Static properties of weak fine-grained soils mixed with recycled crumb rubber tires

Propriétés statiques des sols faibles à grains fins mélangés avec des pneus de caoutchouc recyclés recyclés

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ABSTRACT: As more states opt to ban waste rubber tire from their landfills, there is an increasing demand to find alternative uses to avoid improper disposal, which can lead to breeding grounds for mosquitos carrying dangerous diseases, other health and environmental concerns as well as fire hazards. One possible use for these discarded tires involves mixing crumb rubber, prepared by shredding waste tires, with weak fine-grained soils in order to improve their geotechnical properties. This study examines the potential improvement in the static properties of weak fine-grained soils as a result of the addition of crumb rubber tire. Five different sizes of crumb rubber tires were mixed into five different types of soils in six different proportions and the results were used to examine the improvements on compaction characteristics, coefficient of permeability, compressibility, and shear strength. The results show that the addition of crumb rubber causes an increase in the maximum dry unit weight, the unconfined compressive strength, the coefficient of permeability, and the compression index. It is seen that the friction angle and cohesion intercept increase with the addition of crumb rubber. However, when the percentage of crumb rubber added to the soil is increased, the friction angle and cohesion intercept do not change significantly.

RÉSUMÉ: Comme plus d'États préfèrent interdire les pneus de caoutchouc à leurs sites d'enfouissement, il existe une demande croissante pour trouver d'autres utilisations pour éviter une mauvaise élimination, ce qui peut entraîner des zones de reproduction pour les moustiques transportant des maladies dangereuses, d'autres problèmes de santé et d'environnement ainsi que des risques d'incendie. Une utilisation possible pour ces pneus éliminés implique le mélange de caoutchouc, préparé par déchiquetage de pneus usés, avec des sols fragiles et faibles afin d'améliorer leurs propriétés géotechniques. Cette étude examine l'amélioration potentielle des propriétés statiques des sols faibles à grain fin en raison de l'ajout de pneus caoutchouteux en poudre. Cinq différentes tailles de pneus de caoutchouc en poudre ont été mélangées en cinq types différents de sols dans six proportions différentes et les résultats ont été utilisés pour examiner les améliorations sur les caractéristiques de compactage, le coefficient de perméabilité, la compressibilité et la résistance au cisaillement. Les résultats montrent que l'ajout de caoutchouc à la miombre entraîne une augmentation du poids unitaire maximum de l'unité sèche, de la résistance à la compression non confinée, du coefficient de perméabilité et de l'indice de compression. On voit que l'angle de frottement et l'interception de cohésion augmentent avec l'ajout de caoutchouc de miettes. Cependant, lorsque le pourcentage de caoutchouc en poudre ajoutée au sol augmente, l'angle de frottement et l'interception de cohésion ne changent pas de manière significative.

KEYWORDS: Weak clays; crumb rubber tires; compaction behavior; shear strength; permeability; friction angle; compressibility

1 INTRODUCTION

In the United States, over 300 million rubber tires are scrapped annually (ReRubber, LLC 2013). As a result, a growing environmental, health and safety concern is the safe and proper disposal of these tires, which are not biodegradable. In landfills, these tires occupy large amounts of scarce space due to their shape and bulkiness resulting in 38 states banning whole tires and 12 states banning all tires from their landfills (RMA 2014, Masad et al. 1996). The bans on tires from landfills has triggered their improper disposal, which poses several major health and environmental hazards. For example, the accumulation of water in and around the tires can serve as breeding grounds for mosquitos, which can carry deadly diseases such as dengue fever, encephalitis, West Nile virus, and hanta virus, among others. Tires contain several very combustible compounds such as carbon, oil, rubber and sulfur (FEMA 1998) and while tires are not easily ignitable, once ignition takes place, tire fires are difficult to extinguish (FEMA 1998) resulting in the release of toxic smoke, oils and fumes that can cause respiratory and health problems in the local people not to mention the loss of property and possible deaths. Some tire fire incidents include the October 1996 Falling Springs Road Fire in Garfield County, Washington, the February 1997 fire in Washington, Pennsylvania and the August 1997 Fire at the Gila River Indian Reservation in Arizona (FEMA 1998). In 1990, in an attempt to reduce the improper disposal of scrapped tires, Congress passed the Recycling Incentives as a means to encourage individuals to find alternative uses for scrapped tires. Since then, a variety of alternate uses have emerged including in playgrounds and football fields as well as with paving materials (Al-Tabbaa and Aravinthan 1998). In geotechnical engineering, shredded scrap tires have been successfully implemented in landfill applications, as drainage layers in roads, for compressible inclusions behind abutments, as lightweight fill for embankments, retaining walls and bridge abutments, among others (Jesionek et al. 1998, Humphrey et al. 2000).

One area where the use of discarded rubber tires may be advantageous that has not been extensively studied is the use of rubber tires for soil stabilization (Al-Tabba and Aravinthan 1998). Previous research by Tiwari et al. (2012), Kim and Santamarina (2008), and Foose et al. (1996) showed improved properties of sandy materials via reinforcement with shredded rubber tires. They have shown that such reinforcement can lead to better compaction characteristics, higher shear strengths, lower unit weights, and better drainage characteristics without substantially impacting the compressibility. However, works related to the impact of shredded rubber tires on the properties of weak clays is limited.

Two sizes of tire chips were mixed with a low plasticity clayey soil in five different proportions of 10, 20, 30, 40 and 50% by volume in the study conducted by Cetin et al. (2006). The tire chips were classified as fine tire chips if they were finer than the No. 40 sieve or coarse tire chips if they ranged in size between the No. 4 and No. 10 sieves. Cetin et al. (2006) concluded that an increase in the normal stress or a decrease in the percenrage of tire chips will result in a decrease in the coefficient of permeability. They also found that an increase in the percentage of tire chips resulted in a decrease in the friction angle and an increase in the cohesion intercept if the mixtures contained less than 40% tire chips. On the other hand, for the mixtures containing more than 40% tire chips, the opposite trend was observed in that the cohesion intercept would decrease and the friction angle would increase. Li and Zhang (2010) examined the effect of the addition of granulated rubber to a loess soil to find similar results for the friction angle and cohesion intercepts of the mixtures. They also showed that the maximum dry density decreases, while the optimum moisture content increases as a result of the addition of tire chips into the clayey soils tested.

In this study, five different types of fine-grained soils were mixed with five different sizes of crumb rubber at six different proportions. The resulting mixtures were used to determine the vartion in the compaction characteristics, unconfined compressive strengths, coefficients of permeability, drained shear strengths, and compressibility as a result of the addition of crumb rubber.

2 MATERIALS AND METHODS

2 .1 *Materials*

In this study, five different types of fine-grained soils were prepared from dry, commercially available minerals. Specifically, the soils tested included (i) kaolinite, (ii) granular kaolin, (iii) montmorillonite, (iv) a mixture of 50% montmorillonite with 50% granular kaolin, and (v) a mixture of 50% montmorillonite with 50% quartz. The Atterberg limits and USCS classifications for these soils are presented in Table 1. The procedures outlined in ASTM D 4318-10 were used to determine the Atterberg limits.

Table 1. Atterberg limits of soils used in this study.

Soil	LL	PI	USCS Classification
Kaolinite	73	28	MH
Granular kaolin	45	16	ML
Montmorillonite	486	431	CH
50% montmorillonite with 50% granular kaolin	255	194	CH
50% montmorillonite with 50% quartz	209	180	CH

The five different sizes of crumb rubber used in this study were supplied by ReRubber, LLC. The sizes of the crumb rubber are (1) between 1.40 mm to 3.35 mm (6-14 mesh crumb rubber), (2) between 0.5 mm to 1.68 mm (10-30 mesh crumb rubber), (3) 0.297 mm to 0.5 mm (30-50 mesh crumb rubber), (4) 0.178 mm to 0.297 mm (50-80 mesh crumb rubber), and (5) 0.075 mm to 0.178 mm (80-200 mesh crumb rubber). The crumb rubber was added to the soils at six different proportions of 0% (no crumb rubber), 2%, 4%, 6%, 8%, and 10% by dry weight. The mixtures were used to conduct all of tests using the procedures outlined below.

2 .2 *Methodology*

The maximum dry density and optimum moisture content were determined using the Harvard miniature compaction device in molds with a diameter of 35.6 mm and a height of 71 mm. The compaction was conducted in five layers with 25 blows per layer applying a total energy of approximately 6400 kN-m/m^3. The samples from the device were directly used to determine the unconfined compressive strength. Previous work by Biabani (2012) has shown that the results from the Harvard miniature compaction device match with the results obtained from the standard Proctor test.

ASTM D 2166-13 was followed to determine the unconfined compressive strength. The samples from the Harvard miniature compaction test were sheared at a rate of 0.5% per hour until the peak strength is achieved. If the peak strength is not obtained within 15% axial strain, the test was terminated at 15% axial strain.

The coefficient of permeability was determined using a falling head permeameter. To conduct this test, mixtures of the soils with the appropriate size and percentage of crumb rubber were mixed with de-ionized water corresponding to the liquid limit of the parent soil. Once the sample was placed in the permeameter and reasonable flow through the sample was achieved, the change in the water level in the burette was recorded for a total of 4 hours in 1 hour increments to calculate the coefficient of permeability.

Consolidation tests were conducted on mixtures of kaolinite and crumb rubber. The test was conducted in accordance to ASTM D2435/D2435M-11 under the consolidation pressures of approximately 24 kPa, 48 kPa, 96 kPa, 192 kPa, 383 kPa, 766 kPa, and 1532 kPa. At the end of the primary consolidation at the maximum vertical pressure of 1532 kPa, the vertical pressure was reduced and the sample was allowed to swell under the pressures of 766 kPa, 383 kPa, 192 kPa, 96 kPa, 48 kPa and 24 kPa. The results were used to determine the compression and swelling indices of kaolinite mixed with crumb rubber.

Mixtures of kaolinite and crumb rubber were tested in a direct shear device using the procedure outlined in ASTM D3080/D3080M -11. The samples were consolidated to normal stresses of 50, 100, 150 and 200 kPa. The consolidation process was monitored using the real-time logarithm of time versus vertical deformation curves. At the end of the primary consolidation, the samples were sheared at a rate calculated using the procedure in ASTM D3080 under the assumption that the sample would reach the peak shear strength at the horizontal displacement of 1 mm. The friction angle and cohesion intercept were determined for the mixtures of the kaolinite and crumb rubber.

3 RESULTS AND DISCUSSION

The variation in the maximum dry unit weight with the percentage and size of crumb rubber is shown in Figure 1. The compaction curves resulting from the tests conducted could not be presented here due to limited space. These figures may be found in Obaid (2016) and Koirala (2015). The results in Figure 1 show that the maximum dry unit weight appears to increase with the addition of up to 2% to 4% crumb rubber of any size. The addition of crumb rubber in quantities greater than 4% results in a decrease in the maximum dry unit weight, but the maximum dry unit weight remains greater than that of the parent soil. Similar figures, prepared for the remaining four soils tested, showed the same behavior. In mixtures with kaolinite or granular kaolin as the parent soil, the maximum dry density would decrease as the size of the crumb rubber used increased. However, in mixtures with montmorillonite, the opposite behavior, that is a reduction in the maximum dry unit weight with an increase in the size of the crumb rubber, was observed. Inconsistent trends were observed in the effect of the size of crumb rubber on the maximum dry unit weight in the mixtures with 50% montmorillonite. It was noted that there was little variation in the maximum dry unit weight when 10% crumb rubber of any size was added to any of the parent soils tested.

The variation in the unconfined compressive strength with the percentage and size of crumb rubber is shown in Figure 2. The stress-strain curves resulting from the unconfined compressive strength tests are presented in Obaid (2016) and Koirala (2015). The maximum unconfined compressive strength is found to occur when between 2% and 4% crumb rubber is added to the parent soil regardless of the size of the crumb rubber used. The addition of more than 4% crumb rubber of any size into the parent soil would cause a reduction in the maximum unconfined compressive strength. However, the maximum unconfined compressive strengths of the mixtures with crumb rubber was always greater than the unconfined compressive strengths of the parent soils. The effect of the size of the crumb rubber on the maximum unconfined compressive strength was similar to that stated for the maximum dry unit weight. That is, the maximum unconfined compressive strength increased with an increase in the size of the crumb rubber used in mixtures with kaolinite and granular kaolin as the parent soils, but decreased with an increase in size in mixtures with montmorillonite as the parent soil. Trends for the mixtures with 50% montmorillonite in the parent soil were inconclusive and require further research.

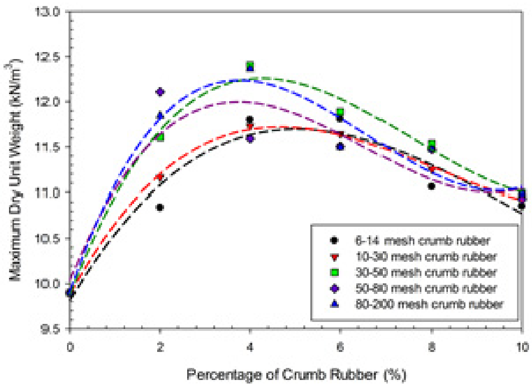

Figure 1. Variation in maximum dry unit weight with size and percentage of crumb rubber when kaolinite is the parent soil.

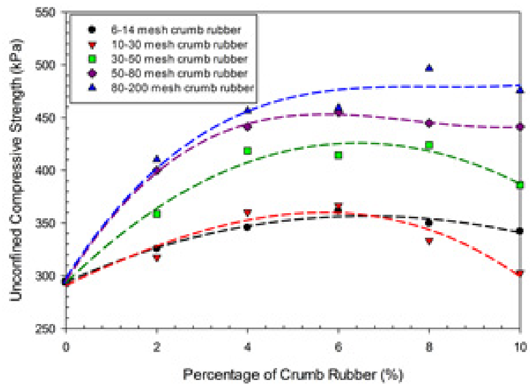

Figure 2. Variation in maximum unconfined compressive strength with size and percentage of crumb rubber when kaolinite is the parent soil.

Shown in Figure 3 is the variation in the coefficient of permeability with the percentage and size of the crumb rubber. The results showed that the addition of crumb rubber resulted in an increase in the coefficient of permeability. This increase was most substantial when 2% crumb rubber was added to the parent soil. The addition of more than 2% crumb rubber did not result in any substantial additional changes in the coefficient of permeability. When the parent soil was kaolinite, the increase was within one order of magnitude. However, when the parent soil was montmorillonite, the coefficient of permeability was seen to increase by two orders of magnitude.

The variation in the compression and swelling indices with the percentage of crumb rubber are shown in Figures 4 and 5, respectively for kaolinite mixed with 80-200 mesh crumb rubber. The compression index increases when up to 4% crumb rubber is added to the soil, but with the addition of more than 4% crumb rubber, the compression index decreases. On the other hand, the swelling index decreases with the addition of the crumb rubber to kaolinite.

The failure envelopes obtained for the sample mixed with different proportions of 6-14 mesh crumb rubber are shown in Figure 6. The variation in the friction angle and the cohesion intercept with the percentage of crumb rubber is shown in Figures 7 and 8, respectively. It is seen that the friction angle and cohesion intercept increase with the addition of crumb rubber. However, as the percentage of crumb rubber added to the soil is increased, the friction angle and cohesion intercept do not change significantly.

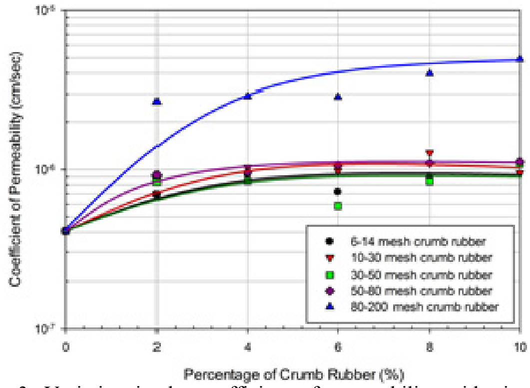

Figure 3. Variation in the coefficient of permeability with size and percentage of crumb rubber when kaolinite was the parent soil.

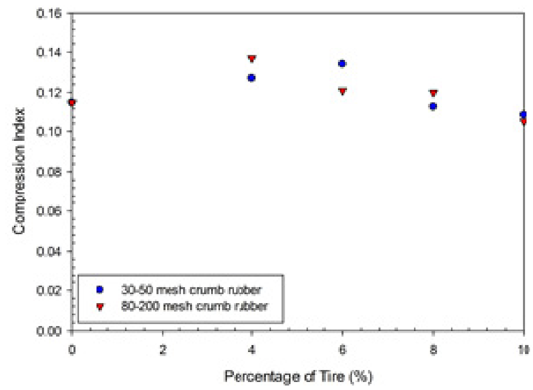

Figure 4. Variation in the compression index with the percentage and size of tire when kaolinite is the parent soil.

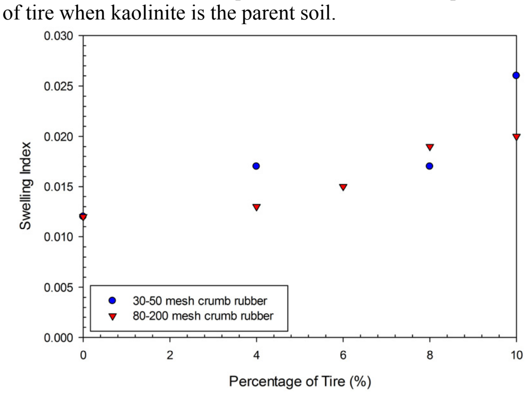

Figure 5. Variation in the swelling index with the percentage and size of tire when kaolinite is the parent soil.]

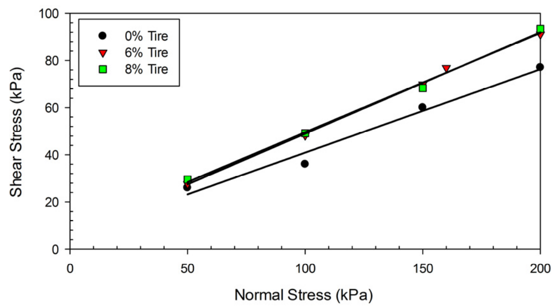

Figure 6. Failure envelopes for mixtures of kaolinite with 6-14 mesh crumb rubber.

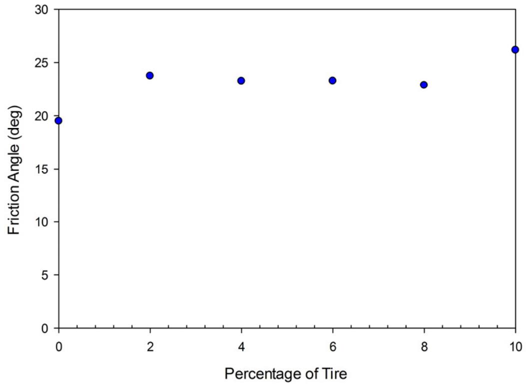

Figure 7. Variation in friction angle with percentage of crumb rubber.

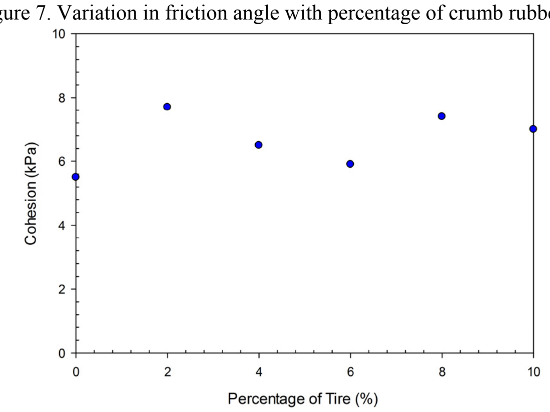

Figure 8. Variation in cohesion intercept with percentage of crumb rubber.

4 CONCLUSIONS

Five different types of fine-grained soils were mixed with 5 different sizes of crumb rubber in 6 proportions. The mixtures were used to determine the changes in the compaction characteristics, unconfined compression strengths, coefficients of permeability, shear strength and compressibility as a result of the addition of crumb rubber. The maximum dry unit weight was found to increase with the addition of crumb rubber with the maximum increase occuring when 2% to 4% of crumb rubber of any size was added. The unconfined compressive strengths followed in a similar pattern. The greatest increase in the unconfined compressive strength occured when between 2% and 4% of crumb rubber of any size was added to the parent soils. The coefficients of permeability were found to increase by approximately one order of magnitude when crumb rubber was added to kaolinite and by approximately two orders of magnitude when crumb rubber was added to montmorillonite. Results from the consolidation tests indicated that the addition of crumb rubber to the soils resulted in an increase in the compression index when less than 4% crumb rubber was added. On the other hand, when more than 4% crumb rubber was added to the soils, an increase in the proportion of crumb rubber presented caused a decrease in the compression index. Increase in both the cohesion intercept and the friction angle was observed when crumb rubber was added to the soil. However, the increase in the proportion of the crumb rubber in the mixtures of clays with crumb rubber had little influences on the values of the cohesion intercepts and friction angles.

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6 REFERENCES

Al-Tabbaa A. and Aravinthan T. 1998. Natural clay-shredded tire mixtures as landfill barrier materials. *Waste Management* 18, 9-16.

ASTM D2435/D2435M. 2011. Standard test methods for one-dimensional consolidation properties of soils using incremental loading. *ASTM International*.

ASTM D3080/D3080M. 2011. Standard test method for direct shear test of soils under consolidated drained conditions. *ASTM International*.

Biabani, M. 2012. Compaction Characteristics of Different Clay Minerals in Standard Proctor and Harvard Miniature Compaction Test, MS Project, Civil & Env. Engineering Department, California State University, Fullerton.

Cetin H., Fener M., and Gunaydin O. 2006. Geotechnical properties of tire-cohesive clayey soil mixtures as a fill material. *Engineering Geology* 88, 110-120.

FEMA. 1998. Special report: scrap and shredded tire fires. U.*S. Fire Administration Federal Emergency Management Agency, USFA-TR-093*.

Foose G.J., Benson C.H., and Bosscher P.J. 1996. Sand reinforced with shredded waste tires. *Journal of Geotechnical Engineering* 122(9), 760-767.

Humphrey D.N., Whetten N., Weaver J., and Recker K. 2000. Tire shreds as lightweight fills for construction on weak marine clay. *Proceedings of the International Symposium on Coastal Engineering in Practice* 611-616.

Jesionek K.S., Humphrey D.N., and Dunn, R.J. 1998. Overview of shredded tire applications in landfills. *Proceedings of the Tire Industry Conference*.

Kim H.H. and Santamarina J.C. 2008. Sand-rubber mixtures (larger rubber chips). *Canadian Geotechnical Journal* 45, 1457-1466.

Koirala J. 2015. Influence of size and quantity of shredded rubber tires in modifying the geotechnical properties of weak clays," *Masters Thesis*, *California State University, Fullerton.*

Li Z.H. and Zhang H.Y. 2010. "Shear strength of granulated rubber and loess mixtures as lightweight geomaterials. *Proceedings of the 2010 International Conference on E-Product, E-Service and E-Entertainment* 1-4.

Masad E., Taha R., Ho. C. Papaginnaki, T. 1996. Engineering properties of tire/aoil mixtures as a lightweight fill. *Geotechnical Testing Journal* 19, 297-304.

Obaid Z.T.A. 2016. "Improving weak clay properties with shredded rubber tires," *Masters Thesis California State University, Fullerton*.

ReRubber, LLC 2013. Rubber technology reinvented. ReRubber.com, 10 July 2013.

Rubber Manufacturers Association (RMA). 2014. 2013 U.S. scrap tire management summary," <http://www.rma.org/download/scrap-tires/market-reports/US_STMarket2013.pdf>.

Tiwari B., Ajmera B., Moubayed S., Lemmon A., and Styler K. 2012. Soil modification with shredded rubber tires. *Geotechnical Special Publication* 211, 2414-2423.