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Experimental Investigation of the Densification Properties of Clay Soil Mixes with Tire Waste

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Abstract

The annual increase in production of industrial wastes, including scrap tire, has created several challenges for societies. Incorporating the wastes as raw materials has been proposed in different industries, using waste tire as physical additives and investigating the geotechnical properties of this mixture can reduce the environmental pollution, as well as offering economic and technical benefits. Clay soils are abundant in southern regions of Tehran where scrap tire is also produced in large quantities every year. Therefore, provided the chance, incorporating these wastes into the soil mix is significant as regards both geotechnical properties and environmental considerations. As a fundamental means of investigation in construction activities, in particular road construction, the compaction test is useful in determining the maximum density and the optimum moisture content of the soil. In this study, considering that this research has not yet been investigated for Tehran clay and has environmental benefits while having engineering application, the optimum moisture content and maximum dry density of the clay mixed with two types of additives (waste tire powder and granules) at various mass fractions (2, 4, 6, 8, 10, 20, and 30 wt%) using standard compaction tests were investigated. The results suggested that the variations of the optimum moisture content and the maximum dry density in both clay mixes demonstrate a certain and predictable trend as the waste content increases. In other words, by increasing the percentage of waste in the mixture, the optimum moisture content is increased, and this increase in the mixture of the tire powder and clay is more than granule and clay. In addition, by increasing the percentage of waste, the maximum dry weight of the mixture was reduced, and this reduction in the mixture of tire powder and clay is almost higher than that of tire granule and clay. Furthermore, relations were presented to estimate the maximum density and the optimum moisture content of the mix to be applied in practice.

Keywords: Tehran Clay; Tire Powder; Tire Granule; Compaction; Geotechnical Properties; Environmental Geotechnics.

1. Introduction

Our inclination toward urbanization and automation increased the generation of all types of wastes including paper, tire, metals, glass, and plastic. There are different methods of waste control, among which are reusing, burning, and burying. Aside from some of these methods that are damaging to the environment, the industrial reuse of wastes is a notable approach in both technical and environmental terms, a subject which has been addressed by several researchers. Waste tire accounts for a large portion of wastes today and controlling and reusing it offers several environmental benefits [1].

Site investigation and site characterization for civil engineering projects is of great importance and has been studied by various researchers [2, 3]. After site investigation and site characterization as need, if the soil is not suitable for the

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project, suitable soil improvement methods should be performed. Different soil improvement methods including use of piles, compaction, dynamic compaction, injection, and physical and chemical methods have always been a matter of interest to researchers and engineers to improve weak and problematic soils in different construction projects [4-6]. The best improvement method is selected based on the type of soil in the region and the construction project. The clay soil is an example of a problematic soil that several researchers have attempted to improve. Various physical and chemical approaches have been considered as one of the best low-cost soil improvement methods by researchers. Cement, bitumen, sand, fibbers, lime, rubber and plastic wastes are a few examples of materials that have been incorporated as additives into soil mixes to improve their properties. In an attempt to enhance the ductility and strength of the mix and to make use of the wastes, scrap tire has been used in different civil engineering applications as a physical additive to asphalt, concrete in granule, powder, and chip forms [7-13]. Considering that few studies have addressed the utilization of scrap tire, the incorporation of the wastes into the clay soil as a physical additive can be valuable as regards the environment and sustainable development. Using wastes to modify the properties of materials and to consume them in road construction can be practically valuable and offer technical benefits.

Determining the dry density and the optimum moisture content of the materials are one of the basic, preliminary actions to ensure the suitable compaction of the different layers of the road. Using the clay soil and scrap tire mix for road construction is contingent upon providing the maximum dry density and the optimum moisture content at different waste tire contents. The waste tire is available in powder and granule forms that are both abundant and allow for an even soil mix. Furthermore, the southern parts of Tehran are rich in low-plasticity clay soils with significant geotechnical specifications that are important to be improved by engineering solutions [14]. Drawing on an experimental plan, soil and tire waste characterization, and classification tests, this study investigated the optimum moisture content and the maximum moisture content of a mix of Tehran clay and waste tire in powder and granule forms, presenting relations to be used in engineering applications.

In the following, the materials, their physical and geotechnical specifications, and the experimental methods are discussed separately and, additionally, the research literature on the application of scrap tire in civil engineering is reviewed. In Results Analysis section, the compaction tests conducted on different mixes with different tire wastes and Tehran clay are analysed and compared. Later, the results of the study are presented in Conclusion section.

2. Literature Review

Prompted by environmental concerns and the favourable mechanical properties of the waste material (such as excellent resistance and damping), utilizing various types of scrap tire produced by industrial machinery, agricultural equipment, and public and private vehicles in crumb, chip, granulated, and fibber forms is common in many fields of civil engineering including pavement, water-resistant systems, concrete, and landfills. As regards the clay and waste tire mix, the subject has been addressed by few studies that will be reviewed in the following.

Trouzine et al. (2012) investigated the impact of waste tire powder on the liquid limit and the consolidation properties of clay soils. The study revealed that the addition of the waste tire powder enhances the compression index while reducing the liquid limit in clay soils [15]. Moreover, Sarvade and Shet (2012) evaluated the effect of waste tire powder additives on the Atterberg limits, the maximum dry density, and the optimum moisture content of high-plasticity clays [16]. The results of the study indicate that adding 5% waste tire powder to a high-plasticity clay reduces the liquid and plastic limits by 6%. Furthermore, the plasticity index is initially increased with increasing the tire content but begins to decline eventually. From the standpoint of compaction test parameters, this study demonstrates that by adding waste tire powder to clay, its maximum dry density is steadily reduced while the extent of this reduction depends on the waste tire powder. The optimum moisture content of the soil was associated with a decreasing trend as the waste tire content was increased up to 10%, after which it began to increase. Kalkan (2013) addressed some geotechnical properties of a mix of clay and waste tire fibbers including compaction and uniaxial strength [17]. It was found that the maximum dry density and the optimum moisture content decrease with increasing the added tire fibbers, such that the best strength properties were achieved at a 2% tire fibber content. Wang and song. (2015) studied the effect of adding waste rubber to compressive strength of cemented treated soil using compressive strength tests [18]. According to this study, in the cement content of 20%, the rubberized cemented soil showed better plasticity properties than the soil without rubber content. Tiwari et al. (2014) investigated the geotechnical properties of a clay and waste tire mix through compaction tests, reporting the effect of tire crumbs on the maximum dry density and the optimum moisture content [19]. In addition, Hambriao and Pakaraddi (2014) reviewed the methods of soil improvement using different materials [20]. Behaviour of tire granule in geosynthetic reinforced soil wall were investigated by Ramirez et al. (2015) [21].

Seins et al. (2016) evaluated the properties of a clay and waste tire powder mix with the help of compaction and uniaxial tests, reporting that increasing the waste tire powder content reduces both parameters, while the uniaxial strength was not considerably affected by adding small amounts of the additive (around 5%) to the soil [22]. In another study, Tajdini et al. (2016) investigated the strength of clay and tire crumb mix, reporting an increase in the internal friction angle by adding 10% tire crumbs to the mix [23]. Effect of addition of tire on clay soil stabilization were investigated by Ravichandran et al. (2016) [24]. Their findings show that tire have desirable effects in permeability and CBR values. Mukerjiee and Mishra (2017) studied the consolidation of a bentonite-sand mix, reporting that adding up to 10% waste tire chips reduced the compression index of the soil [25]. Yadav and Tiwari (2017) investigated a cement-consolidated clay and waste tire fibber mix with the help of uniaxial, CBR, and compaction tests. The results suggested that adding 7.5% waste tire fibber to the clay in addition to the cement provides an excellent filler material for the reinforcement of retaining walls and the foundation of low-traffic roads [26].

3. Materials and Methods

Given the practical value of this study and its results for future technical and engineering activities, natural clay and the powder and granules of the following specifications were acquired and mixed. Tests were carried out on the soil and tire mixture in accordance with the following specifications.

3.1. Tehran Clay

One of the goals of this research is to use its results in practical projects. Since natural clay from southern areas of Tehran was used in this study, the results can be helpful in practical applications. The liquid limit, the plastic limit, and the plasticity index of the soil were equal to 36, 16, and 20, respectively, and it features a specific gravity of 2/65. The optimum moisture content and maximum dry density of the clay soil were obtained equal to 19 % and 16/5 gr/cm^3 respectively and unconfined compression strength of the clay soil was 250 Kpa. The color of Tehran's clay is brown. At the depth of 2 m from which the samples were taken, the soil has a natural moisture content of around 16% which is approximately at the plastic limit. Given the significance of the Casagrande chart in classifying fine-grain clays, the Casagrande chart corresponding to the employed clay is presented in Figure 1.

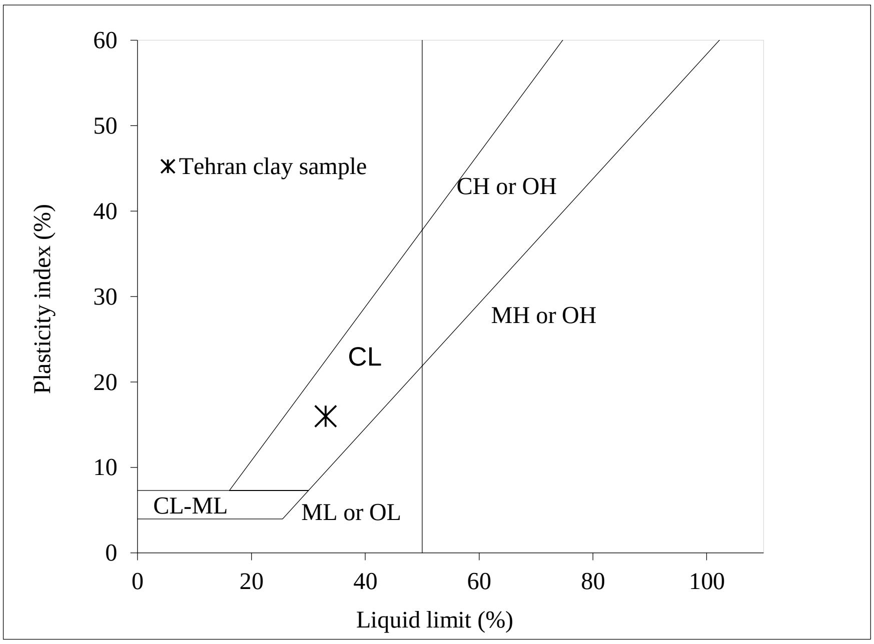


Figure 1. Tehran clay sample's location in the Casagrande chart

According to the figure, the clay used in this study falls among low-plasticity soils in the CL region of the diagram. Figure 2 illustrates the gradation of the Tehran clay. According to the figure, most of the soil passes through the no. 200 sieve.

3.2. Tire Waste

To evaluate the impact of the size of the incorporated tire on the geotechnical properties, two different sizes -the gradation of which is illustrated in Figure 2- were acquired from the market. Figure 3a and 3b show images of the incorporated waste tire powder and granules.

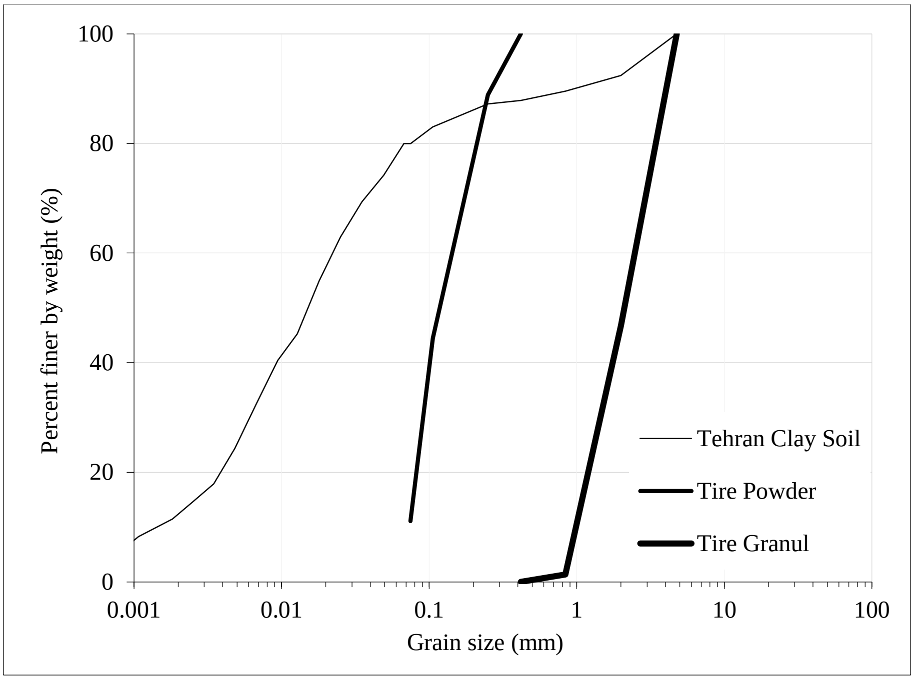


Figure 2. Gradation curve of tire granule, tire powder and Tehran clay

Figure 3. Tire materials used in this research a. Tire powder, b- Tire granule

3.3. Clay-Tire Mixture

The clay and tire powder mix can be prepared by different techniques including volumetric and weight methods. Given the difficulties associated with volumetric methods of incorporating waste tire into clay soils, this study relied on mixing by weight. In this regard, dry soil and powder were blended at certain mass fractions according to Table 1. In Figure 4, a mixture of dry soil and granular tire as well as a mixture of dry soil and tire powder plus pure Tehran clay were used in this research are shown. It is observed that the pure soil color is brown and addition of tire waste causes darkening of the mixture due to the black color of the tire.

3.4. Methods of Experiments

The clay was characterized by Atterberg limit and specific gravity tests in compliance with the ASTM standard and common practice. Furthermore, ASTM standard compaction tests were employed to investigate the compaction parameters of the clay and waste tire mix. During the compaction test, first, a sufficient amount of dry soil was blended with [powdered or granulated] waste tire. Water was then added to the mix and it was left for 24 hours in a bag to allow moisture diffuse uniformly throughout the mix. Later, the compaction test was conducted on the specimens to obtain the optimum moisture content and the maximum dry density for all fourteen mixes according to Table1. To measure the moisture content of the samples, the sample was first removed from the compaction mold using a jack, and then a sample of them was placed inside the oven and the moisture content was determined using the standard ASTM test method. Extracting a sample containing 20% tire and clay granules from the compaction mold is shown in Figure 5. For manual data acquisition, standardized forms have been used and the metric measurement system has been used to represent the data in this research.

Table 1. The percentage of clay soil and tire waste composition

Sample No.	Soil type	Tire granule percentage							Tire powder percentage						
		2	**4**	**6**	**8**	**10**	**20**	**30**	**2**	**4**	**6**	**8**	**10**	**20**	**30**
1		☒													
2			☒												
3				☒											
4					☒										
5						☒									
6							☒								
7	Tehran Clay (CL)							☒							
8									☒						
9										☒					
10											☒				
11												☒			
12													☒		
13														☒	
14															☒

Tehran clay

Clay + 2% powder

Clay + 4% powder

Clay + 6% powder

Clay + 8% powder

Clay + 10% powder

Clay + 20% powder

Clay + 30% powder

Clay + 2% granule

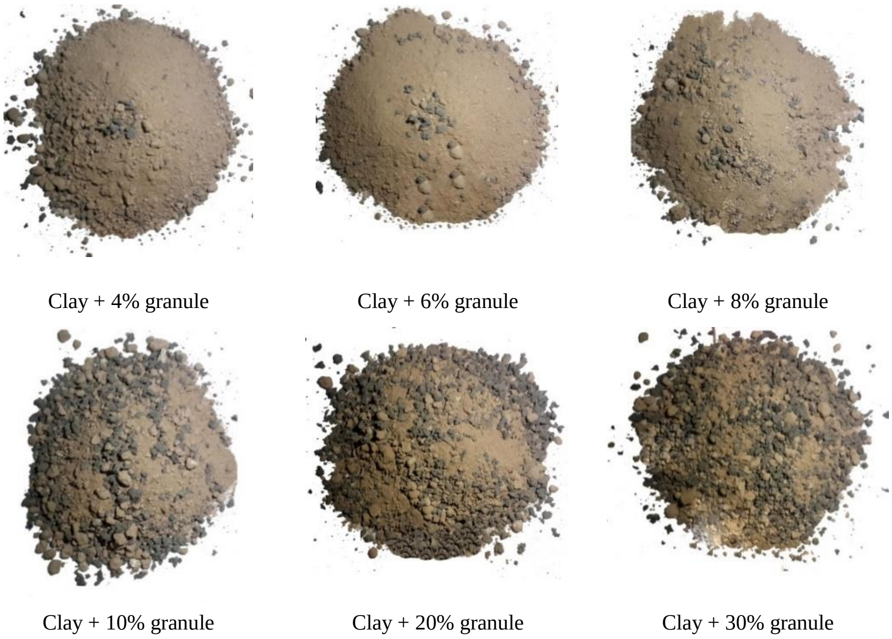


Figure 4. The various mixture of dry soil and granular tire as well as a mixture of dry soil and tire powder plus pure Tehran clay

Figure 5. Remove the sample containing 20% tire granule + clay from the compaction mold

4. Results Analysis and Discussion

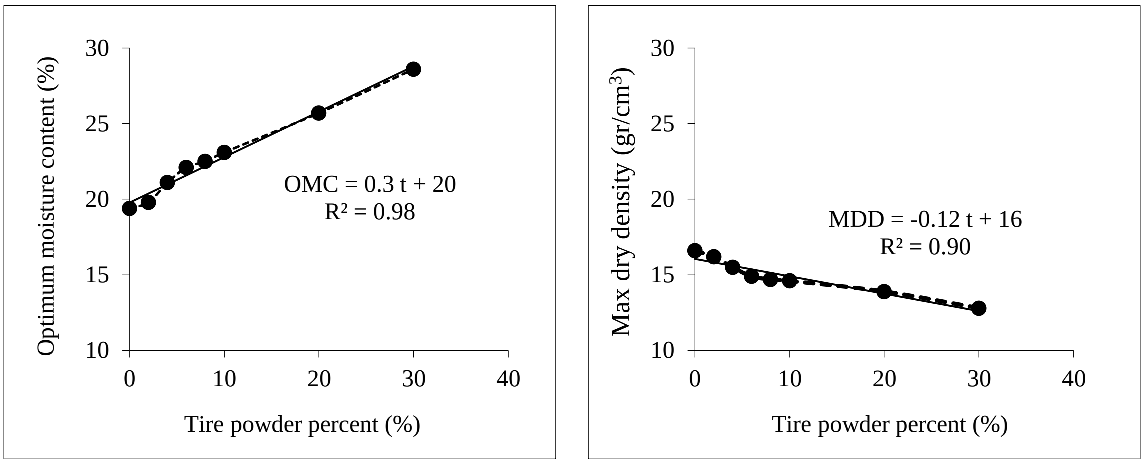
This section, first, discusses the impact of tire powder on the optimum moisture content of Tehran clay and also the effect of tire granules on the optimum moisture content and the maximum dry density. In the following, the two materials (incorporating waste tire powder and granules) are compared in maximum dry density and optimum moisture content. In addition, according to the diagrams, correlations are presented for engineering applications.

Figure 6a illustrate the variations of optimum moisture content and maximum dry density in the clay and tire powder mix. It is evident that increasing the waste tire powder content increases the optimum moisture content of the soil. The reason for increasing the optimum moisture content with increasing tire powder percentage is that the moisture content of a soil is equal to the ratio of moisture content of a soil to the amount of dry soil. As the amount of tire increases, the amount of soil decreases, so the optimum moisture content will also increase. The variation is linear in general, and the 0.98 correlation coefficient shows an excellent correlation between the waste tire powder wt.% and the optimum moisture content of the soil. The following relation is proposed between the Optimum Moisture Content (OMC) and the waste tire powder wt.% (t):

$$OMC=0.3\ t + 20 \tag{1}$$

According to Figure 6-b, the maximum dry density of the soil decreases with increasing the added waste tire powder. The reason for the reduced maximum dry density of the mixture with increasing tire powder percentage is that the density of tires is less than the net dry density of the pure clay soil. Therefore, by increasing the percentage of tire, the amount of specific weight of the mixture decreases. The variations are linear in general, and the 0.90 correlation coefficient shows an excellent correlation between the waste tire powder wt.% and the maximum dry density of the soil. The following relation is proposed between the Maximum Dry Density (MDD) and the waste tire powder wt.% (t):

$$MDD = -0.12\ t + 16 \quad (2)$$

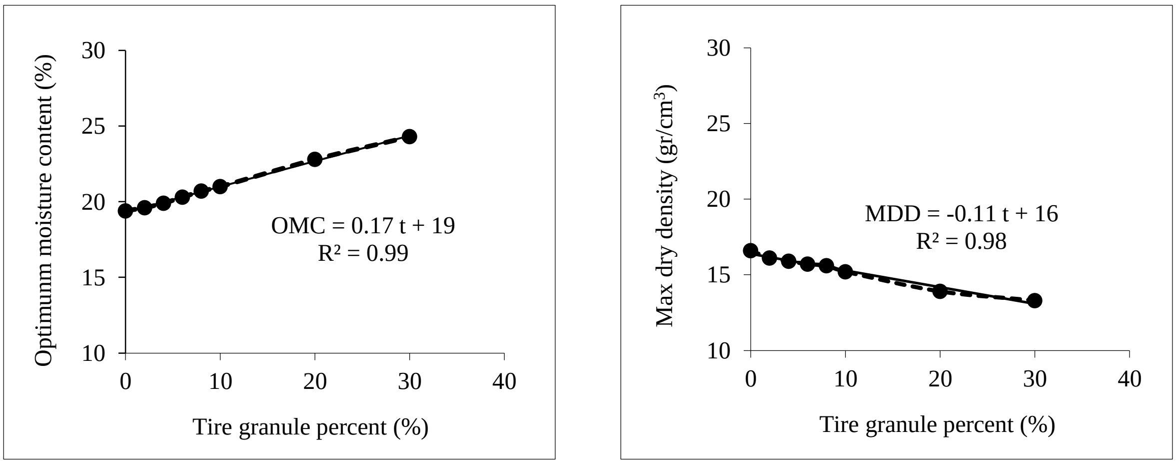


a) Optimum moisture content **b) Maximum dry density**

Figure 6. The amount of maximum dry unit weight and optimum moisture content variation of the mixture by increasing the percentage of tire powder

Figure 7a illustrates the variations of OMC and MDD in the clay and granulate waste tire mix. It is evident that, similarly to the waste tire powder, increasing the waste tire granules wt.% increases the OMC linearly. The reason for increasing the optimum moisture content with increasing tire granule percentage is similar to the mixture of clay and tire powder. As the amount of tire increases, the amount of soil decreases, so the optimum moisture content will also increase. Amount of the 0.99 correlation coefficient suggests an excellent correlation between the waste tire content and the OMC. The following relation is proposed between the OMC and the waste tire powder wt.% (t):

$$OMC = 0.17\ t + 19 \quad (3)$$



a) Optimum moisture content **b) Maximum dry density**

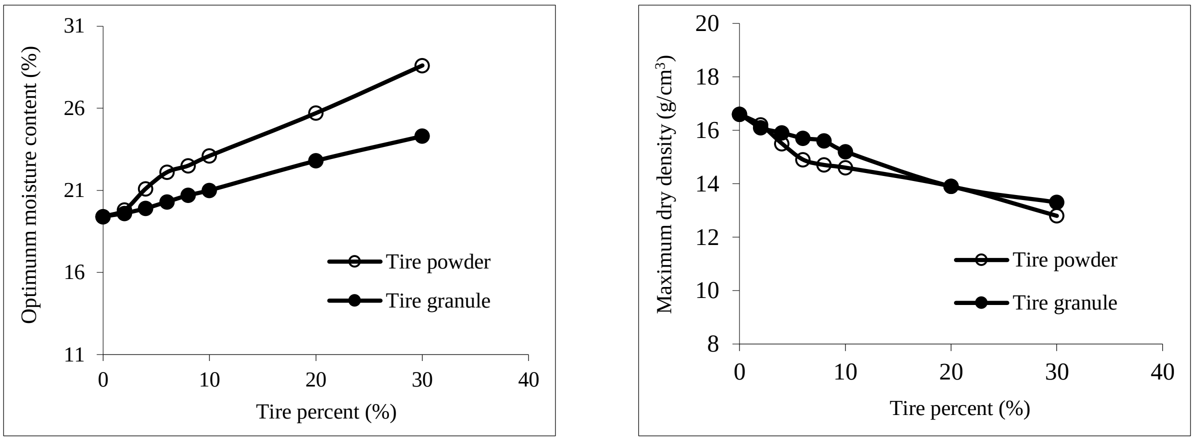
Figure 7. The amount of maximum dry unit weight and optimum moisture content variation of the mixture by increasing the percentage of tire granule

According to Figure 7b, similarly to the case with waste tire powder, the MDD of the soil increases with increasing the added waste tire granules. The variations are linear, and the 0.98 correlation coefficient shows an excellent correlation between the waste tire content and the MDD of the soil. The reason for the reduced maximum dry density of the mixture with increasing tire powder percentage is similar to the mixture of clay and tire powder and because of the lower dry density of the tire granule related to the dry density of the pure clay soil. Therefore, by increasing the percentage of tire, the amount of specific weight of the mixture decreases. The following relation is proposed between the MDD and the waste tire powder wt.% (t):

$$MDD = -0.11\ t + 16 \tag{4}$$

Comparing mixes of clay and powdered and granulated waste tire in OMC and MDD demonstrates the impact of the size of the wastes on clay soil compaction curves. The particle size is effective on the OMC and the MDD, and knowing the range of variation of these parameters can help make accurate engineering decisions in practice. Figure 8-a plots OMC variations against the waste tire wt.% for the two mixes (clay with waste tire powder and granules). According to the figure, the OMC exhibits an increasing trend with increasing both waste tire powder and granule contents. Furthermore, it is evident that by increasing the waste tire wt.%, the difference between the OMC of the clay mixes incorporating waste tire powder and granules becomes larger. Comparing the specimens containing waste tire powder and granules in their OMC shows the parameter to be greater in the clay incorporating powdered waste tire.

The increase in the OMC after the addition of waste tire can be attributed to the fact that OMC is defined as the ratio of the weight of water to the dry soil, while the incorporated waste tire is not taken into account when calculating the moisture content. Moreover, tire absorbs less water than soil. As a result, the moisture content is naturally greater in specimens with added waste tire. Furthermore, given the fact that powdered waste tire is capable of absorbing more moisture than the granulated waste tire, the specimens with added tire powder feature larger moisture contents.



a) Comparison of optimum moisture content **b) Comparison of maximum dry density**

Figure 8. Comparison of maximum dry density and optimum moisture content of clay mixtures and various tire wastes (tire powder and tire granule)

The tire grain size can also be effective on the MDD of the soil. Comparing mixes of clay and powdered and granulated waste tire in MDD demonstrates the impact of the size of the wastes on clay soil compaction curves. Figure 8-b plots MDD variations against the waste tire wt.% for the two mixes (clay witsh waste tire powder and granules). According to the figure, the MDD exhibits a decreasing trend with increasing both waste tire powder and granule contents. Furthermore, it is evident that by increasing the waste tire content (wt.%), the MDD demonstrate a significant change in either of the clay mixes incorporating waste tire powder or granules. Comparing the MDD of the specimens with added waste tire powder and granules reveals that this parameter is almost the same for both mixes.

The reason for the reduced MDD of specimens with added waste tire compared to pure soil is the smaller density of tire relative to clay soil. Moreover, the identical dry density of the clay mixes with added waste tire powder and waste tire granules can be justified by the fact that tires of different sizes are almost similar in density.

It is always essential to use an optimal amount of physical or chemical additives for soil improvement. This study investigated the MDD and the OMC of two Tehran clay mixes with added waste tire powder and granules, proposing relations to estimate the two parameters. Taking into account that employing these mixes in practice requires further details and knowledge with regard to their geotechnical properties, pairing the findings of this study with other experimental results and determining the best mixes with the required geotechnical specifications can be useful.

5. Conclusion

The present study evaluated the impact of powdered and granulated waste tire on the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) of a Tehran clay soil. The results suggest that increasing the added waste tire powder and granules increases OMC of the clay and reduces MDD of the soil. The reduced MDD of the mix does not necessarily translate to a reduced strength and the reason for the decrease in the parameter is the small density of tire compared with soil, and the strength of the mix can be evaluated and studied. Comparing clay soil mixes with powdered and granulated waste tire in OMC indicates that the parameter exhibits a more drastic increase in the specimens with added waste tire powder, which is due to the smaller grain size of the additive and its better absorption properties. An MDD comparison of the clay soil mixes with added waste tire powder and waste tire granules reveals the decline of the parameter in both mixes with increasing the waste tire content. Given the fact that the waste tire powder and granules have almost the same densities, the MDD is similar in the two mixes. Furthermore, considering the fact that powdered and granulated waste tire exhibit uniform and predictable behaviors in the soil mix, it is safe to say that they form a homogeneous mix and can be estimated in practice accurately. Relations were also presented in this study for estimating the MDD and the OMC of clay mixes incorporating waste tire powder and granules that can be used in engineering activities.

6. Conflicts of Interest

The authors declare no conflict of interest.

7. References

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