AUT Journal of Civil Engineering

AUT J. Civil Eng., 8(1) (2024) 3-16
DOI: 10.22060/ajce.2024.22739.5846

Experimental Study on the Effect of Waste Rubber Powder and Zeolite Replacement on Cemented Sandy Soil

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ABSTRACT: Soil improvement involves a variety of approaches. Among them, the addition of specific materials has been widely adopted in the literature. Colossal numbers of worn tires are released into the environment every year. It will cause serious environmental issues. Moreover, the cement production process causes detrimental consequences for the environment, but it still is considered as one of the main options in construction projects. So, the main purpose of this research is to find suitable alternative methods to decrease cement usage. In this paper, the effect of adding zeolite and waste rubber powder on the unconfined compression strength (UCS) of soil was investigated. Two types of sandy soil were adopted in this study, SP and SW soil. In order to improve these two types of soils, 4% by weight cement, 0, 0.25, 0.5, and 0.75% rubber powder, and 0, 10, 30, and 50% zeolite replacement with the cement during curing periods of 7, 14, and 28 days were considered. According to the compaction test results, by increasing the percentage of rubber powder, the maximum dry density and the optimal moisture content of both types of soils decreases. However, with zeolite addition, the maximum dry density of both types of soils has decreased and the value of optimum moisture has increased. The optimum percentage of zeolite and rubber powder in SW soil was 30% and 0.5% respectively, while in SP soil these amounts were 10% and 0.25% respectively.

Review History:

Received: Nov. 08, 2023
Revised: Aug. 14, 2024
Accepted: Sep. 20, 2024
Available Online: Sep. 20, 2024

Keywords:

Sandy Soil
Waste Rubber Powder
Zeolite
Cement
UCS Test

1- Introduction

Cement addition has been a common method for improving the geotechnical engineering properties of soils for decades. Cement usage is a versatile and reliable technique among engineers. [1,2]. While the cement industry has adopted the most modern technologies to reduce pollution, but different stages of cement production processes and transportation have a great share in the environmental pollution. Researchers proved that producing one ton of cement and clinker in Iran will emit 0.655 and 0.79 tons of CO_2 gas respectively [3]. The main characteristics of loose and uniform sandy soils are their low strength and non-adhesion. To stabilize this type of soil, the use of cement is one of the most widely used options [4]. Finding a suitable alternative to cement can protect the environment. While, pozzolans, which have been used as an alternative to cement for a long time in construction, can greatly solve the problems. Pozzolans such as zeolite are able to increase the compressive strength and durability of soil by being replaced with cement. It saves energy consumption in cement production and reduces pollution [5]. Natural zeolites are formed as a result of volcanic activity. By reaching the sea, the hot lava, water, and salt from the sea react with each other which, led to the production of crystalline solids known as zeolites for thousands of years [6,7]. Categorizing zeolites into different types is not easy at all. [8]. Zeolites are crystalline aluminosilicates of alkaline or alkaline earth metals such as sodium, potassium, magnesium, strontium, barium, and calcium, which are formed from compounds $[AlO_4]^{5-}$ and $[SiO_4]^{4-}$. The structure of zeolite is shown in Figure 1. Equation 1 states the general chemical formula of zeolites; Where M^+ is the alkali metal cations and M^{2+} is the alkaline earth cations [9].

$$[(M^+,M^{2+}_{0.5})AlO_2]x.[SiO_2]y.[H_2O]z \quad (1)$$

Waste tires cause environmental problems for instance they have the potential to fire [11]. Many researches have investigated to find different ways to reuse worn tires. One of them is replacing it with traditional materials. Research on this issue continued until ASTM finally introduced the material from worn tires as new materials in 1998 with the introduction of a standard called the D6270 [12]. Cement Addition to soil causes a change in the maximum specific dry weight and optimum moisture content. The ACI Committee states that cement causes a change in maximum dry density and optimum moisture content, but these changes are not

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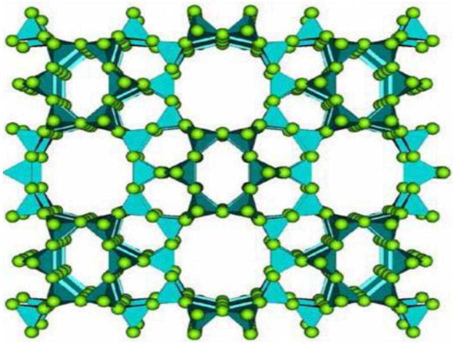

Fig. 1. Structures of zeolites [10]

predictable [13]. MolaAbasi and Shooshpasha (2016) investigated the effect of zeolite replacement with cement in sandy soil samples of Babolsar (IRAN). They concluded that by replacing 30% zeolite with cement compared to non-zeolite samples, the unconfined compressive strength increased between 20 to 78% [14]. In another study, expansive soils were stabilized by using zeolite and lime. [15]. Hong (2015) investigated the geotechnical properties of stabilized sandy soil with zeolite in different weight percentages of 25, 50 and 75%. The results showed that by increasing the weight ratio of zeolite in the mixture, the optimum moisture content tends to increase and the maximum dry density tends to decrease [16]. Kordnaeij et al. (2019) investigated the effect of injection and replacement of zeolite with cement in loose sandy soil. The results revealed that by increasing the amount of zeolite by 30% of cement, the strength increases and then decreases [17]. Ahmadi et al. (2021) investigated the stabilization of expansive clay by replacing 0, 10, 30, 50, 70 and 90% zeolite and 6, 8, 10 and 12% cement. The experimental results showed that by increasing zeolite to 30% of cement, the unconfined strength of soil increased and then decreased. On the other hand, by increasing the amount of zeolite replacement, the amount of soil rupture strain has increased [18]. Izadpanah et al. (2021) investigated the effect of zeolite on mineralogical changes leading to the development of compressive strength of cement-sand mixtures. The mixtures consist of 8% Portland cement type II and the replacement of natural zeolite (clinoptilolite) instead of cement with values of 0, 35, 60, and 90% on Babolsar sand. An unconfined compression test was carried out for various zeolite percentages in the same curing time. Strong adhesion in the Interfacial Transition Zone (ITZ) resulted in densely compacted mineralogy in the presence of 35% zeolite, which promoted the Unconfined Compressive Strength (UCS) [19]. Soltani et al. (2021) investigated the effect of zeolite and tire granules on cement stabilization of the sand. Their results showed that by replacing 30% of zeolite and 7.5% of rubber granules, the uniaxial strength and strainability of the samples reached their maximum value [20]. Sarajpoor et al. (2020) investigated the dynamic behavior of sandy soils improved by crumb rubber. The experimental results showed that the dynamic properties of improved sandy soil are directly affected by the amount of rubber and confining stress. They found that adding crumb rubber to sandy soils reduced the relative density and shear modulus of the soil [21]. Akbarimehr et al. (2020) investigated the effect of mixing recycled rubber in three forms with clay: granular, filamentary, and laminated. Results showed that by increasing the size of the tire, the stress and strain of the samples increased. Also, the presence of crumb rubber particles compared to the powder state increases the strength of the samples by 10 to 25% [22]. Anvari et al. (2017) used tire patches to improve sandy soil. The experimental results showed that the addition of the tire in pieces increased the shear strength of the samples, while in the samples with granular and powder form, the shear strength of the samples decreased. By adding 5% rubber powder at a relative density of 50%, the internal friction angle of the samples increases from 35.1 to 39.2. While in the sample with a relative density of 70 and 90%, the addition of grain tire has reduced the internal friction angle of the samples [23]. To examine the behavior of fine-grained soils improved with granular rubber tires as a suitable replacement for concrete piles in old buildings, Ghareh et al. (2020) used waste rubber tires in three different dimensions (<1 mm, 1-2 mm, and 2-4 mm) and six weight ratios (0%, 0.5%, 1%, 2.5%, 5%, 7.5%, and 10%). The results showed that adding these rubber tires could reduce the density, optimum moisture content, and settlement, it also increases the shear strength parameters and bearing capacity of the soil. The best weight ratio to increase the strength and reduce the settlement of this soil contained 5% of rubber tire smaller than 1 mm in size will lead to a 46% increase in bearing capacity and 70% decrease in the settlement of the soil around the Razavi holy shrine [24].

Using zeolite can meet the desired strength while reducing cement amount, and consequently reduces the detrimental environmental effects of the cement production process. On the other hand, using zeolite as a natural and cheap mineral in Iran can be suitable for improving sandy soil. Using waste rubber powder not only has economic advantages but also will clean the environment, reduce chemical consumption, prevent water and soil pollution, and prevent potential fires. Researches all around the world have researched in the field of adding zeolite and rubber powder in order to improve soils' properties separately, and have led to a favorable effect on their geotechnical properties. The present study investigated the effect of zeolite and rubber powder replacement simultaneously on the unconfined compression strength (UCS) of two types of cement-stabilized sandy soils.

2- Experimental Program

In order to study the effect of the replacement of zeolite and adding waste rubber powder on unconfined compression strength (UCS) of sandy soils, two types of soils which are well-grained sandy soil (SW) and poorly-grained sandy soil (SP) were considered and a total of 102 UCS test has been performed. In order to improve these two types of soils, 4% by weight of cement, 0, 10, 30, and 50% of zeolite replacement

Table 1. Experimental program

Variables	Details
Soil Type	SW and SP
Cement Agent	Portland (Type II)
Zeolite Type	Clinoptilolite
Zeolite Content	0, 10, 30 and 50% of Cement Content
Rubber Powder	<0.7 mm
Rubber Powder Content	0, 0.25, 0.5, 0.75 and 1%
Curing Time	7, 14 and 28 Day

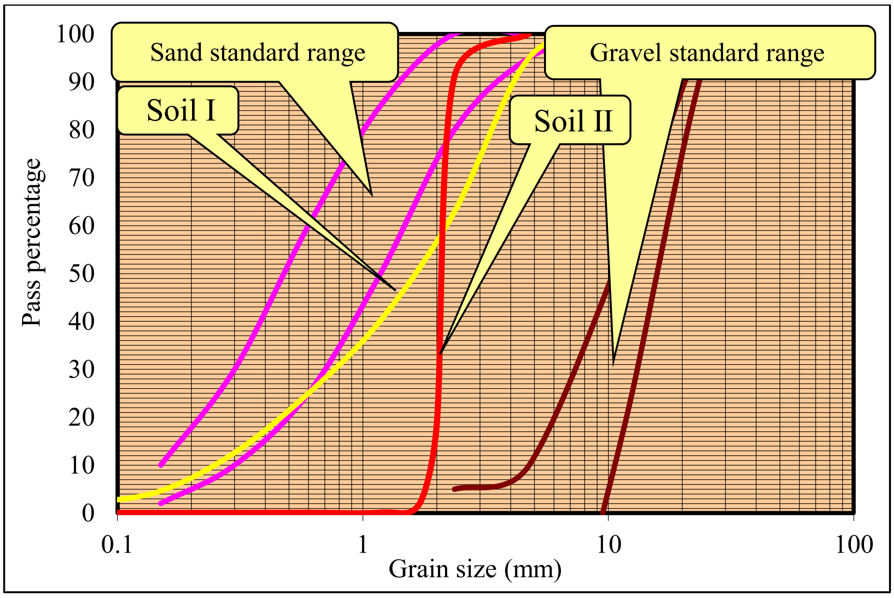

Fig. 2. Sandy soils gradation curve

with cement and 0, 0.25, 0.5, 0.75, and 1% of rubber powder in curing time of 7, 14 and 28 days were used. Details of materials are shown in Table 1.

3- Material and Method

3- 1- Soil

The first type is non-uniform with an average particle size of 1.8 mm and the second type is uniform with an average particle size of 2.36 mm. The granulation diagrams of both soils are shown in Figure 2 and its physical characteristics are shown in Table 2.

3- 2- Cement

In this research, Portland cement (type II) was used. According to ASTM C150 [31], this type of cement is defined as modified Portland for making concretes that require moderate hydration temperature and moderate sulfate attack. The specific surface area of this cement is 3081 gr/cm^2.

3- 3- Zeolite

The zeolite is clinoptilolite, which is prepared from the Kavan mine in Semnan province in Iran. The physical and chemical characteristics of this type of zeolite are shown in Tables 3 and 4.

3- 4- Rubber powder

Waste rubber powder is 24 mesh (particle size less than 0.7 mm) with a purity of about 95%. The chemical properties of rubber powder are listed in Table 5.

4- Laboratory Tests

4- 1- Compaction test

The compaction test was done according to ASTM D698 [26] shown in Figure 4.

4- 2- Construction of specimens

To make samples, at first 4% cement, 0, 10, 30, and 50%

Table 2. Physical characteristic of sandy soils

Characteristic	Soil Type I	Soil Type II	Standard
Soil Type	SW	SP	ASTM 2487 [25]
W [%]	11.1	8.43	ASTM D698 [26]
$\gamma_{d\ max}$ [gr/cm^3]	2.01	1.59	ASTM D4253/4 [27,28]
$\gamma_{d\ min}$ [gr/cm^3]	1.85	1.47	
e_{max}	0.432	0.806	
e_{min}	0.318	0.6	
Gs	2.63	2.65	ASTM D854 [29]
D_{50}	1.8	2.36	ASTM C136 [30]
C_U	8.4	1.34	
C_C	1.21	0.925	

Table 3. Physical characteristics of zeolite

Characteristic	Value
Water Absorption	65 [%]
Average Particle Size	38 [μ]
Dry Density (γ_d)	0.64 [gr/cm3]
Hardness (Ec)	0.683 [mmohs/cm]

Table 4. Chemical characteristics of zeolite

Composition	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	S	LOI
Value (%)	72.98	11.63	1.29	0.188	1.53	1.56	1.89	2.68	0.015	0.052	0.02	6.89

Table 5. Chemical characteristics of rubber powder

Composition	Carbone	Oxygen	Zink	Sulfur	Silicon	Magnesium	Aluminum
Value (%)	88	8.82	1.8	1	0.19	0.12	0.07

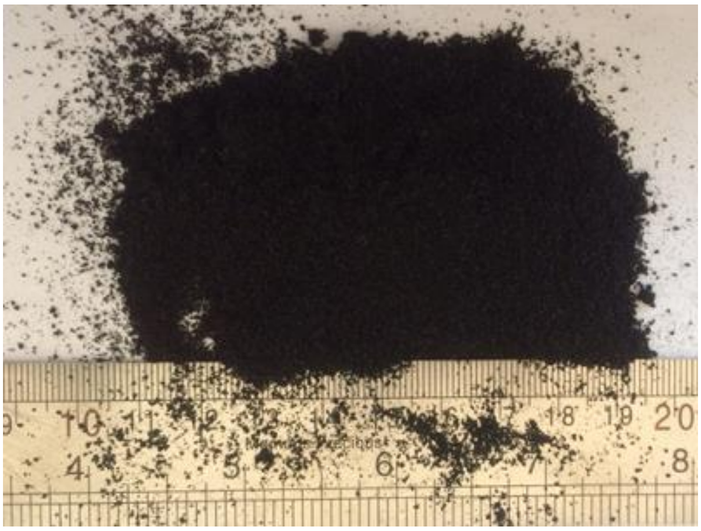

Fig. 3. Rubber powder used

Fig. 4. Compaction test – a: equipment and b: hammering

zeolite instead of cement, 0, 0.25, 0.5, 0.75, and 1% rubber powder are mixed with base soil. Then proper amount of water is added to the samples and is mixed till the homogeneous samples are made. As chemical reactions are fast, water is added at the end. Based on compaction test results and mold volume, water, soil mass, and all additives amounts are measured. The mixture is compacted in molds in 5 layers by 25 tap of static hammer. Since the average size of soil particles are 1.8 and 2.36 mm in SW and SP respectively, PVC molds were used which have 34 mm inner diameter and 70 mm height. All molds were cutter vertically to make samples easily out of molds. For better curing, molds were covered by wet clothes and then by plastic covers to prevent evaporation. Finally let the samples to be cured for 7, 14, and 28 days. After the curing period, the soil is in room temperature for 24 hours and ready for UCS test based on ASTM D2166. Figure 5 shows making and curing procedures. Finally SW sample with 4% cement, 30% zeolite, and 0.5% rubber powder, also SP sample with 4% cement, 10% zeolite, and 0.25% rubber powder with 28 days of curing time were chosen for SEM.

5- Result and Discussion

The main purpose of these experiments is determining the optimum amount of zeolite and tire rubber. Past research showed that the best weight ratio for rubber in fine-grained soils is less than 10% by weight in order to increase the

Fig. 5. Sample making and curing– a: PVC mold, b: mixing materials, c: curing

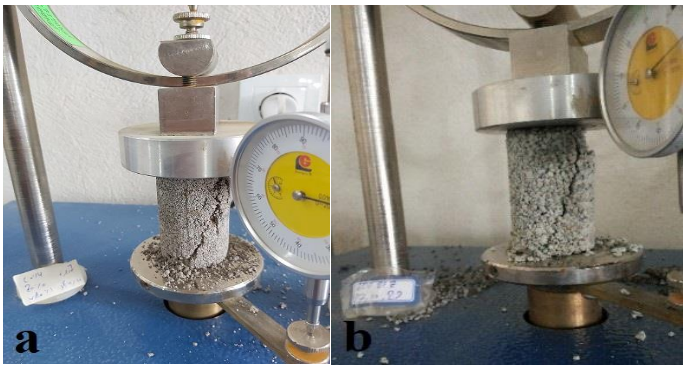

Fig. 6. Improved sample by cement, zeolite, and rubber powder at the moment of rupture – a: SW and b: SP

strength [33]. These results may be because of the low density of rubber tire, so rubber in high percentages can prevent soil particle connection. Figure 6 shows samples in the rupture moment.

5- 1- The effect of rubber powder and zeolite on the soil compression properties

By increasing the percentage of rubber powder, the maximum dry density (MDD) and the optimal moisture content (OMC) of both types of soils decreased. Zeolite addition makes the maximum dry density (MDD) and optimal moisture content (OMC) of both types of soils decrease and increase respectively which can be due to the water absorption property of zeolite (Figure 7).

5- 2- The effect of cement on the UCS test

The stress-strain diagram of the stabilized samples with the addition of 4% cement with the curing time of 7, 14, and 28 days is shown in Figure 8. Cement addition leads to more strength and strain in both soil types. Rupture strain in SP is slightly higher than SW soil due to more pores in SP.

5- 3- The effect of zeolite on the UCS test

Stress-strain diagrams of cement samples with 0, 10, 30 and 50% zeolite replacement at 14 and 28 days of curing time are shown in Figure 9. Zeolite does not provide strength during 7 days of curing time since zeolite does not cause pozzolanic reactions in the short term. In SW, the maximum unconfined stress goes for 30% zeolite replacement with cement which has 55 and 84% more strength in 14 and 28 days of curing time, respectively. Also, the rupture strain of the stabilized sample with 30% zeolite replacement is higher than the non-zeolite sample, which indicates an increase in the soft and ductile behavior of zeolite samples compared to cement samples. On the other hand, in SP, the maximum unconfined stress goes for 10% zeolite replacement with cement which has 13 and 32% more strength than non-zeolite samples in 14 and 28 days of curing time, respectively. The difference in the optimum amount of zeolite replacement with cement in well-grained (SW) and poorly-grained (SP) sandy soils can be due to the presence of fine-grained in SW which leads to more cohesion and connection between soil particles. Fe_2O_3, SiO_2, and Al_2O_3 are elements in zeolite that

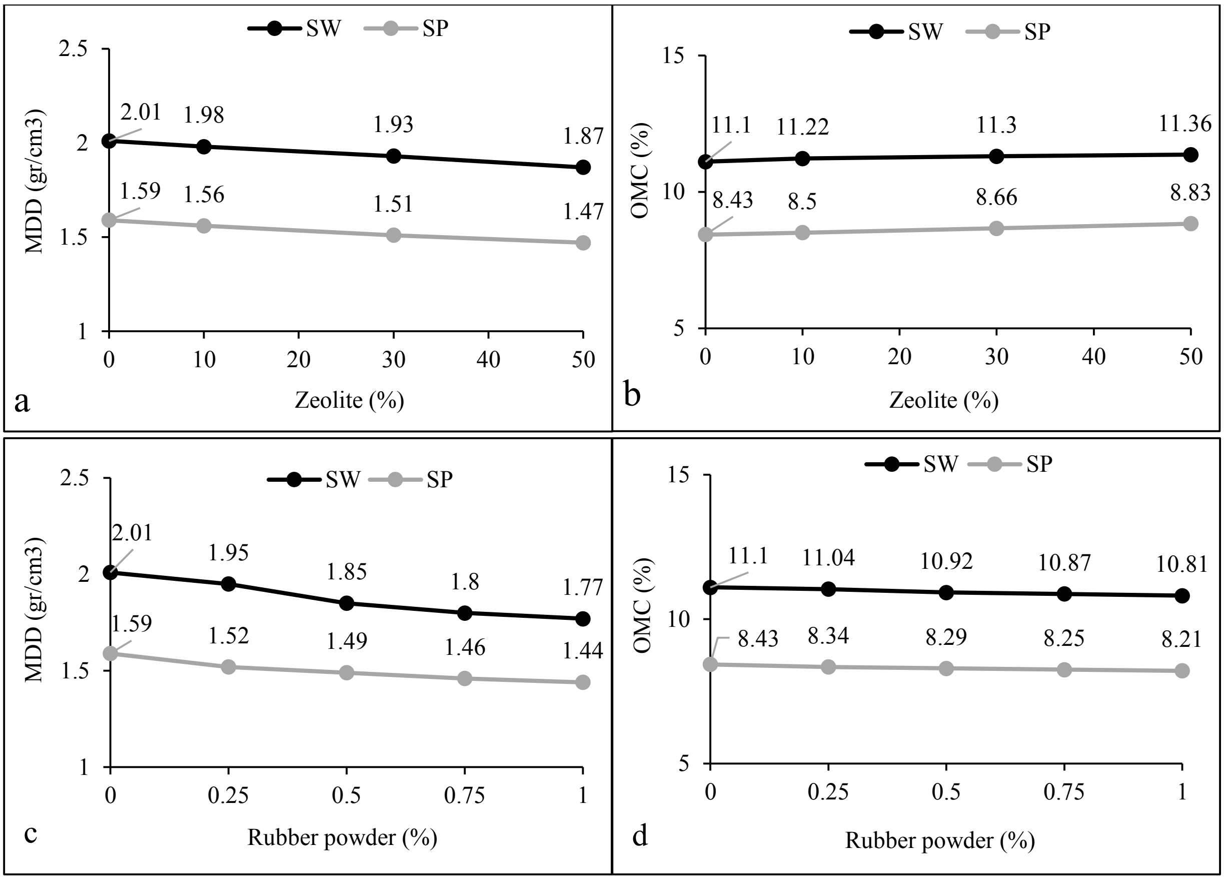

Fig. 7. Compression test results – a: MDD by adding zeolite, b: OMC by adding zeolite, c: MDD by adding rubber powder, b: OMC by adding rubber powder

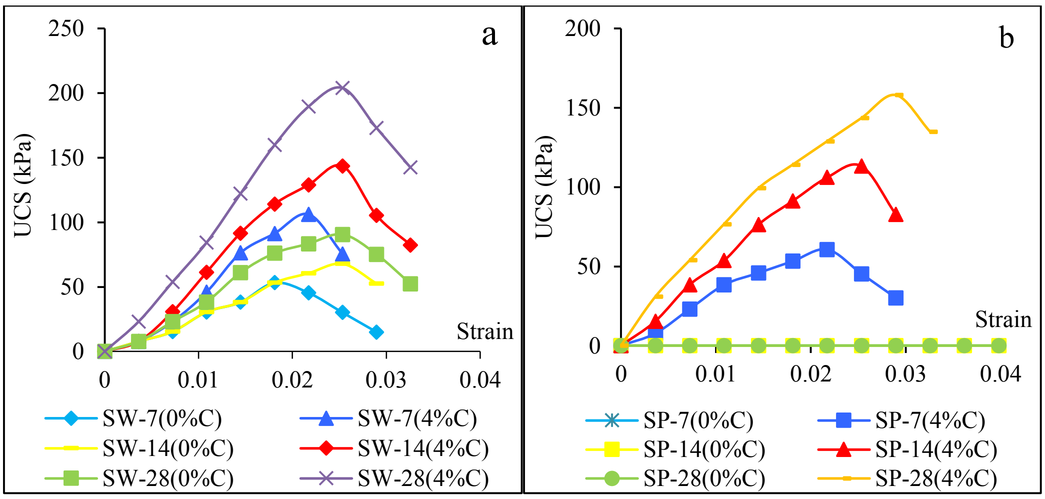

Fig. 8. Stress-strain diagram in cemented samples with 7,14 and 28 days curing period– a: SW and b: SP

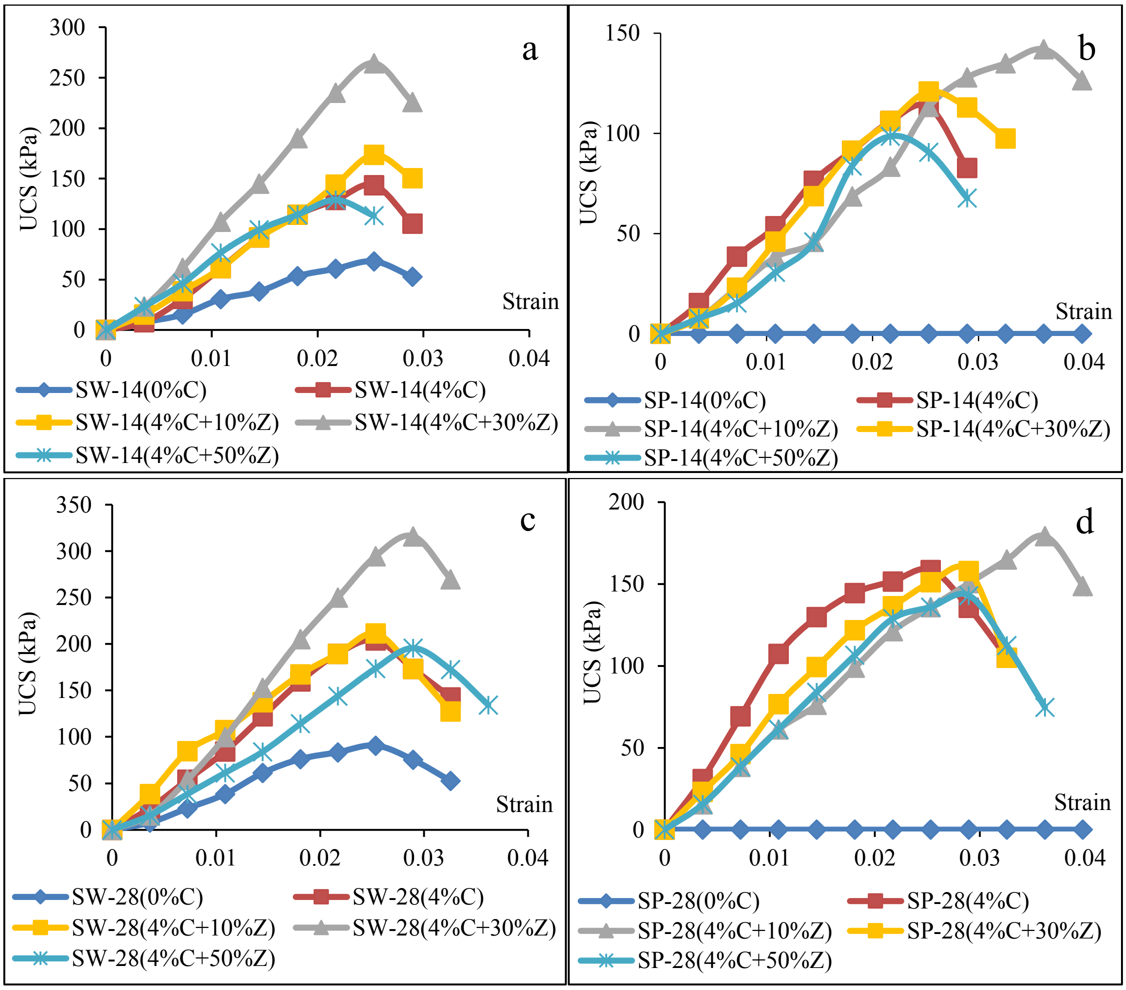

Fig. 9. Stress-strain diagram samples stabilized by cement and zeolite replacement in curing period of 14 and 28 days – a: SW, b: SP, c: SW and d: SP

begin some chemical reaction with cement elements which bond soil particles by making CSH and CAH. Finally leads to more compressive strength in soil. The sudden drop after the stress-strain diagram reaches the maximum strength in samples with additives is probably due to the joining of fine cracks and brittleness. This sudden drop is less in samples with rubber powder.

5- 4- The effect of rubber powder and zeolite on the UCS test

According to Figures 10 and 11 the effect of zeolite and rubber powder on the stress-strain behavior of samples stabilized with 4% cement can be seen. Samples with zeolite have higher strain than specimens without zeolite. Adding zeolite to samples with rubber powder, increased the strain. It can be due to the effect of zeolite reactions on the composition, which fills the pores of specimens and leads to stabilization and cohesiveness. It is noteworthy that substances such as zeolite also have a catalytic behavior and make pozzolanic chemical reactions better and faster.

On the other hand, the reason for the increase in uniaxial strength with the addition of rubber powder is the removal of brittleness, the change of its deformability under higher stresses without causing cracks. Practically, the presence of rubber powder has increased the flexibility of the samples. It should be noted that according to Figures 10 and 11, the increase in uniaxial strength due to the addition of rubber powder requires more deformation. In fact, the deformation increases both due to the addition of that rubber powder and due to the addition of zeolite. This feature is important in road construction because the cracks created in the road structure, which is always under harmonic stresses, are reduced. Therefore, it can be said that the dynamic behavior is probably improved due to the addition of zeolite and rubber powder.

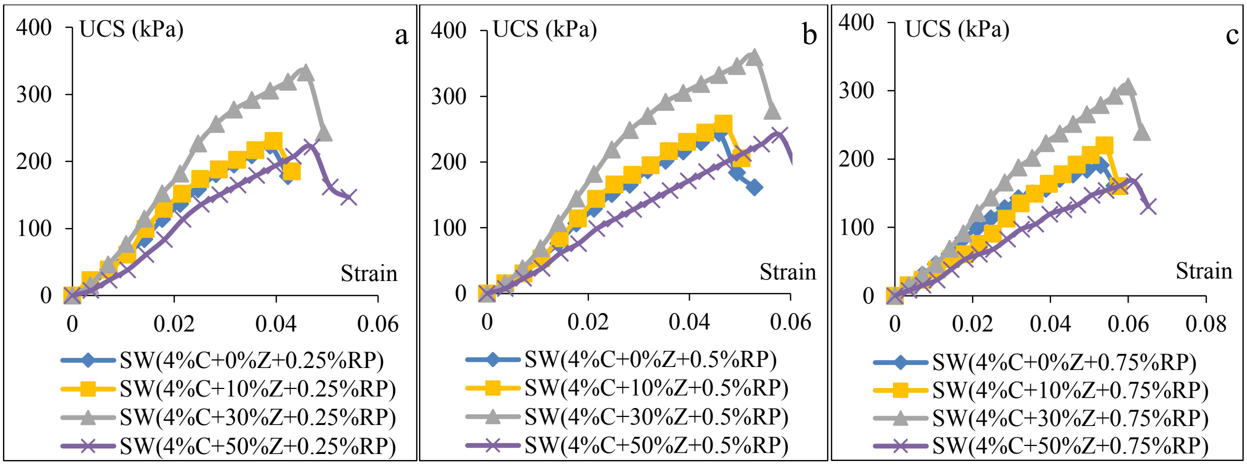

Fig. 10. Stress-strain diagram of stabilized samples (SW) by cement, zeolite and rubber powder replacement in curing period of 28 days – a: 0.25% rubber powder, b: 0.5% rubber powder, c: 0.75% rubber powder

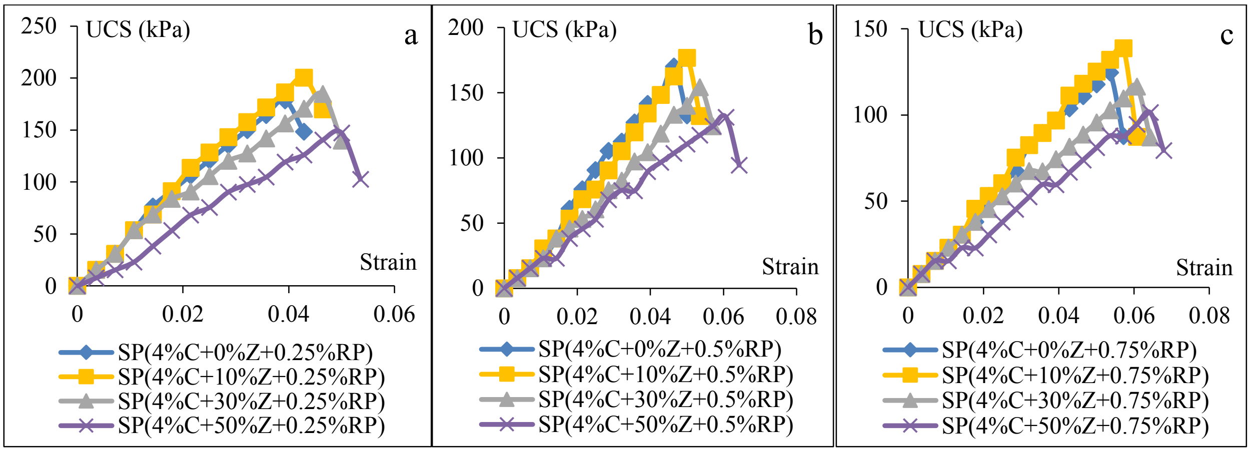

Fig. 11. Stress-strain diagram of stabilized samples (SP) by cement, zeolite and rubber powder replacement in curing period of 28 days – a: 0.25% rubber powder, b: 0.5% rubber powder, c: 0.75% rubber powder

5- 4- 1- Well-grained sandy soil (SW)

Stress-strain diagrams of SW samples with cement, zeolite, and rubber powder are shown in Figure 10. Zeolite and rubber powder addition to the samples with 4% cement, have more strain. Moreover, the unconfined strength of SW is higher by adding 30% zeolite and 0.5% rubber powder.

5- 4- 2- Poorly-grained sandy soil (SP)

Figure 11 shows the stress-strain diagram of stabilized sandy soil (SP) with cement, zeolite, and rubber powder. By adding zeolite and rubber powder to the samples with 4% cement, the strain has increased, which shows the ductile behavior of the samples at the moment of rupture. Samples with 10% zeolite and 0.25% rubber powder has reached the optimum level.

The results of the unconfined compression strength test on stabilized sandy soils (SW) with cement, zeolite, and rubber powder with a curing period of 14 and 28 days are shown in Figure 12-a. As can be seen, by adding 4% cement to this soil, the unconfined compressive strength increased from 67.97 kPa to 143.49 kPa during the curing period of 14-day and from 90.62 kPa to 203.914 kPa during the curing time of 28-day. Also, by replacing 30% zeolite with cement, the unconfined strength of the soil at the curing time of 14 and 28 days has reached 264.33 kPa and 316.022 kPa, respectively, it has experienced more than tripled in strength. Now, by adding 0.5% rubber powder to the stabilized sandy soil with 4% cement and 30% zeolite replacement, the unconfined strength with curing time of 14 and 28 days has reached 309.372 kPa and 359.591 kPa, respectively.

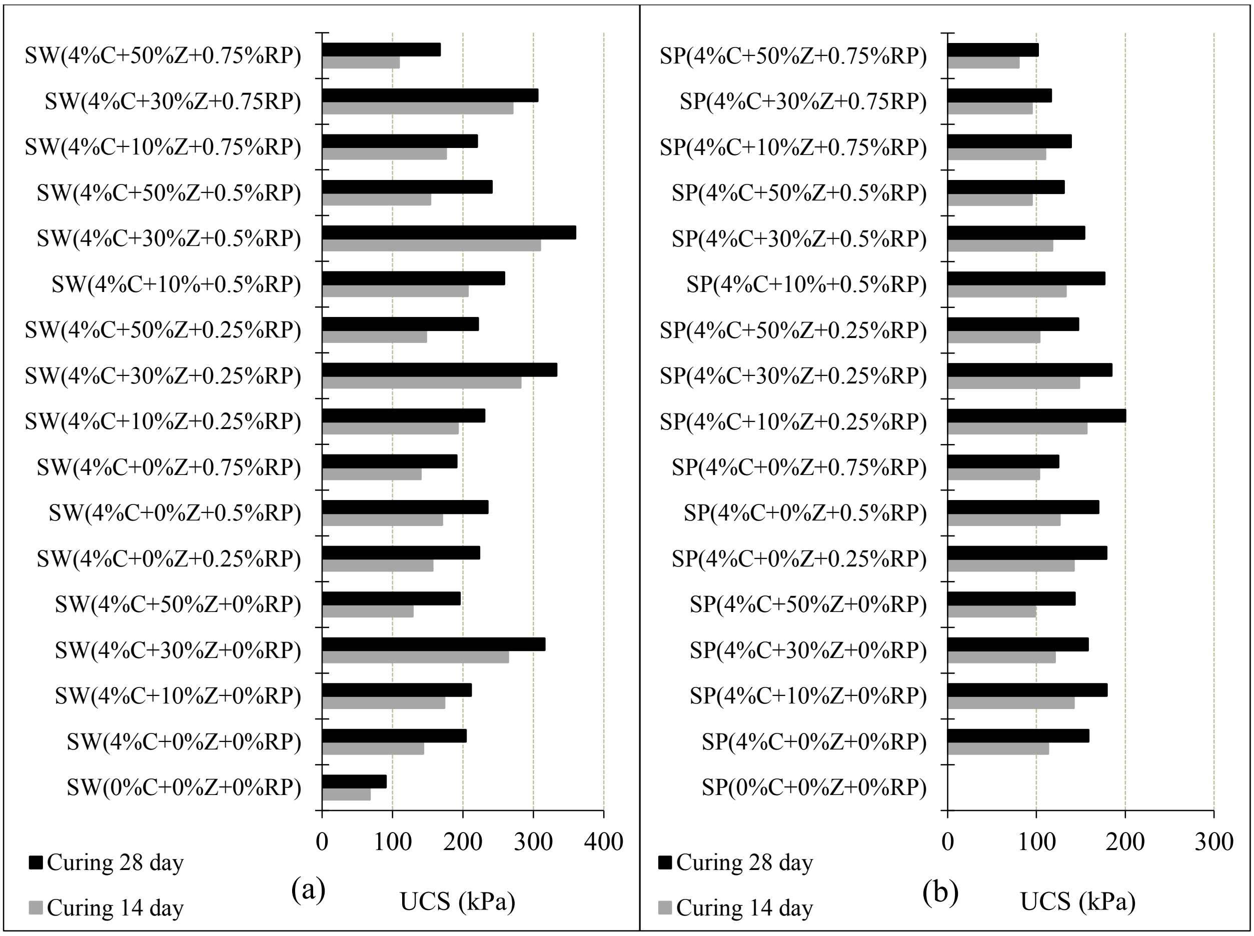

Fig. 12. UCS result of stabilized samples with cement and replacement of zeolite and rubber powder in curing period of 14 and 28 days – a: SW and b: SP

The unconfined strength test results of poor-grained sandy soil (SP) stabilized with cement, zeolite, and rubber powder are shown in Figure 12-b. As can be seen by adding 4% cement to this soil, the unconfined strength increased from 0 kPa to 113.286 kPa during the curing time of 14-day and from 0 kPa to 158.6 kPa during the curing time of 28-day. Also, by replacing 10% zeolite with cement, the unconfined strength of the soil in 14 and 28 days of curing time has reached 141.897 kPa and 179.238 kPa, respectively. By adding 0.25% rubber powder to the stabilized sand with 4% cement and 10% zeolite replacement, the unconfined strength of the soil at 14 and 28 days of curing time has reached 156.33 kPa and 200.248 kPa, respectively.

5- 5- Soil morphology

Samples were combined with the optimal percentage of zeolite with 28 days of curing time and were imaged by electron microscopy (SEM) which are shown in Figures 13 and 14. As can be seen in Figures 13-a and 14-a, there are pores in SP soil and the soil particles have very little cohesion. On the other hand, in SW, fine-grained particles surround the larger grains of sand and thus create cohesion.

Cement addition to base soil, as shown in Figures 13-b and 14-b, has filled the partial pores of the base soil. However, there are still pores, and even in parts where one of them is specified in Figures 13-b and 14-b, the formed bond between the grains is weak, so there is a possibility of cracking during static or dynamic loading.

According to Figures 13-c and 14-c, adding 30% zeolite to SW and 10% to SP, makes more pores fill and the individual grains are attached to each other and the soil texture will be bulky that can conclude why the uniaxial strength and ductility of the specimens increase due to the addition of zeolite. As can be seen in Figures 13-c and 14-c, the mass around each grain has become much stronger and denser due to the hydration reaction, so stronger bonds have been formed.

According to Figures 13-d and 14-d, by adding 0.5%

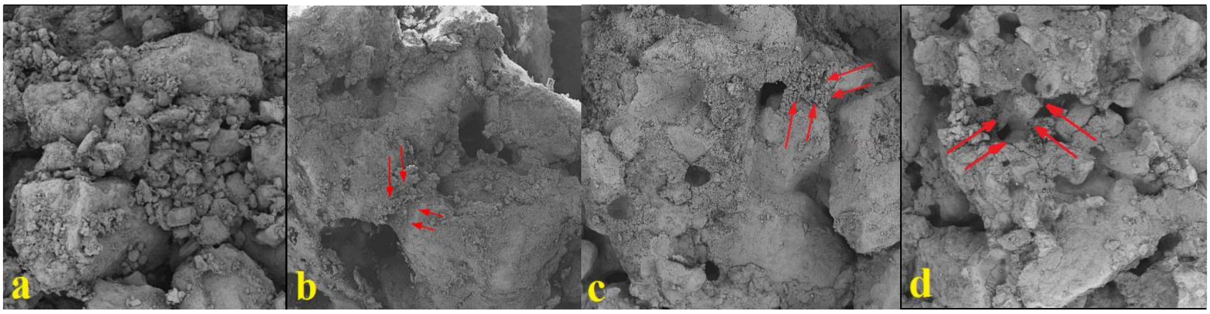

Fig. 13. Electron microscope image (SEM) with 30x magnification (SW) – a: base soil, b: soil with 4% cement, c: soil with 4% cement and 30% zeolite, d: soil with 4% cement, 30% zeolite and 0.5% rubber powder

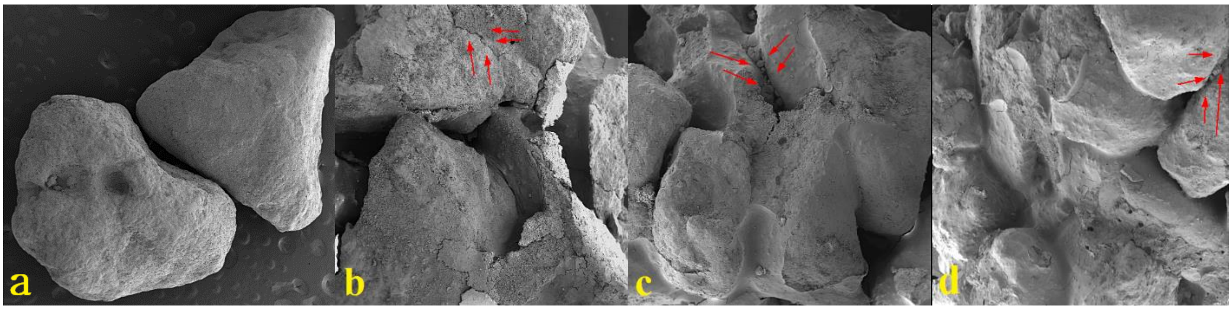

Fig. 14. Electron microscope image (SEM) with 30x magnification (SP) – a: base soil, b: soil with 4% cement, c: soil with 4% cement and 10% zeolite, d: soil with 4% cement, 10% zeolite and 0.25% rubber powder

rubber powder to SW soil and 0.25% rubber powder to SP soil, more pores are filled and the soil texture is changed, so more mass is seen than in the previous state in Figures 13-c and 14-c. In other words, adding rubber powder to the samples makes a massive compound by filling pores. The reason that rubber powder can increase soil strength is that rubber can endure stresses due to hydrational heat and bond soil particles.

6- Conclusions

Using zeolite and recycled rubber powder to be replaced with cement, not only reduces cement consumption but also has environmental benefits. Moreover, soil properties were improved and cement consumption was reduced, so it is a way to use worn tires which have detrimental effects on the environment. The results are as follows:

By increasing the percentage of rubber powder, the maximum dry density (MDD) and the optimal moisture content (OMC) in both soil types are dropped, However, by zeolite addition, the maximum dry density (MDD) of both types of soil is decreased and the amount of optimal moisture content (OMC) has increased which can be due to the water absorption property of zeolite.

By cement addition, rupture stress is increased in both fine-grained (SW) and poorly-grained (SP) sandy soils. Also, more curing time causes more unconfined compressive strength and rupture strain in samples. Bare SP soil does not have compressive strength at all. Comparing the results in these two soils shows that the strain rupture of SP is slightly higher than SW; while has less stress. This could be due to more pores between the SP soil particles. Also, cement addition to SW has a steeper slope in increasing the unconfined strength of stabilized samples than SP soil.

The optimum percentage of zeolite replacement with cement in SP and SW is 10% and 30%, respectively. In this replacement design, the unconfined strength of SW and SP compared to samples without zeolite replacement during 28 days of the curing period increased 84 and 32%, respectively, and in 14 days of the curing period, 55 and 13%. Also, by zeolite replacement, the rupture strain is increased, which indicates the soft behavior of the soil at the moment of failure. In well-graded sandy soil (SW) 30% zeolite replacement with cement, increases the stress and strain rupture of the samples and in higher quantities the unconfined strength of the samples is decreased. The reason for this difference is that there are more pores in SP samples, which can place a higher percentage of zeolite between its pores in a way that prevents the hydration process.

There is a steeper slope in increasing unconfined strength by replacing zeolite with cement in SW than SP. This indicates that stabilization and improvement in well-graded sandy soil will be due to the presence of fine particles and as a result, better bonding between soil grains.

The optimum amount of additives that lead to the highest strength in fine-grained sandy soil is 4% cement, 30% zeolite, and 0.5% rubber powder. While in poorly graded sandy soil these amounts are as follows: 4% cement, 10% zeolite, and 0.25% rubber powder.

Electron microscope images showed that by adding 30% zeolite to SW soil and 10% zeolite to SP soil with a mixture of base soil and 4% cement, more pores were filled than in samples without zeolite. It becomes less isolated and the soil texture becomes more massive. By adding 0.5% rubber powder to SW soil and 0.25% rubber powder to SP soil, more pores are filled, and the soil texture is changed and becomes more massive than before.

References

[1] Yilmaz, E., Belem T., Benzaazoua, M. (2015). “Specimen size effect on strength behavior of cemented paste backfills subjected to different placement conditions.” Engineering Geology, 185, pp. 52-62.

[2] Horpibulsuk, S., Suddeepong, A., Suksiripattanapong, C., Chinkulkijniwat, A., Arulrajah, A., Disfani, M. (2014). “Water-void to cement ratio identity of lightweight cellular-cemented material.” Journal of Materials in Civil Engineering, 26(10), pp. 1096-1105.

[3] Bildrici, M. (2019). “Cement production, environmental pollution and economic growth: evidence from China and USA.” Clean Technologies and Environmental Policy, 21, pp. 783-793.

[4] Gunaratne, M. (2013). “The foundation engineering handbook.” Taylor and Francis Group, CRC Press.

[5] Tobon, J., Restrepo, O., Paya, J. (2010). “Comparative analysis of performance of portland cement blended with nano silica and silica fume.” Dyna Magazine, 163, pp. 37-48.

[6] Harpel, C. J., Kyle, P. R., Dunbar, N. W. (2008). “Englacial tephrostratigraphy of Erebus volcano, Antarctica.” Journal of Volcanology and Geothermal Research, 177, pp. 549-568.

[7] Weckhuysen, B. M., Yu, J. (2015). “Recent advances in zeolite chemistry and catalysis.” Chemical Society Reviews, 44(20), pp. 7022-7024.

[8] Baerlocher, C., McCusker, L., Olson, D. H. (2007), Atlas of zeolite framework types, Elsevier Science.

[9] Fertu, T., Gavrilescu, M. (2012). “Application of natural zeolites as sorbents in the clean-up of aqueous streams.” Environmental Engineering and Management Journal, 11(1), pp. 867-878.

[10] Weitkamp, J. (2000). “Zeolites and catalysis.” Solid State Ionics. 131, pp. 175-188.

[11] Turer, A. (2012). “Recycling of Scrap Tires.” Material Recycling-Trends and Perspectives, Intech Open Publisher, pp. 195-212.

[12] ASTM D6270-08, (2014). Standard Practice for Use of Scrap Tires in Civil Engineering Applications.

[13] ACI Committee 230. (1997). “State of the Art report on soil cement.” ACI. 230.1R-90. American Concrete Institute, Farmington Hills, Michigan, pp. 1-23.

[14] MolaAbasi, H., Shooshpasha, I. (2016). “Influence of zeolite and cement additions on mechanical behavior of sandy soil.” Journal of Rock Mechanics and Geotechnical Engineering, 8, pp. 746-752.

[15] Demirbas, G. (2009). “Stabilization of expansive soils using bigadic zeolite.” PhD Thesis, University of METU, Ankara, Turkey.

[16] Hong, S. (2015). “Geotechnical laboratory characterization of sand zeolite mixtures.” Master Thesis, USA.

[17] Kordnaeij, A., Ziaie Moayed, R., Soleimani, M. (2019). “Unconfined compressive strength of loose sandy soils grouted with zeolite and cement.” Soils and Foundations, 59, pp. 905–919.

[18] Ahmadi Chenarboni, H., Lajevardi, S. H., MolaAbasi, H., Zeighami, E. (2021). “The effect of zeolite and cement stabilization on the mechanical behavior of expansive soils.” Construction and Building Materials, 272, 121630.

[19] Izadpanah, S., Shooshpasha. I., Hajiannia, A. (2021). “The impact of zeolite on mineralogy changes and compressive strength development of cement-treated sand mixtures through microstructure analysis.” Scientia Iranica, 28(3), pp. 1182-1194.

[20] Soltani, M. S., Jiryaei Sharahi, M., Amelsakhi, M. “Effect of zeolite and tire granules on cement stabilization of the sand.” Amirkabir Civil Engineering Journal, 54(2), pp. 759-774.

[21] Sarajpoor, S., Kavand, A., Zogh, P., Ghalandarzadeh, A. (2020). “Dynamic behavior of sand-rubber mixtures based on hollow cylinder tests.” Construction and Building Materials, 251, 118948.

[22] Akbarimehr, D., Eslami, A., Aflaki, E. (2020). “Geotechnical behaviour of clay soil mixed with rubber waste.” Journal of Cleaner Production.

[23] Anvari, S. M., Shooshpasha, I., Soleimani Kutanaei, S. (2017). “Effect of granulated rubber on shear strength of fine-grained sand.” Journal of Rock Mechanics and

Geotechnical Engineering, 9, pp. 936-944.

[24] Ghareh, S., Akhlaghi, F., Yazdani, K. (2020). "A study on the effects of waste rubber tire dimensions on fine-grained soil behavior." Journal of Rehabilitation in Civil Engineering, 8(3), pp. 15-33.

[25] Annual Book of ASTM D2487 Standards. (2012). "Standard test method for sieve analysis of fine and coarse aggregates." American Society for Testing and Materials, West Conshohocken.

[26] Annual Book of ASTM D698 Standards. (2012). "Standard test methods for laboratory compaction characteristics of soil." American Society for Testing and Materials, West Conshohocken.

[27] Annual Book of ASTM D4253 Standards. (2012). "Standard test methods for minimum index density and unit weight of soils and calculation of relative density" American Society for Testing and Materials, West Conshohocken.

[28] Annual Book of ASTM D4254 Standards. (2012). "Standard test methods for maximum index density and unit weight of soils and calculation of relative density." American Society for Testing and Materials, West Conshohocken.

[29] Annual Book of ASTM D854 Standards. (2012). "Standard test for specific gravity of soil solids by water pycnometer." American Society for Testing and Materials, West Conshohocken.

[30] Annual Book of ASTM C136 Standards. (2012). "Standard test method for sieve analysis of fine and coarse aggregates." American Society for Testing and Materials, West Conshohocken.

[31] Annual Book of ASTM C150 Standards. (2012). "Standard specifications for cements." American Society for Testing and Materials, West Conshohocken.

[32] Annual Book of ASTM D2166 Standards. (2012). "Standard test method for unconfined compressive strength of cohesive soil." American Society for Testing and Materials, West Conshohocken.

[33] Al-Bared, M. A. M., Marto, A., Latifi, N. (2018). "Utilization of recycled tiles and tyres in stabilization of soils and production of construction materials–A state-of-the-art review." KSCE Journal of Civil Engineering, 22(10), pp. 3860-3874.

HOW TO CITE THIS ARTICLE

A. R. Karimi, M. Amelsakhi, R. Yousefi, A. A. Amooei, Experimental Study on the Effect of Waste Rubber Powder and Zeolite Replacement on Cemented Sandy Soil, AUT J. Civil Eng., 8(1) (2024) 3-16.

DOI: 10.22060/ajce.2024.22739.5846