Properties of Desert Sands Reinforced with Ground Tire Rubber in Kuwait

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ABSTRACT: The abundance of waste tires in Kuwait created a major problem requiring disposal sites and causing environmental and safety problems especially in the summer months as the temperature often exceeds 50°C. Numerous fires have occurred causing air contamination and health hazards. To find useful uses of ground tire rubber an extensive laboratory testing program was carried out using rubber aggregates produced locally as additive in small quantities up to 20% by weight to the local surface sands of Kuwait. Testing included grain size, unit weight, Modified Proctor compaction, permeability, direct shear, consolidation, and CBR tests. The effect of increased rubber content on the different properties was measured. The results indicate a reduction of the density and CBR, an increase in the permeability and compressibility and no change in the angle of friction ϕ with increasing rubber content. Therefore, the use of rubber additive is beneficial for many practical applications such as light weight fill, as a drainage layer, and on the grounds of sporting facilities, and in embankment construction.

KEYWORDS: Desert sands, Soil properties, Soil tests, Ground tire rubber, Fill, Waste disposal.

1. INTRODUCTION

Millions of waste tires are disposed each year in Kuwait. The shortage of disposal sites and the high temperature in the summer months which exceeds 50°C has created many problems. Numerous fires have occurred causing air contamination, safety and health hazards. In absence of useful uses the Kuwait municipality has given waste tires from dump sites, to foreign companies in return for one dollar a tire. Most recently the largest tire disposal site in Raheyya, Kuwait containing 12 million tires is being cleaned by cutting the tires in pieces and storing it in containers in Al-Salmi border area. Lateron it will be used in several industrial applications.

The above problems has motivated interest in finding useful applications of shredded tires and ground tire rubber as additive to the local sandy soils in various construction applications. Such applications include embankment construction (Bosscher et. al. 1992), hot mix asphalt pavements (Ganiron Jr. 2014), light weight fill, and as a drainage layer in land fill sites (Reddy and Marella 2001) and improving the dynamic properties of sand (Feng and Sutter 2000). Other applications include the upper layer of playgrounds for various sports activities to increase its flexibility and damping capacity.

While most studies used shredded tires to improve certain soil characteristics (Sheikh et al. 2013, Mashiri et al. 2015), very few explored the use of ground tire rubber (GTR) except when used as an additive to the bituminous mixture. Since there is only one source of ground tire rubber (GTR) in Kuwait (Green Rubber Tire Recycling Plant, 2013) which produces rubber particles ranging in size from 1 to 5 mm, it was decided to employ this material in the present research. The plant produces small amounts since the current applications are rather limited to the playgrounds, and playfields for sports activities.

Laboratory testing is often carried out to determine the properties of the local soils with rubber additive (Christ and Park 2010). The properties of the surface sands in Kuwait which consist of poorly graded windblown fine sand with no gravel and very little fines was previously examined in detail (Ismael et al. 1986). To explore the possible uses of GTR in Kuwait, an extensive geotechnical laboratory testing program was carried out using a local surface sand and ground tire rubber (GTR) additive in the amount of 0 to 20% by weight. Testing included basic properties, compaction, direct shear, consolidation and CBR tests. Based on test results several useful applications for GTR are recommended. These would use large quantities of tires in various earth construction applications.

2. THE TESTING PROGRAM

The amount of ground tire rubber additive employed in the testing program was 0, 2.5%, 5%, 10%, and 20% by weight. The following tests were performed:

1. Mechanical analysis to determine the grain size distribution curves according to ASTM D422 standard.
2. Modified Proctor compaction tests, method A, on samples 101.6 mm diameter and 116.4 mm height according to ASTM 1557 standard.
3. Direct shear tests on samples prepared at maximum density and optimum moisture content. The samples were 63 mm diameter and 20 mm thick. Test were carried out according to ASTM D 3080 standard.
4. Falling head permeability tests on samples prepared at maximum dry density and optimum moisture content. The samples were 100 mm diameter, and 130 mm height. Constant head tests could not be carried out since the fine rubber particles blocked the exit connecting to the piezometric tubes.
5. Consolidation tests on samples compacted to the maximum dry density and optimum moisture content according to ASTM D 2435 standard. The samples were 75 mm diameter and 20 mm thick.
6. CBR tests on soaked samples compacted to 95% of the maximum dry density in a 152.4 mm diameter mold according to ASTM D 1883 standard.

3. SAMPLE PREPARATION

Samples for direct shear tests, permeability and consolidation test were prepared in four layers by tamping to reach the required density. The size of the samples is determined by the size of the mold of the standard laboratory test equipment. Since the samples were compacted to the maximum dry density and optimum moisture content, the change of diameter and height between the different tests will have no effect on the soil structure with the density and void ratio being the same.

4. TEST RESULTS

Table 1 shows the technical data for the used GTR which was provided by the Green Rubber Tire Recycling Plant. Figure 1 shows the grain size distribution curves for the clean sand employed in testing and the fine ground rubber aggregate. The rubber aggregate is classified as SP or poorly graded sand, and the clean sand is also classified as SP or poorly graded sand according to the Unified Soil classification System. It is noted from Figure 1 that the sand has no gravel size and the GTR has less than 5% gravel size. This indicate that the gravel size in the samples in the testing program will be regligible and not exceeding 1% of the sample weight if 20% GTR is employed.

Table 1 Technical data from chemical analysis of the used ground rubber tire (GTR)

Tests	Results
Ash content, % wt.	6.3
Acetone extractable, % wt.	1.5
Loss on heating @ 105 deg. C for 2 hrs, % wt.	0.77
Free mineral content, % wt.	0.44
Total organic matter (LOI @ 550 deg. C)	92.8
Iron as Fe_2O_3	0.27

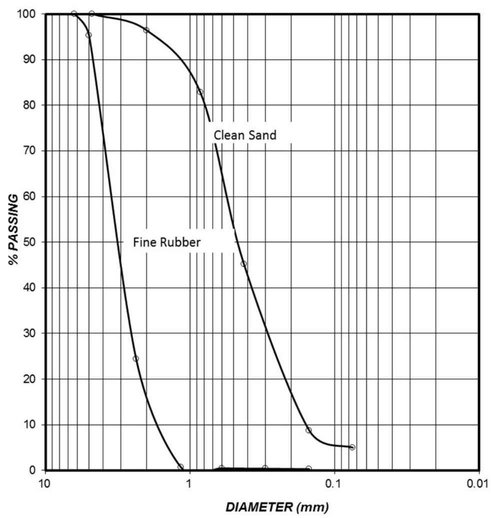

Figure 1 Grain Size Distribution Curves

Figure 2 show the compaction test results. As the percent of rubber increased the maximum dry density and the optimum moisture content decreased. With 20% rubber the maximum density decreased from 1913 kg/m^3 to 1560 kg/m^3 or about 18.5% decrease with a corresponding reduction of the optimum moisture content from 10.7% to 8.5%. This indicate a substantially lighter weight material with the addition of rubber aggregates. Christ and Park (2010) found that the unit weight of the mixture decreased with the addition of rubber to the sand.

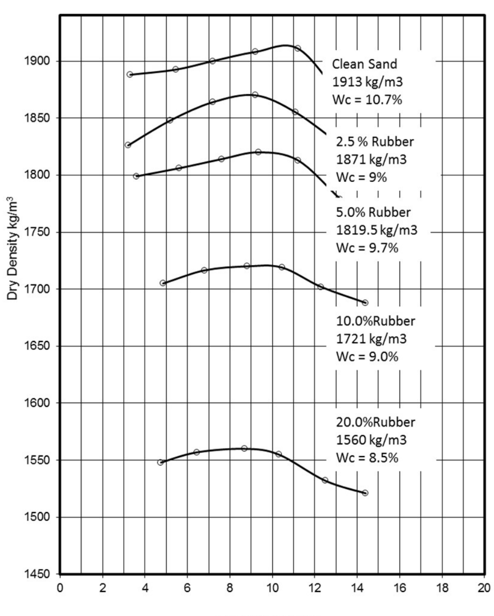

Figure 2 Compaction Test Results

Falling head permeability tests on samples compacted to maximum density and optimum moisture contents showed that the coefficient of permeability k remained relatively unchanged up to 10% rubber content at about 4.5×10^{-4} cm/sec. However with 20% rubber additive the k value increased to 13.6×10^{-4} cm/sec or three times its original value. Figure 3 shows the variation of the coefficient of permeability with the rubber aggregate content. Since the GTR is coarser than the surface sand (Figure 1) it presence will lead to increased permeability. However, small amouts up to 10% had no influence on the results. With further increase in the rubber content, above 20% it is expected the permeability will increase substantially leading to a free draining permeable soils.

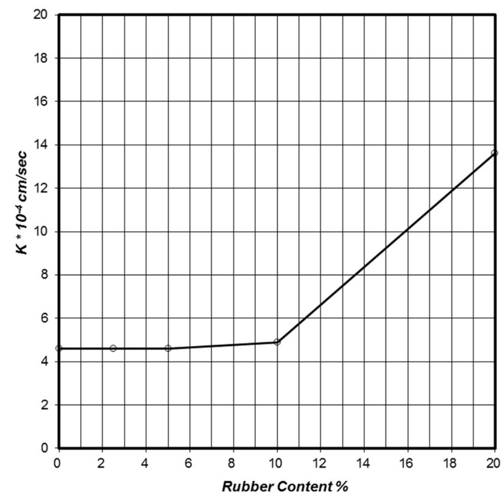

Figure 3 Variation of the coefficient of permeability with rubber content

CBR tests on soaked samples compacted to 95% relative compaction indicated a significant drop in the CBR value with increasing rubber content. Figure 4 show the variation of the CBR with rubber content. Table 2 is a summary of all test results with the numerical values of the measured parameters. As shown the CBR dropped from 22 for clean sand to 3 for sand with 20% rubber additive.

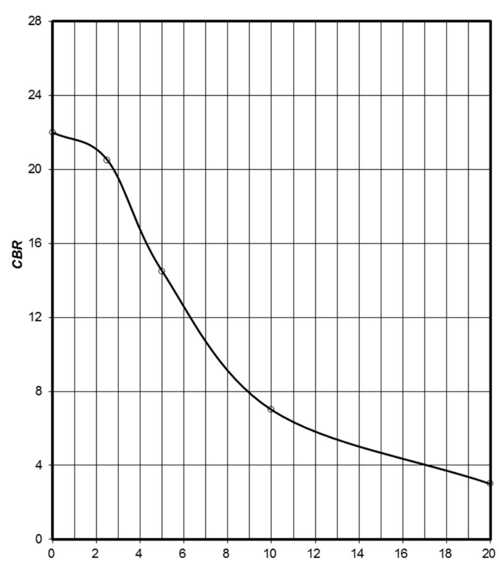

Figure 4 Variation of the CBR with rubber content

Table 2 Summary of test results

	Clean sand	Rubber				
		2.5%	5%	10%	20%	100%
ρ_{dmax} (kg/m^3)	1913	1871	1819.5	1721	1560	
ϕ'°	35	35.3	36	36*	36	27
c (kN/m^2)	13.1	12.8	11.2	17.2*	10.6	10.6
k value (cm/s)	4.59×10^{-4}	4.6×10^{-4}	4.59×10^{-4}	4.9×10^{-4}	13.6×10^{-4}	
ρ_d (kg/m^3)	1817	1777.5	1728.5	1635	1482	
CBR	22	20.5	14.5	7	3	0.15
C_c	0.015	--	--	0.035	0.060	
C_s	0.009	--	--	0.009	0.014	

*Average from two tests
--Not measured

Direct shear tests were performed on samples compacted to maximum density and optimum moisture content with rubber content 0, 2.5%, 5% 10% and 20%. For a rubber content of 10% the test was repeated since the cohesion c obtained was higher than the values for rubber content 5% & 20%. Both tests yielded c value of 19.65, 14.7 kN/m^2 respectively with an average value of 17.2 kN/m^2. A summary of the shear strength parameters c′, ϕ' are given in Table 2. As shown these parameters remained nearly unchanged for the range of rubber content employed herein except for the c' value at 10% rubber which exceeded the average value by about 5 kN/m^2. However, with rubber additive the shear stress vs. shear displacement indicated softer response and increased compressibility. Table 3 and Figure 5 indicate that the shear displacement at maximum shear stress increased by about 80% on average with 20% rubber additive indicating increased compressibility.

Table 3 Shear displacement at maximum shear stress in the direct shear test

% rubber	Normal Stress, σ_n					
	σ_n = 31.5 kPa		σ_n = 63 kPa		σ_n = 125.9 kPa	
	τ_{max} kPa	Δ mm	τ_{max} kPa	Δ mm	τ_{max} kPa	Δ mm
0	35.8	1.83	56	2.088	101.4	2.093
20	34.6	3.284	55.3	3.931	101.9	3.666

Consolidation tests were carried out on samples with rubber content 0, 10% and 20%. The samples were compacted to maximum dry density and optimum moisture content. The void ratio vs. effective pressure e-log curves are shown in Figure 6. The compression index Cc and swell index Cs were determined and their values are given in Table 2. Cc increased from 0.015 for clean sand to 0.06 for sand with 20% rubber. This is a four fold increase in compressibility. The swell index also increased to a lesser degree from 0.0099 to 0.0140; nearly a 40% increase.

A summary of the coefficient of consolidation Cv at different effective pressures is given in Table 4. The values of Cv decreased by about 20% on average with the addition of 20% rubber for the pressure range 50→400 kPa. This indicates that longer time is required to achieve a certain degree of consolidation compared to clean sand possibly due to the increased compressibility. However, at 10% GTR some Cv values increased compared to clean sand. It is obvious that the results vary and depend on the applied pressure and the GTR content.

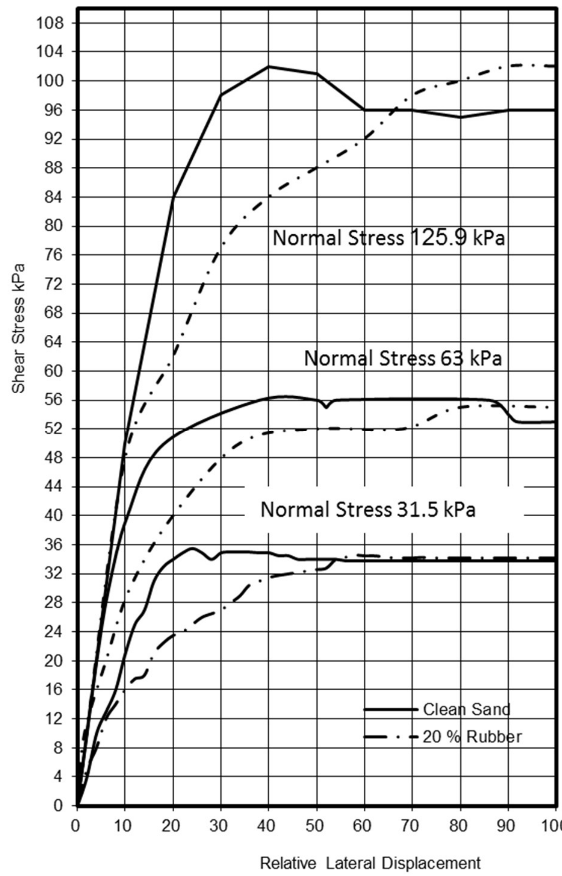

Figure 5 Variation of shear stress with relative lateral displacement for clean sand and for sand with 20% rubber content

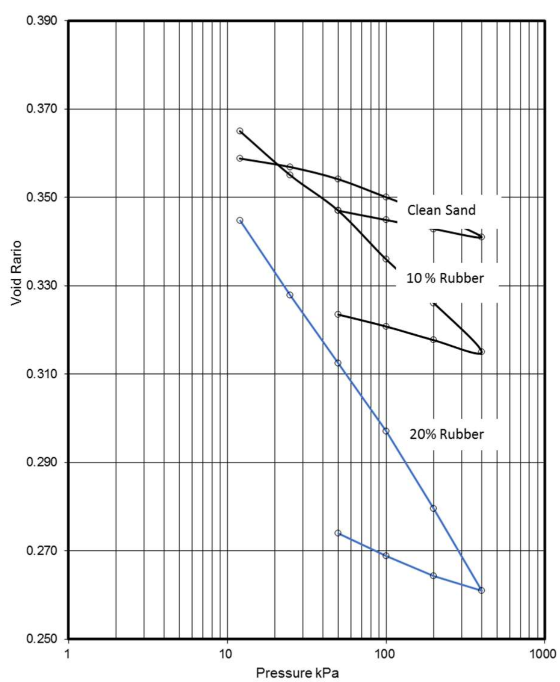

Figure 6 e-log σ plots from consolidation tests

Table 4 Variation of C_v with normal stress for clean sand and sand with rubber aggregates of 10% and 20% from the consolidation tests

Pressure kPa	C_V mm^2/min		
	Clean sand	10% rubber	20% rubber
12	3784.5	4010.7	3948.6
25	3608.1	3822.9	3395.6
50	3891.9	4093.5	3673.6
100	5947.2	3963.2	3244.9
200	3758.4	4199.2	3570.8
400	4068.2	2928.0	3694.5

5. DISCUSSION AND PRACTICAL APPLICATIONS

In view of the compaction test results shown in Figure 2 it is clear that using ground tire rubber additive produces a light weight soil with densities ~20% less than clean sand if 20% rubber additive is employed. This soil can be used as a light weight embankment fill to reduce pressure on the ground particularly on soft clays and loose sands. This is since the applied pressure being equal to γH, where γ is the unit weight of the fill and H the height, will be smaller. It can also be used as fill around foundations and retaining walls. Neglecting the effect of the small cohesion c, the lateral force on these earth structures being equal to ½ $\gamma H^2 K$, where K is the coefficient of lateral earth pressure will be reduced by the same ratio. Thus both the applied vertical pressure and the lateral earth pressure vary linearly with the unit weight of fill. It is also noted that the coefficient of lateral earth pressure will not change as the angle of friction ϕ' remained unchanged.

Light weight fill containing ground tire rubber may be used in low lying areas with soft or weak soil conditions to raise the ground level prior to road construction or prior to placement of culverts and pipelines. Since the applied overburden pressure will be smaller the elastic and the consolidation settlements will decrease.

Considering the results of the permeability tests, it is observed that the coefficient of permeability k increased by 3 times for the soil with 20% rubber additive as shown in Figure 3 and Table 2. Since the value of k did not increase significantly a larger percentage of rubber additive or larger size scrap tire shreds is required to produce a free draining sandy soils. It can be used in practice as a drainage layer in landfill (Reddy and Marella 2001) and in highway construction (Cetin et al. 2006).

Noting the low CBR values obtained (Figure 5 and Table 2), ground tire rubber is not recommended as a stabilizing agent for subgrade soils. However, it can be used as an additive in hot mix asphalt (HMA) pavements to improve pavement performance. Similar findings were reached by Paul Cosentino et al (2014).

The greater compressibility observed from the results of the consolidation tests and the direct shear tests when ground tire rubber is employed can be beneficial in many practical applications including the surface layer of playgrounds, sports fields such as football, basketball, and tennis courts.

It should be emphasized that the above findings are applicable for the fine ground tire rubber 'GTR' employed herein. As previously indicated larger size shredded tires has been employed by several researches (Edil & Bosscher 1994), Foose et al. 1996, Kim and Santamarina 2008, Zornberg et al. 2004, Lee et al. 1999, Rakaraddi et al. 2014, and Meddah et al. 2014 and can have many practical applications. These include embankment and highway construction and ground improvement.

If ground tire rubber (GTR) and shredded tires are used in the above applications large quantities of tires will be required, and they will be transformed into a useful building material thus alleviating the problems associated with disposal sites and environmental impacts.

6. CONCLUSIONS AND RECOMMENDATIONS

The geotechnical properties of desert sands reinforced with ground tire rubber (GTR) in Kuwait was examined by a geotechnical laboratory testing program. Based on test results the following conclusions were reached:

1. Mixing surface sands with ground rubber tire resulted in light weight material with compacted densities ~20% lower than for clean sands for rubber content equal 20%.
2. The coefficient of permeability increased with the addition of rubber by nearly 3 times at a rubber content of 20%.
3. Direct shear tests revealed no change in the shear strength parameters ϕ' within the range rubber content employed herein which was limited to 20% by weight. However, the shear displacement at maximum shear stress increased substantially with the use of rubber additive.
4. The CBR test results indicate a significant reduction of the CBR values from 22 for clean sands to 3 for sand mixed with 20% ground tire rubber.
5. The soil compressibility increased substantially with rubber content as indicated from the consolidation tests. The compression index C_c and the swell index C_s increased by 4 and 1.5 times respectively with a rubber content of 20%.
6. Several practical applications were recommended including light weight backfill, embankment construction, drainage layers, and in the surface layers of sport related play fields, and play grounds.
7. It is recommended to extend the present study to include larger GTR content, and larger size shredded tires and to explore its potential use by laboratory and field testing programs.

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