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Behavior of Strip Footings Resting on Sand Mixed with Tire-Chips

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Abstract

Scrap tires are undesired urban waste and the volume is increasing every year. Tires have characteristics that make them not easy to dispose, and potentially combustible. Utilizing waste materials as an alternative to using virgin construction materials, made from nonrenewable resources, in civil engineering applications is currently one of the most important environmental issues. The unique properties of tire chips such as strength, high frictional resistance and flexibility can be exploited in a beneficial manner in geotechnical applications. In this research, tire chip mixed randomly with various percentages by weight up to 30% of sand and two different sizes of tire chip. Laboratory California Bearing Ratio (CBR) and other laboratory model tests are conducted to investigate the benefits of using tire chips as lightweight inclusion to improve the bearing capacity and control settlement of strip footing on sandy soil. The results indicate that the addition of tire chip increase the CBR strength of the sand significantly, it's about 29% for size (5-9) mm and 19.5% for size (10-20) mm at the tire chip percentage of 20%, improved the bearing capacity and modifies the load -settlement behavior of the footing Sice the used of tire chips reduced settlement about 22%.

Keywords: Improvement Soil; Waste rubber; Tire chip; Sand; CBR Test; Strip footing

تصرف الأسس المستمرة المستندة على التربة الرملية المخلوطة مع قطع المطاط

الخلاصة

تعتبر الإطارات القديمة من النفايات غير الحضرية غير المرغوب بها والتي حجمها يتزايد كل سنة. للإطارات خواص تجعلها صعبة الإتلاف وفعلا قابلة للحرق. حاليا استعمال الفضلات كبديل لمواد البناء الأصلية جعل من استعمال المواد الغير قابلة للتجديد احد أهم القضايا البيئية المستعملة في تطبيقات الهندسة المدنية. ان الخصائص الفريدة للمطاط مثل القوة، مقاومة الاحتكاك العالية، والمرونة يمكن ان تُستغل بطريقة مفيدة في تطبيقات الهندسة الجيوتكنيكية. في هذا البحث تم تحضير النماذج بأخذ عدة نسب للمطاط من الوزن الجاف للتربة تصل الى 30 %وبقياسين مختلفين وخلطها عشوائيا مع الرمل. في هذا البحث تم إجراء فحص California Bearing Ratio (CBR) وفحص موديل مختبري لدراسة فائدة استخدام قطع المطاط الخفيفة الوزن في تحسين قابلية التحمل الرمل وكذلك السيطرة على الهبوط في الأسس المستمرة المستندة على الترب

الرملية. أظهرت نتائج الفحوصات أن زيادة نسبة قطع المطاط يزيد قيمة CBR للرمل بشكل ملحوظ وبحوالي 29% للقياس (5-9)ملم و29.5% للقياس (10-20)ملم, وكذلك تحسين علاقة الحمل-النزول للاساس الشريطي حيث ان نسبة نقصان الهبوط 22%.

Introduction

One of the problems associated with socio-economic development of a world is waste disposal. In engineering and transportation sector one of the wastes generated is scrap tire and it poses serious environmental problem. Majority of them end up in the already congested landfill or becoming mosquito breeding places. Worst when it is burnt. Economically and environmentally feasible alternatives have been investigated for recycling of scrap tires. Tires have characteristics that make them not easy to dispose, and potentially combustible. For these reasons, there is a strong need to find beneficial ways to recycle or reuse tires. Civil engineering applications constitute one of the major markets for scrap tires. They have been used in various areas such as leachate collection systems, landfill cover, artificial reefs, clean fill for road embankment, road bed support retaining wall, bridge abutment backfill and similar projects. Using tire shred material for civil engineering application has several advantages. Most important property is that tire shreds are lightweight material. There are many benefits of using shred tires as lightweight fill in embankment or retaining wall since tire shreds are non-biodegradable and thus more durable. Also it is inexpensive compared to other lightweight material Granular mixtures can be engineered to exhibit exceptional properties.

Early studies of sand–rubber mixtures were prompted by the large number of discarded tires ([1], [2] and [3]). Eventually, many construction applications of sand–rubber mixtures, or rubber chips alone, were explored, including highway embankments ([4], [5] and [6]), lightweight fill ([7], [8], and [9]), backfill for retaining walls ([10], [11] and [12]), and subsurface drainage systems [13].

In general, sand–rubber mixtures exhibit low void ratio, high compressibility, low mass density, high friction angle, and high attenuation ([11], [1], [14], [8], [15], [16], [17], [18], [19], [20], [21] and [22]). [23] introduces evaluation of the feasibility of using tire shred –sand mixtures as a fill material in embankment construction and studied effect of Tire shred–sand mixtures, on the other hand, were found to be effective in inhibiting exothermic reactions. When compared with pure tire shreds, tire shred–sand mixtures were found to be less compressible and possessed higher shear strength.

Tire chip have been used as fill and embankment materials in highway applications since the mid-1980s. Although the primary motivation for using tire chip in these projects was to find a means to reuse scrap tires, other advantages can also be accrued. For example, because they are light, tire chip are useful in constructing lightweight embankments over soft ground ([24], [25], and [26] and [27]). [28] introduces recent Japanese experiences related to scrapped tire for geotechnical applications. Techniques for using tire shreds and chips are classifiable into two categories: tire chip mixed and not mixed with soil. Tire chip mixed with soil include cement treated with high ductility and toughness while non-cement treated is intended to reduce liquefaction potential during earthquakes. A summary of laboratory studies and field demonstrations using shredded tire and their mixtures with soils as lightweight geomaterials can be found in [29]. Usually, the unit weight of tire shreds or tire chips are up to six times lower than that of conventional backfill materials such as cohesionless soil.

The engineering properties of tire chip and tire chip mixed with sand have been investigated **([1], [14], [16], [9])** and [20], demonstrating the possibility of using tire chips as lightweight fill material

On the other hand, [30] evaluated the interaction coefficients between geosynthetic reinforcement and fill material, which were tire chips, sand, and rubber–sand mixtures. The interaction coefficients greater than 1.0 indicate that there is an efficient bond between the fill and the geosynthetic reinforcement, and usually occur when resistance is provided by strike-through and restrained dilatancy. [31] also studied the interaction between the geogrid and the tire chip–sand mixture including the determination of the index properties of the backfill materials, the shear strength parameters, the interaction coefficients, and the efficiency of geogrid reinforcements in tire chip–sand backfills.

Materials

The material employed in this study is consisted of tire chip–sand mixtures. Standard test are conducted to obtain its physical properties, as shown in Table (1). The specific gravity test of sand was conducted by ASTM D854-02, but for tire chips, the procedures in ASTM D1895-03, were adopted. The specific gravity of sand is 2.64 while that of tire chips is 1.16. The procedures of sieve analyses, which are provided in ASTEM D422-63, were adopted to investigate the particle-size distribution curves of sand. The particle-size distribution curve of the sand is shown in Figure (1), According to the Unified Soil Classification System (USCS); the sand can be classified as poorly graded (SP) (see Table 1). The tire rubber used in this study was cut randomly into a chip of size (fine chip), (5-9) mm and (coarse chip), (10-20) mm and thickness of 0.7mm with irregular shape due to the random cutting process, Figure (2).

Table (1): Physical properties of sand

Properties	**Index value**
Specific Gravity (G_s)	2.64
coefficients of uniformity (Cu)	0.9
coefficients of curvature (Cc)	2.5
Dry Unit Weight(γ_d) and Void Ratio (e)	$\gamma_{d\ min}$ =14.6 kN/m^3, e_{max}=0.73 $\gamma_{d\ max}$=17.8 kN/m^3, e_{min}=0.42
Angle of Internal Friction (Ø) for: Dr = 64%, $\gamma_{d\ used}$ =16.5 kN/m^3, e_{used}=0.54	Ø=35.8°
Unified Soil Classification System (USCS)	SP

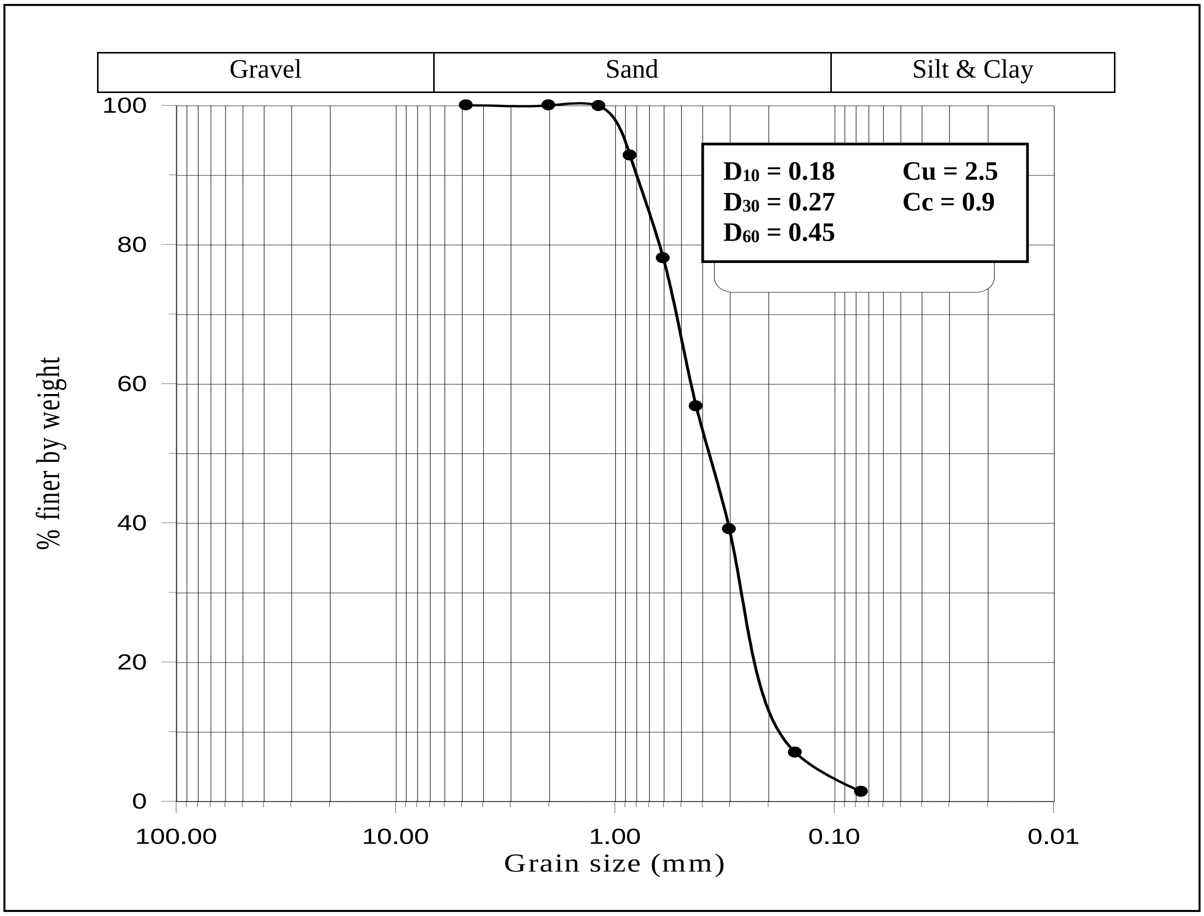

Figure (1): Grain Size Distribution of the sand

Figure (2): Tire chip size (5-9)mm and size(10-20)mm

The physical properties and the chemical composition of tire chips are tabulated in Table (2) and Table (3) respectively.

Table (2): Physical Properties of Tire Chip (*)

Properties	**Index value**
Specific Gravity	1.16
Density	1.16 g/cm^3
Ultimate Tensile Strength	9 Mpa (N/mm^2)
Elongation	150 %
Hardness	64
Absorption	1.12 %

(*)Physical properties test was made by the National Center for Construction Laboratories (NCCL).

Table (3): Chemical Composition of Scrap tires [32]

Description	% by weight as received	% by weight, dry basis
Proximate analysis		
Moisture	0.62	-
Ash	4.78	4.81
Volatile Matter	66.64	67.06
Fixed Carbon	27.96	28.13
Total	100	100
Elemental mineral analysis(Oxide form)		
Zinc	1.52	1.53
Calcium	0.378	0.380
Iron	0.321	0.323
Chlorine	0.149	0.150
Chromium	0.0097	0.0098
Fluoride	0.001	0.0010
Cadmium	0.0006	0.0006
Lead	0.0065	0.0065

Experimental study

The experimental study involved conducting a series of compaction test using a vibratory compaction according to ASTM 4253-00, to evaluate the effect of adding various percentages of tire chips to sand.

In Al-mustansiriya University\ soil laboratory of Civil Engineering College a series of laboratory California Bearing Ratio (CBR) tests on the sand specimen and randomly tire chip-sand specimens which were carried out to examine the effects of tire chip on the ultimate strength of tire-soil mixture. Testing was conducted on specimens with tire inclusion of 10%, 20% and 30%, for chips size of (5-9) mm and (10-20) mm, as shown in Figure (3). The CBR tests were carried out according to ASTM D 698 B. Specimens were molded in a steel CBR mould with an inside diameter of 152mm and height of 175mm. The samples were compacted using a vibratory compaction (ASTM 4253-00, 2000). These experimental data are utilised to assess the overall influence of tire chip on the behavior of strip footing on sandy soil by performing a series of laboratory model tests[32] as unmixed and randomly mixed sand with tire chip. The tests conducted inside model box made of steel plate of 3mm thickness, with 28cm internal length, 25cm width and 25cm depth. The front side of the box (25cm×25cm) is made of hard glass of 10mm thickness to view the deformation mechanism during the test. The model strip footing is made of steel with dimensions of 3× 3×27cm long Schematic diagram of test configuration shown in Figure (4). The general test set up is shown in Figure (5). The box of test filled with sample by dropping the sand or mixture from the cone of 2.5mm aperture size, which is moved horizontally by hand at a height of 50cm that gives a relative density of about 64% at which the is considered to be in medium condition then the dial gauges are installed at their position carefully to record the soil and footing settlements. The datum bar with its whole system is pressed down; the load is applied incrementally by means of surcharge weights (5kg ≈ 49.05N).

Figure (3): Sample of mixture sand- tire chip of size (10-20)mm

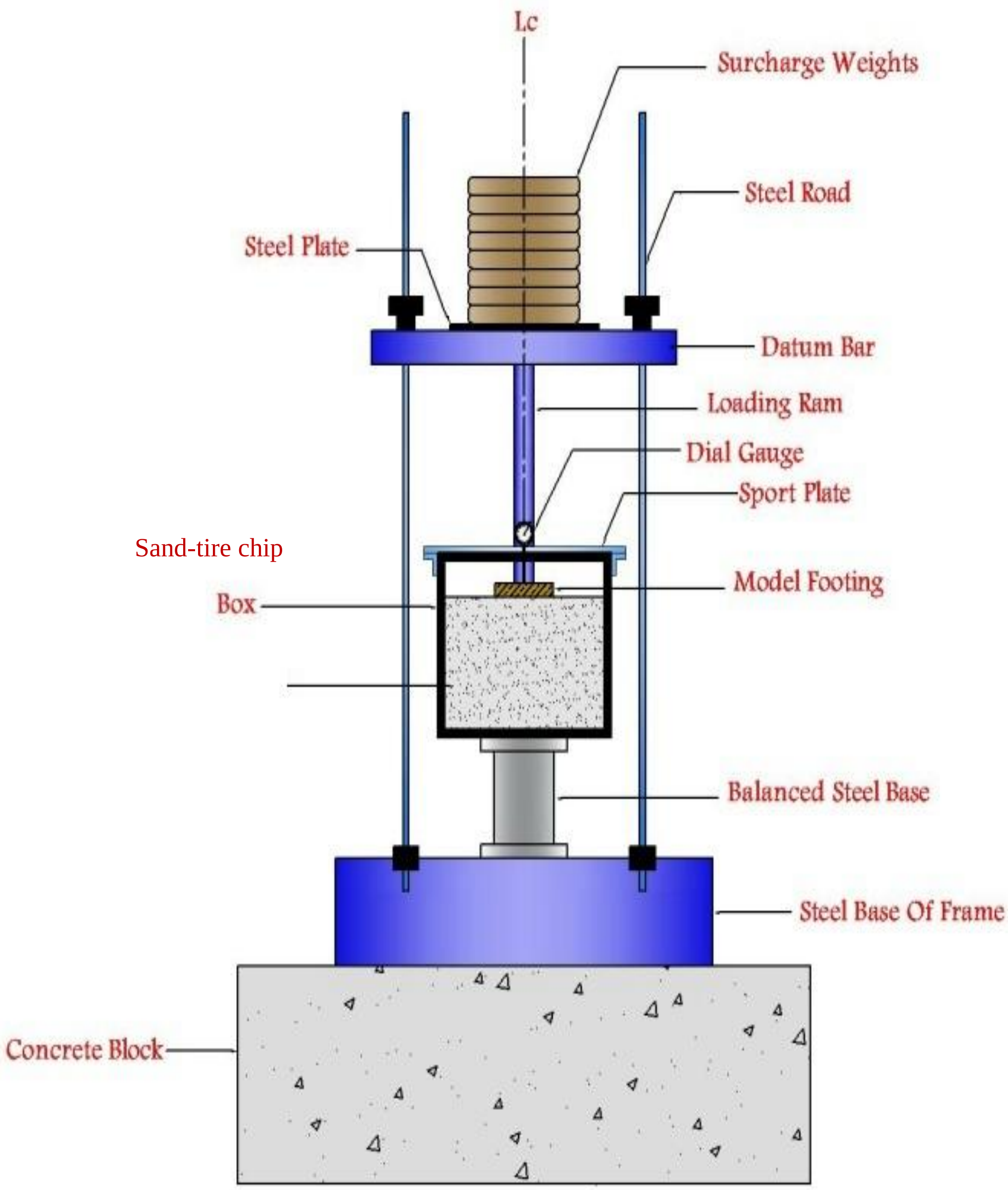

Figure (4): Schematic diagram of test configuration (after [32]).

Figure (5): Test set up (Soil Laboratory of Civil Eng. / Al-mustansiriy University)

Results and Discussion

Effect of Size on Maximum Dry Unit Weight

Results of vibration test of basic mix indicated that smaller chips gave higher density consequently the strength. As shown in Table (4) and Figure (6), the density of the mixture of tire chips and sand decreases linearly with increasing percentage of sand, since the specific gravity (Gs) of the sand is larger than that of the tire chips and the decreasing value increase with the increasing chip size. The specific gravity (Gs) of the sand and tire chips is 2.64 and 1.16 respectively. The results agreed with the investigation of Imtiaz Ahmed and C. W. Lovell (1993) [7] stated that **"The chip unit weight is not very sensitive to the size of chips. However, a trend of increasing unit weight with increasing chip size is found, except in the case of vibratory compaction. In this case the maximum unit weight decreases with increasing chip size**".

Table (4): Vibration Compaction Results from Tests on Tire Chips–Sand Mixtures

Tire chips (% by weight)	Max. dry unit weight (kN/m^3)	
	Size(5-9)mm	Size(10-20)mm
0	17.8	17.8
10	16.49	16.41
20	14.93	14.03
30	14.29	13.40

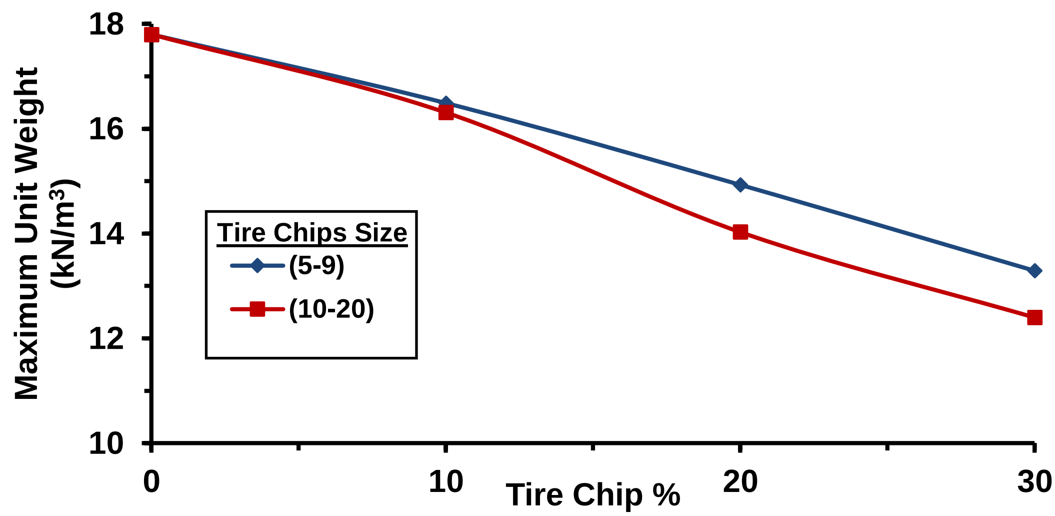

Figure (6): Vibration Compaction Test on Tire chips and Sand Mixture with Various Mixing Ratios

Effect on CBR

The results of CBR test (dry condition) and the effect of adding two sizes of tire chips on CBR strength of samples are explained in the following. At first, CBR of soil without tire is tested. The sand test relative density (Dr) was chosen to be (64%); the related dry unit weight (γ_d) is (16.5 kN/m^3). On this regard CBR of soil in dry condition is 14.8 as shown in Table (5) and Figures (7) and (8). The CBR was increased with increasing of tire chip percentage and its about 29% for size (5-9)mm and 19.5% for size (10-20)mm at the addition of 20%. However the strength decreases as the tire percentage increase beyond 20%. This is attributed to the performance of the mixture, which behaves more homogeneous at 20% (optimum percent), on other hand beyond this percent it can be noticed a reduction of CBR value due to concentration of tire chips. Since tire shreds have a high degree of compressibility because rubber is its main component and their void ratio is relatively high. Compressibility can be decreased by mixing tire chips with sand to reduce the void ratio [14].

Table (5): CBR Results from Tests on Tire Chips–Sand Mixtures

Tire chips (% by weight)	CBR %	
	Size(5-9)mm	Size(10-20)mm
0	14.8	14.8
10	16.3	15.7
20	19.1	17.8
30	17.7	16.9

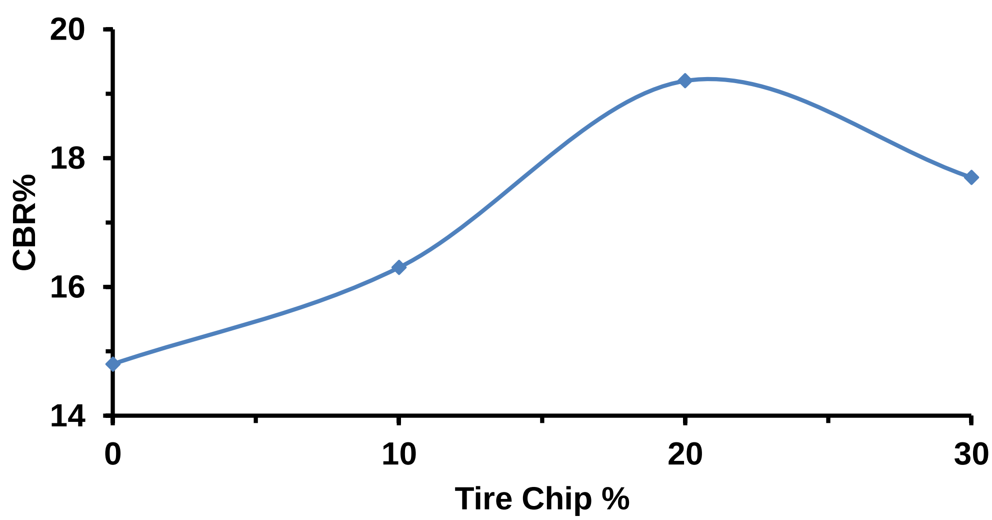

Figure (7): Effect of content of (5-9) mm tire chip on CBR.

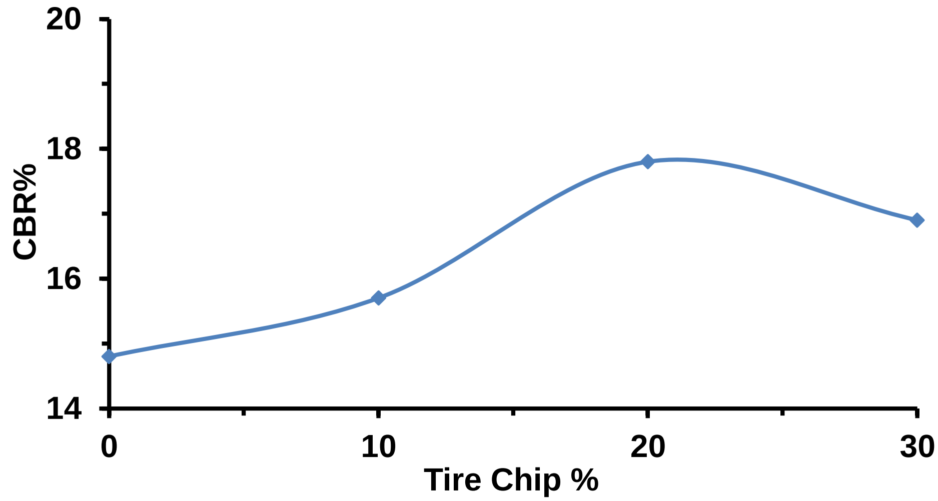

Figure (8): Effect of content of (10-20) mm tire chip on CBR.

Effect on Settlement

The model test results of the current investigation are given in Table (6). The evaluation of ultimate bearing capacity was conducted according to the criteria suggested by [34] which define the ultimate load as the point where the slope of load settlement curve first reaches zero or a steady minimum value. Figures (9) and (10) show model test results. The results showed that at the same loading level the settlement of strip footing on sand-tire chips mixture was about 22% less than in the case of pure sand, and the ultimate bearing capacity of the mixture noticeably increase up to two time its value in the case of pure sand up to percentage 20% tire chips, beyond this value the bearing capacity tend to decrease, an efficient interaction of the tire chip with the soil becomes very difficult and consequently weak nonhomogenous mixture will result.

Table (6): Results of the Model Tests

Material	Tire chip size (mm)		q_{ult} (kPa)	Settlement (mm)
Pure sand	-		122	6.7
Sand-tire chip mixture	(5-9)	10%	129	6.3
		20%	148	5.5
		30%	145	5.8
	(10-20)	10%	124	6.4
		20%	134	5.9
		30%	135	6.1

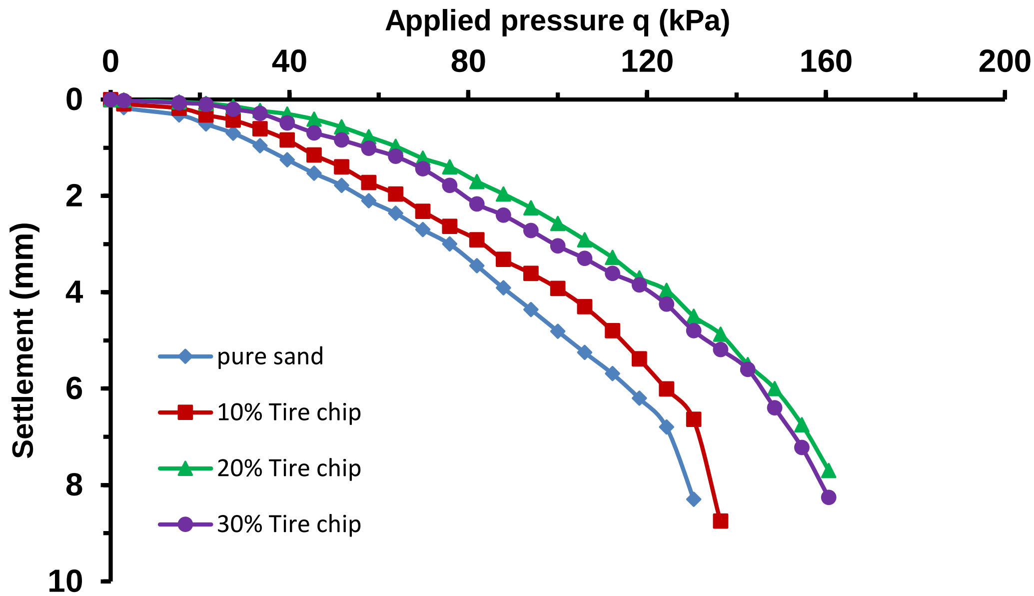

Figure (9): Effect of content of (5-9) mm tire chip on settlement.

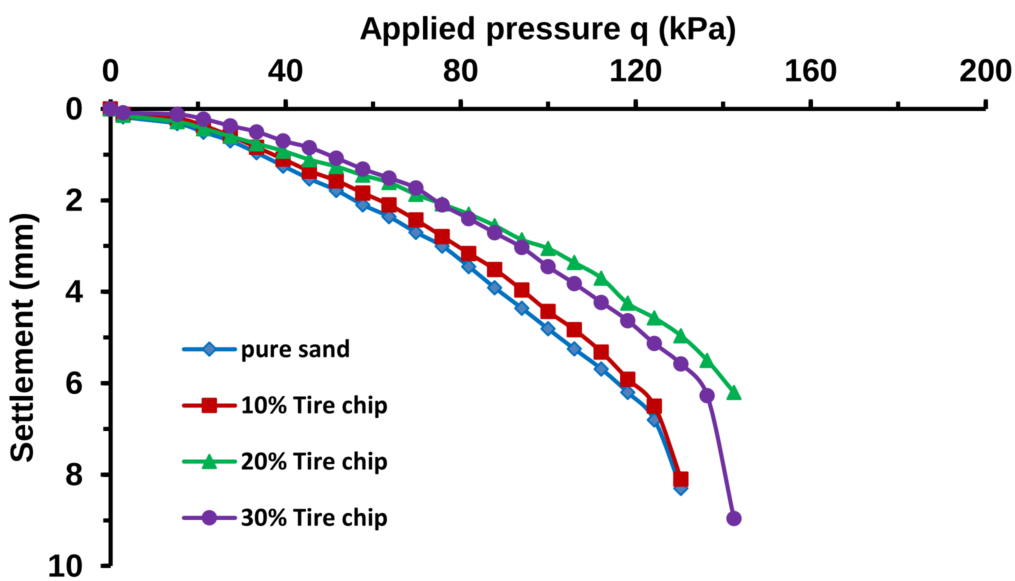

Figure (10): Effect of content of (10-12) mm tire chip on settlement.

Conclusion

Overall results of the work induced in this study support the use of tire chips (the smaller chips than the coarse chips), as environmentally acceptable light weight inclusion in soil improvement application, as following:

1. The CBR results indicate that the increasing of tire chip percentage increased the CBR strength of sand significantly and it's about 29% for size (5-9)mm and 19.5% for size (10-20)mm at the tire chip percentage of 20%.
2. The results of model tests showed improving of bearing capacity and modify the load-settlement behavior of the footing since the using of tire chips reduced settlement about 22% and increased the ultimate bearing capacity of the mixture significantly.

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