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# Fiber-reinforced sand strength and dilation characteristics

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**Abstract** Randomly distributed fiber reinforcement is used to provide an isotropic increase in the sand shear strength. The previous studies were not consistent regarding the fibers effect on the volumetric change behavior of fiber-reinforced sand. In this paper, direct shear tests are conducted on 108 specimens to investigate the effects of the fibers content, relative density, normal stress and moisture content on the shear strength and volumetric change behaviors of fiber-reinforced sand. The study investigates also the possibility of using dry fiber-reinforced sand as an alternative to heavily compacted unreinforced moist sand. The results indicate that the fibers inclusion increases the shear strength and dilation of sand. Moisture suppresses the fibers effect on the peak and post-peak shear strengths, and dilation. Dry loose fiber-reinforced sand achieves the same shear strength of heavily compacted unreinforced moist sand, yet at more than double the horizontal displacement.



## 1. Introduction

Soil reinforcement is an efficient mechanical technique for soil stabilization. Soil reinforcement can be achieved either by the inclusion of continuous strips or sheets within the soil mass (systematically reinforced soil) or by the inclusion of short discrete randomly distributed fibers. Systematic reinforcement improves the strength in certain directions. However, continuous planes of weakness develop at the soil–reinforcement interface. Randomly distributed reinforcement, on the other side, provides an isotropic behavior and limits the development of weak planes.

Reinforcing the soil with short randomly distributed fibers has been a point of investigation in the past decades. Unlike systematically reinforced soil, the shear strength of randomly reinforced soil is evaluated by estimating the change in the shear strength parameters due to the fibers inclusion. The shear strength parameters are usually measured using conventional shear strength tests such as the direct shear and triaxial tests. Ranjan et al., Al-Refeai and Al-Suhaibani, Zornberg, Consoli et al., Ibraim and Fourmont, and Diambra et al. [1–6] observed that the fibers inclusion increases the soil shear strength.

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The previous studies did not reveal a consistent trend with respect to the effect of randomly distributed fibers on the volumetric change behavior of fiber-reinforced sand. Consoli et al. [4], and Michalowski and Zaho [7] demonstrated that the inclusion of fibers inhibited the dilation of sand in triaxial tests. Based on plate load tests results, Consoli et al. [8] deduced also that the fibers suppress the sand dilation. Consoli et al. [9] reported that fiber-reinforced sand having a relative density of 50% exhibited minor changes in the dilation angle during shearing unlike unreinforced sand at the same stress level. However, Ibraim and Fourmont [5], and Diambra et al. [6] reported that fiber-reinforced sand exhibited higher dilation tendency than unreinforced sand.

The effect of moisture on the shear strength and volumetric change behaviors was not investigated with the required level of detail in the literature. Lovisa et al. [10] were among few researchers who investigated the effect of the moisture content (range of 0.0–3.0%) on the behavior of fiber-reinforced sand, based on direct shear tests results. Lovisa et al. [10] found that the moist reinforced specimens had a lower peak friction angle than the dry reinforced specimens at the medium dense and very dense states.

Despite the numerous studies conducted to investigate the behavior of fiber-reinforced sand, the behavior is not completely understood due to the discrepancies in the results and the limited number of investigated parameters in some studies, as shown above. This paper aims at conducting a comprehensive experimental study on the shear strength and volumetric change behaviors of dry and moist unreinforced and fiber-reinforced sand using the direct shear apparatus. The effects of the normal stress, relative density, moisture content and fibers content are investigated. The traditional 60 mm-wide direct shear apparatus was employed by many investigators [10–12]. The direct shear box used in this study has plan dimensions of 100 mm × 100 mm, which helps to minimize the size effect of the fibers on the results.

This study investigates four main aspects of the fiber-reinforced sand behavior: the peak shear strength, the post-peak shear strength, the volumetric change during shearing and the effect of moisture content change on the dry side on the shear strength and volumetric change behaviors. The fiber-reinforced sand behavior is compared with the corresponding unreinforced sand behavior.

Many earthworks applications require compacting unreinforced sand to 95% of the maximum dry density in the modified Proctor test at the optimum moisture content. In Egypt, many quarries provide poorly graded sand, which needs a heavy compaction effort and a large amount of water to achieve an acceptable relative density. In addition, water sources are very limited in remote areas. Hence, earthworks could be a costly package of the project. The conducted study in this paper aims also at assessing the possibility of mixing dry sand with fibers at a moderate compaction effort instead of heavily compacting moist unreinforced sand in earthworks applications.

## 2. Experimental testing program

### 2.1. Tested materials

The tested sand is poorly graded siliceous sand, according to the Unified Soil Classification System (USCS). The sand specific gravity equals 2.64, and the maximum and minimum voids ratios equal 0.72 and 0.48, respectively. Fig. 1 shows the grain size distribution, and Fig. 2 shows the compaction curve based on the modified Proctor test results. The maximum dry density equals 17.5 kN/m$^3$, and the optimum moisture content equals 12.8%. The fiber-reinforced sand specimens are prepared by mixing the sand with 6.0 mm-long polypropylene fibers (RHEOFIBRE-BASF). Table 1 shows the fibers properties.

### 2.2. Parametric study

Laboratory specimens are prepared with relative density ($D_r$) values of 25%, 60% and 90% in order to investigate the behaviors of loose, medium dense and very dense sands, respectively. The specimens are sheared at three normal stresses ($\sigma_n$) of 50, 100 and 200 kPa, and four moisture contents ($W_c$) of 0.0%, 4.0%, 6.0% and 10.0%. The moisture contents are chosen on the dry side of the optimum moisture content. The fibers content ($\mu$) is defined as the ratio between the fibers weight ($W_f$) and the solid particles weight ($W_s$), as shown in Eq. (1).

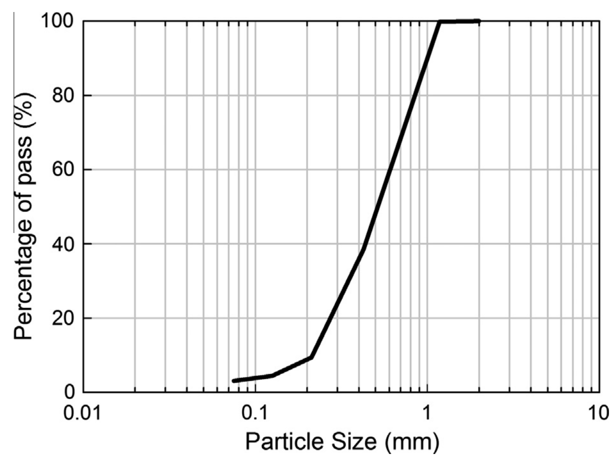


**Figure 1** Grain size distribution of tested sand.

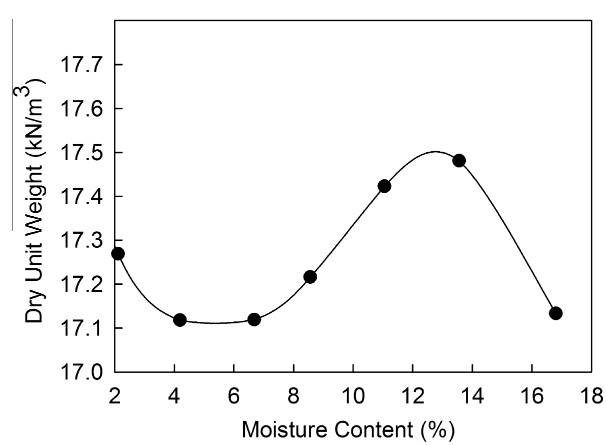


**Figure 2** Modified proctor test results.