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Improving Shear Strength of Soft Clay by Using Torn Belts Chips

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Abstract

Random throwing of industrial waste has a significant impact on the environment unless it takes into account the conditions of engineered destroying and/or re-used. Taking the advantage of re-using waste materials in engineering projects represents a well-planned project in order to resolve a lot of engineering problems for some difficult soils. The objective of this study was to evaluate the capability and effects of Rubber Shreds (RS) from scrap torn belts towards improving the shear strength of soft clay. A direct shear tests were conducted on soft clay-RS mixture. The following parameters were investigated to study the influence of RS content, water content, normal stress, and dilation ratio. From experimental test results it was found that previous parameters affecting the shear strength of soft clay. Increasing RS content was found effective in improving the shear strength of soft clay when the normal stress increases provided that fixed water content used in the mixture. Cohesion, c and angle of friction, ϕ were increased by ratio of (1.4-2.3) and (1.5-2) respectively. However, it was revealed that RS content mustn't exceed the liquid limit level of soft soil. If the water content increases and exceeding the liquid limit level of soft clay, shear strength, cohesion and angle of friction will begin to decrease by reduction percentage of (15%-55%) and (20%-45%) respectively in spite of 30% rubber inclusion. The dilation ratio was highly affected by water content increment; disturbed path of dilation ratio were observed with increasing water content in soil mixture.

Keywords: *Improvement, very soft clay, rubber shreds, direct shear, shear strength.*

1. Introduction

Soft soil can be found everywhere especially throughout the coastal area. This soil deposit generally consists of unconsolidated soil strata predominantly clays, silts or mixtures of both. The main concern about soft clay is the low shear strength which typically varies with loading, drainage conditions and amount of settlement. Geotechnical works in deep deposit of highly compressible soft clay are often associated with problems such as excessive differential settlement, negative skin friction and bearing capacity failure. In short, improving footing stability, increasing bearing capacity, cost reduction, preserving the environment and reducing settlements are the primary purposes of reinforcing such soil mass. For example, the horizontal stress induced in retaining wall structural system would be only one-half lower than conventional backfill, which leading to a less expensive retaining structure design and these materials can be assigned as new method for improving the shear strength of soft soil [1].

[2] Investigated full scale retaining wall of 4.88 m height constructed with horizontal earth pressures of 35.9 kPa, surcharges and varying magnitudes of outward wall rotation were measured. The horizontal stress at rotation about the base of 0.01 H was about the same for used tire shreds. Moreover, the horizontal stress at this rotation using shreds was about 35% less than active stress expected for conventional granular backfill.

[3] Conducted a laboratory study for preliminary assessment of the mechanical behavior of shredded tire backfills. A triaxial testing program was conducted to investigate the stress-strain relationship and strength of tire chips-sand mixture. The numerical modeling results suggest tire shreds, particularly when mixed with sand, may be effectively used as backfill.

Mixtures of sand and tire chips present un intermediate response between those of pure sand and pure tire chips. Rubber-sand mixture has an initial tendency to contract, followed by dilation. This is a typical response of sand, but the range of strains for which there is contraction is wider than sands, and dilatancy is much less. [4] mentioned that in geotechnical related works, lightweight materials are mostly taken as filling materials for road construction purposes. This will reduce or minimize the foundation requirements, reduce land cutting for mountainous area, prevent settlement and shorten construction times. In case of retaining wall, lighter fill will reduce the lateral earth pressure thus reducing the structural requirements of the wall including the foundation. [5] studied the effect of adding small particles of waste tire rubber on swelling potential of an expansive soil from Colorado. The index properties and compaction parameters of the rubber, expansive soil, and rubber-soil mixture tested were determined. One dimensional swell consolidation tests were performed and found out that rubber-soil mixtures are more compressible than untreated soil; both the swell percent and the swelling pressure are significantly reduced by the addition of rubber to the expansive soil.

[6] Studied the use of rubber strips with length less than 25 mm and diameter less than 3.6 mm. Mixture compositions is 10% by dry-weight of tire buffing with low plasticity kaolin clay, tested using triaxial test. Their findings showed that the strength in both drained and undrained condition is higher than that of clay alone. However, this is provided that a certain limiting level of confinement of 200-300 kPa is applied, above this threshold the presence of inclusions tends to degrade the strength of the clay. [7] investigated the reinforcement of sandy soil polymer fiber material, the test results on model square footings showed that bearing capacity and subgrade reaction were increased due to fiber materials. Vertical settlement analysis were achieved for both experimental and predicted settlement, the results showed that the difference in analysis and experimental results are still in accepted limits in the view of footing settlement design criteria. The lateral and vertical restraint in the values of initial settlement at small loads can be avoided from the random fiber distribution in the sandy soil below the footing. The fiber materials also prevent the failure lines in soil below the footing to propagate in flow direction of failure towards the tensile arc strain locations. Finally, the soil behavior in terms of bearing capacity, settlement reduction and restraining the initial vertical settlement of footing during early stage of loading is improved. Comparison between experimental and predicted (calculated) settlement below the footings showed that the difference in ranges were within accepted limits for foundation settlements design. From the literature studied it was found that the particle size, shape, the mix proportion of RS and soft clay properties are considered as strong parameters that may influence the shear strength of soft soil-RS mixture.

2. Rubber Particle Size

Size of rubber shred particles plays an important role in defining the soft soil strength. If the particle size is too large, it is difficult to be tested by conventional soil laboratory equipment. Statistical and theoretical analysis of reported properties suggests that the engineering properties of rubber particles on small scale specimens are generally representative of larger shred size particles [8]. Figure (1) shows small shredded belt particles that were used in testing program of this study.

3. Rubber Particle Shape

Shape of particle can be of many types such as angular, plate, circular, etc. However, particle shape may affect the strength of rubber-soft clay mixture if the appropriate shape is not been identified. This has been proven by results tested by past researchers. Angular rubber particles [9] and [10] were found to decrease the unconfined compression strength of clay. With above concerned problem, the research has been done to investigate the feasibility of using torn belt chips to reinforce soft clayey soil. Direct shear tests were conducted on mixtures of soft clay and rubber shreds particles from scrap torn belts with different water content. In Iraq, soft clayey soil can be found especially throughout the coastal area in the south part of Iraq (i.e. Fao city).

4. Material Used

In summary the research has been conducted to investigate the properties of soft clay when mixed with shredded rubber from scrap torn belts towards improving the shear strength of soft clay based on the testing program shown in Table (1). Torn belts (RS) (i.e. rubber shreds from scrap torn belts) contains two basic materials; rubber, and fiber. In order to improve the properties of soft clay, shredded belt chips are being used and mixed with compressible weak clayey soil. Their unit weight being about one-third of the soft soil, the rubber-soil mixture would apply a smaller overburden stress resulting in a lower settlement and an increased global stability of soft clayey soil. In order to prepare soft soil-RS mixture, firstly, amount of soft clay is mixed thoroughly with half desired percentage of water to obtain uniformity then mixed with the percentage of RS to obtain a uniform mixture (i.e. percentage of RS used was by dry weight of the soft clay). The remaining water percentages is sprayed onto the surface of the soft soil-RS mixture and then mixed thoroughly and stored in plastic bags for (12-18) hrs to achieve the stable mixture condition. Finally, the soil mixture filled in shear box by tamping method to prevent any voids that can be developed between tamped layers followed by procedure of [11], such tamping method is to enhance the preparation of soft clay samples in shear box due its natural consistency (i.e. tamping method achieved for both bottom and top soil layers). For ease of reference, the abbreviations for ‘RS’ and ‘WC’ will be denoting as rubber shreds and water content respectively. The total series of test that will be carried out with three normal loading for each test, 5 kg (49.033 N), 10 kg (98.066 N) and 15 kg (147.099 N) of 21 tests is summarized in Table (1).

Table 1,
Testing Program.

No.	Types of Test	Moisture Content, WC (%)	No. of Tests
1	Soft Clay + 0% RS	40	3
2	Soft Clay + 10% RS	40	3
3	Soft Clay + 30% RS	40	3
		60	3
		80	3
		100	3
4	Soft Clay + 50%RS	40	3

5. Soft Clay

The soil used in this study is classified as lean clay (CL) based on the unified soil classification system, the physical geotechnical properties are listed in Table (2).

Table (2),
Physical Geotechnical Properties of Soft Clay

Property	Units	Value
Natural Water content, W	%	46-48
Plastic Limit, PL	%	26
∗Liquid Limit, LL	%	46
Plasticity Index, PI	%	20
Specific gravity, G_s	-	2.55
Natural Moist Unit weight, γ_t	kN/m^3	16.2-17.5
Natural Dry Unit weight, γ_d	kN/m^3	11.1-11.8
Initial void ratio, e_o	-	1.12-1.25
Maximum Dry Unit weight, γ_d /e	kN/m^3	14.8/0.69
Optimum Water content, W	%	15.4
Compression Index, C_c	-	0.25-0.27
Activity, A	-	0.85
Unified Classification	-	CL

*Natural water content in soil is ≥ than LL.

6. Shredded Belt

In engineering industry sector, belts, tires, and other rubber materials poses serious environmental problem. Majority of these wastes end up in landfill waste. The torn waste belt (i.e. used in equipment cooling units) was proposed in the testing program with the dimension in average are (1.5 to 2.0 mm) in width, (2 to 2.5 mm) in thickness and (9.5 to 9.8 mm) in length as shown in Figure (1).

Fig. 1. Raw Shredded Belt.

7. Direct Shear Test

Direct shear test (drained test) is a method for investigating the shear strength of soil beside other methods such as unconfined test and triaxial compression test. It differs somewhat from the other two in that they are “compression” tests (i.e. shear failure is affected by a compression force), whereas in direct shear test the shear failure caused by a shear force along a predetermined horizontal surface. The direct shear test can be performed on both cohesion and cohesionless soils, and it can evaluate both cohesion, c and angle of friction, ϕ. These parameters are used to evaluate a soil's shear strength. A 100 mm x 100 mm shear box was used in this study and the selected running shearing machine speed was at rate of 0.006 mm/sec. The normal loads used on the samples were 5 kg (49.033 N), 10 kg (98.066 N) and 15 kg (147.099 N).

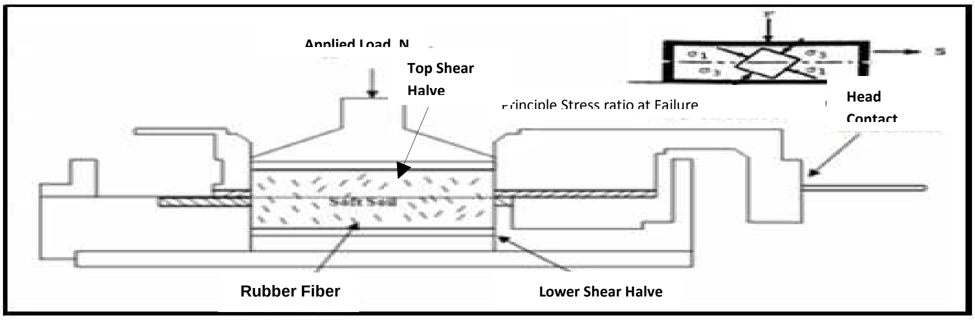


Fig. 2. Direct Shear Test.

8. Test Results and Discussions

The behavior of soft clay-RS mixture was investigated in order to evaluate the influence of RS content on shear strength of soft soil under three normal loadings; 5 kg (49.033 N), 10 kg (98.066 N) and 15 kg (147.099 N). The following main parameters were discussed from obtained testing results; effects of different RS content with fixed moisture content and effects of different moisture content with fixed RS content on the shear strength of mixtures.

9. Effect of Rubber Shreds with Fixed Water Content on the Behavior of Soil Mixture

9.1. Shear Stress Versus Horizontal Strain

From Figure (3) shown the shear stress at failure for soft clay-RS mixture increases as the normal loading increased. The shear stress versus εh relationships showed strain hardening behaviors up to failure till the soil reaches the ultimate or critical states criteria where they continue to distort at a constant rate. Dilation process happens when the shearing machine keeps encountering soft and hard particles which make the shearing stress low and high at different stage of loadings. Shear stress of mixture vs. RS content and/or normal stress is shown in Figure (4) indicating that maximum shear stress increases with increasing the percentage of RS content and the value of maximum shear stress at failure increases as the normal stress increased as well. A summary of maximum shear stress for 5 kg (49.033 N), 10 kg (98.066 N) and 15 kg (147.099 N) loading for each test is tabulated in Table (3)

Table 3,
Maximum Shear Stress Obtained at 40% WC.

Tested Sample	**Maximum Shear Stress (kPa)**			**Cohesion, C (kPa)**	**Angle of Friction, ϕ**	****Ratio of improvement in Angle of Friction**
	Normal Load (kg)					
	5	10	15			
*40 % WC+ Soft Clay + 0% RS	5.2	6.8	8.3	3.6	17.62°	-
40 % WC+ Soft Clay +10% RS	7.5	10.1	12.2	5.0	26.4°	1.50
40 % WC+ Soft Clay + 30% RS	10.7	14.3	16.2	7.8	30.5°	1.73
40 % WC+ Soft Clay + 50% RS	12.4	16.1	19.0	8.4	37.12°	2.15

* Water content in soil mixture is < than LL.

** Rate of improvement in friction angle were highly pronounced from test results than cohesion values.

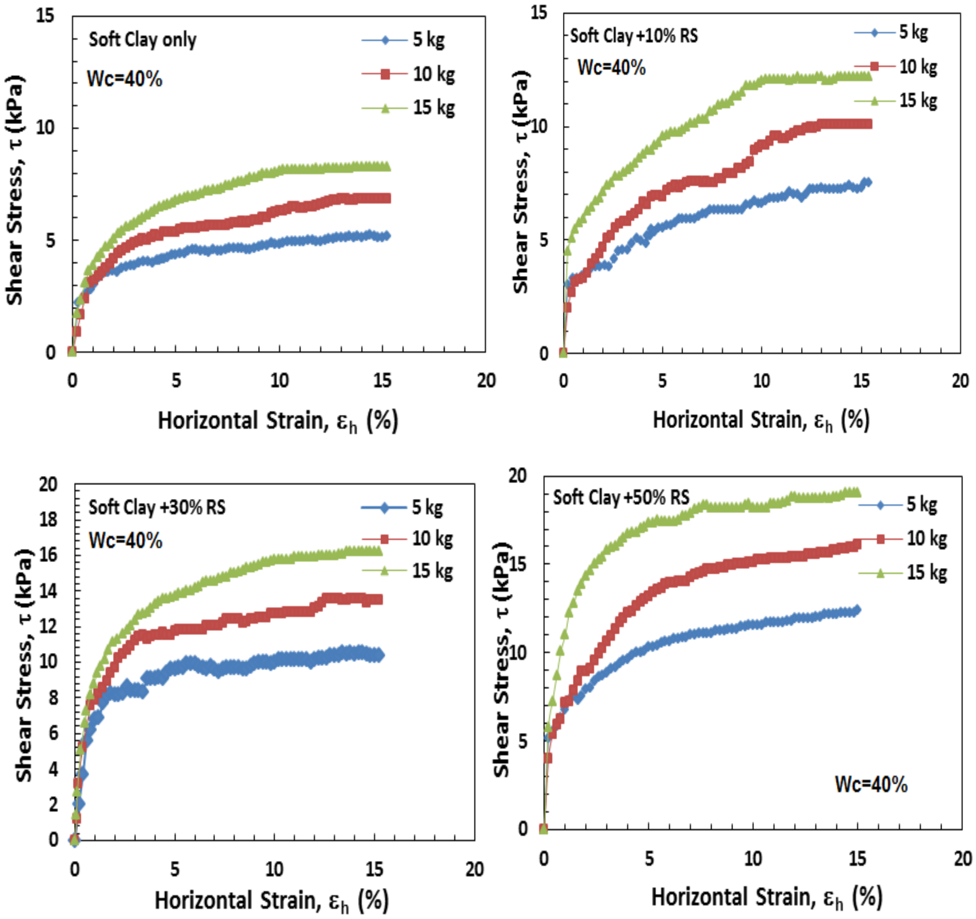


Fig. 3. Shear Stress vs. Horizontal Strain at 40% WC.

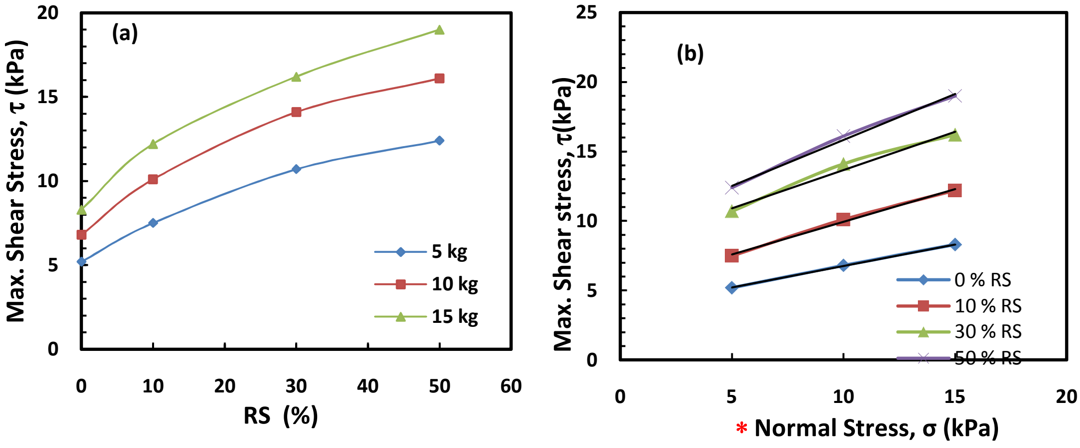


Fig. 4. (a) Maximum Shear Stress vs. RS Content, (b) Max. Shear Stress at Failure vs. Normal Stress. (*The values of friction angle (ϕ) and Cohesion (C) are obtained by drawing a common tangent to effective-stress Mohr's circles (Mohr-Coulomb envelope) for various tests).

9.2. Vertical Strain Versus Horizontal Strain

Figure (5) showed the contractive soil behavior during shear stage which is due to simultaneous elastic and plastic strains developed at shear stage for both soft clay and rubber particles. The vertical displacement increases as normal loads increases (minus sign on the value of vertical strain represents the compression). The vertical displacement reduced with increasing the RS content due to restraints of these rubber materials at the failure plane that create zone of complex and higher principal stress ratio at failure (σ'_1/σ'_3). Finally the trend behavior of vertical strains values was found to be affected by RS content as shown in Table (4).

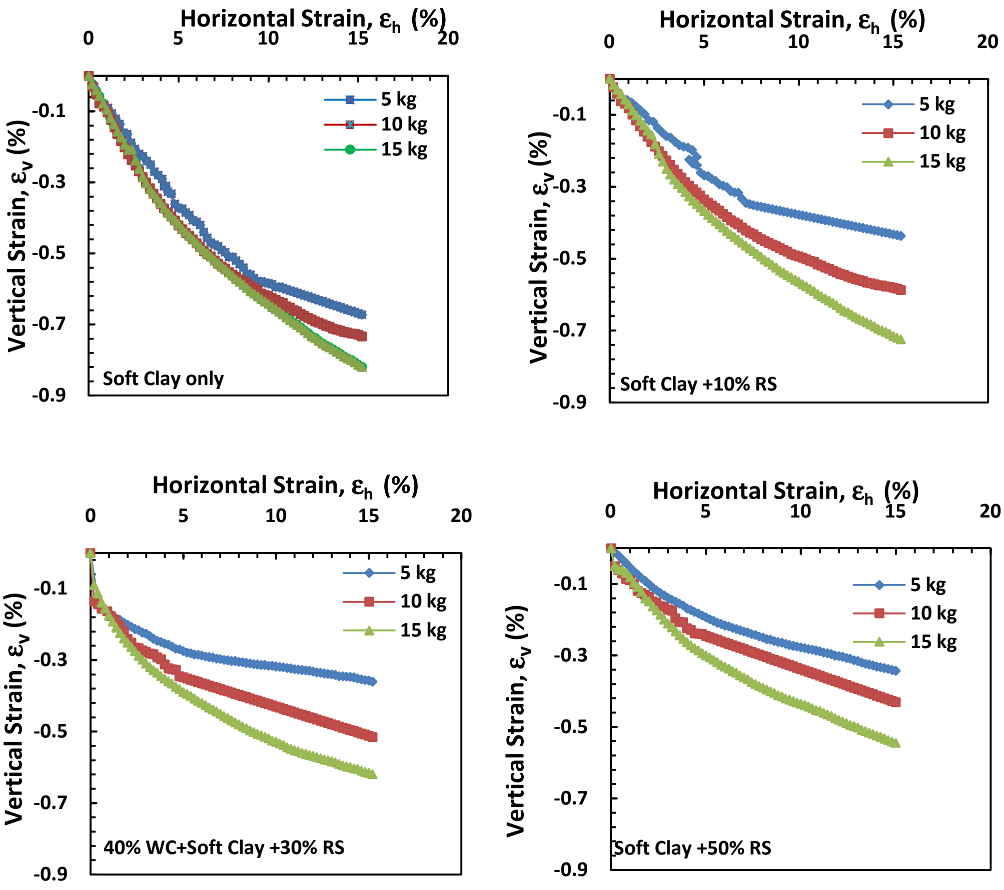


Fig. 5. Vertical Strain vs. Horizontal Strain at 40 % WC.

Table 4 ,
Maximum Vertical Displacement (Strain) Observed at 40 % WC.

Tested Sample	Maximum Vertical Strain, ε_v (%) Normal Load (kg)		
	5	10	15
40 % WC+ Soft Clay + 0% RS	0.672	0.733	0.819
40 % WC+ Soft Clay + 10% RS	0.432	0.585	0.716
40 % WC+ Soft Clay + 30% RS	30.36	0.515	0.618
40 % WC+ Soft Clay + 50% RS	0.337	0.424	0.537

9.3. Dilation Ratio versus Shear Stress Ratio

From Figure (6) in terms of rate of dilation, the soil exhibits moderate Dilation Ratio (DR) at the beginning of shear stage then a lower dilation ratio observed at the end of shearing stage. The shear stress ratio at failure is reduced with increasing normal stress.

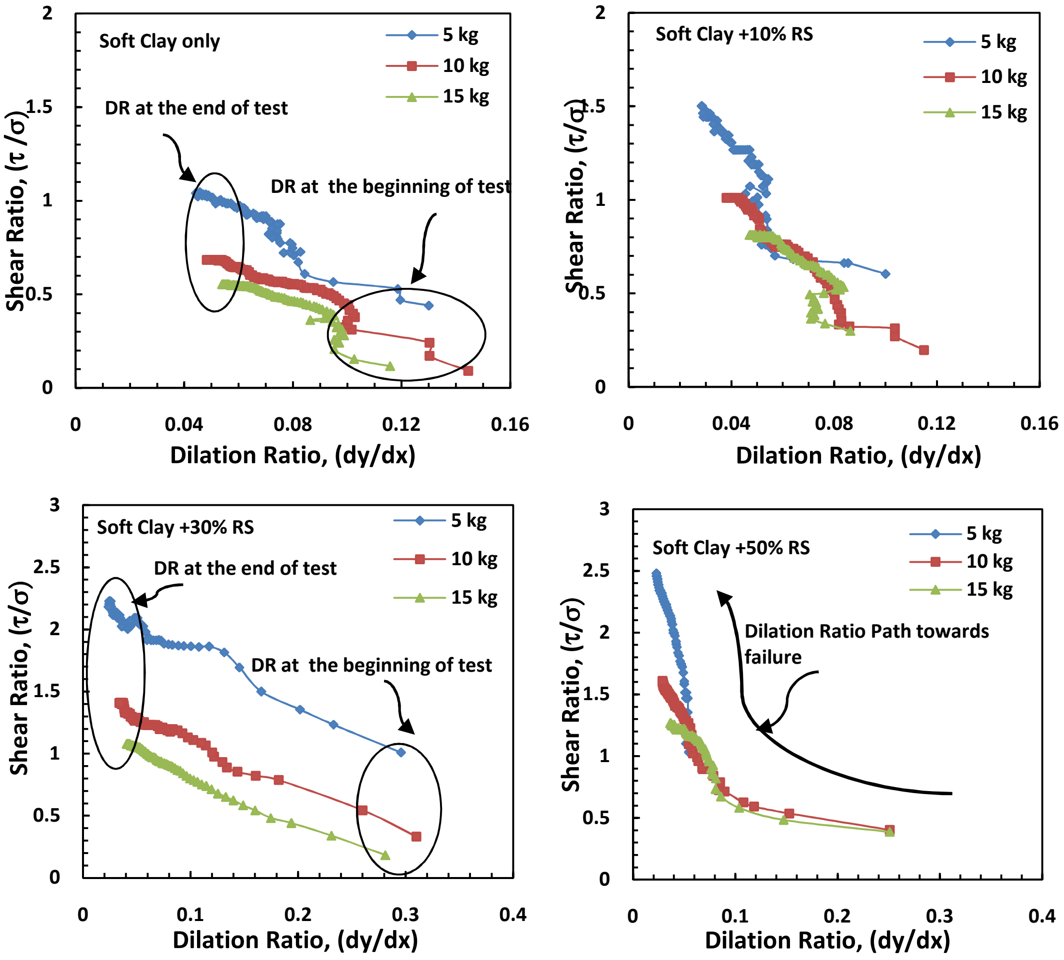


Fig. 6. Shear Ratio vs. Dilation Ratio at 40 % WC, Improved Behavior with Increasing RS%

10. Effects of Different Moisture Content with Fixed RS Content on the Behavior of Soil Mixture

10.1. Shear Stress Versus Horizontal Strain

The purpose of this series of experiment is to observe the effect of increasing moisture content along with fixed RS content at 30% on the shear strength of soil mixture. Test results of shear strength of soft clay-RS mixture are shown in Figure (7) which indicates the maximum shear stress decreases with increasing water content. Figure (8) showed the shear strength of soft clay-RS mixture reduces as the water content increased. A summary of maximum shear stress values for 5 kg (49.033 N), 10 kg (98.066 N) and 15 kg (147.099 N) loading for each test are tabulated in Table (5) and as the water content increases and exceeding the liquid limit level of soft clay, cohesion and angle of friction will begin to decrease.

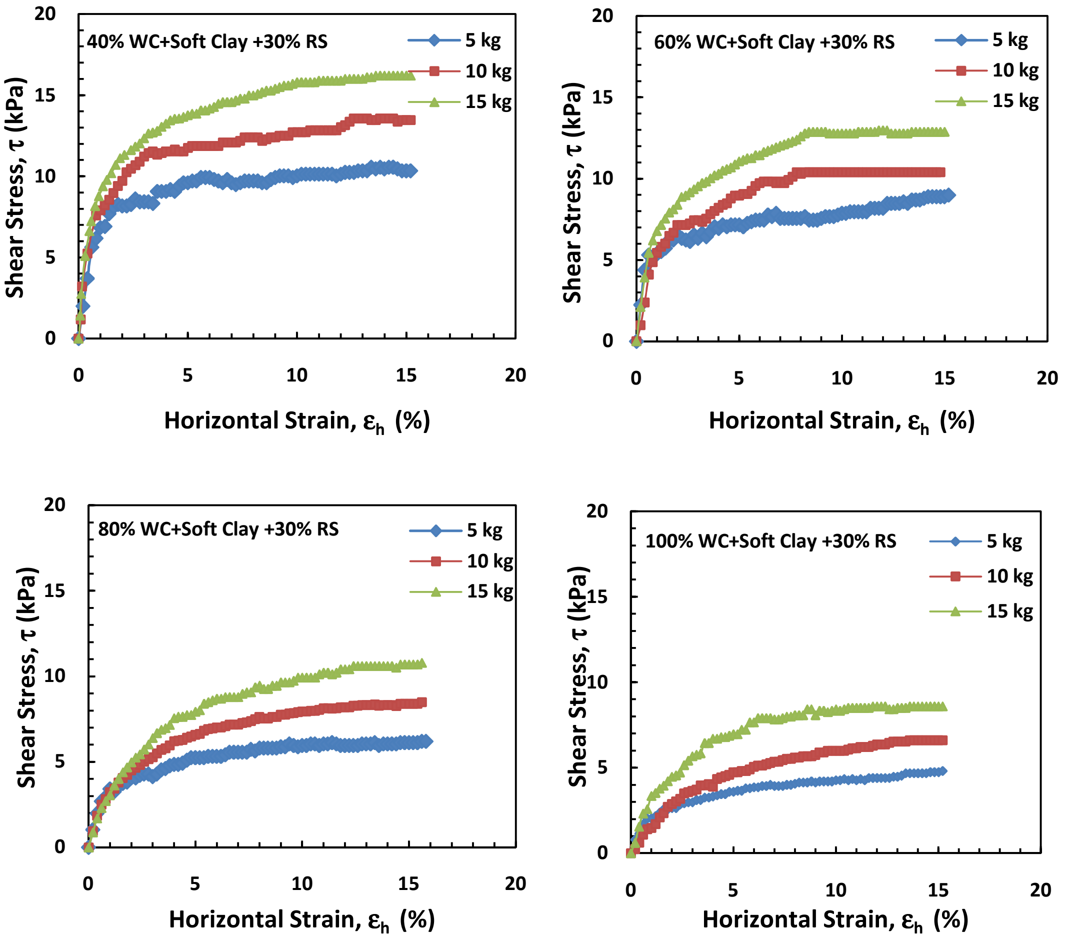


Fig. 7. Shear Stress vs. Horizontal Strain at 30% RS.

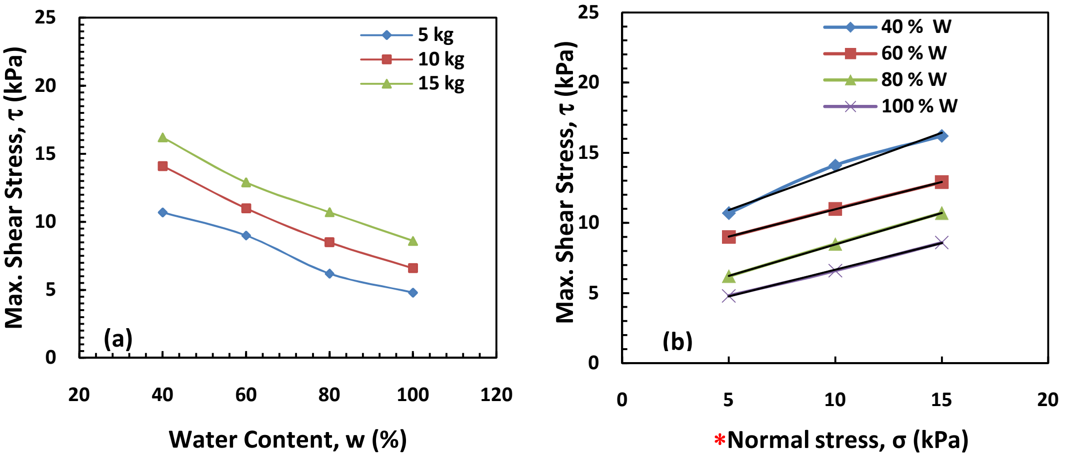


Fig. 8. (a) Maximum Shear Stress vs. Water Content; (b) Maximum Shear Stress vs. Normal Stress at 30% of RS Content (*The values of friction angle (ϕ) and Cohesion (C) are obtained by drawing a common tangent to effective-stress Mohr's circles (Mohr-Coulomb envelope) for various tests).

Table 5,
Maximum Shear Stress Obtained at 30 % RS.

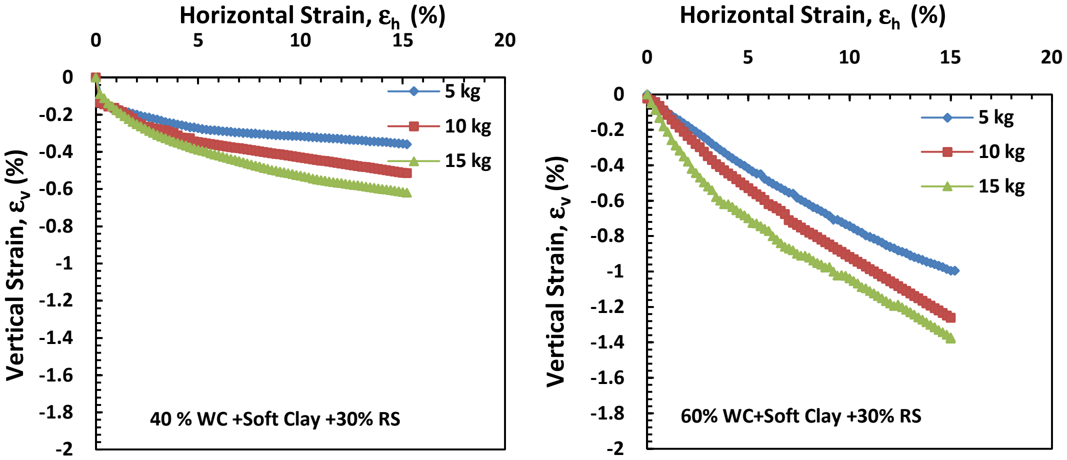
Tested Sample	**Maximum Shear Stress(kPa)**			**Cohesion, C (kPa)**	**Angle of Friction, ϕ**	**% of Reduction in Friction Angle**
	Normal Load (kg)					
	5	10	15			
40%WC+ Soft Clay +30%RS	10.7	14.1	16.2	7.8	30.5°	-
60%WC+ Soft Clay +30%RS	9.1	11.0	12.9	6.6	24.1°	20
80%WC+ Soft Clay +30%RS	6.2	8.5	10.7	4.6	20.38°	33
100%WC+ Soft Clay +30%RS	4.8	6.6	8.6	3.5	16.85°	45

Table 6,
Maximum Vertical Displacement (Strain) Observed at 30% RS.

Tested Sample	**Maximum Vertical Strain, ε_v (%)**		
	Normal Load (kg)		
	5	10	15
40% WC+ Soft Clay + 30% RS	0.36	0.515	0.618
60% WC+ Soft Clay + 30% RS	0.899	1.261	1.371
80% WC+ Soft Clay + 30% RS	1.058	1.347	1.475
100% WC+ Soft Clay + 30% RS	1.162	1.453	1.743

10.2. Vertical Strain Versus Horizontal Strain

Figure (9) shows the pronounced contraction soil behavior (i.e. highly compressed) and the values of vertical strains increases as the water content increased. Table (6) shows the effect of water content on the vertical strain values; test results showed that increasing WC causes increasing the vertical strain regardless of the RS content.



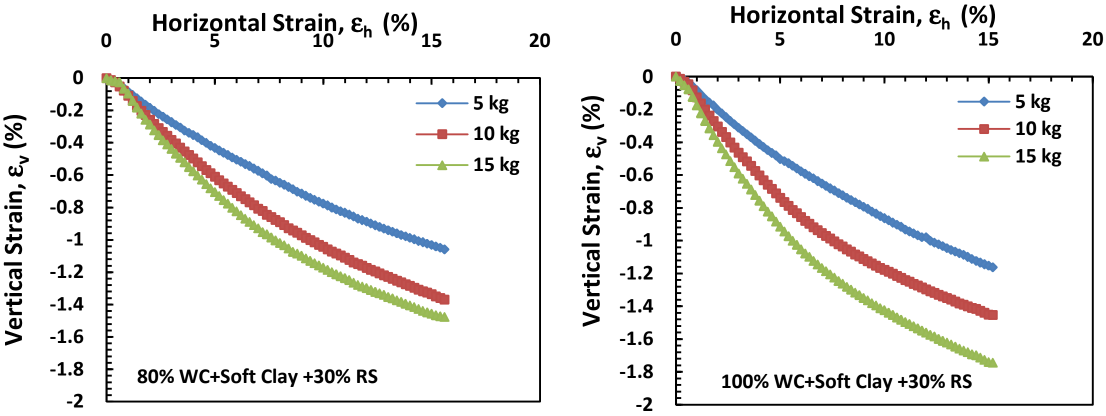


Fig. 9. Vertical Strain vs. Horizontal Strain at 30% RS

10.3. Dilation Ratio versus Shear Stress Ratio

From Figure (10) the shear ratio decreased as WC increased along when exceeding liquid limit of soft clay. The dilation ratio path was highly disturbed from the beginning of the test up to the failure stage (inverted S-shape) especially at higher water content in soil mixture.

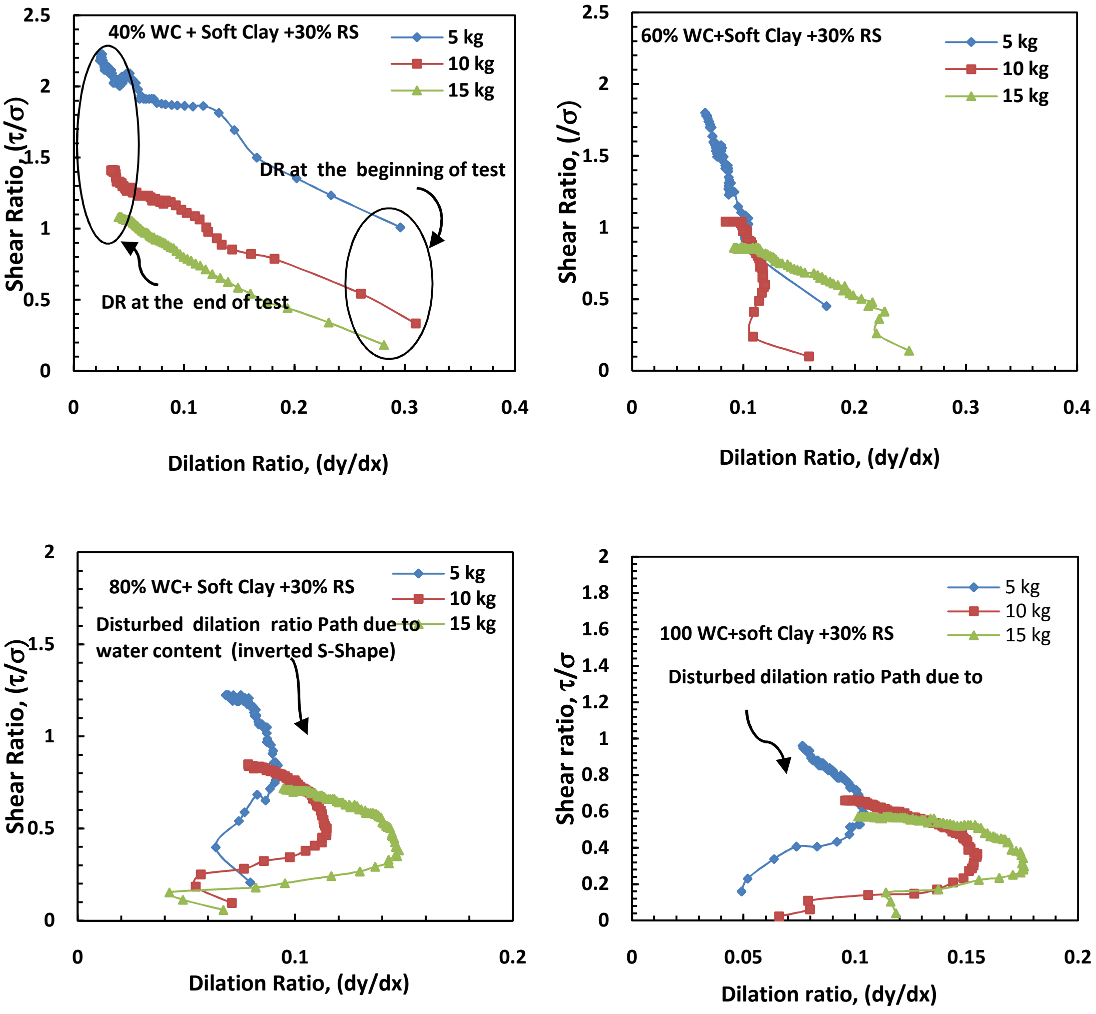


Fig. 10. Shear Ratio vs. Dilation Ratio at 30% RS, Disturbed Behavior with Increasing WC.

11. Conclusions

From series of tests carried out on soft clay-RS mixture using direct shear test; the following conclusions are drawn from this study:

- Effect of rubber shreds with fixed water content on the behavior of soil mixture

In general the failure criteria for soft clay-RS mixture based on maximum shear stress, vertical settlement, and dilation ratio values at failure are defined as follows; gradual increase in shear stress as the shear strain increases until an approximately constant shear stress - critical state is attained. Contraction or compressive volumetric strains (i.e. for the soil mixture) become stiffer mixture as the shear strain increases until reaching the critical state of soil mixture. Increasing RS content was found effective in improving the shear strength of soft clay with increasing the normal stress. Cohesion, c and angle of friction, ϕ were increased as well. The vertical displacement reduced with increasing the RS content which is due to restraints of these rubber materials at the failure planes that create zone of complex and higher principal stress ratio at failure (σ'_1/σ'_3). The shear strength of soft clay-RS mixture increased by ratio of (1.40 to 2.3) for 10% RS to 50% RS respectively with fixed water content of 40%. The settlement (i.e. vertical strain) reduced by (13% to 50%) for 10% RS to 50% RS respectively. The shear strength increment and/or settlement reduction are compared with (40% WC and 0% RS content). The soil exhibits moderate Dilation Ratio (DR) at the beginning of shear stage then a lower dilation ratio observed at the end of shearing stage and gradually reduces the shear stress ratio at failure with increasing normal stress. It may be due to soil consistency as soft mixture state and fabric assembly of rubber particles in the prepared samples, sliding would be initiated on the horizontal plane, once the motion occurred, the soil would tend to move into the void spaces of rubber particles developing a downward directional component as vertical strain, indicating contraction behavior of soil mixture.

- Effect of water content with fixed rubber shreds on the behavior of soil mixture

The behavior of soft clay at 30 % RS content mixture mixed with different water content (40% WC to 100% WC) as follows. The reason after selection of higher water content greater than liquid limit of soil in this study; is to investigate the behavior of soil mixture in case of water content is increased in soil ground improved with such technique. The shear strength reduces as the water content increased even when the rubber shreds is available in soil mass for different normal stress values. Cohesion, c and angle of friction, ϕ were reduced with increasing water content. The shear strength of soft clay-RS mixture is reduced by ratio of (15% to 55%) for 60% WC to 100% WC respectively. The settlement increased by (2.2 to 3.2) for 60% WC to 100% WC respectively. The shear stress at failure was decreased as WC increased. The dilation ratio path was highly disturbed from the beginning of the test up to the failure stage (inverted S-shape was observed) especially at higher water content in soil mixture. The shear strength reduction and/or settlement increment are compared with (40% WC and 30% RS content). Such behavior cause finally increasing the settlement and /or contractive soil behavior of soil mixture.

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تحسين مقاومة القص للتربة الطينية الضعيفة باستخدام رقائق الاحزمة الممزقة

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الخلاصة

رمي النفايات الصناعية بشكل عشوائي له تأثير كبير على البيئة ما لم تراعى الشروط الهندسية في أتلافها. أن امكانية الافادة من هذه النفايات وأعادة استخدامها في المشاريع الهندسية يمثل تخطيطا جيدا لحل الكثير من المشكلات الهندسية التي تعاني منها بعض الترب الصعبة. الغرض من هذه الدراسة هو تقويم قابلية وتأثير أستخدام شرائح من الاحزمة الممزقة لتحسين مقاومة القص للترب الطينية الضعيفة. تم تبني فحص القص المباشر على خليط من قطع المطاط المقطعة والتربة. وقد تم دراسة العوامل التالية: نسبة القطع المطاطية، محتوى الماء، مقدار الاجهاد العمودي المسلط، وكذلك (Dilation Ratio). لوحظ من خلال النتائج العملية أن العوامل أعلاه تؤثر على مقاومة القص للتربة. زيادة محتوى RS سببت تحسين مقاومة القص للتربة الطينية مع زيادة الاجهاد العمودي ومن خلال محتوى مائي ثابت. لوحظ أن التماسك وزوايا الاحتكاك الداخلي ازدادتا أيضا بشرط عدم تجاوز نسبة RS عن حد السيولة للتربة الطينية الضعيفة. أن هذه العوامل تتأثر بشكل كبير في حال زيادة محتوى الماء عن محتوى حد السيولة حيث لوحظ نقصان كل من التماسك وزواية الاحتكاك الداخلي. نسبة (Dilation Ratio) تأثرت كثيرا بزيادة نسبة الماء فلوحظ تشوه مسار (Dilation Ratio) بزيادة نسبة الماء في خليط التربة.