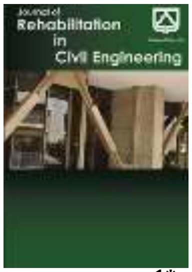

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A Study on the Effects of Waste Rubber Tire Dimensions on Fine-Grained Soil Behavior

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ABSTRACT

Mashhad city is located on alluvial deposits where the expanded area of this city, especially the central and eastern areas surrounding Imam Reza holy shrine, are built on weak and fine-grained deposits. Therefore, the soil improvement would be inevitable due to construction of high-rise buildings such as hotels and commercial complexes in these areas, as well as restructuring old buildings. Today, the use of waste rubber tire to stabilize the soil is not only efficient to secure human health and clean the environment but also as an inexpensive additive to improve the behavior of problematic soils. In this research, 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%) were investigated in a laboratory scale to examine the behavior of fine-grained soils reinforced with granular rubber tires as a suitable replacement for reinforced concrete piles in old buildings. The results showed that adding these rubber tires could reduce the density, optimum moisture content, and settlement, and increase 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 five percentage of rubber tire smaller than 1 mm in size leading to a 46% increase in bearing capacity and a 70% decrease in the settlement of the soil around the Razavi holy shrine.

1. Introduction

Mashhad is one of the major cities in the country that has been built on young alluvial deposits, where expanded regions, especially the adjacent areas of the Razavi holy shrine, are built on fine sediments with reported weak bearing capacity and numerous settlements. Therefore, soil improvement for high-rise structures such as hotels and

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commercial complexes, and soil reinforcement in old buildings around the Razavi holy shrine are one of the most important issues for geotechnical experts.

Studies done on Mashhad alluvial sediments show that the sediments are mostly fine-grained and soil type is CL-ML. In some areas of the city, in which the dominant texture is coarse-grained soils, fine-grained sediments are observed as interbedded lenses [1].

Hafezi Moghaddas and Ghazi prepared an ultimate bearing capacity map of Mashhad city based on the results of direct shear, triaxial, and standard penetration tests of 200 boreholes data. According to this map, bearing capacity decrease as the soil is fine-grained toward the east of Mashhad city, so that for the surface foundation with depth and width of 1 m, the central and eastern regions of the city are located in low and very low bearing capacity soils [2].

So far, numerous studies have been done on the geotechnical properties of Mashhad alluviums [1-7]. However, only few investigations evaluated the effects of additives in improving the strength properties of these alluvial. These studies are limited to the improvement of gypsum soils of the south and northeast of Mashhad with the use of lime or granular soil with different physical and chemical properties with in this study area [8-10].

Due to the high sensitivity of problematic soils under buildings and other structures, the use of various methods and materials to increase the bearing capacity and mechanical properties of soils has been the subject of many studies from the past to the present. These studies have mainly focused on soil improvement using soil consolidation and soil reinforcement methods. The most common soil consolidation methods consist of physical, chemical, mechanistic, electric, and biologic consolidation methods [11]. Each of these improvement methods has its disadvantages and problems, such as high cost or inefficiency of these methods in some areas. For this reason, researchers are seeking new ways to solve these problems. For example, cement production, despite its importance and effective role in the construction industry, not only destructs the nature due to the removal of sand from the riverbed resulting in floods and landslide phenomena, but also produces millions of tons of by-products including dust, toxic gases, and heavy metals accounting for 7% of carbon dioxide production, which, in addition to environmental pollution, cause global warming.

Other methods of soil improvement include bentonite slurry injection, which requires the use of special equipment and rads for injection and considerable cost payment. In addition, high levels of salts in bentonite accelerate the corrosion of the bar. Because of its tendency to water absorption and swelling, lack of moisture and volume reduction leads to cracks and vulnerability in the concrete.

Pollution and transportation costs, problems with water supply in arid and semi-arid areas, and safety equipment in construction sites to protect the skin and eyes of workers are problems with using lime for soil improvement. Limitations of the Jet Grouting method include the requirement for expert personnel, the project execution time, the costs of both the project and the equipment, and the time required to replace or repair defective pieces.

Accordingly, the geotechnical properties of the soils from the central and eastern areas of the city were studied in this research. Besides, because of problems with traditional methods such as improvement using cement and lime, it is necessary to use alternative materials that not only improve the soil strength properties but also are economical and reduce environmental pollutions. The aim of this study, therefore, is to investigate the behavior of cylindrical soil cells reinforced with rubber tires as a quick and easy solution and a suitable replacement for reinforced concrete piles in old buildings with asymmetric settlement in the vicinity of the Razavi holy shrine.

Implementation of these cylindrical soil cells in construction projects using the soil of the project site, in addition to the high speed, easy implementation, and low cost, is environmental-friendly due to the removal of tires from the earth.

In this research, the soil of the southeast of the Razavi holy shrine was reinforced with 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%) were studied on a laboratory scale. The overview of cylindrical soil cells to reinforce the isolated footings and reinforced soil under the strip footings are presented in Figures 1 and 2, respectively.

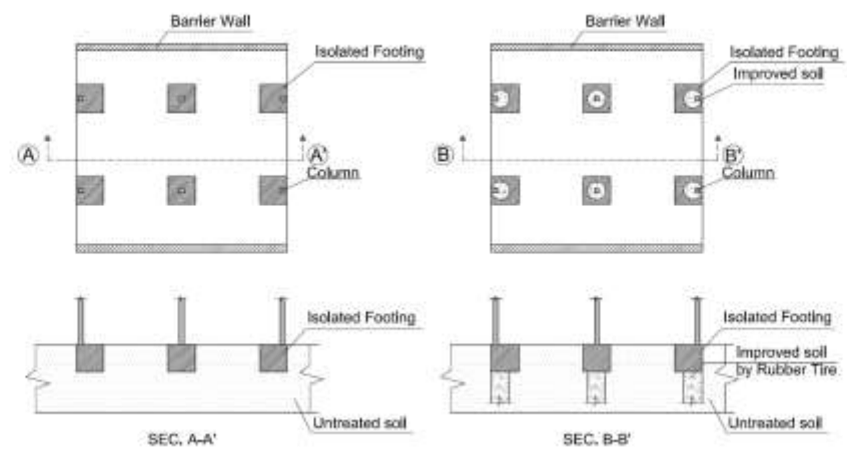


Fig. 1. Overview of isolated footing located on unreinforced soil and reinforced soil cells with rubber tires.

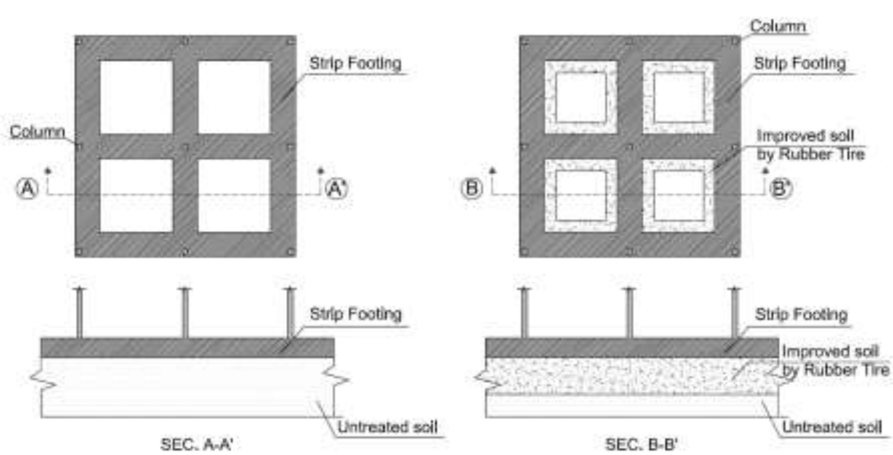


Fig. 2. Overview of strip footing located on unreinforced and reinforced soil with rubber tires.

About 1.5 billion tires are manufactured in the world per annum and 1000 million tires reach the cessation of their subsidiary life every year. This number can gain up to 1200 million tires per year by 2030 [12]. These discarded tires are disposed to either landfill, stockpiled or burnt off, which causes serious health and ecological problems. The recycling and reuse of these discarded waste tires can only minimize their environmental impacts. Many attempts have been made for the utilization of waste tires in concrete, asphalt pavement, waterproofing system, membrane liner, etc. However, knowledge about their utilization in geotechnical engineering is minimal and even scarce especially for cohesive soil [13]. Properties of tire wastes such as durability, strength, resiliency, and high frictional resistance are the most significant parameters for consideration in the design of highway embankments [14]. In the modern history of soil stabilization, the concept and principle of soil reinforcement were first developed by Vidal. He demonstrated that the introduction of reinforcing elements into a soil mass increases the shear resistance of the medium [15,16].

Recycled tires can be used to reinforce clay soils due to their high durability, elasticity, and frictional resistance. The use of recycled tires in cemented and non-cemented clay not only solves problems with clay soils, such as low strength, high compatibility, and low permeability but also presents a new solution to dispose of this hazardous waste [13]. In another study, the load-deformation behavior of rubber fiber-reinforced cemented clayey soil was examined through laboratory tests such as unconfined compressive strength (UCS) and split tensile strength (STS) tests. The clayey soil was stabilized with 3 and 6% cement content, and the inclusion level of rubber fibers was kept at 0, 2.5, 5, 7.5, and 10%. The study revealed that adding rubber fibers (up to 2.5%) to clayey soil led to marginal improvement in UCS and STS. The inclusion of rubber fibers to cemented clayey soil caused decreases in UCS and STS. Maximum increase of absolute toughness and toughness index of cemented clayey soil was observed with the addition of 7.5% [17].

A study on the applications of tire wastes in shallow footings reported that the presence of eccentric loads significantly reduced the load-bearing capacity of the soil. Based on experimental results, the optimum quantity of waste tire and the depth of reinforcement recommended were 30% (by weight) and 1B, respectively [18].

The impact of adding waste tire chips was examined on poorly graded sand. Test results showed that the residual strength increased by increasing the tire chip contents, and normalized residual shear strength was reasonably constant and increased up to 4 percentages with increasing tire chip contents [19].

The strength of soil samples was tested with addition of 5%, 10%, 15% and 20% crumb rubber. It was found that an optimum percentage of crumb rubber (10%) improved the soil strength up to 30% compared to that without crumb rubber, and that adding extra crumb rubber led to a decrease in soil strength [20].

Bekhiti et al. studied the influence of waste tire rubber fibers on unconfined compressive strength, swelling behavior, swell-consolidation, loading-unloading tests, and ductility of stabilized bentonite clay soil by cement using tire rubber fiber contents of 0, 0.5, 1, and 2%. They found that the UCS of fiber-reinforced cemented specimens increased with the addition of cement content and cement improved the durability and hardness of clay soil samples, with maximum UCS and ductility behavior at a rubber fiber content of 2% [21]. Kolhe and Langote studied the effect of rubber tire shred (0-10%) on engineering and index properties of black cotton soil. They found that the CBR values increased with the rising percentage of rubber tire shred with a maximum value of 8% for rubber tire. They also observed considerable decreases in the cohesion values and a remarkable increase in the angle of friction with an increasing percentage of the rubber tire shred. It was found that the rubber tire could be used effectively in road construction and pavement design due to an improvement in the CBR value [22]. Yadav and Tiwari examined the effect of waste rubber fibers on the strength properties of uncemented /cemented clay using three percentages of cement (0%, 3%, and 6%) and five percentages of rubber fiber (0%, 2.5%, 5%, 7.5%, and 10%). They found that the addition of rubber fibers up to 2.5% increased marginally the unconfined compressive strength and split tensile strength of uncemented clay [23]. Tafti and Emadi studied the mechanical properties of four soil samples with different grading reinforced with six different fiber contents. They detected that the positive impact of recycled tire fibers on the soils with finer grading was higher than those with coarser grading. Moreover, the fibers could enhance the properties of examined soils and increase their chance of being used in some geotechnical applications, e.g. as subgrade or sub-base materials in road construction [24].

Srivastava et al. studied the geotechnical properties of black cotton soil, which were partially replaced with 2-4.75 mm (coarse fraction) and 2.0 mm-75 microns (fine fraction) shredded tire waste. Addition of 30–50% of shredded tire waste in expansive black cotton soil reduced considerably the volume change potential of the black cotton soil. They also concluded that the addition of shredded tire waste to black cotton soil resulted in reduced swelling and shrinkage characteristics of the black cotton soil [25].

Kalkan investigated the influence of silica fume–scrap tire rubber fiber mixture inclusion on the geotechnical properties of clayey soils. The fibers were applied in lengths of 5 mm-10 mm at 1%, 2%, 3%, and 4% of the mixture weight. Based on the results, adding only fibers to the clayey soil reduced maximum dry density and optimum moisture content. At 2% fiber content, the unconfined compressive strength of the examined soil increased about 90%, the cohesion rose 2.8 times, and the internal friction angle increased from 16 to 32° [26].

Akbulut et al. studied the modification of clayey soils using 2% rubber fibers of 10-15 mm length. They subjected unreinforced and reinforced samples to unconfined compression, shear box, and resonant frequency tests to determine their strength and dynamic properties. The waste fibers improved the strength properties and dynamic behavior of clayey soils. They concluded that scrap tire rubber, polyethylene, and polypropylene fibers could be successfully used as reinforcement materials for the modification of clayey soils [16]. Miller and Rifai reported that the shrinkage crack reduction and hydraulic conductivity of compacted clay soil increased with an increase in fiber content [27]. The effect of granulated rubber dimensions was examined on the properties of expansive soils. Results indicated that critical state friction angles of the 6.7-mm granulated rubber mixture were slightly greater than 4.8-mm granulated rubber [28].

2. Methodology

2.1 Materials

2.1.1 Soil

The soil used in this research was taken from the southeast area of Mashhad city, Iran. Figure 3 shows the images of the urban area and the soil taken from the study area. The classified type of soil was defined as CL-ML based on the sieve and hydrometer tests. The mechanical properties of pure soil were evaluated using the standard tests and the results are presented in Table 2. The X-ray diffraction (XRD) test is usually used to determine the chemical structure and type of clay minerals of the soil, which was performed on pure soil samples with high accuracy. The results of the XRD test showed high percentages of quartz, calcite, and dolomite minerals comprising the main soil phase (Fig. 5). Also, all standard tests for the determination of soil mechanical and mechanical properties were performed to determine soil strength parameters (Table 1).

Fig. 3. A soil sample taken from the adjacent area of the Razavi holy shrine in Mashhad.

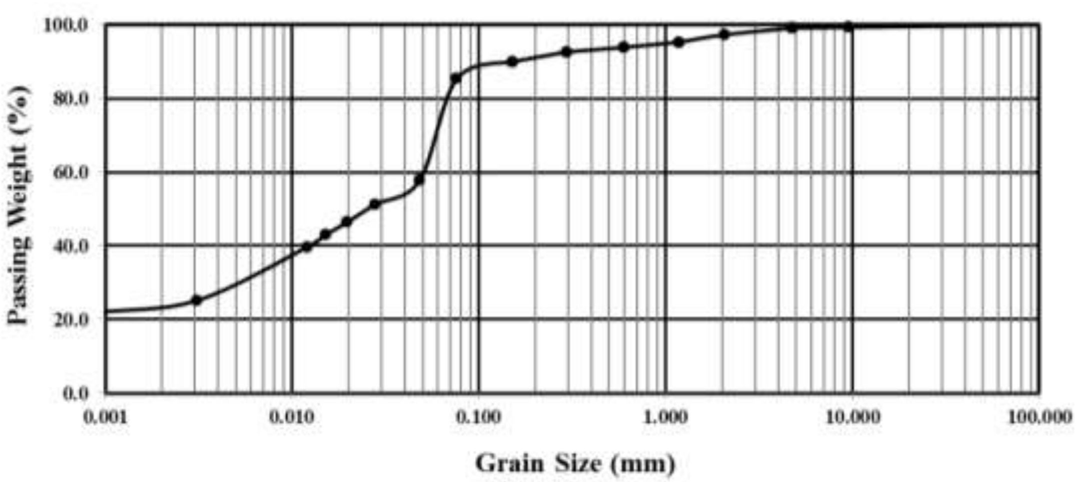


Fig. 4. Grading curve of studied soil.

Table 1. Geotechnical properties of studied soil.

Characterizes	Value	Standard
G_s	2.64	ASTM D 854-87
Maximum Dry Density (Kg/cm^3)	16.95	ASTM D 698-78 (standard)
Optimum Moisture (%)	15	ASTM D 698-78 (standard)
Plasticity Limit (PL) (%)	17	ASTM D 4318-87
Liquid Limit (LL) (%)	22	ASTM D 4318-87
Plasticity Index (PI) (%)	5	ASTM D 4318-87
Maximum Compressive Strength (kPa)	43	ASTM D 2166-87
Internal Friction angle (Degree)	25.15	ASTM D 3080-90
Cohesion (Kg/cm^2)	0.25	ASTM D 3080-90
Gravel (%)	3	ASTM D 422-87
Sand (%)	12	ASTM D 422-87
Silt and Clay (%)	85	ASTM D 421-58
Soil Type	CL-ML	USCS

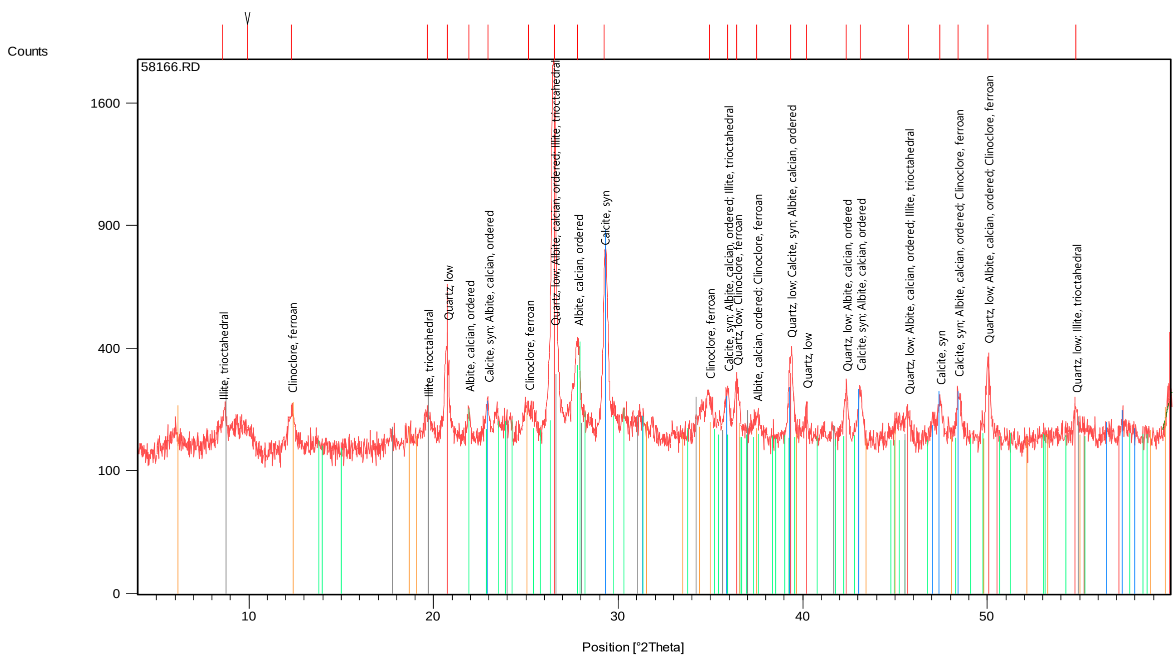


Fig. 5. Results of soil X-ray diffraction test.

2.1.2. Reinforced Elements

In order to investigate the effect of reinforced element dimensions on soil mechanical properties, rubber tires were used in three sizes of powder (less than 1 mm), granular of 1-2 mm, and granular of 2-4 mm (Fig. 6). The rubber tires were produced by a waste rubber recycling factory located in Mashhad-Neyshabur Road. Some of the physical characteristics of these elements are presented in Table 3.

Table 2. Mechanical properties of reinforced elements.

Characteristic \ Dimension	<1 (mm)	1-2 (mm)	2-4 (mm)
Density (gr/cm^3)	0.75	0.84	0.99
Unit Weight (gr/cm^3)	0.58	0.63	0.71

(a) (b) (c)

Fig. 6. Reinforced elements: a) Powder (<1 mm). b) Granular rubber tire (1-2 mm), c) Granular rubber tire (2-4 mm).

3. Laboratory Tests

The effects of reinforced elements on soil geotechnical properties were evaluated by standard laboratory tests on all specimens, including the compaction test, Atterberg limit, unconfined compressive strength test, and shear strength test (Direct Shear). The tests were done according to the ASTM standards for three sizes and six different weight contents of rubber tires. Table 3 summarizes the experiments on all the pure and reinforced soil specimens.

One of the most important issues to the performance of these experiments and preparing the specimens is to determine the ratio of soil and the tire rubber. The past studies show that in fine-grained soils, the best weight ratio is less than 10% by weight to increase the strength [29]. These results may because of the low density of rubber tire in comparison with soil, which occupies greater volumes with an equal weight of soil. For this reason, if the weight ratio increases, the connection of tires with the soil particles will decrease and the rubber particles will attach to each other, thereby reducing the geotechnical properties of the soil.

Also, according to the research, in order to prevent soil particles agglomeration and also to ensure the moisture homogeneous dispersion in the laboratory specimens, depending on the soil type, the specimens should be kept in a closed container for several hours, the minimum time is presented in table 4.

According to table 4, the studied specimens in this research were kept in containers at the heat above 25° C for 24 hours. To increase the accuracy of the results, for each weight ratio, two similar specimens were prepared and repeated the tests. The results indicate the accuracy of the experiments. It should be noted that in cases where the two specimens had different results, repeatability was performed until the accuracy of the laboratory studies.

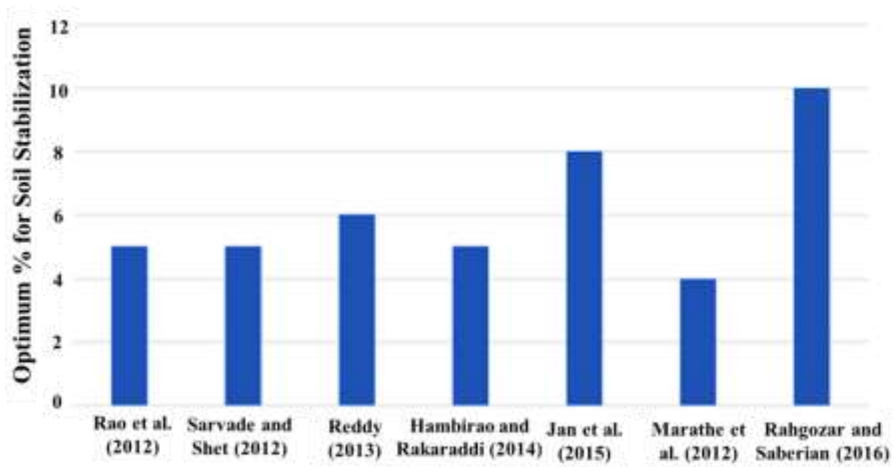


Fig. 7. Optimum Percentage of Tire Rubber Additive Proposed by Various Researchers for Soil Stabilization [29].

Table 3. Different tests done on pure and improved soil specimens.

Experiment		Proctor Compaction	Unconfined compressive Strength	Direct Shear	Atterberg Limit	XRD
Particle size	Weight ratio					
< 1 mm	0	✓	✓	✓	✓	✓
	0.5	✓	✓	✓	✓	
	1	✓	✓	✓	✓	
	2.5	✓	✓	✓	✓	
	5	✓	✓	✓	✓	
	7.5	✓	✓	✓	✓	
	10	✓	✓	✓	✓	
1-2 mm	0.5	✓	✓	✓	✓	
	1	✓	✓	✓	✓	
	2.5	✓	✓	✓	✓	
	5	✓	✓	✓	✓	
	7.5	✓	✓	✓	✓	
	10	✓	✓	✓	✓	
2-4 mm	0.5	✓	✓	✓	✓	
	1	✓	✓	✓	✓	
	2.5	✓	✓	✓	✓	
	5	✓	✓	✓	✓	
	7.5	✓	✓	✓	✓	
	10	✓	✓	✓	✓	

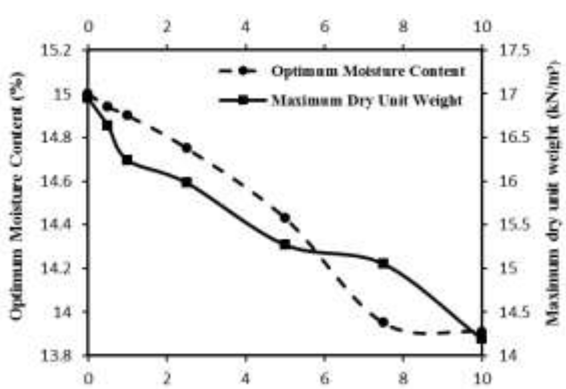
Table 4. Preparation Method of Dry Soil Specimens- Stopping time.

Soil Classification (ASTM D2487)	Minimum Time (Hours)
SP, SW, GP, GW	Not Necessary
SM, GM	3
SC, GC, OL, CL, ML	18
PT, OH, CH, MH	36

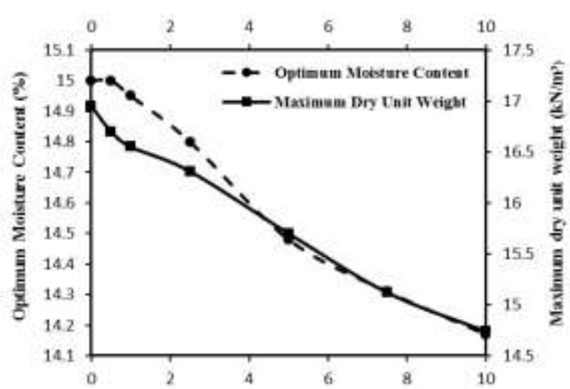
4. Result and Discussions

4.1. The Effect of Rubber Tires on the Maximum Dry Density of Soil

To determine the optimum moisture content and maximum dry density of pure soil and reinforced specimens, a standard compaction test was carried out in accordance with ASTM D 698-78 (standard) and the results are presented in Figure 8. As expected, due to lightweight and low water absorption of rubber tires, optimum moisture content and maximum dry density decreased by increasing the percentage of rubber tires. To evaluate the effect of rubber tires dimensions, specimens reinforced with the rubber powder showed a more significant decrease in dry density as a result of the lower weight of rubber powders than the larger dimensions of granular rubbers. The highest drop in density was observed in specimens with 10% rubber powder content, which reduced the density from 16.95 to 14.19 kN/m^3. Optimum moisture content for this specimen dropped by about 7%. The decrease in the optimum moisture content of reinforced specimens is because of low water absorption by rubber tires, and reduction of their density to pure soil may be due to the low density of rubber tires and reduction of compaction effect because of the elastic properties of rubber tires. These results correspond to those of other researchers [17,26,30-32].



(a)



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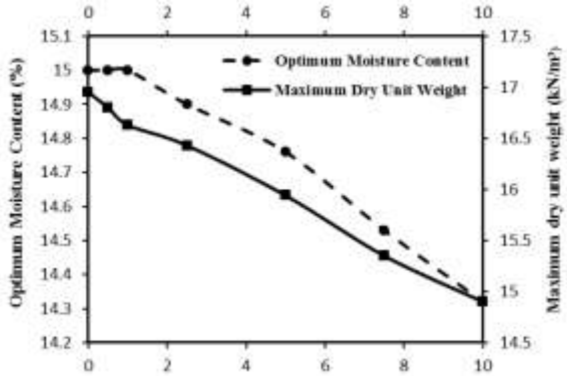


(c)

Fig. 8. Maximum Dry Density and Optimum Moisture Changes with Increasing Content and Dimensions of Rubber tire. a) soil Reinforced with Rubber Powder. B) Soil Reinforced with 1 to 2 mm granular rubber. C) Soil Reinforced with 2 to 4 mm granular rubber.

4.2. The Effects of Reinforced Elements on Soil Swelling Potential

The results of the Atterberg tests (Fig. 13) indicate that the rubber tires in low quantities increase the liquid limit and plastic limits and decrease the plasticity index of the soil. The trends of increasing and decreasing Attererberg limits are reversed by increasing the weight ratio of the reinforced elements. These changes can be justified by the fact that the rubber tires at low weight ratios were inserted well among the soil particles. Moreover, changes of soil state from liquid to plastic require extra moisture due to the distance between the soil particles. With an increase in rubber tires content, however, these elements are bonded together acting as a bridge between soil particles. However, the soil components come together as small clusters and therefore require less water for liquid and plastic forms due to the smaller soil volume. This is more apparent with an increase in the size of rubber tires.

The swelling index of clay soils based on soil plasticity characteristics are presented in Table 5 [14]. According to the plasticity index (Fig. 9), a liquid limit of less than 30 in all specimens, and according to the standard, the studied soil is placed in the low swelling class and the reinforced elements also did not change the degree of swelling potential.

Table 5. Estimate of Soil Swelling Potential Based on Plasticity Index.

Swelling Potential	Liquid Limit (%)	Plasticity Limit (%)
Low	<30	0-15
Moderate	30-40	10-35
High	40-60	20-55
Very High	> 60	> 35

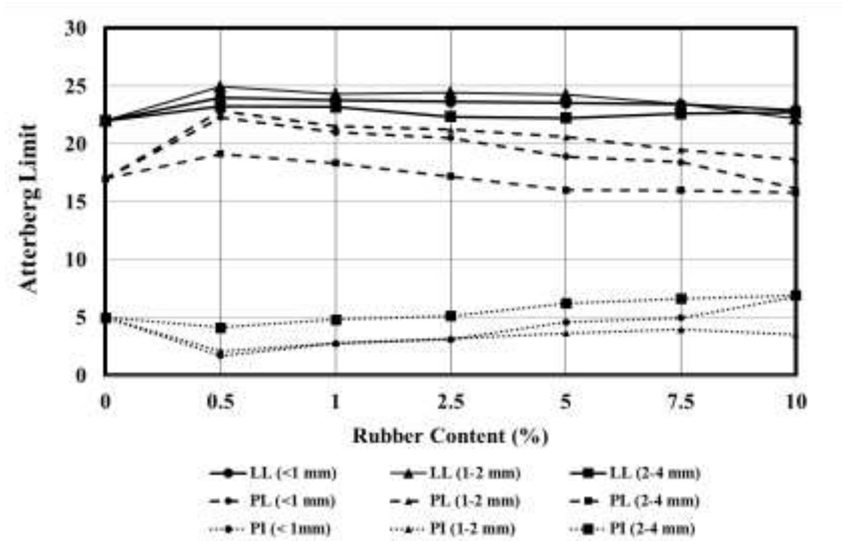


Fig. 9. Changes in Atterberg limit of Soil with Different weights content of rubber tires.

4.3. Soil Shear Strength Parameters

One of the important issues in the study of soil stability for the design of foundation, retaining walls, embankments, and other structures is having sufficient information about shear strength parameters of the soil (internal friction angle and cohesion). At this stage, the direct shear test was performed on sample soils in accordance with ASTM D 3080-90 standard. The tests were done in three normal stresses (50, 100, and 150 kPa) under the undrained condition with a speed of 0.5 mm/min.

The results of direct shear tests indicate that the internal friction angle significantly increased in most of the specimens reinforced with larger elements. Besides, the cohesion significantly improved in the specimens with smaller elements (Fig 10). The internal friction angle of the reinforced specimens increased 8%, 17%, and 32% respectively, in the specimens with 5% rubber powder, 7.5% granular rubber (1-2 mm) and 7.5% of granular rubber (2-4 mm) .This can be justified by the fact that the reinforced specimens with larger elements behave as coarse-grained soil, leading to increased internal friction angle. In addition, by applying the shear force and placement of reinforced elements among the soil particles, the lateral pressure from the soil grains is applied to the rubbers, resulting in increases in interlocking, strength, and internal friction angle of the specimens. These results are consistent with those of previous studies [28,33]. The changes of cohesion in reinforced specimens with different dimensions of granular rubber tires (Fig. 11) reveals that the cohesion parameter rises in specimens reinforced with rubber powder, but it drops with increasing dimensions of reinforced elements.

The highest increases in the cohesion of specimens are 71%, 54%, and 68% respectively in specimens reinforced with 10% rubber powder, 5% granular rubber (1-2 mm), and 5% granular rubber (2-4 mm). Reduction of cohesion with increasing dimensions of reinforced elements can be assigned to their reduced connection and consequently a decrease in the soil cohesion due to the placement of larger reinforcing elements among the soil particles.

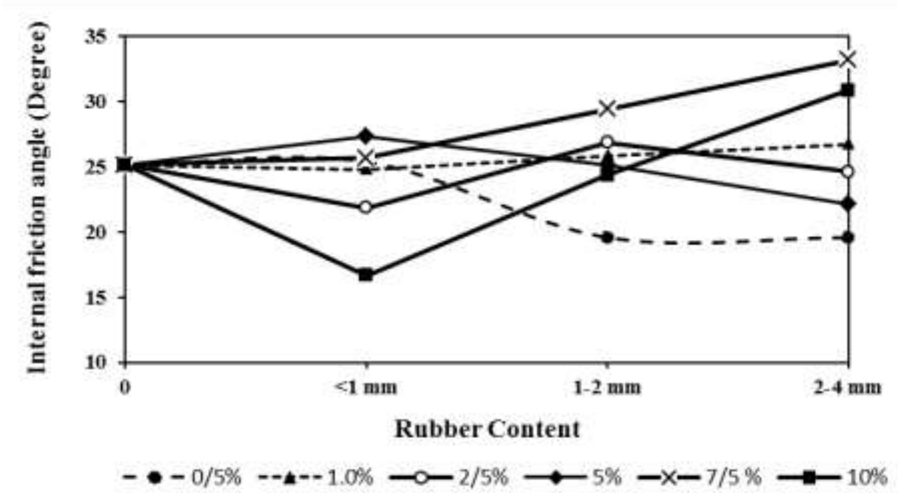


Fig. 10. Internal friction angle Changes in Reinforced Specimens.

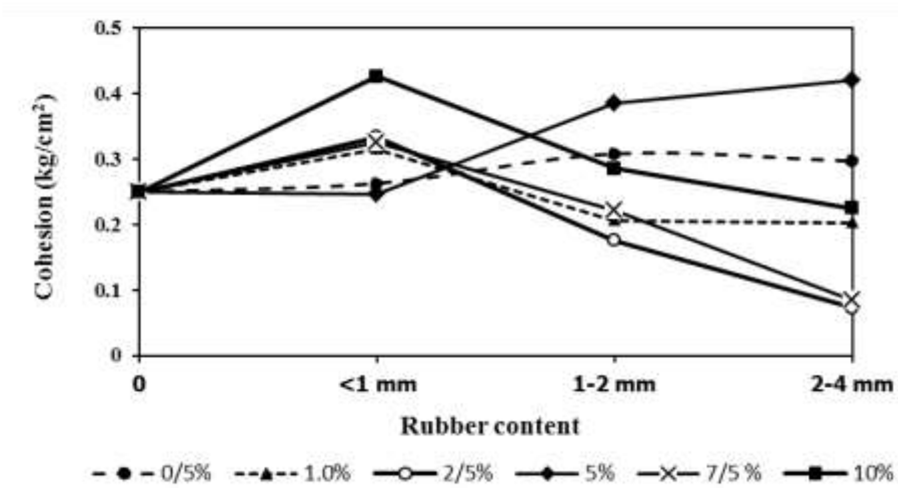


Fig. 11. Cohesion Changes in Reinforced Specimens.

4.2. Soil Compressive Strength Changes

The purpose of this laboratory test is to determine the unconfined compressive strength of reinforced and unreinforced soil. To this end, the specimens were prepared according to ASTM D 2166-87 standards.

To reduce the error and improve the reliability of the results, three similar specimens were prepared for each weight ratio. Figures 12-14 show the behavior of specimens reinforced with granular rubber tires in three sizes and different weight ratios after performing the tests and fracturing in laboratory conditions.

The results of unconfident compressive strength tests are shown in Figure 15 (a - f), which are significant in terms of dimensions and weight percentage of rubber content. As shown in this figure, the specimens reinforced by rubber powdered have the maximum strength, and dimensions of the granular rubber (12 mm) have the least effect on the soil compressive strength. Even in some weight percentages, these specimens have less strength than unreinforced soils. The strength of soil increased in reinforced specimens with powder and granular rubber of 2-4 mm dimensions in all weights ratios, with the highest strength in a specimen reinforced with 5% of powder rubber, leading to a 46% increase in the soil strength.

Yadav and Tiwari showed an optimum amount of 5% for rubber tires, which is in accordance with those of Srivastava et al. [25,32]. Other studies indicate that the contacts between the soil particles reduce with an increase in the amount of rubber tire and that the behavior of specimens is controlled by the tires [30,34,35].

Another significant soil geotechnical parameter is the settlement of soil. The results of this study showed that the settlement of specimens decreased in all reinforced specimens with increasing compressive stress, and the lowest amount of settlement was recorded in the specimen with the highest compressive strength (Fig. 16).

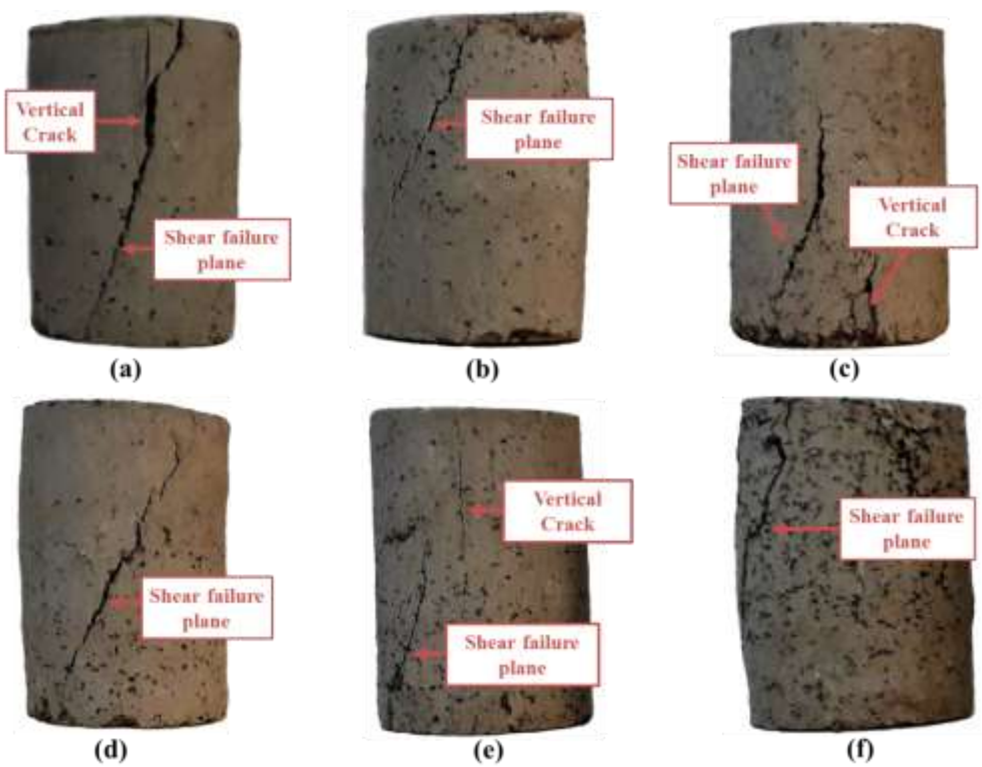


Fig. 12. Reinforced specimens with rubber powder: a) 5%, b) 1%, c) 2.5%, d) 5%, e) 5.7%, and f) 10%.

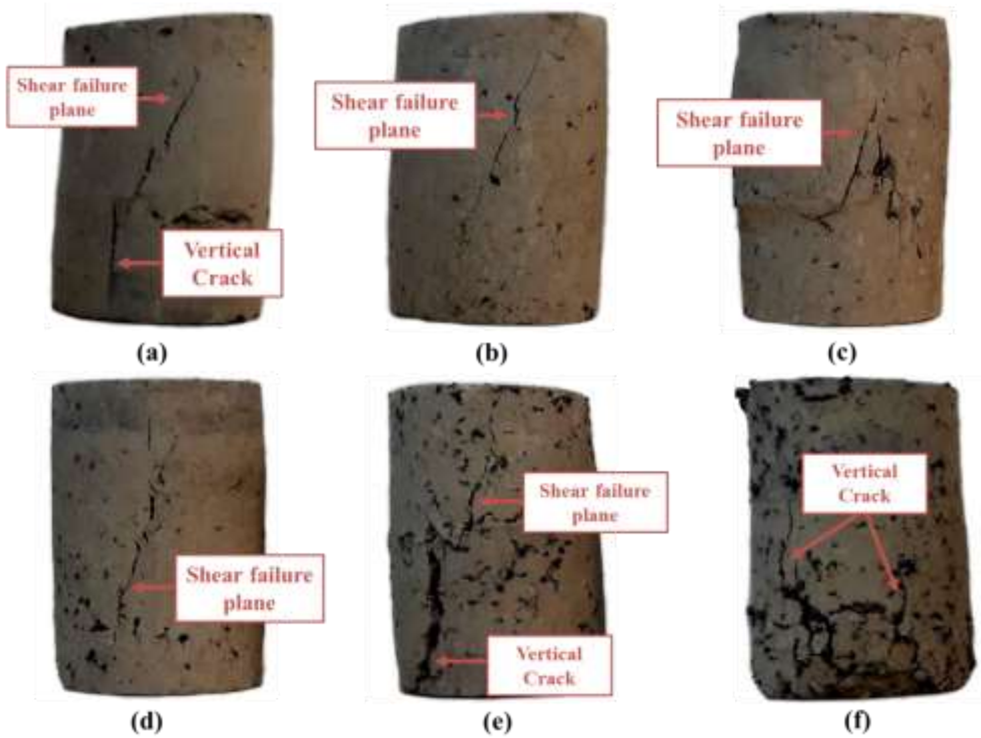


Fig. 13. Reinforced specimens with granular rubber (size 1-2 mm): a) 5%, b) 1%, c) 2.5%, d) 5%, e) 5.7%, and f) 10%.

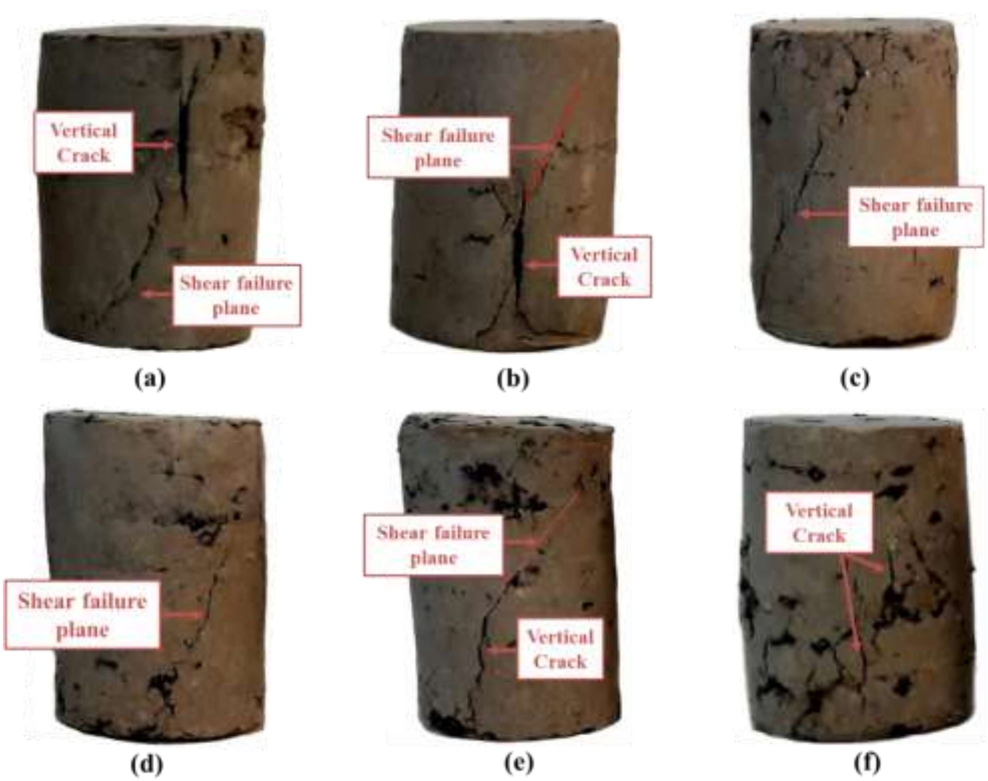
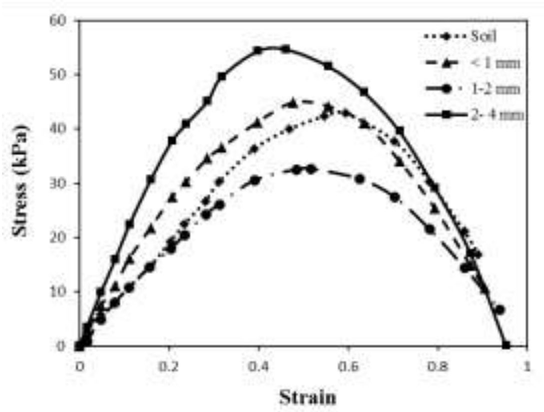
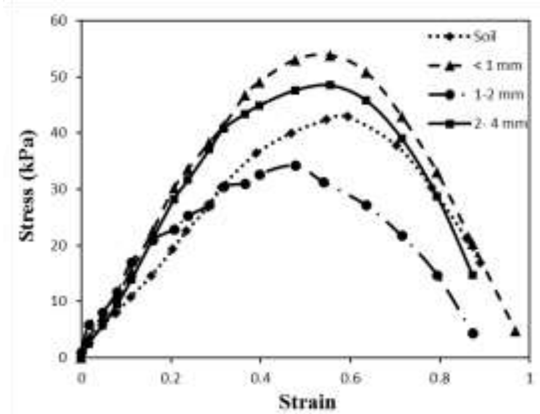


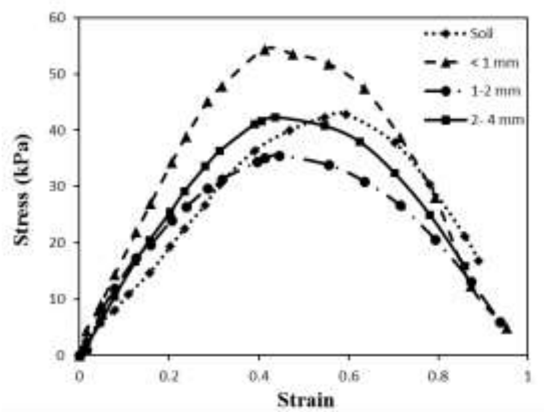
Fig. 14. Reinforced specimens with granular rubber (size 2-4 mm): a) 5%, b) 1%, c) 2.5%, d) 5%, e) 5.7%, and f) 10%.



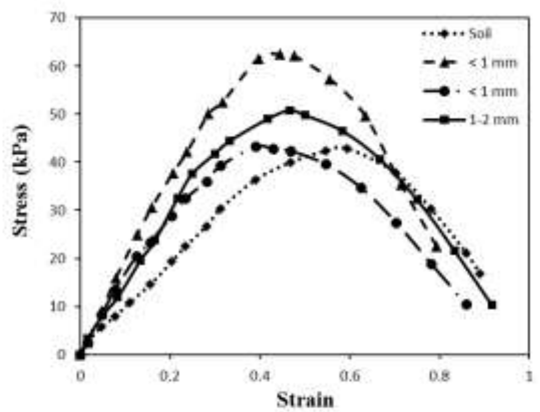
(a)



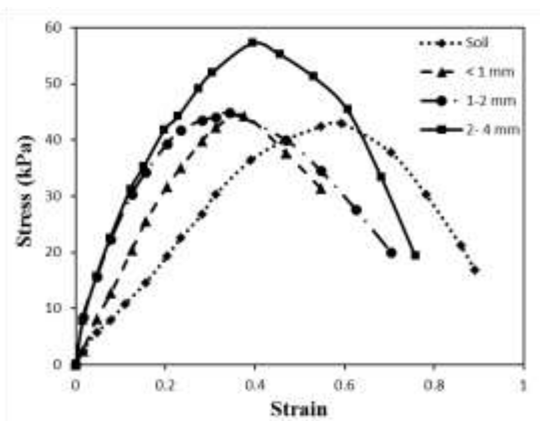
(b)



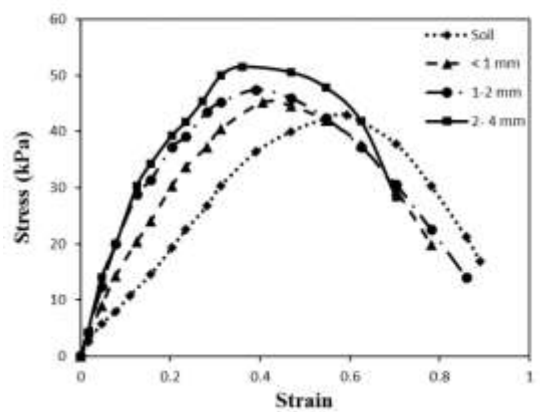
(c)



(d)



(e)



(f)

Fig. 15. Results of the compressive strength test in soil reinforced with rubber crumb in various combinations (percentage) and sizes: a) 0.05. b) 1. c) 2.5. d) 5. e) 7.5. f) 10.

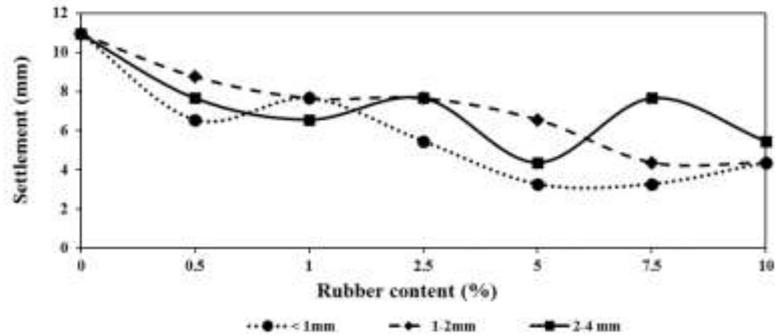


Fig. 16. Changes in the settlement of reinforced soil specimens.

5. Conclusions

This study sought to determine the geotechnical properties of soil specimens reinforced with granular crumb rubber, including the strength parameters, density, swelling index, settlement, internal friction angle, and cohesion. The results of this research can be summarized as follows:

1. Maximum dry density and optimum moisture content of reinforced soil decreased due to the light density and low water absorption of crumb rubber. As such, all the reinforced specimens had lower maximum dry density and optimum moisture than the pure soil, which was more evident in the specimens reinforced with rubber powder.

2. The test results of unconfident compressive strength show that the addition of rubber powder and 2-4 mm rubber granular in all weight ratios and 1-2-mm granular rubber in weight ratios of 7.5% and 10% led to the increased load-bearing capacity of the soil. Besides, the presence of granular rubber in all dimensions and ratios reduced the soil settlement susceptibility.

3. The optimum combinations of powder and granular rubber (1-2 and 2-4 mm) were 5, 10, and 7.5%, respectively. The compressive strength of specimens with rubber powder was 46% more than pure soil, and the settlement in this specimen dropped to 70%.

4. Based on the results of direct shear tests, the existence of granular rubber, especially in larger dimensions, caused the soil to act as granular soils, and the internal friction angle increased up to 32% in specimens reinforced with 7.5% of granular rubber (2-4 mm). The cohesion parameter increased in most specimens reinforced with rubber powder and the cohesion decreased with increasing dimensions.

5. The rubber tires in low quantities increased the liquid limit and plastic limits and decreased the plasticity index of the soil. The trends of increasing and decreasing of Attererberg limits were reversed with increases in the weight ratios of reinforced elements. The presences of crumb rubber in small amounts had no effects on the soil swelling index degree.

6. Our laboratory studies showed that specimen reinforcement with 5% of rubber powder is an optimum content of granular rubbers in the soil.

In conclusion, the use waste rubber tires in optimum weight ratio not only improves the soil strength parameters but also removes the waste tires from the ground surfaces and reduces the environmental pollution.

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