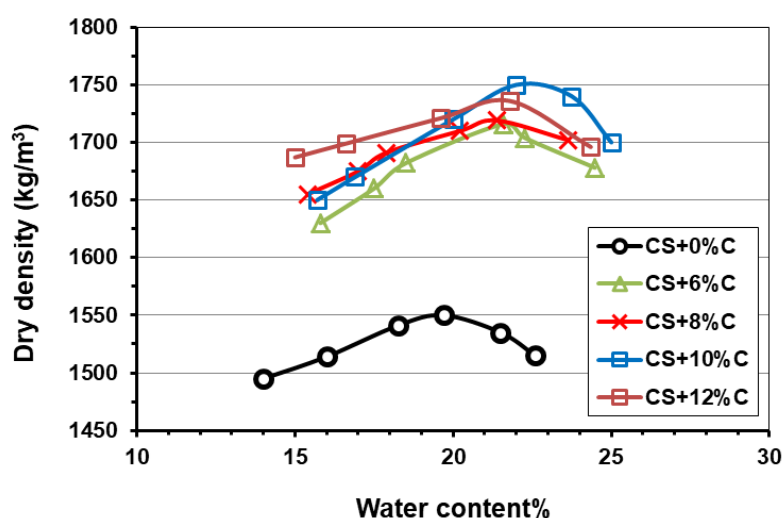


Fig. 4 – Proctor curves for the clayey soil and stabilized soil with different amounts of cement

4.2 Unconfined compression strength results

The results of unconfined compressive strength of the clayey soil with different cement contents (6%, 8%, 10%, and 12%) are presented in Figure 5 at different curing times. A clear improvement of the unconfined compression strength is seen on the samples incorporating amounts of cement. The increase in unconfined compressive strength is attributed to the soil-cement reaction. When the pore water of the soil reacts with cement in the specimens, it bonds the components together; thus it creates a strong mixed soil resulting in high unconfined compressive strength [22]. The tendency of the strength curves of the soil cement indicates a continuous increase of the strength even over the 28 days age. The enhancement of the compression strength caused by the introduction of the cement reached its maximum for the 10% cement content (see Figure 5). The 12% cement content does not show the same level of strength in the soil samples as for those of the 10%. The latter is maybe the optimum content of cement needed for stabilizing the clayey soil of Zebabdja region.

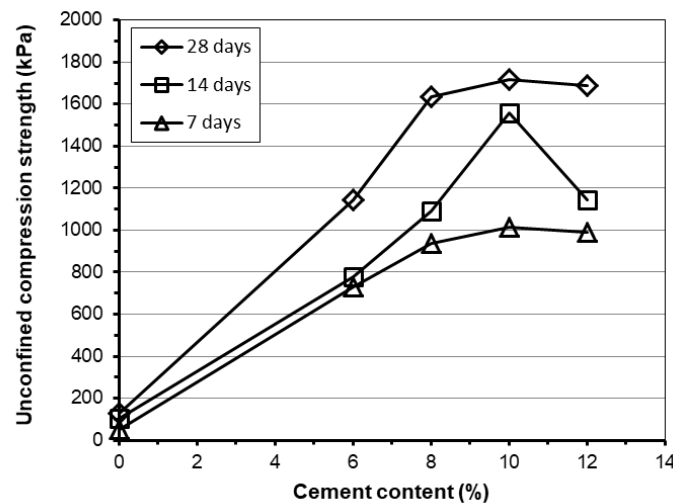


Fig. 5 – Unconfined compression strength of the soil as function of the cement content for different ages

4.2.1 Effect of the feather fiber contents on the unconfined compression strength of the clay soil

The evolution of the unconfined compressive strength of the clay samples with curing time for the different chicken feather fiber contents is shown in Figure 6. The soil samples develop strength gradually with the curing time, particularly before 14 days. It is observed that there is not a significant increase of the compressive strength of the soil with feather fibers after 14 days, except for the soil without feather fibers. The inclusion of the feather fibers into the clayey soil has probably affected the evolution of the compression strength with time as seen in the figure after the fourteen days age. Furthermore, it is clear that the inclusion of CFF has enhanced the compressive strength of the control soil according to the CFF contents. It is noted that the best performance was obtained at 2%. The increase in the compressive strength almost tripled compared to that of the control soil. The increase of the strength was also observed by other researchers [23].

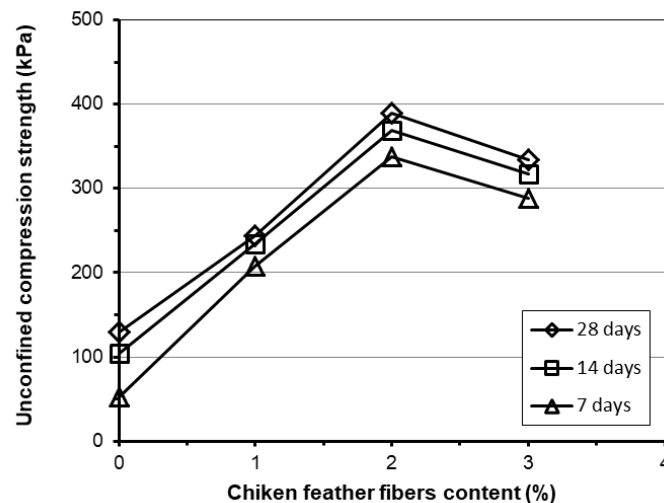


Fig. 6 – Unconfined compression strength of the clayey soil as function of curing time for control soil with different contents of CFF

4.2.2 Influence of chicken feather fiber contents on the characteristics of the clayey soil incorporating 10% of cement

The mechanical behavior of the soil treated with 10% of cement as a function of the chicken feather fiber percentages for different ages is plotted in Figure 7. The obtained results show an enhancement of unconfined compressive strength

with increasing feather fibers percentage up to 2%. It is observed that this improvement becomes more important with the increase of the curing time. The observed increase in the unconfined compressive strength of the reinforced soil may be attributed to fibers intersecting any developing failure zone through the interlocking and interweaving of fibers with the soil particles [10]. It is noted that over this rate (10%), the reinforced soil strength begins to decrease indicating the inverse effect of incorporating feather fibers. The maximum compressive strength value of the soil treated with 10% of cement was obtained for 2% of CFF inclusion at 28 days. This indicates that there is an optimum fiber content at which reinforcement benefit is the maximum in terms of bond strength and friction between soil particles and fiber. Patel and Singh [21] found that the unconfined compressive strength of the cohesive soil reinforced with glass fibers reaches its maximum value at 0.75% fiber content. The value of the strength corresponding for the studied soil is approximately 1900 kPa, which is equivalent to 13 times the value of the strength of the untreated control soil. The process to combine cement with chicken feather fibers may constitute a very interesting engineering solution in stabilizing the clayey soil.

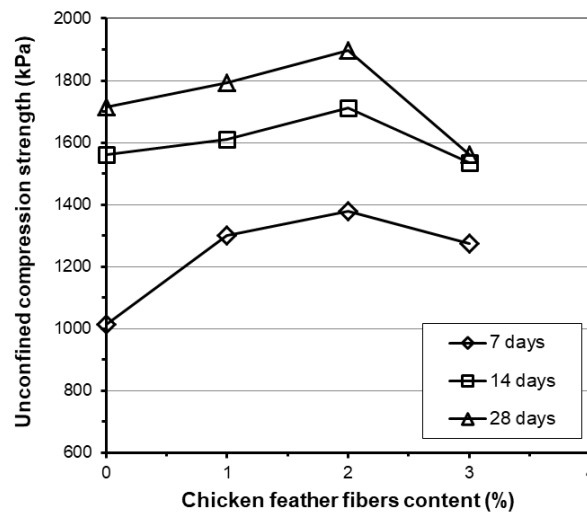


Fig. 7 – Unconfined compression strength of the stabilized soil with 10% cement as function of the chicken feather fibers content for different ages

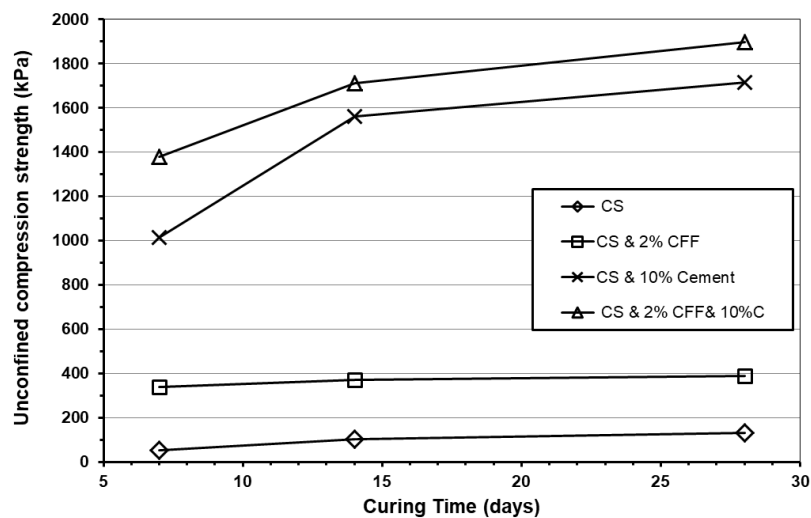


Fig. 8 – Comparative curves evolution for stabilized soil with 10% cement & 2% inclusion of CFF

4.2.3 Influence of the mix composition on the unconfined compression strength of the clayey soil

In the Figure 8, it is plotted the evolution of the unconfined compression strength of the clay soil including both cement and chicken feather fibers with the curing time in the aim to show the effect of each parameter. The rate of enhancement of

compressive strength of the control soil reinforced with 2% of chicken feather fibers inclusion, control soil containing 10% of cement content and soil with 2% of chicken feather fibers plus 10% of cement content are equivalent to two times, 12 times and 13 and half times respectively. The addition of the cement to the control soil is the most important change observed on the mechanical behavior of the soil sample. The effect of incorporating the animal fibers in the clayey soil was less with regard to the cement effect. Many research works demonstrated the great effect to add cement to the clayey soil [22].

4.3 Shear strength results

The influence of feather fiber inclusion in Zebabdja clay stabilized with 10% cement at optimum water content and respective maximum dry density on the variation of the shear strength parameters was studied. For each clay mixture, three direct shear tests were conducted for axial stresses of 100, 200 and 300 kPa. The tests were conducted until the rupture of the soil specimens.

4.3.1 Shear strength of the control soil

The relation between shear stresses and horizontal displacements of the control soil subjected to the aforementioned axial stresses is illustrated in Figure 9. For all normal stresses, the shear stresses of the control soil increase with the increase of the horizontal displacement and reach the peak value and do not show any clear reduction. It can be seen also that increasing in normal stress (σ_n) leads to the increase of the peak strength of the clayey soil. It is thought that the increase in peak stress is highly dependent on the normal stress.

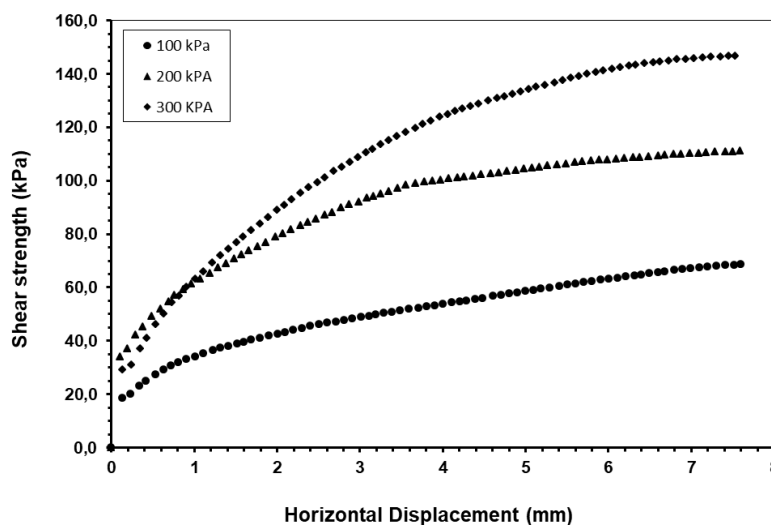


Fig. 9 – Shear stress-strain curves for the control soil at different normal stresses

4.3.2 Influence of 10% of cement addition on the control soil shear strength

The relation between shear stress and horizontal displacement of the control soil and the stabilized soil with 10% cement, subjected to the axial stress values of 100, 200 and 300 kPa is illustrated in Figure 10. It can be seen from this figure that the effect of the addition of the cement to the clayey soil is significant at all normal stresses except for the axial stress of 100 kPa. The soil specimens did not indicate a distinct peak value before reaching the constant critical stress. It is noted that for the axial stress value of 200 kPa and 300 kPa, the shear stress of the soil stabilized with 10% cement is not higher than that of the control soil up to the shear corresponding to the horizontal displacement value of 5.6 mm. Over this value, the soil stabilized with 10% cement shows a clear increase at both normal stress of 200 and 300 kPa with a regard to that of the control soil. The rate of shear strength increase is 12% and 15% at the normal stress of 200 and 300 kPa respectively. Such observation is reported in some research works [24]. It is deduced that the addition of 10% of cement to the clayey soil results in an improvement of the soil strength characteristics. Some authors explain this change by the decrease of the liquid limit of the mixing soil [25]. Other investigators said that the improved compressive strength results

indicated previously will be reflected on the engineering properties as shear strength [26]. At high normal stress (300 kPa), the shear strength of the stabilized soil shows a peak strength equal to 168 kPa at 7.5 mm of the horizontal displacement.

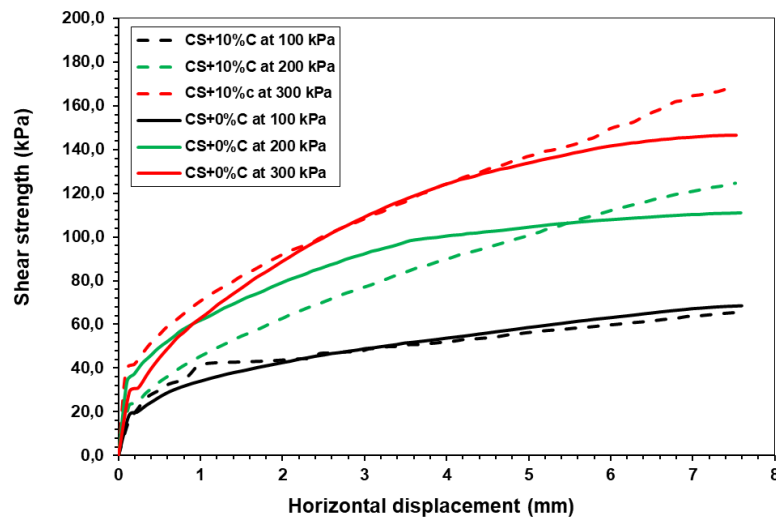


Fig. 10 – Shear stress vs strain of stabilized soil with 10% cement at different normal stress

4.3.3 Influence of introducing chicken feather fibers on the stabilized soil shear strength

In Figure 11, it is represented the stress- strain relationship of the clayey soil stabilized with 10% cement incorporating different percentages of chicken feather fibres at different normal stresses. The introduction of the chicken feather fibres leads to the increase of the shear stress at failure of the stabilized soil at all the normal stresses. This finding is consistent with the works reported by Naeini and Sadjadi [27].

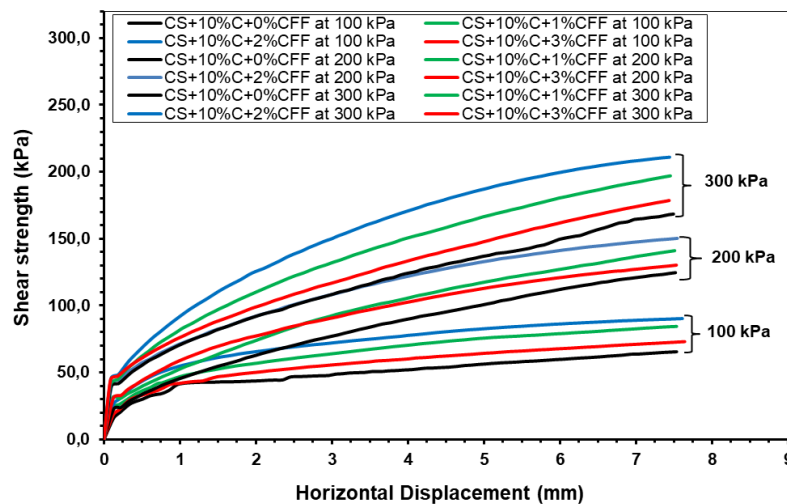


Fig. 11 – Shear stress-strain relationship of stabilized soil with 10% Cement incorporating different amounts of chicken feather fibers

The increase in the shear strength soil is proportional to the increase in chicken feather fibres content till the percentage of 2% fibres. Beyond this rate, the shear strength is decreasing. Incorporation of randomly chicken feather fibres in the stabilized soil acts as plant roots, which fortifies the stabilized soil by additional frictions and interlocking [28]. Some authors attribute the improvement of the behaviour of the clayey soil to the soil-fibre interfacial friction. As the fibre content increases, the contribution of the interfacial friction becomes larger [29]. Some other researchers states that fibre reinforced soil behave as a composite material in which fibres of relatively high tensile strength are embedded in a matrix

of soil. Shear stresses in the soil mobilize tensile resistance in the fibres, which in turn imparts greater strength to the soil [28].

In Figure 12, it is shown the peak shear stress as function of the chicken feather fibre at all normal stresses. The influence of incorporating fibres is more significant at the percentage of 2% of CFF than that at 3% of CFF. For instance, the increase percentage in peak shear stress at the normal stress of 300 kPa is 17%, 25% and 6% corresponding to the inclusion fibres of 1%, 2% and 3% respectively. It is concluded that the amount of 2% of chicken feather fibres introduced in the stabilized clay constitutes the optimal value to get the higher shear stress.

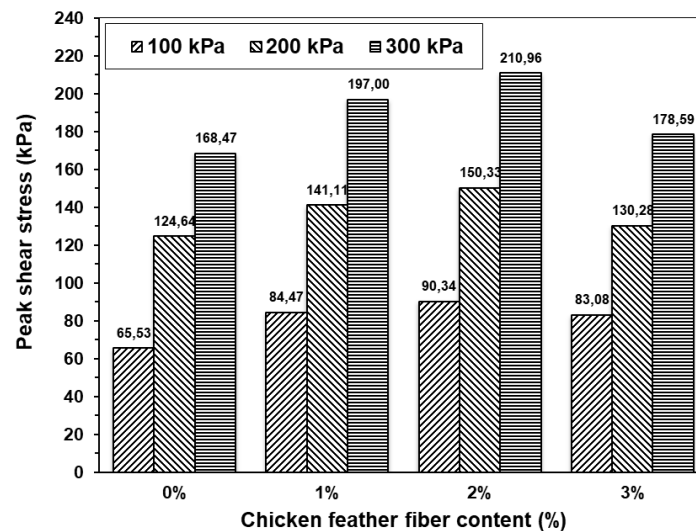


Fig. 12 - Peak shear stress of the stabilized soil as function of the fiber content

4.3.4 Influence of the chicken feather fibers incorporated in the stabilized soil on the geotechnical parameters

The cohesion and the friction angle can be calculated with respect to the relationship shear stress-axial stress and trend line of the stabilized soil shown in Figure 13. These results are summarized in Table 4. Addition amounts of animal fibre have a significant effect on the development of the cohesion and the internal friction. As stated in Figure 13, the cohesion increases with the increase of the amount of fibres added to the clayey soil up to 2% and then decreases slightly with addition amounts of fibres. This finding is consistent with the work conducted by Naeini and Sadjadi [27] on the effect of waste polymer on shear strength of unsaturated clays. The increase in cohesion of the fibre reinforced soil may be due to the increase in the confining pressure because of the development of tension in the fibre. The decrease in cohesion of the fibre reinforced soil with addition amount of fibres (more than 2% fibre content) may be due to separation of clay particles due to the addition of fibres [27].

Table 4 – Influence of the chicken feather fibers inclusion on the cohesion and the friction angle of the clayey soil

Mixture soil	Cohesion (kPa)	Friction Angle (Deg)
CS + 10%C+ 0% CFF	16.61	27.23
CS + 10%C+ 1% CFF	28.33	29.36
CS + 10%C+ 2% CFF	29.92	31.10
CS + 10%C+ 3% CFF	21.82	27.68

The internal friction angle of the fibre reinforced soil follows the same trend as the cohesion (see Table 4). Increasing the fibre content in the clayey soil leads to the increase of the friction angle. The maximum friction angle is observed at 2% fibre content, which indicates the optimum chicken feather fibre based on shear strength results. Beyond this optimum rate, the observed shear parameters decrease. It is thought that high fibre content resulted in poor mixing with less contact between soil particles, reducing the availability of soil matrix for holding the fibre and the development of a sufficient bond between the fibres and the soil [30].

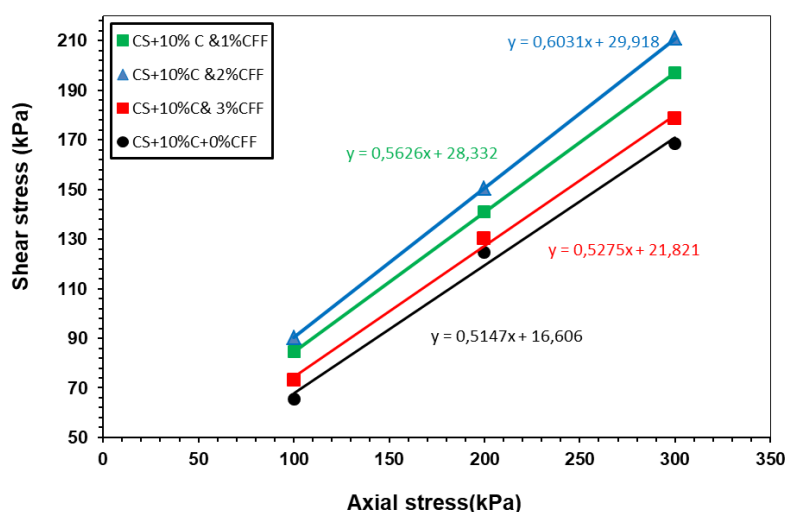


Fig. 13 – Variation of the shear stress as function of the axial stress for different amounts of chicken feather fibers

5 Conclusions

An experimental program was conducted to investigate the individual and combined effects of cement stabilization and chicken feather fibres inclusions on the unconfined compressive strength and shear strength parameters of the clayey soil. The results showed that the enhancement of the compression strength of the clayey soil reached its maximum value (1720 kPa) for 10% cement content. The latter is considered the optimum content of cement needed for stabilizing the clay of Zebabdja region. It is also found that the inclusion of the chicken feather fibres into the treated soil (clay) has improved the compressive strength of the clay three times compared to that of the untreated soil and the best performance was obtained at 2% of fibre content. For comparison purpose, it is noted that the addition of the cement to the control has the most effect observed on the mechanical behaviour of the soil sample and the effect of incorporating the animal fibres in the clayey soil was less. When applying normal stresses, the soil control shear stresses increase with the increase of the horizontal displacement and reach the peak value without indicating any clear reduction.

The present study demonstrates that incorporating randomly chicken feather fibres in the clayey soil stabilized with 10% cement is able to increase the shear strength soil proportionally to the fibres content. The amount of 2% of chicken feather fibres introduced constitutes the optimal value to get the highest shear stress and pervades a ductile behaviour to the material. The addition of the chicken feather fibres to the clayey soil results in a substantial increase of both shear parameters; the friction angle and the cohesion and consequently contribute to the increase of the total strength of the soil mixture.

Finally, the technique of using a waste material such as chicken feather fibres in a soil stabilized with cement is a very effective method of improving the load bearing capacity of the soil and its engineering parameters.

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