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Effect of Broken Tile Waste on Strength Parameter of Dune Sand

Mohammad Khabiri* and Bahareh Ebrahimialavijeh

Faculty of Civil Engineering, Yazd University, Yazd, Iran.

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Abstract

Nowadays, the limitation of borrow resources with suitable soil in the roadbed, especially in sandy soil areas, has caused the existing soils to be improved by engineering methods. Since the focus in the central regions of Iran is on the tile industry, and a large part of the soil in the region is sand, so broken tile waste (BTW) is recommended to stabilize the pavement subgrades. Because sand and broken tile wastes have not enough adhesion, so a small amount of cement has been used to create the adhesion. In the present study, two Particle size of tile wastes at10%, 20% and 30% by soil dry weight and cement at 2.5%, 5% and 7.5% by soil dry weights have been used. Unconfined compressive strength, California Bearing Ratio (CBR) and durability tests were performed for created mixtures. Results showed that increase in cement content has led in increase the durability, CBR and compressive strength, but in CBR test, increasing the BTW content up to 20% caused increasing the CBR and above this has a reverse effect. The CBR was increased from 19% to maximum 83% and 89% for fine-grained and coarse-grained BTW, respectively. The maximum unconfined compressive strength was 3.7MPa and 3.2MPa for coarse and fine-grained BTW, respectively. Durability test also showed that increasing the BTW (both coarse and fine-grained)content up to 20% is optimal.

Keywords: Dune sand, stabilization, Tile Waste, CBR test, Compressive test, freeze-thaw cycle

1. Introduction

Usually, quicksand is not ideal for bearing the pavement loading alone at the site of road and railway building. Mechanical properties of sand soils are affected by soil structure, density, grain distribution, shape and mineralogy, soil interlocking degree, particles adhesion and shape. Non-sticky fine-grained soils such as quick (dune) sand, are not applicable unlimitedly and without additional adhesives in the flexible pavement of subgrade.

Compressive strength and operation against wet environmental conditions and freezing of dune sand soils are among the most important issues in the geotechnics and pavement engineering. Another environmental problem is the production of broken tile waste (BTW), which in Iran the production of this waste reaches at least 4000 tons. It can save a lot and benefit the ecosystem if it can be used optimally. In other countries with a ceramic tile industry, the development of such waste materials is also high. By replacing these wastes, the amount of cement usage for stabilizing this type of soil is reduced. Therefore, in the present study by replacing particles with coarser dimensions and adding adhesion materials, the strength of sand subgrades can be reinforced. This means that both improvement methods including modification grading and adhesion can be used simultaneously.

One of the methods for improvement and modification of subgrade soil is using the stabilizing methods. Various materials such as lime, cement and some polymeric materials have been used by several researchers for soil stabilization (Dutta, 2008; Tang et al., 2007; Rezaeimalek et al., 2017; Mousavi and Karamvand, 2017; Al-Tabbal and Al-Zboon, 2019, Liu et al., 2019; Saride et al., 2013; Consoli et al., 2010). Using cement in soils has increased strength parameters of soil and also has increased the soil fragility (Jamshidi et al., 2018). Using waste materials in development projects has led to a reduction in costs and also helped the environment. The waste materials include recycled asphalt and waste construction materials (Khabiri, (2010)). Using recycled asphalt in the soil has led to increase in bearing capacity and strength soil and has made the soil suitable for use in base or subbase layer (Hasan et al., 2018; Mousa et al., 2017; Alhaji and Alhassan, 2018; Cabalar et al., 2016a and Cabalar et al., 2016b). James and Pandian (2014) investigated the effect of broken ceramic on the compressive strength of clay soil stabilized with cement. Their results showed that increasing the broken ceramic percentage will increase the compressive strength of clay stabilized with cement. Application of BTW in loose black clay has improved strength parameters of the soil for use in subgrade construction (Raghudeep et al., 2015; Al-slaty, 2018). Same results were obtained for expansive soil (Rani et al., 2014; Sumayya et al., 2016; Kumar et al., 2015; Sabat, 2012). Ameta et al. (2013) investigated the application of waste tile in the dune soil. The results of direct cutting and CBR test indicate the improvement in the strength parameters of dune soil by adding broken tile. Cabalar et al. (2017) studied the use of construction and demolition materials with clay and natural aggregate utilization for road pavement subgrade. They found that the use of construction and demolition materials could be mixed with clay at specific contents for road pavement subgrade in order to reduce the environmental and economic problems across the world.

* Corresponding author e-mail: mkhabiri@yazd.ac.ir

Cabalar et al. (2016 b) found that the addition of construction and demolition materials to the clay reduced the optimum moisture content and increased the unconfined compressive strength. Also, the swelling percentage of the clay was found to decrease with an increase in the amount of waste material.

Therefore, given the necessity of using these soil improvement methods in the sand subgrades and also the emphasis on the use of tile wastes, more detailed studies are needed to be done in this field. This study aims to investigate the effect of the addition of tile wastes in different sizes, fine and coarse-grained, with different cement ratio, also investigates the effect of research variables on the stabilized sand subgrade by using pavement subgrade-related standard tests including soil capacity bearing ratio (CBR), durability and unlimited compressive strength. Also, the effect of freezing in the Freeze-thaw cycle has been investigated. The elasticity module obtained from different soil cases in numerical analysis software was used and the amount of deformation of modified subgrade soil and rutting life were calculated separately. The innovation of the present study is the simultaneous investigation the effect of two sand subgrade modification methods on the performance, and also the effect of use of BTW on the sand subgrade soil modification which has not been addressed in the previous studies.

2. Materials and methods

2.1 Sample Preparation

The soil used in this analysis is sandy soil from the Ardakan-Yazd plain (Figure 1), which is located at a latitude of 29°36 to 33°22 in the north and a longitude of 52°48 in the east and 56°36 in the north. This type of soil can be found in wide areas of middle-east and other countries with the climate of desert regions. The specifications of this soil have been defined based on the ASTM standard and are provided in Table 1.

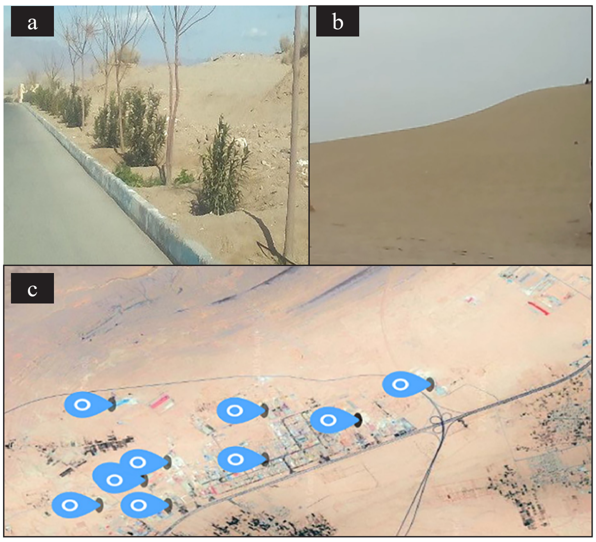

Figure 1. (a). Position of the path along the dune sands. (b). The volume of dune sand hills. (c). Location of tile factories located in the studied area.

Figure 2 shows the grading of this soil, which based on this grading and the specifications of Table 1 as well as based on the ASTM: D421, D422 standard, the naming of this soil will be SP. Thermal conductivity of these type of soils in terms of (w/m°k) is 0.795.

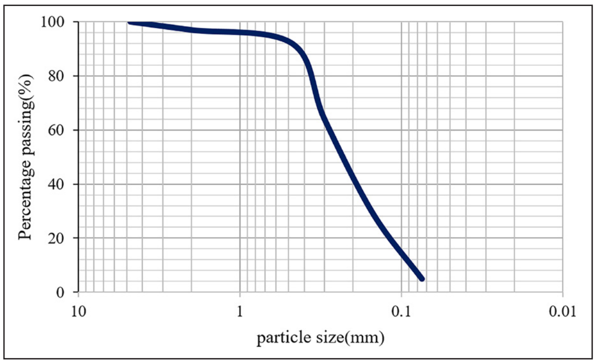

Figure 2. Particle size distributions for sand.

Based on the studies of Golami et al (2015), the findings of the XRF test of the chemical sand compounds used in the geographical area of the present research are beyond the range of the change in Table 2.

Table 1. Specifications of dune sand soil sample of Ardakan-Yazd plain area.

Specifications	Standard No	Unit	Content
Liquid limit	ASTM: D 4318-00	%	4
Plastic Limit	ASTM: D 4318-00	%	-
Moisture content	ASTM:D2216-98	%	3
Optimum moisture content	ASTM:D698-00	%	8
Maximum dry density	ASTM:D698-00	gr/cm3	1.75
Specific gravity	ASTM:D4546-08	-	2.64

Table 2. Specifications of dune sand materials of the studied area, XRF test results, chemical compounds decomposition.

Detected element	Quantity (%)
SiO_2	48
Al_2O_3	8.3
MgO	4.5
P_2O_3	14
TiO_2	8
MnO	0.1
CaO	22.5
Na_2O	0.8
K_2O	19
Others	8.5

The cement used in the present study is manufactured from a cement type 2 plant with the commercial name “Tejarat Mehriz” which has the characteristics so that it can be used in general civil engineering projects and its specifications are provided in Table 3.

Table 3. Physical and chemical specifications of cement used in the present study.

<table>
<tr><th colspan="2">Chemical Properties of Cement</th><th>Abbreviation</th><th>Amount(Percent)</th></tr>
<tr><td colspan="2">Silicon oxide</td><td>SiO2</td><td>20</td></tr>
<tr><td colspan="2">Aluminium oxide</td><td>Al2O3</td><td>6</td></tr>
<tr><td colspan="2">iron oxide</td><td>Fe2O3</td><td>6</td></tr>
<tr><td colspan="2">Magnesium oxide</td><td>Mg O</td><td>5</td></tr>
<tr><td colspan="2">Sulfur trioxide</td><td>SO3</td><td>3</td></tr>
<tr><td colspan="2">Weight loss due to blush</td><td>-</td><td>3</td></tr>
<tr><td colspan="2">Remaining insoluble</td><td>-</td><td>0.75</td></tr>
<tr><td colspan="2">Three calcium aluminates</td><td>C3A</td><td>8</td></tr>
<tr><td colspan="2">Physical properties of cement</td><td colspan="2">Amount</td></tr>
<tr><td colspan="2">The specific surface area of 1 square centimeter per gram</td><td colspan="2">2800</td></tr>
<tr><td colspan="2">Extension of the autoclave test (percent)</td><td colspan="2">0.8</td></tr>
<tr><td rowspan="2">Setting time of ordinary Portland cement</td><td>Basic (min)</td><td colspan="2">45</td></tr>
<tr><td>Final(hours)</td><td colspan="2">6</td></tr>
<tr><td rowspan="3">Compressive (MPa)</td><td>3days</td><td colspan="2">10</td></tr>
<tr><td>7days</td><td colspan="2">17.5</td></tr>
<tr><td>28days</td><td colspan="2">31.5</td></tr>
<tr><td colspan="2">Heat hydration calories per gram</td><td colspan="2">70</td></tr>
</table>

Broken tile waste (BTW) was supplied from tile plants in the studied area with the commercial name "Meybod Tile Factory," which at first had sizes 20cm×20cm and 30cm×60cm, and part of the tile was broken or split into two parts and was broken manually with the compaction hammer in the laboratory. Figure 3 provides a sample of these broken, fine-grained and coarse-grained tiles along with other materials used in this analysis.

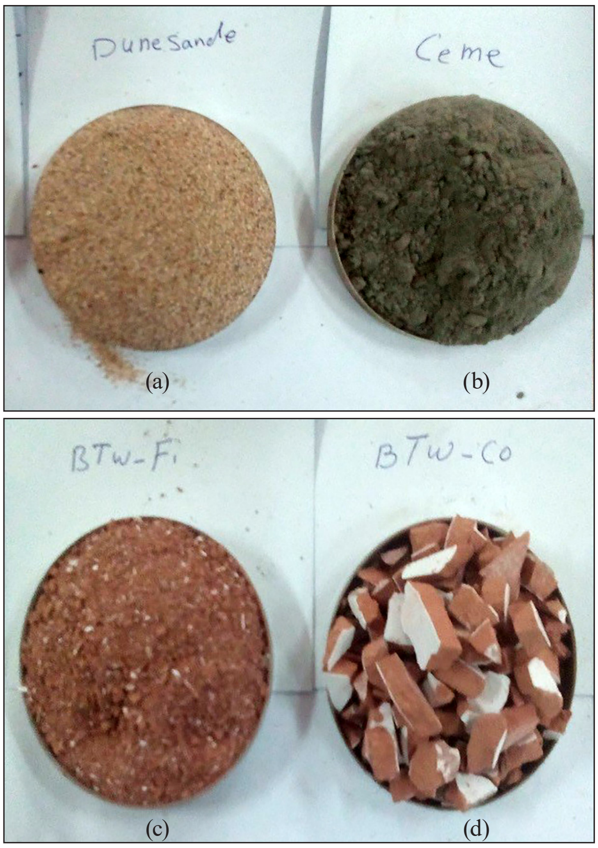

Figure 3. Consumable materials in the present study (a) dune sand, (b) cement type 2, (c) fine-grained BTW, (d) coarse-grained BTW.

Based on the findings of Tavakolia et al. (2013) and the grading of these two forms of broken tiles, the chemical components are differentiated by Figure 4 and Figure 5. The fine-grained and coarse-grained separation screening was 0.425 mm and the maximum size of the broken tile waste was 10 mm. Some of the specifications for these broken tile waste are given in Tables 4-5.

Table 4. Specifications of chemical compounds decompositions of tile.

Detected element	Quantity (%)
SiO2	69
Al2O3	18.5
MgO	0.72
P2O3	0.03
TiO2	0.73
SO3	0.06
MnO	0.08
CaO	1.5
Na2O	2.01
K2O	1.63
Fe2O3	4.81
LOI	0.5

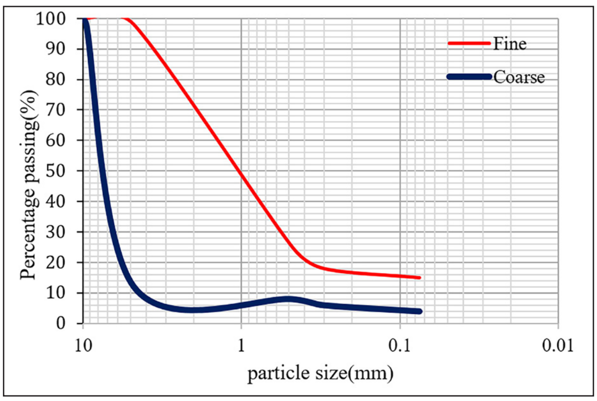

Figure 4. The particle size distribution of broken waste material (coarse-grained and fine-grained).

Table 5. Physical specifications of fine- and coarse-grained waste broken tiles.

Properties	Standard. No	Dimension of broken tile waste	
		Coarse-grained	Fine grained
Absorption of water	ASTM: C642-06	5	7
Particle Shape	IS- 2386-63	cubical angular-shaped	unpredictable
Bulky density	ASTM: C29-03	(gr/cm3) 2.33	(gr/cm3) 2.35
Coefficient of thermal conductivity	ASTM: C177-04	(w/m°k) 1.04	

3. Sample preparation and testing methods

Based on the previous researches include (Shooshpasha and Shirvani, 2015) and (Rudramurthy et al., 2019), the cement content for sand soils is in the range of 2.5% to 9% by soil dry weight. The maximum content of granular and solid wastes for addition to soils is about 15% (Prasanna, 2019). In the initial review of this study and before the main study it was found that the extreme use of broken tile waste has led to non-uniformity of the mixture and even has led to lack of adhesion which is in accordance with results of researches (Fauzi et al., 2016). In this study, the cement content was of 2.5%, 5% and 7.5% and BTW content was 10%, 20% and 30% by soil dry weight. Durability tests were also done for Freeze-thaw cycle. Since the road construction operation is done in a short time, the curing time was selected as 3 days. During the curing time, the samples were kept in a plastic bag to prevent moisture change. Based on the ASTM: C-109-07 standard, test specimens were made for durability and compressive strength tests and also these tests were done based on the ASTM: C-666-03 standard. For mixing the specimens, first, the sand was mixed with BTWand then the cement was added to the mixture and in less than 15min, it was entered in the standard mold and was compacted with a small hammer.

For determining the bearing capacity of modified sand subgrade soil a CBR test was done based on the ASTM: D1883-99 standard. For moisture used in the mixture, constant moisture (i.e.optimum moisture content) plus the percentage of water absorbed by the BTW and half of cement weight were added to the mixture.

4. Results and discussion

4.1. Compaction test

In this experimental study, the compaction test was performed for 6 different mixtures. The results of the present study can be applicable for compressive in the site. At Inroads pavement, operational standards defined minimum compaction of 95%, where of course is based on the road type and the amount of traffic (Kim and Kim, 2007). Figure 5 indicates the highest dry density difference at 5 percent of the cement material for both the fine-grained and the coarse-grained. According to this figure 5, it has been shown that the optimum moisture content and the maximum dry density of the soil has increased by addition to the untreated soil. It was found that the more the BTW became finer, the required moisture increased an also the maximum dry density is increased too. Increasing the coarse-grained BTW content in the soil reduced the optimum moisture and maximum dry density. In coarse-grained BTW, the glazed surface inhibits water absorption, which decreases the optimal soil moisture content. Also, the large grain size of the tiles and their lower density compared to sand particles, as well as the non-cohesive, will reduce the maximum dry density of the stabilized soil. Results of Taha et al. (2002) showed that increasing the recycled materials has a direct effect on the increasing the optimum moisture (Taha et al., 2002), when the particles are coarse, the water absorption of the ceramic particles is also higher than that of the sand particles, so they need more water per unit volume. Variations of maximum dry density of modified sandy soil is due to variation of BTW percentage and also due to the adhesion between sand soil particles.

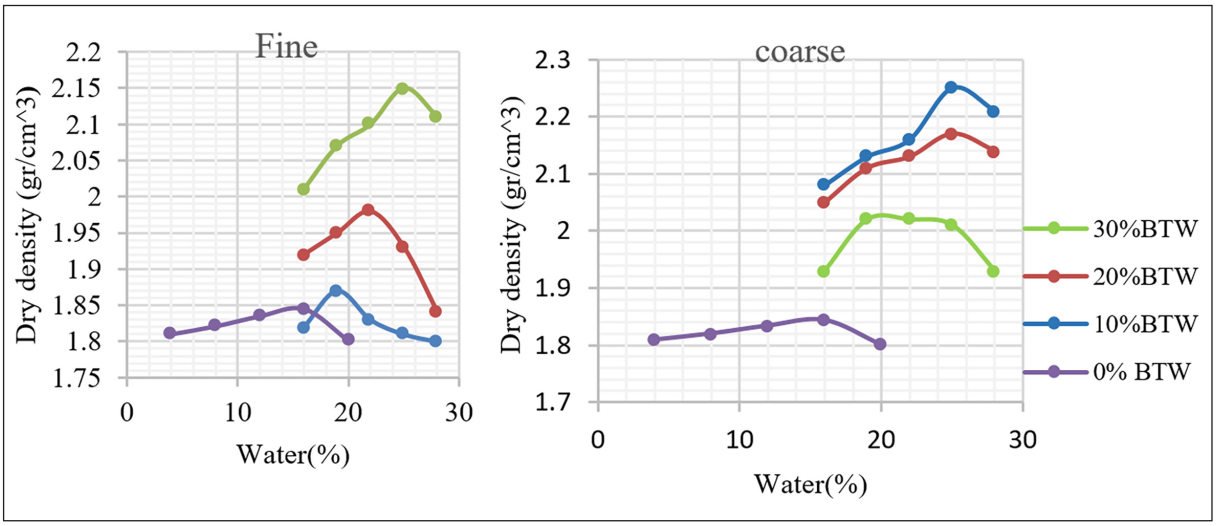

Figure 5. Variations of maximum dry density and optimum moisture in different percentages of BTW and cement (5%).

4.2. California Bearing Ratio test of sand

In the design of pavements, based on international standards, it is important to research the CBR of the subgrade to be specified (Patel et al., 2019) and hence the CBR variations with different content fine- and coarse-grained BTW and different content of cement have been studied and the results are shown in Figure 6. According to Figure 6, the addition of cement and BTW to the soil has increased the bearing capacity. Increasing the content of cement increases the bearing capacity and increasing the BTW content up to 20% increases the bearing capacity and then a decrease in bearing capacity is observed, which is quite evident in the figure. The test results show that the coarse-grained BTW has a higher bearing capacity. Therefore, the highest bearing capacity is obtained in soil that stabilized with 7.5% cement and 20% BTW, which was 89% for coarse-grained BTW and 83% fine-grained BTW. The bearing capacity of untreated soil is equal to 19%, so the carrying capacity with these stabilizers has increased more than 4 times.

4.3. Durability and compressive strength of stabilized soil

One topic which happened in subgrades is the possibility of freeze-thaw cycle occurrence. In the present study, the strength reduction in 3, 6 and 12 repeats of freeze-thaw cycles at moderate cement content and optimum content of BTW (20%) was investigated. These tests were performed for 5cm cubic specimens. The results showed that 3 and 6 cycles have not significant effect on stabilized sand soil and the reduction is about 3%, but in 12 repeats of freeze-thaw cycle, the reduction in strength reaches to 18%. These results are shown in Table 6. The coding of the samples in Table 6 is BXYC or BXYF. "X" represents the content of cement (%), "Y" the content of BTW (%), "F" means fine-grained BTW and "C" means coarse-grained BTW. The results of previous studies (Simonsen and Isacsson, 2001; Zhou et al., 2018; Xu et al., 2019) also showed that the number of cycles has a significant effect on the reduction of stabilized sand soil.

Table 6. Compressive strength variations of cubic specimen at different freeze-thaw cycle.

Sample Code	Compressive strength (Pa)		
	3 cycles	6cycles	12 cycles
B2025F	8	7	6
B2050F	17	16	13
B2075F	28	26	22
B2025C	11	10	9
B2050C	23	22	18
B2075C	36	34	32

It can be seen that the effect of freeze-thaw cycle for sand soil with coarse-grained BTW is less than fine-grained BTW. The reason may be due to the high thermal capacity of tile, which the finer it is, the heat transfer increases as a result of the increase in the specific surface and the internal thermal variations are also increased. For this purpose, it is recommended that in the regions with cold weather and the long period of frost the coarse-grained BTW be used for stabilized sand soils.

Figure 7 shows the compressive strength of soil stabilized with different content of cement and BTW. According to Figure 7, the addition of cement and BTW, both have increased the compressive strength of sand soil. Increasing the cement content has increased the compressive strength of the soil. Increasing the fine-grained BTW increased the compressive strength, but increasing the coarse-grained BTW by up to 20% increased the compressive strength, and no significant effect was observed. Increasing the dimensions of the BTW has also increased the compressive strength. Therefore, the highest compressive strength was observed in the soil stabilized with 7.5% cement and 20% coarse-grained BTW, which is 3.7 MPa.

These results are in good agreement with results of Hossain et al. (2019) which concluded that excessive additives do not have a significant effect on increased strength.

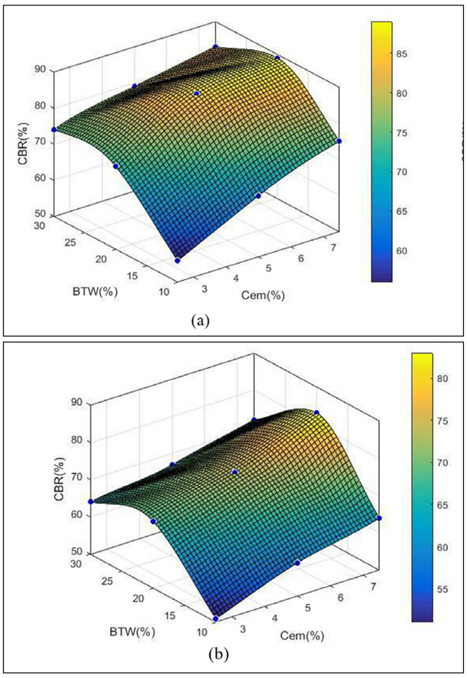

Figure 6. 3D plot of BTW-cement percentage variations in CBR (a) coarse-grained BTW and (b) fine-grained BTW.

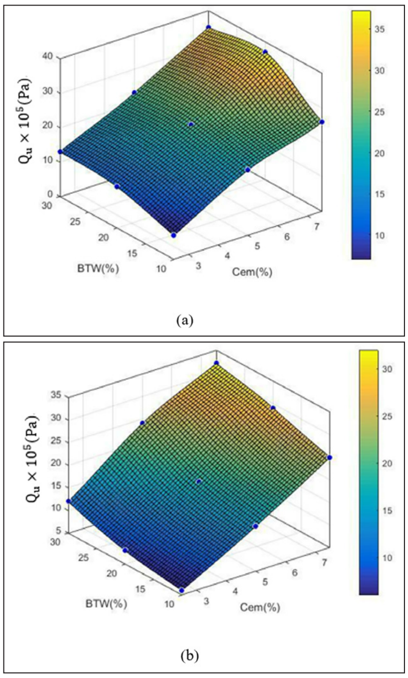

Figure 7. Compressive strength variations at different content of BTW-cement after 3-days curing. (a) coarse-grained BTW and (b) fine-grained BTW.

4.4. SEM image of samples

The SEM image of soil stabilization is shown in Figure 8, in which the distribution of the particles was uniform. Figure 8 indicates that the addition of cement to the sand-BTW mixture created adhesion between the particles. Increasing the adhesion of the particle increases the compressive strength and the bearing capacity.

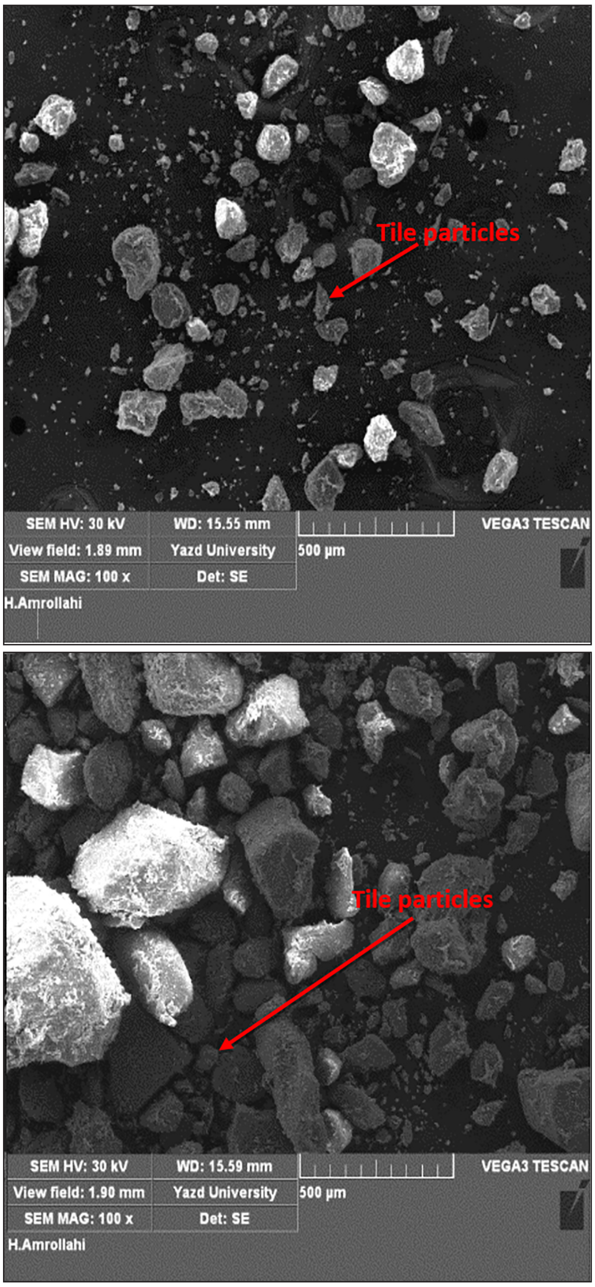

Figure 8. Grading plot of BTW and dune sand grains, (the right) coarse-grained and (the left) fine-grained.

5. Conclusions

Behavior of durability and strength of dune sand of subgrades having cement and BTW was studied in this study. 18 mixtures of this sand soil with different ratio of additives were made and tested. A series of load tests were conducted on the improved pavement test sections with cement and BTW reinforcement and the following conclusions can be drawn:

Results obtained from compaction test for different mixtures of cement, sand and BTW, shows that by adding coarse-grained BTW up to 20%, more optimum moisture than fine-grained, but the more moisture in-field compaction, the easier it will be to operate.

In regions with high freezing conditions, use of coarse-grained BTW is more proper than fine-grained BTW for providing enough strength of frozen subgrade. Besides, by considering the cost of breaking the tiles to smaller dimensions, use of coarser-grained BTW is more economical.

In sand soils by an extensive increase in BTW, and because the volume of adhesive materials around the BTW particles is reduced then the divided stress on the adhesive cement and mortar increased and the fracture possibility increased too and as a result, the resistance against loading decreased.

Adding BTW to the soil increases the bearing capacity of the sand. Also, increasing the dimensions of BTW will increase the bearing capacity. For fine-grained and coarse-grained tiles, the bearing capacity has increased from 19 to a maximum of 83% and 89%, respectively (for 7.5% cement and 20% BTW).

Addition of BTW has increased soil compressive strength. Increasing the amount of BTW and increasing its dimensions has increased the compressive strength and improved the durability against freeze–thaw cycle. The highest strength of soil stabilized was observed in 7.5% cement for20% coarse-grained BTW or 30% fine-grained BTW. This value is 3.7MPa and 3.2MPa for coarse and fine-grained BTW, respectively.

Finally, using BTW in both type of fine- and coarse-grained according to reinforcing sand subgrade and environmental issues, the proper amount of these materials and the ratio of cement can be different based on the type and chemical compounds mixture of tile. In line with these researches, the real conditions of such sand subgrades can be investigated in full scale, and in addition, ceramic waste, which is another form of tile, can be used in future studies.

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