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Influence of the Sawdust on the Behavior of Clay Soils

Mahmoud M. Abu Zeid*

Civil Engineering Department, Faculty of Engineering, Qena, South Valley University, Egypt
*Corresponding author: eng_abuzeid@yahoo.com, eng.abuzeid@eng.svu.edu.eg

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Abstract Soil treatment with many different materials such as lime, fly ash, cement with bentonite and chemical injection was used to embrace good soil. The soil characterizations led to choose the best additive material which improves its behavior. In this article, the sawdust waste was added to a swelling soil to upgrade a stabilized its specification. Building traditional houses in some areas of the Egyptian countryside uses clay mixed with sawdust as cemented materials. The sawdust has used in this paper with different percentages 0, 1, 3, and 5% by weight of the clay soil. Many tests have been used such as index, strength and swelling specifications to study the behavior of clay- sawdust mixtures. The result indicated that the indirect tensile strength for air-dried samples increased, by increasing the sawdust ratio around 1.75%, and the swelling potential also decreased to about 32%.

Keywords: *soil stabilization, sawdust waste, strength, clayey soil*

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1. Introduction

Expansive soils were detected in many different places in the world. The expansive soil term is used for soils that have potential shrinkage and swelling property under changing water content. Swelling and expansive soil were found in many governorates of Egypt such as Sohag, Assiut and Sina etc. As regards as to overcome the swelling problem, the theoretical analysis has been established. Many scientific types of research were applying different materials to stabilize expansive soil under different conditions. Thomas et al., were used lime to define the effectiveness of hydrated lime and Portland cement on three Texas clays. They were studying many variables to estimate twice of treatment, pulverization, compaction efforts, moisture conditions and a range of curing times. Using lime treatment proved that is better resistance to moisture damage after soil compacted very well. The use of cement treatment gave higher compressive strength than lime treatment [1]. Hesham, 2013, investigated that using cement kiln dust (CKD) alone and add cement to cement kiln dust to reduce the swelling and upgrade their geotechnical properties. Many samples of expansive soils form El-Kawther quarter, Sohge governorates have been investigated. It is concluded that adding the cement kiln dust and cement kiln dust with lime led to a decrease in maximum dry density and an increase in the optimum water content. Besides that, the unconfined compressive strength values were increased using cement kiln dust and cement kiln dust with lime at 7 days curing time. Additional ultrasonic longitudinal (Vp) and shear (Vs) velocities values were also increased by the addition of the cement kiln dust and the cement kiln dust with lime at 7 days curing time. Increment of the curing time from 7 to 28 days led to an increase in both unconfined compressive strength and ultrasonic velocities values. Free swelling percent of the studied soil was reduced from 80.0% to 0.0% after the treatment [2]. **Bayat** et al., were add two types of stabilized material for swelling soil (cement/ lime) to investigate the mechanical properties. They concluded that when adding lime or cement, positive acting of some properties was improved such as plasticity index, moisture content and maximum dry unit weight. Besides that the adding cement to sample led to an increase of unconfined compressive strength (UCS) for that samples. They have defined the relationship between modulus (E_{50}) and uniaxial compressive strength, treatment time and additive (cement or lime) content [3]. Hussein et al., 2018 studied and investigated the clayey soils in Iraq, and they found that around 35% of soft clay which causes many problems for civil and geologist engineer during the implementation of civil works. Throughout this investigation focus on soil stabilized by using sawdust ash with different percentages; 0, 2,4,6,8 and 10% of the weight of dry samples. They carried out that, the mixture of sawdust improves the soil characterization; reduction in specific gravity, maximum dry density and compression coefficient, [4]. Ali et al., 2017 studied the soil behavior according to add cementing agents such as lime, cement and another byproduct such as fly ash and slag. The treatment of swelling soil leads to be a challenge to the designer builds infrastructure plans on clay deposits which improve the geotechnical properties. This investigation addressed some fundamental and successful soil improvement used in the civil engineering field [5]. Bangladesh was suffering a big problem of combustion residues ash which comes from bypass from electricity production. Combustion residues ash was used as a stabilizer to improve the mechanical properties of swelling soils. They were adding different percentage of wood ash (0, 5, 7.5, 10, and 12.5) % by weight of samples which contain 30% CaO to upgrade the mechanical properties such as unconfined compressive strength (UCS), shear strength parameters, workability, and compaction and compressibility characteristics. the test result signifying that the soil could be made lighter with the increase of moisture content, strength, and reduction of compressibility due to the addition of ash content [6]. Sun et. al. 2018 improved the expansive soil by adding sawdust, they studying many mechanical properties unconfined compressive strength, shearing strength characteristics, and cyclic wetting-trying behavior of stabilized soil were studied. They have mentioned the optimum addition of sawdust was 7.5%. They recommended that the soil upgraded by adding sawdust , so both swelling potential and swelling pressure decrease with the increasing of sawdust addition. Besides that, some mechanical properties increased according to sawdust increased tile reach 7.5 % such as UCS, shear strength and cohesion and friction. The addition of sawdust can effectively reduce the influence of drying and wetting cycles on the volumetric change and the shear strength parameters of soil [7]. Abdullah et al., 2017, they have used the cement kiln dust as a byproduct to improve the sabkha soil. Soil improvement was not only by mechanical methods, but by chemical methods. x Soil treatment by adding chemical stabilization to improve the engineering properties of treated soil x. They try to find the percentage of cement kiln dust to upgrade of sabkha soil, samples were provided with 2% cement and 10%, 20% or 30% CKD and are tested to determine their unconfined compressive strength (UCS), soaked California bearing ratio (CBR) and durability. They used advanced techniques, such as the scanning electron microscope (SEM), energy dispersive X-ray analysis (EDX), backscattered electron image (BEI) and X-ray diffraction analysis (XRD). It is noted that the sabkha soil mixed with 2% cement and 30% CKD could be used as a sub-base material in rigid pavements. The incorporation of CKD leads to technical and economic benefits [8].

One of the most important material as bypass of cement industry is Cement kiln dust (CKD) which increased diagrammatically, the authors give an overview to find out the economical and efficient means of using cement kiln dust (CKD) in different applications such as soil stabilization, pavements, roads, waste product stabilization, and agriculture, etc. They focused on the chemical reaction between soil and cement. They studied the chemical compounds found in soil; quartz, feldspar, dolomite, calcite, montmorillonite, kaolinite etc. react with the chemical constituents found in different identified chemicals stabilizers. That helps in upgrade and improves the texture, increase the strength and reduce the swell characteristics of the various soils. By examining the values obtained ideal values are obtained at a 50% proportional mix of CKD in total percentage [9]. Hussein et al, 2018, according to the geologist survey and investigation for Iraqi especially the southern part they found soft clayey soil around 35%. So, they studying weak soil to upgrade their mechanical properties to ready for suing in construction and infrastructure using of various stabilizers such as sawdust ash. The samples were collected from soft clay to upgrade by using sawdust (SDA) with different percentages; 0, 2, 4, 6, 8 and 10% by dry weight of soil sample. The stabilized soils , with 4 and 10% ash content, resulted in low CBR values 1.6-1.2% which can be used as sub-base. The SDA can be considered as a cheap and acceptable stabilizing agent in road construction for improving most of the geotechnical properties of the soft clayey soil [10]. Zhuhai et al, 2017 tried to change the chemical properties of soft soils using the stabilizers or binders to increase the strength and stiffness of the originally weak soils. They were investigating the mechanical properties swelling soil after additional Saw Dust Ash, the properties ware measured, such as index properties of parent soil, Atterberg Limits, compaction characteristics and UCC of both parent soil and soil treated with sawdust ash and lime. X All samples were collected according to Indian Code X. This investigation carried out that, lime with sawdust as corrective material was best encouraging. One can easily realize after the results that with a small percentage of activators, SDA and industrial waste can be efficiently used in soil stabilization. This can reduce the construction cost of the roads particularly in the rural areas of developing countries like India [11,12,13,14,15].

2. Plan of Study

2.1. Materials

The studied area contained silty clay soil that samples included 94% soil pass form sieve No. 200. Throw checking samples were gray to black color X it considered expansive X. The depth of the design pit reaches to 2.5 m below the ground surface. The results indicated that free swelling around 120%, so its expansive. The sawdust shape was 15 -25 mm as long and the thickness of 0.5 mm as shown in Figure 1. The wood floor was collected from the locally available sawmill and was simply burned to prepare ash. In this arrangement, pulverized wood was kept in a steel box of 1.5m× 1.5m in dimensions. Five thermocouples with a connecting data logger were used for measuring the burning temperature. Briquettes were used as fuel to start and maintain the wood ash contained about 30% CaO, which is the key factor for improving soil properties.

Figure 1. Preparation of Sawdust waste

2.2. Applied Tests

2.2.1. Index Tests

Tested samples were collected by the author's team , all properties for that samples were obtained according to

ASTM D1140-00R06 and tableted in Table 1. Sample characterization was evaluated related to ASTM. sample preparation regarding as fine as No. 200 (75 µm) according to ASTM D1140-00R06X. The determination of materials finer than No.200 (75-µ-m) is carried out as described in ASTM. Liquid Limit, Plastic Limit, and Plasticity Index are obtained as described in ASTM D4318-10. The shrinkage limit is obtained as described in per IS 10077. The standard compaction test is also carried out as described in ASTM D0698-07E01. The free swelling readings are obtained from the application of their standard tests described in per IS: 2727-1977. The results are shown in Table 1.

Table 1. The index properties of the natural clay soil

Test	Wc %	L.L %	P.L %	S.L %	P.I %	Ɣ, dry $_{max}$ (t/m^3)	O.M. C %	F.S %
Result	12	40.1	22	10.6	18.1	1.76	17	120

2.2.2. Strength Tests

Unconfined compression tests have been used in most of the experimental programs to verify the effectiveness of the treated soil. The sample has been prepared to be ready for strength test, the dimensions of cylindrical specimens; 36 mm diameter and 71 mm length; were determined according to ASTM D-2166. Shear strength parameters, *c* and Φ, were determined by the direct shear test (ASTM D 3080) of the compacted soil specimens (60 mm diameter and 25 mm height). Settlement characteristics of soils were determined by performing the consolidation test (ASTM D-2435) on the samples of 63.5 mm diameter and 25mm height.

The most common test to determine the strength of the material was defined as follow:

i) The unconfined compression test, as mentioned in ASTM D2166-06.
ii) The direct shear test, as illustrated in ASTM D3080-04.
iii) The indirect tension test on dry samples, as described in ASTM D3967-08.

In each test, all tested samples were prepared to be suitable according to standard Proctor mold. Dry density and water content were investigated. Samples dimensional were 25 mm, 60 mm diameter and length respectively. The forced applied vertically and the vertical stress increased gradually 0.5, 1.0 and 1.5 Kg\cm$^{2.}$ Compressive and tensile strength were measured according to ASTM. Brazilian test was used to determine indirect tensile, X for prepared the sample, the Brazilian test set is shown in X, Figure 2.

For samples with length *L=2D*, the tensile stress can be determined as in Eq. 1:

$$\sigma = \frac{2F}{\pi DL} \quad (1)$$

Where *D* and *L* are the diameter and length of the cylindrical samples

2.3. Swelling Tests

Samples were prepared and tested as mentioned in IS: 2727-1977. The tested clay was passed from sieve No. 40. The swelling potential tests according to ASTM specification are carried out on clay samples without adding the sawdust. Their values have reached 120%. The clayey soil was put in the mold of the consolidation test at max. dry density and optimum water content. The loading system was increased by 0.25 kg/cm^2 on samples, vertically to simulate the field test, dial gauge was fixed over samples to measure daily increases for samples through 3 days until dial reading constantly.

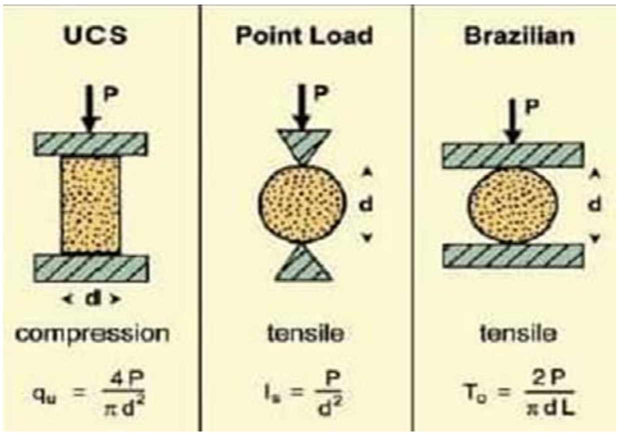

Figure 2. Compression, Tensile and Brazilian test.

3. Experimental Work

3.1. Sawdust Waste

The specification of sawdust according to size and other properties, refer to some reference it used sawdust ash and mention the physical properties and chemical composition of the used sawdust ash [6]. Also, many researchers mentioned to used sawdust as its to stabilize the soft clay beside that the adding hay to improve the soft clay behavior. The liquid, plastic and shrinkage limits are obtained for each clay-sawdust waste mixture, the assumption to add sawdust as a percentage of the weight of clay (0,1,3 and 5 %). The compaction test is carried out on each mixture. The results are summarized in Table 2, Figure 3, Figure 4 and Figure 5, indicate the relationships between the water content and maximum dry density. The relationship between optimum water content and maximum dry density is illustrated in Figure 4., and the comparison between S.L and optimum water content is shown in Figure 5.

Table 2. Maximum dry density with different sawdust percentage

0%		1%		3%		5%	
Max. dry	water	Max. dry	water	Max. dry	water	Max. dry	**water**
1.64	5	1.63	7.5	1.63	6	1.55	**7.5**
1.72	12.5	1.67	12	1.67	9	1.63	**11**
1.75	15	1.73	15	1.7	12	1.68	**15**
1.72	17.5	1.7	18	1.67	17	1.67	**18**
1.63	22.5	1.65	21	**-**	-	1.64	**21**

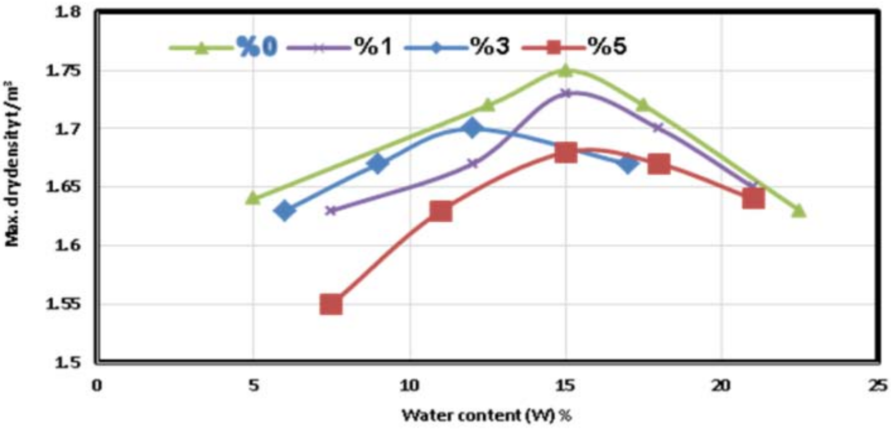

Figure 3. The maximum dry density with different sawdust percentage

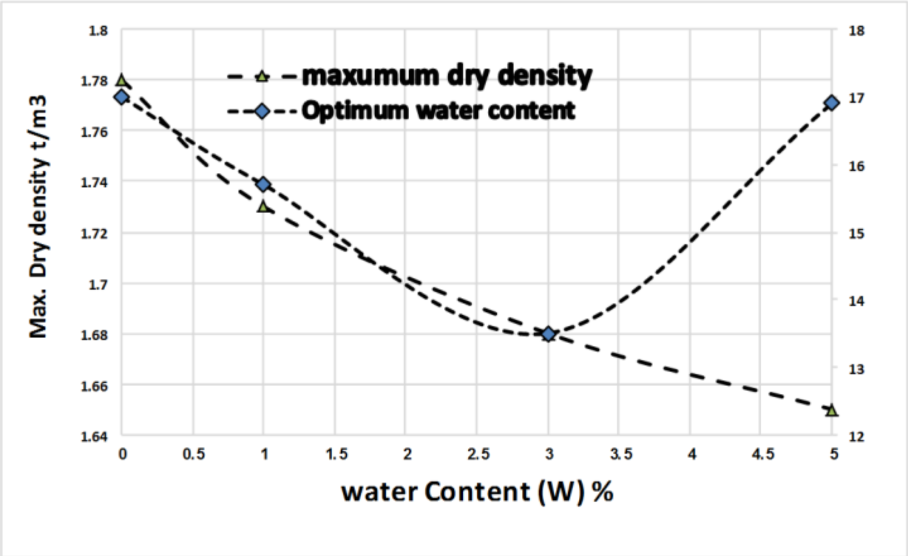

Figure 4. Optimum water content and maximum dry density

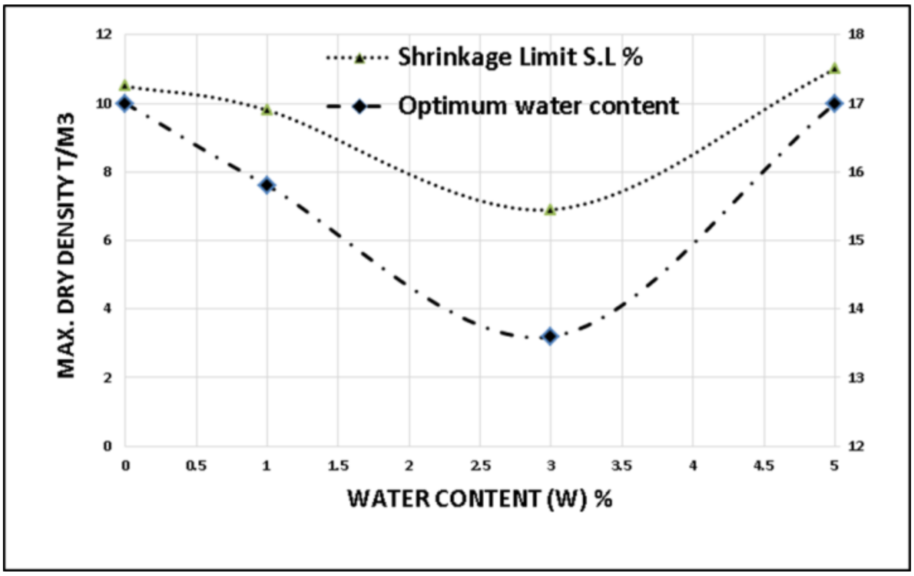

Figure 5. Comparison between S.L and Optimum water content

3.2. Strength Properties of Different Samples

According to mechanical properties and more scrutinized for results, the unconfined compression test is carried out on many samples Xand the average is obtained. The samples were cylindrical with a diameter of 2.5 cm and 6.0 cm in length. The results are shown in Figure 6 and Figure 7, the direct shear test is carried out on the clay-sawdust waste mixture. The compaction is carried out using the optimum water content and maximum dry density of the mixture as mentioned. The loading rate was 0.5, 1 and 1.5 kg/cm^2 and the test was carried out till failure and the results are shown in Figure 8 and Figure 9.

Cylindrical samples were prepared related to ASTM (length twice of diameter) were measured in the Brazilian test. Figure 10 represents of the Brazilian test set. The results of the indirect tension tests were measured and maximum swelling deformation with and without sawdust addition, Figure 11.

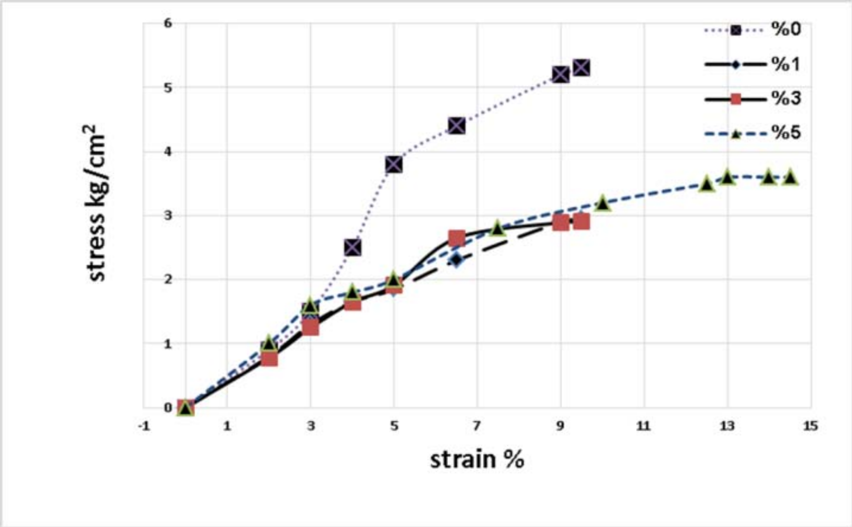

Figure 6. Results of unconfined compressive strength test

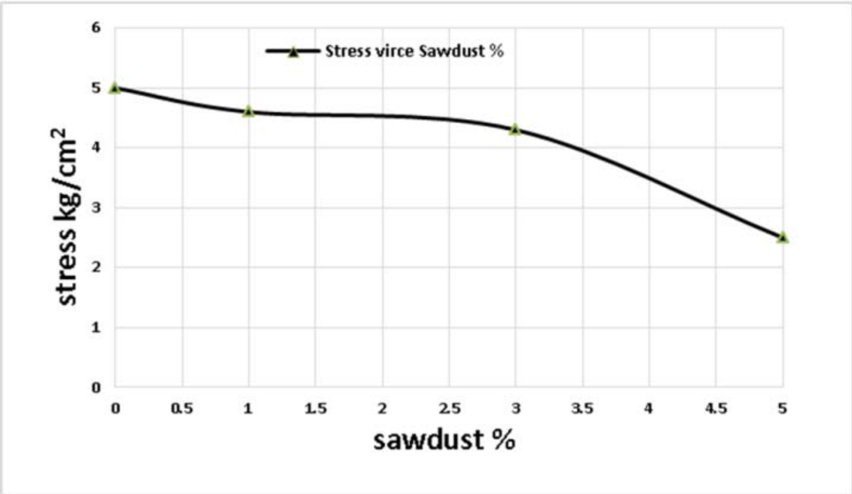

Figure 7. Sawdust ratio with unconfined compressive strength

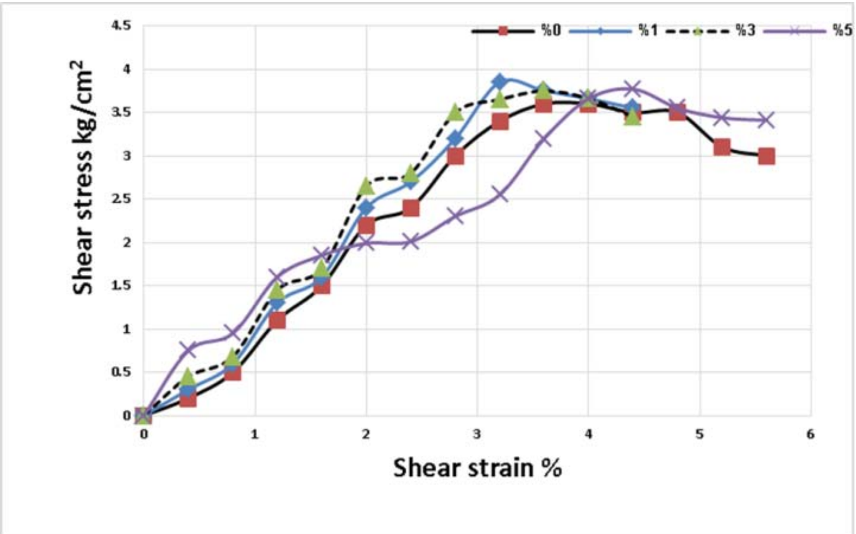

Figure 8. Direct shear test under vertical stress of 1 kg/cm^2

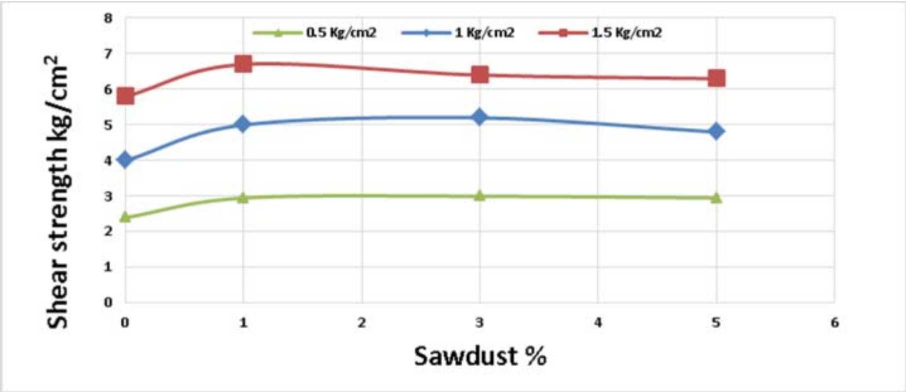

Figure 9. Shear strength under 0.5, 1, and 1.5 Kg/cm^2

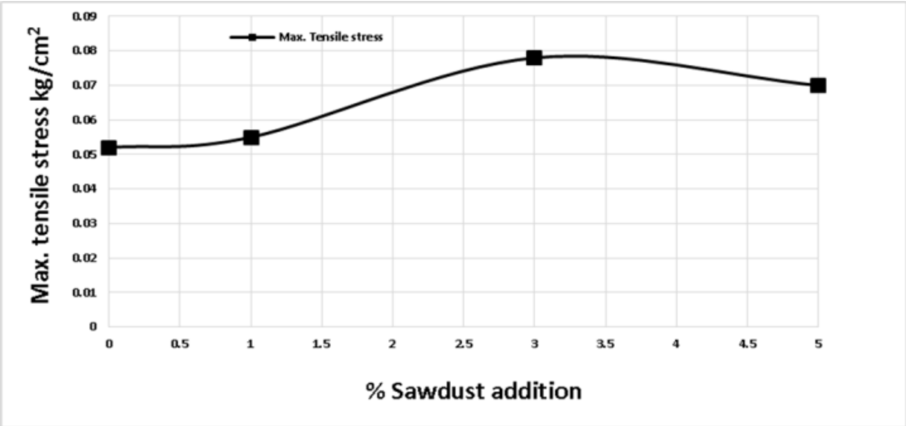

Figure 10. Indirect tension test for air-dried samples (Brazilian test)

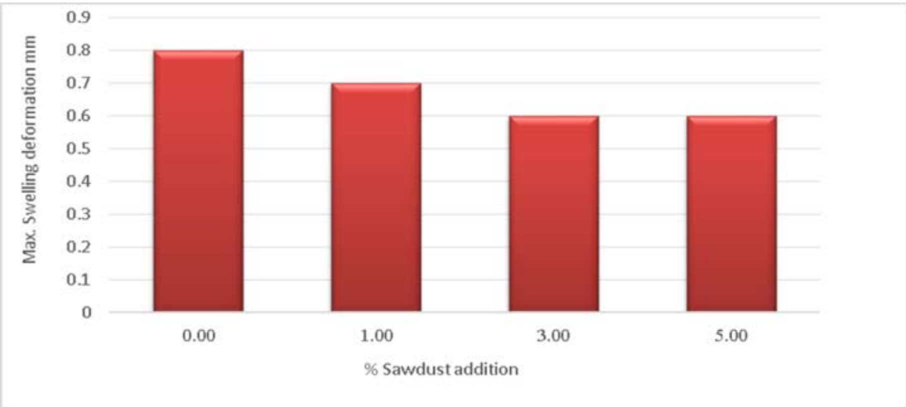

Figure 11. Maximum swelling deformation with and without sawdust addition

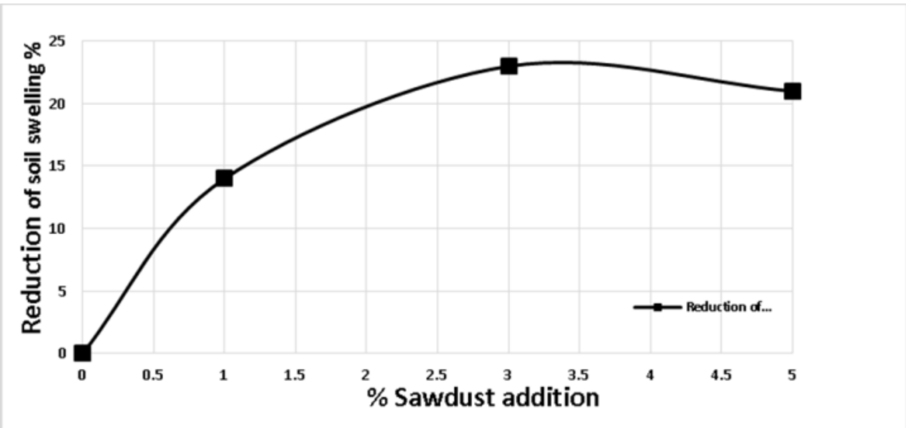

Figure 12. Reduction of swelling deformation with sawdust addition

3.3. Swelling Properties of the Clay-Sawdust Waste Mixture

The test of free swell is carried out on each clay-sawdust mixture and the results are presented in Table 2. The test of swelling potential is applied on a consolidation cell loaded with 0.5 kg/cm^2 as initial conditions. This test is done according to the steps mentioned before. The dial gauge reading is recorded after three days for each mixture. Also, this test is redone at least three times for certainty and the average is taken. Furthermore, the experimental results are presented in Figure 12. The index properties of the clay with and without Sawdust waste addition are tabulated in Table 2. As shown in Figure 3 and Figure 4, the optimum water content with maximum dry density is plotted. From these Figures., it is obvious that the maximum dry density is decreased with the sawdust waste percentage increasing. Furthermore, this is normal behavior due to the weight of the dry soil is decreased with the increasing of sawdust waste addition. Also, the optimum water content is decreased with the increasing of the sawdust waste addition to 1.5% sawdust waste percentage, which tends to increase gradually. Also, the optimum water content behavior is nearly the same as the shrinkage limit of the clay-sawdust waste mixtures behavior. The liquid and plastic limits have no considerable changes. Shrinkage limit, X one of the Atterberg limits X, is linked widely with a lot of plasticity-based soil behaviors. Such correlations have been found to exhibit poor performance in a great majority of these cases. In the recent, it has been brought out that the shrinkage limit of natural soil does not depend on plasticity characteristics, and it is primarily governed by the relative grain size distribution of the soil [3]. The shrinkage limit has considerable variations, as for example in Figure 5 the shrinkage limits decrease with the increase of sawdust waste addition until 1.5 % which begins to increase. This behavior is very near to the optimum water content behavior that indicates the shrinkage limit does not depend on the plasticity of the soil rather than the particle size distribution, Figure 5. Also, have considerable behavior changes as the compaction results of the clay-sawdust waste mixture.

4. Experimental Results with Discussion

The experimental tests of two swellings are done on each of the clay-sawdust mixtures. Firstly, X the test is the free swell test and its results are presented in Table 2. It is clear that the free swelling value is decreased with low values these sawdust waste increasing addition, Table 2. This can be due to floating Sawdust waste above the water in the jar of the free swell test. Secondly, the test on the samples mixture is the swelling potential test. This test is done as mentioned before. Vertical stress of 0.25 kg/cm2 is applied to the samples to show the field conditions. In the field, nearly the small buildings only, that can run the risk of swelling. For this reason, vertical stress of 0.25 kg/cm2 is applied to the samples. The maximum swelling deformation for each mixture is shown in Figure 12. Furthermore, the addition of 1% sawdust waste decreases the swelling deformation from 0.83 mm to 0.60 mmAlso, the swelling deformation is reduced to about 23% of its original value without adding sawdust waste. The relation between the deformations and unconfined compression stresses is presented in Figure 6 and Figure 7. The decrease in the compression strength of the mixture is associated with increases in sawdust waste percentage. Moreover, this may be due to the fact that the addition of fibers to clay weakens the ability of the clay to withstand compression forces. Also, this can be due to the fact that the sawdust waste grains create weak planes in the clay pastel which accelerates the failure. In general, the addition of sawdust waste to the clayey soil increases the shear stress of the soil. The relation between the percent of sawdust waste addition and the maximum shear stress is presented in Figure 8 and Figure 9. The shear stress is increased with the increasing of the normal stress on the samples as shown in Figure 8. The best ratio of sawdust waste addition appears to be 1%. The sawdust waste grains make cementation links between the clay particles which help increase its shear strength. The indirect tension was applied to the clay-sawdust mixture samples, Figure 10. This test is done on air-dried samples to see the effect of sawdust waste addition on the tensile strength of the dry clay samples. These tests??? are done to identify more about the phenomenon of building houses by Egyptian villagers, with the clay-sawdust waste mixture. The results proved that the addition of sawdust waste to the clayey soil increases its tensile strength. The best ratio of sawdust waste seems to be 1% that achieves the maximum tensile stress for the air-dried clayey samples mixtures, Figure 11. The walls of the old village houses carry the vertical loads, that change to small horizontal forces in the clay mixture blocks which induce tensile stresses. In this case, the Sawdust waste grains make cementation between clay particles which introduce a type of reinforcement.

5. Conclusions

This paper presents a study of adding sawdust waste to clayey soil. No impressive or sensible change in the Atterberg limits is happened because of the addition of sawdust waste. The optimum water content is decreased with the increasing of sawdust waste addition to 1% and then begins to increase with the increasing addition of sawdust waste. Also, the maximum dry density is decreased with the addition of sawdust waste until 1%. The shrinkage limit is decreased with the increasing addition of sawdust waste until 1% and is increased with the higher addition of sawdust waste. The unconfined compression strength of the clay is decreased with the increasing of the added sawdust waste ratio. Furthermore, the direct shear strength of the clay is increased notably with the addition of sawdust waste even 1% and also, this increase is approximately more than 20%. The tensile strength of the air-dried sawdust waste-clay mixtures is increased with the increasing ratio of sawdust waste. Moreover, the increase of the tensile strength is about 30% with the addition of 1% sawdust waste. The best ratio of sawdust waste addition appears to be 1%. Finally, the swelling potential under 0.25 kg/cm^2 is decreased with the addition of sawdust waste and also, this decrease is about 20% with a 1% sawdust waste ratio.

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