

EFFECT OF FREEZING AND THAWING ON THE STRENGTH AND DURABILITY OF SANDY SUBGRADE CONTAINING FIBRILLATING NETWORK FIBER FOR PAVEMENT

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ABSTRACT

One of the challenges of road construction is encountering soils with lack of required strength and durability. Nowadays, various stabilization techniques are applicable for improving the engineering properties of soils. In the present study, dune sand, as subgrade of pavements, was treated using various contents of fibrillating network (FN) fiber and cement. Dune sand has low bearing capacity that makes it unsuitable for construction activities such as pavement applications. The common solution is improving the strength properties of dune sand so that it can be used for civil engineering projects. Stability of subgrade is very important since the layer provides the stability for the whole pavement structure and the upper layers, namely subbase, base, and asphalt layers. In this regard, compression strength and California bearing ratio (CBR) tests were carried out. Freezing-thawing cycle is one of the most important factors affecting the mechanical properties of soils. Several researchers reported that freezing-thawing cycle could change the physical and mechanical behaviours of soils. The influence of freezing and thawing (up to 18 cycles) on the properties of samples was also studied. Based on the results, the inclusion of FN-fiber to the sand led to increasing the ductility and compressive strength. Also, the addition of cement reduced the ductility, and increased the compressive strength. By increasing the freezing-thawing cycles, the soil strength significantly decreased. Results showed that the stabilized sand soil as subgrade layer led to reducing the compressive strain under the applied wheel load, and therefore reduced the possibility of rutting failure of subgrade.

KEYWORDS

Freezing and Thawing, Sand, Fibrillating network fiber, Cement, Subgrade

INTRODUCTION

Freezing-thawing cycle is one of the most important factors affecting the mechanical properties of soils. Several researchers reported that freezing-thawing cycle could change the physical and mechanical behaviours of soils [1]. These changes may negatively affect the performance of pavement structure including subgrade. It has been reported that cohesion, elasticity modulus, tangent modulus, and compression strength of soils decreased after freezing-thawing process [2,3,4].

Stabilization and reinforcing techniques have been used in road construction projects to improve the strength properties of subgrade. Cement is generally used for improving the stability of subgrade [5]. Cement kiln dust was added to the oil-contaminated sand that resulted in increasing

the compressive strength and bearing capacity. Addition of cement to soils led to increasing the compressive strength, shear strength, and bearing capacity, and also increased the soils brittleness [6,7]. Decreasing the internal water content in the cement stabilized soil resulted in producing higher amounts of calcium carbonate which led to an increase of the compressive strength [8]. In some regions where is the possibility of sulfate attack, cement with lower aluminate content had better engineering performance in stabilization of the sand soil [9].

Inclusion of fiber to soil causes the interlocking between the soil particles and the fiber that results in generation of friction forces. The forces, resulted from interlocking and friction, mobilize the tensile strength in the mixture [10]. It has been reported that by addition of fibers to the soils, the shear and tensile properties, the optimum moisture content, compression strength, and shrinkage limit of the soils increased [11]. By increasing the fiber content, the ultimate bearing capacity improved, and settlements of the footing rested on the fiber-reinforced sand decreased [12]. Addition of fiber to the cement-stabilized soils led to improving the soil strength parameters and also increases the ductility of the samples which is one of the main criteria for flexibility [13]. Resistance to tensile strength is one of the important weaknesses of the soil. The presence of soil-reinforcing fibers increases the shear strength of the soil mixture. These fibers reduce the accumulation of stabilized and hardened soil, increase vulnerability and increase resistance to fatigue and increase the hardness of the mixture. These network fibers as Forta are made from a large number of single-stranded fibers. When these fibers are added to the stabilized soil, due to the mixing and abrasion of the aggregates on top of each other, the structure of these fibers opens from the transverse direction and creates a large number of single strands in the soil, which leads to very good control of primary cracks. Another advantage of these fibers is that they do not absorb water and have a very high resistance in acidic and alkaline environments, which has led to its widespread expansion in recent years. As it was already mentioned, freezing and thawing affect the strength and stability of pavement layers. Several studies have been evaluated the effects of freezing-thawing process on the cement-treated soils; however, very limited information exist about the influences of freezing-thawing process on the cement-fiber-treated dune sand used as subgrade of pavements. Therefore, the aim of this study is to evaluate the effects of cement and fibrillating network fiber on the strength properties of dune sand for pavement subgrade applications. Compression strength and California bearing ratio tests were carried out in the laboratory on the sand samples stabilized with different contents of FN-fiber and cement.

MATERIALS AND METHODS

Sand soil

Based on the AASHTO soil classification, the soil used in the present study was classified as fine sand (A-3). Gradation curve and mechanical properties of the soil are presented in Figure 1 and Table 1, respectively. Figure 1 also shows the compaction test results of the soil. Maximum dry density and optimum moisture content of the sand obtained from Figure 1(b) is also provided in Table 1. Figure 2 shows a view of the sand used and the soil operation volume related to the road construction.

Cement

Chemical additives and possible cementitious additives, including pozzolans and water, are hardened materials with special engineering properties. In this study we will investigate and introduce the application of cement in the road construction industry. In this study, Portland cement type II was also used. Different percentages of cement were added to the soil at 2.5%, 5%, and 7.5% by dry weight of the soil. These contents of cement were previously used by other researchers [14]. Figure 3(a) shows a view of cement used. Chemical compositions of the cement

obtained from XRF results are provided in Table 2. Table 3 summarizes the physical properties of the Portland cement.

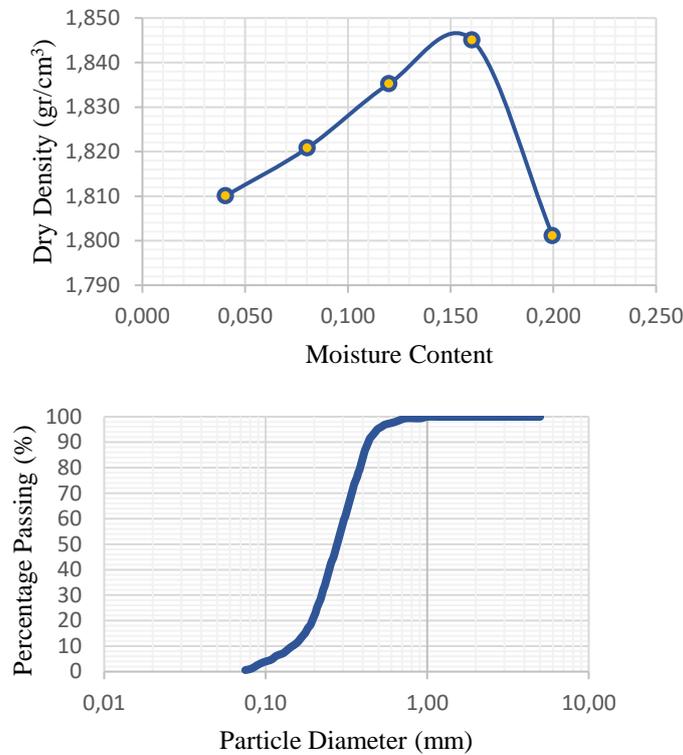


Fig. 1- Gradation curve(above), and compaction test results of the soil (below).



Fig. 2- A view of the sand collected from the planned site for the construction of the pavement.

Tab. 1 - Mechanical properties of the sand soil.

Parameter	Content	Unit	Standard used
Soil classification	A-3	-	AASHTO M 145 or ASTM D3282
G_s	2.7	-	ASTM D-854
CBR	28.5	(%)	ASTM D-1883
C	0.1	(kPa)	ASTM D-3080
ϕ	46	(degree)	ASTM D-3080
ω_{Opt}	16	(%)	ASTM D-698
γ_{max}	1.845	(g/cm³)	ASTM D-698



Fig. 3 - A view of the Portland cement type II (left), and FN-fiber (right)

Tab. 2 - Chemical compositions of the Portland cement type II used in the experiments.

Chemical compositions	Percentage (%)
SiO ₂	20
Al ₂ O ₃	6
Fe ₂ O ₃	6
MgO	5
SO ₃	3
LOI	3
Insoluble residue	0.75
C3A	8

Tab. 3 - Physical properties of the Portland cement.

Physical properties	Value	
Specific area of 1 cm ² /g	2800	
Expansion of autoclave test (%)	0.8	
Setting time with Vicat method	Initial (min)	45
	Final (hour)	6
Compressive strength (kg/cm ²)	3 day	100
	7 day	175
	28 day	315
Hydration heat (Cal/g)	70	

Fibrillating Network Fiber

The fiber used in the present study is classified as Fibrillating Network fiber (FN-fiber), which was added to the soil by 1%, 1.5%, and 2.5% by dry weight of the soil. Similar contents were also used by other researches [15]. In this study, a commercial fiber, known as "Forta" fiber, was used. Table 4 shows a view of the FN-fiber and its properties, respectively. Compared to two-dimensional fibers, 3D fibers can be used in advanced technologies due to their properties such as thickness, shear strength, tear tolerance and damage that are important for many applications. In addition, its multi-directional structures can lead to increased stiffness and strength characteristics by further strengthening the thickness. Soil and fiber mixture samples. Compression strength test was conducted based on ASTM C-109 standard. Compressive strength was measured using 2 kN loading capacity compression device. To investigate the effects of freezing and thawing process on the strength properties of the samples, different cycles of freezing-thawing were considered based on ASTM D-560 standard. Bearing capacity of the soils is one of the effective and important parameters in road and pavement constructions. For this purpose, California bearing ratio (CBR)

test was conducted based on ASTM D-1883 standard. Compressive strength experiment, measuring deformation in the failure moment and the California bearing ratio for samples with different content of cement and FN-fiber was carried out. FN-fiber in 1%, 1.5% and 2% and cement in 2.5%, 5% and 7.5% by the dry weight of soil are added to the soil. For constructing sample, sand, given the desired frame volume and calculated density in compaction experiment, cement and FN-fiber in defined weight ratio respect to dry weight of soil are weighed and used. The mentioned materials with optimum moisture content plus the same content of cement, water were added and were mixed to obtain the uniform and homogeneous mixture. Resulting compound is molded and compacted. For curing, it was kept in the enclosure to perform the chemical reaction of the cement in the compound and to increase the strength of the samples, for three days and then was experimented [16]. Figure 4 shows an image of samples used in the experiment.



Fig 4- Stabilized sand samples with cement and reinforced with FN-fibers (right). Close view of reinforced and stabilized samples (left)

RESULTS AND DISCUSION

Compressive Strength and Deformation Experiment

Compressive strength and deformation in the failure moment of soil mixed with cement and FN-fiber were measured. Addition of FN-fiber and cement, will improve the sand soil strength. In Figure 5, the view of how the fiber and soil are interlocked is shown. FN-fiber in soil are deformed after applying the normal force and the interlocking created between soil particles and fiber in this stage and also the friction force between soil particles mobilized the tensile force in fiber and increase the compressive strength [17]. In Figure 7 and Figure 8 the simultaneous effect of cement and FN-fiber on the compressive strength and deformations is shown. In fixed FN-fiber content, by increasing the cement content, the compressive strength and deformation are increased and reduced, respectively. In fixed cement content, by increasing the fiber up to 1.5 %, the compressive strength increased and after this content reduced. Therefore, fiber content up to optimum amount will lead to increase in compressive strength [18]. But, the amount of change of deformation shows an incremental trend by increasing the FN-fiber content. Therefore, according to Figure 6, maximum compressive strength is obtained in 7.5 % of cement and 1.5 % of FN-fiber. In Figure 7, soil mixed with the minimum amount of cement and the most FN-fiber has the maximum deformation.



Fig. 5 - The view of how FN-fibers and soil interlocked, application of FN-fibers for preventing crack in loading moment

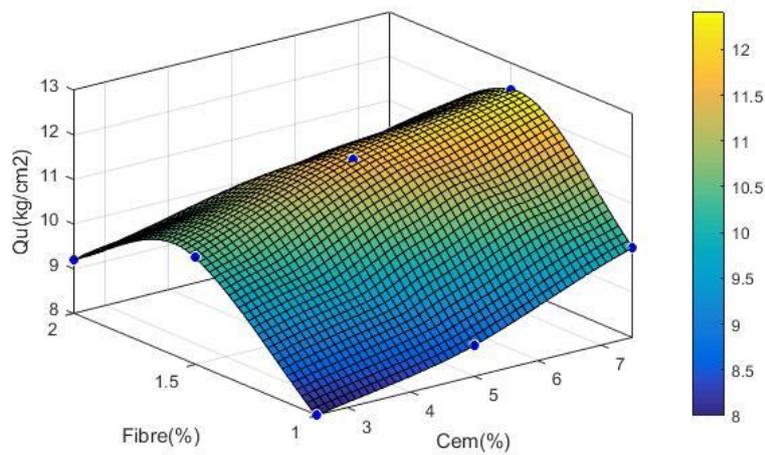


Fig. 6 - Investigation of the simultaneous effect of FN-fibers and cement on the compressive strength of modified sand soil

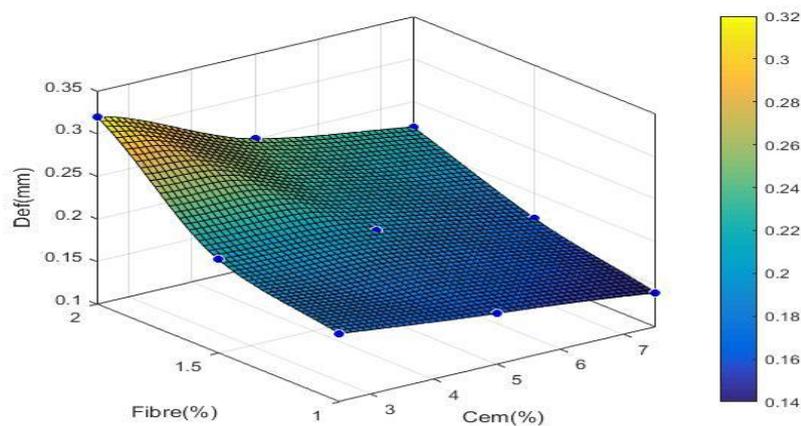


Fig. 7- Investigation of the simultaneous effect of FN-fibers and cement on soil deformation

CBR Test

In order to more proper investigation of efficacy of this type of soil improvement in road construction, CBR test was used. Figure 8 shows the effect of simultaneous mixture of cement and FN-fiber on the CBR value and as can be see, in fixed FN-fiber content, increasing the cement content, the value of the California bearing ratio is increases too. Increasing the FN-FN-fiber content, in fixed content of cement, lead to decrease in California bearing ratio. According the result obtained from previous deformation experiment, this result seems acceptable. Therefore, maximum amount of California bearing ratio same as deformation in previous section is obtained in mixing soil with minimum FN-fiber content and maximum cement content.

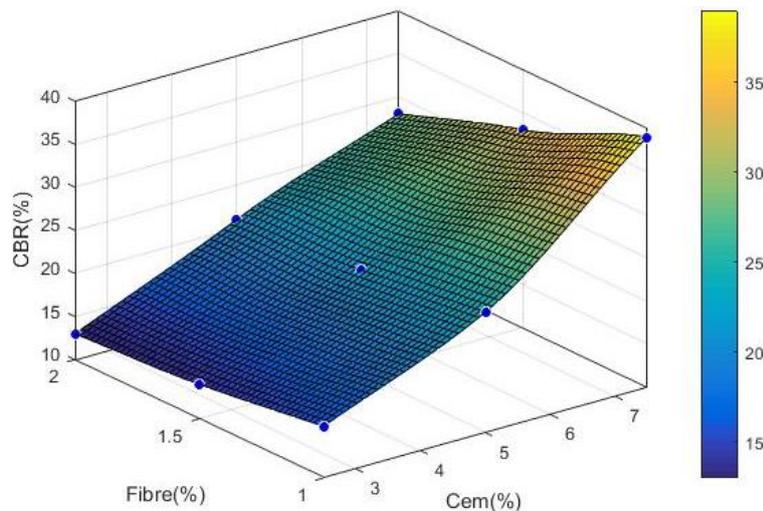


Fig. 8 - Investigation of the simultaneous effect of FN-fibers and cement on CBR

Figure 9 shows the changes of soil elasticity module in simultaneous mixing of cement and FN-fiber. Some researchers in their researches sought to find the relation between California bearing ratio and modulus of elasticity [19]. In all available relation, the California bearing ratio and elasticity modulus have direct proportion. Therefore, by increasing the cement ratio, the elasticity modulus of soil increases too and the maximum value of elasticity modulus in soil mixed with maximum cement content and minimum FN-fiber content is achieved.

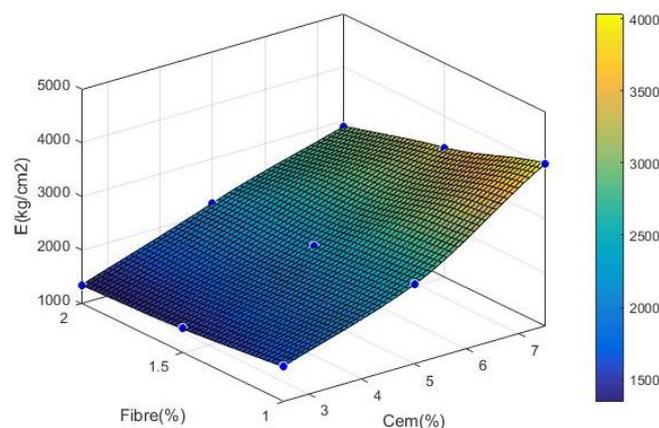


Fig. 9 - Investigation of the simultaneous effect of FN-fibers and cement on elasticity modulus

Freezing-Thawing Cycle

Another parameter investigated in the present study, is the strength loss due to applying freezing-thawing cycle. Results are shown in Figure 10. The standard for carrying out the experiment is ASTM D-560. According to that freezing-thawing cycle in sand subgrade, specifically in desert areas is limited and small, the few cycle numbers are selected for the present study. As can be seen, increasing the number of freezing-thawing cycles, will increase the strength loss. Such that, up to 25 percent of strength of stabilized layer will reduce. Past research has shown similar results, with the use of the freeze-thaw cycle significantly reducing soil stability. [20]. Gazavi and Roustaei, (2010) showed that increasing the number of freezing-thawing cycle, results in decrease of compressive strength of soil and stabilized soil up to 20-25 percent [21].

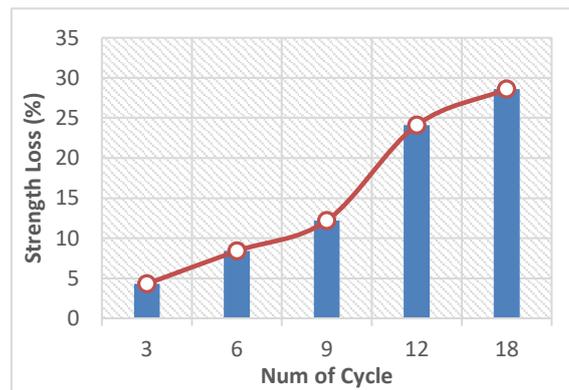


Fig. 10 - The effect of number of freezing-thawing cycle on the amount of strength loss

CONCLUSION

With aim of increasing the durability and the strength of sand bed and improving the pavement, cement and FN-fiber were used in different content. In order to investigate the effect of this type of improvement on the performance of sand layer in the road pavement, compressive strength, deformability and California bearing ratio were measured and finally, the results were used in software analysis. The obtained results are as follows.

1. Adding cement and FN-fiber to soil, improved the compressive strength of soil. In fixed FN-fiber content, by increasing the cement content, compressive strength was increased up to 25 percent. In fixed cement content, increasing the FN-fiber content up to an optimum value, increased the compressive strength, and by further increase compressive strength decrease.
2. In fixed cement content, by increasing the FN-fiber content, deformation in the failure moment increases and in fixed FN-fiber content, by increasing the cement content, deformation reduces, and in other words, the presence of FN-fiber results in the ductile behaviour of the stabilized layer.
3. Minimum FN-fiber ratio and maximum cement content, results in maximum California bearing ratio and elasticity modulus. Compare with Primary pure soil, in this case the California Bearing Ratio and elasticity modulus tripled.
4. Applying freezing-thawing cycle, reduced the soil strength and by increasing the number of cycles the rate of this reduction of strength increases. So that, the initial resistance of the sample is reduced up to 25%.

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