INTERNATIONAL JOURNAL OF SUSTAINABLE CONSTRUCTION ENGINEERING AND TECHNOLOGY
VOL. 13 NO.3 (2022) 59-67

© Universiti Tun Hussein Onn Malaysia Publisher's Office

IJSCET

http://penerbit.uthm.edu.my/ojs/index.php/ijscet

ISSN : 2180-3242 e-ISSN : 2600-7959

International Journal of Sustainable Construction Engineering and Technology

Investigation of Mechanical Properties of Quicksand Stabilized with Bitumen Emulsion and Reinforced with Waste Polypropylene Fibers and The Effect of Freeze and Thaw on Its Performance

Zohreh Ghafoori Fard[1], Mohammad Mehdi Khabiri[1]*, Ahmad Mohajeri[1]

[1]Road and Transportation Engineering,
Yazd University, Civil Engineering Department University Blvd, Safeties, Yazd, 98195-741, IRAN

*Corresponding Author

DOI: https://doi.org/10.30880/ijscet.2022.13.03.006
Received 24 July 2021; Accepted 19 March 2022; Available online 10 December 2022

Abstract: The existing quicksands in the desert are among the problematic soils whose stabilization has been considered by experts. Emulsion bitumen is one of the environmentally friendly stabilizers of these sands. Also, the method of reinforcement with (fibers) has many advantages due to the increase in soil strength in the same way and the formation of thickness in the soil mass. The aim of this study was to investigate the effect of polypropylene fibers and emulsion bitumen on improving sandy soil properties and the effect of freeze-thaw cycles on the behavior of soils stabilized by these two substances; For this purpose, samples of aeolian sand soil with 0%, 0.25%, 0.5%, 0.75% and 1% waste polypropylene fibers of 0, 5, 10, 15% bitumen emulsion were made and tested for California load-bearing capacity and uniaxial compressive strength. Also, to evaluate the effect of freeze-thaw cycle, the samples were subjected to uniaxial resistance test after enduring 3 and 7 freeze-thaw cycle. The results show that the addition of fibers and bitumen to the sand first increases the specific gravity and CBR and decreases from one percent onwards by increasing the fibers of these two parameters; It has compressive strength and ultimate strain with increasing fiber percentage; In general, increasing the percentage of fibers from 0 to 1% on average increases the compressive strength by 91% and the final strain by 54% and increasing the percentage of bitumen from 5 to 15% on average increases the compressive strength by 4% and the final strain by 13%. In addition, the results show that the compressive strength of the samples decreases by an average of 15% and 19% after withstanding 3 and 7 freeze-thaw cycle, respectively; However, after enduring 3 and 7 freeze-thaw cycle, the compressive strength increases with increasing the percentage of fibers to 75%.

Keywords: Emulsion bitumen, low temperatures, chipseal, pavement improvement, surface settlement

1. Introduction

Reinforced soil has been used by humans for many years, while the origin of this method of soil reinforcement can also be traced to examples of natural patterns. For example, the soil on the slopes of mountains with steep slopes, with the growth of plants whose roots are in the ground can be strengthened and stabilized against slippage and instability. Today, soil stabilization is widely used in road and transportation engineering in road construction, because in any construction project, including road construction, bed soil is one of the most important materials used. In general, in road construction, the quality of the bed soil, its load tolerance, sensitivity and vulnerability to atmospheric factors, play a

**Corresponding author: mkhabiri@yazd.ac.ir*

decisive role in the selection of pavement layers [1][2]. On the other hand, the increasing need of communities for various transportation networks such as highways, railways, airports and related technical buildings such as bridges and tunnels has led to a significant increase in roads and transportation networks in various areas, including swamps, deserts and sandy beaches which often have unsuitable soil [3][4].

There are several improvement methods for road bed soil, including removing poor soil and replacing it with suitable materials or improving the engineering properties of local soil in various ways. The choice of improvement methods depends on several factors such as soil type, fine grain type, area and depth of compaction and soil strength improvement, permeability, access to equipment and materials and improvement costs [5]. Today, due to the special importance of economic issues, engineers turned to waste or cheap materials for soil stabilization [6]. Objectives of soil bed improvement can improve the geotechnical properties of the soil, including increasing soil bearing capacity, subsidence control and deformation of road beds [7]. A significant part of Central Asia southeast of the Middle East and the whole of Asia is covered with windswept sands [8] which has hindered the development of large-scale development projects. Numerous scientific studies show that hydrocarbon molecules are good stabilizers for quicksands [9]. Among these, emulsion bitumens have various advantages in terms of environmental performance, economics and unique properties [10] [11]. So far, several studies have been conducted in the field of soil stabilization, including sandy soils with bitumen products, the results of which show the positive effect of this type of bitumen on soil stabilization and improving the geotechnical properties of sandy soils stabilized with hydrocarbons and finally proper pavement performance [12]. For example, the results of a study conducted in 2015 by J. Bisanal and Badiger showed that soil stabilization with bitumen emulsion has a significant effect on improving soil properties, because bitumen emulsion in soil acts as an adhesive between soil particles and reduces soil permeability, too [13]. Also in another study conducted by Sing Batra and Sing Aurora in 2016 on the effect of cationic emulsion bitumen on soil shear strength, the results showed that the shear strength of soil stabilized with bitumen is about 56% higher than the shear strength of unstabilized with bitumen [14]. In a study in 2017, Kumar and Bensal, stating that any structure, whether it is a building or road pavement, needs infrastructure and the key point of a stable structure is its stability and strength, studied the effect of bitumen on sandy soil and they found that stabilization of sand with the help of bitumen significantly increases the compressive strength and CBR [15]. In 2018, Rajesh Jin and Namdeo, emphasizing that the bed soil is considered to be the most basic construction material, conducted a study entitled stabilization of sandy soil using emulsion bitumen, in which the strength of soil stabilized with bitumen from Marshall strength was evaluated and the results showed a significant effect of bitumen on soil strength [16]. In addition, in 1392 Hajiannia et al. in a study found that although bituminous materials are very effective in stabilizing and improving sandy soils, however, in soil saturation conditions, reducing the friction angle and adhesion of samples fixed with petroleum and bitumen materials, their strength is significantly reduced. Also, if the percentage of fine grains is more than a certain amount, due to the reduction of adhesion between sand, oil and bitumen, it will reduce the strength of the samples [17].

On the other hand, in recent years, soil remediation using fibers, especially waste fibers of various materials, has been considered by researchers [18]. For example, Sudhakaran et al., stating that the rapid development of urban areas and the increase of construction and civil engineering activities leads to a shortage of land with favorable soil conditions in terms of soil type and the use of weak soils that make local necessary for development activities through stabilization techniques.,investigated the effect of fibers on soil. He concluded that the addition of fibers to the soil improved soil properties, including tensile strength and California Bearing Ratio [19]. In a study, James Wang et al. Examined the effect of fibers on sandy soil and found that increasing the percentage of fibers could significantly distribute the load in different parts of the test sample and prevent rapid failure of the sample. In fact, it can be said that with increasing the percentage of fibers, the strength of sandy soil samples increases, which results in the performance and design of pavement is of particular importance [20]. In 2015, Sugenchi studied the effect of polypropylene fibers on soil stabilization in a study entitled "The effect of these fibers on soil swelling." The results of this study show that polypropylene fibers reduce the percentage of soil swelling [21]. Also, Estabragh et al. In a study investigated the effect of propylene fibers on soil. They performed compressive strength and tensile strength tests on soil samples stabilized with different percentages and lengths of fibers and concluded that the strength of fiber-reinforced soils increases with increasing fiber content and fiber length [22].

As mentioned, many studies have been done on the effect of bitumen emulsion of propylene fibers in soil, including sandy soil, the effect of bitumen emulsion of polypropylene fibers on soil improvement, including sandy soil. However, a comprehensive study on the effect of ice melting cycles on the behavior of soils stabilized by these two substances has not been done so far. The aim of this study was to investigate the effect of polypropylene fibers and emulsion bitumen on improving the properties of sandy soils and the effect of ice melting cycles on the behavior of soils stabilized by these two materials.

2. Materials and Research Methodology

2.1 Used Quicksand

In this study, quicksand around the city of Yazd has been used. An area of 15 square kilometers was selected for sampling. Then, by sampling 5 points, it was determined that the sands of the area have almost the same granulation.

These samples were selected as representative of the soil of the region to use in the research. The soil grading diagram is presented in figure (1) and its general characteristics are presented in table (1).

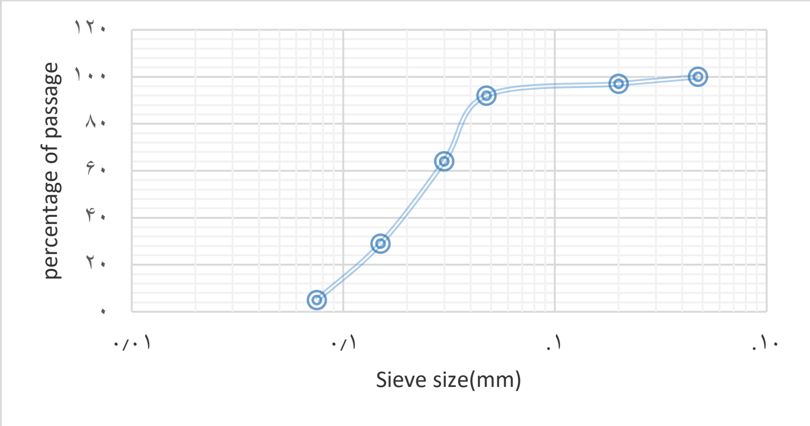

Fig. 1 - The chart of granulation of quicksand used in this research

Table 1 - Properties of quicksand used in this research

Plasticity index	Maximum dry specific gravity($\frac{gr}{cm^3}$)	Optimum moisture percentage	Moisture percentage	Specific gravity	Depth of survey	Soil classification	Area
0	1.85	8.2	1	2.71	0.25	SP	J_1
0	1.79	9.3	1.2	2.66	0.15	SP	J_2
4	1.91	10.1	0.8	2.75	0.25	SP-LL	J_3
2	1.87	6.9	1.1	2.73	0.2	SP-ML	J_4
2	1.72	7.6	1.05	2.56	0.3	SP-ML	J_5

2.2 Bitumen Emulsion Used

In general, bitumen emulsions have a low specific gravity, a specific gravity about 1, and a low evaporation point of less than 70 ° C. Basically, bitumen emulsion has a positive polarity (Most bitumen emulsion of refineries and bitumen factories in Iran is cationic). The chemical components and bitumen properties of the emulsion used in this study are presented in Table (2).

Table 2 - Technical specifications of emulsion bitumen used in this study

Test		Result	Regulations	
			Min	Max
Kinematic sluggishness at 50 ° C		430	400	1000
Percentage of bitumen remaining		65	65	-
24-hour stability		1%	-	1%
Sieve test		0.01 %	-	1%
Tests on the remaining asphalt	Degree of penetration	115	100	-
	Angiic properties	40	40	-
	Percent solubility	99.7	97.5	-

2.3 Polypropylene Fibers

Polypropylene fibers, which are produced by the polymerization of propylene as a single-stranded polymer, are called PP for short. According to previous studies, the percentage of polypropylene fibers between 1% to 4% of the soil weight of these fibers is used [23]. For this purpose, polypropylene fibers with the specifications of Table (3) with an average length of 12-14 mm, with percentages of 0, 0.25, 0.5, 0.75 and 1% were used.

Table 3 - Technical specifications of polypropylene fibers used in this research

5500-7000	Young module mp	12-16	Average fiber length (mm)	Physical and mechanical properties
35	Tensile strength $\frac{N}{mm^2}$	0.91	Specific weight of fibers $\frac{gr}{cm^3}$	
160	Thaw point (degrees Celsius)	18-30	Medium fiber diameter mμ	
124-145	Percentage of elastic elongation	0.5	Maximum moisture absorption (%)	
	CH_3)]--[CH_2 –CH)		Chemical formula	Chemical performance
	C C | | (−C − C−)$_n$ | | C C		Formula feature	

The characteristics of these fibers include non-freezing resistance to environmental conditions and non-destruction of these fibers in acidic environments; Also, the main purpose of using these fibers is to increase the ductility of stabilized sand, which in fact these fibers increase its flexibility due to their high tensile capacity [24]. Figure 2 shows the location of sand, fiber and bitumen emulsion soils, as well as a sample of stabilized soil.

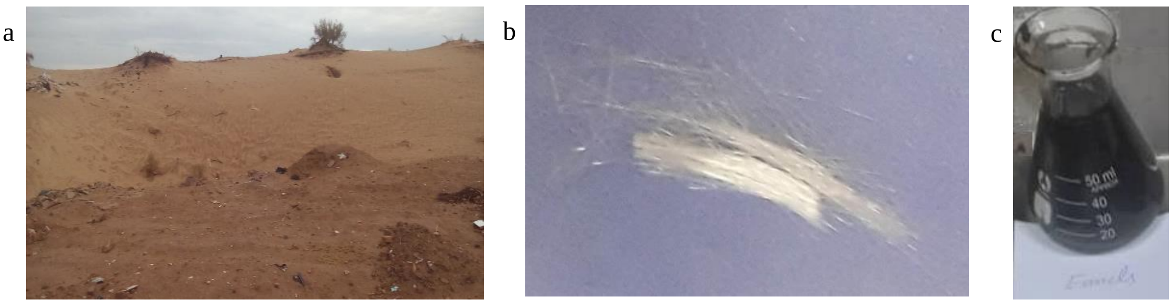

Fig. 2 - (a) Quicksand collection area; (b) the fibers used in this research; (c) emulsion bitumen used in this research

3. Research Method

The sand used in this study was first mixed dry with 0, 25%, 5%, 75%, 1% fibers dry. Then different percentages of bitumen emulsion 0, 5, 15, 10 percent of bitumen emulsion were added to it. They were then compacted at the optimum moisture content obtained from the standard compaction test (ASTMD 678). The emulsion was kept in the environment for 4 hours to ensure the completion of the bitumen breaking process. From each combination, three samples were made to reduce the error and the average test result of these numbers was selected. ASTMD 2166 standard was used to determine soil strength. An oven with a controllable temperature of 0.1± was used to determine the freezing effect and temperature on the performance of the stabilized mixture. Figure 3 shows the laboratory equipment used and a sample of the proven materials.

The use of more than 1% of fibers causes it to be very difficult to mix with soil. In addition, the simultaneous use of polypropylene fiber emulsion economically requires that a low percentage of fibers be selected. The mixed samples were made at a temperature of 25 ° C in uniaxial test molds (5 cm in diameter) and divided into five categories. The freeze-thaw cycle with 7 and 3 replications was considered for comparison. In other words, freeze-thaw cycle according to ASTMD S 66 standard, uniaxial compression test was performed on samples at optimum humidity. Also, CBR and uniaxial compressive strength tests were performed to determine the final strength of soils at optimum moisture.

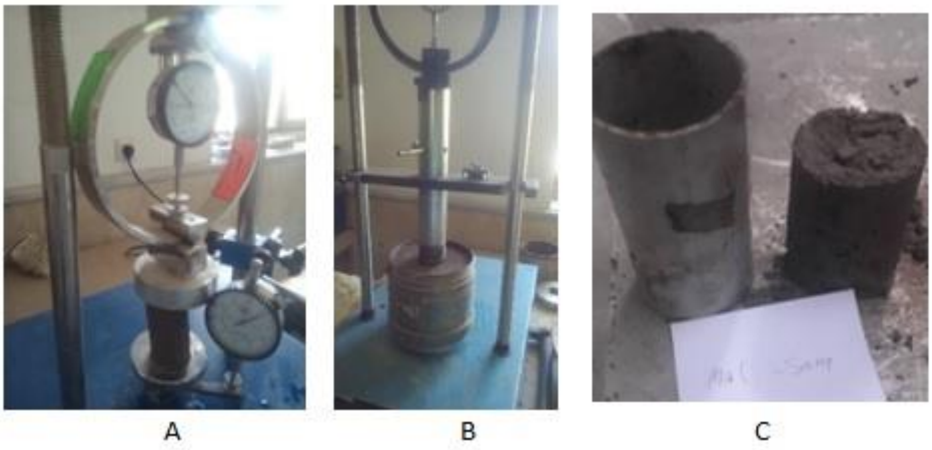

Fig. 3 - (a) Uniaxial resistance test equipment; (b) CBR test equipment; (c) sample made of laboratory samples

4. Results and Discussion

4.1 CBR Bearing Capacity Test Results

Finally, CBR test was performed to determine the final strength of soils at optimum moisture. Figure 4 shows the test results and changes in CBR and maximum specific dry weight relative to bitumen and fiber content.

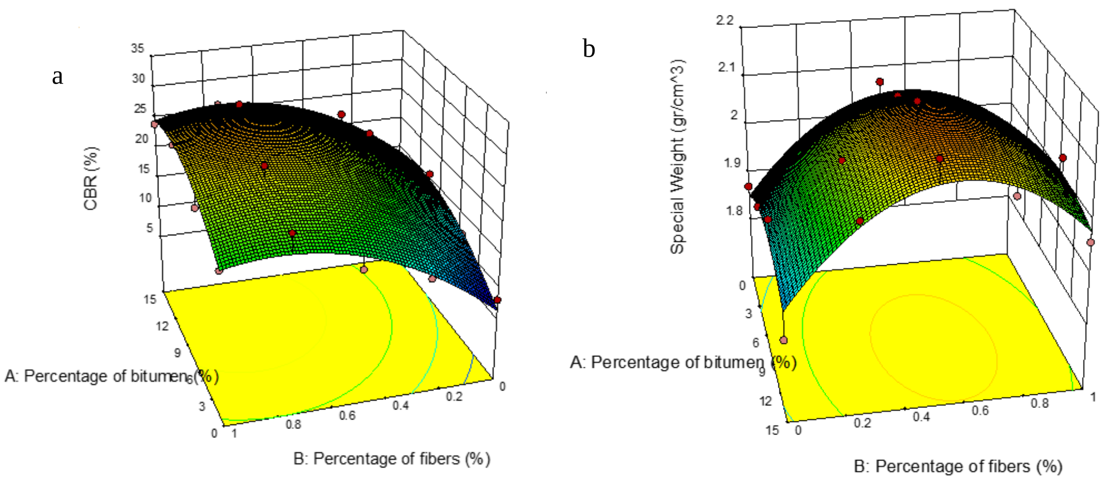

Fig. 4 - (a) Diagram of CBR changes with respect to different percentages of fibers and emulsion bitumen; (b) graph of changes in specific gravity with respect to different percentages of fibers and emulsion bitumen

According to Figure 4, the addition of fibers to the sand first increases the specific gravity and CBR. And from there on, as it increases due to the filling of the empty space between the sand particles, the specific gravity and CBR decrease; this process also applies to increasing the percentage of emulsion bitumen, because initially, increasing the percentage of bitumen causes the sand particles to stick better and the soil to compact better. But from one percent onwards, with the increase of bitumen, the particles that make up the sand slide together and the compaction does not work well. In fact, compaction energy is wasted.

4.2 Uniaxial Test Results

In order to determine the maximum tolerable strength of sandy soil samples stabilized with emulsion fibers in this study, uniaxial compressive strength test was performed. The results of the experiment are shown in figure 5.

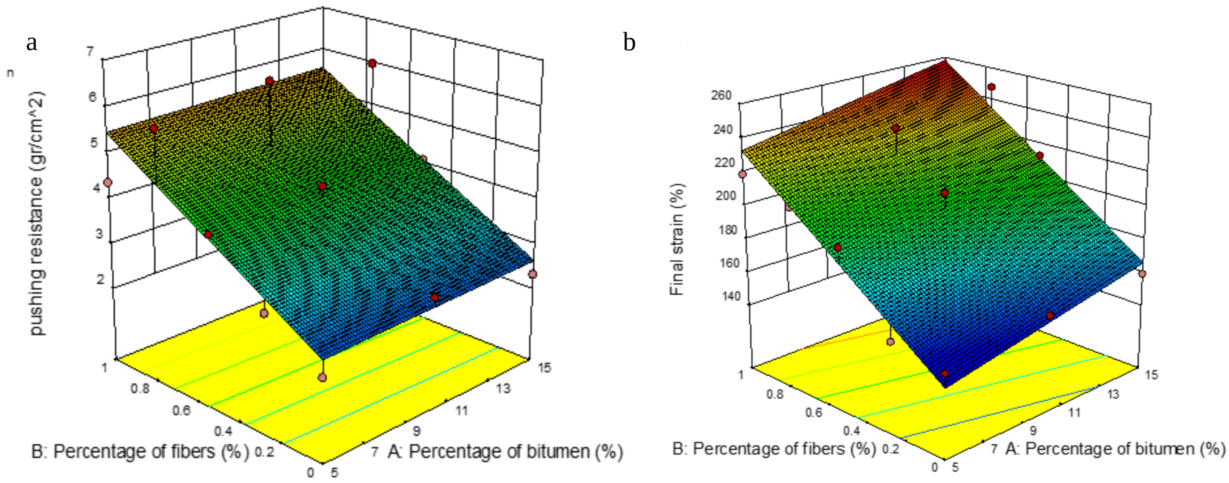

Fig. 5 - The effect of fibers and emulsions on uniaxial compressive strength and final strain

As can be seen in Figure 4, increasing the percentage of emulsion bitumen and the percentage of fibers increases the compressive strength and final strain of sand soil. The highest compressive strength and final strain are related to 75% of fibers and 15% of bitumen. Meanwhile, the effect of fiber percentage has a significant effect on these two parameters; In general, increasing the percentage of fibers from 0 to 1% on average increases 91% compressive strength and 54% final strain; Also, increasing the percentage of bitumen from 5 to 15% on average increases the compressive strength by 4% and the final strain by 13%.The reasons for the increase in strength and final strain of sand soils can be pointed out that by adding bitumen emulsion to the soil, the particles stick to each other and also by increasing the percentage of fibers between sand particles and some kind of friction between particles increases. Table 4 shows the results of the above experiments. These results are consistent with the results of Chobasti et al.'s research on the effect of fibers on soil behavior and Matif et al.'s research on the effect of emulsion bitumen on soil behavior [25] [26].

Table 4 - Results of experiments performed in this study

CBR	Deformation (0.1 mm)	Uniaxial compressive strength $\frac{gr}{cm^2}$	Density specific gravity $\frac{gr}{cm^3}$	Percentage of bitumen emulsion	Percentage of fibers
8	-	-	1.87	0	
12	149	2.14	1.91	5	
16	157	2.76	1.97	10	0
13	159	2.31	1.83	15	
13	-	-	1.96	0	
17	154	2.93	1.99	5	
24	169	3.12	2.07	10	0.25
22	179	3.09	2.04	15	
16	-	-	2.07	0	
21	196	4.10	2.11	5	
25	208	4.29	2.17	10	0.5
24	213	4.10	2.14	15	
23	-	-	2.02	0	
27	209	5.91	2.04	5	0.75
31	238	6.23	2.09	10	

26	248	5.98	2.06	15	
19	-	-	1.94	0	1
22	219	4.37	1.98	5	
26	241	4.86	2.04	10	
24	254	4.54	1.96	15	

4.3 The Effect of Freeze-Thaw on the Performance of Sandy Soil Mixed with Fiber Emulsion

As mentioned, to determine the effect of freeze-thaw cycles on sand soil stabilized with bitumen and waste polypropylene fibers, the samples were subjected to 3 and 7 cycles of freeze-thaw, and then uniaxial compressive strength test was performed on them. The results are given in Table 5. According to Table 5, it can be concluded that the compressive strength of the samples decreases by an average of 15% and 19% after enduring 3 and 7 cycles of freeze-thaw, respectively. At a constant percentage of emulsion bitumen, with increasing the percentage of fiber rupture, a softer behavior occurs. However, the reason for this behavior can be attributed to the high tensile strength of polypropylene fibers to freeze-thaw cycle.

Table 5 - Results of uniaxial resistance test after freeze-thaw cycles

Uniaxial compressive strength in the number of different freeze-thaw cycles		Percentage of bitumen emulsion	Percentage of fibers
7	3		
2.01	2.07	5	0
2.41	2.55	10	
2.14	2.21	15	
2.47	2.64	5	0.25
2.97	3.04	10	
2.86	2.95	15	
3.27	3.76	5	0.5
3.41	3.96	10	
3.29	3.81	15	
4.51	4.74	5	0.75
4.69	5. 64	10	
4.31	5.31	15	
3.54	3.87	5	1
3.67	3. 94	10	
3.42	3.76	15	

5. Conclusion

The aim of this study was to investigate the effect of polypropylene fibers and emulsion bitumen on improving sand soil properties and the effect of freeze-thaw cycles on the behavior of soils stabilized by these two substances; For this purpose, samples of aeolian sand soil with 0, 0.25, 0.5, 0.75 and 1% polypropylene fibers and 0, 5, 10, 15% emulsion bitumen were made. They were tested for California load-bearing capacity and uniaxial compressive strength. Also, to evaluate the effect of freeze-thaw cycle, the samples were subjected to uniaxial resistance test after enduring 3 and 7 freeze-thaw cycles. The results of this research are as follows:

- Adding fibers and bitumen to sand, first increases the specific gravity and CBR and from one percent onwards with increasing the fibers, these two parameters decrease.
- Increasing the percentage of emulsion bitumen and the percentage of fibers increases the compressive strength and final strain of sandy soil, which has the highest compressive strength and final strain related to 75% of fibers and 15% of strength.

- The effect of fiber percentage has a significant effect on these two parameters of compressive strength and ultimate strain; In general, increasing the percentage of fibers from 0 to 1% on average increases 91% compressive strength and 54% final strain.
- Increasing the percentage of bitumen from 5 to 15% on average increases the compressive strength by 4% and the final strain by 13%.
- The compressive strength of the samples decreases by an average of 15 and 19% after withstanding 3 and 7 cycles of freeze-thaw, respectively.
- After enduring 3 and 7 cycles of freeze-thaw, the compressive strength increases with increasing the percentage of fibers to 75%.

Acknowledgement

We would like to thank FarshRah for supporting this research. The generosity and expertise of one and all have improved this study in innumerable ways and saved me from many errors; those that inevitably remain are entirely my own responsibility.

References

[1] P. Sherwood, *Soil stabilization with cement and lime*. 1993.

[2] H. Afrin, “A review on different types soil stabilization techniques,” *Int. J. Transp. Eng. Technol.*, vol. 3, no. 2, pp. 19–24, 2017.

[3] S. A. Aiban, “A study of sand stabilization in eastern Saudi Arabia,” *Eng. Geol.*, vol. 38, no. 1–2, pp. 65–79, 1994.

[4] K.-O. Ngozi and I. I. Ezegbunem, “Bearing capacity improvement of sandy soils at Oleri community using cement stabilization,” *J. Niger. Assoc. Math. Phys.*, vol. 49, no. 1, pp. 295–300, 2019.

[5] J. P. Guyer, *An introduction to soil stabilization for pavements*. Guyer Partners, 2018.

[6] M. Saberian and M. M. Khabiri, “Experimental and numerical study of the effects of coal on pavement performance in mine haul road,” *Geotech. Geol. Eng.*, vol. 35, no. 5, pp. 2467–2478, 2017.

[7] A. A. Firoozi, C. G. Olgun, A. A. Firoozi, and M. S. Baghini, “Fundamentals of soil stabilization,” *Int. J. Geo-Engineering*, vol. 8, no. 1, pp. 1–16, 2017.

[8] H. Long *et al.*, “Holocene moisture variations over the arid central Asia revealed by a comprehensive sand-dune record from the central Tian Shan, NW China,” *Quat. Sci. Rev.*, vol. 174, pp. 13–32, 2017.

[9] S. Andavan and B. M. Kumar, “Case study on soil stabilization by using bitumen emulsions--A review,” *Mater. Today Proc.*, vol. 22, pp. 1200–1202, 2020.

[10] G. Slaughter, “Environmental comparison of cutback bitumen and bitumen emulsions for sealing roads, *TOWARDS SUSTAINABLE LAND TRANSPORT CONFERENCE*,” 2004.

[11] M. M. Khabiri, P. Sadeghi, and O. Ansari, “Investigation of Emulsion Bitumen Adhesion to Aggregates in Chipseal at Various Temperatures for Low-Cost Pavement Management,” *Int. J. Sustain. Constr. Eng. Technol.*, vol. 12, no. 2, pp. 70–79, 2021.

[12] M. K. Sarcheshmah, M. M. Khabiri, and H. K. Sanij, “Investigating the Rheological Properties of Bitumen Clay Emulsion with Different Bentonite Emulsifiers for Pavement Application.,” *Pet. Coal*, vol. 62, no. 3, 2020.

[13] M. G. Bisanal and R. Badiger, “Study on stabilization of soil using sea shell and bitumen emulsion,” *Int. J. Innov. Res. Sci. Eng. Technol.*, vol. 4, no. 7, 2015.

[14] S. S. Batra and J. S. Arora, “Effect of cationic bitumen emulsion on shear strength parameters of soil,” *Int. J. Res. Eng. Technol.*, vol. 5, no. 09, 2016.

[15] V. Kumar and R. Bansal, “An experimental study on the behavior of a sandy soil by using cutback bitumen,” *Int. J. Multidiscip. Curr. Res*, vol. 5, pp. 1134–1137, 2017.

[16] [16] R. Jain and T. Namdeo, “Stabilization of Sandy Soil with Use of Bitumen Emulsion,” *Int. Res. J. Eng. Technol.*, vol. 5, no. 04, 2018.

[17] A., Hajian.S. Kasaian, "Evaluation of the effect of melting and freezing cycles on uniaxial compressive strength of stabilized wind-blown sand with oil residue, National Conference on Applied Civil Engineering and New Achievements," ,p.1-8, 2013,

[18] S. Tiwari and N. Tiwari, “Soil stabilization using waste fiber materials,” *Int. J. Innov. Technol. Res.*, vol. 4, no. 3, pp. 2927–2930, 2016.

[19] S. P. Sudhakaran, A. K. Sharma, and S. Kolathayar, “Soil stabilization using bottom ash and areca fiber: Experimental investigations and reliability analysis,” *J. Mater. Civ. Eng.*, vol. 30, no. 8, p. 4018169, 2018.

[20] P. Jamsawang, P. Voottipruex, and S. Horpibulsuk, “Flexural strength characteristics of compacted cement-polypropylene fiber sand,” *J. Mater. Civ. Eng.*, vol. 27, no. 9, p. 4014243, 2015.

[21] A. S. Souganci, “The effect of polypropylene fiber in the stabilization of expansive soils,” *Int. J. Geol. Environ. Eng.*, vol. 9, no. 8, pp. 994–997, 2015.

[22] A. R. Estabragh, S. Ranjbari, and A. A. Javadi, “Properties of clay soil and soil cement reinforced with

polypropylene fibers," *American Concrete Institute*, 2017.
[23] P. Murthi, R. Saravanan, and K. Poongodi, "Studies on the impact of polypropylene and silica fume blended combination on the material behaviour of black cotton soil," *Mater. Today Proc.*, vol. 39, pp. 621–626, 2021.
[24] E. Richaud, B. Fayolle, and P. Davies, "Tensile properties of polypropylene fibers," in *Handbook of properties of textile and technical fibres*, Elsevier, 2018, pp. 515–543.
[25] A. J. Choobbasti, M. A. Samakoosh, and S. S. Kutanaei, "Mechanical properties soil stabilized with nano calcium carbonate and reinforced with carpet waste fibers," *Constr. Build. Mater.*, vol. 211, pp. 1094–1104, 2019.
[26] A. G. Mathew and A. S. Paul, "Soil stabilization using Bitumen emulsion and cement combination as additive," *J. Earth Sci. Eng.*, vol. 8, pp. 66–74, 2018.