Effect of rubber tire on behaviour of subgrade expansive Iraqi soils

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Abstract
In this study focuses on improving an expansive soils geotechnical properties treated by tire crumble and decreasing the natural contamination by this waste material. The waste rubber of tire in the form of crumble with size ranging between 0.08 to 2 mm with proportion from 0 to 10% was used in this examination. Routine tests such as compaction, unconfined compressive strength, consolidation and swelling pressure test have been done on untreated and treated soils with crumble tire rubber. According to the test results it was found that, the maximum dry density of treated samples decrease with increased tire crumble content, while a slight reduction in the optimum moisture content was found simultaneously. Also, the results of unconfined compression tests showed that, the crumble tire rubber could not improve the properties despite the fact that the soil still in the hardened consistency. In like manner results demonstrate that using crumble rubber might be successful procedure in upgrading the soil characteristics against swelling potential of soils by approximately 29.8, 43.4, 49.3% 14.77 times than untreated soil for (1, 3, 5, 10%) tire crumble rubber content. In addition the results show increasing crumble tire rubber content from 1 to 5% gave low displacement values by about (26.01 - 43.9)% than its value in untreated samples. Finally, it has additionally seen that using of crumble tire rubber aides in decreasing the compression index, consolidation coefficient, permeability coefficient and volume change coefficient.

Key words: Compressibility, expansive soil, Shear strength, rubber, swelling.

1. Introduction
The term of swelling soil can be utilized for depicting soil which incorporates a change in volume because of trading the measure of the amount of the soil water content (Nelson and Miller, 1992). In Iraq and a few countries of the world expansive soils are a overall problem, this exceptionally plastic soil may make splits and harm on the asphalts pavement, railroads, thruway dikes, roadways, building establishments, channel and store, water lines, sewer lines and so forth.( Seed et al., 1962, Kormonik and David, 1969; Gromko, 1974). So these soils characteristics must be studied because of the issues that might be caused to these structures which are based on these sorts of soil and afterward study the strategies for treatment.

A few techniques are accessible for stabilizing swelling soils for example (additives of chemical, rewetting, replacement of soil, control of compaction, and control of moisture, loading surcharge and thermal methods (Nelson and Miller 1992; Steinberg 1998)). These investigations were a noteworthy
achievement yet they have neglected to decide the related designing properties (Ahmed et al. 2015), accordingly new techniques are as yet being explored to enhance properties of strength and diminish the behavior of swelling soils (Al-Tabbaa and Aravinthan, 1998; Puppala and Musenda 2000).

2. Literature Review

Many types of waste for example industrial wastes, marble dust, some plastic materials, and fly ash are explored to be utilized as added substance materials for stabilizing expansive soils and to enhance the presentation of banks and fills by lessening displacement, rate of settlement and pressures of earth, and by enhanced the bearing capacity of these structures) (Bernal et al. 1997; Fattah et al. 2011and Cabalar et al. 2014, 2015).

Few investigations have been led on the wastes addition to high plasticity clay soil. Following investigations were on the impact of tire powder and other wastes of tire on the geotechnical properties of soils.

Cetin et al. (2006) blended 2 types of chip tire with silty clay; their outcomes showed that the (τ) increments by up to thirty percentages for fine and twenty percentages for coarse chip tire mixtures. The value of (c) increases as the substance of tire chips increments up to (40%) for both fine and coarse blends, and the (Ø) reduction. After forty percentages, while the (c) reductions, the (Ø) increments.

O¨zkul and Baykal (2007) ) researched impact of rubber fibre reinforcement on the τ behavior of clay have CL, they outcome that the commitment of rubber fibres to the clay quality diminishes as rising restriction level and nearness of rubber fibres led to decrease the clay strength. For this soil, the confining stress in the range of 200 and 300 kPa.

Trouzine etc. al. (2012) studied the effect of adding scrap tier rubber fiber on behavior of two clayey soils, they observed the decrease of swelling potential for ten percentage tire rubber scrap substance is about (1.5) for the CL as compared with CH and for twenty, twenty five and fifty percentage tire rubber scrap amount the decrease is approximately similar for the two clayey soils. Additionally reduce pressure of swelling is somewhat increasingly huge in CH soil with ten, twenty five and fifty percentage of tire rubber scrap than in CL soil with the similar scrap amounts.

Young etc.al. (2016) examined the physical and chemical properties of tire shreds as a replacement for aggregates in embankments or as backfill. The results demonstrated that the (Ø and c) ranged from (15 to 32°) and (349 to 394 N/m²) as the size of particle range from (50 to 300 mm), moreover, as the tire shred size increased, compressibility increased.

Solanki etc. al. (2017) investigate the direct shear test of soil-tire mixture using crumb rubber at different percentage 0.5, 0.075, 0.25, 0.50, 0.75, 1.0. The results showed that the shear strength increased with the increasing content of rubber up to 0.75% by weight and the value of angle of internal friction increases with increment in percentage of the rubber tire strips. Also Less percentage of rubber tire chips are giving optimum value and maximum dry density.

Rahil and Abd-Almunicem, (2018) examine the behaviors of machine foundations laying on sand granular tire rubber mixtures 0, 8, and 12% after saturation, the comes about appeared that the amplitude of displacement sufficiency diminished and the settlement increment for soaked sand compared to dry sand beneath the same conditions. Blending granulated tire rubber with soaked sand diminished the amplitude of displacement, settlement, and pore water excess; the range of percentages of decrease was from (19% to 73%, 40% to 70%, and 24% to 60%) individually.

3. Research Objective

Most the above researchers have attempted to improve the engineering properties of expansive soils by using waste materials and eliminating these wastes from the environment they focused on the low-plasticity clay (CL) and high-plasticity silt (MH). Therefore, in this study, different percentages of waste tire rubber crumble (1%, 3%, 5% and 10%) of the dry weight of soil, having particle sizes of greater than 0.075 mm, are used to stabilize the CH. The present work objective is studying the impact of tire rubber waste crumble on the maximum
dry density, optimum moisture content, and one dimensional swell response of swelling soil, consolidation and compression coefficient. Also study enhanced in shear strength properties ($c$ and $\phi$).

4. Experimental work

4.1 Materials used

4.1.1 Soil

Soil utilized in this research was all set by mixing 50% of non-expansive soil (kaolinite) with 50% bentonite Na-base in the laboratory. The bentonite base-Na and kaolinite soil were brought from the (State Company for Geological Survey and Mining) in Baghdad city. The samples were subjected to testing of physical properties program which includes specific gravity, liquid and plastic limits, distribution of grain size, compaction test, unconfined compression test and consolidation test. All the experimental work and tests were carried out in the Soil Mechanics Laboratory/Engineering College/Al-Mustansiriya University in Baghdad city. Figure (1) show the grain size distribution test for untreated soil and crumble tire rubber, were done indicate by ASTM-D-422-00, the figure shows that the soil are consisted of 94% clay and 6% silt that classified as silty clay according to ASTM classification and designated as (CH) in the USCS. Table (1) shows the properties of soil employed in the present work. According to the grain size curve crumble tire rubber was classified as sand particles. Therefore, by adding crumble tire rubber to the soil sample, the percentage of clay in the mixture can be reduced.

![Figure 1: Grain Size Distribution of Soil Particle and crumble tire rubber.](image-url)
Table 1: Physical and Chemical Properties of Soil

| Properties                      | Value   | Test Method     |
|---------------------------------|---------|-----------------|
| specific gravity                | 2.74    | ASTM D854       |
| Liquid limit (%)                | 93      |                 |
| Plastic Limit (%)               | 45      |                 |
| Plasticity Index (%)            | 48      | ASTM D4318      |
| Max. dry unit weight (kN/m³)    | 14.3    |                 |
| Optimum moisture content (%)    | 22.5    | ASTM D1557-99T |
| Passing Sieve No.200 (%)        | 94      |                 |
| Classification according to USCS| MH      | ASTM D2487-00  |
| pH                              | 8.03    |                 |
| SO₃ (%)                         | 0.45    | BS(1377)        |
| T.S.S. (%)                      | 0.76    | BS(1377)        |
| Gypsum content (%)              | 0.96    | BS(1377)        |

4.1.2 Tire rubber crumble

Rubber in granular form was made by scrap tires from a manufacturing plant of tire in Iraq, Babylon, into small pieces as shown in Plate (1). Table 2 demonstrated the properties of tire rubber crumble as given by the tire industrial facility.

Plate 1: Tire Rubber Crumble

Table 2: Tire Rubber Physical Properties

| Property                        | Value              | Specification     |
|---------------------------------|--------------------|-------------------|
| specific gravity                | 0.88               | ASTM D6270-98    |
| Void ratio, e                   | 1.5-2.5 (Uncompacted) |                 |
|                                 | 1.2-0.9 (Compacted) |                 |
| Modulus of elasticity, E        | 1240-5173 kPa      | ASTM D6270-98    |
| Poisson’s Ratio, μ              | 0.5                |                   |
| Capacity of water absorption    | 2%-4%              |                   |
4.1.3 Modified Proctor Test
Modified Proctor tests, according to ASTM-D-1557-70 were directed to assess the compaction properties of the swelling soil-crumb tire rubber mixtures. Distinctive tire rubber crumble content (0%, 1%, 3%, 5%, and 10%) with a known amount of water was added to expansive soil. Maximum dry density and optimum moisture content of each swelling soil-crumb tire rubber mixtures that obtained were utilized for the preparation of specimens for unconfined compressive strength, one-dimensional consolidation and swelling pressure tests.

4.1.4 Unconfined compression Test
Specimens of cylindrical shape with 3.8 cm diameter and 7.6 cm height were utilized to assess the unconfined compressive strength of the swelling soil-crumb tire rubber mixtures as per ASTM-D-2166-00. The specimens of soil-crumb tire rubber mixes were set up at the maximum dry density and optimum moisture content. The specimens were compacted to a known volume by tamping until the desired unit weights were reached then extracted from the mold by using sample extractor.

4.1.5 One-Dimensional Swell Test
One-dimensional swell test is conducting according to (ASTM D4546–14) for evaluating the swelling potential of the swelling soil-crumb tire rubber mixture; the samples were compacted to a known volume by tamping until the desired unit weights were reached inside the metal rings of 7.5 cm diameter and 2.0 cm thickness. The samples in the ring were set in the consolidation cells and saturated under an additional pressure of 7 kPa. The swelling of the samples started soon after the addition of distilled water to the consolidation cells.

4.1.6 One-Dimensional Consolidation Test
Odometer test is the routine test to determine and evaluation the value and ratio of the total and differential settlement of a structure. In this study after the soil samples have reached maximum swelling value directly the consolidation stage starts as indicated by (ASTM D2435/D2435M – 11), the first stage of consolidation is loading process and the increment was 1, 2, 4, 8, 16, 32, and 64 Kg, each load increment was applied for 24 hours.

4.1.7 Max. Dry density
Figure (2) demonstrated the results of compaction test for untreated and the treated expansive soil with different crumble tire rubber content and Figure (3) demonstrated the tire rubber crumble content effect on the maximum dry density. It may be seen from these figures the maximum dry density decreased as the rubber content increased until reaching an approximate constant value at 10% tire rubber content, while little decrease in optimum moisture content found for tire rubber percentage greater than 1% as shown Table 3. The reduction in the maximum dry density can be attributed to the low specific gravity of the rubber tire that reduces compaction efficiency as compared to clayey soil.
Figure 2: Compaction Curve for Untreated and Treated Soil.

Figure 3: Effect of Tire Rubber on the Max. Dry Density.

Table 3: Compaction Test Results.

| Tire rubber (%) | Max. dry unit weight (kN/m$^3$) | Optimum moisture content (%) |
|-----------------|---------------------------------|-----------------------------|
| 0               | 14.4                            | 24.8                        |
| 1               | 14.1                            | 24.5                        |
| 3               | 14.0                            | 23.7                        |
| 5               | 13.8                            | 23.7                        |
| 10              | 13.6                            | 23.5                        |
4.1.8 Unconfined Compressive Strength

The results of unconfined compression test for untreated soil and soil treated with tire rubber crumble shown in Figure (4). The results demonstrate that the untreated soil failed at most elevated point which it is 155.98 kPa at 5.2% strain and based on the classification of unconfined compressive strength as presented by Das and Sobhan (2014) the soil is stiff. When adding 1% tire rubber content, the soil failed at most elevated point which it is 144.1 kPa at 5.9% strain, but the soil is still with consistency of stiff soil, a similar way was noted as the rubber tire content increment to 3% and 5%. This can be credited to the loss of contact and holding between the clay and rubber tire crumble. After 5% of rubber tire crumble content, the UC strength of the treated soil diminished to 85.4 kPa that prompted lessen the range of consistency of soil (stiff soil to soft soil). This decrease in unconfined compression strength might be a direct result of poor interfacial mechanical interaction among rubber and soil particles and increase in the swelling soil samples voids when tire rubber crumble added.

Figure 4: Stress-Strain Curves from Unconfined Compression Test.

Figure (5) demonstrates the tire rubber content effect on cohesion of expansive soil-tire rubber mixture. It tends to be seen from these results the maximum range of tire rubber that kept stiff consistency is 5% and beyond this value the decrease rate in cohesion was about 45.2 times untreated soil. The results of UC strength test were shown in Table (4).

Figure 5: Effect of Tire Rubber on Cohesion.
Table 4: Unconfined Compressive Strength Test Results.

| Tire rubber (%) | Unconfined compressive strength (kPa) | Undrained cohesion (kPa) | Failure Strain (%) |
|-----------------|--------------------------------------|--------------------------|------------------|
| 0               | 155.89                               | 77.945                   | 5.2              |
| 1               | 144.1                                | 72.05                    | 5.9              |
| 3               | 140.6                                | 70.3                     | 5.9              |
| 5               | 134.1                                | 67.05                    | 5.9              |
| 10              | 85.4                                 | 42.7                     | 3.9              |

4.1.9 Swelling potential and swelling pressure

The potential of swell ($S_p$) was defined as (Kalkan, 2013).

$$S_p = \frac{\Delta H}{H_f}$$

Equation (1)

where:

- $\Delta H =$ difference in height which is ($H_i - H_f$),
- $H_i =$ Initial height of the sample, and
- $H_f =$ Final height of the sample.

Figure (6) shows the time-swelling relationship for different rubber tire content. It can be indicated from this figure that the soil reached maximum swelling at 20 days and swell potential is reduced by adding rubber tire, the swell percentage being to reduce from 13.2% to almost 6.68% for rubber tire range from (1% to 5%) respectively, then increased untie approximately approach from untreated soil for 10% tire rubber content.

![Figure 6: Relationship between Swelling Potential and Time for Different Tire Rubber Content.](image-url)
Figure (7) demonstrated tire rubber crumble effect on the swelling potential, the potential decreased as the rubber tire content increased, this reduction rate in swelling potential was about 29.8 to 49.39 times the untreated soil for crumble tire rubber content (1 to 5%) might be because of ability of rubber tire to attract water from soil.

The pressure of swelling ($P_s$) was resolved as the pressure at $e_o$ of the samples found from the curve of $(e - \log p)$. Figure (7) demonstrated the tire rubber crumble content effect on swelling pressure, the ($P_s$) value decreased from 121.6 kPa to 82.95 kPa for rubber tire range from (1% to 5%) at that value increased to 99 kPa for tire rubber 10%. The decrease rate in ($P_s$) was about 11.91, 19.32, 31.78 and 17.84 times untreated soil for the rubber tire content from 1%, 3%, 5% and 10% is the aftereffect of the way made by the particles of rubber for the dispersal of pore pressure, likewise substitution of swelling soil by non-swelling particles of rubber which can experience the tensile stress induced due to the swelling of soil particles.

4.1.10 Consolidation test results

The results of consolidation tests are displayed as $e - \log p$ as plotted in Figure (8), while Figure (9) show the relationship between the applied load and settlement for each samples of soil with different tire rubber content. The granular particles of rubber that behave like sand particles which enhanced the stiffness and lessens the settlement of the soil since its go about as flexible bad in the mixture (Ho et al. 2010). The reduction rate in settlement about 16.33, 16.99, 36.60 and 12.41 times untreated soil under pressure of 200 kPa and 2.86, 6.68, 22.29 and 6.05 times untreated soil under pressure of 800 kPa. Table (4) shows the parameters obtained from consolidation test results that included compression index ($c_i$), consolidation coefficient ($c_v$), permeability coefficient ($k$) and volume change coefficient ($m_v$). Figure (10) shows the effect of rubber tier on $c_i$, $c_v$ under a pressure of 200 kPa and permeability coefficient ($k$).
Figure 8: Pressure – Void Ratio Relationship

Figure 9: Load – Settlement Relationship
5. Conclusions
This paper studied the possible use rubber tire to improve the properties of expansive soil; the following points can be drawn:

- The maximum dry density decreased as the rubber content increased, lower density of the mixture at higher rubber content while little decrease in the optimum moisture content were found for tire rubber percentage greater than 1%.
- The incorporation of the higher amount of rubber content greater than 5% reduces the unconfined compression strength although that the soil maintained stiff consistency. While the axial strain at failure of the soil increments somewhat with the increase in the rubber content.
- Addition of rubber to swelling soil caused an impressive decrease in the swell potential and the rate of decrease was about 29.84, 43.4, 49.39 and 14.77 times untreated soil for rubber content 1%, 3%, 5% and 10% respectively.
- The compression index and consolidation coefficient of soil decrease from 0.22 to 0.156 and 24.47 to 24.39 m²/year separately as the amount of rubber increments.

### Table 5: Consolidation Test Results

| Tire rubber (%) | m_v (m³/kN) x 10⁴ | C_v (m²/year) | K (m/sec) x 10⁹ |
|-----------------|--------------------|---------------|-----------------|
| 0               | 3.07               | 24.47         | 2.635           |
| 1               | 1.95               | 13.02         | 2.800           |
| 3               | 1.88               | 30.67         | 3.010           |
| 5               | 2.83               | 78.04         | 5.098           |
| 10              | 2.93               | 86.32         | 8.622           |

Figure 10: Effect of Tire Rubber on C_c, C_v, and k.
• Permeability coefficient of treated soil increased from 2.635 \times 10^{-9} to 8.662 \times 10^{-9} as rubber content increased from 1\% to 10\%.

• The accurate in determination of the fitting measure of rubber content depends on sort of soil and the required properties for improvement. Additionally, the utilization of rubber tire takes care of the issues of tire wastes control and it is satisfactory measure environmentally.

• Finally, using tire rubber crumble can be reduced stabilization costs and this stabilization procedure may be suggested for light weight structures, light traffic road base stabilization and backfilling for retaining structures.

6. Data availability
The writers affirm that the information supporting the discoveries of this investigation is accessible inside the article or it's strengthening materials.

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9. List of notations

\( \Delta H \) height difference
\( H_i \) Initial height of the sample
\( H_f \) Final height of the sample
\( S_p \) swell potential
\( P_s \) swelling pressure
\( c_c \) compression index
\( c_v \) consolidation coefficient
\( k \) permeability coefficient
\( m_v \) volume change coefficient