Assessment of strength development of cemented desert soil

Talal S. Amhadi[1,*] and Gabriel J. Assaf[1]
[1] *Department of Civil Engineering and Construction, École de Technologie Supérieure, University of Québec, 1100 Rue Notre-Dame Ouest, Montréal, QC H3C, Canada*

Abstract

For highway construction or any superstructure, on dune sand, designers and construction teams must ensure that the foundation soil is stable enough to provide support for the applied loads. Sand dunes are stretched across Libyan deserts that make road construction a challenge because of the poor soil base. Replacement of such a weak soil is very expensive and not economically feasible, and, in many cases, there is no alternative soil nearby. This study used two different mix designs aimed at stabilizing the existing base course using a mix of dune sand and manufactured sand with a small percentage of Portland cement. Compaction, unconfined compressive strength and California bearing ratio tests were conducted on the treated sample with a varying cement proportion of 0%, 3%, 5% and 7% by weight. The first tests were done with a mix of 50% dune sand and 50% crushed sand that is shown to have excellent results. For a more economic design, this study also included testing of another mix design with 70% dune sand and 30% crushed sand; laboratory results show this 70%/30% mixture was appropriate to use as a base-treated material for road construction material. This mix resulted in overall superior performance. Its use will reduce the cost of road construction by saving materials and time, and it will also have lower environmental impacts in desert areas. This study has shown that the stabilization of weak material (desert sand) by using cement improves the strength characteristics of the treated soil.

Keywords: desert sand; base course; cement; soil stabilization; California bearing ratio; unconfined compressive strength

*Corresponding author:
talal.amhadi.1@ens.etsmtl.ca

Received 19 May 2019; revised 5 June 2019; editorial decision 3 July 2019; accepted 3 July 2019

1. INTRODUCTION AND BACKGROUND

In the southern region of Libya, the presence of abundant silica sand can be used as a local material in the construction of roads. This will help in preserving regional resources and avoids excessive pollution, helping vilify the impact on the environment due to transported materials. When the available soil is very weak, the stabilization process of soil depends on increasing the engineering characteristic of the soil and making it stable. This process reduces the compressibility and permeability of the targeted mass of the soil, thereby increasing its strength, bearing capacity, durability and to reduce the cost of construction by using the local available materials [1, 2].

Using cement as a binding agent to stabilize soils is common road pavement construction. Up to 2% cement added to soil modifies soil properties. Quantities greater than this can result in substantial property changes [3]. Soils with >2% organic materials do not respond well to stabilization with cement due to the hydration effects introduced by the organic materials; this hydration may adversely affect the strength of the resulting soil [4]. The resulting characteristics of these cement-stabilized sands can be described as having properties of both rock and soil [5]. The exact results depend on factors including soil type, method of compaction, stabilizing agent and the exact percentage of agent used. Adding cement affects the maximum dry density (MDD), as well as its optimum moisture content (OMC); nonetheless, rates of change are not standard [4]. The OMC and the maximum specific gravity of dry soil vary with the amount of cement kiln dust [6].

2. LITERATURE REVIEW

Road construction greatly depends on the practice of improving soils on which pavement materials are applied. Soil stabilization can be defined as any process that results in a more stable soil. In contrast, the traditional approach of chemical stabilization is to add lime, bitumen or Portland cement [7]. Broadly, soil stabilization allows engineers to enhance or create a given

International Journal of Low-Carbon Technologies 2019, 14, 543–549

doi:10.1093/ijlct/ctz047 Advance Access publication 14 October 2019

property to make it useful for an engineering application. Through stabilization, many soils that previously had to be rejected can now be used in engineering projects [8]. The following are engineering qualities that can be made better or made usable by stabilization: deformation resistance (i.e. stiffness), shearing resistance (i.e. improving soil strength) and wears resistance (i.e. durability); other factors affected are a lowering of levels of dust, a lowering of the tendency of wet clay soils to swell and an increase in the overall water resistance of unsealed roads [9]. Soil stabilization requires a binding agent, such as cement. Cement can be used as the primary binding agent for stabilization, or it can be used in combination with lime and fly ash. As such, the chemical reaction of the cement does not depend on the minerals in the soil; it only needs water that can be found in most soils [10].

To improve the geotechnical properties of fine sands that do not meet industry values for roads [11], one method is to eliminate poor-quality sand and instead use a higher value, crushed sand that was treated chemically or mechanically [12]. Such methods can increase the level of geotechnical property of the entire structure and provide greater stiffness and strength through approaches that can be applied at the construction site itself [12]. Therefore, reinforcement of the soil is a technique for improving the engineering properties of the soil that lead to developing parameters such as shear strength, compressibility, density and permeability [13]. Thus, the main purpose of strengthening the mass of the soil is to increase its stability, increase its carrying capacity, as well as decrease lateral deformation and settlements [14].

Several studies have examined the use of sand in road construction and proposed various methods for its stabilization and efficiency [15]. Some authors suggest sand stabilization using bitumen or polymer emulsions. Due to the difficulties with the delivery of polymer and bitumen binders and the presence of local, hydraulic cement that was produced in many developing countries, pressed sand concrete was adopted as the preferred choice for the sand material [16]. In other studies, the mechanical properties offered by the treatment of hydraulic binders or by the production of sandy concrete are improved [17].

E. Jones *et al.*, [18] carried out research on the effect of using an epoxy resin and polyamide hardener to stabilize soils composed of clay and silt. They used a one-to-one ratio of epoxy resin to polyamide hardener for their additive mixture, concluding that admixing as much as 4% stabilizer to the clay-silt soil made substantial improvements to the load-bearing of the soil, defined by its unsoaked California bearing ratio (CBR). Increasing the curing environment temperature leads to greater strength formation. The curing time was as low as 3 hours for the stabilization agent.

Typically, at the point of cement stabilization, all necessary components are added. Hydration occurs with the addition of water, and calcium silicate hydration strengthens the soil or bonds soil particles. The properties of the subgrade are improved at a low cost by stabilizing with cement and substituting, adding or discarding material. An additional thickness of the base directly relates to lower subgrade stress [19]. Bitumen can also be incorporated with moist or diverse aggregates. Specific optimal moisture is also needed to certify an equal dispersion of the bitumen throughout the mix. The resilient modulus parameter is raised through bitumen stabilization of the raw material [20]. Adding emulsion to the layers of pavement improves the water-resistant qualities and improves surface cohesion; this allows a road to be opened for use soon after construction, while at the same time limiting the raveling of the base layer [21].

Soil stabilization is done upon determining that it is more economical to improve the qualities of an abundantly available material than to transport a better material to the job site [22]. It is often the best economic solution. Other economic advantages include reducing the project duration. Soil stabilization can be 30% cheaper than transporting new materials to a site [22]. Soil stabilization brings a number of environmental benefits compared to traditional methods due to the energy savings by making use of locally sourced materials and the consequent reduction in the impact of transport [23].

The quality construction materials are becoming rare in desert regions. Therefore, where traffic volumes are low, roads become less cost-effective due to the higher price of manufactured aggregate. The desert has a lot of dune sand; however, it has relatively little of the good quality material that is necessary for the road structure. So far, road construction in the south of Libya has depended on a combination of good quality material (gravel and sand), brought from the northern part of Libya. The soil in the southern part of Libya is not of a quality that makes good roads; therefore, to use it, engineers must improve soil characteristics such as strength, compressibility and permeability. This is because the foundation of all the structure is ultimately supported by the soil. The underlying hypothesis is that a cement–soil mix is the best way for construction roads.

The main goal of this paper is to study the feasibility of developing and using an improved dune–sand cement mix as a pavement construction material in desert regions where dune sand is prevalent. This study uses two different mix designs, 50% natural and 50% manufactured sands (50%/50%) and 70% natural and 30% manufactured sands (30%/70%) to compare the results for each mixture to stabilize the base course layer using dune sand and manufactured sand with a small percentage of Portland cement content. The laboratory tests were conducted for compaction, CBR and unconfined compressive strength (UCS).

3. MATERIALS AND EXPERIMENTAL STUDIES

More efficient soil stabilization can be designed only with a better understanding of the pertinent physicochemical processes and related stabilization mechanisms. Research on chemical conditioning of natural desert sands indicates that increasing soil aggregation is the principal factor in soil improvement. Stabilizing sand with cement is the best technique in terms of strength and other practical factors. With the benefit of such research, it has been

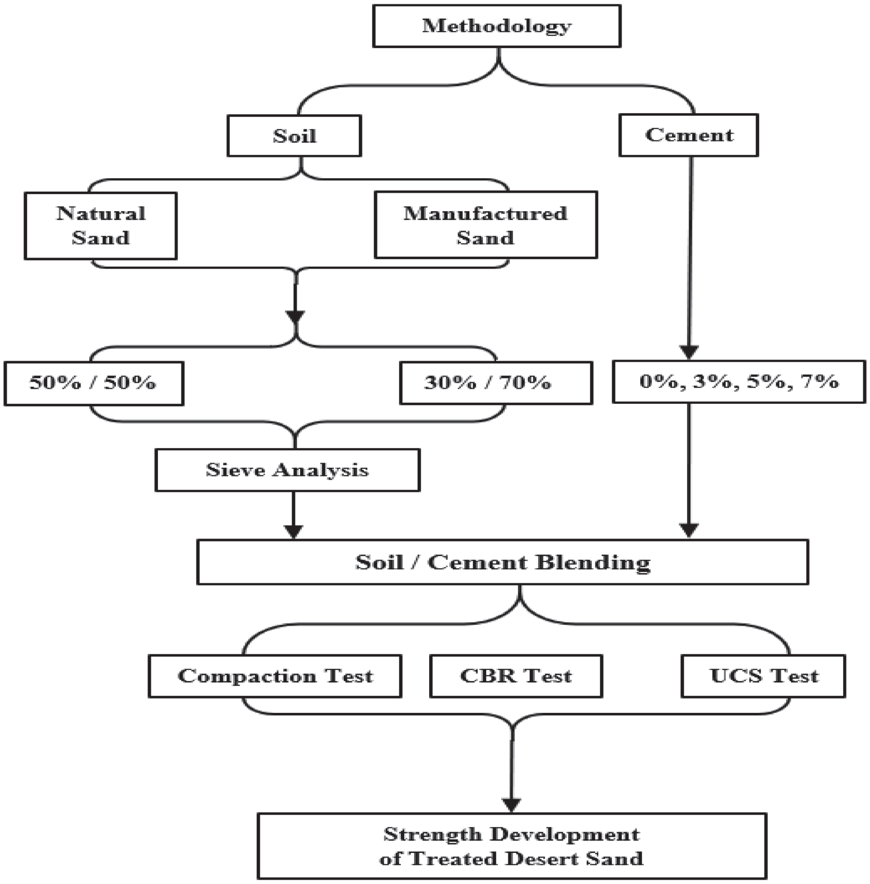

Figure 1. *Flow chart of the experimental program.*

found that the best materials for stabilization are fine aggregates (manufactured and natural sand) and cement. Therefore, these are the construction materials used in this study. A schematic representation of the methodology conducted in this study is shown in Figure 1.

3.1. Materials

The fine aggregates in the current study were brought from the southern part of the Libyan Desert. Particles size ranges from 0 to 5.0 mm, i.e. fine round natural sand and angular manufactured particles shape as per the Standard Classification System; the results of the two mixtures are shown in Table 1. The grain size distribution for two mixtures of sand is illustrated in Figure 1. A great variety of cement is commercially available, depending on the soil in question and the targeted strength of the final soil. For this project, a Libyan-made Portland cement was chosen and applied in small quantities. The properties of the Portland cement are in Table 2.

3.2. Experimental studies

3.2.1. *Compaction tests*

Laboratory compaction tests have conducted to determine the percentage of compaction and the water content required to achieve the desired properties, as well as to control the design to achieve the desired compaction and water content. Tests for compaction of sand-cement mixtures in the

Table 1. *Physical and geotechnical properties of two mixtures with fine aggregate.*

Properties	Mixture (30%/70%)	Mixture (50%/50%)
Fineness modulus	5.19	4.84
Medium size (D50)	5.00	3.50
Uniformity of the coefficient (Cu)	4.59	3.81
Coefficient of curvature (Cc)	1.12	0.61
Liquid limit (LL) (%)	–	–
Plastic limit (PL) (%)	–	–
Plasticity index (PI) (%)	–	–
Soil classification (USCS)	GW	SP
Soil Fraction	**Parameter**	
Silt and clay size (%)	0.25%	0.18%
Gravel (%)	58.23%	59.53%
Sand (%)	41.53%	40. 30%

*USCS :Unified Soil Classification System
*GW: Well-graded gravel
*SP: Poorly-graded sand

Table 2. *The properties of the Portland cement.*

Compound	%
SiO2	18.20
CaO	59.03
MgO	1.80
Al2O3	5.09
Fe2O3	3.15
Na2O	0.18
K2O	0.29
SO3	2.65
Loss on ignition (LOI)	7.91
Materials not solvent	1.02
Properties	**Test result**
Time setting: Vicat test (min)	
–Initial set	172
–Final set	247
Air contents of mortar (%)	7.3
Autoclave expansion (%)	0.8
Compressive strength (MPa)	
–Three days	10
–Seven days	30.5
–Twenty-eight days	Min 42.5–max 62.5

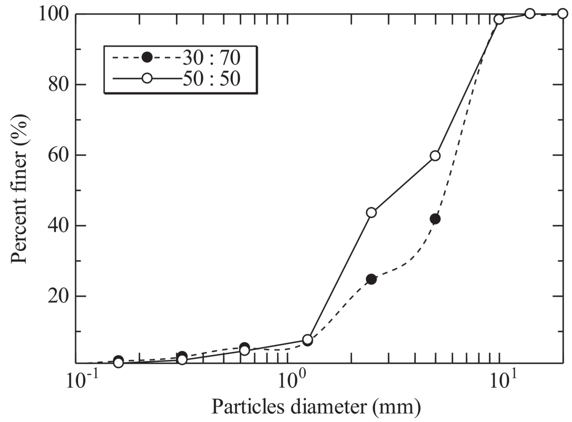

Figure 2. *Gradation curves for two mixtures of sand.*

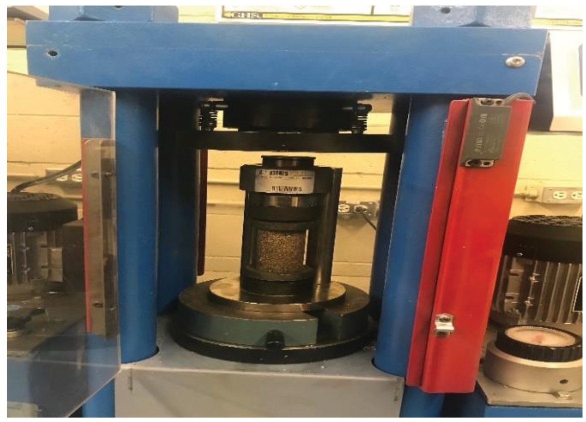

Figure 3. *UCS machine test and specimen.*

desert were carried out in accordance with [28]. The compaction test was carried out for both mixtures, the first mixture consisted of 50% of the sand manufactured and 50% of natural sand and using different percentages of Portland cement, comprising 0%, 3%, 5%, 7%. The second mixture consisted of 30% of manufactured sand and 70% of natural sand with the same percentage of Portland cement. Water was added as needed to facilitate the mixing and compaction process.

3.2.2. *CBR test*

The experimental test in this work is used to determine the bearing capacity of compacted soil's layers. All samples with optimum moisture content were placed in a five-layer mold. Each layer of the mixture was compacted with a hammer of 4.5 kg with 25 blows. Total weight of each the sample was 4.5 kg. After the compaction was completed, the upper ring of the mold was removed, and the surface of 8 samples was smoothed by using the steel ruler. Finally, samples were tested using CBR testing according to [29]. The dial gauge that measured penetration was tared to zero and then the load was applied. Values for each 0.5 mm of penetration were noted and the final CBR values were obtained, pertaining to the greater of 2.5 mm and 5.0 mm penetration. These eight mixes underwent penetration testing with the loading machine. The initial mix used 50% manufactured sand and 50% natural sand and using 0%, 3%, 5%, and 7% of Portland cement. The second mixes used 30% manufactured sand and 70% of natural sand with the same percentages of Portland cement.

3.2.3. *UCS test*

The test (UCS) is to determine the compressive strength of the mixture, which has sufficient cohesion for testing in an unlimited state. The mixture was prepared in accordance with [30], using samples with a diameter of 50 mm and a height of 100 mm as shown in Fig 3. For each sample, thorough mixing assured a homogeneous paste, taking care to limit the time to set up of the specimens (mix and compact) to less than 1 h, which is shorter than the initial setting time of the Portland cement used. Three specimens of every cement-soil mixture were tested at 0.1 mm/min. The diameter should be at least 30 mm, and the ratio of height to diameter should be from 2 to 2.5. The samples were placed in a humidity room for 7, 14, and 28 days. The average of UCS for three samples treated with cement after 7, 14 and 28 days of curing time was obtained using a hydraulic machine for the value of compressive strength with a load of 140 ± 70 kPa/s as shown in Fig. 3. Finally, the value of compressive strength (MPa) was computed by dividing the maximum load (N) by the cross-sectional area (mm^2).

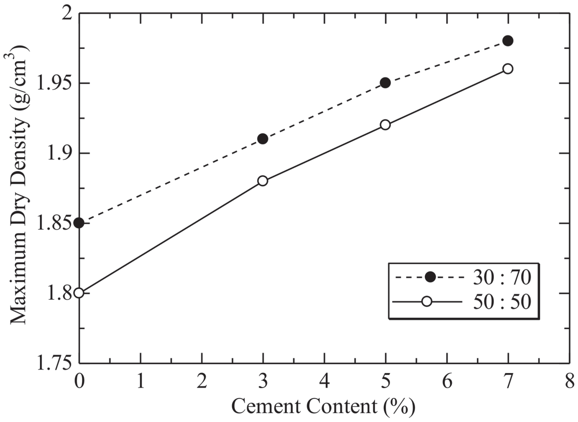

Figure 4. *Effect of cement content on dry density of treated soil.*

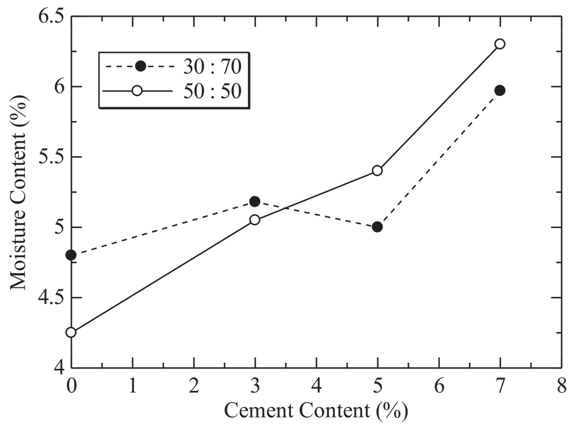

Figure 5. *Effect of cement content on moisture content of treated soil.*

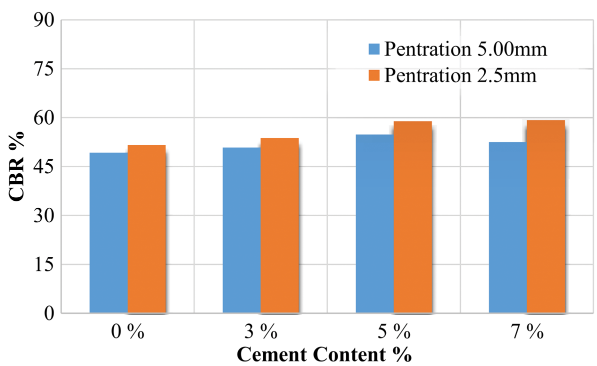

Figure 6. *Variation of CBR value with cement content (50%/50%).*

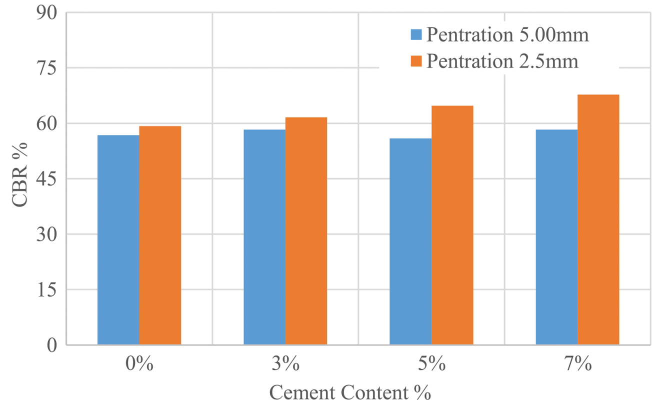

Figure 7. *Variation of CBR value with cement content (30%/70%).*

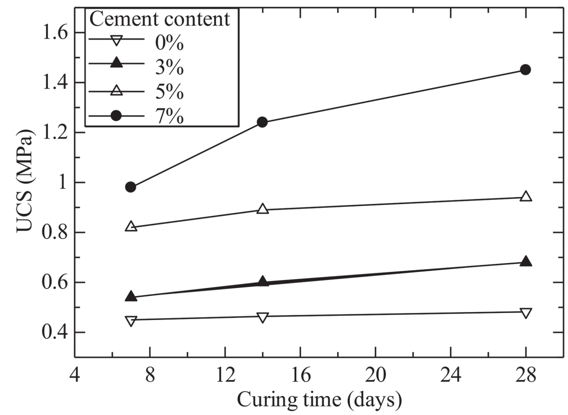

Figure 8. *The compressive strength vs the percentage of cement (50%:50%).*

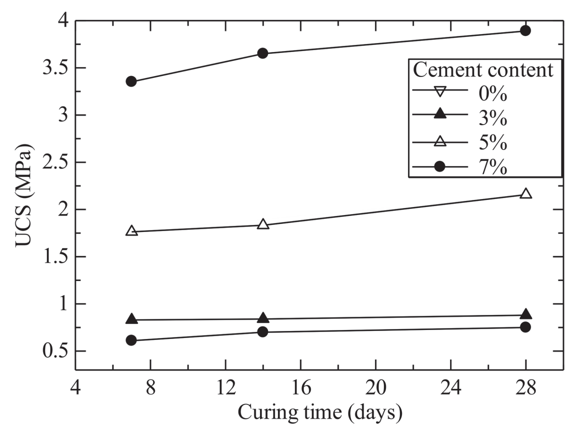

Figure 9. *The compressive strength vs the percentage of cement (30%: 70%).*

4. RESULTS AND DISCUSSION

4.1. Moisture–density test results

Figures 4 and 5 portray the influence of different percentages of cement on the water content and dry density for both mixtures 50%/50% and 30%/70%, the important factors that affect the strength of the cement-soil stabilization is the dry density of the compacted soil. In fact, MDD of cement hydration varies by adding water. This can be explained by using a form of experimental results of the total void ratio of a mixture containing soils with different grain sizes. When small particles are found added to a matrix of large particles, the overall ratio of void decreases until all voids are filled with small particles. This means that the density of the dry density increases to a certain ratio of mixing small particles to large particles. Fig. 4 presented the values of MDD with cement content for both mixes 50%/50%

and 30%/70%, respectively. From these figures, there is a slight increase in the MDD of sand-cement mixes with an increase in the cement content. The variation of OMC for each of the various cement contents has relatively the same trend is illustrated in Fig. 5, for both mixtures 50%/50% and 30%/70%. Finally, the sand mixture 30%/70% have obtained high values of MDD than those from the sand mixture 50%/50%.

4.2. CBR Results

The results of the mixture 50%/50%, natural and manufactured sands using different percentages of Portland cement, of 0%, 3%, 5%, 7% are illustrated in Fig. 6; the values of CBR at the penetration of 2.5 mm for this mixture are 51.59%, 53.70%, 58.86%, and 59.19 %, respectively. At 5 mm penetration, the values are 49.29%, 50.86%, 54.85%, and 52.50%. Fig. 7 shows the results of the mixture 30%/70% manufactured and natural sands with the same percentages of Portland cement, where the CBR value, at the penetration of 2.5 mm are 59.26%, 61.64%, 64.02%, and 67.72 %, respectively. At the penetration of 5 mm, the values are 58.5%, 60.01%, 57.59%, and 60.01 % respectively. The CBR values of mix 30%/70% for both penetration 2.5 mm and 5 mm are shown in superior performance than the values of the mix 50%/50%. Moreover, the highest value of CBR at (30%/70%) was achieved by the stabilized soil with 7% cement for both penetration at 2.5 mm is 67.72% and 58.26 at 5 mm, respectively. This result suggests using a higher percentage of natural sand and gives a better outcome in terms of CBR values compared to other mixtures.

4.3. UCS results

From the UCS test results indicated in Figures 8 and 9, it is obvious that the cement and curing days have significant effects on the UCS of the specimens. This shows mutual dependence when an increase in the cement content increases the strength of the mixture due to cement hydration, which fills the pores of the voids, thus increasing the rigidity of its structure, forming a large number of rigid bonds in the soil. For the cement-only treated soils, after 28 days of curing, the UCS increased significantly from 0.6 MPs to 3.8 MPs and 0.5 MPs to 1.5 MPs, respectively by increasing the percentage of cement from 3 to 7% for the two mixtures 30%/70% and 50%/50%. However, for mixture 30%/70% after 28 curing days, the stabilized specimen with 7% cement provided the highest value of UCS at 3.8 MPs, which was about 7 times more than the untreated soil. As results, an increase in the cement content led to an increase in UCS.

5. CONCLUSION

This research evaluated the effects of using soil stabilization on locally sourced desert sand in a base course mix in flexible road pavement. For this compaction, CBR and UCS tests were performed on the two mixtures of sands with diverse percentages of cement. The experiment results illustrate that low-grade materials were satisfactorily stabilized a mixture of 70% dune sand and 30% crushed sand; these two sand mixes were then treated with a mix of Portland cement (namely 0%, 3%, 5% and 7%) resulting in the desired soil stability. The test results indicate that the MDD and the OMC of mix 50%/50% and mix 30%/70% were found to increase with the increase in the cement content. The counterintuitive results of the CBR tests can be accounted for by the fact that the soil particles in the 30%/70% mix are more consistently surrounded by the cement. Because of this, the sand particles can tolerate a higher force, shown in the greater CBR results. The increase in the CBR in terms of the cement percentages is predictable, with the higher amounts of cement showing better results. The high percent of the natural sand in the mix 30%/70% is the right way to find the mechanical performance and the strength of sand–cement mixtures. The increase in UCS is not linear for both the mixtures of sands. The value of UCS strength increases by adding the proportion of cement content and curing time, which indicates that the relative compressive strength was found after 28 days. Overall, this study has shown that there are both economic and practical reasons to favor using the mix with a higher percentage of desert sands.

ACKNOWLEDGEMENTS

The first author would like to thank the Department of Civil Engineering at École de Technologie Supérieure for providing all the facilities to carry out the experiments.

REFERENCES

[1] Panwar K, Ameta NK. Open access stabilization of fine sand with ceramic tiles waste as admixture for construction of embankment. *American Journal of Engineering Research (AJER)*, 2016;**5**:206–12.

[2] Almadwi Fathi S, Assaf Gabriel J. Finding an optimal bitumen and natural sand balance for hot mix asphalt concrete in hot and arid regions. In: *Proceedings of the 5th GeoChina International Conference—Civil Infrastructures Confronting Severe Weathers and Climate Changes in HangZhou, China*, 2018, Springer: Cham pp. 1–12.

[3] Bell FG. 2005. *Engineering Tretment of Soils*. London and New York: Taylor & Francis Group.

[4] Barclay Robert T, Casias TJEA, David A. Crocker, De Graffenreid Richard L, Hess John R, Roof Harry C, Dennis W. Super, *et al.* State-of-the-art report on soil cement. *ACI Materials Journal*, **87** 1990.

[5] Collins BD, Sitar N. Stability of steep slopes in cemented sands. *J Geotech Geoenviron* 2011;**137**:43–51.

[6] Millera GA, Azadb S. Influence of soil type on stabilization with cement kiln dust. *Constr Build Mater* 2000;**14**:89–97.

[7] Thagesen B. *Highway and traffic engineering in developing countries*. CRC Press, 2005.

[8] Amu OO, Bamisaye OF, Komolafe IA. The suitability and lime stabilization requirement of some lateritic soil samples as pavement. *Int J Pure Appl Sci Technol* 2011;**2**:29–46.

[9] Zumrawi M. A study on mechanical stabilization to improve marginal base materials in Khartoum. *International Journal of Science and Research (IJSR) 3*, 2014;**3**:1716–21.

[10] Makusa GP. Soil stabilization methods and materials in engineering practice: State of the art review. *Luleå tekniska universitet*, 2013.

[11] Almadwi FS, Assaf GJ. 2017. Performance testing of paving mixes for Libya's hot and arid conditions, using Marshall stability and SUPERPAVE

gyratory compactor methods. In *International Congress and Exhibition Sustainable Civil Infrastructures: Innovative Infrastructure Geotechnology*, pp. 313–23. Springer, Cham, 2017.

[12] Almadwi TS, Assaf GJ. The Effect of Using Desert Sands and Cement to Stabilize the Base Course Layer of Roads in Libya. In *Civil Infrastructures Confronting Severe Weathers and Climate Changes Conference*, pp. 140–150. Springer, Cham, 2018.

[13] Mahdi S, Sheikhzadeh M, Mahdi S, Zadhoush A. A simple review of soil reinforcement by using natural and synthetic fibers. *Constr Build Mater* 2012;**30**:100–16.

[14] Binici H, Aksogan O, Shah T. Investigation of fibre reinforced mud brick as a building material. *Construction and Building Materials*, 2005;**19**:313–8.

[15] Tingle JS, Newman JK, Larson SL *et al.* Stabilization mechanisms of nontraditional additives. *Transportation research record*, 2007; **1989**:59–67.

[16] El Euch Khay S, Neji J, Loulizi A. Compacted sand concrete in pavement construction: an economical and environmental solution. *ACI Materials Journal*, 2010;**107**.

[17] Asi IM, Wahhab HIA, Al-amoudi OSB *et al.* Stabilization of dune sand using foamed asphalt. *Geotechnical Testing Journal*, 2002;**25**:168–76.

[18] Jones E, Ajayi-Majebi A, Grissom W *et al.* Epoxy-resin-based chemical stabilization of a fine, poorly graded soil system. *Transp Res Rec* 1991;**1295**:95–108.

[19] Prusinski JR, Bhattacharja S. Effectiveness of Portland cement and lime stabilizing clay soils. *Transp Res Rec* 1999;**1652**:215–27.

[20] Saleh MF. New Zealand experience with foam bitumen stabilization. *Transportation research record 1868* 2004;**972**:40–9.

[21] Liebenberg J, Visser A. Stabilization and structural design of marginal materials for use in low-volume roads. *Transp Res Rec* 2003;**1819**:166–72.

[22] Al-Swaidani A, Hammoud I, Meziab A. Effect of adding natural pozzolana on geotechnical properties of lime-stabilized clayey soil. *Journal of Rock Mechanics and Geotechnical Engineering* 2016;**8**:714–725.

[23] Rammal MM, Jubair AA. Sand dunes stabilization using silica gel and cement kiln dust. 2015;**18**:179–91.

[24] ASTM. 2012. *Standard test methods for laboratory compaction characteristics of soil using modified effort*. *D1557*.

[25] ASTM D1883. 1999. *CBR (California Bearing Ratio) of Laboratory-Compacted Soils*. *Changes*, Vol. **04**. 1–8.

[26] ASTM. 2007. *Standard test methods for compressive strength of molded soil-cement cylinders. D1632.*