EFFECT OF MODIFYING AGGREGATES BY RAP AND THE SIMULTANEOUS USE OF ADHESIVES FOR THE STABILIZATION OF A SANDY PAVEMENT SUBGRADE

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Abstract

The improvement, reconstruction and repair of roads in recent years have increased the content of recycled asphalt in pavements. Using these materials in road construction projects because they reduce the costs, will also be of great help in improving environmental issues. In the present study, dune sand, which can be found in most desert area soil but does not have proper strength and loading capacity for a subgrade, was used. In order to increase the strength parameters of dune sand, various contents of cement and recycled asphalt were examined in California Bearing Ratio (CBR) and compressive strength tests. The results showed that the addition of cement and recycled asphalt can increase compressive strength and bearing capacity and reduce rupture deformations. In a stabilized sample with 27.5% recycled asphalt, increasing the cement from 7.5 to 12.5% increased the compressive strength by 1.045 times, which is the highest amount of change in the samples studied. The maximum CBR and minimum rupture deformations are related to 35% of the recycled asphalt and 12.5% of the cement. The predicted functions of the compressive strength, deformation and CBR depend on two variables of the cement content; the recycled asphalt was then calculated using the response surface method

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Key words

- Dune sand,
- Cement, RAP,
- Response surface method,
- Soil stabilization.

1 INTRODUCTION

Stabilizing soil and improving soil strength parameters in order to use it in road construction are widely discussed topics in civil engineering. Stabilizing materials that have been used by various researchers for improving soil and increasing the soil's bearing capacity include cement, lime and some polymer materials (Liu et al. 2019; J. Muhammed, 2019; Khabiri, 2010; Rezaeimalek et al. 2017; Kumar, et al. 2019). A lime-silica fume mix in dune sand will increase the adhesion and angle of the friction (Fattah et al. 2016) and, in collapsible soils, can lead in decreasing potential collapses and increasing the bearing capacity (Fattah et al. 2016). Using cement kiln dust can increase the shear strength and bearing capacity in sand (Albusoda and Salem, 2012) and can increase

the compressive strength and bearing capacity in oil-contaminated sand (Nasr 2014). In regions which are in danger of sulfate attacks, cement with a lower aluminate content performs better in stabilizing the sand soil (Liu et al. 2019). The addition of cement to soil increases the compressive strength, shear strength, and bearing capacity of the soil and also increases the brittleness of soil (Jamshidi Chenari 2018). Increased compressive and tensile strength with the addition of various types of cement have also been reported. Using fiber in stabilized soil with cement not only improves soil strength parameters, but also increases the rupture strains and makes the sample ductile (Estabragh et al. 2017; Saberian and Khabiri 2018; Malidarreh et al. 2017).

Expanding the use of recycled materials and industrial waste as building materials in construction projects as material for stabilizing

subgrade soil is a suitable solution, both economically and environmentally. One of these waste materials is pavement asphalt. In order to increase the efficiency of road pavements or eliminate the existence of damage on a pavement surface, repairing and reconstructing of a pavement is essential, it can lead to increases in the content of pavement asphalt. Reusing these materials in road construction reduces the operating cost of projects and helps to improve environmental effects (Faysal et al. 2016). Using recycled pavement asphalt in bed soil increases the soil's elasticity module, which indicates the suitability of this mixture for stabilizing road bed soil (Hasan et al. 2018). Adresi et al. (2018) investigated the effect of the addition of recycled asphalt on a stabilized layer with cement. In wet samples (which were tested for simulating winter conditions at a temperature of 25 °C), increasing the recycled asphalt content and cement content reduced and increased the compressive strength, respectively. Similar results were observed in a mixture of recycled asphalt and crushed stone material stabilized with cement (Dokovic et al. 2019) and sand or gravel stabilized by cement and recycled asphalt (Ghanizadeh et al. 2018). Increasing the content of recycled asphalt reduced the value of CBR. Accordingly, Mousa et al. (2017) recommended a content of recycled asphalt of 60% and 20% for the subbase and base layers, respectively. The addition of recycled asphalt to soil can lead to an increase in the tensile strength of soil (Isola et al. 2013). A mixture of recycled asphalt and intact aggregate stabilized with cement is an appropriate option for an application to the base layer in road construction (Taha et al. 2002). Using recycled asphalt pavement materials while creating a flexible pavement increased the compressive strength, elasticity module and CBR (Li et al. 2008). Alhaji and Alhassan (2018) used recycled pavement asphalt for stabilizing loose black clay. The results showed that the addition of recycled asphalt decreased the potential inflation. By increasing the content of recycled asphalt up to 30%, the compressive strength and elasticity module were first increased and were higher than the amount they decreased. The addition of recycled pavement asphalt in loose black clay soil increased the California bearing ratio and made this soil appropriate for use in a subbase layer in light traffic (Alhaji and Alhassan, 2018). The use of recycled asphalt in sand increased the soil's strength in undrained cyclic triaxial tests (Yokohama and Sato, 2019). Dune sand is a soil which does not have proper bearing capacity as subgrade soil (Tiwari et al. 2016). Given that a part of the available land for construction in a desert area is sand dune soil, addressing the issues related to the improvement and increasing the strength of these type of soils seems necessary. In the present study, the stabilization of this soil by mixing it with cement and recycled asphalt was investigated in order to

increase the efficiency of sand dune soil. The compressive strength, deformations in ruptures as well as the California bearing ratio of the stabilized sand samples were measured with different contents of cement and recycled asphalt. Using the response surface method, the functions of compressive strength, deformation in rupture, and CBR in terms of recycled asphalt and cement content were calculated.

2 MATERIALS

2.1 Soil

The soil used in the present study is categorized in the fine sand class (A-3) based on the AASHTO classification. After performing soil identification tests, the particle size distribution graph and some of the mechanical properties of the soil tested, were shown in Fig. 1 and Table 1, respectively. Fig. 2 shows an image of the sand used and the amount of earthwork related to the construction of a road and pavement. A compaction test was repeated 5 times on the soil sample and the dry density and moisture were calculated. The dry density in terms of the moisture shown in Fig.1, the maximum dry moisture and the optimum moisture were calculated from the test and are shown in Table 1.

Table 1. Specification of the soil used in the research.

Parameter	Content	Unit	Standard used
Soil classification	A-3	-	AASHTO
G_s	2.7	-	ASTM D-854
CBR	19	(%)	ASTM D-1883
C	0.1	(kPa)	ASTM D-3080
	46	(degree)	ASTM D-3080
	16	(%)	ASTM D-698
	1.845	(gr/cm ³)	ASTM D-698

2.2 Cement

The material used in the present study to improve the strength parameters of the sand soil was cement, which was added to the soil with 7.5%, 10% and 12.5% by dry weight of the soil. These cement

Fig 1. (a) Particle size distribution graph and (b) soil compaction curve used in the research.

Fig 2. (a) The location of the removed sand sample and earthwork volume (b) sand sample.

contents have been used by other researchers (Caro et al. 2018). Fig. 3 shows an image of the cement used in this study. The physical and chemical specifications of the cement used in the present study are shown in Tables 2 and 3, respectively.

Table 2. Chemical specification of Portland cement Type 2 used in the test.

Chemical properties	Content (%)
SiO ₂	20
Al ₂ O ₃	6
Fe ₂ O ₃	6
MgO	5
SO ₃	3
Weight loss due to frying	3
Insoluble residue	0.75
C ₃ A	8

Table 3. Physical specification of Portland cement Type 2 used in the test.

Physical properties	Value	
Specific area of 1 cm ² /gr	2800	
Expansion of autoclave test (%)	0.8	
Setting time with the 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/gr)	70	

2.3 Recycled asphalt

Another stabilizer material is recycled asphalt, which was added to the soil with 20%, 27.5% and 35% by dry weight of soil. After

Fig 3. A sample of the cement used in the tests.

separating the bitumen, the available aggregations were graded; the aggregation curve is shown in Fig. 1(a). The content of bitumen available in the recycled asphalt studied and based on the ASTM D-2172 standard was 5.5 percent. An image of the recycled asphalt is shown in Fig. 4.

3 METHODOLOGY

In the present study, the stability of the dune sand soil using cement and recycled asphalt was investigated. In order to be informed of the positive effects of this type of improvement in road construction, given the available loadings in road paths, the determination of the compressive strength, the value of deformation in the rupture and the bearing capacity call for the necessary tests. In the compressive strength test for creating samples, the ASTM C-109 standard was used. An investigation of the bearing capacity is an effective and important parameter in pavement and road construction. The compressive strength and the value of deformations in the rupture were measured using a 2kN loading device. For this purpose, the CBR test

Fig 4. (a) Depot location of recycled asphalt and (b) recycled asphalt used in stabilizing the dune sand soil.

was used based on the ASTM D-1883 standard with different contents of recycled asphalt and cement. After performing the required tests using the response surface method and Design Expert software, the predictive functions of the compressive strength, deformation in the ruptures, and CBR were calculated. The variables of these functions were the amount of cement and recycled asphalt.

3.1 Preparation of the samples

The compressive strength test, measuring deformations in the ruptures, and the California bearing capacity test were performed with different contents of cement and recycled asphalt. Recycled asphalt with 20%, 27.5% and 35% by dry weight of the soil and cement with 7.5%, 10% and 12.5% by dry weight of the soil were added to the dry soil. The cement and recycle asphalt were weighed and used (by dry weight of soil) for constructing the sample, given the moisture content and dry density calculated in the compaction test. These materials were mixed with water in order that a uniform and homogeneous mixture could be obtained. The mixture obtained was poured in the mold and compressed. For curing the cement, the samples were maintained in a closed environment and were then tested. Fig.5 shows an image of the samples used in the test.

4 RESULTS AND DISCUSSION

4.1 Deformation and compressive strength test

The stabilized samples with cement and recycled asphalt were tested under compressive force and compressive strength tests, and the amounts of deformations in the ruptures were recorded. As can be seen from Fig. 6, increasing the cement content at a fixed recycled asphalt percentage led to an increase in the compressive strength. The maximum variations in the stabilized samples were seen in 27.5% of the recycled asphalt, so that by increasing the cement content from 7.5% to 12.5%, the compressive strength increased 1.045 times. At a fixed cement content, increasing the recycled asphalt by up to 27.5%, led to an increase in the compressive strength; after this content a reduction was observed. Therefore, the maximum compressive strength in 27.5% of the recycled asphalt and 12.5% of the cement was measured. Fig. 7 shows the deformations of the failure with different contents of cement and recycled asphalt. According to Fig. 7, increasing the cement and recycled asphalt can decrease the deformation rate. Therefore, the minimum deformation rate at the failure moment is related to the sample stabilized with 12.5% of cement and 35% of recycled asphalt. The increase in cement will

Fig 5. (a) Dune sand soil samples stabilized with cement and recycled asphalt. (b) Close-up view of stabilized soil.

Fig 6. The effect of RAP content (recycled asphalt) on the compressive strength with different cement contents.

Fig 7. The effect of RAP content on the deformation at the moment of failure with different cement contents.

Fig 8. Stabilized sample after the compressive strength test.

increase the adhesion and the coherence between the soil particles and asphalt. This factor probably reduced the deformation rate of the sample at the failure moment, and it can be seen in Fig. 7 that the increase in cement has a greater effect on the reduction of the deformation rate of the samples than the increase in the amount of the recycled asphalt. The stabilized sand soil sample is shown after its failure.

4.2 CBR test results

A test that is important in road construction projects is the CBR test and the determination of the soil bearing capacity of the subgrade. A CBR test was performed with different cements and recycled asphalt contents for the stabilized samples. Fig. 9 shows the CBR variations due to the variations in the content of the stabilizer materials. At a fixed cement content, increasing the recycled asphalt content increased the California bearing ratio. Similar results were observed with the constant recycled asphalt with an increase in the cement content. It is noteworthy however that the increased rate of CBR due to the increase in the cement content is higher than the recycled asphalt. In the stabilized sample with 20% of the recycled asphalt, by increasing the cement content from 7.5 to 12.5%, the California bearing ratio increased 1.714 times. The maximum content of CBR was obtained in the stabilized sample with 35% of the recycled asphalt and 12.5% of the cement.

4.3 Analysis of the response surface

The response surface method was used with Design Expert software for predicting the compressive strength function, the deformation at the moment of failure and the CBR two related variables, including the recycled asphalt and cement contents. The recommended function of the software for all three variables is of the second order type. Table 4 shows the recommended second order function and the regression value. Three dimensional views of the variation of the compressive strength, deformation at the moment of failure, and the CBR with different cement and recycled asphalt contents are shown in Figs. 10-12, respectively.

Fig 9. The effect of RAP content on the CBR with different cement contents.

Table 4. Recommended function of the response surface method.

Variable	Suggested Functions	R – square
Q_u (kg/cm ²)	$-179.69732 + (11.13793 \times \text{Cem}) + (9.53103 \times \text{RAP}) + (0.21333 \times \text{Cem} \times \text{RAP}) - (0.6869 \times \text{Cem}^2) - (0.19188 \times \text{RAP}^2)$	0.9689
Def (mm)	$2.20479 + (0.27911 \times \text{Cem}) - (0.015724 \times \text{RAP}) + (4.93333 \times 10^{-3}) \times \text{Cem} \times \text{RAP} - (0.035172 \times \text{Cem}^2) - (1.15249 \times 10^{-3}) \times \text{RAP}^2$	0.9796
CBR (%)	$18.76832 + (2.80067 \times \text{Cem}) - (2.88270 \times \text{RAP}) + (0.12531 \times \text{Cem} \times \text{RAP}) + (0.19458 \times \text{Cem}^2) + (0.043024 \times \text{RAP}^2)$	0.9897

Fig 10. 3D display of the simultaneous effects of cement and recycled asphalt on the compressive strength. **Fig 11.** 3D display of simultaneous effects of cement and recycled asphalt on deformations in the rupture moment.

5 CONCLUSION

The California bearing ratio and compressive test for various cement and recycled asphalt contents were performed in order to study the stability of dune sand soil using cement and recycled asphalt. The results of the compressive strength, deformation rate at the moment of failure, and the CBR rate of the samples show that:

1. At a fixed recycled asphalt content, increasing the cement content increased the compressive strength, where most of the changes were related to the samples stabilized with 27.5% of recycled asphalt, which increased the compressive strength 1.045 times. Also, with a fixed cement content, the increase in the recycled asphalt up to 27.5% increased the strength; subsequently, a reduction was observed.
2. By increasing the cement and recycled asphalt, the deformation rate at the moment of failure decreased. The minimum deformation rate at the moment of failure was related to the sample stabilized with 35% of the recycled asphalt and 12.5% of cement. The cement had a greater role in reducing deformation rate of the samples than the recycled asphalt.
3. The maximum measured CBR is related to the samples stabilized with 35% recycled asphalt and 12.5% of cement. Therefore, increasing both the cement and recycled asphalt content increased the California bearing ratio.
4. In order to predict the compressive strength function, deformation at the moment of failure and the California bearing ratio, the response surface method was used. The recommended function is of the second order type, where the regression obtained was higher than 0.96 for all three functions, which indicated an acceptable level of precision of the function calculated.

Fig 12. 3D display of the simultaneous effects of the cement and recycled asphalt on the CBR.

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