Laboratory Behavior of Clay-Tire Mixtures

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Abstract: In the present study, a number of undrained triaxial tests were carried out on the specimens made of pure clay and compacted clay-tire chip mixtures. The results of triaxial tests indicated that adding more than about 20-30% tire to the clay doesn’t reduce the shear strength in comparison with the associated values of pure clay. Also, the results showed that at low consolidation stress, maximum excess pore water pressure occurs in the specimens with tire content of about 20%. At high consolidation stress, excess pore pressure within the specimens made of 10% tire-chips is maximum.

Key words: Clay-tire mixtures · Triaxial test · Shear strength · Pore water pressure

INTRODUCTION

A number of waste tires are produced with the development of utilizing various vehicles that enter the environment and causing serious problems. Rubber Manufacturer’s Association [1] estimates that about 300 million tires were generated in the USA in 2005 and the total number of scrap tires consumed in end-use markets reached approximately 260 million tires. It also estimates that about 190 million scrap tires remained in stockpile at the end of 2005 in the USA.

Official Iranian Statistics estimated that about 20 million tires were produced in the country in 2005 [2] and estimated that about 10 million scrap tires were added to the existing stockpile annually in Iran. Due to this effect in the last decade considerable research and development has been carried out for the use of tire crumbs in asphaltic pavement layers in Iran [3]. Therefore, it is essential to find beneficial ways of recycling and/or reusing tires.

According to Humphrey [4], using scrape tires in civil engineering applications are advantageous because of their low density, high durability and high thermal insulation and in many cases least cost compared to other fill materials. These materials are used for reinforcing soft soil in road construction [5, 6], as lightweight fill materials [5, 7-9], as an additive material to asphalt [10, 11], as a source for creating heat [8] and as landfill barrier materials [12-14].

Bosscher et al. [15] reported that an embankment constructed with sand–tire shreds operated satisfactorily even when subjected to heavy loads. They also found that the long-term settlement of such embankment could be alleviated if a soil cap with a thickness of 1 m overlies the sand–shred mixtures. Bosscher et al. [5] performed large-scale models of tire-chip embankments in a confining wooden box at the Univ. of Wisconsin. They also constructed and loaded a test embankment parallel to the access road to a landfill near Madison, Wis. They showed that tire chip–soil mixtures exhibit a significant initial plastic compression under load.

Lee et al. [8] carried out triaxial tests on both pure tire-chips and tire-chips mixed with sand. Youwai and Bergado [16] carried out drained triaxial compression tests on shredded tire-sand mixtures mixed at different ratios. With an increasing proportion of sand in the mix, the strength and unit weight increased and deformation due to isotropic compression decreased. The deformation was significantly reduced when the sand in the mixture was more than 30%.

Previous studies have mainly concentrated on determining engineering properties of pure tire-chips and/or various mixtures of tire-chips with sand as a lightweight fill material for embankment construction because of its high strength and low unit weight.

Recently, several studies have investigated the behavior of clay – tire mixture. Cetin et al. [17] added two types of tire chips to clay. They indicated that the shear strength increases up to 30% for fine and 20% for coarse tire chip mixtures. Cohesion increases as the value of tire-chips increases up to 40% for both fine and coarse
mixtures while the angle of internal friction decreases. After 40%, however, while the cohesion decreases, the angle of internal friction increases. As the percent of tire-chips increases, the fine and coarse tire-chips mixtures under lower normal pressures do not show considerable vertical strains or volume change during shear. However, under higher normal pressures, originally high negative vertical strains for the clayey soil alone decrease considerably for the fine tire-chip mixtures or become slightly above zero or positive for the coarse tire-chips mixtures up to 50%.

They concluded that the dry densities of clay-tire chip mixtures are less than that of pure clayey soil.

Özkul and Baykal [18] used a triaxial testing program to investigate the influence of rubber fiber reinforcement on the shear behavior of low plasticity clay. Standard triaxial compression tests were conducted at effective confining stresses ranging from 50 to 300 kPa. They found that the contribution of rubber fibers to the strength of clay decreases with increasing levels of confinement. A limiting confining pressure exists beyond which the presence of rubber fibers tend to degrade the strength of the clay. For the soil tested this limiting confining stress was between 200 and 300 kPa.

When confinement stresses are below this limiting value and drained conditions prevail, the peak strength of the composite specimens is higher, occurs at greater strains and has higher post peak strength compared to that of clay alone. When subjected to undrained loading, composite specimens again have higher peak strengths but show faster strength development compared to samples of clay alone. In addition, it has been shown that the deformation behavior of the clay is significantly changed.

The previous studies show that the effects of tire-chips content and chips size have not been completely investigated on the behavior of mixtures of clay-tire chips, especially at undrained loading condition. For this purpose, a number of undrained triaxial test are carried out on the specimens made of compacted pure clay and clay-tire chips mixtures. Then, the obtained results are compared with the associated behavior of pure clay and an analysis is performed in terms of tire-chips content and its size.

**Experimental Procedure**

**Materials and Sample Preparation:** A lean clay was used as cohesive material which is introduced with AC symbol in this article. Summary of some specifications of the clay are listed in Table 1.

<table>
<thead>
<tr>
<th>Specification</th>
<th>AC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid limit, LL (%)</td>
<td>33</td>
</tr>
<tr>
<td>Plasticity index, PI (%)</td>
<td>12</td>
</tr>
<tr>
<td>Specific gravity, G_s</td>
<td>2.698</td>
</tr>
<tr>
<td>Soil classification</td>
<td>CL</td>
</tr>
</tbody>
</table>

Table 2: List of specimens with some specifications

<table>
<thead>
<tr>
<th>Name of specimens</th>
<th>Clay (%)</th>
<th>W_u (%)</th>
<th>w_p (%)</th>
<th>( \gamma_{	ext{max}} ) (kN/m^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC100</td>
<td>100</td>
<td>0</td>
<td>19.50</td>
<td>16.35</td>
</tr>
<tr>
<td>R1-AC90</td>
<td>90</td>
<td>10</td>
<td>19.46</td>
<td>14.84</td>
</tr>
<tr>
<td>R1-AC80</td>
<td>80</td>
<td>20</td>
<td>19.00</td>
<td>14.31</td>
</tr>
<tr>
<td>R1-AC70</td>
<td>70</td>
<td>30</td>
<td>18.89</td>
<td>13.59</td>
</tr>
<tr>
<td>R2-AC90</td>
<td>90</td>
<td>10</td>
<td>17.75</td>
<td>15.44</td>
</tr>
<tr>
<td>R2-AC80</td>
<td>80</td>
<td>20</td>
<td>16.10</td>
<td>13.90</td>
</tr>
<tr>
<td>R2-AC70</td>
<td>70</td>
<td>30</td>
<td>15.25</td>
<td>13.63</td>
</tr>
<tr>
<td>R3-AC90</td>
<td>90</td>
<td>10</td>
<td>19.54</td>
<td>15.20</td>
</tr>
<tr>
<td>R3-AC80</td>
<td>80</td>
<td>20</td>
<td>18.00</td>
<td>14.40</td>
</tr>
<tr>
<td>R3-AC70</td>
<td>70</td>
<td>30</td>
<td>16.25</td>
<td>13.80</td>
</tr>
</tbody>
</table>

The tire-chips used in the mixtures sieved and those retained between two frequent sieves selected as tire part of the mixtures. The tire-chips were prepared in three different sizes and added to the pure clays. These materials were called as R1, R2 and R3 with average size of 1.28, 3.56 and 5.53, respectively. Specific gravities of these materials respectively are 0.812, 0.912 and 0.988. The grading curves of tire chips and clayey soil are depicted in Figure 1.

A number of specimens made of pure clay and clay-tire chip mixtures were prepared. Mixed specimens were prepared by dry mixing of clay with tire percentage (w_u) of 10%, 20% and 30% (by weight). Standard Proctor compaction tests were performed on the specimens to obtain maximum dry unit weight (\( \gamma_{	ext{max}} \)) and optimum water content (w_p) [19]. Names of tested specimens as well as some of their specifications are listed in Table 2. In the name of specimens, R1, R2 and R3 shows the tire-chips used in the mixtures and AC stand for the clay matrix. The numbers denote the clay percent in weight; e.g., the specimen made of 80% AC clay and 30% R1 tire-chips was named as R1-AC70.

Soil specimens were compacted into a mold that was suitably sized for triaxial testing, with density of 95% of maximum dry unit weight at 1% wet of their respective optimum values. A special splitting type cylindrical mold of 50 mm diameter and 100 mm height was used.
Testing Procedure: Once the specimens were extruded from the mold they were set up in triaxial cell of apparatus. To saturate the specimens, distilled water was transmitted through them and then incremental backpressure saturation was applied. The final saturation of the samples was estimated from the last B-value of 0.97. The specimens were consolidated under three different effective confining stresses of 100, 200 and 300 kPa. Standard consolidated undrained (CU) triaxial testing procedures were followed [20]. Shearing was applied to the specimens with deformation rates of 0.05 mm/min until reaching up to 18% strain.

Typical Test Results: Typical results of the tests on AC100 and R3-AC70 specimens are presented in Figures 2 and 3. These figures show variations of deviatoric stress (\(\Delta \sigma_t\)) versus axial strain (\(\varepsilon_a\)), excess pore water pressure (\(\Delta u\)) versus \(\varepsilon_a\), and shear stress (\(q\)) versus mean normal effective stress (\(p'\)). In the next sections, the effect of tire content and its grain size on the behavior of soil specimens is investigated.

Analysis of Results
Effect of Tire-chips Content
Stress-strain Behavior: In order to evaluation of the effect of tire content on the behavior of specimens, a comparison of the stress-strain behavior of clay-tire mixtures with different amounts of \(\omega_t\) was compiled. A typical result of these comparisons for R2-AC specimens under \(\dot{\varepsilon}_t=300\) kPa is presented in Figure 4. In general, it can be observed that in low strain levels, the pure clay is stiffer than the clay-tire chip mixtures. In contrast, in high strain levels the trend is different; some mixtures are stiffer than the pure clay and some others are weaker than the pure clays. In general, the effect of tire-chips on the stress-strain curves is not considerable.
Shear Strength: For evaluating the effect of tire content on the shear strength of specimens, the variations of shear strength of specimens are plotted in terms of tire-chips content (Figure 5). As illustrated in this Figure, for consolidation stress of 100 and 200 kPa, the shear strength reduces as the tire content increases (as compared with associated values of pure clay) and it reaches a minimum value in a given tire content, respectively at $e_0$ of 10% and 30%. After this given value of $e_0$, as tire content increases within the mixtures the shear strength increases. For the $p^* = 300$ kPa, the shear strength of R-AC90 specimens are more than that of pure clay. Then with increasing of tire content the values of shear strength reduce.

In addition, to investigate the effect of tire chips on the value of shear strength parameters, variations of internal friction angle ($\phi'$) and cohesion ($c'$) versus tire contents are depicted in Figure 6. It is observed that friction angle is maximum for the specimen of $\omega_0 = 10\%$ and it decreases as the amount of tire-chips increases. The $\phi'$ values of R3-AC80 and R3-AC70 specimens are lower than the associated value of AC100 specimen.

Variation trends of cohesion parameter are strictly in contrast with the trends of $\phi'$. The values of $c'$ are minimum for the mixed specimens with $\omega_0 = 10\%$. Thereafter, adding tire-chips to the clays causes the cohesion values increase.
Fig. 6: Variations of a) friction angle, and b) cohesion, versus tire content

Fig. 7: Secant deformation modulus versus tire chips content for: a) AC, and b) ACB, clay mixtures

Fig. 8: Maximum values of $\Delta u$ versus tire-chips content for $\sigma''$: a) 100 kPa, b) 200 kPa, and c) 300 kPa
Deformability: Secant deformation modulus ($E_{so}$) is an index of specimen deformability. Therefore, variations of $E_{so}$ for the specimens, obtained from stress-strain curves, versus tire-chips content are indicated in Figure 7. In general, it is seen that, irrespective of clay matrix, the values of secant deformation modulus decrease with an increase in the tire-chips content; in other words, the deformability of specimens is increased as $\omega_s$ increases. The rate of reduction with increasing $\omega_s$ is considerable for the higher values of $\sigma'$. 

Excess Pore Water Pressure ($\Delta u$): Maximum values of shear-induced pore water pressure ($\Delta u_{sw}$) versus tire chips content are presented in Figure 8. This figure shows that at low consolidation stress, maximum excess pore water pressure occurs in the specimens with tire content of 20%. At high consolidation stress, excess pore pressure of specimens of AC clay plus 10% tire is maximum.

Stress Path: The comparatively evaluation of stress paths of the triaxial tests indicated that adding of tire-chips to clay changes tendency of specimens during shearing. Specimens made of AC100 clay tend to contract during shearing, while inclusion of tire-chips causes them to exhibit dilative behavior.

SUMMARY AND CONCLUSIONS

In the present study, a number of undrained triaxial tests were carried out on the compacted clay-tire mixtures and the behaviors were compared with those of the pure clay. The results of triaxial tests indicated that adding more than 20-30% tire-chips to the clay don't reduce the shear strength in comparison with the associated values of pure clay. In addition, the values of friction angle and cohesion are dependent on the tire-chips content. Since the cohesion between compacted tire-chips is more than the cohesion between low plastic clay particles, therefore inclusion of tire chips heightens the cohesion values of mixtures.

Also the results showed that maximum excess pore water pressure change due to adding tire-chips, but it is not considerable. Finally, it can be concluded that possible usage of clay-tire mixtures as light construction material exists in the earth fills and other earth structures, without considerable reduction in shear strength. Hereby, it can be managed the waste tire materials and embedded them within the ground.

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Notation

- $E_{so}$ = Secant deformation modulus
- LL = Liquid limit
- PI = Plasticity index
- $p'$ = Mean normal effective stress
- $w$ = Water content
- $w_t$ = Tire content
- $\Delta u$ = Shear-induced excess pore water pressure
- $\Delta u_{sw}$ = Maximum shear-induced excess pore water pressure
- $\gamma_s$ = Dry density
- $\sigma'$ = Effective consolidation pressure
- $\Delta\sigma$ = Deviatoric stress

REFERENCES