Proceedings of the 8th World Congress on Civil, Structural, and Environmental Engineering (CSEE'23)
Lisbon, Portugal – March 29 – 31, 2023
Paper No. ICGRE 121
DOI: 10.11159/icgre23.121

The Effect of Granulate Waste Tires on the Geotechnical Properties of Clays

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Abstract – Disposal scrap tires are environmental issue and lead to economic problems. To minimize these problems, it was necessary to find safe ways to reduce the harms on environmental issues. The viable solutions to the recycling and reuse of discarded waste tires as an additive in construction materials has always gained attentions of researchers due to their positive effects on material properties and reduction of environmental problems. This study is to investigate the effect of granulate waste tires on the mechanical properties of low plasticity clay (CL) through a series of laboratory tests. Granulate waste tires with sizes range from 1.18 mm to 2.36 mm in diameter were added into the clay at four different percentages by dry weight of the clay. The samples were subjected to basic index tests, California bearing ratio (soaked and unsoaked), unconfined compression and modified proctor tests. The tests have clearly shown that the consistency limits improve gradually. A reduction in specific gravity and maximum dry density with a little reduction in optimum moisture content was marked with increase granulate waste tires content. The liquid limit, and plastic limit slightly decrease with the increase of granulate waste tires. The UCS of the clay-granulate waste tires mixtures decreases with the increase in the granulate waste tires content. Despite this, the value of UCS still stiff and improve the axial strain at peak axial stress. The CBR in soaked and unsoaked condition of both type of soils decrease as the content of granulate waste tires increases. This study concluded that disposal tires can effectively use to improve the mechanical properties of low-plasticity clayey soil. Recommendation of the material to be used in different civil engineering construction application and reduces its impact on environment and health.

Keywords: Granulate waste tires; specific gravity; Consistency limits; compaction characteristics; strength properties.

1. Background of Study

The environment can be defined as a group of biological, chemical, natural, geographic and climatic factors surrounding man and surrounding the spaces that he inhabits that determines the human activity, trends and affects his behavior and system of his life. In recent years, large quantities of tires are stockpiled due to increasing in the number of cars passing on their roads. Thus, stockpiles of waste tires will continually increase, unless new techniques are developed to beneficially reuse of recycle tire [1]. Consumed car tires considered as solid waste, and are mainly made of rubber reinforced with iron wire; considerable research has been performed on the mutagenic and carcinogenic properties of chemicals associated with the rubber industry. Many chemicals, some of which are mutagens and carcinogens, have been identified in the emissions from both the controlled and uncontrolled burning of rubber tires [1].

Disposal of discarded waste tires is one of the primus problems faced by the industries and government of many countries because it has a momentous share in the solid waste. About 1.5 billion tires are produced in a year, throughout the world and per annum almost 1000 million tires reach the end of their useful life. In India, a phenomenal increase in the number of automobiles has been noticed. In year 2010-2011, the total production of tires was 124.3 million and became 146.1 million in the year 2014-2015 [2].

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].

The use of wastes, especially tire wastes, can be considered as one of the physical and chemical improvement methods for soil. The use of waste tires has a very significant history in civil engineering. These wastes have been used in different ways including asphalt additives, concrete additives and as a soil physical improver in different forms such as tire powder, crumb tire and tire chips. The use of tire wastes aimed at improving resistance and ductility [3].

Using tire wastes in embankment construction is increasing because of the limited availability of natural resources, and the increasing cost of disposal. Because of their low unit weight, high strength and widespread availability, tire wastes are finding increasing use as lightweight fill for embankment construction on weak, compressible foundation soils [5&6]

The impact the tires may have on the quality of surface or groundwater that may come into contact with them has also been evaluated in a number of investigations indicating that tire chips do not cause significant contamination.

Park [7] found that the tire chips have relatively high volatile organic chemicals sorption capacity based on batch sorption tests on scrap tire chips. This suggests yet another innovative application in which tire chips are used to eliminate chemicals from contaminated water. Therefore, in a contaminated environment tire chips may even have a beneficial function as a sorptive medium [7].

2. Materials and Experimental Program

As the research mainly aimed at examining the effect of granulate waste tires on the geotechnical properties of low-plasticity clayey soils, natural soil materials and tire materials were used to make research results applicable and to make the results usable in practical projects. As per the technical specifications, the tire materials and clay soils used in this research are as follows:

2.1 Soils

The soil used in this study from Al-Marj city eastern part of Libya. The clay soil was categorized as low-plasticity clay (CL) based on the USCS (Unified Soil Classification System). The grain size distribution curves of investigated soils is shown in Figure 1, while the index properties and natural characteristics of these soils are listed in Table 1.

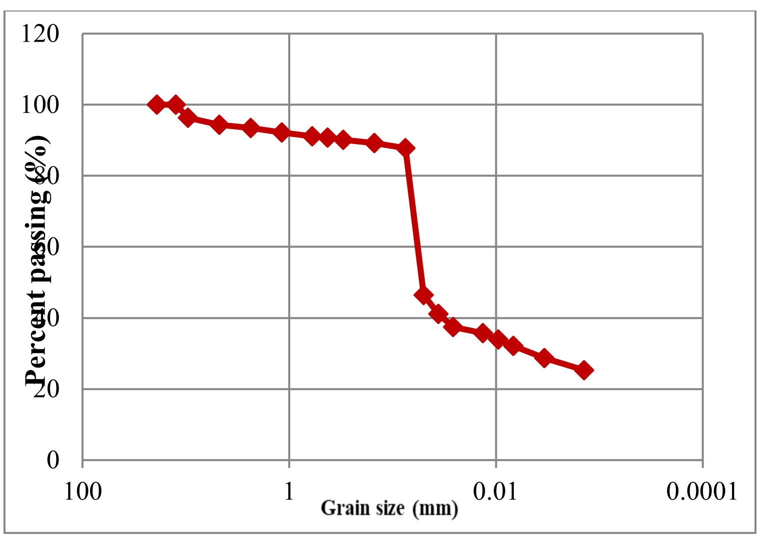

Fig.1: Grain-size distribution of used clay (CL)

Table 1: Properties of the used clays

Soil Property	Value
Specific Gravity	2.53
Liquid limit %	45
Plastic limit %	15.9
Plasticity index %	29.2
Gravel %	5.5
Fine Sand %	2.9
Coarse to medium Sand %	3.8
Silt and Clay %	87.8
USCS Classification	CL
AASHTO Classification	A-7-6
Natural Moisture Content %	7.76
Maximum Dry Density (g/cm^3)	1.73
Optimum Moisture Content %	16
Cohesion (kPa)	71
Unsoaked CBR Value %	52
Unconfined Compression Strength (kPa)	141

2.2 Granulate Waste Tires

Granulate waste tires used in this study is a recycled rubber from automotive and truck scrap tires, it should be noted that the steel in the waste tires has been removed. The granulate waste tires used are irregularly shaped, and varies from 1.18 mm to 2.36 mm in diameter. The average specific gravity was found to be 1.009 based on two replicate tests.

2.3 Clay-Granulate Waste Tires Mixture

Different methods can be selected for mixing clay soil and tire powder including weight and volume methods. In this study, air-dried soil and clay-granulate waste tires with certain weight percentages were mixed to prepare an appropriate combination. The soil was dried at (100 ± 5) °C for 24 hours, to ensure disposal of the natural water content, granulate waste tires with certain weight percentages (5%, 10%, 15% and 20%) were mixed manually to prepare an appropriate combination of clay-granulate waste tires. Table 2 shows the weight composition of soil and granulate waste and clay.

2.3 Testing Program

The tests for the Atterberg limits, including the liquid limit and the plastic limit, are the conventional tests used according to ASTM procedure. Modified Proctor tests were conducted to evaluate the compaction characteristics of the clay-granulate waste tires mixture. Table 2 illustrates the properties studied on the pure clay and clay-granulate waste tires mixture.

Table 2: Weight composition of clay and clay-granulate waste tires mixture

Granulate waste tires (%)	Soil type	Granulate waste tires (%)					
		Grain-size distribution	Specific gravity	Consistency limits	Compaction characteristics	Shear properties	Strength properties
0		√	√	√	√	√	√
5			√	√	√	√	√
10	CL		√	√	√	√	√
15			√	√	√	√	√
20			√	√	√	√	√

Various tests were carried out in the laboratory as per ASTM for finding the index and other important properties of the clay and clay-granulate waste tires mixture. The conventional methods were used as per ASTM are summarized in Table 3.

Table 3: Standard designation of the tests

Test	Sieve Analysis	Specific Gravity	Consistency limits	Modified Proctor	Californian Bearing Ratio	Unconfined compression strength
Standard Designation	ASTM D-421 [8]	ASTM D-854 [9]	ASTM D-4318 [10]	ASTM D-1557 [11]	ASTM D-1883 [12]	ASTM D-2166 [13]

3. Results and Discussion

3.1 Specific Gravity

A reduction in specific gravity marked with increase granulate waste tire content as shown in Table This reduction in the values of specific gravity of clayey soil with the increasing of granulate waste tires, because the granulate waste tires is a granular material with low specific gravity. Other investigators have agreed with this results [14].

Table 4: Granulate waste tires vs. Specific gravity

Granulate tires	0%	5%	10%	15%	20%
G_s	2.53	2.36	2.22	2.11	2.02

3.2 Consistency Limits

The findings of LL and PL of clay are presented in Table 5. It was noticed that the tests were performed only on CL soil, and Figure 2 and Figure 3 showed slight decrease as the granulate waste tires increased.

Table 5: Granulate waste tires vs. LL and PL

Granulate tires (%)	LL (%)	PL (%)
0	45.06	15.9
5	30.83	15.3
10	28.39	13.3
15	25.95	12.5
20	25.87	12.2

Figure 2 shows the changes of the LL of low-plasticity clay soil by adding granulate waste tires. It shows that the LL reduces as the granulate waste tires percentage increasing. The reduction is highly significant when 5% granulate waste tires is added. Also Figure 3 shows slight decrease in PL as the granulate waste tires increase, the overall percentage decrease was about 23% when adding 20% of granulate waste tires. These results are agreed with results reported by other investigators [3&18].

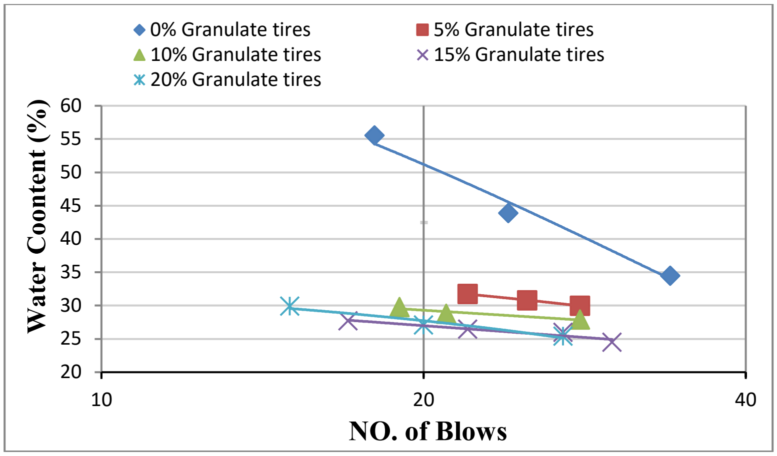

Fig.2. Liquid limit curves of clay-granulate waste tires mixtures

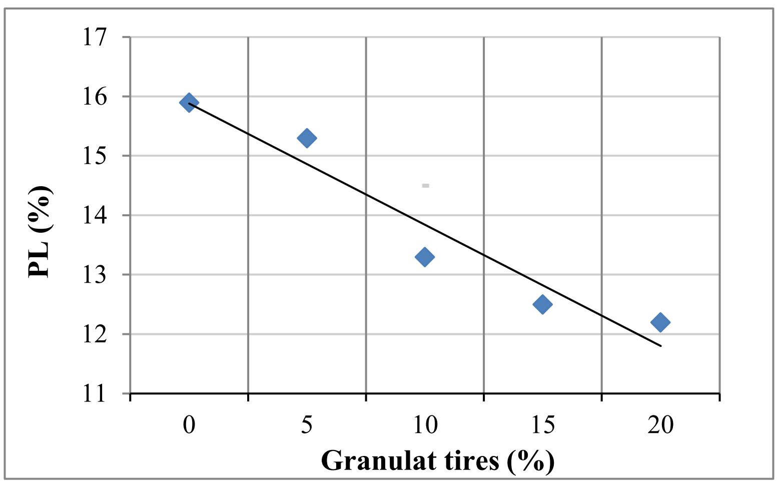

Fig.*3*: Plastic limit vs. Granulate tires (%)

The fact that the decrease in the consistency limits when adding granulate waste tires to the clay may be attributed to that the granulate waste tires is considered a non-plasticity material, Thus, adding it to clay soil reduces liquid and plastic limit. The use of granulate waste tires improves such property and system efficiency, which has been proved in this study through research tests and reduction of the consistency limits. This is considered as one of the advantages of granulate waste tires in engineering applications.

3.3 Compaction Characteristics

The results of modified Proctor test are the maximum dry density corresponding to the optimum moisture content. Table 6 shows the results of the effect of granulate waste tires on MDD and OMC for clayey soil.

Table 6: Granulate waste tires vs. MDD and OMC of Proctor compaction test

Granulate tires %	MDD (g/cm^3)	OMC %
0	1.73	16
5	1.68	16.3
10	1.59	16.2
15	1.52	16.5
20	1.52	16.7

Through the results shown in Figure 4, the MDD of the clay was reduced from 1.73 g/cm3 to 1.52 g/cm3 as granulate waste tires increased up to 20%. In fact, the decrease in the MDD when increasing the granulate waste tires additive of sample may be attributed to the light weight nature of granulate waste tires. The resilience of the tires rubber reduces compaction efficiency, which may also lead to the reduction in the MDD of the mixtures [15]. Also [4], [16], and [17] used same type of clay and reported similar results.

On the other hand, Figure 4 shows almost unchanged in OMC with increase in percentage of granulate waste tires. [6] shows in their investigation that the OMC of the clay remains unchanged with the increase in the content of rubber.

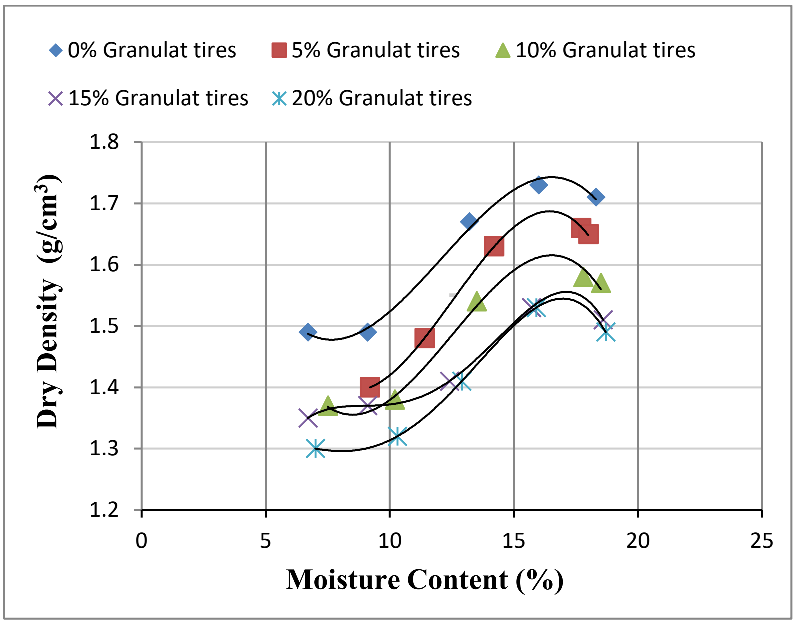

Fig.:4 Proctor compaction curves of clay-granulate tires mixtures

3.4 California Bearing Ratio Characteristics

Californian Bearing Ratios tests (CBR) were conducted on clay and clay-granulate waste tires mixture, to determine the soaked and unsoaked CBR values. The CBR values of the clay and clay-granulate waste tires mixture in soaked and unsoaked condition are summarized in Table 7.

Table 7: Granulate waste tires vs CBR values

Granulate tires (%)	Soaked CBR (%)	UnSoaked CBR (%)
0	11	52
5	7	25
10	6	18
15	3	9
20	3	7

Figure 5 and Figure 6 shows the obtained soaked and unsoaked CBR values of clayey soil respectively. It is inferred that the CBR values of both soaked and unsoaked condition has a significant decrease with increase of percentage of granulate waste tires, which may be attributed to the increase in contact points between crumb rubber particles and high resilience of rubber particles which leads to the decline of strength, these results are similar to researchers [18&19].

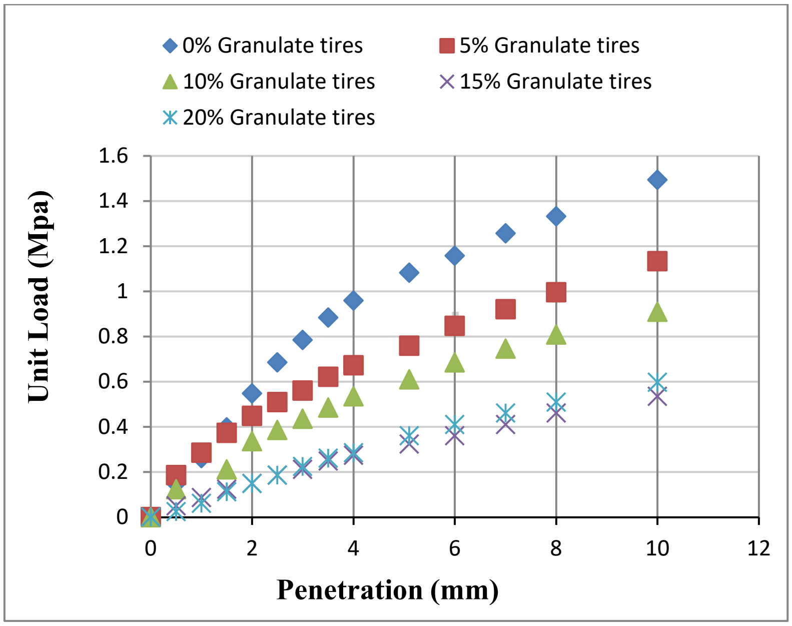

Fig.5: Unit Load-penetration curves of clay-granulate tires mixtures in soaked condition

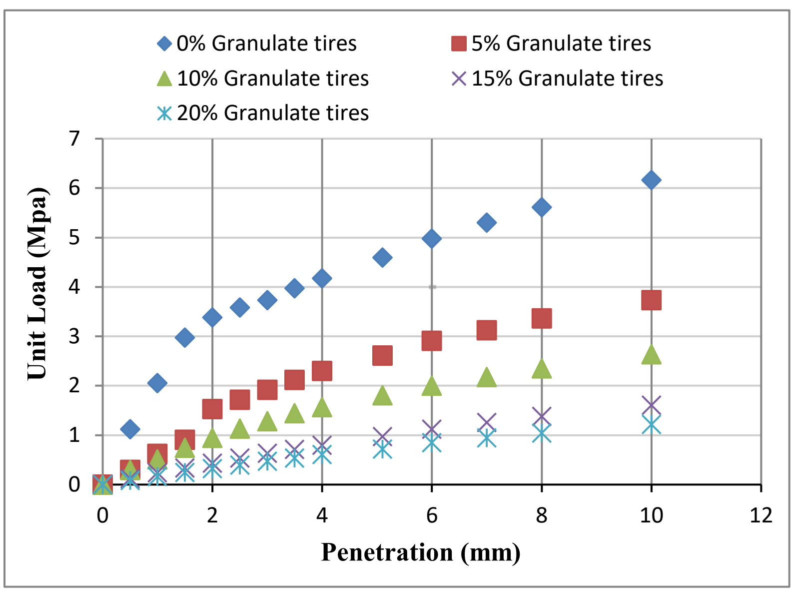

Fig.6: Unit load-penetration curves of clay-granulate tires mixtures in unsoaked condition

3.5 Shear Properties Characteristics

The unconfined compression strength test is used to determine the cohesion and shear strength of soil. It is an index for checking the short-term stability of foundation and slopes. The UCS values of the clay and clay-granulate waste tires mixtures are summarized in the respective Table 8.

Table 8: Granulate waste tires vs. UCS

Granulate tires (%)	UCS Value (kPa)
0	141
5	125
10	116
15	110
20	104

The UCS of clay-granulate waste tires mixtures specimens decrease descending with an increase in the granulate waste tires content according to Figure 8. It decreases from 141 kPa to 104 kPa at 0% and 20% granulate waste tires respectively, which is similar to the observation made by Saini [20]. Poor interfacial mechanical interaction between granulate waste tires and clay particles and increase in the voids of the clay samples with the addition of granulate waste tires particles may have lead to the reduction in UCS [23].

The loss of friction and bonding between the clay and granulate waste tires particles may have led to the reduction in UCS [21]. Although the value of UCS when adding 20% granulate waste tires is still stiff.

The effect of inclusion of granulate waste tires on the axial strain corresponding to peak axial stress of the clayey soil evaluated by the laboratory investigation is shown in Figure 7. Failure strain of the clay-granulate waste tires specimens improved from 10.24% to 11.1%, 12.49% to 13.51% at 5%, 10%, 15% and 20% of granulate waste tires, these results confirmed with Yadav [2].

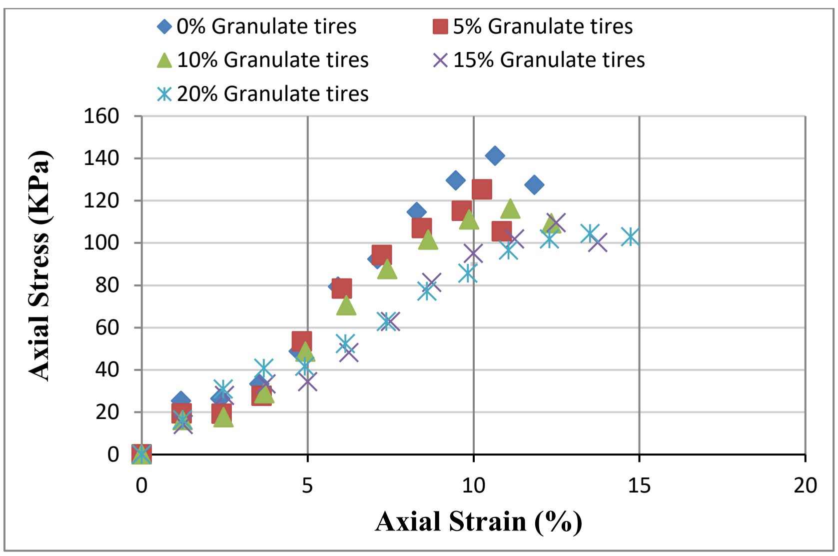

Fig.7: Axial stress-strain behavior of clay-granulate waste tires mixtures

The increase in the axial strain of clay when adding granulate waste tires corresponding to the failure axial stress may be accredited to resilient behavior of the rubber crumbles [18], elastic reaction generated by the granulate waste tires during compression results into prevention against generation of cracks [22], and the elastic compression of the rubber results into strain hardening of the clay after reaching the peak axial strain [23].

4. Conclusion and Recommendations

Based on the present study, granulate waste tire can effectively use to improve the mechanical properties of clayey soils. Investigation results show that the reuse of tire as a physical additive can improve the properties low-plasticity clay soils in engineering applications. Based on testing results of clay-tire mixture, the following conclusions can be drawn:

1. The results indicate that the liquid limit and plastic limit decrease with the increase of granulate waste tires.
2. The results showed that the maximum dry density of clay decrease with the increase in granulate waste tires. While the optimum water content shows almost unchanged in clayey soil.
3. Unconfined compressive strength of the clay-granulate waste tires mixtures decreases with the increase in the granulate waste tires content. Despite this, the value of unconfined compressive strength still stiff.
4. The Californian Bearing Ratios in soaked and unsoaked condition of both type of soils decrease as the content of granulate waste tires increases.
5. Adding granulate waste tires of 20%, the axial strain at failure increase from 10.65% to 13.51%, respectively.
6. The study recommends using 20% of granulate waste tires in case of reducing lateral stress on retaining walls, or used as a fill material in embankment construction due to its low unit weight.
7. The study recommends conducting chemical tests to find out the reactions can occur between the granulate waste tires and the clay.
8. Permeability property is one of the most important soil properties, especially in hydraulic constructions, the study recommends to use of granulate waste tires and investigation its effect on the permeability of clay soils.

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