Determination the Effect of Using Rice Straw and Tyre Chips on Shear Strength of Sandy Soil Using Triaxial Test

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Abstract: The environmental wastes caused by agriculture and industrial development are increasing. In Egypt, millions of tons of natural and synthetic wastes are disposed every year. Hence, one of the cheapest and most effective ways to eliminate those wastes and protect our environment is recycling them by mixing with soil. This research presents an experimental study about the effects of mixing rice straw (RS) and tyre chips (TC) with two types of sand on the properties of the mixtures. So, this research discusses two types of natural and synthetic waste and two types of soils, namely Gamasa sand (S1) and Yellow sand (S5). Six types of mixtures and two control specimens have been tested to determine the basic soil and shear strength characteristics for each of them. Triaxial experiments were performed on various sand- rice straw (RS) and tyre chips (TC) mixtures using static triaxial apparatus. Samples were constructed at the maximum dry density and optimum moisture content to consider engineering applications in dry regions. Finally, this study recommended a proposed mixture of (S5) with 1% (RS) and 5% (TC) by weight of soil to produce (S8) which has the best enhanced soil shear characteristics comparing with the other mixtures. Various advantages of using synthetic and natural fibers with soil have been discussed.
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1. Introduction

Soil reinforcement is defined as a process used to improve the engineering (mechanical) characteristics of soil and is to improve its stability, to increase its bearing capacity, to reduce settlement and lateral deformation. In this way, using waste materials generated from agricultural and industrial processes which defined as natural and synthetic fibers to reinforce soil is an old and traditional idea. Consequently, randomly distributed fiber reinforced soils have recently attracted attention in geotechnical engineering.

Recently, fiber is generally divided into two main categories: one is the natural fibers like rice straw, wheat straw, coir, bagasse, and jute,….etc. because they have the advantages of availability and low cost and the disadvantage of environmental pollution when burned or not. Others are synthetic (man- made) fibers, such as polypropylene fiber, polyvinyl alcohol fiber and nylon fiber,….etc. It can be seen as a waste, not reusable, non biodegrable and environmentally pollutant such as the water bottles, the car’s tires and the plastic bags,….etc[1]. Generally, the use of wastes as alternate soil improvement material has had a great deal of interest in recent years. Agricultural (natural) wastes such as Coconut (coir) fiber, Sisal, Palm fibers, Jute, Flax, Barely straw, Bamboo, Cane[1], rice straw, wheat straw[2, 4], natural vernacular fibers of Grewia Optivia (Beul) and Pinus Roxburghii (Chir Pine) [5], Short Hibiscus cannabinus fibers[6] and Industrial (synthetic) wastes such as Polypropylene (PP) fibers, Polyester (PET) fibers, Polyethylene (PE) fibers, Glass fibers, Nylon fiber, Steel fibers, Polyvinyl alcohol (PVA) fibers[1], waste fishing net[7], wool fibres of various fibre lengths[8], polyester fibres[9], Waste Gypsum Board Paper[10], polypropylene fibers[11], Synthetic wick fibers[12], Waste Plastic Bottle Strips[13, 14], polyethylene terephthalate (PET) fibers[15], Lime[16], Tyre Ash material burnt in air[17], recycled aggregates from demolition waste[18, 19], Ground Granulated Blast Furnace Slag (GGBS)[20], Crushed Glass[21, 22], waste sawdust [23,24]. A combination of several material such as polypropylene fibers and fly ash[25], polypropylene fiber and four types of agriculture wastes (wheat straw, rice straw, jute)[3], cement and polypropylene fiber[26], silica fume–scrap tire rubber fiber mixture[27], recycled gypsum and waste plastic trays[28], polyethylene waste material and cement[29], rice husk ash and cement[30], cement, lime and rice husk ash (CLR)[31], marble dust and fly ash[32]. Egypt is very rich in agro-waste resources. One of the most abundant and readily available agro-waste resources in the country is rice straw. Rice straw has become a very serious problem in Egypt due to the huge production of straw of about 5.236 million tons /year. Being a suitable material for insects and pests. Rice straw is considered a problem for the farmers who store it near their houses or fields. The farmers then burn the straw causing black clouds and severe pollution in the Egyptian atmosphere. Rice grown in Egypt from two million feddans (two billion acres) to 1.6 million feddans. According to the Egyptian Environmental Affairs Agency/Egyptian Ministry of Environment/annual report for agricultural waste. Dated 16/9/2018[33].

Using the sand box model to simulate the slope failure mechanism under reinforced and unreinforced soil using rice straw fibers. Slope stability may increase significantly by adding rice straw to sandy soil. Generally, whenever rice straw proportion increases the slope stability. The optimum rice straw content that gives the maximum stress in the form of slope stability is in the range of 0.75 % by weight. Sand mixed with 1.0 % rice straw by weight leads to increasing the angle of internal friction (Ø) by 46.63%, as compared by only the host sand[34].

The disposal of used tyres is a huge environmental problem in Egypt. About 20 million tons of waste tyres material per year in the year (2017) caused by the Egyptian vehicle industries development and the rate of the massive increase of imported cars. Burning the used tyres is the most popular concept in Egypt. Burning the used tyres as a cheap fuel for brick and pottery industries. A lot of toxic fumes produced from the burning process that is an environmental pollutant. The disposal process of the used tyres is considered a major problem in the waste stream as it is highly found everywhere. Providing a new concept for Egypt to benefit of scrap tire and resolving a local environmental problem by using it with soil for soil improvement is very important. [35, 36].

Sand particles are brittle, but was found to be more ductile with rubber mixed. Using of recycled tyres in the applications of civil engineering as a lightweight material has been growing in the last two decades. Mixing recycled tires in various shapes and ratios with different types of soils have been used as backfilling on slopes, retaining walls and embankments. Recently, using it under foundations as a damping material in hazard seismic areas has a huge importance. Many types of tests have been performed to investigate the mechanical properties of recycled tyres mixed with sandy soils such as various types of triaxial and consolidometer tests. The use of recycled tyres and sand mixtures has a huge effect on unit weight, shear strength, stiffness and deformation modulus (E_{50}). Generally, mixtures unit weight decreased with the increasing of tyres content ratio and the failure behaviour of the mixtures changed from brittle to ductile behaviour. The ductile behaviour of the sand-tyres mixtures had many advantages such as increasing the seismic isolation layers beneath the foundations of structures in seismic zones. All types of the sand – tyres mixtures had been decreased the shear strength of the mixtures except the 5% tyres content in the mixture by weight, which exhibited higher shear strength[37].

In this paper, six types of mixtures and two control specimens have been tested to determine the basic soil characteristics and shear strength characteristics for each of them. Triaxial experiments were performed on various sand- rice straw (RS) and tyre chips (TC) mixtures using static triaxial apparatus. Samples were constructed at the maximum dry density and optimum moisture content to consider engineering applications in dry regions.

2. Research Objectives

The main objectives of this research are to reuse the natural and synthetic waste materials to enhance the basic characteristics of soil to have a clean and clear environment. Mixing this wastes with different types of sandy soils both in a single or double form to have a strong soil to build projects. Investigate the effects of mixing the natural waste rice straw (RS) and the synthetic waste tyre chips (TC) in several manners with two types of sand (namely Gamasa sand (S1) and Yellow sand (S5)) on the properties of the mixtures. Finally, Determination the basic soil and shear strength characteristics, Compare the results and give notices are the first goal.

1. Testing equipment

Using Triaxial Digital machine manufactured by (The APS GmbH Company) with its brand Wille Geotechnik®. It enables the engineer to determine exactly the mechanical and physical properties of a soil was employed in all triaxial experiments on samples with 70 mm diameter and 140 mm high. To record the load, deformation, and inner and outer specimen pressures, an automatic data logger system was used. Using Linear Variable Deferential Transformers (LVDTs) with a displacement range of about 40 mm and load cell with a capacity of 20 KN, axial strains and axial load were measured, respectively. Cell pressure and pore pressure were also recorded by using two pressure transducers connected to the data logger system. This apparatus and others used in this research exist in soil mechanics and foundation laboratory, Engineering Faculty, El-Mansoura University, Egypt.

2. Materials

2.1Raw Sand

The engineering properties of used materials were determined by conducting laboratory tests according to the American Society for Testing and Materials (ASTM Standards). The following sections present the different properties of the study materials.

Based on the previous data, a two main groups of triaxial tests were performed on two main types of sandy soils. The first was Gamasa sand with (S1) symbol. The main source of this type of sand is the northern coastal areas in Egypt, especially in the area extending from the city of Gamasa, El- Dakahlia governorate to the city of Baltim, Kafr El-Sheikh governorate along the northern Mediterranean seacoast. The second was yellow sand with (S5) symbol. The main source of this type of sand is the sand quarries in El-Sharkia governorate. The clean sandy soil used in these tests (S1 and S5) was obtained locally. The used sandy soils have been classified as poor graded sand (SP) according to the Unified Soil Classification System (USCS) with (ASTM D2487-06)[*38*]. The specific gravity for the used soils (S1) and (S5) is (2.683544) and (2.642706) respectively, according to (ASTM D854 – 06)[*39*].

The effective diameter for the two types of sand particles at D_{10} is (0.17 and 0.21) mm respectively. According to the gradation curve, shown in Figure 1, the uniformity coefficient is (1.71 and 0.85) and the curvature coefficient is approximately (1.17 and 2.24) respectively. Figure 2. a shows Modified Proctor Test results for soils S1, S2, S3 and S4. While, Figure 2. b shows Modified Proctor Test results for soils S5, S6, S7 and S8. The resultant Soil properties are summarized in Table 1.

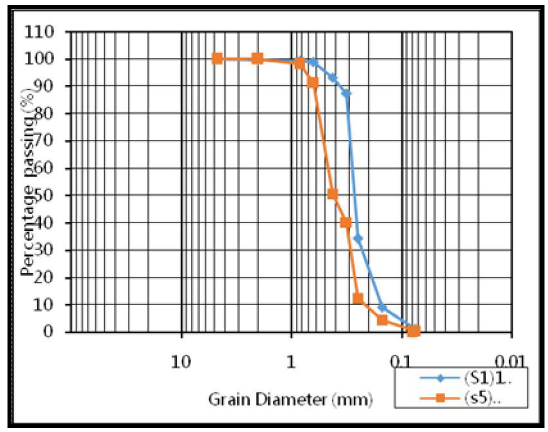


Figure 1 Gradation Curve for Raw Sand Soils S1 and S5.

Table 1Compaction Characteristics of Mixtures Derived From Modified Proctor Test (Laboratory Study).

Symbol	Soil Type	O.M.C %	M.D.D (gm/cm3)
S1	Gamasa sand	7.25%	1.744
S2	Gamasa sand+1% Rice straw (RS)	10.25%	1.694
S3	Gamasa sand+5%Tyres (TC)	6.50%	1.733
S4	Gamasa sand+1%Rice Straw (RS) +5%Tyres (TC)	10.50%	1.695
S5	Yellow sand	9.75%	1.711
S6	yellow sand+1%RiceStraw (RS)	11.25%	1.653
S7	yellow sand+5%tyres (TC)	11.70%	1.68
S8	yellow sand+1%RiceStraw (RS)+5%tyres (TC)	13.50%	1.644

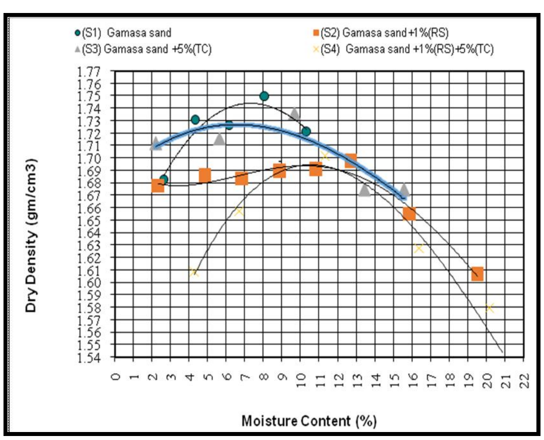


Figure 2. a. Modified Proctor Test Results for Soils S1, S2, S3 and S4.

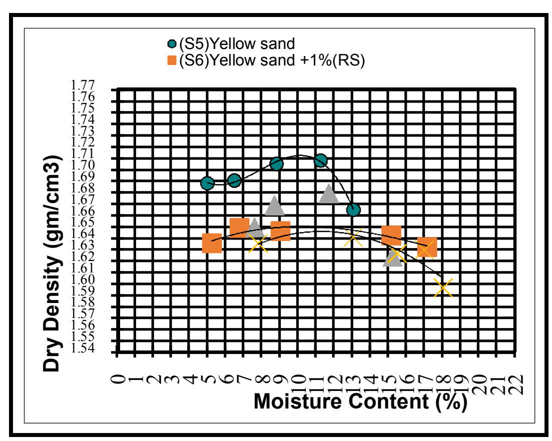


Figure 2. b. Modified Proctor Test Results for Soils S5, S6, S7 and S8.

3. Rice Straw (RS)

3.1. Definition and Source

Rice straw (RS) is one of the crop residues that can be used in civil engineering as construction material and soil improvement. The part between the root crown and the grain head is known as a straw. The internal and external shape of a single straw is cylindrical. It consists of silica, lignin, and cellulose. The cylindrical shape is stable by its nature and the microscopic waxy coat. The approximate diameter and length is about 6mm and 800 mm respectively. Every single straw has 4 or 5 internodes, before using rice straw the grains must be removed then it can be cut into the length what study needed. To use the rice straw as reinforced material by mixing it with several types of soils, the required length which can be used in soil lab. should be 10-30 mm. So, it can be well-distributed in soil samples. Therefore, rice straw (RS) was cut to approximate length 10-20 mm and the internodes as possible as usual in the middle [40]. The source of rice straw (RS) is the agriculture fields localized at Sherbin city, El-Dakahlia governorate, Egypt.

3.1.2 Increasing Durability of Rice Straw (RS) Using (SH) Agent

The most popular material used to increase rice straw durability is (SH) agent. It is a water solution and it composed of modified polyvinyl alcohol, which diluted in water, the ratio 6%is the modified polyvinyl alcohol content ratio in the solution, its density is 1.09 g/cm^3. The rice straw smaller water absorption is the better for anti-decay experimental results, which indicates that SH agent goes into the internal pores, blocks the entrance, enhances its water resistance, the maximum elongation and maximum tension occurred which is the bigger the better. The improvement of the mechanical properties of rice straw could be occurred after soaking in SH agent. The SH agent was non-pollutant and non-toxic as shown in the Experimental results[40].

3.1.3 Tyre chips (TC)

Over the past decades, several scientific studies have been performed about the application of recycled rubber in the improvement of soil characteristics. The main purpose was to increase using it in engineering applications, especially in geotechnical projects, paying attention to possible environmental pollutions caused by these materials is very important. Understanding the properties of sand-rubber mixtures are essential to evaluate its performance in geotechnical applications [36,37]. Table 2 presents the different properties of the used tyre chips (TC) and the source of the used tyre chips is generated from local factory produce tyre chips, shreds and powder which localized at Sherbin city, El-Dakahlia governorate, Egypt. A typical weight is approximately 110 N (25 lb) for new automobile and light truck tires and 556 N (125 lb) for new truck tires. The average weight of scrap automobile tires is 89 N (20 lb) and 445 N (100 lb) for truck tires [41]. The tyre chips (TC) were used in the laboratory tests is according to (ASTM Standards- D6270 − 08 (Reapproved 2012))[42].

Table 2 Typical Composition of Tyres [41].

Material	Percentage (%) by Weight
Natural Rubber	14
Synthetic Rubber	27
Carbon Black	28
Steel	14 – 15
Fabric, fillers, etc.	16 – 17

4. Specimens Preparation

Figure 3. a. Soil Sample S4.

Figure 3. b. Soil Sample S8.

For the two types of soils, using the appropriate amount of dry sand as (S1 and S5). Mixing dry sand + 5 % tyre chips (TC) by sand weight as (S2 and S6), dry sand + 1% rice straw (RS) by sand weight as (S3 and S7) and dry sand + 5%tyre chips (TC) + 1% rice straw (RS) by sand weight as (S4 and S8). Water was added to the mixture and the mixed materials were then compacted in five layers providing almost the maximum dry density at optimum water content. Figures 3 (a and b) showing (S4 and S8) soil samples after preparation in the lab. Table 1 shows compaction characteristics of mixtures derived from Modified Proctor Test according to (ASTM standards. D1557 – 09)[43]. All specimens were prepared in the same manner and at about the same compaction energy.

5. Experimental work

Figure 4. a. Preparation of Soil Sample S8 in Triaxial Cell.

To evaluate the improvement of soil strength, a group of triaxial compression tests was performed on natural and synthetic fibers rein forced 2 main types of sandy soil samples. Unconsolidated undrained (UU) tests were carried out on sand samples as a control sample and fiber-reinforced sandy soils, according to (ASTM standards. D2850- 95 (Reapproved 1999))[44]. The compressive strength of a soil is determined in terms of the total stress, hence, the resulting strength during loading depends on the pressure developed in the pore fluid. In this test method, fluid flow is not permitted from or into the soil specimen as the load is applied, therefore the resulting pore pressure, and hence strength, differs from that developed in the case where drainage can occur. To determine the stress–strain and strength characteristics of control and reinforced sandy soils with various fiber types and contents, a series of triaxial tests were performed. The test specimens are partially saturated and compacted according to their max. dry density and optimum water content, consolidation may occur when the confining pressure is applied and during shear, even though drainage is not permitted. Hence, if several partially saturated specimens of the same material are tested at different confining stresses, they will not have the same undrained shear strength. The applied axial load under strain-controlled conditions with a strain rate of (0.42 mm/min), the confining pressure is equal to 100 kPa, 200 kPa and 300 kPa to define the shear strength parameters. Used strain rate calculated according to (ASTM Standard D 2850, 1995 (Reapproved 1999)) [44] and equal to (0.3% /minute) of the sample height. Using of tyre chips (TC) is according to (ASTM Standards- D6270 − 08 (Reapproved 2012))[42]. Figure 4. a. shows preparation of soil sample (S8) in triaxial cell. Figure 4. b. shows shear failure in Soil sample (S1).

Figure 4. b. Shear failure in Soil Sample S1 in Triaxial Cell. 3. Results and Discussion

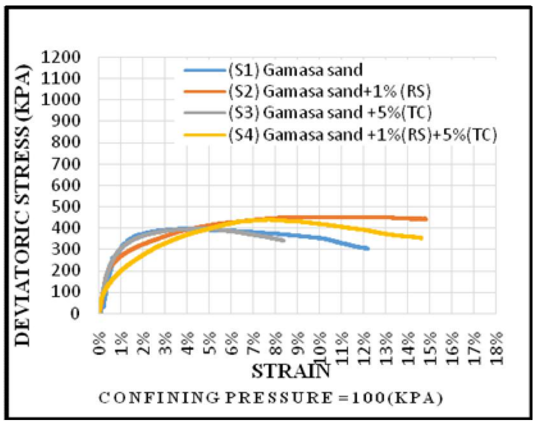
The following results can be obtained from laboratory studies. Stress-strain curves for every type of soil with confining pressure 100, 200 and 300 kpa shown in Figure 5 (a, b and c) and Figure 6 (a, b and c). Mohr's circle graph and deduced angle of internal friction and cohesion values shown in Figures 7 (a, b, c and d) **and** 8 (a, b, c and d). Angle of internal friction, cohesion, poisson's ratio, modulus of elasticity and shear modulus values obtained for every type of mixtures shown in Table 3. Figures 9 (a and b) shows relations between Soil Shear strength and applied vertical stresses for all types of mixtures. From Figures 2 (a and b), it can be deduced that the soil type (S8) has min. value of M.D.D =1.644 gm/ cm^3. It means that the adding of synthetic and natural fibers to the soil (S5) decreases the soil density and has the max. advantage of light weight soil to use. Also, the optimum water content has significantly increased by using the previous mentioned additives to soil samples. From Figures 5 and 6, it can be deduced that at determining values of strain between 5% and 6.5% and the value of adjacent shear stresses has not significantly affected for all soil types. Also, the significant effects of the shear stress values appear after the 5%, 6% and 6.5% strain with 100, 200 and 300 kpa of confining pressures respectively. For all types of soil the max. deviatoric stresses increases with the increase of the confining pressure. For the host soil samples S1 and S5 without any additives it can be seen that the residual stress, decrease rapidly more than other types of soil mixtures. It means that this types of host soil more liquefiable than others. Generally, additives decrease the potential soil liquefaction. Linear increase between applied vertical stress and soil shear strength accompanied by an increase in confining pressure 100, 200 and 300 kpa for all types of tested soil as shown in Figure9 (a and b).

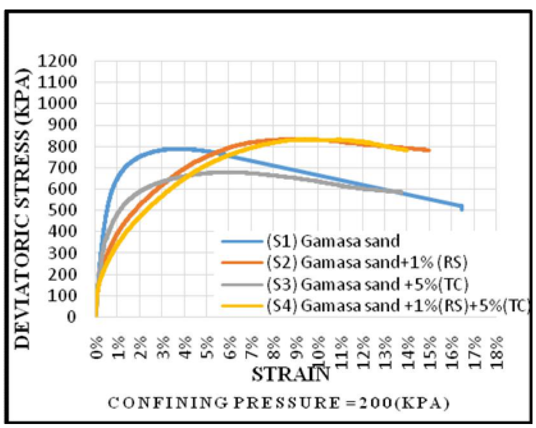
Table 3Laboratory Soil Characteristics for different mixtures.

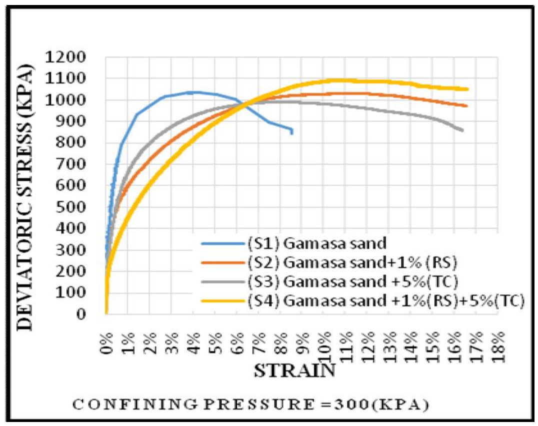
Symbol	Soil Type	O.M.C %	M.D.D (gm/cm^3)	Ø°	C (kpa)	E (kpa)	µ %	G (kpa)
S1	Gamasa sand	7.25%	1.744	37.933	25	39609.79465	0.635754212	12107.50196
S2	Gamasa sand+1% (RS)	10.25%	1.694	39.204	19	37590.21551	0.605755329	11704.83909
S3	Gamasa sand+5%(TC)	6.50%	1.733	36.183	21	49526.76788	0.631531396	15178.00025
S4	Gamasa sand+1%(RS)+5%(TC)	10.50%	1.695	38.374	23	18289.26108	0.622746479	5635.279854
S5	Yellow sand	9.75%	1.711	35.51	44	76350.68471	0.455502201	26228.29586
S6	yellow sand+1%(RS)	11.25%	1.653	36.164	39	25075.17508	0.38526281	9050.692368
S7	yellow sand+5%(TC)	11.70%	1.68	39.032	21	67691.68547	0.404915499	24091.01668
S8	yellow sand+1%(RS)+5%(TC)	13.50%	1.644	35.976	61	14648.06336	0.374310804	5329.239688

Where:

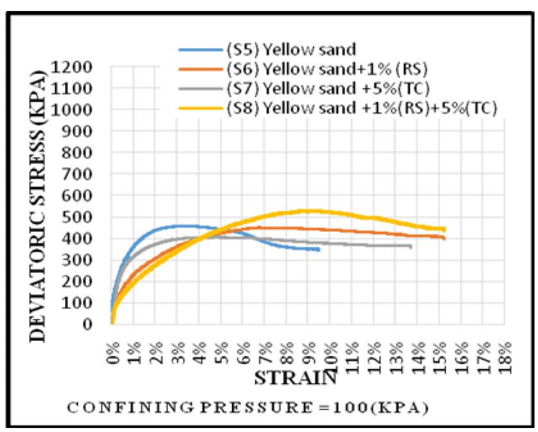
O.M.C	Optimum moisture content %	E	Moduluse of Elasticity (kpa)
M.D.D	Max. dry density (gm/cm^3)	µ	Poissson' ratio %
Ø	Angle of internal friction (degree)	G	Shear Modulus (kpa)
C	Cohesion (kpa)		

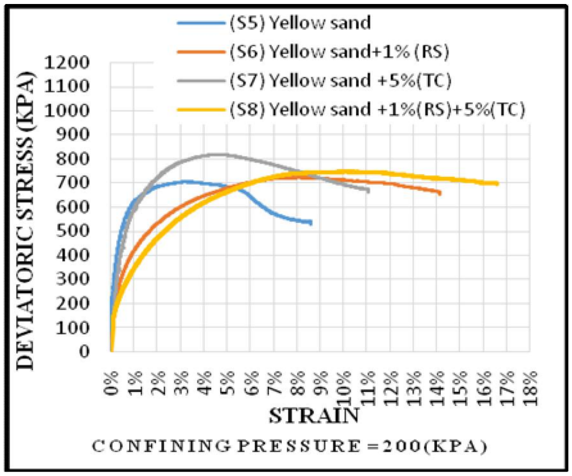


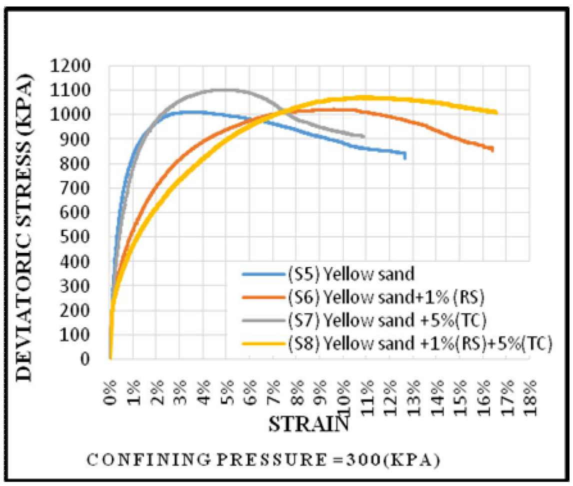




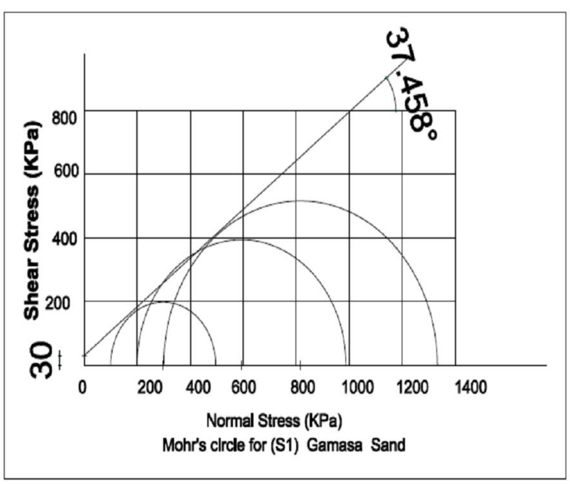
Figures 5 (a, b and c) Stress – Strain Curves for Soil Mixtures S1 through S4with Different Confining Pressures.

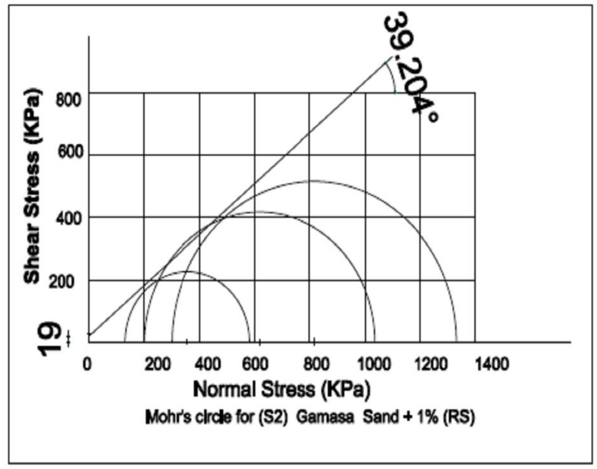


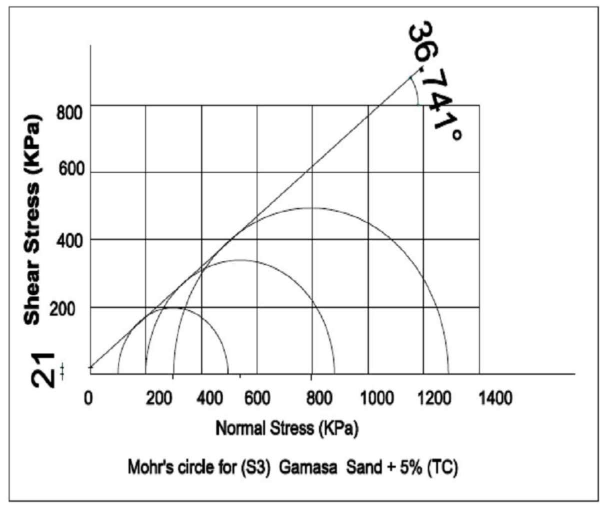


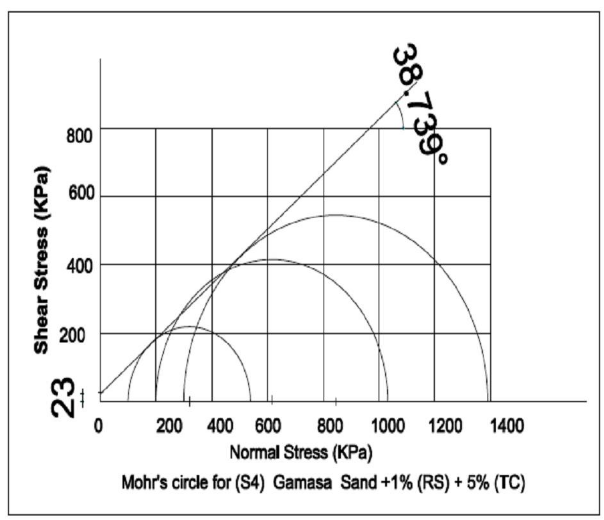


Figures 6 (a, b and c) Stress – Strain Curves for Soil Mixtures S5 through S8 with Different Confining Pressures.

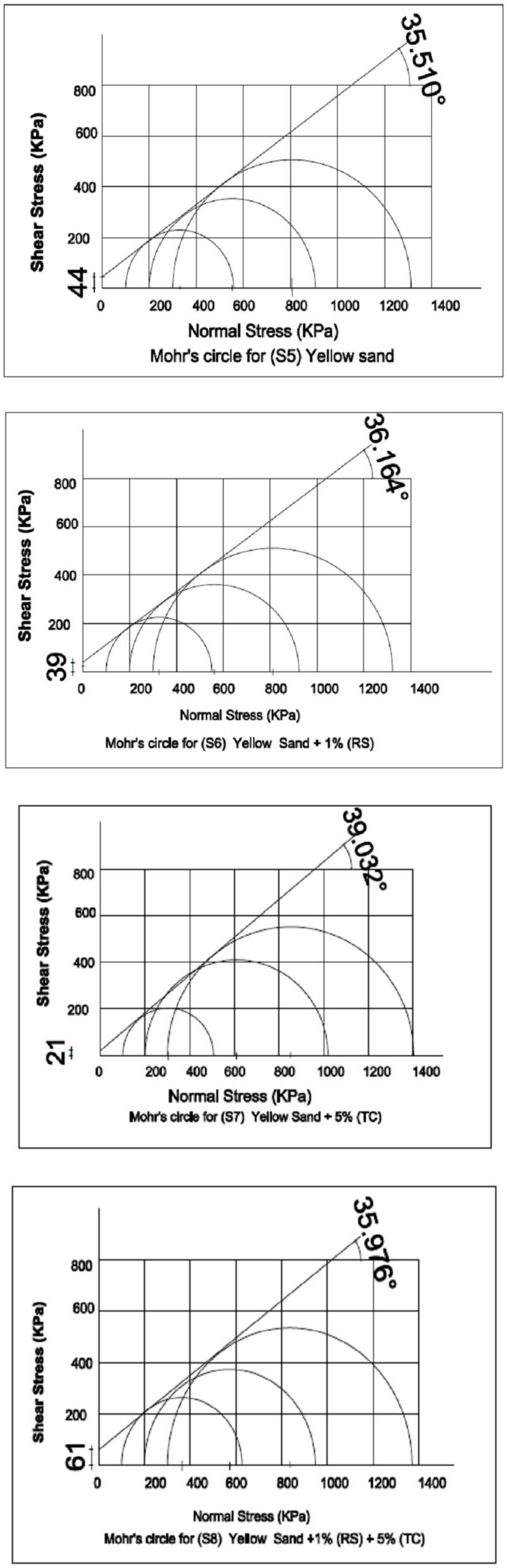








Figures 7 (a, b, c and d) Mohr's Circles and Deduced (C & Ø) Values for Soil Mixtures S1 through S4



Figures 8 (a, b, c and d) Mohr's Circles and Deduced (C & Ø) Values for Soil Mixtures S5 through S8

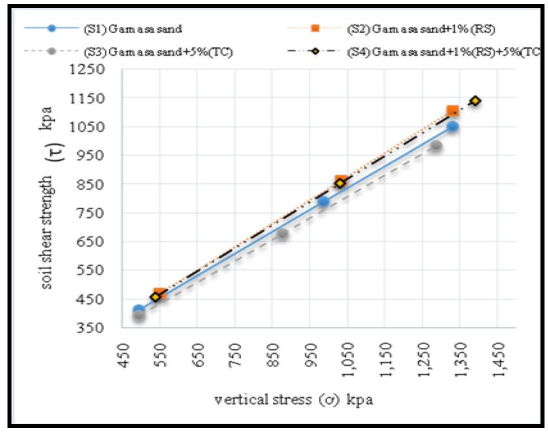


Figure 9. a. Soil Shear Strength Vs Applied Vertical Stresses for Gamasa sand group.

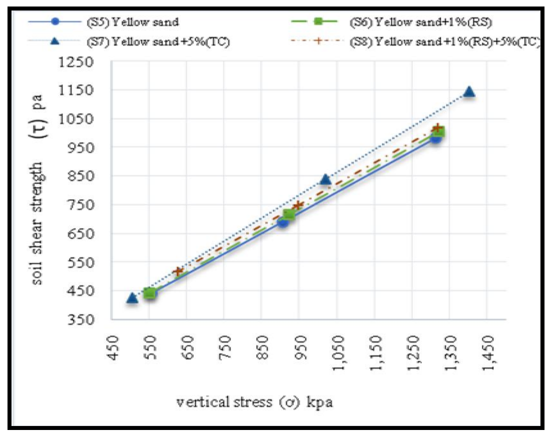


Figure 9. b. Soil Shear Strength Vs Applied Vertical Stresses for Yellow sand group.

4. Conclusions

As a result of this study, the following can be concluded:

a) The used sand samples which, enhanced by a 1% rice straw by weight of sand as a modified alternative method to increase ductility and decrease maximum dry density by 2.86% and 3.39% and increase the optimum moisture content by 41.38% and 15.38% for (S1) and (S5) respectively.

b) Adding (RS) to the sand samples (S1) and (S5) enhance the angle of internal friction (Ø) by 3.35% and 1.84% respectively and decrease the cohesion (C) for the examined samples.

c) Using tyre chips (TC) with percent 5% by weight of sand samples achieves best soil characteristics with (S5) samples more than (S1) samples.

d) Adding (TC) to (S5) to produce (S7) and to (S1) to produce (S3). So, it has a positive effect on (S7) soil characteristics and negative effect on (S3).

Comparing the soil sample (S7) with (S5) one can find that maximum dry density decreased by 1.82% and the optimum moisture content increased by 20%. Also, the value of angle of internal friction increased by 9.92% which be the best increasing ratio.

e) Finally, adding (RS) and (TC) to (S1) to produce (S4) and to (S5) to produce (S8) enhancing the soil characteristics. The angle of internal friction (Ø) increased by 1.16% and 1.312% for (S4) and (S8) respectively. Also, the cohesion increased by 38.64% for (S8) only.

f) Comparing (S4) and (S8) with (S1) and (S5) one can find that the maximum dry density decreased by 2.81% and 3.91% and the optimum moisture content increased by 44.83% and 38.46% respectively.

g) The final result is the soil mixture (S8) almost has the best soil characteristics.

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