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Performance of Plastic Powder on Calcareous Soil Stabilization

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ABSTRACT

Calcareous soils are widely distributed in many regions of the world, including the Arabian Peninsula, especially the central and northern regions, as well as in Saudi Arabia, Iraq, Syria and Iran. The properties of those soils are of a collapsing nature, especially when moistened, because they contain calcareous salts, which are hydrated calcium carbonate. This study sheds light on the possibility of improving the properties of these soils by adding plastic powder from used or stock tires by different mixing ratios (2%, 4%, 6% and 8%) and tested them in the laboratory using a laboratory model manufactured specifically for the requirements of this study. 50 loading tests were carried out on 5 natural calcareous soils with different Calcium Carbonate content and square base with 15 cm width. The study showed a significant improvement in the maximum bearing capacity of the soil by adding (4%) of this additive, as the ultimate bearing capacity increased more than 4 times compared to the untreated one. Recycling spent rubber contributes to preserving the environment by getting rid of these unwanted materials, and at the same time improving the properties of those soils after mixing them with certain weight ratios and thus contributing to protecting the environment.

1. INTRODUCTION

Soil is the main and important factor in determining the validity in terms of its ability to bear external loads, which include live and dead loads and dynamic loads that may be exposed to it as a result of earthquakes or other factors. The foundation design criterion depends primarily on the ability of the soil to bear these external loads and its subsidence [1]. There are a number of structural problems that may face the work of a civil engineer as a result of the presence of soils with engineering problems and the exposure of the foundations of buildings and soil to external factors such as the difference in the percentage of moisture as a result of rain or other factors, which leads to the failure of the structure or the emergence of some cracks as a result of erecting the foundations of buildings on undesirable soils such as swelling soils, gypseous or calcareous soils, which causes a differential subsidence of the foundations and a sudden collapse may occur as a result of the impact of those soils when wetting and the melting of the salts. As shown in Figure 1.

Figure 1. Failure of structures resting on Calcareous soils

Usually, soils containing More than 10% Calcium carbonate is called calcareous [2]. Experimental study used bentonite to improve properties of calcareous soil, it is found that little decrease in angle of internal friction when added (3-9)% bentonite [3]. In general, the behavior of calcareous soil is similar to gypseous soil but the gypseous soil is more collapsible than calcareous soil. It is found from this study that the use of lime injection piles has reduced the collapse potential settlement of gypseous soil by a promising matter [4]. It is completely different from the fine-grained disjointed case that is formed by sedimentation in the soil as a result of reactions between calcium bicarbonate or carbonic acid and free alkalis in the ground [5]. The most important differences are in the degree of solubility and aqueous dissolution. The most common form of calcium carbonate in nature are calcite, as shown in Figure 2.

Figure 2. Calcareous soil appearance

The compressibility and bearing capacity of calcareous soil are differed from region to other. In the South China Sea has a high calcium carbonate content, large particle size, high compressibility, and low bearing capacity, while sand from the Kish Island in the Persian Gulf and Agami sand from Egypt have low compressibility and high bearing capacity [6]. There are many experimental studies investigated the properties of calcareous soil [7-14], and from these properties can determined the suitable treatment problems of soil.

There are a number of solutions and treatments proposed and studied by researchers to find solutions to engineering problems for those soils using stabilizers and additives such as lime, cement and quicklime [15].

1.1 Related work

There is a limited number of studies dealing with the treatment of this type of soil one of these studies are by using chemical additives (Kerosene oil, Crude oil, Gas oil). The settlement was reduced for a foundation placed on calcareous soils with different content co calcareous soil 70% and 50% in a laboratory model. The improvement criterion was the reduction in the subsidence of the base by adding these additives. The results showed an improvement in the subsidence of the foundation after mixing the soil with these chemical additives, where the subsidence of the foundation was reduced to more than 60%, as shown in Figure 3 [9]. However, these chemical methods of treatment remain unsatisfactory due to the lack of durability of these petroleum materials over time as a result of the exposure of the soil to washing or evaporation with time. Therefore, there was a need to find physical methods of treatment that would be more permanent and less expensive.

There was a need in the past three decades to study the possibility of recycling some of the accumulated materials that are not friendly to the environment, namely used car tires, which are a burden after the increase in their numbers as a result of the escalating development in this field and the industrial revolution, and to study the possibility of benefiting from these materials and harnessing them to improve the properties of high-collapse calcareous soils after grinding used tires and mixing it with such collapsible problematic soil. This study deals with the behavior of calcareous soils subject to external load and the possibility of improving their bearing capacity by mixing them with rubber powder resulting from used tires. The results of this study, which was conducted on five types of natural calcareous soils, showed a significant improvement in the bearing capacity of the soil by adding the plastic mixture resulting from the spent tires, especially 4%, where the soil bearing capacity was increased more than 4 times if compared to the untreated model.

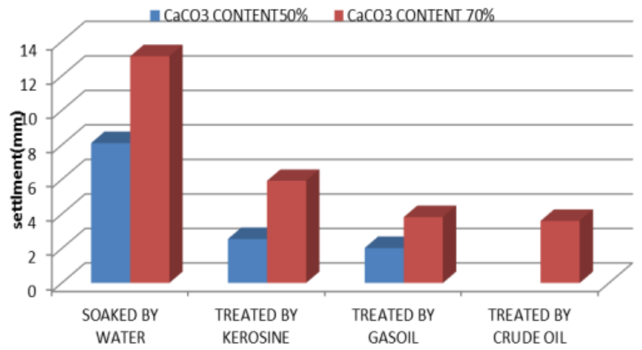

Figure 3. Improvement of calcareous soil using different oil derivatives [9]

2. EXPERIMENTAL WORK

This study includes taking samples of natural soils from sites with different calcium carbonate content, where a number of laboratory tests were conducted on them, analyzing and extracting results for their properties, and then conducting tests on them using a laboratory model that simulates the behavior of a foundation placed on calcareous soils.

2.1 Soil used

Samples of natural soils were taken from different regions and laboratory tests were conducted on them according to the international system of examination (ASTM), which included conducting chemical tests such as the percentage of dissolved salts, the percentage of lime, chlorides and acidity, and also included the study of physical properties such as the limit of plasticity, limit of fluidity, maximum density, collapse, friction angle and cohesion for the two wet and dry states. Tables 1 and 2 show data for the soils used in this study.

Table 1. Physical properties of soils used in the study

Property	S1	S2	S3	S4	S5
USCS	SM	SM	SM	SM	SM
Gs	2.49	2.48	2.43	2.45	2.46
L.L	15	16	14	19	22
P.L.	N.P	N.P	N.P	N.P	N.P
Ø dry	28	30	34	36	40
C dry kN/m^2	7	9	10	10	12
Ø wet	22	25	27	29	31
C wet kN/m^2	5	6	5	6	9
γ max kN/m^3	17	16	17	18	19
o.m.c %	14	13	12	11	11
C.P.%	16	22	27	30	37

Table 2. Chemical properties of soils used in the study

Property	S1	S2	S3	S4	S5
T.S.S%	24	32	45	57	66
CO_3 %	10	14	20	24	28
$CaCO_3$ %	22	30	42	51	60
O.M %	0.6	0.4	0.4	0.3	0.2
CL %	0.05	0.06	0.07	0.07	0.08
PH	7.3	7.5	7.1	7.9	7.8

2.2 Rubber tire powder

Old car tires from the quarries were chosen in the treatment of the collapse of calcareous soils after mixing it with the soil in different weight ratios. This material was used after stripping them of the metal wires as shown in Figure 4-a. As for the grinding process for tires, it was done using a locally manufactured scraping and hammering tool to obtain rubber tires granules of equal diameter ranging between (0.75-1 mm) as shown in Figure 4-b. the chemical composition of rubber plastic granules result from old tires are shown in Table 3.

Table 3. Chemical composition of rubber tires granules results from old tires

Composition	Concentration %
Hydrocarbon content	55.05
Ash content	6.16
Carbon black content	29.85
Acetone extract	8.38
Volatile matter	0.56
Polymer analysis	Styrene-butadiene rubber (SBR)

(a) used car tires from the quarries

(b) rubber tires granules

Figure 4. Plastic powder used in the study from used car tires

2.3 Laboratory model and equipment's

The laboratory model contains the following details and parts:

1- A reinforced iron container to hold the calcareous soil model.

2- The foundation of a square iron pallet with a width of 15 cm.

3- The bearing structure is composed of a loading jack, an electronic pressure gauge and a differential landing gear for the foundation.

Figure 5. Model test equipment's and parts

The parts of the laboratory model were assembled and manufactured under the supervision of technicians with experience in laboratory equipment and with high craftsmanship. The manufactured device includes a container made of galvanized iron with a thickness of 3 mm and is reinforced from the sides to ensure that no dents and pressures occur on the sides. The container with dimensions of 400 * 400 * 600 mm is painted from the outside and inside with anti-rust paint. Slides were made from the base of the container to facilitate its removal from the device for the purpose of replacing the soil after the completion of the examination as shown in Figure 4. The foundation was represented by a square section of iron billet with a thickness of 8 mm and a width of 15 cm, for carrying out a loading test on it, simulating a real foundation and studying its behavior on calcareous soils treated with rubber powder additive. The loading structure is made of thick u section iron sections and perforated from the top with three levels on both sides to facilitate control of the loading jack level. The hydraulic loading jack designed to deliver a pressure of up to 2 tons is connected by bolts to the upper section of the loading structure as shown in Figure 5. The jack consists of two parts: the pressure part, and the control part with the manual arm.

2.4 Test methodology

The natural calcareous soil is placed after drying and passing it through sieve No. 4 in the iron container. The soil is divided into three sections. Each part is stacked to a height of 15 cm inside the container after wetting the soil with water with a constant moisture level of 4% for all models of soil. The soil is compacted using a cylindrical weight of 10 kg, free-falling from a height of 60 cm. The soil is compacted until the height of the first layer is reached 15 cm and this process is repeated for the second and third layers until the full height is 45 cm, the surface soil level is settled and the foundation is placed in the center of the model.

An electronic settlement gauge was placed on each side of the footing to measure mean total settlement, then installing the hydraulic jack and make sure that the oil valve of the jack is closed before starting to load. The electronic load gauge is placed between the base and the hydraulic jack. The hydraulic jack is gradually compressed until the loading gage touches the surface of the foundation and begins to record the initial reading, then reduce the pressure. This process is repeated three times to ensure an even distribution of the load, uniform settlement and the absence of voids under the foundation during loading. The rest of the test steps are completed by starting with applying constant stresses and taking the readings to fall, and so on until the model fails, the highest values of soil bearing stress was recorded and thus the examination ends. Gradual loading is started and the foundation settlement is read in conjunction with the applied stress by the hydraulic jack fixed to the fixed monorail loading structure. The soaking test includes providing the laboratory model with a water control system consisting of a tank with a capacity of 0.25 cubic meters and a rubber tube connected to an immersion level control device installed from the top of the iron container to ensure continuous supply of water throughout the immersion test period. The steps are repeated again after replacing the soil model and until the completion of the examination of the five models of calcareous soils with different contents.

3. RESULTS AND DISCUSSION

50 tests were conducted on 5 samples of natural calcareous soils with different calcium carbonate content, including dry and soaking tests for 24 hours and tests on models treated and untreated with rubber tires powder after mixing soils with 5 percentages of this additive. The loading test was conducted on a square footing with a width of 15 cm to measure the ultimate bearing capacity of each soil and to study the effectiveness of this additive in reducing the collapse of calcareous soils used and to choose the optimal percentage of addition in the cases of dry and soaking tests.

3.1 Dry model tests

Figures from 6 to 10 represent the relationship between stress and strain for samples of 5 types of natural calcareous soils with different calcium carbonate content (22%, 30%, 42%, 51% and 60%) treated with the rubber tire powder additive in mixing ratios (0%, 2 %, 4%, 6% and 8%). The results of the load test on a square footing showed a clear improvement in the ultimate bearing capacity of the soil after mixing it with this additive, increased (3.5 times, 3 times, 2.25 times and twice) for the first soil model with a calcium carbonate of 22% and treated with this additive with (4%, 6%, 8%, 4% and 2%) respectively, if compared to an untreated model for the same soil, as shown in Figure 6. The increase in ultimate bearing capacity for second soil containing 30% of calcium carbonate was increased (3.5 times, 3.7 times, 2 times and 1.1 times) using the additive (4%, 6%, 8% and 2%), respectively, compared to an untreated model from the same soil, as shown in Figure 7. While the increase in the bearing capacity of the third soil containing 42% calcium carbonate was increased (4 times, 3.3 times, 3 times and 2 times), for treated model by mixing it with (4%, 6%, 8% and 2%) respectively, as shown in Figure 8. The increase in the ultimate bearing capacity of the fourth soil with 51% calcium carbonate was (5 times, 4 times, 3.2 times and 3 times) using the additive in mixing ratios (4%, 6%, 8%, 2%) respectively, as shown in Figure 9. On the other hand, for the fifth soil with a 60% of calcium carbonate, the increase in the ultimate bearing capacity of soil was increased (5.6 times, 4 times, 3 times and 2 times) by using the additive in mixing ratios (4%, 6%, 8% and 2%), respectively, as shown in Figure 10.

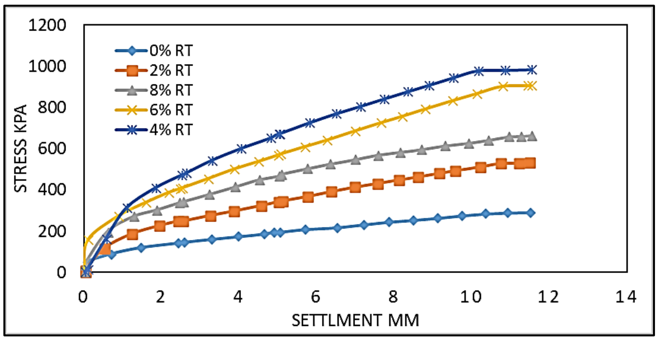

Figure 6. Loading test for first soil with 22% calcium carbonate, treated with rubber tire powder dry test

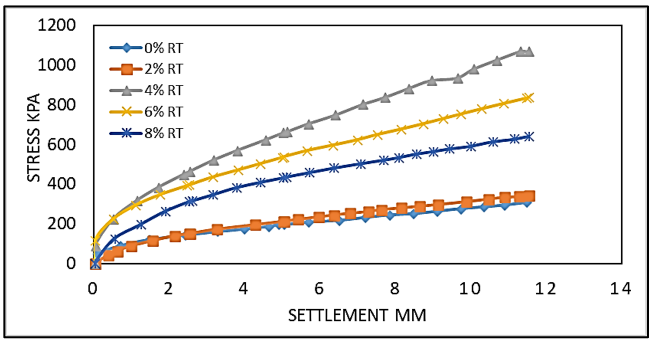

Figure 7. Loading test for second soil with 30% calcium carbonate treated with rubber tire powder, dry test

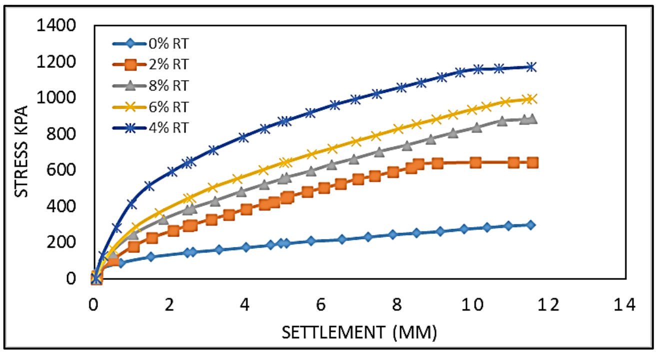

Figure 8. Loading test for third soil with 42% calcium carbonate, treated with rubber tire powder, dry test

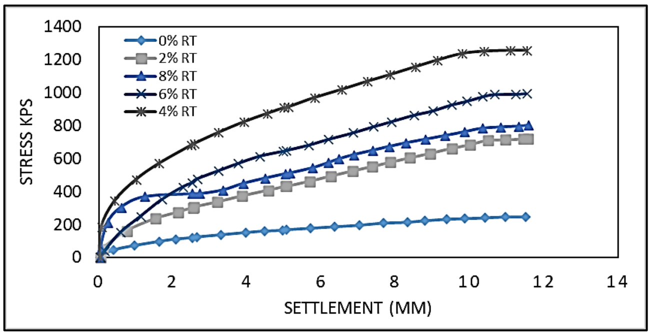

Figure 9. Loading test for third soil with 51% calcium carbonate, treated with rubber tire powder, dry test

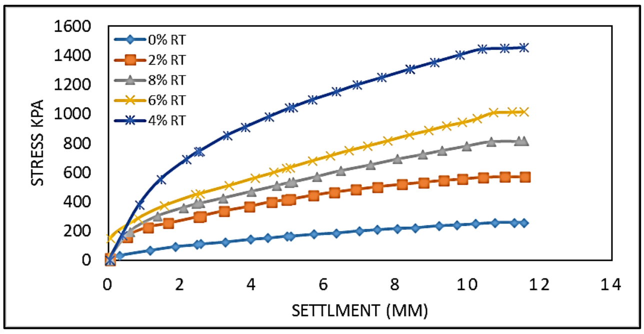

Figure 10. Loading test for third soil with 60% calcium carbonate, treated with rubber tire powder, dry test

It can be distinguished from the results that the best ratio of mixing the additive with the five soils used in the dry test was 4%, where the bearing capacity of the soil increased by 3 to 5 times compared to the untreated models. On the other side, increasing the mixing ratio of this additive to more than 4% is less effective, and this may be due to the increase in the soil's compressibility and weakness after adding more than this percentage to the dry calcareous soil and the lack of cohesion with the soil particles, in addition to the fact that the compressibility of those soils in the dry state is considered acceptable, even without treatment for the bonding of soil particles with calcium carbonate that form filler materials and form solid layers or conglomerates that resemble rocks in texture as a result of their bonding with soil particles after exposure to atmospheric conditions for successive years, with this, the results were satisfactory, and generally, there was a clear increase in the ability of soils in dry tests in general.

3.2 Wet model tests

Figures 11 to 15 show the loading tests for the five models of calcareous soils with a content of (22%, 30%, 42%, 51% and 60%) treated with rubber tire powder mixed with it at the rates of (0%, 2%, 4%, 6% and 8%) for testing the soaking models with water for 24 hours.

Figure 11 shows the relationship of stress with settlement for the first calcareous soil with calcium carbonate content of 22%, where the results showed an increase in the ultimate bearing capacity of the soil (4 times, 3.8 times, 3 times, 1.8 times) for soils mixed with additives at rates of (4%, 6%, 8% and 2%), respectively. Compared to the untreated model.

Figure 12 shows the relationship of stress with settlement for the second calcareous soil with 30% calcium carbonate content, where the results showed an increase in the ultimate bearing capacity of the soil (3.5 times, 3 times, 3 times, 1.5 times) for soil mixed with additives at rates of (4%, 6%, 8% and 2%) respectively, compared to the untreated model.

Figure 13 shows the relationship of stress with settlement for the third calcareous soil with calcium carbonate of 42%, where the results showed an increase in the ultimate bearing capacity of the soil (5 times, 5 times, 4.5 times, 4 times), for soils mixed with additives at rates of (4%, 6%, 8% and 2%), respectively compared to the untreated model.

Figure 14 shows the relationship of stress with settlement for the fourth calcareous soil with 51% calcium carbonate content, where the results showed an increase in the ultimate bearing capacity of the soil (5.8 times, 3.3 times, 3.7 times, 3 times), for soils mixed with additives at rates of (4%, 6%, 8% and 2%) respectively compared to the untreated model.

Figure 15 shows the relationship of stress with strain for the fifth calcareous soil with calcium carbonate content of 60%, where the results showed an increase in the ultimate bearing capacity of the soil (4 times, 3 times, 2.8 times, 2.4 times), for soils mixed with additives at rates of (4%, 6%, 8% and 2%) respectively compared to the untreated model.

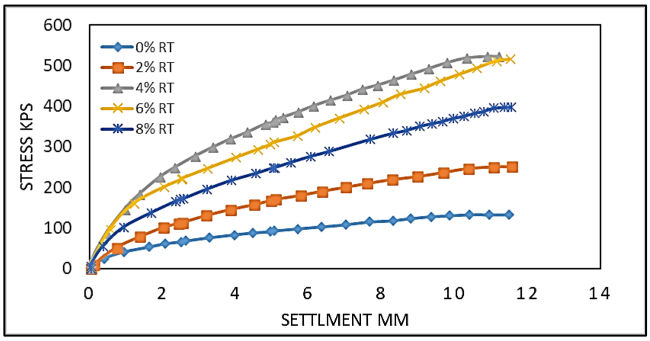

Figure 11. Loading test for first soil with 22% calcium carbonate, treated with rubber tire powder, soaking test

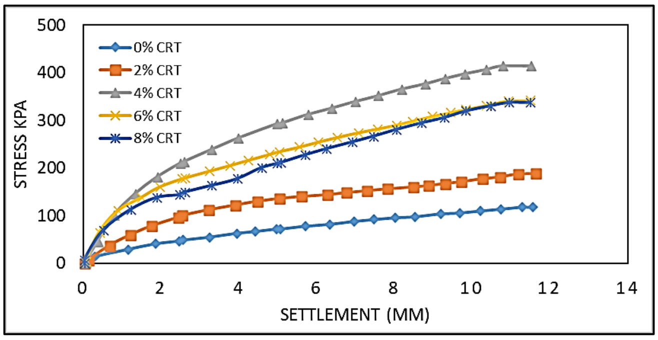

Figure 12. Loading test for second soil with 30% calcium carbonate, treated with rubber tire powder, soaking test

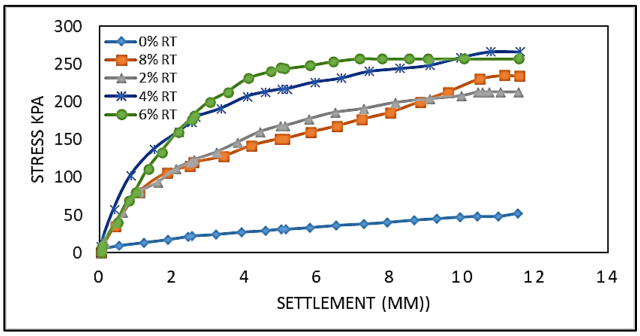

Figure 13. Loading test for third soil with 42% calcium carbonate, treated with rubber tire powder, soaking test

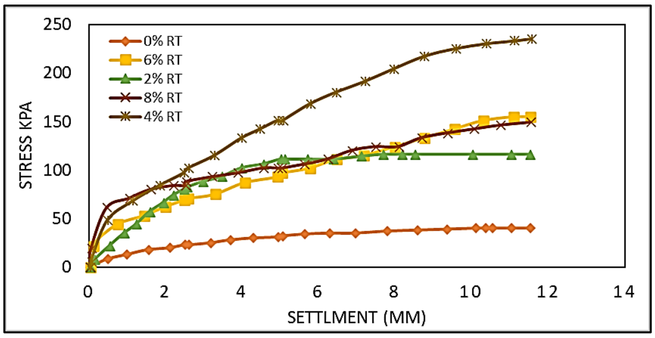

Figure 14. Loading test for fourth soil with 51% calcium carbonate, treated with rubber tire powder, soaking test

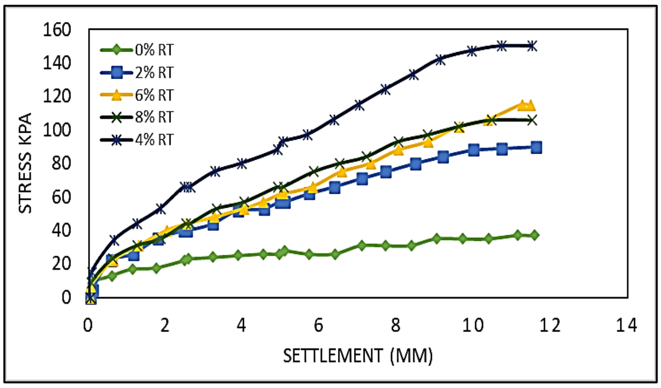

Figure 15. Loading test for fifth soil with 60% calcium carbonate, treated with rubber tire powder, soaking test

It can be noted that the treatment by adding rubber tire powder in soaking test of calcareous soil models was very effective for all models used in the scope of this study, and gave promising results in reducing the collapse of calcareous soils and an increase in their ultimate bearing capacity by 3 to 5 times after mixing the soil with 4% of This additive, therefore, can be recommended as a successful method of treatment. It is noted from the results that by increasing the percentage of additives to more than 4%, the amount of improvement was less, this may be due to the increase in the compressibility of the soil after mixing it with high percentages of rubber tire powder, 6% and 8% due to poor cohesion between the soil particles and the additive and an increase in the isolation between the two media caused by this material. If it is present in high proportions, it may lead to weak bonding and the occurrence of more subsidence. With this, all ratios were effective in improving the properties of calcareous soils used in the study.

3.3 Summary of main results

The calcareous soils in their dry state are strong soils with acceptable compressibility and high bearing capacity, as shown in Figures 6 to 10. While the bearing capacity of calcareous soils decreases by immersing it in water as shown in the Figures 11 to 15, and the reason for this decrease is that by immersing the soil with water the reason for the weakness of the soil due to the dissolution of the lime particles that are adjacent to the soil grains, creating gaps that fill with water, and soil compaction occurs. The compressibility increases as the lime content in the soil increases, by adding the spent tire powder in different proportions, it reduced the compressibility of the five limestone soils and increased their bearing capacity in the dry and wet examinations, as shown in Figures from 6 to 15.

Figure 16 represents the relationship between the higher stresses the mixing ratio of tire powder for the five calcareous soils tested at dry condition. It can be seen that the most improvement percentage was obtained by mixing soils with 4% of the additive, and the most obvious soil in which improvement is the fifth soil with the highest calcium carbonate content of 60%, and there is a large discrepancy between the values of the greatest stress with the mixing ratios. On the other hand, it appeared that the improvement rate for the first soil with calcium carbonate content of 22% was less variance than it is compared with other soils used in this study.

Figure 17 shows the relationship between the highest stress and mixing ratios of rubber tire powder additive in the wetting or soaking assay of five soils. It is noticed from the data that the response of the first soil with the lowest calcium carbonate content of 22% was the largest, while the response of the third soil was the lowest among the rest of the soils. This behavior may be attributed to the different degree of acidity of the two soils, as it is known that some substances are less soluble in water than others. The reason for this difference is due to the discrepancy in the crystal energy of each soil, and the energy involved in the interaction between the solvent and dissolved ions during the dissolution of the crystals. Soil is more soluble, Where the solubility of weak acid salts depends on the pH of the solution, and among the important examples of these salts in analytical chemistry are oxalates, sulfides, hydroxides, carbonates, sulfates and phosphates, where the hydronium ion unites with the negative salt ion to form a weak acid and the solubility of salt increases.

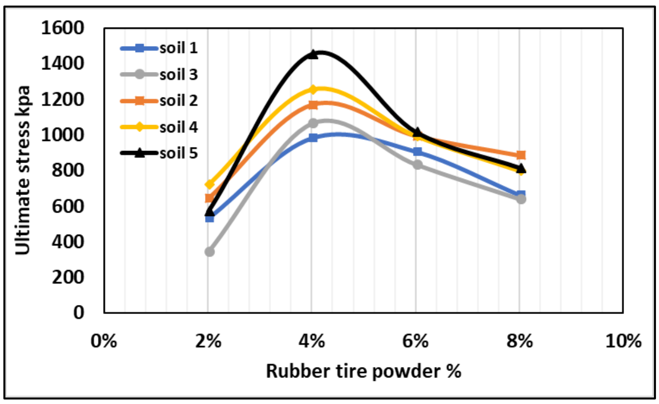

Figure 16. Summary of results for calcareous soils used in the study, treated with rubber tire powder with different percentages, dry test

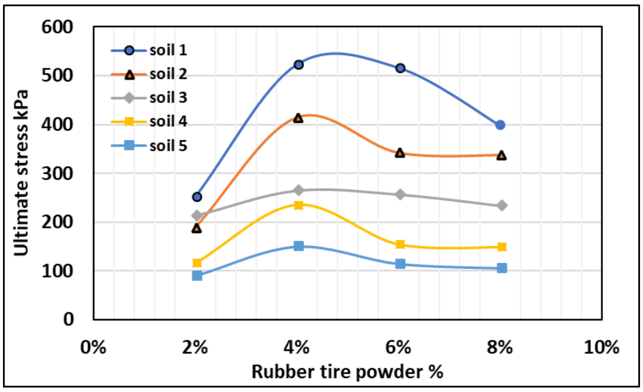

Figure 17. Summary of results for calcareous soils used in the study, treated with rubber tire powder with different percentages, wet test

4. CONCLUSIONS

Calcareous soils are a burden to the civil engineer in general and the geotechnical engineer in particular, because of their collapsing properties, causing structural problems for the buildings erected on them.

The reason behind choosing this additive is that it does not interact with soil components and its compounds like other known additives that may lead to an increase in the amount of sulfite as in cement, or damage to the environment and living organisms as well as by adding bituminous materials, oil derivatives and asphalt emulsions, in addition to its effect on building foundations. On the other hand, the durability of the plastic materials resulting from the spent tires is very good and is not affected by the process of washing the soil in the case of washing, compared to the rest of the chemical additives that have little durability and lose their effectiveness with time.

The ratios in this study for the used tire powder additive have been adopted based on previous research that was approved, and it is the most effective and economical ratio. It was noted that all proportions of this additive gave promising results in improving the bearing capacity of calcareous soils used in this study. The first soil with lower calcium carbonate content responded well, and showed more improvement than the rest of the soil in the soaking test, while the fifth soil responded to the greatest improvement in the dry test.

The use of this additive proved efficient in reducing the subsidence of the used laboratory model, and the best mixing ratio of rubber tire powder was (4%), as the ultimate bearing capacity of the soil increased more than (4) times compared to the untreated model.

In future studies, it is recommended to go about suggesting other additives that contribute to improving calcarious soils, such as adding aggregates resulting from construction waste or adding slag from factories. It is also recommended to prepare a study on the effect of reinforcing with local materials and study the effect of the number of reinforcing layers on improving the engineering properties, reducing subsidence and increasing the bearing capacity of limestone soils. The ability to improve these types of soils.

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NOMENCLATURE

C	Soil cohesion kN/m^2
C.P	Collapse potential of soil
G.s	Specific gravity of soil
L.L	Liquid Limit of soil
O.M	Organic material
O.M.C.	Optimum moisture content

Greek symbols

Ø	Angle of internal friction
γ	Unit weight of soil

Subscripts

T.S.S.	Total soluble salts
RT	Rubber Tire
N.P	Not plastic
S1	Soil 1