Effect of Randomly Distributed Fibre Reinforcements on Engineering Properties of Beach Sand

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ABSTRACT

Mechanism of fibre-reinforced soil has made it an instant success in geotechnical and highway engineering practices for temporary as well as for permanent structures. Since ancient times, fibre-reinfored soil is being frequently used in civil engineering applications. Previous studies were not consistent regarding the effect of fibres on the volumetric change behavior of fibre-reinforced sand. In this paper, various tests were performed to investigate the effect of fibre reinforcement on engineering properties of beach sand. The results indicate that the inclusion of fibres increases shear strength and decreases dilation of sand. Permeability and porosity values increased with the addition of fibre content because of the absence of potential barrier between solid particles in the media.

KEYWORDS: Dilation, Shear parameters, Beach sand, Fibre – reinforcement, Permeability.

INTRODUCTION

Randomly distributed fibre reinforcement inclusion in sand has been extensively studied in the past decades. However, in foundation applications, sand will rarely be in dry condition. Fibre inclusions introduce an apparent cohesion intercept to the soil in the dry state, which remains almost unchanged by an increase in water content. The peak friction angle was expressed as a function of the relative density of sand for both reinforced and unreinforced cases (Lovisa et al., 2010). In fact, any reinforcement, being inextensible or extensible, has the main task of resisting the applied tensile stresses or preventing inadmissible deformations in geotechnical structures, such as retaining walls, soil slopes, bridge abutments, foundation rafts,… etc., In this practice, the reinforcement acts as a tensile member coupled to the soil by friction, adhesion, interlocking or confinement, thus improving the stability of the soil mass.

In the recent past, reinforcing soil with short randomly distributed fibres has become of key significance in investigations. Unlike systematically reinforced soil, the shear strength of randomly reinforced soil can be evaluated by estimating the change in strength characteristics owing to the inclusion of fibres. In general, the shear parameters can be typically obtained using the direct shear and tri-axial tests. It was revealed that the inclusion of fibres increases the soil shear strength (Ranjan et al., 1996; Al-Refeai and Al-Suhaibani, 1998; Zornberg, 2002; Consoli et al., 2003; Ibraim and Fourmont, 2006; Diambra et al., 2010).

Consoli et al. (2011) studied the effect of monofilament polypropylene fibres as soil

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reinforcement. From this study, it was observed that for a given fibre content, the unconfined compressive strength (UCS) (q_u) is dependent on both porosity and cement content of the mixture. Increasing porosity results in a reduction in q_u, whereas increasing cement content results in an increase in q_u. Similarly, a different study by Marandi et al. (2008) used natural palm fibres as soil reinforcement at varying amounts relying on fibre lengths tested at 20 mm and 40 mm. The results pointed out that stress–strain behavior was markedly affected by palm fibre inclusion. In specimens without palm fibres, a distinct failure axial stress was accomplished at an axial strain of approximately 1.23%, whereas palm fibre-reinforced specimens exhibited more ductile behavior at a constant palm fibre length (L_f). With an increase in fibre inclusion (W_f), the maximum strength and residual strength increase, while the difference between the two decreases. Furthermore, Puppala and Musenda (2000) statistically analyzed the effectiveness of fibre reinforcement on strength, swell and shrinkage characteristics of expansive clays. The results obtained showed that fibre reinforcement enhances the UCS of the soil and reduces both volumetric shrinkage strain and swell pressure of expansive clays.

It is worth mentioning that previous studies did not reveal a consistent trend with respect to the effect of randomly distributed fibres on the volumetric change of fibre-reinforced sand. Consoli et al. (2009) and Michalowski and Zaho (1996) demonstrated that inclusion of fibres inhibited the dilation of sand in tri-axial tests. Based on plate load test results, Consoli et al. (2003) deduced that fibres suppress the dilation of sand. Consoli et al. (2009 reported that fibre-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 (2006) and Diambra et al. (2010) reported that fibre-reinforced sand exhibited higher dilation tendency compared to unreinforced sand. The influence of fibre reinforcement on shear strength of sand has been examined by various investigators. Several parameters, such as confining stress, fibre type (natural or synthetic), volume fraction, density, length, aspect ratio, modulus of elasticity, orientation and soil characteristics, including particle size, shape and gradation, have been studied using monotonic loading in direct shear tests, consolidated drained tri-axial tests or unconfined compression tests (Shiva Prashanth Kumar and Darga Kumar, 2016).

The review of literature presented in the above section shows that previous studies have dealt with the effects of length and amount of fibre reinforcement on soils. However, not many studies were conducted to study the performance of sandy soils treated with fibre reinforcement. This paper tackles the effect of fibre reinforcement inclusion on engineering properties of beach sand. Brief discussion along with obtained results are furnished in the following sections.

Experimental Program

Materials and Methods

The sand procured in this study was gathered from Manginapudi beach located near Machilipatnam in Andhra Pradesh State, India. Basic properties of selected sand have been evaluated as per respective Indian standard code of practice and are furnished in Table 1. The grain size distribution curve of sand is illustrated in Fig. 1. From this figure, it can be observed that the predominant fractions in soil are fine fractions ranging between 0.425 mm and 0.075 mm. Based on the coefficient of curvature (C_c) and coefficient of uniformity (C_u), the selected sand can be characterized as poorly graded. The maximum dry density (MDD) and the optimum moisture content (OMC) of soil are noted as 16.1 kN/m^3 and 5.4%, respectively. The specific gravity of soil is noted as 2.66.

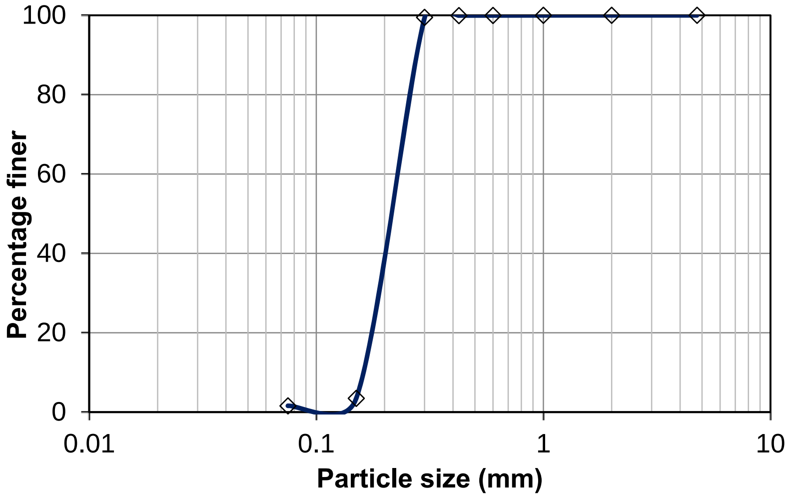

Figure (1): Grain size distribution of sand

Table 1. Engineering properties of sand

Property	
Gravel (%)	0
Coarse sand fractions (%)	0
Medium sand fractions (%)	0.05
Fine sand fractions (%)	98.4
Silt and clay (%)	1.55
Effective grain size, D_{10} (mm)	0.15
Coefficient of uniformity, C_u	1.53
Coefficient of curvature, C_c	0.93
Maximum void ratio, e_{max}	0.73
Minimum void ratio, e_{min}	0.61
Optimum moisture content[£], OMC (%)	5.4
Maximum dry density[£], MDD (kN/m^3)	16.1
Specific gravity, G_s	2.66

[£]Obtained from standard proctor compaction test.

In recent days, varieties of fibres are available in the market for reinforcing soil subgrade. Among the available fibres, recron-3S polyester fibre has been selected because of being well significant in real-time projects, especially in India, as suggested in the literature (Koteswara Rao et al., 2012; Muhammed Nawazish and Praveen, 2015; Nandan A. Patel and Mishra, 2015). The key properties of fibres are presented in Table 2. The pictographic view of fibres is shown in Figure 2. The percentages of fibres used were 0.5, 1, 1.5 and 2.0 % by dry weight of soil from workability perspective relying on earlier studies (Malekzadeh and Bilsel, 2012; Miller and Rifai, 2004; Puppala et al., 2006).

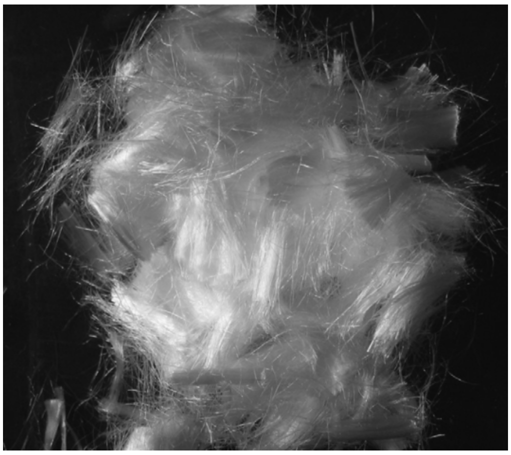

Figure (2): Pictographic view of fibres

Table 2. Physical properties of fibres

Property	Value
Fibre type	Single fibre
Specific gravity (G)	0.91
Length of fibre used (mm)	6
Diameter of fibre used (mm)	0.034
Breaking tensile strength (MPa)	350
Modulus of elasticity (MPa)	3500
Fusion point (°C)	165
Burning point (°C)	590
Acid and alkali resistance	Very good
Dispensability	Excellent

Parametric Study

The specimen is sheared at three normal stresses (σ_n) of 50, 100 and 150 kPa at obtained OMC and MDD. The fibre content (μ) is defined as the ratio between the fibre weight (W_f) and solid particle weight (W_s), as shown in Eq. (1).

$$\mu = \frac{W_f}{W_s} \qquad (1)$$

The void ratio (e) is defined as the ratio between volume of voids (V_v) and volume of solid particles ($V_{s(r)}$). It can be further written as the fibre volume (V_f) as part of the solid particle volume, so that the final equation can be written as:

$$e = \frac{V_v}{V_{s(r)}} = \frac{V_v}{V_{sand} + V_f} \qquad (2)$$

Knowing the fibre content (μ), the specific gravity of sand and fibres, (G_s) and (G_f), respectively, the dry unit weight (γ_d) and the unit weight of water (γ_w), the void ratio is calculated from Eq. (3). The dry unit weight of fibre – reinforced sand can be defined as given in Eq. (4).

$$e = \frac{G_s . G_f . \gamma_w}{G_f + G_s . \mu} \frac{1+\mu}{\gamma_d} - 1 \qquad (3)$$

$$\gamma_d = \frac{W_s + W_f}{V_{sand} + V_f + V_v} = \frac{W_s\,(1+\mu)}{V_{sand} + V_f + V_v} \qquad (4)$$

Similarly, porosity (n) is defined as the ratio between volume of voids (V_v) and the total volume (V). Furthermore, it can be derived from phase relationships as given in Eq. (5).

$$n = \frac{V_v}{V} = \frac{e}{1+e} \qquad (5)$$

Soil – Fibre Interaction

Visual inspections indicate that the increase in fibre content leads to an increase in unitary coherent mixture; hence, the tensile strength between soil particles can be enhanced. Fig. 3 shows the interfacial mechanism between soil particles and fibres. It can be further observed that the composite material is difficult to slip one solid particle over the other. So, finally it can enhance the tensile strength.

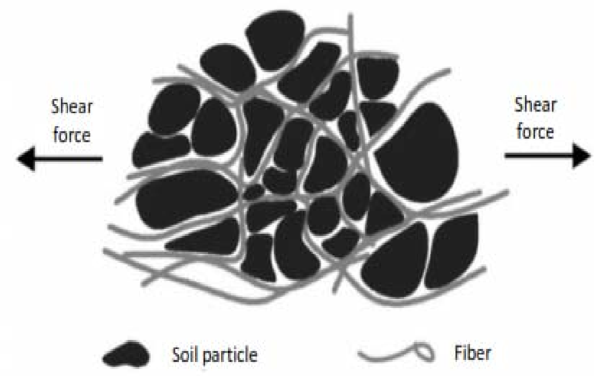

Figure (3): Interfacial mechanism between soil and fibres

Testing Procedures

Grain size distribution was performed as per IS: 2720 (Part 4) – 1985. Standard proctor compaction test was carried out as per IS: 2720 (Part 8)-1983. The determination of shear parameters (i.e., cohesion (c) and angle of internal friction or friction resistance (∅)) was carried out as per IS: 2720 (Part 13) - 1986. The permeability of soil was evaluated as per IS: 2720 (Part 17) – 1986.

RESULTS AND DISCUSSION

In this study, several tests were performed to understand the consequences of fibre content on engineering properties of beach sand. The accomplished study on unreinforced and fibre -reinforced soil enables exploring the shear strength, permeability and volumetric change behaviors of sand in an elaborative way. Moreover, the significance of fibre addition to sand and future applications are highlighted in the following sections.

Effect of Fibres on Compaction Characteristics

The effect of fibre inclusion on compaction characteristics has been studied. Fig. 4 shows compaction curves obtained from standard proctor compaction test for untreated and fibre - treated soils. The variations of OMC and MDD with added percentage of fibres are presented in Fig. 5. Both parameters followed similar trend. It can be noticed that OMC decreases from 5.4% to 3%, whereas MDD decreases from 15.17 kN/m^3 to 16.18 kN/m^3. These variations are due to smaller weight of fibres compared to that of solid particles considered. Similarly, the optimum range of water content decreased, because there is no possibility of water absorption with the available sand particles.

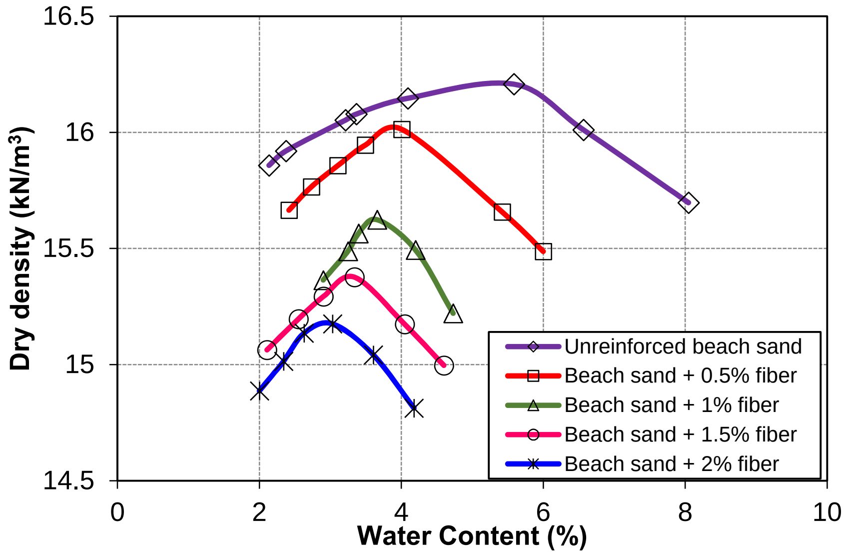

Figure (4): Effect of fibres on proctor compaction curves

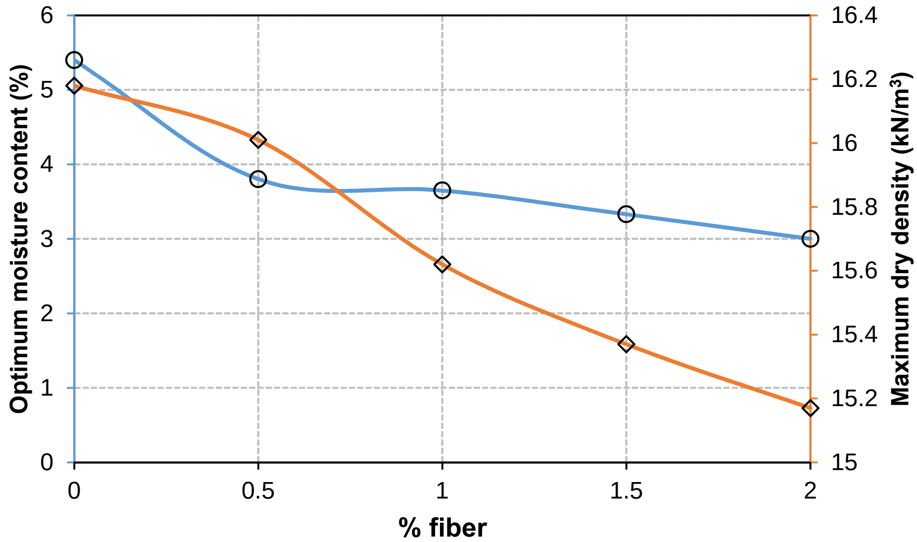

Figure (5): Effect of fibres on OMC and MDD of beach sand

Effect of Fibres on Frictional Resistance and Dilation Angle

Fibre inclusion increases the peak and post-peak shear strengths of sand, although it is not involved in the initial tangent stiffness. There is a threshold value of fibres content of 0.5% above which the post-peak to peak shear strength ratio remains almost unchanged (Eldesoukey, 2013; Shiva Prashanth Kumar and Darga Kumar, 2016). Fig. 6 shows the variations of internal friction (∅) and dilation angle (ψ) with added percentage of fibres. It can be noticed that frictional resistance increased from 33º to 47º with addition of fibre content because of the interface between fibre and soil particles, which results in mobilizing higher friction values (Jiang et al., 2010). Therefore, mixing fibres with sand in the loose state could be a good alternative for compacting unreinforced sand using water from the shear strength perspective.

The dilation angle (ψ), defined as the change in vertical displacement ($\Delta\delta_v$) divided by the change in horizontal displacement ($\Delta\delta_h$), increases with continued shearing until maximum ψ is reached, and then the dilation angle decreases. Similar trend was also observed in this investigation. The maximum ψ increased from 1º to 5.6º with increased fibre contents. However, the introduction of moisture causes the specimens to be less dilative. Increasing the moisture content on the dry side does not affect the volumetric increase. Therefore, moisture inhibits the effect of fibre content on dilation.

Effect of Fibres on Permeability and Porosity

The soil sample was prepared at the obtained OMC and MDD and allowed for full saturation over a period of 24 hours prior to the test. Constant head permeability test procedure was followed to achieve the coefficient of permeability (k) for respective percentages of fibre content. Fig. 7 presents the variations of k and porosity (n) with added fibre content. Both parameters followed a comparable trend. As it can be observed, k increased from 2.0E-03 to 9.8E-03 cm/s, whereas porosity increased from 0.378 to 0.421. This is because of smaller surface area compared to solid particles, whereas there is no potential barrier between the solid particles in the media. Therefore, k values increased respectively. The porosity values are also proportional to the void ratios obtained during experimentation.

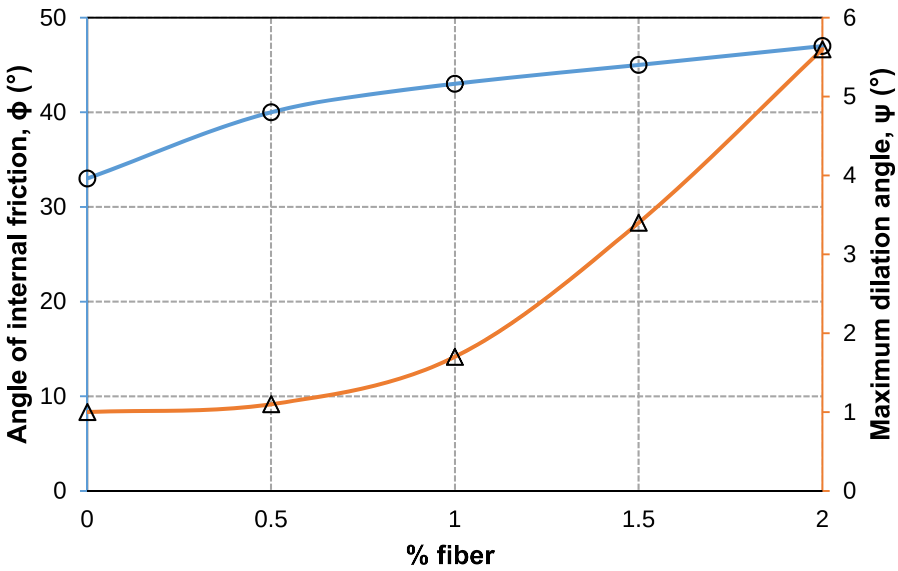

Figure (6): Effect of fibres on frictional resistance and dilation angle

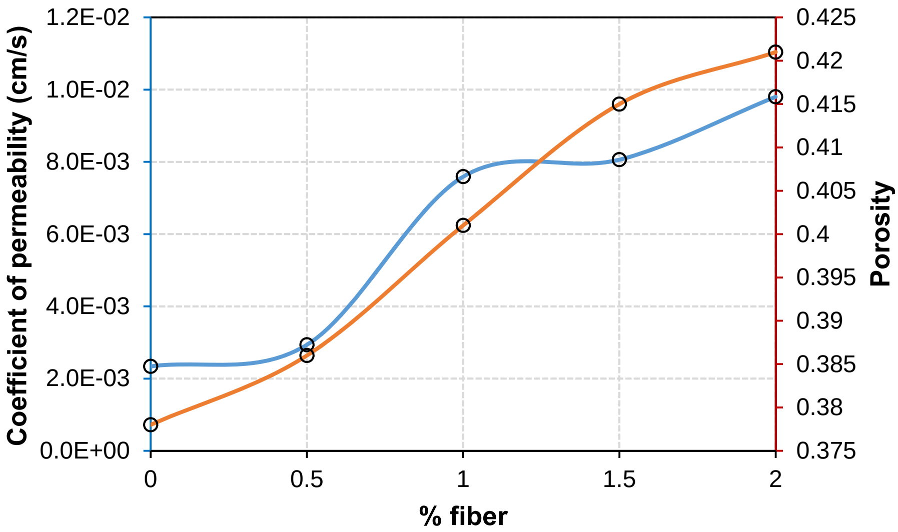

Figure (7): Effect of fibres on permeability and porosity

Best Fit Agreement

The void ratio at the steady state can be calculated by knowing the initial volume and the vertical displacement at the steady state condition. The reinforced specimens, on the other side, show increased volume change at the end of the test; i.e., their post-peak shear strengths are not the steady state or critical state strengths. Figs. 8 and 9 present the best fit line (BFL) agreement between normal stress and void ratio after shear for untreated and treated fibres, respectively.

These figures indicate a universal proportion between the two selected quantities. The relatively higher scatter is attributed to the few data points used to establish the correlation and the approximation in determining the value of the post-peak shear strength, which is not exactly equal to the steady state strength of fibre-reinforced sand.

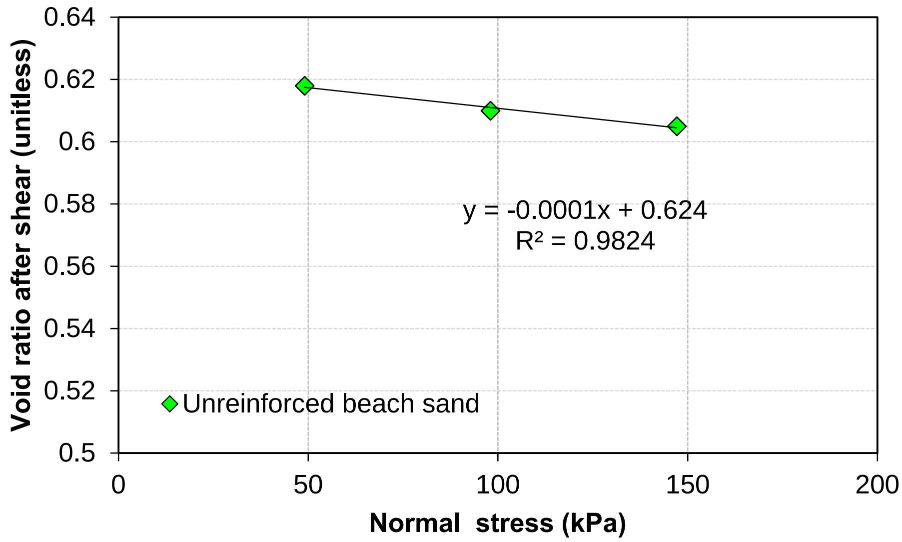

Figure (8): Best fit line (BFL) of unreinforced beach sand

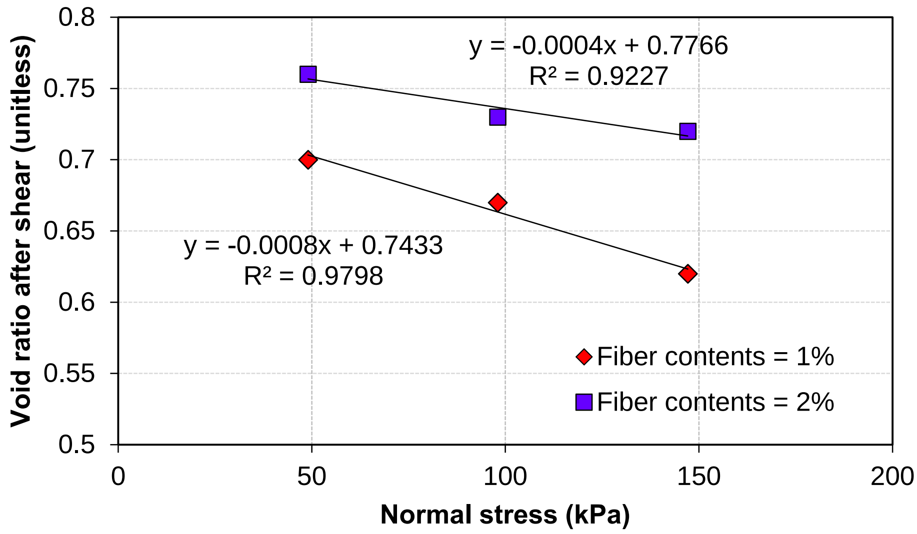

Figure (9): Best fit line (BFL) of dry 1%- and 2%- reinforced beach sand

CONCLUSIONS

Various tests are conducted on unreinforced and fibre-reinforced soil samples prepared at different test conditions. The main conclusions of the study are summarized in the following points:

- The optimum moisture content and maximum dry density decreased with added percentage of fibre content.
- Frictional resistance increased with addition of fibre content, because of the interface between fibre and soil particles, which results in mobilizing higher friction values.
- The maximum dilation angle increased with addition of fibre content. However, the introduction of moisture causes the specimens to be less dilative.
- Permeability and porosity values increased with addition of fibre content because of no potential barrier between the solid particles in the media.

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