IJTE, Vol. 8/ No.2/ (30) Autumn 2020, pp. 199-210

Research Paper

Effect of Fine Recycled Asphalt Aggregates and Cement Additives on the Sandy Subgrade Performance

Mohammad Mehdi Khabiri [1,*], Rajiv Kumar[2], Mohammad Mehdi Majidi Shad [3]

Received: 13.02.2019 Accepted: 06.12.2020

Abstract

In different parts of the world, road pavements are on dune sandy subgrade, where road construction is not possible without amendments. In this regard, various methods, such as mixing soil with other materials like lime, cement, bitumen, geotextiles, chemical compounds, etc to improve the soil grading, have been considered. In this research, the simultaneous effect of incorporating fine reclaimed asphalt pavement aggregates (FRAPA) for improving grading and cement application as the binder of the dune sand was investigated to enhance subgrade strength properties. The soil was mixed and replaced by three different doses of crushed recycled asphalt FRAPA (5, 15, and 25 percent) Similarly, the soil was replaced by 2.5, 5, and 7.5 percent of cement; in each mixing step, samples were prepared using static compaction method. Specimens were tested in uniaxial compressive strength (UCS) after saturation at the temperature of 25°C for 3 and 7 days curing period. Some of the results of this study showed that the increase of cement itself does not have much effect on increasing the strength properties of the soil but the use of FRAPA can significantly improve its properties. The maximum compressive stress strength and soil elastic modulus were obtained in the ratio of mixing 7.5% cement and 15% FRAPA. In the next step, the experimental results were selected as inputs in the numerical models and from the results of the finite element analysis the optimal thickness for subgrade improvement was chosen; where the thickness of 20 cm was obtained accordingly.

Keywords: Fine recycled asphalt pavement aggregates (FRAPA), dune sand, cement additives, pavement subgrade, flexible pavement modeling.

[*] Corresponding author. E-mail: mkhabiri@yazd.ac.ir
[1] Associate Prof., Road and Transportation Eng., Civil Engineering Department, Yazd University, Yazd, Iran.
[2] Assistant Prof., Department of Civil Engineering, National Institute of Technology, Jalandhar, India.
[3] Ph.D. Student., Road and Transportation Eng., Civil Engineering Department, Yazd University, Yazd, Iran.

1. Introduction

Due to the importance of the subgrade in construction projects such as road infrastructures, the soil amendment to improve its physical and mechanical properties have for long been a favorite topic among civil engineering specialists. The presence of problematic soils in road construction projects is one of the major problems. The weakness of shear strength and the lack of tensile strength in sandy soils has led to the development of methods for improving sandy soils. The use of cement materials helps to increase the shear strength of the sandy soils; but using these materials costs a lot [Banzibaganye, Twagirimana and Kumaran, 2018].

Increasing public awareness of climate change and environmental issues involved transportation professionals in incorporating green concepts into transportation planning, design, construction, and operation methods [Kumar, et al. 2018; Nameghi, et al. 2019]. On the other hand, modification of the soil grading as a road improvement method is always considered. The use of recyclable and waste materials for improving pavement subgrade and its layers has been the subject of many studies [Shahiri and Ghasemi, 2017; Nazarinasab, et al. 2017], including that the use of the metal slag for increasing the mechanical strength of the subgrade and hardening of the soil layers is effective [Ayan, et al. 2016]. The pavement subbase layer has a lot of significance in the reduction of road construction project cost because it uses a large amount of resources, therefore, unused and waste materials can be used in subgrade and subbase layer. They can be stabilized by lime to increase the layer strength [Khabiri, 2010]. In another study, the use of various recycled materials in the pavement layers has been investigated, and their effect on reinforcing performance of the pavement layers along with their environmental benefits is highlighted [Xuan, Molenaar and Houben, 2015].

The recycled asphalt aggregate is also a waste material while repairing road pavements. The use of granular stone material is one of the ways to increase the shear strength of soils [Kim and Lee, 2018], the more coarse-grained the subgrade materials, the more the soil bearing strength. The dune sand and sandy soil are plentiful in the world, and are spreading due to climate change, while expanding roads and constructing routes on them are unavoidable. Therefore, it is necessary to extend the performance life of pavement in these areas by modifying the subgrade. Extensive studies have been carried out to improve the properties of sandy soils by using various additives. According to studies on the use of RAP aggregates, they increase the strength of the pavement sandy layers and double layer's resistance [Taha, et al., 1999].

According to the results of other studies, RAP aggregate in pavement layers reduces the cost of pavement construction even by half, less raw materials are consumed and the cost of recycled materials decreases [Mousa, 2019]. The use of RAP aggregates to improve the properties of sandy subgrades has been the subject of many studies in recent years [Mousa and Mousaod 2017]. According to the laboratory studies, various percentages of recycled asphalt have been added to the dune sand and most of the laboratory tests are based on the CBR test. The results of this study indicate that the best ratio for asphalt is 20% by the weight of the dune sand [Kalpakci, Feaq and Canakci, 2018]. The application of various experiments to control the performance of pavement layers containing RAP aggregates indicates that we can use them up to 100% in sand layers [Seferoglu and Akpinar, 2018]. Because of the low adhesion of the dune sand particles, the use of binder aggregates for enhancing the shear strength is common in improving the sand subgrades; in some cases, the emulsion bitumen and in other projects cement is used [Bleakley, et al., 2016].

The study intends to use the recycled fine aggregate from RAP as a solution to improve the strength of pavement subgrade aggregates. On the other hand, the cement is used to modify the low adhesion of sandy soils and silty sand. Therefore, the main question that current study seeks to answer is to determine the optimal percentage of cement and RAP aggregates, also the effect of using these aggregates on the vertical deformation rate of the pavement subgrade is studied. Next, with finite element method, using the Ever-Stress software, a 3D model of the regular asphalt pavement was constructed and the thickness effect of the modified subgrade layer on the rutting performance of the flexible pavement was examined and compared.

2. Materials and Methods

In this research, after the preparation of sandy subgrade samples from around the highway, as shown in Figure 1, the RAP aggregates were also prepared from the paved asphalts of the asphalt pavement of the main road between Ardakan-Naein. In this section, the technical specifications of the used RAP, sand, and cement materials and their properties are presented. In the next step, the specimens were made of different percentages of the aggregates.

2.1 Fine RAP Aggregate (FRAPA)

Fine RAP aggregates were selected according to the ASTM-D3524 standard, passing through 4.75 mm sieve (#4) On average, more than 60% of the raw materials were smaller than this size. Figure 2 illustrates the prototype and grading of RAP aggregates. The percentage of the bitumen content in the initial RAP obtained by the ASTM-D5261 was 5.51%.

2.2 Dune Sand

The sandy soils, due to their fine-grained and non-sticky structure can increase the extent of pavement deformation and its settlement. On the other hand, this type of soil is one of the most abundant soils in the central desert area of Iran, the Thar region of Rajasthan in India and other deserts in the world, which is very promising for construction of substructures. So, soil samples from the Iran central desert were received and tests were considered to identify their physical specifications.

Figure 1. a) The location of preparing the subgrade sandy aggregates and b) The deposit of RAP aggregates c) Used RAP aggregates

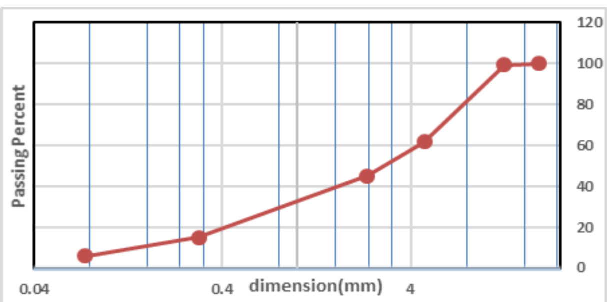

Figure 2. Grading of the Rap aggregates

Table 1 shows the specifications, and Figure 3 also shows the grading graph for this soil type. Scanning electron imaging is a method that can be used to observe and evaluate the shape and status of the particles forming the subgrade ingredients in different scales with a clear resolution. This imaging technique also shows the pores distribution and the aggregates concentrations with acceptable magnification. Figure 4 shows the distribution of dune sand particles, their shape is rounded and they are mostly the same size.

Table 1. Specifications of dune sand in the central desert areas

Soil Specification	Test Standard	Amount
classification of soil (AASHTO)USCS3	ASTM D-2487	(A-1-b) SP
Plastic Limit	ASTM D-4318	Not.
Liquid Limit	ASTM D-854	0
Plastic Index	ASTM D-2487	None. PI
Specific Gravity, G_s	ASTM D-2487	2.63
Initial moisture (%)	ASTM D-2216	0.60

2.3 Portland Cement

In order to create the minimum required adhesion in the subgrade soil, the cement is necessary, which its physical and chemical characteristics are presented in Table 2. The cement used in the manufacture of samples is Portland cement type 2 produced by the cement factory of Tejarat-Mehriz. Portland cement used should meet the requirements of the ASTM C150 standard [ASTM, 2019].

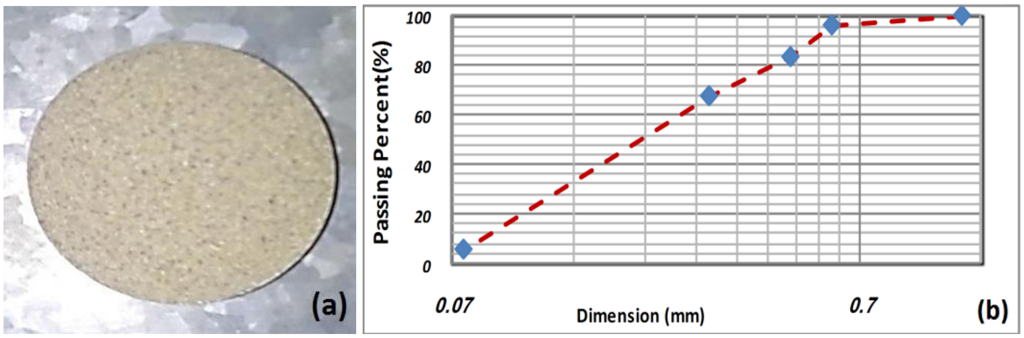

Figure 3. a) Sample used dune sand; and b) dune sand grading

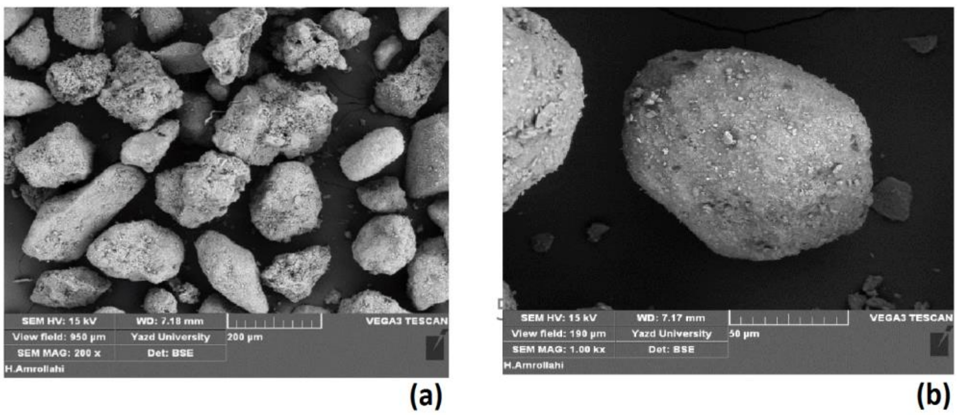

Figure 4. a) Uniformity of the size of dune sand particles; and b) the shape of dune sand aggregate

Table 2. Specifications of used Portland cement

Chemical Properties of Cement		**Abbreviation**	**Value(%)**
Silicon Oxide		SiO_2	20
Aluminum Oxide		Al_2O_3	6
Iron Oxide		Fe_2O_3	6
Magnesium Oxide		Mg O	5
Sulfur Trioxide		SO_3	3
Weight loss due to blush		-	3
Remaining insoluble		-	0.75
Three calcium aluminates		C3A	8
Physical properties of cement		**Amount**	
Specific surface area of 1 square centimeter per gram		2800	
Extension of the autoclave test (percent)		0.8	
Setting time of ordinary Portland cement	Basic (min)	45	
	Final(hours)	6	
Compression (Kg/cm^2)	3days	100	
	7days	175	
	28days	315	
Heat hydration calories per gram		70	

2.4 Samples preparation and testing

Water used to prepare the samples is urban drinking water. In accordance with current standards, samples should be kept under saturated moisture conditions at 25°C during curing. In this research, curing periods of 3-day and 7-day were considered for the samples. The mixtures of 5, 15 and 25% ratios of FRAPA and cement content in 2.5, 5 and 7.5% were considered. Three cubic samples with different FRAPA contents and 5% cement as the median among stated samples were also placed in 3 and 7 freeze-thaw cycles in order to determine the strength of the samples fixed in different environment conditions. The reason for choosing this low number of cycles in the freeze-thaw cycle test was that the sandy subgrade is found in the desert and warm areas where the number of freezing periods in these areas is few. Then, the uniaxial compressive strength (UCS) test was performed according to ASTM D 85-2166 standard. To perform the test, each sample was loaded at 1.5 mm/min in a uniaxial compressive strength (UCS) test machine after the curing period. In order to prevent error in determining the uniaxial compressive strength (UCS) of each sample, three samples were made for each mixing ratio. These 3 samples were loaded and the mean uniaxial compressive strength (UCS) of samples was considered as the uniaxial compressive strength (UCS) for each mixing ratio. Also, according to the stress-strain diagram, for each mixing ratio, the elasticity modulus was determined. To choose the modulus, the linear gradient was adopted that connected the stress-strain curve of the aggregates to the origin of the coordinates to a point on the curve equal to 50% of the maximum resistance of each aggregate. Figure 5 shows the concentration of sand containing particles of FRAPA, 15%, where the setting of the aggregates among the dune sand particles with good magnification is visible.

The presence of cement between the mixed particles increases the resistance and decreases the deformation of the samples. Figure 6 shows samples in part and the expansion of ice-crystals in the samples.

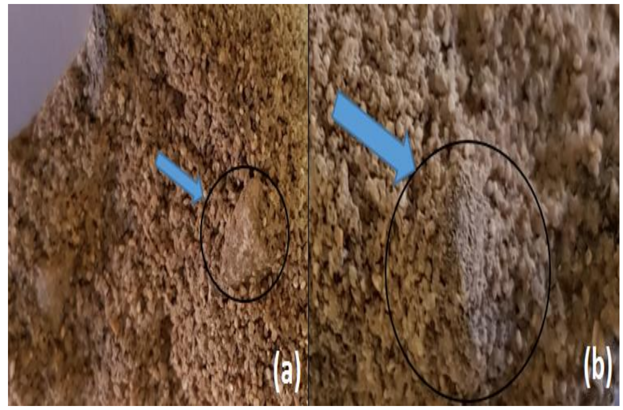

Figure 5. a) The FRAPA mixed with sand (lower magnification), b) The distribution of the aggregates among dune sand particles (in 15%)

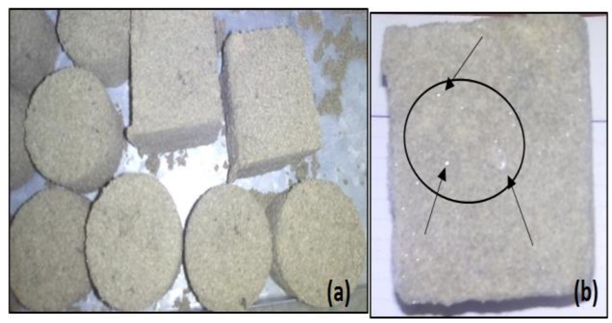

Figure 6. a) Cubic and cylindrical samples. b) Cubic sample to determine the effect of freeze-thaw cycle with surface ice-crystals

For encoding the samples, this procedure was used: the number after the letter R is the percentage of the FRAPA; and, the number after the letter C is the percentage of cement (with a coefficient of 10); and, SC stands for cubic shape, SY stands for cylindrical shape, and the last number represents the number of days of curing for SY samples and the number of freeze-thaw cycles for SC samples. For example, the R25C50SY3 is a three-day curing cylindrical sample with a FRAPA content of 25%, and the percentage of cement is 5%.

While testing specimens uniaxial compressive strength (UCS), the end surface of the ready mixture were placed on a thin nylon layer to create the minimum friction between the loading plates. Since uniaxial test was not possible without using binder in the sand, the mixtures containing different percentages of Portland cement binder were prepared. For the freeze-thaw cycles, the freezing temperature of the samples was -18°C and their melting temperature was selected according ambient temperature [Rasul, Ghataara and Borrow, 2018].

3. Modeling of the pavement

After specifying the materials in the laboratory process, it is possible to use software modeling to create the final model with the characteristic of the regular pavements. To do this, the EverFE.2.11 software which is a finite element analysis tool was selected on a three-dimensional scale, where, the length and width of all layers were considered to be 200 cm, and the specification and thickness of the layers is shown in Table 3. The presented elastic modulus value for different layers of pavement is chosen in accordance within the range obtained by previous studies [Bozbey, et al., 2018; Samb, et al., 2018]. The selected model was subjected to the AASHTO 8.2 ton standard axial load with dual tires and a contact pressure of 600KPa. For thickness fixation, 15, 20 and 30 cm thickness were used. In this analysis, the goal is to determine pavements vertical deformation under the wheels load, therefore the horizontal motion of the pavement layers was limited in such a way that the pavement layers cannot move along the axes of X and Y. The dimensions of the mesh are chosen so that they are smaller in the areas near the loading center and get coarse in size, further from the loading center. Figure 7 shows an example of the developed model, along with the meshing process and loading conditions of the pavement model.

This study was conducted in two parts, the laboratory and software modeling. The results of experiments and modeling are discussed below.

Table 3. Properties of pavement layers aggregates used in the software analysis

Layer	Thickness(cm)	Elastic Modules (Kg/cm^2)	Poisson Ratio
Asphalt	7.5	20000	0.35
Base	15	800	0.35
Treated Subgrade	15-20-30	Laboratory Test Result	0.40

4. Results and Discussion

4.1 Uniaxial compressive strength (UCS)

Figure 8 depicts the axial stress variations introduced for different specimens at 3 and 7-day curing time. As can be seen, the maximum of uniaxial compressive strength (UCS) in both treatment periods increases with increasing cement percentage. But increasing FRAPA initially increases the maximum compressive strength and then decreases the uniaxial compressive strength (UCS), which means that increasing FRAPA by more than 15% leads to the weakened bonding between sand particles. This is probably due to a worse gradation of mixtures with higher amount of fine RAP which leads to weaker interlocking between aggregate particles, resulting in a further decrease in shear strength of the mixtures. The maximum compressive stress was obtained in the ratio of mixing 7.5% cement and 15% FRAPA.

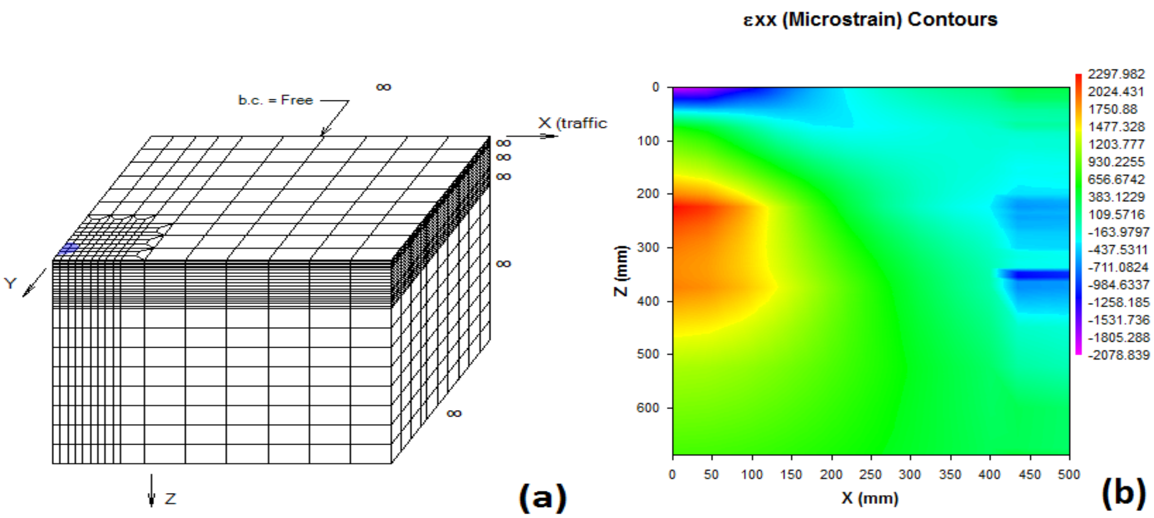

Figure 7. a) The geometric specification and meshing of the pavement layers, b) compressive strain on the subgrade

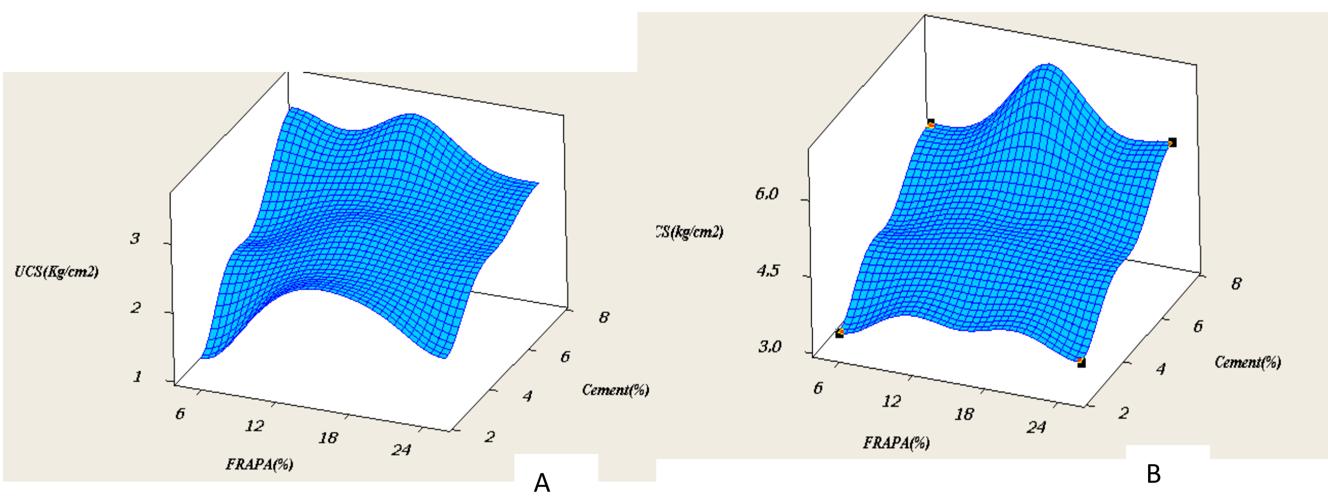

Figure 8. Uniaxial compressive strength (UCS) introduced for different specimens a) 3-day, b) 7-day treatment

Also, Figure 9 shows the failure moment of samples containing FRAPA; it is observed that the samples are broken in the diagonal direction in the weakened plate due to the presence of coarse RAP aggregates. On the fracture surface, the presence of large coarse aggregates is shown with a greater magnification (as Figure 5)

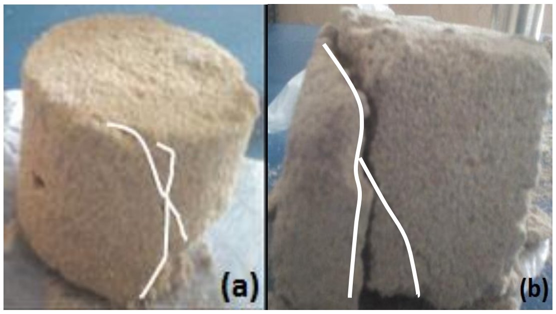

Figure 9. The surface of rupture of vertical axis cracking in the a) cylindrical and b) cubic samples on the failure plate after uniaxial compressive loading

Figure 10, shows the variation of uniaxial compressive strength (UCS) in different freeze-thaw cycles for cubic samples. The samples as expected lost more strength while increasing the number of freeze-thaw cycles.

The uniaxial compressive strength of cubic samples by average decreases 6% after 3 freeze-thaw cycles and also with the increase of cycles up to 7, samples strength decreases by an average of 23% that is somehow an acceptable amount. Samples containing 5 and 25% of FRAPA lost more strength. This could be a result of reaching lower compaction in these samples, which is a reason for having more pores area in the sand-RAP structure.

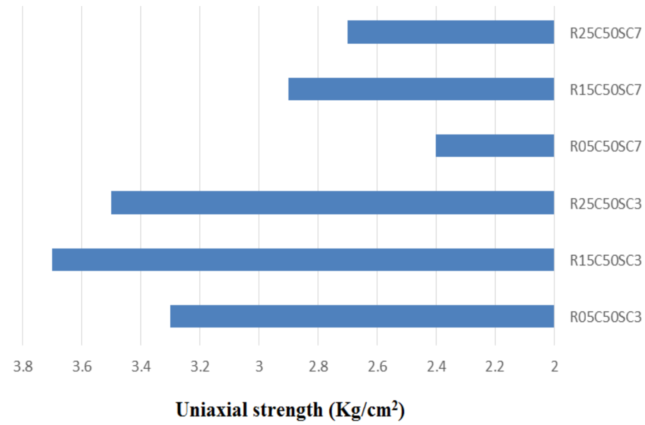

Figure 10. Uniaxial strength (Kg/cm^2) variation diagram of the sample refined with cement (5%) in two different freeze-thaw cycles

4.2 Variations of Elasticity Modulus

The effect of different percentages of FRAPA and cement on the elastic modulus (Es) variation of stabilized soil was examined. Figure 11 shows the variations of elastic modulus for several samples, which have been computed for different percentages of cement, in all of them FRAPA is constant at 15%. The performance of increasing the cement on the elastic modulus of the mixture sand containing FRAPA and cement is evident, which is due to the increase of adhesion between the sand particles forming the subgrade because of the increases in cement hydration products amount in the mixture. The elasticity modulus of samples containing less than 7.5% cement, decreases by an average of 37%.

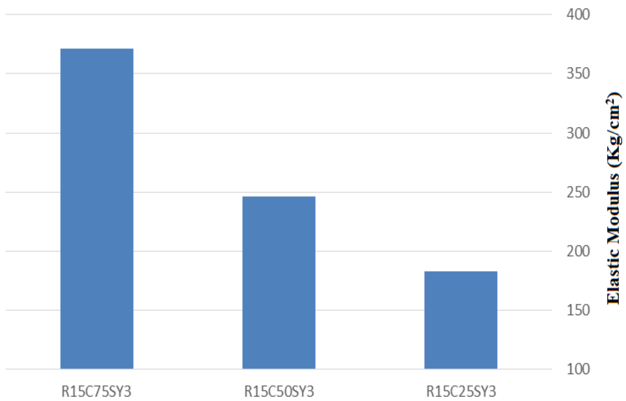

Figure 11. Elastic Modulus (Kg/cm^2) of sandy soils improved with FRAPA (15%) for different percentages of cement

4.3 Simulated compressive strain of Treated Sandy Subgrade

In the analysis of this study, the maximum vertical compressive strain centered at the top of the subgrade was considered as a criteria for assessing the asphalt pavement rutting resistance. Figure 12 shows the effect of cement volume and the thickness of the stabilized bed on the pavement response. As can be seen from the diagram, the use of stabilized subgrade aggregates has a positive effect on the lifetime of the asphalt pavement rutting, so that the increase in the cement percentage has a reduction effect on the strain of the subgrade, but the increase in the thickness of the stabilization has a higher role in decreasing these strains. In this diagram, it can be seen that increasing the percentage of cement from 5 to 7.5% will not have much effect on rutting performance. It can be said that from a certain point, increasing the percentage of cement does not have an almost noticeable effect on reducing the critical strains of the pavement.

According to the finite element model results, the thickness of 20 cm was obtained as the optimal thickness for subgrade treatment. The amount of vertical strain is reduced by up to 40% and therefore the life of the pavement is increased up to several times.

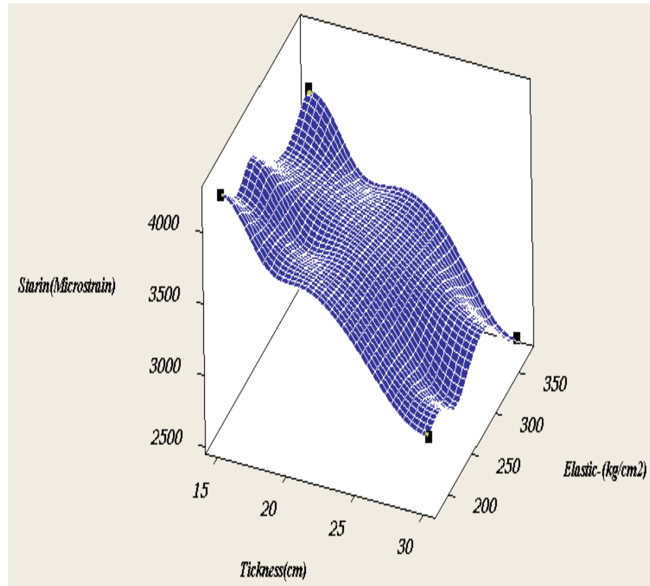

Figure 12. Effect of increasing thickness and cement values on the compressive strain changes of the treated subgrade

5. Conclusion

Preparation of the foundation is important to ensure a high quality and long-lasting pavement structure that does not require excessive maintenance. Therefore subgrade soil treatment with various materials to improve the strength and resilient modulus characteristics of the soil has been investigated by many agencies. In this study, the improvement of the sandy soil subgrade of the road pavements was examined by adding FRAPA and cement. According to the performed experiments and modeling analysis, the results obtained can be summarized as follow:

- Uniaxial compressive strength and elasticity modulus of the samples containing FRAPA and cement increases with increasing cement percentage to a certain point.

- The uniaxial compressive strength of the samples containing higher amounts of FRAPA (25% compared to optimal 15%) is reduced.
- Also results show that cement variation has a positive effect on upper layers deformation so that by increasing the percentage of cement, the amount of strain on the subgrade soil decreases, but after a certain limit, increasing the percentage of cement does not have an almost noticeable effect on reducing the pavement critical strains.
- The reduction in uniaxial compressive strength of the cubic shaped samples in the freeze-thaw cycle test had an acceptable range, although treated samples with the median considered amount of studied FRAPA showed better strength due to reaching lower void among mixture particles.
- The uniaxial compressive strength for samples increased about 50 to 100% by having 4 more days in the curing period.
- Increasing the thickness of the stabilized layer also has a significant effect on subgrade compressive strain reduction. In other words, implementing the FRAPA-cement modified sandy subgrade with the optimal thickness from an economic point of view reduces costs due to less maintenance need and increasing pavements service life.
- The results of adding FRAPA and cement to sandy subgrade samples in order to strengthen the roadbed, showed that these materials have improved the structural performance of pavement and on the other hand have the potential to help roads sustainable development, however, due to the extent factors involved in subgrade performance, still there is further need of assessing the new admixture in subgrade soil.

6. Acknowledgment

We would like to thank Eng. Sabouhi, Mohammadi-Anai and Heidari-Firoozabadi, who helped in part of the procurement of materials and results of the tests by their efforts in providing dune Sand, cement and FRAPA.

7. References

- ASTM C150 , C150M-19,(2019), "standard specification for portland cement", ASTM International, West Conshohocken, PA, pp. 10.

- Ayan, V., Khavandi, A., Omer, J. R. and Limbachiya, M. C. (2016) "Toughness performance of recycled aggregates for use in road pavement", International Journal of Transportation Engineering (IJTE), Vol. 3, No. 3, pp. 171-179.

- Banzibaganye, G., Twagirimana, E. and Kumaran, G. S. (2018) " Strength enhancement of silty sand soil subgrade of highway pavement using lime and fines from demolished concrete wastes" , International Journal of Engineering Research in Africa. Trans Tech Publications, Vol. 36, pp. 74-84.

- Bleakley, A. M., Cosentino, P. J., Al-Obaydi, R., and Balan, F. B. (2016) "Reclaimed asphalt pavement-sand blends stabilized with asphalt emulsion and portland cement", Transportation Research Board, No. 16, pp. 13-68.

- Bozbey, I., Kelesoglu, M., Demir, B., Komut, M., Comez, S., Ozturk, T., Mert, A., (2018) "Effects of soil pulverization level on resilient modulus and freeze and thaw resistance of a lime stabilized clay", Cold Regions Science and Technology, Vol.151, pp. 323-334.

- Kalpakci, V., Faeq, R., and Canakci, H. (2018) "compaction and CBR properties of

RAP/sand blends in Iraq" , Arabian Journal of Geosciences, vol.11, No.21 , pp. 663.

- Kim, Y., and Lee, K. (2018) "Evaluation of physical properties for hot-in place recycling mixtures applied for maintenance project in national highway", Inte jour.vol.18, pp.142-142.

- Khabiri, M. M. (2010) "The effect of stabilized subbase containing waste construction materials on reduction of pavement rutting depth". Electronic Journal of Geotechnical Engineering, vol.15, pp.1211-19.

- Kumar R., Appa Roa G., Ryntathiang T.L. (2018), "Green road approach in Indian road construction for sustainable development. ", Urban Ecology, Water Quality and Climate Change. Water Science and Technology Library, vol. 84. Springe, pp. 107- 119.

- Mousa, R., and Mousod, M. (2017) "Viability assessment of using a blend of reclaimed asphalt pavement and sand in road construction: case study in Egypt",Report, No. 17-06, pp.447.

- Mousa, R. M., (2019) "cost–benefit analysis of rap–sand blend applications in road construction". Transportation Research Record, Doi: 03611981188234,pp.34-95.

- Nameghi, I., and Aghayan, I. Behzadian, R., Mosaberpanah,. M. (2019) “Investigating the Effect of Using Cross-Linked Polyethylene Waste as Fine Aggregate on Mechanical Properties of Hot Mix Asphalt". International Journal of Transportation Engineering (*IJTE*), Vol.7,No.3, pp.233-247.

- Nazarinasab, A., Ghasemi,. M., Marandi, S. (2017) "Performance Improvement of Porous Asphalt Mixtures using Crumb Rubber and Steel Slag Powder" International Journal of Transportation Engineering (*IJTE*), Vol.6,No.2, pp.99-110.

- Rasul, J. M., Ghataora, G. S., and Burrow, M. P. (2018) "The effect of wetting and drying on the performance of stabilized subgrade soils". Transportation Geotechnics, No.14, pp.1-7.

- Samb, F., Berthaud, Y., Ba, M., Fall, M., andBenboudjema, F. (2018) "Nonlinear Mechanical Behavior Analysis of Flexible Lateritic Pavements of Senegal (West Africa) by FEM for M.-E". Pavement Design. Geotechnical and Geological Engineering,vol. 36.No.5), pp.2939-2956.

- Seferoğlu, A. G., Seferoğlu, M. T., and Akpinar, M. V. (2018) "Investigating the mechanical behavior of reclaimed asphalt pavement (rap) bases in large scale test box". Teknik Dergi, vol.30, No.6), pp. 1.-10.

- Shahiri, J., and Ghasemi, M. (2017) "Utilization of soil stabilization with cement and copper slag as subgrade materials in road embankment construction". International Journal of Transportation Engineering (*IJTE*), Vol.5,No.1, pp.45-58.

- Taha, R., Ali, G., Basma, A., and Al-Turk, O. (1999) "Evaluation of reclaimed asphalt pavement aggregate in road bases and subbases". Transportation Research Record: Journal of the Transportation Research Board, No.1652 , pp. 264-269.

- Xuan, D.X., Molenaar, A.A.A., Houben L.J.M., (2015), “Evaluation of cement treatment of reclaimed construction and demolition waste as road bases”, J. of Cleaner Production, No.100, pp. 77-83.