

Geotechnical Properties of Rubber Tires and Sediments Mixtures

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Abstract— An experimental work was undertaken to study the effect of rubber tires on the geotechnical properties of a dredged sediment, using a mixing ratio of large size. For comparison, two types of soil were studied (dredged sediment from Fergoug dam and Tizi Tuff from the north west of Algeria). Taking into account the high compressibility and the low water absorption of the rubber tires, grain size analysis, density, Atterberg limits analysis, chemical composition, direct shear tests, loading-unloading tests, modified Proctor and CBR tests are performed on the two soils and their mixtures with different scrap tire rubber (10, 20, 25 and 50%). The results show that liquid limits and plastic indexes decrease with the scrap tire rubber content and that the decrease is more significant for soil with high plasticity. Cohesion also decreases with scrap tire rubber content when the internal friction angle is vacillating. Compression and recompression indexes increase gradually with the scrap tire rubber content and the variation for compression index is more significant for the two soils. Compaction characteristics and CBR values decrease with scrap tire rubber content. The CBR values for $W=3\%$ are important compared to those with $W=5\%$ excepted for mixture with (75% tuff and 25% scrap tire rubber). The results show that the scrap tire rubber can be used as a reinforcement material for dredged soil, but with a content that should not highly affect the compressibility.

Keywords—sediments; waste tires; rubber; valorizing; tests; geotechnical

I. INTRODUCTION

The world's reservoirs are currently filling up with sediments at a rate of approximately 1% per year [1, 2]. This implies that within about 50 years, the world's water storage in reservoirs will be half of the current storage, which will have large economical and environmental consequences, especially in semi-arid environments where many reservoirs have been built for water supply, irrigation, flood control and production of electricity [3]. Fergoug dam is one of many others that have such problems. It is located in the North-West of Algeria, at the bottom of the Atlas buttresses, approximately 20 km in the south of the town of El-Mohammadia (province of Mascara) (Figure 1). The total catchment area of Fergoug is estimated to

be 8340 km². The average altitude is about 790 m with a maximum altitude of 1454 m [4].

In its actual position the Fergoug dam is an earthfill dam with an initial capacity of 17 million m³ in 1970. In 1977, its capacity fell to 9.67 million m³, with an annual rate of silting exceeding one million of m³ [4]. Several methods of valorization are available such as the sediments dredging re-use. These methods understand valorization with physics, chemical, biological, immobilization, thermal additives [5-13].

Pneumatic waste is polluting and cumbersome. It constitutes a varied population by size, degrees of ageing, wear, shapes of ears. The worn tires are composed primarily of synthetic rubber, carbon dioxide, silicon and steel. Algeria generates over than 26000 tons of waste tires per year [14]. Waste tires can be disposed in landfills or tire stockpiles. There are several methods of recycling tires in the field of civil engineering e.g. as a retaining wall and as a decorative element [15-16].



Fig. 1. Localisation of sites

Currently several researchers directed their studies on the valorization of the sediments, with the aim of using them in the field of civil engineering, which portrays the greatest need for materials. This work is interested particularly in the valorization of the sediments, with an aim of studying the mechanical behavior of the scrap rubber mixtures compared to other results of Tizi Tuff which is primarily used in the area of Mascara with the same percentage of scrap rubber.

II. EXPERIMENTAL STUDY.

A. Materials and methods

1) Investigated soils

Two soils of different origins and physical properties were selected. The first sample was obtained from a site located in Fergoug in Mascara in the north-west of Algeria. The second sample was a Tuff from the region of Tizi, Mascara in the north-west of Algeria. These two soils were subject to several laboratory identification tests using standard procedures adopted by AFNOR and ISO standards [17-21]. The results are shown in Table I. The specific weight of the Fergoug sample was 24.6 kN/m^3 while that of the Tuff was 25.9 kN/m^3 . The particle size distribution for the soils is shown in Table I. The chemical analysis of the soils was carried out in accordance with [22], and the results are presented in Table II.

2) Tires rubber fibres

Scrap tire rubber fibres can be obtained from tires through two principal processes: (i) ambient, which is a method of processing where scrap tire rubber is processed at or above ordinary room temperature; (ii) cryogenic, a process that uses liquid nitrogen to freeze the rubber until it becomes brittle and then uses a hammer mill to shatter the frozen rubber into smooth particles [23]. Tire rubber fibre consists of a complex mixture of elastomers, polyisoprene, polybutadiene and styrene-butadiene. Stearic acid (1.2%), zinc oxide (1.9%), extender oil (1.9%) and carbon black (31.0%), are also important components of tires [24-25].

TABLE I. SOME PROPERTIES OF THE INVESTIGATED SOILS

Properties	Fergoug Sediment	Tizi Tuff
Liquid limit (%)	38.28	28
Plastic limit (%)	15.09	13
Plasticity index (%)	23.19	15
Specific weight γ_s (kN/m^3)	24.6	25.9
Grains sizes analysis		
Gravel (%)	-	-
Sand (%)	16	40
Silt (%)	28.6	50
Clay (%)	55.4	10
Methylene blue values		
Volume of blue VB (cm^3)	5.5	4.5
Specific surface SST (m^2/g)	115.5	94.5

The used rubber fibre, the same used in [16], is produced from used automobile tires by shredding them mechanically in ambient temperature. Steel was removed by magnetic separation and textile by density. It was not possible to determine the gradation curve for the tire chips as for normal aggregates since they were elongated particles between 5 and 30 mm with an average value of 7 mm: the sample contains

scrap tire rubber fibre (approximately 59% of weight) and scrap tire rubber powder (approximately 41% of weight) with the latter tending to lump together. Scrap tire rubber was characterized by a specific weight of 0.83 and insignificant water absorption. Some behavior parameters of the rubber are given in Table III.

TABLE II. CHEMICAL COMPOSITIONS OF SOILS USED IN THE STUDY

Property	Fergoug Sediment	Tizi Tuff
SiO ₂ (%)	62.68	24.42
Al ₂ O ₃ (%)	7.39	2.65
Fe ₂ O ₃ (%)	0.71	0.58
CaO (%)	12.51	31.48
MgO (%)	0.37	2.61
NaOH (%)	-	4.90
Cl (%)	-	-
P.F ₂ (%)	16.27	33.39

TABLE III. SOME PROPERTIES OF SCRAP TIRE RUBBER FIBRE

Properties	Tire rubber fiber	References
Density (Mg/m^3)	1.153-1.198	Akbulut et al. 2007
Tensile strength (MPa)	16-20	Khorami et al. 2010
Elongation (%)	400-500	Khorami et al. 2010

B. Mixtures design

1) Preparation of soil-rubber mixtures

Because the temperature can alter the rubber, the water content of samples was determined by drying at $35^\circ\text{C}\pm 5^\circ\text{C}$. Samples were considered as completely dry when the difference between two weighings does not exceed 0.2% for an interval of 24 hours. According to some pertinent studies on fibre reinforced soils, the studied percentages of polypropylene are generally 0.05, 0.015 and 0.025% of the weight of the parent soil [26-27] or 0.1, 0.2, 0.3, 0.4 and 0.5% of the weight of the parent soil [28]. For tire rubber fibre, the studied percentages are 1, 2, 3, 4 and 5% of the total weight of the reinforced samples [28]. Fibres and lime or cement with soils were mixed in all of cited studies. Cetin et al. [29] studied mixtures prepared by cohesive soil with 10, 20, 25 and 50% of pure fine and coarse grained tire-chips. For this study, soils were mixed with scrap tire rubber fibre and the contents of fibre were chosen as 10, 20, 25 and 50% by total weight of composite samples. As the fibre tended to lump together, considerable care and time were spent to get a homogeneous distribution of the fibre in the mixtures. The used materials were called S, T and C for Fergoug Sediment, Tizi Tuff and Scrap tire rubber fibre respectively.

2) Preparation of composite soil samples

In many researches, specimens are prepared at optimum proctor or at water content corresponding to the liquid limit. In our study, since the specific weight of rubber is less than half that of soils and used mix ratios are larger (till 50% of scrap tire rubber), the sediment mixtures were prepared with 20% of water content and then specimens were statically compacted in the standard Proctor mould in five layers to ensure uniform dry density. Samples heave were allowed under a seating surcharge of 1 kPa, the choice of this seating surcharge is a result of the great difference of specific gravities of components. After the compaction of the soils and their mixtures, the cylindrical

unreinforced and composite samples were extruded from the mould using a hydraulic jack. The samples were wrapped in plastic to prevent water loss.

Since it is impossible to determine the specific gravities of scrap tire rubber and composite samples with the method described in [18] (because rubber floats on the surface of the liquid), the specific weight of scrap tire rubber is measured by helium pycnometer while those of composite samples are calculated theoretically using each components' dry mass and specific gravities values as follow:

$$G_s = (M_{d1} + M_{d2}) / [(M_{d1}/G_{s1}) + (M_{d2}/G_{s2})] \tag{1}$$

where:

G_s : Specific density (dimensionless)

M_d : Dry mass of specimen (kg)

Table IV presents the different specific gravities of the soils and their mixtures. It can be observed that the value of the specific weight of composite samples decreases with rubber content and reaches its half for the sample with 50% of scrap tire rubber content.

TABLE IV. SPECIFIC WEIGHT OF SOILS, SCRAP TIRE RUBBER AND THEIR MIXTURES.

Rubber content	0%	10%	20%	25%	50%	100%
	<i>Specific weight γ_s (kN/m³)</i>					
Sediment	24.6 ^a	23.0 ^b	21.3 ^b	20.5 ^b	1.6.4 ^b	8.3 ^a
Tuff	25.9 ^a	24.1 ^b	22.4 ^b	21.5 ^b	17.1 ^b	

^a Experimental value, ^b Calculated value

III. EXPERIMENTAL RESULTS AND DISCUSSION

A. Consistency limits

Atterberg limit tests were performed to determine the consistency limits values of the soils and their mixtures according to the methods described in the French standard [17].

1) Effects of scrap tire rubber on the liquid limit

Figures 2 and 3 show the effects of fibre on the consistency limits for S and T soils and their mixtures. The liquid limits are expected to decrease gradually when the scrap tire rubber fibre content increases for the two soils. However, the reduction of the liquid limit for the S soil was considerable.

2) Effects of scrap tire rubber on the plastic limit

For the S soil, the plastic limit decreases gradually for the sample of increased fibre. For the T soil, the plastic limit decreases gradually for the sample of increased fibre. The results of Atterberg limit test indicate that the S soil has a higher value of plasticity index than the Tizi Tuff. The low plasticity of the T soil makes the mixtures less susceptible to fibre compared to the S soil.

The change in consistency limits of mixtures may be due to the mixture type [30], the cation exchange capacity [31-32], and the relative amount of clay mineral in the mixtures [33]. Interestingly, the plastic limits studied for tire-cohesive clayey soil mixtures by [29] stay at first about the same then show some amount of decrease and then stay about the same. These

results are similar to those of typical fine grained cohesive soils with medium plasticity [29].

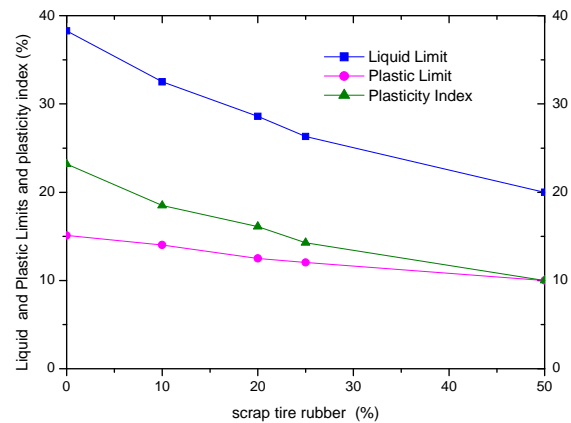


Fig. 2. Effect of rubber tires on the consistency limits of the soil S

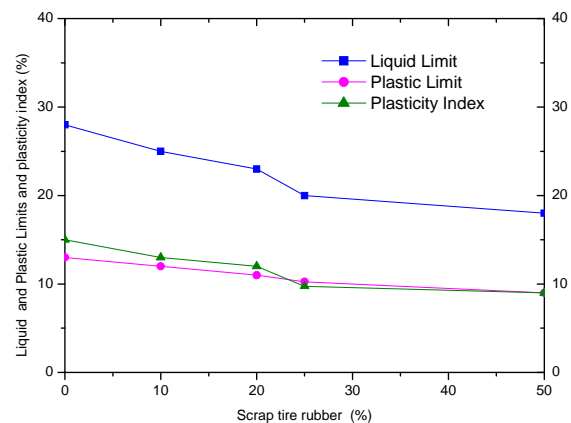


Fig. 3. Effect of rubber tires on the consistency limits of the soil T

Ab-Malek and Stevenson [34] studied the effect of 42 year immersion in sea water on natural rubber; they concluded that absorbed water of rubber has been less than 5% of its dry mass. The literature contains a considerable number of empirical techniques for assessing the swelling potential of soils, which correlated with consistency limits, moisture content, dry density, and depth of the soil samples [35].

B. Direct Shear Tests (DST)

Laboratory DSTs were conducted to measure the shear properties of a soil, including the yield point, the cohesion C and the soil internal friction angle ϕ , as affected by different soil moisture contents and dry bulk densities. This test is carried out according to French standard [36]. Direct shear tests were conducted using an apparatus consisted of a soil shear box, a loading head, a weight hanger, and weights to generate

normal loads. The shear box had two square rings for holding the soil sample. The cross-section of the box was 60 to 60 mm and the height was 50.8 mm. The horizontal displacement of the movable ring was achieved with a motor. The tests are carried out in a damp and pressed state. The line of rupture is obtained following the application of three normal stresses (1, 2 and 3 bar) to obtain more precision for the statistical study. Figure 4 and 5 show the curves of shearing tests. It is noted that there is a decrease in cohesion with the increase of scrap rubber. On the other hand, the line of variation of internal friction angle is almost vacillating depending on the scrap tire rubber content.

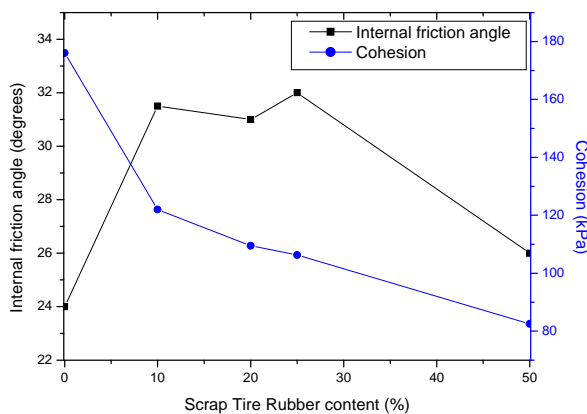


Fig. 4. Effect of rubber tires on cohesion and angle of internal friction of the soil S

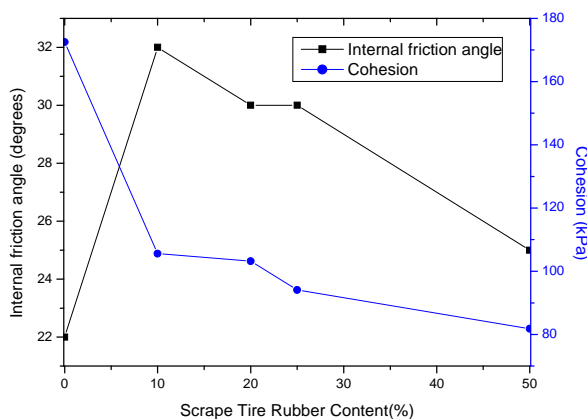


Fig. 5. Effect of rubber tires on cohesion and angle of internal friction of the soil T

C. Odometer tests : Loading–unloading tests

Because tire rubber is highly compressible and its specific weight is less than half that of the soils, a complementary test program under odometer conditions was also performed to obtain additional information on the mechanical behaviour of the soils and the mixtures although the compressibility of

rubber particles is considered negligible compared to the compressibility of the composite skeleton in computation. The compression index C_c and the recompression index C_r were determined for soils and composite samples according to [37].

1) Effect of scrap tire rubber on Compression index.

Figures 6 and 7 show the compression indices for the studied soils and mixtures. It is well known that the compression index C_c is the slope of the linear portion of the pressure void ratio curve on a semi-log plot. The values of C_c are relatively small because the remoulded C_c is always smaller than the undisturbed C_c . The values vary from 0.126 to 0.423 for the Tizi Tuff and its mixtures and from 0.112 to 0.571 for Fergoug Sediment and its mixtures. For the two soils, C_c increases gradually with rubber content.

2) Effect of scrap tire rubber on recompression index

The recompression (swell) index (i.e., slope of the e -log p plot during unloading or decompression) is presented in this study as the decompression index, C_r (Figures 6 and 7). The values of the recompression index C_r of undisturbed soil are generally about 5 times smaller than C_c [38]. For all tested samples, C_r is smaller than C_c and it increases with scrap rubber content. The values of C_r range from 0.114 to 0.261 for the Tizi Tuff and its mixtures and from 0.109 to 0.211 for Fergoug Sediment and its mixtures.

D. Modified Proctor tests

This test is carried out according to the French standard [39]. The optimal water content W_{opt} and the maximum dry density G_{dmax} are determined. The Proctor curves are drawn taking into account the added scrap rubber. The results will be then compared with those obtained on Tizi Tuff. The values of optimum moisture content are 12.1% and 7.94% for respectively S and T soils, whereas the maximum dry density is about 1.97 for T soil which is 17% greater for S soil.

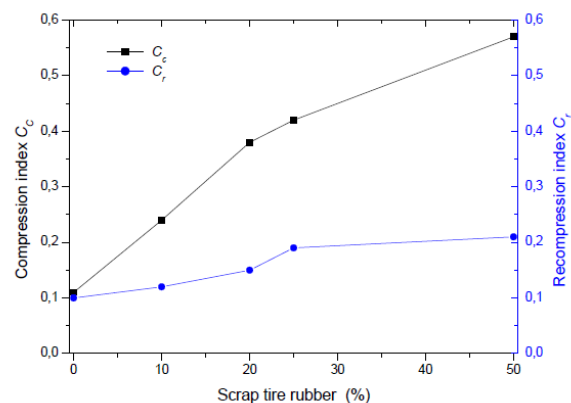


Fig. 6. Effect of tires rubber content on compression and recompression indices of soil S

With the addition of scrap tire rubber contents (Figure 8), the optimum moisture content and the maximum dry unit weights of S and T soils decrease. This can be due to change of the particle size distribution, organic content (especially for sediment) or surface area of the composite samples which can change the soil state from buoyant to semibuoyant.

E. CBR tests

CBR (California Bearing Ratio) values are commonly used in mechanistic design as an indicator of strength and bearing capacity of a sub grade soil, sub base, and base course material used in road and airfield pavements. The CBR of a soil is the ratio obtained by dividing the stress required to cause a standard piston to penetrate 2.5 mm, 5.00 mm, 7.50 mm and 10.00 mm into the soil by a standard penetration stress at each depth of penetration [40]. The CBR may be thought of as an index value comparing the strength of the soil to that of crushed rock. CBR loading values according to different penetration for S and T soils and their mixtures for respectively $W=3$ and 5% are shown in Figures 9 and 10. CBR tests in this study were performed in accordance with [41]. CBR values for S and T soils and their mixtures are given in Table V.

TABLE V. CBR VALUES OF SOILS AND MIXTURES.

Soil mixtures	CBR values ($W=3\%$)	CBR values ($W=5\%$)
100% S	16.56	11.54
90% S+10%C	14.55	8.53
80% S+20%C	7.53	4.52
75% S+25%C	6.52	5.02
50% S+50%C	4.01	3.01
100% T	15.55	12.04
90% T+10%C	14.55	9.03
80% T+20%C	8.03	8.03
75% T+25%C	7.02	7.53
50% T+50%C	4.52	2.51

Results indicate that CBR values for the two soils decrease with scrap tire rubber content. The maximal value of CBR is given for $W=3\%$ for all mixtures except for the mixture of T soil with 25% of scrap tire rubber where the maximal CBR value was obtained for $W=5\%$. The Fergoug sediment needs greater pressure to make power for the penetration than the Tizi Tuff. Thus, the pressure of 3% is more than the pressure of 5%, which proves that water impacts negatively on the compaction characteristics of mixtures. Also the scrap rubber affects negatively on CBR values of soils. The results highlight an appreciable increase in load compaction when the additions of 20% of scrap tire rubber are proceeded.

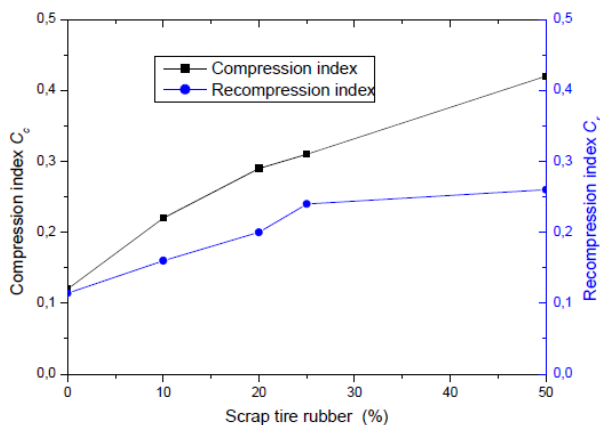


Fig. 7. Effect of tires rubber content on compression and recompression indices of soil T

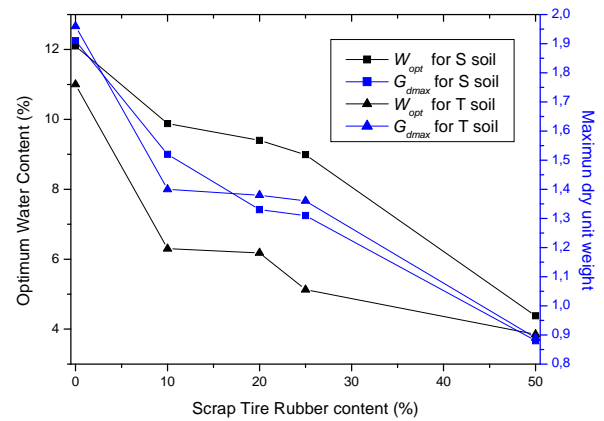


Fig. 8. Evolution of Features Proctor for S and T soils and their mixtures.

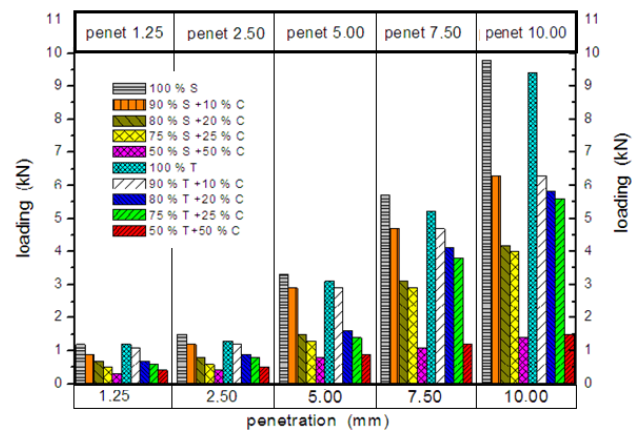


Fig. 9. CBR loading according to different penetration for S and T soils and their mixtures for $W=3\%$.

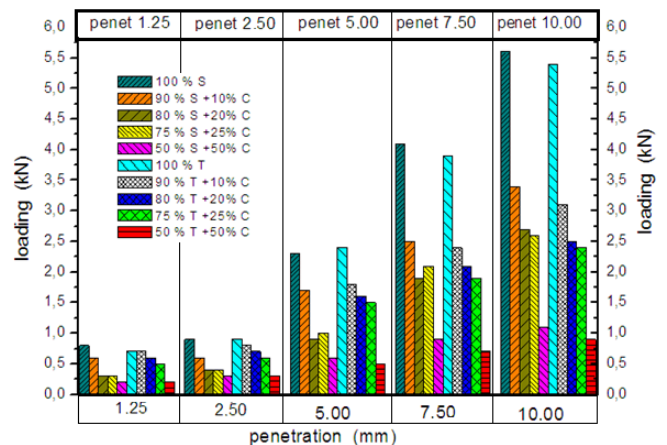


Fig. 10. CBR loading according to different penetration for S and T soils and their mixtures for $W=5\%$.

IV. CONCLUSION

In this study, the effect of scrap rubber content on the geotechnical characteristics of Fergoug sediment and Tizi Tuff were investigated and the following conclusions were drawn:

- Geotechnical's characteristics vary depending on the scrap rubber content: the liquid limit, the plasticity index rundown with the increase of scrap tire rubber content. This decrease is more significant for plastic soil.
- The scrap tire rubber content changed the compaction parameters of Fergoug sediment and Tizi Tuff. The optimum moisture content and specific weight values decreased with the scrap tire rubber contents.
- For shearing tests, a decrease in cohesion with the increase of scrap tire rubber is observed when the variation of internal friction angle is vacillating.
- Compression and recompression indexes increase gradually with the scrap tire rubber content for the two soils. The increase is more significant for the compression index.
- The CBR values for $W=3\%$ are larger than those for $W=5\%$ except for the mixture (75% Tuff + 25% Scrap tire rubber). Thus, the pressure needed for a water content $W=3\%$ is greater than for $W=5\%$. This proves that water impacts negatively on the proctor soil.

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