Efficiency and Durability Assessment of Soil Stabilization using Waste Tire Shreds

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ABSTRACT

Tire waste constitutes an undesirable surplus within urban industrial contexts, presenting a persistent annual increase on a global scale. Consequently, the reduction of tire waste through alternative approaches has attracted the interest of researchers around the world. This study evaluated the efficacy of using tire shreds as soil stabilizers to enhance the strength properties of the mixture in three proportions. Tire shred content of 10, 20, and 30% resulted in reduced CBR values of 3.3, 2.98, and 2.3%, respectively, compared to 4.4% without tire shred content. In addition, the direct shear test revealed that the increase in tire shred content significantly increased shear stress, as 10, 20, and 30% tire shred content resulted in 82.25, 84.14, and 85.87 kPa, respectively. Consequently, tire pieces can be used along with soil as an alternative mixture material in retaining structures.

Keywords-soil stabilization; tire shreds; CBR; shear stress

I. INTRODUCTION

Clay and silt are relatively common forms of soil found throughout the world and are often used to build soil structures such as slopes and highway embankments [1-2]. Building on a weak natural fine-grained subgrade soil could result in major damage and reduced service life of the earthen structure [3]. It is well-recognized that soil stabilization can improve the engineering qualities of soil. One of the most prevalent ways of soil remediation is the practice of mixing tire shreds with the soil [4-9]. Approximately millions of tires are discarded annually from the utilization cycle and deposited in natural environments. The disposal of waste tires poses substantial environmental, health, and safety risks to densely populated contemporary societies [10-11]. Various methods have been employed for the management of waste tires, including, but not limited to, recycling, incineration, and landfilling, and some of them can harm the environment [12-18].

In this context, the industrial reuse of waste tires is important and has attracted considerable attention from many researchers [19-20]. Tire chips, tire powder, shredded tire, tire crumb, tire polishing, and more advanced procedures are used to transform scrap tires into fragments of various shapes and sizes. These materials offer unique properties that improve the quality of geotechnical works, such as durability, strength, lightness, compaction, drainage, and high frictional resistance [21-22]. As a result, mixing these materials with low-shear soil can address geotechnical issues faced by civil engineers, in addition to providing an economical solution to environmental problems [8, 23]. Many studies have investigated the shear strength characteristics of sand and rubber mixtures, underlining the importance of adding some rubber to the sand to increase its shear strength affected by various criteria such as normal stress, tire content, tire aspect ratio, tire length, sand matrix unit weight, and compaction [24-26].

Tire shreds are used tires that have been shredded by a shredder cutter. Several different types of machinery are available for this activity. The size of the tire chips is determined mainly by the equipment. The resulting chopped pieces are generally uneven in shape, with larger dimensions being 2-4 times larger than smaller dimensions, ranging from 1 to 2.38 mm [13, 27]. Large earthwork projects that use recycled tires, such as highway construction, are an ideal application for shredded tires because there is the potential to use large quantities while improving or maintaining the performance of the earthen structure [28-31]. Determining the dry density and optimum moisture content of the materials is one of the fundamental preliminary steps required to enable proper compaction of the various layers of the road. The use of clay soil and tire scrap mix for road construction depends on supplying the highest dry density and optimal moisture content in various tire shred content ratios [20, 31]. The waste tire is available in powder and granule forms, both of which are plentiful and allow for a uniform soil mix [32, 33]. This study investigated the optimal content of Duhok clay granule mix and tire waste shred, using an experimental plan, soil and tire waste characterization and classification tests, and presenting relations for use in engineering applications. This study aimed to evaluate the practicality of tire waste in improving soil quality, promoting sustainable development, and its influence on shear strength, compaction, and CBR when combined with clay soils.

II. MATERIALS AND METHODS

A. Materials

The clay soil used in this study was collected in Duhok governorate (36° 59′ 24.5"N, 42° 39′ 20.7"E) in Northern Iraq. The properties of clay soil are shown in Table I according to the Unified Soil Classification System (USCS) [34].

TABLE I. CHARACTERIZATION TEST RESULTS OF CLAY

Properties	Value
Optimum moisture content (%)	17.7
Plastic limit (%/)	26
Maximum dry density (g.cm^3)	1.778
CBR (%)	4.4
Classification	Well graded

Fig. 1. The tire shreds used in this study.

Tire shreds crafted from discarded tires were used in this study according to [35]. These tires were shredded in a specialized facility that handles old and spare tires obtained from the Zakho Ibrahim Khalil plant. The tire grinding and screening process yielded fiber-like pellets with various shapes, called "shreds", each measuring approximately 1/3 inch in size, as shown in Figure 1. The samples used in the experiments had varied amounts of tire shreds: 10%, 20%, and 30%.

B. Methods

Experimental tests were carried out to examine how tire buffing and tire powder impact the strength parameters of sand. This study focused on specimens with 5% water content, varying the percentages of tire buffing and powder at 10, 20, and 30%. The addition of rubber grains to the sand results in a decrease in the unit weight of the mixture. The grain size analysis test (sieve and hydrometer) evaluates soil grain size percentages and the distribution of larger particles, following ASTM procedure D422-63 [36]. Figure 2 shows the grain-size distribution curve. Atterberg limit tests were performed on untreated soils using ASTM procedures D423-66 and D424-59 for liquid and plastic limits, respectively. The liquid limit defines the moisture content at which the soil changes from liquid to plastic [37]. Based on the Optimal Moisture Content (OMC) and Maximum Dry Density (MDD) of each mixture, determined by the Proctor compaction test, the required amounts of dry soil and tire shreds were produced according to the ASTM D1157 procedure [38].

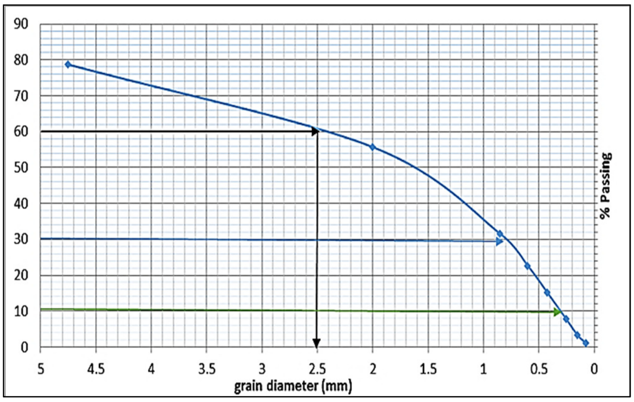

Fig. 2. Grain size distribution curve of the soil.

To find the ideal tire shred content range for improved California Bearing Ratio (CBR) values, CBR tests were carried out using cylindrical samples according to ASTM D1883-16 [39]. CBR values were calculated by exerting pressure on the soil with a cylindrical piston. The piston was inserted into the soil at a constant speed. The CBR values for each soil sample were determined by dividing the measured load by the standard stress for penetrations of 2.5 and 5 mm. Each experiment was repeated twice to verify consistency and the CBR was determined by:

$$CBR = (P_t/P_s) \times 100 \quad (1)$$

where P_t is the corrected test load corresponding to the chosen penetration from the load penetration curve, and P_s is the standard load for the same depth of penetration. A series of direct shear tests were performed to determine the drained shear strength parameters of sand. This study used rectangular samples as shown in Figure 3. Within the testing apparatus, a vertical normal force, denoted as *N*, was applied to the top of the box, while a horizontal force, denoted as *T*, exerted shear action on the specimen along a thin plane between the two halves of the box, acting on the upper part of the box. Following [40], each sample with dimensions of 4×4×2.2 cm was subjected to shear strength testing under three different normal stresses of 1, 2, and 4 kN/m² to determine shear strength parameters. To establish a drained condition, the rate of shear deformation was set to 1.5 mm/min. The determination of the direct shear test proceeded as follows:

$$Corrected\ Area = A = A_o \times (1 - {}^{\delta}/_{3}) \quad (2)$$

$$Shear\ load = P = Proving\ ring\ reading \times Proving\ ring\ constant \quad (3)$$

$$Shear\ stress\ \ \tau = P/A \quad (4)$$

Fig. 3. The specimen of direct shear stress test.

III. RESULTS AND DISCUSSION

The compaction test revealed a distinct inverse relationship between the tire shred content and the modified compaction results. Without tire content (0%), the dry unit weight was 1.778 g/cm³, with a 17.7% OMC. When tire shreds were added to the mixture in proportions of 10, 20, and 30%, the dry unit weight and optimal moisture content decreased to 1.657 g/cm³ and 15.6%, 1.571 g/cm³ and 12.7%, and 1.504 g/cm³ and 11.8%, respectively. This means that as the percentage of tire shred increases, there is a consistent reduction in dry unit weight and a decrease in the optimal moisture content during the modified compaction test. The significance of the CBR test lies in evaluating tire shreds' impact on the soil. CBR was 4.4% without tire shred content. As tire shreds were incorporated into the mixture at 10, 20, and 30%, the CBR values exhibited a decrease reaching 3.3, 2.98, and 2.3%, respectively, as shown in Figure 4. This assessment extends to the Modified Compaction Test and MDD, illustrating how tire shreds increase air space, hinder water absorption, reduce soil stiffness, and weaken the bond between tire shreds and soil particles.

The swell test was used after the CBR test to ensure its result. The initial swell measurement, without tire shred content, was 1.97%. Adding tire shred at 10, 20, and 30% proportions, the swell increased to 2.68, 3.06, and 3.65%, respectively. Tire shred increases the air void in the soil, which causes the swell to expand, as shown in Figure 5.

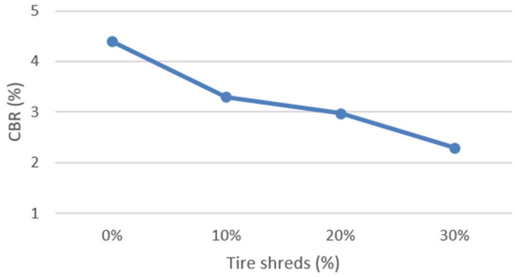

Fig. 4. CBR values of soil with tire shreds.

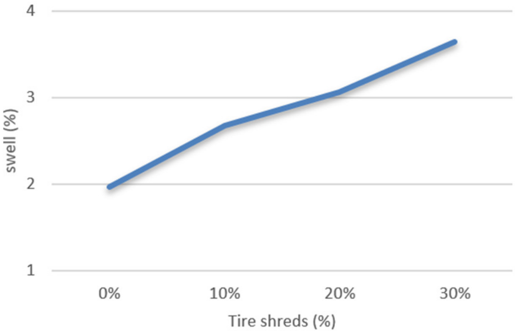

Fig. 5. Swell values of soil with tire shreds.

The results of the direct shear test illustrate a clear trend. With no tire shred content, the recorded shear stress value was 75 kPa. Adding tire shreds to the mixture in proportions of 10, 20, and 30% increased shear stress to 82.25, 84.14, and 85.87 kPa, respectively. Figure 6 shows the relation between normal and shear stress. These findings underscore the direct relationship between increasing tire shred content and increased shear stress. This can be attributed to the contrasting material properties, with the soil being brittle and the tire shreds being ductile. Consequently, the mixture becomes more ductile, resulting in increased shear stress, as the direct shear test is more sensitive to ductile materials compared to brittle ones. Furthermore, the inverse relationship between CBR and the direct shear test results signifies the interplay between the two test methods in assessing material behavior. The cohesiveness test showed that cohesiveness started at 8.71 kPa with zero tire shred content, reduced to 5.79 kPa with 10% tire shred, increased to 7.08 kPa with 20% tire shred, and reached 11.02 kPa with 30% tire shred content. Comparatively, in the triaxial compression test, the angle of the internal friction of sand, as determined by direct shear and strain tests, showed an increase of 2-8°. In the direct shear test shown in Figure 7, the angle of friction was 33.4° without tire shred, 37.2° with 10% tire shred, 37.2° with 20% tire shred, and 34.5° with 30% tire shred. These data illustrate the proportional increase in the angle of friction with increasing tire shred content.

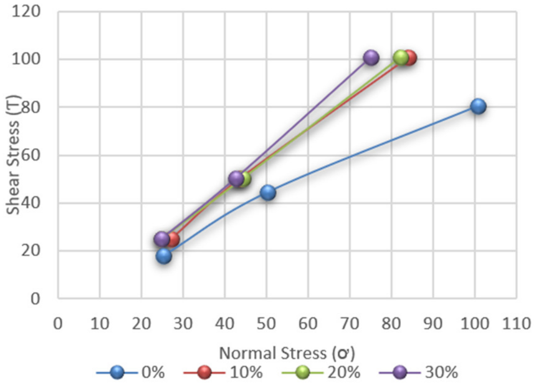

Fig. 6. Relationship between normal and shear stress.

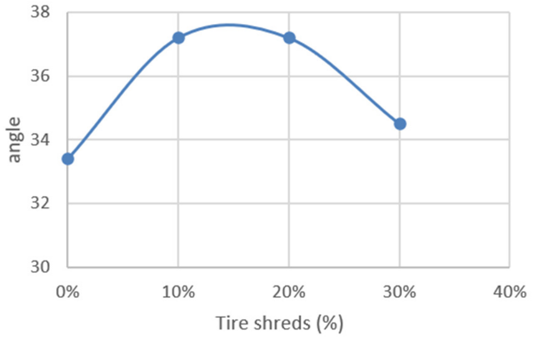

Fig. 7. Relationship between tire shreds (%) and angle of internal friction.

Therefore, as the percentage of tire shred content increased, there was a consistent decrease in dry unit weight and optimal moisture content during the modified compaction test. As the tire shred content increased in the mixture in proportions of 10, 20, and 30%, the CBR values exhibited a decrease, reaching 3.3, 2.98, and 2.3%, respectively, as shown in Figure 4. This evaluation extends to the modified compaction test and MDD, illustrating how tire shreds increase air space, hinder water absorption, reduce soil stiffness, and weaken the bond between tire shreds and soil particles. The swell test after the CBR test validated the CBR result. The initial swell measurement was 1.97% without tire shreds, and by adding tire shreds in proportions of 10, 20, and 30%, the swell increased by 2.68, 3.06, and 3.65%, respectively. Tire shreds increase the air void in the soil, which causes the swell to expand, as shown in Figure 5.

IV. CONCLUSION

This study evaluated the impact of strengthening stabilized soil using tire shreds in various proportions, reaching the following conclusions:

- The study used experimental and analytical methods to investigate the use of a higher tire shred percentage, ranging from 10% to 30%. This contrasts with a prior study that examined a lower tire percentage, ranging from 2% to 15%.
- The importance of the CBR test is to determine how tire shreds affect the soil when their proportion is zero (4.4%). The CBR decreased to 3.3, 2.98, and 2.3% when adding 10, 20, and 30% tire shred content, respectively.
- The decrease in test results can be attributed to soil particles having a higher density than tire particles, which subsequently reduces the OMC. Additionally, the presence of tires increases the void ratio within the soil, resulting in a decrease in the CBR rate.
- The results of the direct shear test when using 10, 20, and 30% tire shred were 82.25, 84.14, and 85.87 kPa. These results highlight a distinct relationship between increased shear stress and tire shred content.
- The incorporation of a higher proportion of tire shreds as soil reinforcement resulted in a reduction in brittleness due to their increased ductility. Additionally, the inclusion of tire shreds mitigated the loss of stiffness caused by alternating wetting and drying cycles, in contrast to the low percentage of tire shreds, leading to an improvement in soil hardness and strength.
- Tire shreds are lightweight materials, and as their proportion in the soil mixture increases, the soil properties are diminished. Consequently, tire shred pieces can be used alongside soil as an alternative material in retaining structures.

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