Effects of Waste Tire on the Shear Strength of Sand

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***Abstract*— Different artificial materials including waste rubbers have been used to improve soil properties for construction purposes. This study evaluates the effect of reinforcement with waste tires on the shear strength of sands. For this purpose, a series of direct shear tests have been performed on a sandy soil reinforced with different forms of waste tires. Increase in the percentage of the shredded tires resulted in an increase in the optimum water content and a decrease in the unit weight of specimens. The results of the direct shear tests show an improvement in the shear strength of reinforced soil samples than unreinforced soils. In addition, a 7% higher mobilized shear strength of the reinforced samples with fiber shredded tires compared to the reinforced samples with sheet shredded tires supports the influence of the forms of waste tires on the shear strength of reinforced soil.**

***Index Terms*— reinforcement, sand, shear strength, waste tire**

I. Introduction

The applications of recycled materials to reinforce soils in steep slopes have been commonly used for a long time. Wide range of materials have been utilized as soil reinforcement elements such as tree roots, metals, and polymeric materials. Evaluation of the characteristics of reinforced soils with different additional elements such as cement, polymer, and Fly Ash has been well studied [1]-[8]. Mixing soil with microfibers that are randomly distributed in the soil, is one of the common reinforcement techniques. In the reinforced soil, the mobilized shear strength is based on the Soil particles-additives interaction, and in this case the friction between the soil particles and the reinforcement elements is essential [9].

Every year, millions of waste tires are come into the nature circulation. For instance, in the USA in 2005, nearly 299 million waste tires were entered into the environment and in Japan this amount was reached to 103 million. This volume of waste tire may lead to health and environment concerns. This numerous volume of waste tires in nature, not only creates contaminated leachate, but also will cause fire and subsequently it will affect the climate change. Even in the developed countries, only 30% of the volume of waste tires is kept at specific sites for the storage of such materials and the remainder is released into the nature [10]. The use of waste tires in industries such as construction material production prevents the contamination of the environment and it entails a great economic benefit. In addition, the lightweight waste tire materials are used in road construction, behind retaining walls, embankments drainage, and insulation materials that can improve the earthquake resistance of soils, as an example [11]-[14]. In these applications waste tires can be in different forms such as powder, sheets, and fibers.

Several studies have already been conducted on reinforced soil with waste tire [15]-[16]. In most of these studies, the optimal percentage and dimension of the added tire chips to soil were investigated in order to reach the maximum bearing capacity. In this study the influence of size and percentage of two different forms of shredded tire, sheet and fiber, on the shear strength of a sandy soil has been examined.

II. Materials

A. Soil

The sand used in this study is collected from Natanz region located in Isfahan - Iran. Sieve analysis, hydrometric, plastic and liquid limit tests are conducted on the soil samples to determine the characteristics of the soil. The particle-size analysis is done based on ASTM D422 [17] and the soil is classified according to Unified Soil Classification System [18]. From soil characterization tests, the type of soil is silty sand, the natural water content of the soil is about 2.5 percent with

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no plasticity properties, and the dry unit weight of soil is 16.67 kN/m^3.

B. Tire

Characteristics and properties of the shredded tires utilized in soil samples are tabulated in Table 1. Hereafter for convenience, symbols A, B, C, and D represent different dimensions of tires in the soil samples. Following ASTM D6270 [19], the percentage of added shredded tires to soil samples that is calculated based on the weight of sand in the samples, are 0.4, 0.8 and 1.2.

TABLE I. TYPE SIZES FOR CAMERA-READY PAPERS

Symbol	Dimensions (mm)	Average ratio of length to thickness
A	2-2.36	2
B	2.36-3.35	3
C	3.35-4.75	4
D	4.75-6.35	5.5

Fig. 1 illustrates two types of shredded tire used in this research which are obtained from a local tire manufacture. Based on the manufacturer specific data, tensile stress of this type of tire is about 150 to 200 MPa and has a density in the range of 1.1 to 1.2 gr/cm^2. To prepare the tire as reinforcement element, the wires inside the tire are removed and then after cleaning the cover of tire, it is grinded by a mill.

Figure 1. Two types of sheet and fiber shredded tires

III. EXPERIMENTS

A. Compaction Test

In this study, a modified compaction test was conducted on the soil samples reinforced with shredded tire in accordance with ASTM D1557 [20]. Samples prepared from a combination of sand and shredded tire were placed in five layers into the compaction mold with 943.9 cm^3 volume and a height of 116.33 cm. After compacting each layer by 25 blows of a 4.54 kg rammer, the mold and compacted sample were weighed. A portion of soil samples was placed in an oven for 24 hours in 105 ℃ to determine the percentage of water content. After calculating dry unit weight in the next step extra water was added to the sample and the compaction test was repeated. The water content value corresponding to maximum dry unit weight in a dry unit weight versus water content plot represents optimum water content.

B. Direct Shear Test

Depending on the soil type in this study, a consolidated undrained direct shear test was conducted [21]. Sieve No. 6 was employed to prepare samples with the dimension of 10 × 10 × 2.29 cm. The samples were kept in closed bags. The test was displacement controlled with an applied displacement rate of 0.59 mm/min. Each sample was tested three times with the normal stress of 50, 100, and 150 kPa.

IV. RESULTS AND DISCUSSION

A. Compaction Test

The results of compaction test on the samples reinforced with different percentages and sizes of shredded tires are presented in Fig. 2. Increasing the percentage of shredded tire rises the optimum water content while decreases maximum dry unit weight. Low specific weight of shredded tire and its elasticity properties are the main reasons of reducing the dry unit weight of the reinforced sand with shredded tire. Moreover, rise of optimum water content is because of higher water absorption by porous particles of shredded tire. The results of these experiments are in a good agreement with the study conducted by Esna-Ashari and Asadi [22].

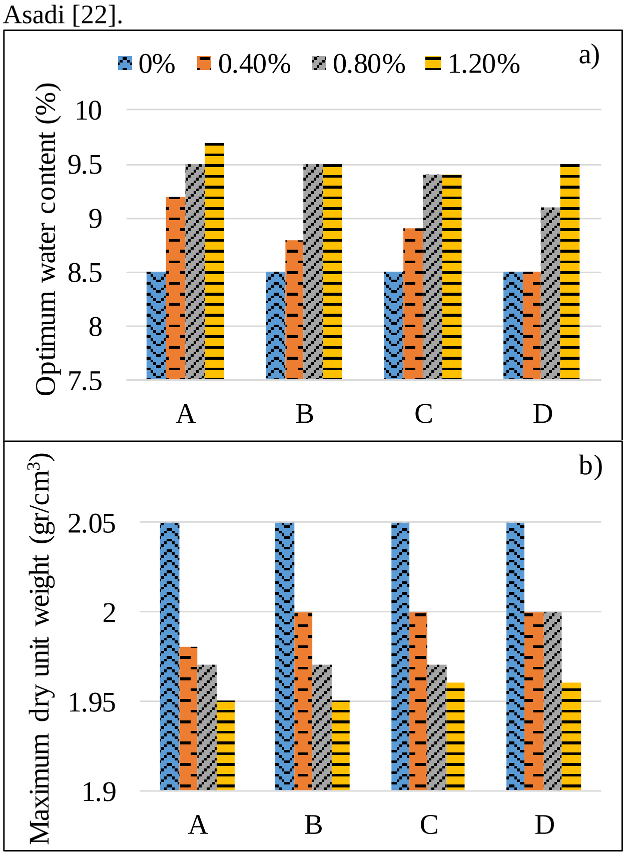

Figure 2. a) Maximum dry unit weight variation of unreinforced and reinforced soil samples with different percentages and sizes of fiber shredded tire; b) optimum water content variation of unreinforced and reinforced soil samples with different percentages and sizes of fiber shredded tire

For a specific shredded tire percentage, an increase in the dimension of the additive resulted in an increase in the maximum dry unit weight. The reason is by rising the size of shredded tire, an unsuitable distribution of reinforcement material in the samples can be observed. As a result, the forces exerted on the sample are significantly absorbed and greater maximum dry unit weight can be achieved.

B. Direct Shear Test

The effective strength parameters in the direct shear test on unreinforced and reinforced soil samples with shredded tire are the friction angle and the adhesion between the particles. Fig. 3 illustrates the peak shear strength against normal stress of unreinforced and reinforced soil samples with different dimensions and percentage of sheet shredded tire (0.4, 0.8, and 1.2%). The relationship between the percentage of sheet shredded tire and shear strength depends on the size of shredded tires. In the reinforced samples with small dimensions of tires (A and B), as the percentage of shredded tire increases, shear strength becomes greater. In the case of samples containing sheet shredded tire with the largest dimension (D), rising the percentage of shredded tire causes the shear strength to decrease. Comparison of peak shear strength-normal stress of unreinforced and reinforced soil samples show larger shear strength is mobilized when the size of sheet shredded tire increases up to size C in the soil samples, while the shear strength decreases by enlarging the size of shredded tire to size D. Sample C with 0.4 percent shredded tire has the highest value of peak shear strength, and its shear strength rises about 9 percent compared to unreinforced soil.

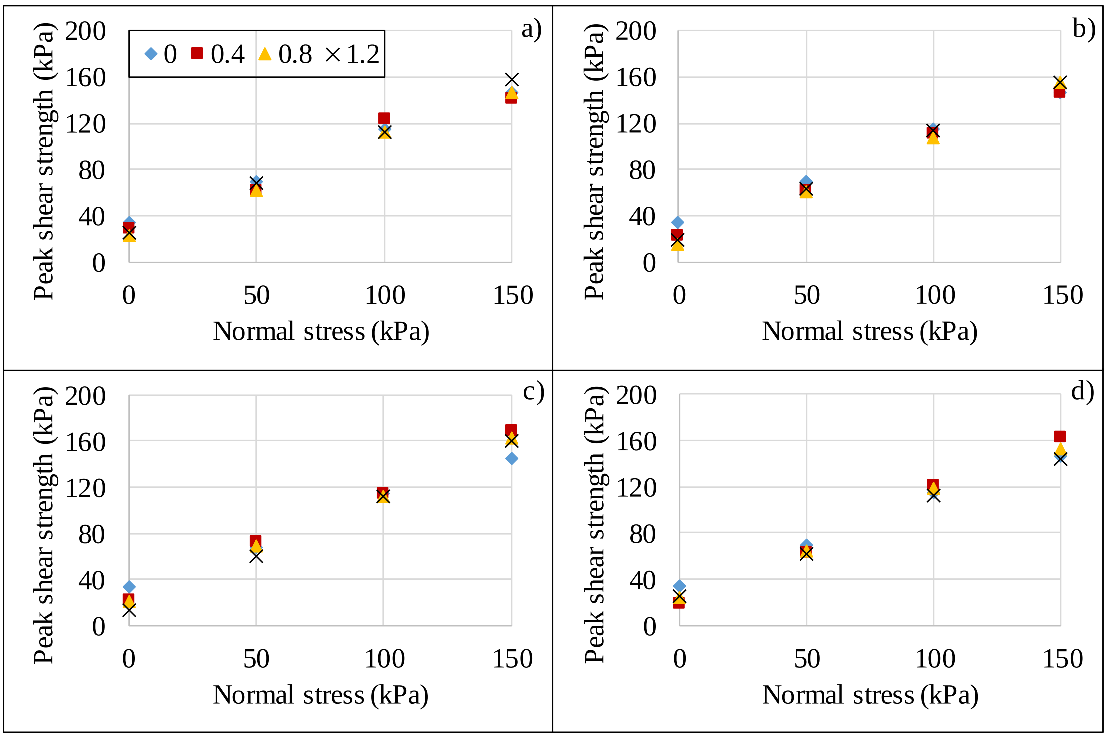

Figure 3. The peak shear strength versus normal stress of unreinforced and reinforced soil samples with shredded sheet tire with dimensions: a) A; b) B; c) C; and d) D.

Similar to reinforced soil samples with shredded sheet tire, the size of shredded tires in the reinforced samples with shredded fiber tires play a significant role in the relationship between the percentage of fibers and shear strength of the samples (Fig. 4). In samples with the fiber size of A, B and C, increasing the percentage of fibers yields greater peak shear strength in most situations. In the case of size D, the peak shear strength rises as the percentage of fibers increases from 0.4% to 0.8%, and then reduces by increasing the percentage of shredded fiber tire to 1.2%. In sample with fiber size of D, the optimal percentage of shredded tire fiber is 0.8% leading to greater shear strength about 16 percent more than the unreinforced sample.

In the reinforced samples with both sheet and fiber tire, the increase of normal stress results greater peak shear strength (Fig. 3 and Fig. 4). In normal stresses of 150 kPa, shredded tire has more influence on rising the peak shear strength of reinforced samples compared to lower normal stresses (50 and 100 kPa). In most cases, under the normal stress of 150 kPa, the reinforced samples show higher peak shear strength than unreinforced samples, whereas, under the normal stress of 50 kPa, that is the opposite because rising the normal stress causes more interaction between soil particles and shredded tires and as a result friction between them increases. In comparison, the shear strength of reinforced samples with fiber elements is more than the samples with sheet tires because the possibility of sliding between soil particles and shredded sheet tires is more than that in the reinforced samples with fiber tire. These results are in a good agreement with the investigation of Edincliler et al. [23]. Moreover, inspection of the reinforced samples after direct shear tests shows that most of the shredded tires are not ruptured due to high shear and tensile strength of tire.

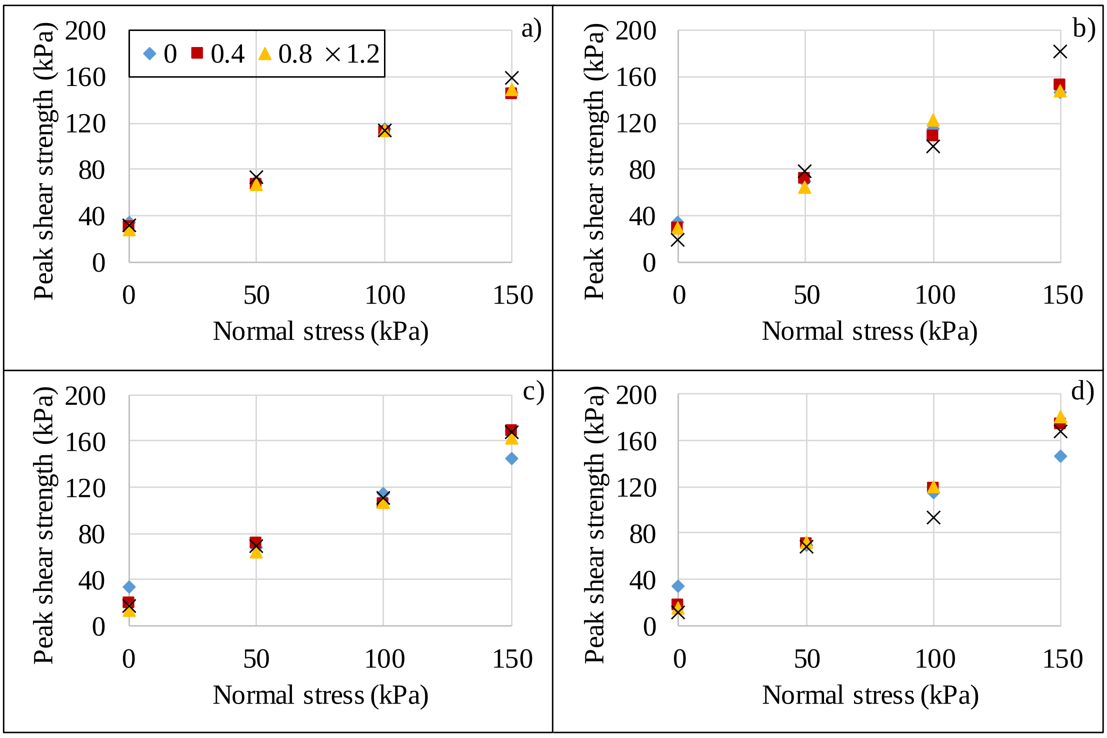

Figure 4. The peak shear strength versus normal stress of unreinforced and reinforced soil samples with shredded fiber tire with dimensions: a) A; b) B; c) C; and d) D

In Fig. 5, the friction angle of reinforced samples with sheet and fiber shredded tire is presented. In the reinforced samples with sheet tire, although the friction angle increases with the size of shredded tire, it is not the case in the samples with the sheet size of D. This is because larger size of sheets in soil raises the possibility of sliding the soil particles and creation of weak plate [24]. Regarding to the effect of shredded sheet tire percent on the friction angle of reinforced samples, in the samples with smaller sheet sizes (A and B), the friction angle increases consistently with the percentage of shredded sheet tire because shredded tiers lose their sheet form due to lower ratio of length to thickness of shredded tire. However, in the reinforced samples with the largest sheet size (D), the friction angle only rises when the percentage of shredded tire change from 0 to 0.4.

For the samples containing shredded tire with fiber shape somewhat different mechanisms are involved. Friction angle enhances with enlarging the size of shredded fiber tire because shredded fiber tire and soil particles perform as a single unit and increasing the size of fibers to some extent helps to improve the functionality of this unit. Each sample considering the size of its fibers has an optimum percentage of shredded tires. In the samples with fiber tire size of C and D, after rising the friction angle with adding fiber tire up to 0.4% and 0.8% respectively, a reduction can be observed (Fig. 5). The results obtained in this study are in a good agreement with the results conducted by Ghazavi et al. [25], Marto et al. [11], Esna-Ashari and Asadi [22], and Esna Ashari and Mirzaee [24].

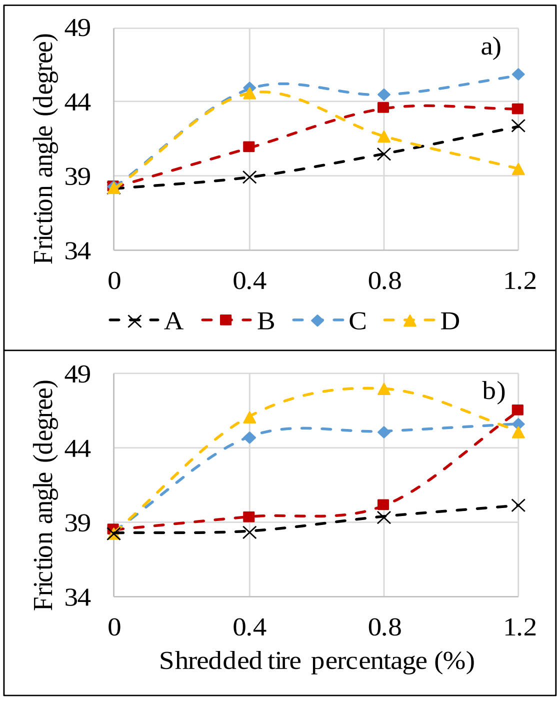

Figure 5. The friction angle of unreinforced and reinforced soil samples versus the percentage of shredded tire with different dimensions: a) shredded tire sheet; b) shredded tire fiber.

In Fig. 6, the relationship between the percentage and size of shredded tire with adhesion of particles is presented. In most cases, a slight decrease in adhesion is observed with increasing the percentage of shredded tire. Regarding to the size of shredded tire, larger size of tire yields lower adhesion. In general, the shredded tire does not play a significant role in the adhesion of the reinforced samples.

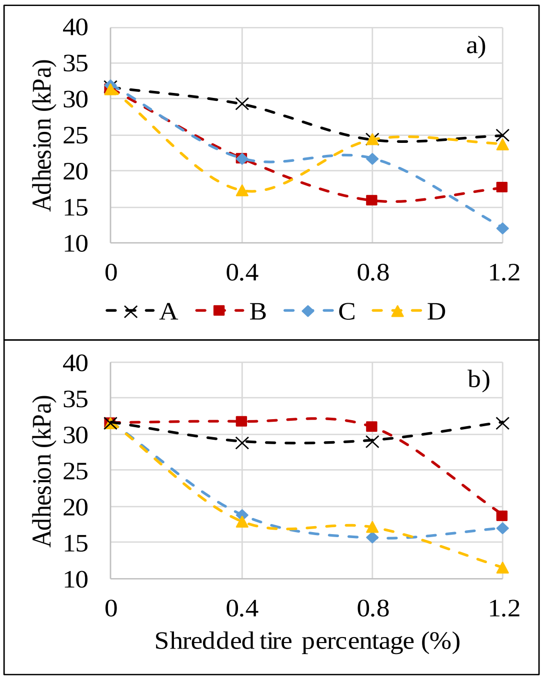

Figure 6. Adhesion of unreinforced and reinforced soil samples versus the percentage of shredded tire with different dimensions: a) shredded tire sheet; b) shredded tire fiber.

V. Conclusions

In this research, the effect of the percentage, size, and shape of waste tire on the shear strength of reinforced sand with shredded tires were investigated. In the case of reinforced samples with shredded fiber tire, 0.8% fiber tire with the size of D (6.3-7.4 mm) enhances the shear strength of the soil samples about 16%. In the reinforced samples with shredded sheet tire, 0.4% sheet tire with the size of C (3.3-4.7 mm) raises the shear strength of the soil samples about 9%. Improving the mobilized shear strength in the reinforced soil samples is mainly due to the friction between shredded tires and soil particles leading to increasing the friction angle. Whereas, the results indicate that the percentage and size of shredded tire do not have a significant influence on the adhesion of the soil samples reinforced with shredded tire. The shape of the shredded tire is also an effective parameter on the shear strength of reinforced sand. Because of the higher surface area of fibers in contact with soil in comparison to sheets, they lead to higher shear strength in the reinforced soil samples. As a future work, a study will be conducted to evaluate the influence of temperature and decomposition of waste tires on the properties of mixed soil-tire by monitoring temperature profile of the mixed soil-tire in a field site [26].

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