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**EXTENDED ABSTRACT**

# The Application of Recycled Tire Polymer Fibers for Shear Strength Improvement of Babolsar Sand

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## 1. Introduction

In recent years soil reinforcement and improvement techniques have gained widespread applications in different aspects of geotechnical engineering. It is apparent that reinforcing/stabilizing a weak/problematic soil is more economical than replacing it with select fills. A contemporary method of soil reinforcement/ improvement is the application of fibers-natural or synthetic (polymeric) with random distribution within the soil (Hejazi et al. 2012). More recently, there has been a trend in utilization of recycled fibers for soil reinforcement/improvement purposes (Valipour et al. 2021). This treatment dwells on the application of Recycled Tire Polymer Fibers (RTPFs) for enhancing the shear strength of Babolsar sand.

## 2. Material Properties and testing scheme

The Recycled Tire Polymer Fibers (RTPFs) are derived from the recycling of automobile tires. An image of the RTPFs is presented in Fig. 1. The RTPFs have a specific gravity of 1.14 and average diameter of 0.67 mm. For the testing program the fibers were cut into 5 mm long pieces; hence, the fiber length to diameter ratio is 7.5. Babolsar sand, that is type of sand sampled from the coast of the Caspian Sea, was implemented in the laboratory testing. The sand was washed and sieved into uniform fractions, from which the target gradation (see Fig. 2) was proportioned for testing. The sand comprises sub-rounded to rounded particles and is classified as SP according to USCS (Unified Soil Classification System).

The fiber-sand mixtures were admixed from dry fractions of the sand and fibers according to:

$$f_c(\%) = \frac{M_f}{M_f + M_s} \times 100 \tag{1}$$

Where; $f_c$ is the fiber content (percent), and $M_f$ and $M_s$ are the dry mass of fibers and sand, respectively. The fiber contents of $f_c$=2%, 4% and 8% were selected for the fiber-sand mixtures.

Direct shear tests on the sand and fiber-sand mixtures were conducted using a conventional direct shear apparatus in accordance with ASTM D3080. The direct shear box accommodates a specimen that is 100 mm × 100 mm in plane and 22 in height. Both the sand and fiber-sand mixtures were reconstituted using the dry tamping method in three layers (each ≈7 mm thick) with the initial (i.e. pre-shear) relative densities of $D_r$=35%, 50%, 65% and 80%. The direct shear tests were performed with the shear displacement rate of 1 mm/min to the maximum shear displacement of 12 mm, under the normal stresses of $\sigma_n$=32, 57 and 107kPa.

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## 3. Results and discussion

### 3.1. Effect of fibers on peak internal friction angle

From the results of the direct shear tests the variations in peak internal friction angle ($\phi_p$) are determined for the sand and fiber-sand mixtures. Accordingly, *i*) for any arbitrary initial relative density ($D_r$) the peak friction angle increases with the increase in fiber content ($f_c$), *ii*) at a constant fiber content ($f_c$) the increase in $D_r$ results in higher peak internal friction angle, and *iii*) the increase in normal stress ($\sigma_n$) leads to lower $\phi_p$ (this outcome stems from the nonlinear peak failure envelope in the $\tau$-$\sigma_n$ plane).

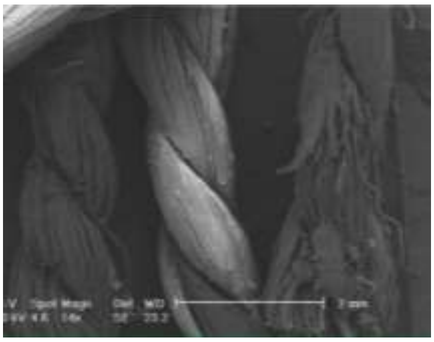

**Fig. 1.** Scanning Electron Microscope of Recycled Tire Polymer Fibers (RTPFs)

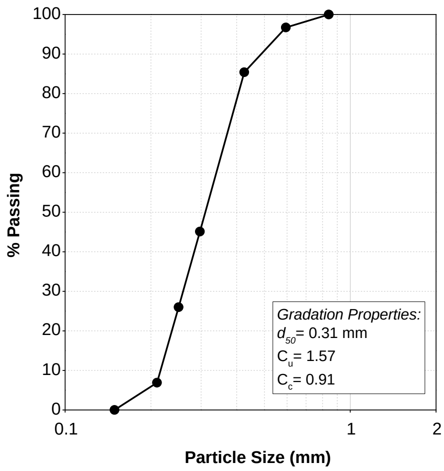


**Fig. 2.** Babolsar sand gradation implemented for testing program

### 3.2. Effect of fibers on maximum dilation angle

The results of direct shear tests enable the evaluation of changes in the maximum dilation angle ($\psi_{max}$) for sand and fiber-sand mixtures. Based on the experimental findings; *i*) for any arbitrary initial relative density ($D_r$) the maximum dilation angle increases with the increase in fiber content ($f_c$), *ii*) at a constant fiber content ($f_c$) the increase in $D_r$ results in higher maximum dilation angle, and *iii*) the increase in normal stress ($\sigma_n$) leads to lower $\psi_{max}$.

### 3.3. Effect of fibers on frictional efficiency

In the reinforcement/stabilization of granular soils the frictional efficiency, $E_\phi$, is defined as the ratio of peak strength for the reinforced soil to peak strength of the original soil, that is:

$$E_\phi = \frac{(tan\phi_p)_{fiber-sand}}{(tan\phi_p)_{sand}} \tag{2}$$

For the fiber-sand mixtures with $f_c$= 2%, 4% and 8%, the average frictional efficiency is 1.15, 1.24 and 1.31, respectively. Hence, the increase in fiber content results in a stronger reinforced/stabilized sand with higher shear strength.

### *3.2. Effect of fibers on residual internal friction angle*

Test results imply that the residual internal friction angle ($\phi_r$) increases with the increase in fiber content ($f_c$); that is to say, fiber addition to the sand is conducive to a stronger load bearing structure for the mixture. In comparison to Babolsar sand with $\phi_r$=39.6°, the fiber-sand mixtures with $f_c$=2%, 4% and 8% have residual internal friction angles of 42.1°, 43.7° and 45.7°, respectively. Therefore, 2%, 4% and 8% fiber addition eventuates to ≈6%, ≈10% and ≈15% increase in the residual internal friction angle ($\phi_r$), respectively.

## 4. Mechanism of fiber-soil interaction

A schematic illustration of the fiber-sand interaction is shown in Fig. 3. Accordingly, when the fiber-sand mixture is subject to shear displacement along the shear plane, the fibers undergo distortion. Hence, as long as the fibers are not pulled out of the sand the tensile stress ($T$) is mobilized within the fibers, which impedes the shear displacement along the shear plane and enhances the shear strength. The fiber pullout from the sand is amenable to the shear stress ($\tau_B$) at fiber-sand contact that in turn depends on soil gradation, particle shape, relative density, etc.

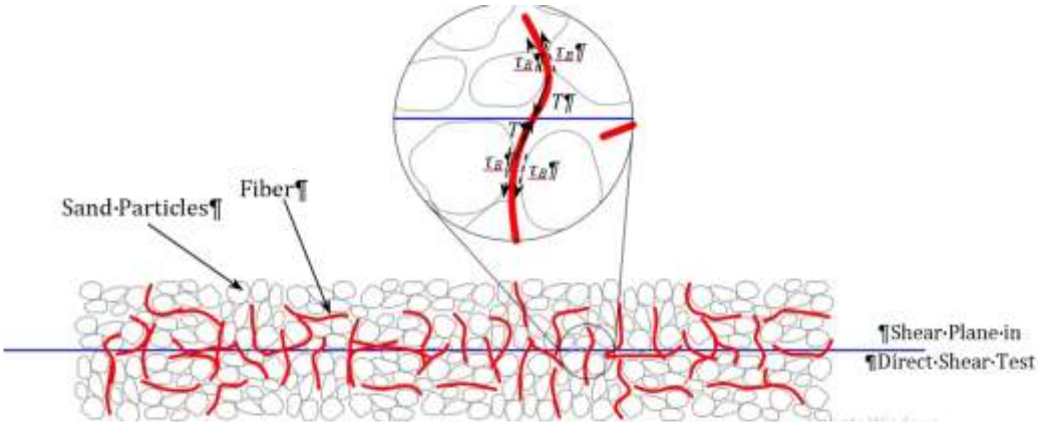


**Fig. 3.** Fiber-sand interaction at the shear plane in direct shear tests

## 5. Conclusions

Direct shear tests were performed on Babolsar sand and mixtures of Babolsar sand with Recycled Tire Polymer Fibers (RTPFs). The main conclusions drawn from the experimental results are as follows:

1- The introduction of RTPFs with random distribution to Babolsar sand results in the increase of peak shear strength as reflected by the increase in peak internal friction angle.
2- Reinforcement of Babolsar sand with RTPFs leads to an increase in the maximum dilation angle.
3- From the viewpoint of soil reinforcement/stabilization the addition of RTPFs is most effective at lower normal/vertical surcharge pressures and higher RTPF content.
4- The sand reinforced with RTPFS may be implemented in applications such as backfills behind retaining walls, reinforced soil walls, and sub-base layers in pavements with low traffic.

## 6. References

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