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POZZOLANIC MATERIALS ROLE IN ENHANCEMENT OF MECHANICAL PARAMETERS OF THE DUNE SAND

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Research on ways to increase the resistance of weak soils to build structures on it has been increased in recent years. The present article provide the effects of different mixtures containing microsilica, cement, polypropylene waste fiber and dune sand on mechanical parameters such as, compressibility, compressive strength, bending strength and durability characteristic. In this study also is investigated evaluation the effect of road subgrade based on proposed material. The used dune sand in this research was obtained from Kashan city where is located in central desert of Iran. The obtained results show that the microsilica and cement could play a major role in reducing the cost and required time for building roads and also building foundation on these types of soils.

Keywords: *dune sand, fiber, cement, microsilica, stabilization*

1. Introduction

In the recent few decades, types of materials are used for stabilizing soils in which the applicability mainly relies on the objectives of stabilization, the types of soil, specific usages, the nature of climate and the economic factors. A wide area of world are covered with dune sand and every year, movement of this dune sand leads to social and health effects for residents of marginal parts of the cities located in these sandy areas. Therefore, stabilization of dune sands are important in construction projects such as road construction projects if do encounter by this kind of soils. This research aimed to provide a simple method and very cheap materials for enhancing strength and durability of this kind of soils. To this end, microsilica was used as a form of pozzolanic materials. Recently, release of microsilica from chimney of factories is led to air pollution. Nowadays, this material is mostly employed in production of some special types of concrete. However, the first aim of this paper is to examine effects of this cheap and abundant material on resistance of dune sand in roads subgrade. There are different methods of sand stabilization that have been previously proposed in the literature such as use of cement [1,2]; cement-by-pass dust [3,4], bentonite [5], coal fly ash [6-8] and asphalt [9].

The second aim of this study is to examine effects of waste fiber of carpet in addition to studying microsilica effect on the examined soil. Generally, soil mixing with fibers creates a combined environment, in which mixture of fiber components with soil seeds can be effective for strength and ductility of soil in different directions. Lee, et al. (1973) [10] conducted studies about use of fibers on soil reinforcement and increase of shear strength of sand mixed with plant fibers in triaxial tests under static loading was also reported. Benson and Khire (1994) [11] investigated effects of changes in shear strength and stiffness of sand using polyethylene chips and concluded that adding polyethylene chips to soil increased California Bearing Ratio (CBR), shear strength and modulus of sand substrate reaction. Ranjan, et al. (1996) [12] conducted triaxial tests on sand samples reinforced with fibers and showed that fibers had a positive impact on shear strength of the samples.

There are various factors that could effect on stabilization process. Karimi and Ghorbani (2011) [13] introduced some of these factors as following:

1. Type of soil and its chemical and physical properties
2. Stabilizer factor
3. Amount of stabilizer
4. Potential use of stabilized soil
5. Soil and stabilizer mixing techniques
6. Economic review

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In this study all the mentioned factor in above are considered and the results shows that the cost of road construction are decreased.

2. Materials and methods used

2.1. Sand

Sand was sampled from north of Kashan city and desert countryside of Maranjab located in central area of Iran. This soil was prepared from depth of two meters and it was attempted to be devoid of organic matter and plant roots (Figure 1).

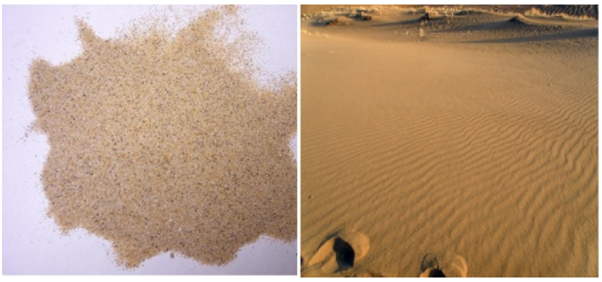

Fig. 1 - Dune sand used in this research

2.1.1. Chemical analysis on the tested soil

The tested soil had chemical characteristics as shown in Table 1 and Table 2.

2.1.2. Grain size analysis on the examined soil

Grain size analysis was performed based on the ASTM D422 (2007) [14]. The following results were obtained from the graph displayed in Figure 2.

Uniformity coefficient Cu=2.53

Curvature coefficient Cc=1.024

According to these results it is concluded that considered soil in this research is from kind of Poor Sand or SP based on unified regulation.

2.1.3. Density test of the soil

According to ASTM standard, density of examined soil is obtained around 1340 Kg/m^3.

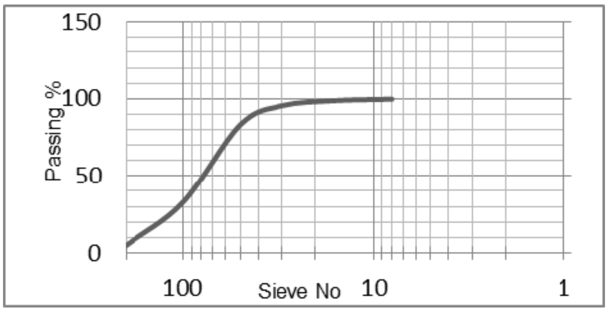

Fig. 2 - Soil Grain size Graph

2.1.4. Modified density testing

Based on the ASTM D1557 (1970) [15], modified density testing was performed on the soil. The graph displayed in Figure 3 is obtained from result of this test.

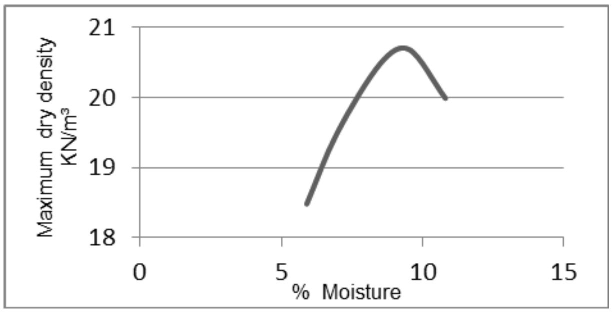

Fig. 3 - Modified density testing Graph.

The following results were obtained from the graph showed in Figure 3

The maximum dry density=20.688 KN/m³

The optimum moisture = 9.53 %

2.2. Microsilica

Microsilica is a very fine pozzolanic material, composed of mostly amorphous silica produced by electric arc furnaces, during the production of elemental silicon or ferro silicon alloys. In Europe, until late 1960s and, in the United States, up to mid-1970s, microsilica was simply released into the atmosphere by industrial

Table 1

Chemical and physical analysis results of examined soil

Description	Sp[(1)] %	Ec[(2)] Ds/m	pH[(3)]	Gypsum %	T.N.V[(4)] %	Physical experiments			
						S[(5)] %	Si[(6)] %	C[(7)] %	Soil type
Value	25.92	5.81	7.85	0	21.26	74	12	14	S.L[(8)]

(1) Saturation Percentage,
(2) Electrical Conductivity,
(3) Acidity,
(4) Total Neutralizing Value
(5) Sand,
(6) Silt (7) Clay (8) Sand with Low adhesion

Table 2

Chemical analysis results of examined soil

Description	CO_3^{2-} %	HCO_3^- %	CL^- %	SO_4^{2-} %	Ca^{2+} %	Mg^{2+} %	Na^+ %	K %
Value	0.00	0.015	0.066	0.202	0.049	0.017	0.055	0.005

smoke. Nowadays, each year, nearly 100,000 tons of this material is currently produced. Iran also has a large level of microsilica production. The microsilica used in this research is in gray color (Figure 4).

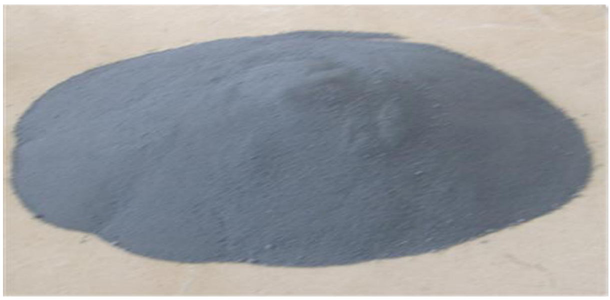

Fig. 4 - Microsilica used in specimens

2.2.1. Chemical analysis on the microsilica

Chemical properties of the examined microsilica in this research are shown in Table 3.

2.2.2. Atterberg limits tests on microsilica

Atterberg Limits tests were carried out on the microsilica based on ASTM D424 (1971) [16] and ASTM D423 (1972) [17]. According to the graph in Figure 5, the content of liquid limit became LL=60.4%.

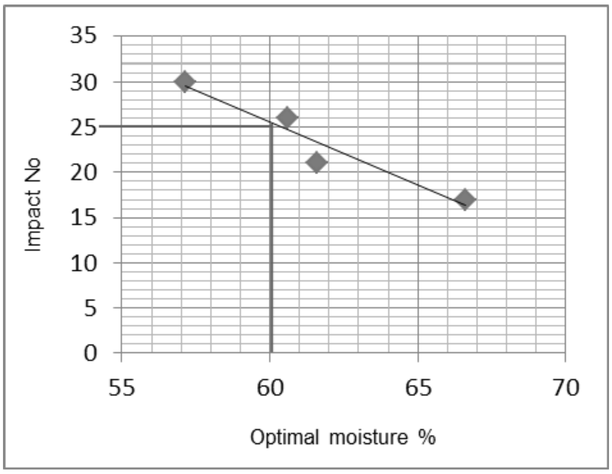

Fig. 5 - Liquid Limits Graph.

Based on plastic limit testing, the amount of the plastic limit was PL =41%; and consequently, the plastic index became PI=19.4%.

2.2.3. Density test of the considered microsilica

The result of density test on the microsilica, according to ASTM, was 249.3 Kg/m^3.

2.3. Fiber

Fibers used in this study were obtained from waste fibers of carpets by carpet factories. These fibers were abundantly found in the Kashan region and were made of polypropylene (PP). The maximum length of the fibers used in this study was 2 cm, which was made by scissors. Also, it is worth noting that the fibers were randomly mixed with soil. Figure 6 shows the sample fibers used in this study. As can be seen from this figure, the fibers were not homogeneous and contained several types of fibers. Also, these fibers are used with colored surface.

Fig. 6 - Sample fibres used in this study.

2.4. Methods used

This paper investigated desert dune sand sampled from Maranjab desert, located in outskirts of Kashan, Iran, using cement, microsilica and fiber. A series of tests were performed to study effect of random distribution of waste polypropylene fibers, cement and microsilica on strength and mechanical parameters of dune soil. Effect of cement, microsilica and fibers together and separately were determined on compressive strength and bending strength, shear strength and durability of the dune soil samples.

3. Results and discussion

3.1. Determining optimum amount of microsilica in the dune soil

3.1.1. Density testing to determine optimum moisture percent and maximum dry density

In order to find the optimum amount of microsilica, at first, according to Table 4, different amounts of microsilica and fixed amount of cement were mixed (these cement percentages were based on the soil type and selected from American Association of State Highway and Transportation Officials (AASHTO) regulations) with the dune soil. Afterwards, for each mix composition, maximum dry density and optimum moisture content were obtained according to the ASTM D1557 (1970) [15] standard (Figure 7).

Table 3

Chemical characteristics of microsilica

Chemical characteristics	MgO %	CaO %	Fe_2O_3 %	AL_2O_3 %	SIO_2 %	C %	Na_2O_3 %	S %	MnO %	P_2O_5 %	LoI %	Moisture %	pH
Value	1.5	1.2	1.1	1	92.85	0.3	0.4	0.05	0.06	0.04	1.2	0.3	7.5

Table 4

Different modes mixing microsilica and soil and cement

Mix composition	Microsilica (%)	Soil(%)	Cement(%)
1	0	94	6
2	5	89	6
3	10	84	6
4	15	79	6
5	20	74	6
6	25	69	6
7	30	64	6
8	35	59	6

Fig. 7 - Density testing based on ASTM D1557-70 standard

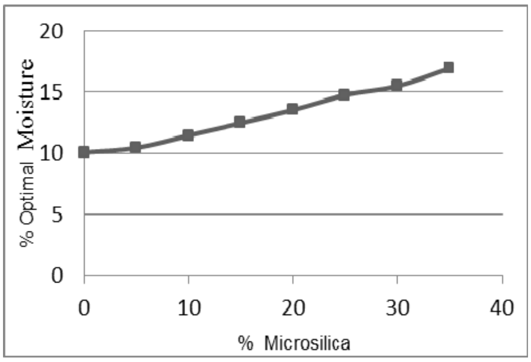

Fig. 8 - Microsilica amount and optimal moisture graph.

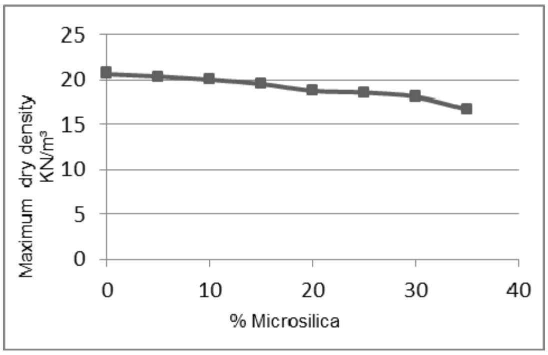

Fig. 9 - Microsilica amount and maximum dry density graph.

As can be seen in Figure 8 and Figure 9, with increase in the amount of microsilica, optimum moisture was increased while the maximum dry density was decreased, which could be due to low density and high surface area of microsilica.

3.1.2. Compressive strength tests on the specimens

Compressive strength tests were carried out on cubic samples with dimensions 7×7×7 cm. The results of these tests are presented in Figure 10. As can be observed, with increasing microsilica, compressive strength of the specimens 28-days increased up to 30% microsilica, after which, it decreased. If compressive strength was as the main criterion, addition of the 30% of microsilica of total weight of the specimen could be considered the optimal amount.

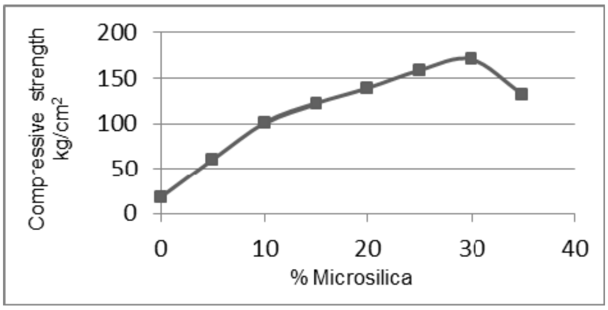

Fig. 10 - Microsilica amount and compressive strength graph.

3.2.Determining optimum amount of fibre in the dune soil

3.2.1.Density testing to determine optimum moisture percent and maximum dry density

To determine optimal amount of fiber in this soil, at first, the optimum moisture content and maximum dry density were determined accordance to the conditions specified in Table 5. Then, for each mix composition, the maximum dry density and optimum moisture content were obtained according to the ASTM D1557 (1970) [15].

Table 5

Different conditions for density test

Mix composition	Fibre (%)	Cement (%)	Microsilica (%)	Dune sand (%)	Total (%)
1	0.25	6	30	63.75	100
2	0.50	6	30	63.5	100
3	0.75	6	30	63.25	100

The results of these experiments are shown in diagram of fiber- maximum dry density in Figure 11 and diagram of fiber-optimum moisture content in Figure 12.

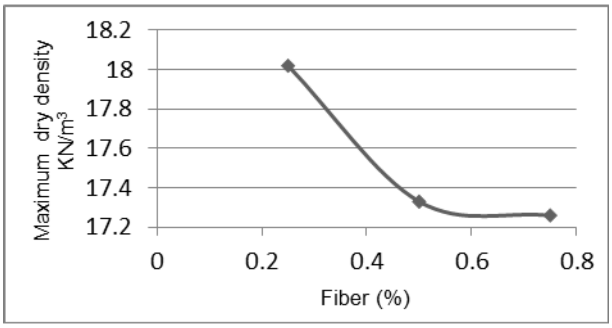

Fig. 11 - The changes diagram of fibre% and maximum dry density (in a mix composition of 30% microsilica + 6 % cement).

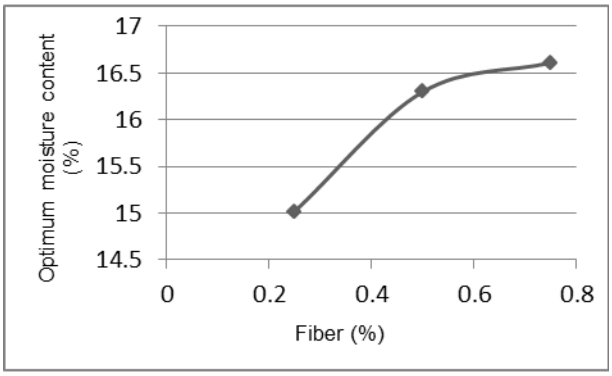

Fig. 12 - The changes diagram of Fibre% and optimum moisture content (in a mix composition of 30% microsilica + 6 % cement).

3.2.2. Compressive strength tests

Compressive strength test on the samples 28-days with size 7×7×7 cm in condition of the optimum moisture content and maximum dry density was performed in accordance with the mix composition specified in Table 5. The obtained results are shown in Table 6 and diagram of fiber-percent-compressive strength in Figure 13.

As can be seen in Figure 13, with increasing the amount of fiber, compressive strength of the samples was reduced. This phenomenon could be due to colors on fibers, which reduced adhesion of the sample to fibers and thus reduced their compressive strength.

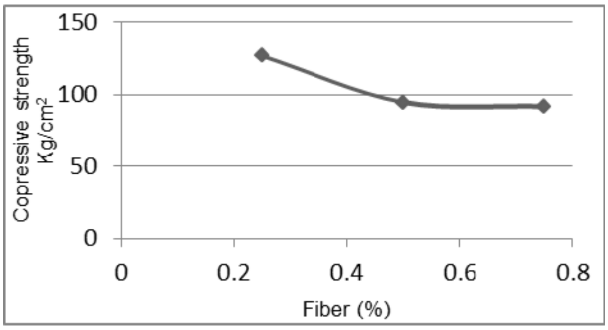

Fig. 13 - Changes graph of compressive strength-fibres percentage.

3.2.3. Small-scale direct shear tests on the specimens

Small-scale direct shear tests on the specimens without and with fibers were performed according to ASTM D3080 [18]. The specimens required of small-scale direct shear test were made based on the conditions specified in Table 7.

Results from small-scale direct shear tests in condition of optimum moisture content and maximum dry density according to Table 7 are shown in Table 8.

The results of Table 8 show that, with increasing fiber to specimens in conditions 3 to 5, adhesion was reduced; this phenomenon could be due to colors on fibers' surface that reduced soil adhesion to fibers. But, angle of internal friction of the specimens increased until 4th mix composition and decreased with increasing fibers; this fiber amount (i.e. 0.50 %) can be an optimal value for the angle of considered specimens internal friction; but, due to a sharp decrease in adhesion, it cannot be approved in this mix composition.

Table 6

Results of the compressive strength average of three specimens

Mix composition	1	2	3
The average 28-day compressive strength (kg/cm²)	126.81	94.82	91.86

Table 7

Determined different condition for the direct shear test

Mix composition	Microsilica (%)	Cement (%)	Fibre (%)	Sand (%)	Total (%)
1	0	0	0	100	100
2	30	6	0	64	100
3	30	6	0.25	63.75	100
4	30	6	0.50	63.50	100
5	30	6	0.75	63.25	100

Table 8

The values of C, Φ obtained from direct shear diagrams

Mix composition	$C^{(1)}$ (KN/m²)	$\Phi^{(2)}$(˚)
1	16.81	39
2	89.58	49
3	65.96	52
4	30.25	65
5	23.36	62

(1) Cohesion (2) Angle of internal friction

Table 9

Different conditions for perform of testing the bending strength

Mix composition	Cement (%)	Microsilica (%)	Fibre (%)	Flowing sand (%)	Total (%)
1	6	30	0.25	63.75	100
2	6	30	0.50	63.50	100
3	6	30	0.75	63.25	100

3.2.4. Bending tests on the specimens

Bending strength tests were performed on the specimens that were made based on specified conditions in Table 9. This test was for determining tolerable bending strength in various states of fibers. The specimens of these experiments were fabricated in dimensions 4×4×16 cm and cured for 28 days as immersed in water (Figure 15).

Fig. 15 - Bending test specimen.

The results of bending strength tests on the specimens containing fibers according to the conditions specified in Table 9 are given in Table 10.

Table 10

Average bending strength of specified conditions

Mix composition	Bending strength (kg)
1	153.67
2	143.75
3	133.75

As can be seen in Table 10, bending strength of the specimens decreased with increasing fiber content. The reason for this phenomenon can be adhesion decrease by increasing fiber content in the specimens. As mentioned in the previous section, reduction of adhesion can be due to color on fibers surface. However, for more investigation, it is required to perform microscopic experiments on the specimens, which was not in the scope of this study.

3.3. Durability testing

The aim of durability testing on the specimens was to investigate built specimens reaction based on the optimum amount of microsilica through consecutive thaw and freezing. This test was performed based on the ASTM D560 (2003) [19]. Due to the poor results obtained from the specimens containing fiber, durability tests were performed on the specimens made without fibers. For this research, the specimens were required to be in size 7×7×7 cm; furthermore, they were cured for 28-days. The maximum and minimum temperatures used in these tests were 40 and -5 degrees Celsius (inquired from Kashan meteorology station), respectively. Following the durability testing, the specimens were tested for compressive strength. The results showed an increase 5 % in compressive strength; this phenomenon could be attributed to the presence of cement in the specimens; however, this issue must be investigated more specifically and accurately.

The result of this test shows that the average of weight loss of the two specimens was 7.34%; which according to AASHTO T161-05 (2008) [20] it was in the standard limit.

3.4. Evaluate the effect of research

To study the impact of this research, one hypothetical road was designed twice; once based on the condition in which the sub-base material was stabilized by the method provided in this research (i.e. 30% microsilica and 6% cement) and once more under the condition in which sub-base material was a mixture of sand and gravel. In both modes, the design was based on the AASHTO method. The obtained results are shown in Table 11.

Table 11 shows that thickness of the sub-base, base and surface layers was reduced to 14.3, 40 and 33 percent, respectively, which would improve the productivity.

Table 11

The layers thickness in economic evaluation

Layer name	Surface layer	Base	Sub base
Layer thickness in the mode that sub base is of kind of stabilized dune sand (cm)	10	15	30
Layer thickness in the mode that sub base is of kind of dune sand and gravel (cm)	15	25	35

4. Conclusions

This article investigated desert dune sand prepared from Maranjab desert, located in outskirts of Kashan, Iran, using cement, microsilica and fiber. A series of tests were performed to study effect of random distribution of waste polypropylene fibers, cement and microsilica on strength and mechanical parameters of dune soil. Effect of cement, microsilica and fibers together and separately were determined on compressive strength and bending strength, shear strength and durability of the dune soil samples. The results of these experiments were as follows:

1. By increasing microsilica and fiber maximum dry density of the specimens is decreased.
2. By increasing microsilica and fiber optimum moisture content of the specimens increased.
3. By increasing microsilica, compressive strength increased up to 30% microsilica and, after that, it decreased.
4. Durability tests showed that, with 30% microsilica and 6% cement, dune sand had reliable durability against consecutive thaw and freezing cycle.
5. The results of this paper showed that thickness of the sub-base, base and surface layers was reduced to 14.3, 40 and 33 percent, respectively (by using of 30% microsilica and 6% cement), which improve the productivity.
6. In compressive strength test of specimens with fiber, by increasing fiber the compressive strength of the specimens is decreased.
7. In direct shear test of specimens with fiber, by increasing fiber the cohesion of the specimens is decreased.
8. In direct shear test of specimens with fiber, it was determined that the optimal amount of fiber for angle of internal friction was 0.5 %.
9. In bending strength test of specimens with fiber, by increasing fiber the bending strength of the specimens is decreased.

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