*Jordan Journal of Civil Engineering,* Volume **15**, No. **4, 2021**

# Improvement of Sandy Soil Using Materials of Sustainable Consideration

***Athraa Mohammed Jawad Alhassani*** [1)*]

[1)] Engineering Faculty, University of Kufa, Najaf, Iraq.
* Corresponding Author. E-Mail: athraam.alhasani@uokufa.edu.iq

## ABSTRACT

The aim of this study is to examine the possibility of enhancing the mechanical characteristics of sandy soil by using environmentally friendly materials, such as cement kiln dust (CKD) and natural palm fibers. Different percentages of palm fibers of 0%, 0.5%, 1% and 1.5% (dry wt.) with a 12-mm length and an aspect ratio of 31.57 were utilized to reinforce plain soil and soil treated with 5% (dry wt.) of CKD. All investigated combinations underwent direct shear and CBR testing. Findings show that adding fiber to the soil improves the shear strength considerably up to a fiber content of around 1%, after which the rate of improvement diminishes. In comparison, palm fiber addition to CKD-treated soil significantly reduced shear strength. Additionally, the findings indicated that palm fibers improved the ductility of the soil and CKD-treated soil. CBR tests revealed that palm fiber improved the CBR value of reinforced soil up to a content of around 1%, beyond which it decreased. Adding palm fiber to CKD-treated soil reduced the CBR value almost at the same rate. The CBR test findings indicate a similar pattern for soaked and unsoaked samples.

**KEYWORDS:** Cement kiln dust (CKD), Palm fibers, Direct shear test, CBR test.

## INTRODUCTION

Today, there is a world-wide interest in sustainable considerations, which attracted researchers to create alternative materials that fulfill design criteria. Soil stabilization is often used to enhance soil properties by adding cementitious agents (e.g. cement, lime, gypsum, … etc.) (Akpokodje, 1985; Miura et al., 2001; Prusinski and Bhattacharja, 1999; Khan et al., 2018). Despite the fact that conventional binders may improve soil behavior, they cause a number of environmental drawbacks, such as carbonate decomposition. Cement produces approximately 7% of $CO_2$ emissions (Gartner, 2004; Matthews et al., 2009; Miller et al., 2018). It is recorded that each ton of cement is anticipated to emit approximately 5/4 tons of carbon dioxide, which is a major greenhouse gas and one of the primary causes of global warming (Kim and Worrell, 2002; Lothenbach et al., 2011; Worrell et al., 2001). Therefore, the development of low-carbon alternative binders that can compete with conventional binders seems to be a priority.

Using industrial by-products as soil stabilizers helps make projects more sustainable and inexpensive (Shafabakhsh and Sajed, 2014). CKD is a by-product material that accumulates in large quantities throughout the globe, causing a significant economic and environmental issue (Ismail and Belal, 2016). In Iraq, there are about 15 cement factories that manufacture approximately two million tons of Portland cement and generate over three thousand million tons of CKD each year (Mosa et al., 2017). The hydration products and chemical processes in CKD are comparable to those seen in cement (Peethamparan et al., 2008). Therefore, the use of CKD as a cement replacement for larger urban or national projects is a feasible alternative.

The behavior of artificially cemented sandy soils, which are often employed to enhance the mechanical characteristics of the soil, has been extensively studied in the literature. These studies discovered that increasing the cement content enhances the shear strength of cemented soils, potentially resulting in brittle behavior without plastic deformation. The brittle propensity,

Received on 15/7/2021.
Accepted for Publication on 7/9/2021.

however, may be minimized or controlled by introducing random dispersed discrete fibers to cemented sand. Additionally, when fibers are combined with granular soil, it has been found that shear strength increases and post-peak strength loss declines (Consoli et al., 2002; Consoli et al., 2009; Noorzad and Zarinkolaei, 2015).

Numerous investigations on the behavior of fiber-reinforced sand have shown that adding fibers improves maximum shear strength and makes the material more ductile (Consoli et al., 2007; Shukla et al., 2009; Ibrahim et al., 2012; Jamei et al., 2013; Botero et al., 2015; Anvari et al., 2017; Choobbasti and Kutanaei, 2017a). Yaghoubi et al. (2018) examined the combined effect of cement and waste tire fibers on mechanical soil characteristics by using unconfined compression tests. It was found that the addition of 3% waste tire fiber to cemented sand improved the unconfined compression strength by 25%. Shen et al. (2021) investigated the strength characteristics of polyester fiber-reinforced soil stabilized with lime or cement. At a specific fiber content, it was shown that fiber reinforcing of lime or cement-treated soil increased the strength and strength characteristics significantly. Additionally, it was revealed that the specimen with a greater fiber content had a higher stress-strain curve than the specimen with a lower fiber content and the fiber-reinforced plain soil demonstrated a ductile failure mode in comparison to the specimens treated with lime or cement.

Many researchers have investigated natural fiber-reinforced soils, owing to the widespread availability of natural fibers and their environmental advantages over synthetic fibers. Palm fiber is a kind of natural fiber characterized by its filament design and distinctive characteristics, which include low cost, light weight, regional abundance, durability and relative strength degradation (Ahmad et al., 2010; Mittal 2021; Mittal and Shukla, 2020). Marandi et al. (2008) performed UCS, CBR and compaction tests on soil samples with and without palm fibers. It was found that increasing fiber content (from 0% to 1%) improved maximum and residual strengths, while decreasing the variance between them for a certain palm fiber length. Ahmad et al. (2010) investigated the effect of palm fibers on the shear strength of silty sand soil by performing triaxial compression tests on samples containing palm fibers of various lengths. Compared to unreinforced silty sand, reinforced silty sand with 0.5 percent-coated fibers 30 mm in length improved friction angle by 25% and cohesion by 35%.

Due to the lack of information about the influence of palm fiber on CKD-treated soil, this study seeks to evaluate the combined effect of palm fiber and CKD on sand mechanical properties. For this purpose, direct shear and CBR tests were conducted on plain soil, soil treated with CKD, reinforced plain soil and reinforced CKD-treated soil.

**Testing Program**

Twenty-four direct shear tests and sixteen CBR tests were performed on samples of unreinforced plain soil (UPS), unreinforced (CKD-treated soil) (UDTS), reinforced plain soil (RPS) and reinforced CKD-treated soil (RDTS) to assess the effect of palm fiber inclusion on soil behavior and (CKD-treated soil). The tested samples were symbolized as shown in Table 1. Different percentages of the content of palm fibers of 0%, 0.5%, 1% and 1.5% (dry wt.) of soil or (soil+CKD) were added. To produce the CKD-treated soil samples, CKD content of 5% by dry soil weight was added. This proportion was found to be the most effective one for improving the behavior of treated sandy soil (Kadhim et al., 1994). CBR values were obtained for soaked and unsoaked samples of each examined combination.

**Materials**

**Used Soil**

The used soil is clean and uniform quartz river sand with basic engineering properties listed in Table 2. Figure 1 depicts the gradation of the soil which is categorized as SP by the USCS.

**Table 1. Symbolization of tested samples**

| Symbol | Description |
|---|---|
| UPS | Unreinforced Plain Soil |
| UDTS | Unreinforced Dust-Treated Soil |
| RPS | Reinforced Plain Soil |
| RDTS | Reinforced Dust-Treated Soil |

**Table 2. Basic engineering properties**

| Characteristics | Value |
|---|---|
| Specific gravity, ($G_s$) (ASTM D854) | 2.67 |
| $D_{10}$ | 0.09 |
| $D_{30}$ | 0.17 |
| $D_{60}$ | 0.22 |
| $C_u$ | 2.44 |
| $C_c$ | 1.46 |
| Soil classification (ASTM D2487) | SP |
| Max. $\gamma_{dry}$ (MDD) kN/m$^3$ (ASTM D698) | 17.66 |
| Optimum moisture content (%) | 12 |

**Cement Kiln Dust (CKD)**

Al-Kufa cement factory in Kufa, Iraq supplied the CKD for this research. Figure 1 shows the gradation of CKD. The physical characteristics and the chemical analysis of the dust are illustrated in Table 3.

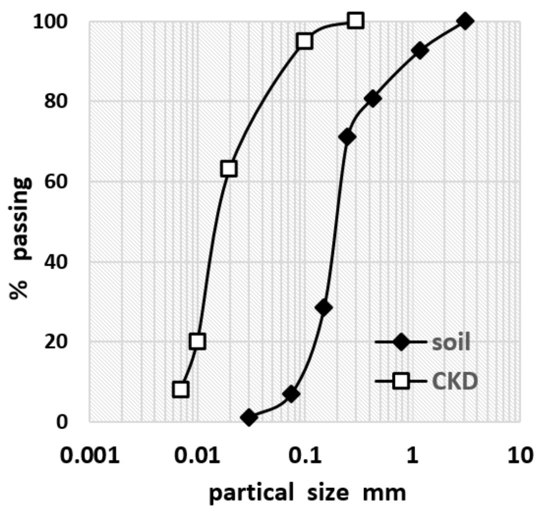



**Figure (1): Gradation curve of the used soil and CKD**

**Palm Fibers**

Palm fiber is a raw mesh that surrounds the stems of date palm trees, as shown in Figure 2. The fibers were manually removed from the mesh, cleaned and lengthened. The palm fibers utilized in this research were 12 mm long and had a 31.57 aspect ratio. The water absorption ability of the fibers was estimated by drenching the fiber specimens in water and weighing them every two hours until the rate of absorption became nearly consistent. Figure 3 shows maximal water absorption of 240 percent after 28 hours of immersion. A tensile strength test was conducted to determine the fiber strength properties. The highest tensile strength of 57.81 MPa was obtained at a 10% strain.

**Table 3. Physical properties and chemical analysis of the CKD**

| **Physical properties** | |
|---|---|
| Color | Light brown |
| Specific gravity | 2.85 |
| **Chemical Analysis (% by weight)** | |
| $SiO_2$ | 14.1 |
| $Al_2O_3$ | 4.7 |
| $Al_2O_3$ | 4.7 |
| $Fe_2O_3$ | 1.97 |
| CaO | 40.17 |
| MgO | 2.79 |
| $SO_3$ | 5.85 |
| $K_2O$ | 3.13 |
| $Na_2O$ | 1.55 |
| Cl | 1.83 |
| (L.O.I) | 24.25 |

**Figure (2): Palm fiber used in this study**

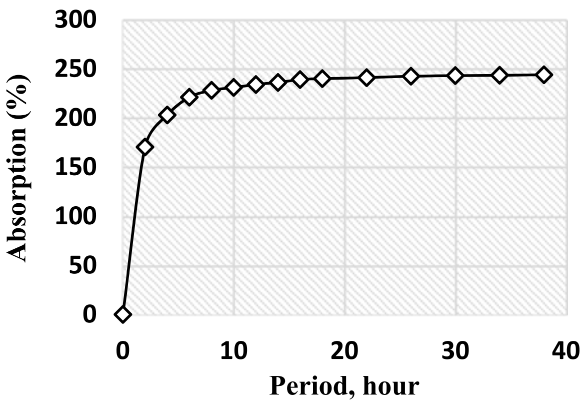



**Figure (3): Water absorption *vs.* period relationship**

**Sample Preparation and Testing Methods**

Four groups of samples were prepared: UPS, UDTS, RPS and RDTS. All prepared samples were compacted to MDD (max. dry density) and at OMC (optimum moisture content), which were previously determined using the standard Proctor test. To prepare UDTS samples, the required amount of oven-dried soil corresponding to the MDD and the required amount of CKD representing 5% of the dry soil weight were initially mixed, after which the required quantity of water corresponding to the OMC was added and well-mixed. To produce samples of RPS or RDTS, the predetermined quantity of water is first added to the soil or (soil-CKD) mixture and well mixed (from trial tests, it was found that adding the water prior to adding the fibers was critical in preventing the fibers from floating). The necessary quantity of fibers is next added, which is 0.5, 1 or 1.5% by dry weight of soil or (soil-CKD) mixture.

For direct-shear testing, samples of cross-section of 60 mm × 60 mm and of 20 mm height were produced. Three specimens were prepared for each direct-shear test and loaded at a rate of (1 mm/minute) under normal loads of 100, 200 and 400 kPa. Static compaction was used to prepare the samples to the desired dry density. The prepared CBR samples were 150 mm in diameter and 175 mm in height. CBR tests were performed on samples that had been soaked and those that had not been soaked. The prepared samples for direct shear and CBR tests that included CKD were packed in plastic bags and stored in a humidity room at a temperature in the range of 25°C for 7 days before testing.

**Discussion of Results and Conclusions**

**Characteristics of Compaction**

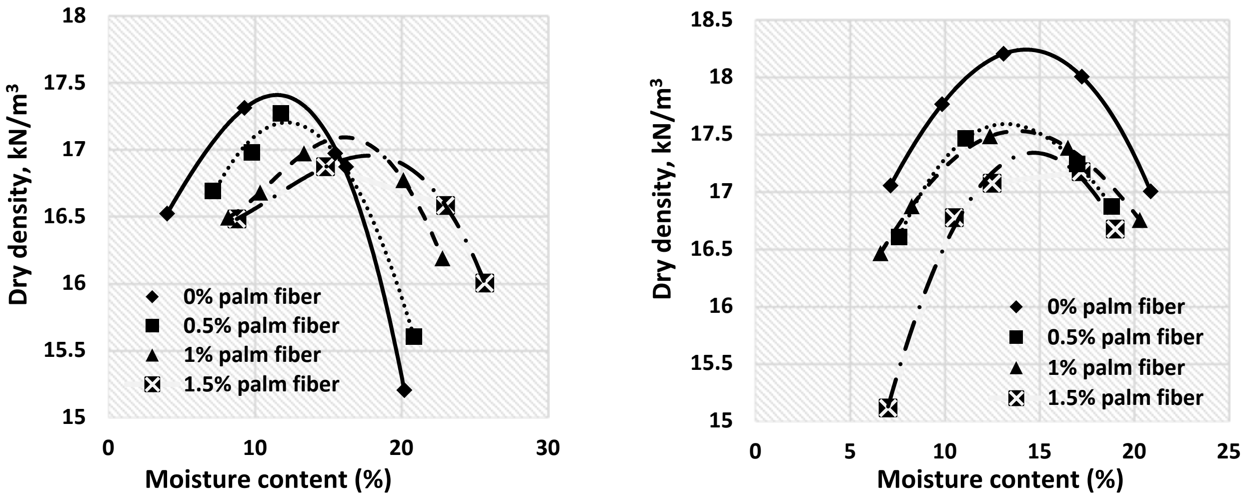
The effect of palm fibers on the compaction characteristics of plain soil and soil treated with CKD was investigated using "standard Proctor compaction test". Figure 4 (a-b) displays the outcomes of compaction tests for soil and (CKD-treated soil) reinforced by 0%, 0.5%, 1% and 1.5% palm fiber content. It is found that the OMC and MDD of UPS are 12% and 17.66 kN/m$^3$, whereas those of UDTS are 13.5% and 18.25 kN/m$^3$, respectively. By comparing these findings, it is clear that UDTS has a greater MDD and OMC than UPS. The increase in MDD is due to the CKD particles filling the empty spaces and therefore better packing together up to a certain CKD content, in addition to the fact that the CKD solid particles have a greater specific gravity than the replacement soil. The increase in OMC associated with CKD-treated soil is owing to the CaO contained in CKD having a high affinity for water.

MDD values as a function of palm fiber content are shown in Figure 5. From this figure, it is concluded that the MDD of RPS and RDTS declined considerably as the palm fiber percentage increased. The reduction in MDD is because of the substitution of light palm fibers with heavy soil particles or (soil-CKD) mixtures. Figure 6 shows the influence of palm fiber inclusion on the OMC value. In general, it is clarified that with a larger content of palm fiber, OMC for both RPS and RDTS increases. This increase may be attributed to the high water soaking up ability of the palm fibers.

**Direct-Shear Test Parameters**

Figures 7 and 8 show the distribution of shear stress and shear strain for plain soil and CKD-treated soil, respectively, reinforced with different percentages of palm fibers of 0%, 0.5%, 1% and 1.5%, obtained *via* direct shear test at 400 kPa normal pressure. Other normal pressures (i.e., 100 and 200 kPa) showed similar patterns, but for the sake of brevity, they were not shown here. According to Figure 7, plain soil behavior is significantly affected by palm fiber reinforcement. It is obvious that as the palm fiber increases, the shear strength improves up to a palm fiber content of around 1% beyond which it decreases. Furthermore, the strain associated with the peak shear stress is increased by increasing the palm fiber content. The physical contact of soil particles and fibers may be ascribed to this, which increases soil strength and improves its mechanical behaviour. It is a recognized fact in the literature that when fibers are introduced to soil, shear stress between the soil grains is transferred to the fibers in the form of tensile strength. As a consequence, soil behavior changes from brittle to ductile and the soil matrix strength improves (Tang et al., 2007; Cristelo et al., 2012; Consoli et al., 2013; Botero et al., 2015; Anggraini et al., 2017).

Adding the palm fiber to CKD-treated soil reduced the shear strength, as shown in Figure 8. This may be due to a cohesion deficiency that occurred in the soil-CKD mixture because of the existence of palm fiber. Additionally, because of the palm fiber's high water absorption capacity, the hydration process of the CKD material may be incomplete. However, as shown in Figure 8, even though adding palm fibers to the CKD-treated soil reduced its shear strength, the palm fiber content appreciably increased the peak shear stress strain.




a. RPS b. RDTS

**Figure (4): Dry density *vs.* percentage moisture content relationship for different palm fiber contents**

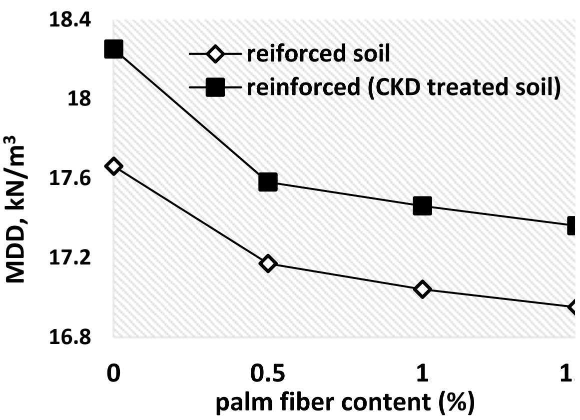



**Figure (5): Effect of palm fiber content on MDD**

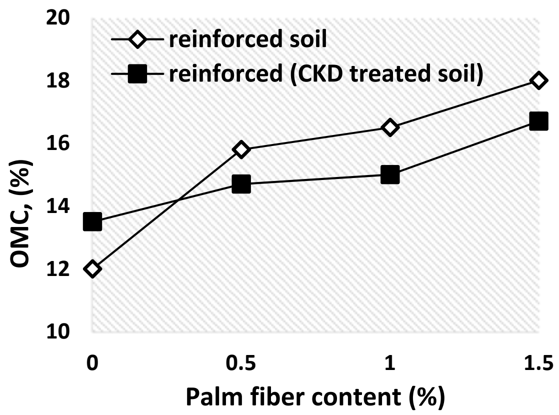



**Figure (6): Effect of palm fiber content on OMC**

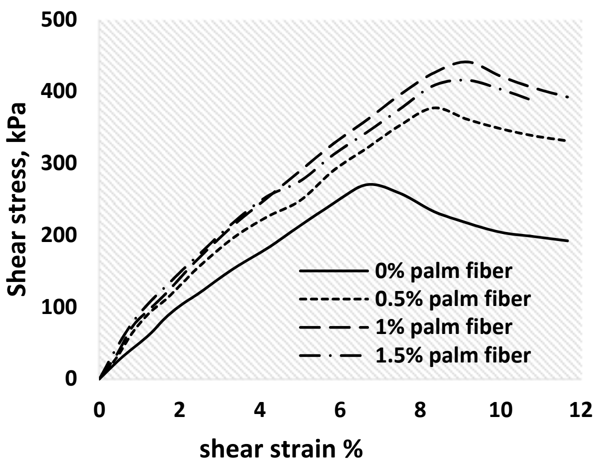



Figure (7): Shear stress *vs.* shear strain relationship for RPS with different fiber contents

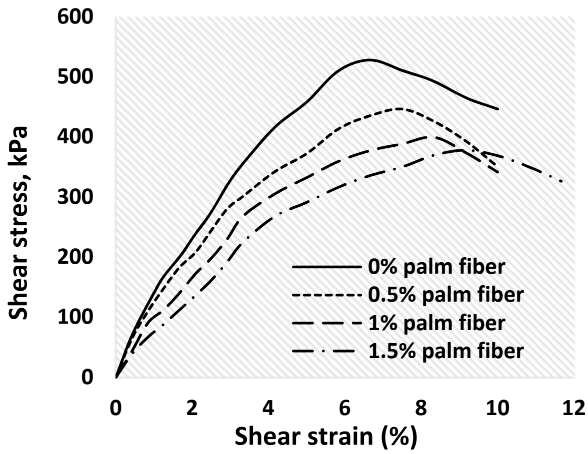



Figure (8): Shear stress *vs.* shear strain relationship for RDTS with different fiber contents

**Failure Envelope and Shear Strength Parameters**

The Mohr-Coulomb failure envelopes (M-C) of soil and CKD-treated soil reinforced with palm fibers are shown in Figures 9 and 10.

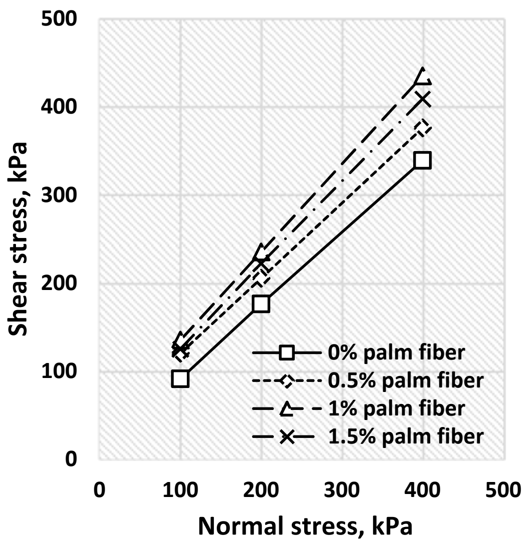



Figure (9): M-C failure envelopes for RPS with different palm fiber contents

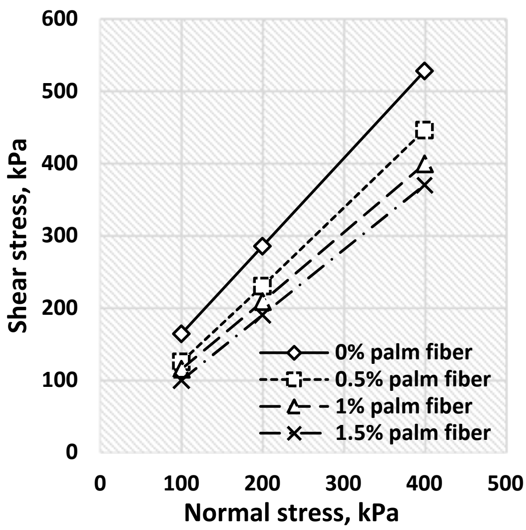



Figure (10): M-C failure envelopes for RDTS with different palm fiber contents

Figures 11 and 12 demonstrate how palm fiber content affects the angle of friction and cohesion intercept, respectively. As shown in Figure 11, the angle of friction of RPS increases until reaching a certain fiber content at which it drops. For example, when palm fiber content is 0.5%, 1% and 1.5%, the relative improvement in internal friction angle is 16%, 30% and 23.7%, respectively. This observation may be explained by the interaction between fibers and soil. Additionally, as shown in Figure 11, the relative improvement in the angle of friction of RDTS is extremely small, increasing by 1%, 2.4 % and 3.45% for palm fiber content of 0.5%, 1% and 1.5%, respectively. Figure 12 shows that the proportion of palm fibers in the reinforced plain soil and CKD-treated soil has a substantial effect on the cohesion intercept. This figure shows that the cohesion of the reinforced soil improved up to a fiber content of around 1%. Following that, the pace of increase was reduced. While the addition of palm fibers decreased the cohesion intercept of the CKD-treated soil, this reduction was found to be proportionate to the fiber content.

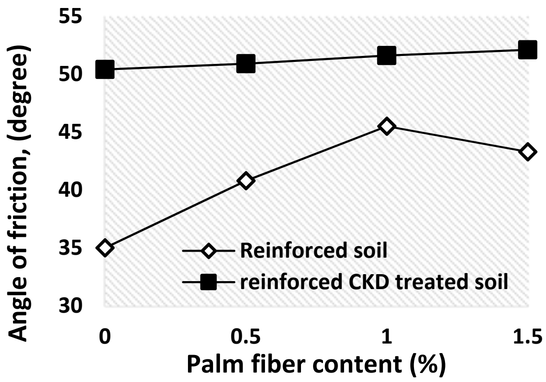



**Figure (11): Variation of angle of friction *vs.* palm fiber content**

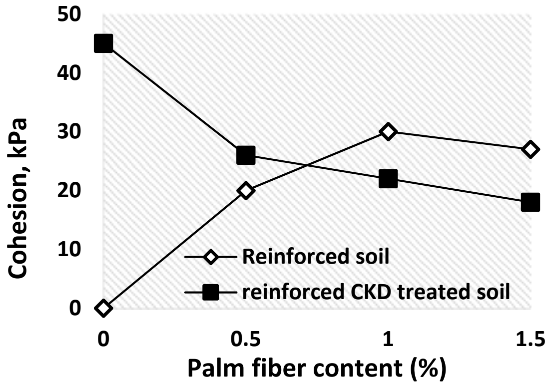
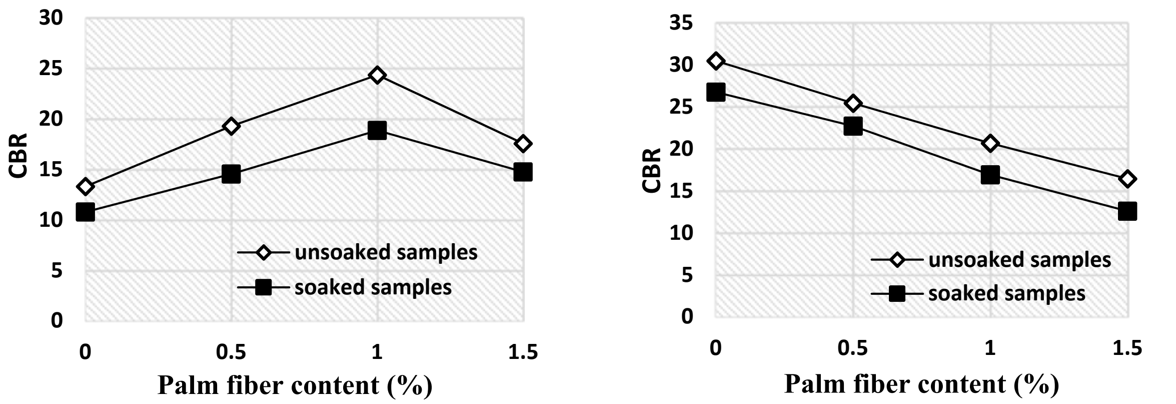



**Figure (12): Variation of cohesion *vs.* palm fiber content**

**CBR Test**

The results of CBR test performed on plain soil and CKD-treated soil reinforced with different palm fiber contents of 0%, 0.50%, 1% and 1.50%, for both unsoaked and soaked samples, are shown in Figure 13 (a-b). As shown in Figure 13-a, palm fibers significantly increase the CBR values of unsoaked and soaked samples. It is found that adding (0.5–1%) palm fibers to plain soil improves CBR strength by (37-60 percent) and (34.8-55.6 percent) for unsoaked and soaked samples, respectively. However, when fiber content is increased to 1.5%, the rate of CBR strength enhancement falls to 32% and 36.8% for unsoaked and soaked samples, respectively. This may lead to infer that having more fibers in the soil than necessary for optimum reinforcing results in the replacement of soil particles with weaker materials, decreasing the bearing strength of the soil.

The results showed a distinct pattern when palm fibers were added to the CKD-treated soil, as shown in Figure 13-b. Adding palm fibers to the CKD-treated soil significantly decreased the CBR value. This reduction was found to be proportional to the fiber content. For unsoaked samples, increasing palm fiber content by 0.5%, 1% and 1.5% decreased the CBR value by 16.48%, 32.1% and 46%, respectively, while adding palm fiber contents of 0.5%, 1% and 1.5% reduced the CBR value by 15.1%, 36.7% and 52.9% for soaked samples.




**a. RPS samples** **b. RDTS samples**

**Figure (13): Variation of CBR ratio with palm fiber content for soaked and unsoaked samples**

## CONCLUSIONS

In light of the results of the tests that were performed, it is possible to make the following conclusions:

1. Reinforcing plain soil and CKD-treated soil with palm fibers reduced MDD considerably.
2. As the palm fiber content increases, the OMC of RPS and RDTS also increases.
3. The addition of palm fiber improved the shear strength of the soil up to a palm fiber content of around 1%, after which it decreased significantly, while the inclusion of palm fiber significantly reduced the shear strength of soil treated with CKD.
4. The strain associated with the peak shear stress increases by increasing the palm fiber content. This finding is recorded for RPS and RDTS.
5. The angle of friction of the RPS improves up to a certain fiber content, after which it decreases.
6. The cohesion of RPS increased up to a fiber content of around 1%. After that, the rate of the increment decreased. The palm fiber inclusion reduced the cohesion intercept of the RDTS and this reduction was found to be proportional to the fiber content.
7. It is found that reinforcing plain soil with (0.5–1%) palm fibers for both unsoaked and soaked samples improves CBR strength, while adding palm fibers to the CKD-treated soil significantly reduced the CBR value.

## REFERENCES

Ahmad, F., Bateni, F., and Azmi, M. (2010). “Performance evaluation of silty sand reinforced with fibers”. Geotextiles and Geomembranes, 28 (1), 93-99. doi:10.1016/j.geotexmem.2009.09.017.

Akpokodje, E.G. (1985). “The stabilization of some arid zone soils with cement and lime”. Quarterly Journal of Engineering Geology, and Hydrogeology, 18 (2), 173-180.doi:10.1144/GSL.QJEG.1985.018.02.06

Anggraini, V., Asadi, A., Syamsir, A., and Huat, B. K. (2017). “Three-point bending flexural strength of cement-treated tropical marine soil reinforced by lime-treated natural fiber”. Measurement, 111, 158-166. doi:10.1016/j.measurement.2017.07.045.

Anvari, S.M., Shooshpasha, I., and Kutanaei, S.S. (2017). “Effect of granulated rubber on shear strength of fine-grained sand”. Journal of Rock Mechanics and Geotechnical Engineering, 9 (5), 936-944. doi:10.1016/j.jrmge.2017.03.008.

Botero, E., Ossa, A., Sherwell, G., and Ovando-Shelley, E. (2015). “Stress-strain behavior of a silty soil reinforced with polyethylene terephthalate (PET)”. Journal of Geotextiles and Geomembranes, 43 (4), 363-369. doi:10.1016/j.geotexmem.2015.04.003.

Choobbasti, A., and Kutanaei, S. S. (2017a). “Effect of fiber reinforcement on deformability properties of cemented sand”. Journal of Adhesion Science and Technology, 31, 1576-1590. doi.org/10.1080/01694243.2016. 1264681.

Consoli, N.C., Casagrande, M.D.T., and Coop, M.R. (2007). “Performance of a fibre-reinforced sand at large shear strains”. J. Geotechnique, 57 (9), 751-756. doi:10.1680/geot.2007.57.9.751.

Consoli, N.C., Rizzatti de Moraes, R., and Festugato, L. (2013). “Variables controlling strength of fibre-reinforced cemented soils”. Proceedings of the Institution of Civil Engineers-Ground Improvement, 166 (4), 221-232. doi:10.1680/grim.12.00004.

Consoli, N.C., Rotta, G.V., and Prietto, P.D.M. (2000). “Influence of curing under stress on the triaxial response of cemented soils”. J. Géotechnique, 50 (1), 99-105. doi.org/10.1680/geot.52.5.382.38705.

Consoli, N.C., Vendruscolo, M.A., Fonini, A., and Rosa, F.D. (2009). “Fiber reinforcement effects on sand considering a wide cementation range”. J. Geotextiles and Geomembranes, 27 (3), 196-203. doi.org/10.1016/j.geotexmem.2008.11.005.

Cristelo, N., Glendinning, S., Fernandes, L., and Pinto, A.T. (2012). “Effect of calcium content on soil stabilization with alkaline activation”. J. Construction and Building Materials, 29, 167-174. doi:10.1016/j.conbuildmat.2011.10.049.

Gartner, E. (2004). "Industrially Interesting Approaches to "Low-$Co_2$" Cements". J. Cement and Concrete Research, 34 (9), 1489-1498. doi:10.1016/ j.cemconres.2004.01.021.

Ibrahim, E., Diambra, A., Russell, A.R., and Muir Wood, D. (2012). "Assessment of laboratory sample preparation for fiber reinforced sands". Canadian Geotechnical Journal, 34, 69-79. doi:10.1016/ j.geotexmem.2012.03.002

Ismail, A.I.M., and Belal, Z.L. (2016). "Use of cement kiln dust on the engineering modification of soil materials, Nile delta, Egypt". J. Geotech. Geol. Eng., 34, 463-469. doi.org/10.1007/s10706-015-9957-6.

Jamei, M., Villard, P., and Guiras, H. (2013). "Shear failure criterion based on experimental and modeling results for fiber-reinforced clay". International Journal of Geomechanics, 13 (6), 882-893. doi:10.1061/ (ASCE)GM.1943-5622.0000258.

Kadhim, S.M., Alhassani, A.M.J., and Fattah, A. (1994). "Effect of cement dust content on soil properties of river sand soil". Journal of Al-Buhooth Al-Tachaniya, 7 (20), 28-49.

Khan, A., Adil, M., Ahmad, A., Hussain, R., and Zaman, H. (2018). "Stabilization of soil using cement and bale straw". J. Development, 5 (9), 44-49.

Kim, Y., and Worrell, E. (2002). "$CO_2$ emission trends in the cement industry: An international comparison". J. Mitigation and Adaptation Strategies for Global Change, 7 (2), 115-133. doi:10.1023/A: 1022857829028.

Lothenbach, B., Scrivener, K., and Hooton, R.D. (2011). "Supplementary cementitious materials". J. Cement and Concrete Research, 41 (12), 1244-1256. doi:10.1016/j.cemconres.2010.12.001.

Marandi, M., Bagheripour, H., Rahgozar R., and Zare, H. (2008). "Strength and ductility of randomly distributed palm fiber-reinforced silty-sand soils". American Journal of Applied Sciences, 5 (3), 209-220. doi.org/10.3844/ajassp.2008.209.220.

Matthews, H.D., Gillett, N.P., Stott, P.A., and Zickfeld, K. (2009). "The proportionality of global warming to cumulative carbon emissions". J. Nature, 459 (7248), 829-832. doi:10.1038/nature08047.

Miller, S.A., John, V.M., Pacca, S.A., and Horvath, A. (2018). "Carbon dioxide reduction potential in the global cement industry by 2050". J. Cement and Concrete Research, 114, 115-124. doi:10.1016/j. cemconres.2017.08.026.

Mittal, A. (2021). "Effect of rice husk ash and stone dust on selecting engineering properties of poor subgrade soil". Jordan Journal of Civil Engineering, 15 (1), 133-141.

Mittal, A., and Shukla, S., (2020). "Effect of random inclusion of kenaf fibers on strength behaviour of poor subgrade soils". Jordan Journal of Civil Engineering, 14 (1), 43-56.

Miura, N., Horpibulsuk, S., and Nagaraj, T.S. (2001). "Engineering behavior of cement-stabilized clay at high water content". J. Soils and Foundations, 41 (5), 33-45. doi:10.3208/sandf.41.5_33.

Mosa, A.M., Taher, A.H., and Al-Jaberi, L.A. (2017). "Improvement of poor subgrade soils using cement kiln dust". J. Case Studies in Construction Materials, 7, 138-143. doi.org/10.22214/ijraset.2019.4422.

Noorzad, R. and Zarinkolaei, S.T. (2015). "Comparison of mechanical properties of fiber-reinforced sand under triaxial compression and direct shear". J. Open Geosciences, 7, (1), 547–558. doi.org/10.1515/geo-2015-0041.

Peethamparan, S., Olek, J., and Lovell, J. (2008). "Influence of chemical and physical characteristics of cement kiln dusts (CKDs) on their hydration behavior and potential suitability for soil stabilization". J. Cem. Concr. Res., 38, 803-815. doi.org/10.1016/j.cemconres. 2008.01.011.

Prusinski, J., and Bhattacharja, S. (1999). "Effectiveness of portland cement and lime in stabilizing clay soils". Transportation Research Record, Journal of the Transportation Research Board, 1652, 215-227. doi:10.3141/1652-28.

Shafabakhsh, G.H., and Sajed, Y. (2014). "Investigation of dynamic behavior of hot mix asphalt containing waste materials, case study: Glass cullet". J. Constr. Mater., 1, 96-103. doi.org/10.1016/j.cscm.2014.05.002.

Shen, Y.-S., Tang, Y., Yin, J., Li, M.-P., and Wen, T. (2021). "An experimental investigation on strength characteristics of fiber-reinforced clayey soil treated with lime or cement". J. Construction and Building Materials, 294, 8. https://doi.org/10.1016/j. conbuildmat.2021.123537.

Shukla, S., Sivakugan, N., and Das, B. (2009). “Fundamental concepts of soil reinforcement: An overview”. International Journal of Geotechnical Engineering, 33, 329-342. doi:10.3328/IJGE.2009.03.03.329-342.

Worrell, E., Price, L., Martin, N., Hendriks, C., and Media, L. O. (2001). “Carbon dioxide emissions from the global cement industry”. J. Annual Review of Energy and the Environment, 26 (1), 303-329. doi:10.1146/annurev.energy.26.1.303.

Yaghoubi, M., Shukla, S.K., and Mohyeddin, A. (2018). “Effects of addition of waste tire fibers and cement on the engineering behavior of Perth sand”. J. Geomechanics and Geoengineering, 13 (1), 42-53. doi:10.1080/ 17486025.2017.1325941.