*Environmental Engineering and Management Journal* February 2019, Vol.18, No. 2, 491-498
http://www.eemj.icpm.tuiasi.ro/; http://www.eemj.eu

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# CHARACTERISTICS OF SOILS IMPROVED WITH POLYETHYLENE TEREPHTHALATE WASTES

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**Abstract**

In this study we investigated the possibilities of using recyclable fine and coarse grain waste obtained by grinding Polyethylene Terephthalate (PET) containers, as light filling materials for different applications (clay dams, highway embankments, and backfills behind retaining structures. Various geotechnical tests were performed on clayey soil and soil-PET mixtures using recycled fine and coarse granules of Polyethylene Terephthalate bottles. The results indicated that the use of the recycled polymer mixed with clayey soils as a filling material is favorable for soil properties. The compaction test results indicate that the optimum dry densities of PET-soil mixtures are less than the optimum dry density of typical soils including the clayey soil used in this study (varying between 13.83 $kN/m^3$ and 12.55 $kN/m^3$). P-wave velocities values were correlated for PET mixtures. The results indicate that data concerning the dependence of P-wave velocity values and PET mixtures percentage can be correlated with a coefficient of determination between $R^2$=0.93 to $R^2$=0.73. Finally, the results show a good potential for using the PET waste as lightweight fill material.

*Keywords:* embankment, lightweight fill, Polyethylene Terephthalate bottles, recycling, soil improvement

*Received: July, 2015; Revised final: January, 2016; Accepted: March, 2016; Published in final edited form: February, 2019*

## 1. Introduction

Technological developments increased along with the amount and diversity of solid waste and this is one of the most important environmental problems. For scientific innovation, and higher living standards, the quest of better materials has become necessary. Polyethylene terephthalate (PET) is one of these materials (Dumitrescu et al., 2011; Erdogan et al., 2015; Nogueda, 2013). PET currently is one of the most used polymeric raw material for food and beverage packaging, because of its safety, durability, recyclability (Carneado et al., 2015; La Mantia et al., 2012; Pillai et al., 2014). In the packaging history, PET bottle packaging has got the astounding development and cannot be compared with other packing materials (Dasgupta and Khurana, 2008; Li et al., 2014). PET consumption (about 15 million tonnes) accounted for 8% of the world plastic production (Bartl, 2014; Shen et al., 2010). About 3.5 million tonnes of PET are used in the manufacture of various packaging types, especially bottles and jars (Reis and Carreiro, 2012). According to a study from Smithers Pira (2012), the global PET consumption is around 19.1 million tonnes by 2017 (Brooks, 2013). This increase is especially due to the massive consumption of packaged beverages in PET bottles. Thus recycling and reusing of these products is one of the popular research areas (Gao et al., 2013).

PET is seen as a noxious material due to its substantial fraction by volume in the waste stream and its high resistance to the atmospheric and biological agents (Benosman et al., 2017; Reis et al., 2011). However, plastic wastes do not create difficulties in

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landfill operations and also do not contribute to the toxicity of leachate from the landfills (Siddique et al., 2008), but they are not iodegradable. Lately, there have been many experimental researches on the reinforcement of soils with synthetic fiber materials (Akbulut et al., 2007; Cetin et al., 2006; Chaduvula et al., 2014; Kalkan, 2013; Kaniraj and Havanagi, 2001; Park and Tan, 2005; Pierce and Blackwell, 2003; Prabakar and Sridhar, 2002; Santoni et al., 2001; Tang et al., 2007; Tang et al., 2010; Vasiliev et al., 2015; Wu et al., 2014; Zhang et al., 2015).

Previous investigations indicate that strength properties of fiber-reinforced soils consisting of randomly distributed fibers are a function of fiber content and fiber–surface friction along with the soil and fiber strength characteristics (Okonta, 2018; Kalkan, 2013). In addition to soil studies, in recent years, a lot of experimental studies were carried out on using waste PET bottles as aggregate in cement-based composites (Akcaozoglu and Atis, 2011; Akcaozoglu et al., 2010; Albano et al., 2009; Corinaldesi et al., 2015; Choi et al., 2009; Frigione, 2010; Koide et al., 2002; Saikia, 2014). In this study, soil improvement was attempted by using such waste products as additives into clays in controlled proportions (15%, 30%, 45%, and 60%). Various geotechnical tests were applied on the samples acquired from filled soils to evaluate whether those can be used as lightweight materials.

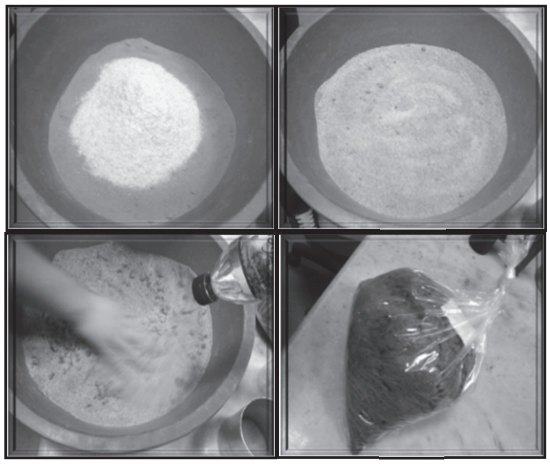
## 2. Experimental studies

Samples were prepared by mixing a high plasticity clayey silt (MH type) soil with 15, 30, 45 and 60% volumes of coarse and fine grained PET aggregates. Particle sizes of fine and coarse grained PET aggregates were used in the range of 0-5 mm and 1-2 mm, respectively. To investigate the geotechnical properties effects and resembling fine and coarse grained soil's behaviors on the cohesive clayey silt soils of fine and coarse aggregates of PET bottles, Adana textile manufacturing plant waste PET bottles aggregates were used.

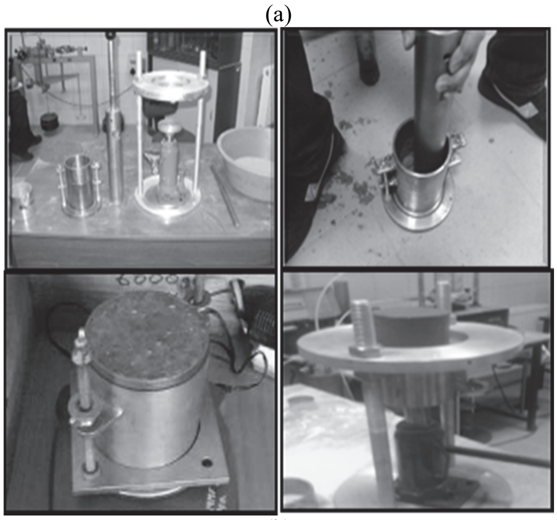
Following the American Society of Testing Materials procedures (ASTM) D 422-63 (2003), Grain size analysis were performed and American Society of Testing Materials Atterberg limits tests were performed in order to classify the clayey silt soils according to the Unified Soil Classification System (USCS). After the classification, the compaction, ultrasonic, uniaxial compressive strength (UCS), and shear box tests were carried, respectively.

### *2.1. Compaction test*

To compare the fine and coarse PET aggregates mixture's optimum moisture content ($w_{opt}$) at the clayey silt soil's maximum dry unit weight ($\gamma_{dry}$), ASTM D 698-00 (2003) and standard proctor (compaction) tests were performed (Figs. 1a-1b).



(a)





(b)

**Fig. 1.** Mixture preparation (a), compaction test apparatus and testing (b) stages

### *2.3. Uniaxial Copressive Strength (UCS) test*

The uniaxial compressive strength (UCS) tests were made on compacted samples prepared at optimum moisture content ($W_{opt}$) and the maximum dry unit weight ($\gamma_{max}$) (ISRM, 2007). The testing procedure of these compacted soils has been applied by two hundred tonnes. The stress rate was applied within the limit of 0.5 MPa/s (Fig. 3).

### *2.4. Shear box test*

To determine shear strength characteristics of clayey silt soil and mixtures under the exposed different normal pressures (27.24 kPa, 55.49 kPa and 81.72 kPa), nine sets of consolidated-undrained (CU) shear box tests were carried out with reference to ASTM D 3080-98 (2003). Pure water was used for saturation of the samples. After waiting 24 hours, the samples have been consolidated. Following the consolidation procedure, the shearing operation was carried out at speed of 1 mm/min under the specified normal pressure.

Drained tests were excepted for "1 mm/minute" faster shear rate of none or minimal drainage. To provide the fine and coarse grained PET aggregates mixture's failure envelope shapes, smaller additional normal pressures were applied. For the first set, pure clayey silty soil samples (100% soil) were used. For second, third, fourth and fifth sets, 15%, 30%, 45%, 60% volumes of fine grained PET aggregate mixture samples were used, respectively. For sixth, seventh, eighth, and nineth sets, 15%, 30%, 45%, 60% volumes of coarse grained PET aggregate mixture samples were used, respectively).

## 3. Results and discussion

### *3.1. Index property analysis*

The soil indices and grain size distribution of the clayey silt soil are given in Table 1. According to the USCS, the clayey soil classifies as a MH soil type, with high plasticity silt. XRD analysis results showed that mineral paragenesis was detected in samples. Generally, it contained Kaolin mineral, Opal-CT, and Feldspat. However, small amounts of Alunut, and Smectite minerals were detected. It was considered that the detected alunitization with effective solfator phase occurred by the effect of dominant hydrothermal alteration. The peak of Kaolin mineral was detected at 7.40 A°, 4.42 A°, and 3.55 A°. The peak of Opal-CT mineral was detected at 4.01 A°, and 2.84 A°. The peak of Feldspat mineral was detected at 4.15, 3.72 and 3.18 A°. Smectite, and Alunite were detected at 14.52 A°; 2.96 and 2.30 A°, respectively (Fig. 4) Particle size distribution of experimental PET aggregates, which has got specific weight of 1.27 is demonstrated in Fig. 5.

The UCINET 6.0 software used to calculate the network's closeness centrality refers to how close one is to the center of the network, and the number of links required to reach critical others in the network. The indices of closeness centralities are classified into 4 types according to the values of out-closeness and in-closeness centrality of actors in the actor-network.

The actors with relatively high out-closeness centrality (>0.937) and high in-closeness centrality (>0.944) determine the FAs in the network translation process (Table 2). FAs are selected from each of the four dimensions of rural society, rural agriculture, leisure experience, and ecological environment.

They are Traditional food, Activity Participation, Leisure Services, and Protective Measures respectively. These four FAs play an important role in translation for the construction of the actor-network, which concentrate on aspects of tourism activity and the dimension of agro-ecological environment. This also means that these FAs are able to take credit for the successes achieved within the rural actor-network, as outside actors are able to bypass its control and influence the rural actor-network directly.

As shown in Table 2, rural tourism actor-network in-centralization and network out-centralization both stand at 13%, indicating that the actor-network resources used in the sample are unlikely to be controlled or dominated by any individual actor and the relationships between the actors are dispersed and scattered. It also indicates that the FAs in the actor-network are highly unlikely to be replaced by other actors with the same status and thus play an equal role in tourism development.

**Fig. 2.** Ultrasonic test of compacted samples

**Fig. 3.** Uniaxial copressive strength

**Table 1.** Some properties of soil

| *Silt (%)* | *Clay (%)* | *Liquid limit (%)* | *Plastic limit (%)* | *Plasticity index (%)* | *Specific gravity* | *Soil type (USCS)* | *Description* |
|---|---|---|---|---|---|---|---|
| 58 | 42 | 53 | 30 | 23 | 2.69 | MH | Clayey silt |

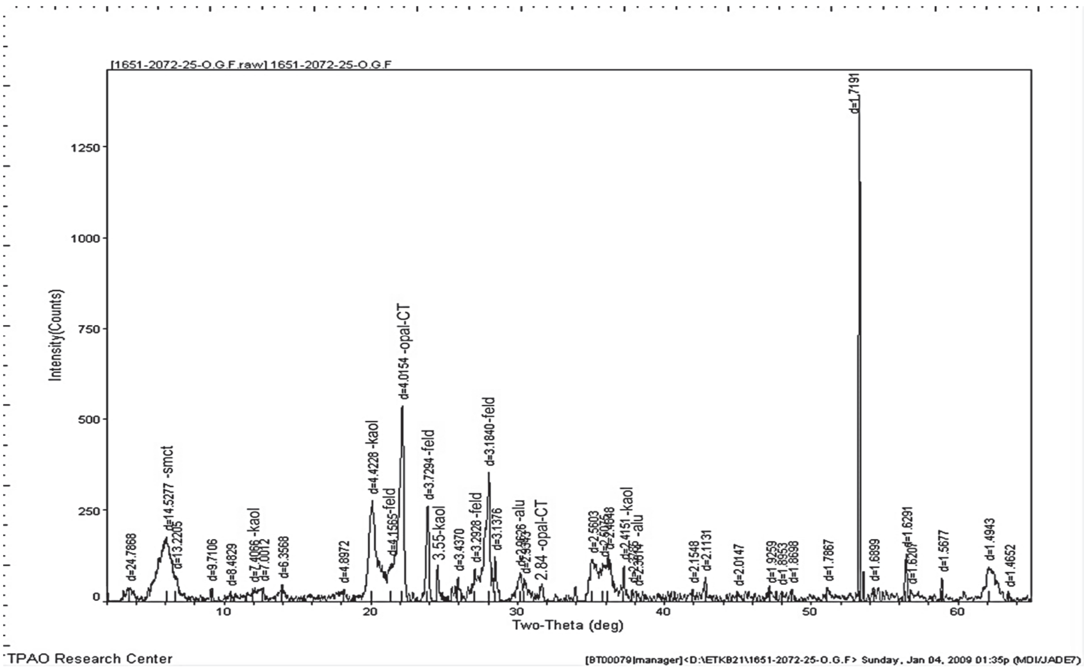



**Fig. 4.** XRD analysis results

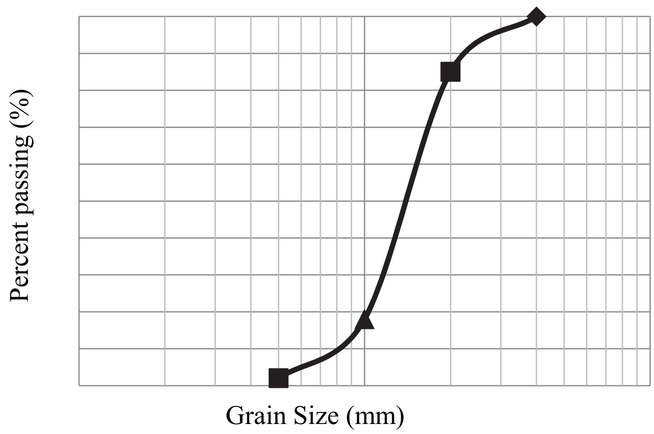



**Fig. 5.** Particle size distribution curve for PET aggregates

*3.2. Compaction test*

Compaction tests were made using lower density landfill materials, which are lightweight PET aggregates mixing with the clayey silt soil to compare both fine (0.5-1 mm) and coarse (1-2 mm) PET aggregate mixtures. The maximum dry unit weights, and optimum moisture contents are measured, respectively, 13.48 kN/m$^3$ and 27% for the pure clayey silt soil; 13.36 kN/m$^3$ and 24% for the 85% clayey silt soil and 15% fine PET aggregates mixture; 12.96 kN/m$^3$ and 23% for the 70 % clayey silt soil and 30% fine PET aggregates mixture; 12.76 kN/m$^3$ and 23% for the 55% clayey silt soil and 45% fine PET aggregates mixture; 12.60 kN/m$^3$ and 22 % for the 40 % clayey silt soil and 60 % fine PET aggregates mixture (Fig. 6a).

The maximum dry unit weights and optimum moisture contents are measured, respectively, resulting: 13.15 kN/m$^3$ and 29% for the 85% clayey silt soil and 15% coarse PET aggregates mixture; 13.04 kN/m$^3$ and 28 % for the 70 % clayey silt soil and 30 % coarse PET aggregates mixture; 12.80 kN/m$^3$ and 27 % for the 55 % clayey silt soil and 45 % coarse PET aggregates mixture; 12.40 kN/m$^3$ and 26 % for the 40 % clayey silt soil and 60 % fine PET aggregates mixture (Fig. 6b). The dry unit weights for both fine and coarse PET aggregate mixtures decrease as the PET aggregates percent increase. For example when fine PET aggregates were mixed with pure clayey silt soil, maximum dry unit weight decreased from 13.53 $kN/m^3$ to 12.75 $kN/m^3$. When coarse PET aggregates were mixed with the soil samples, maximum dry unit weight decreased from 13.53 $kN/m^3$ to 12.46 $kN/m^3$.

### *3.3. Ultrasonic tests*

P-wave velocities were measured for the fine and coarse PET aggregate mixture samples which have prepared at maximum dry unit weight, and optimum moisture content**.** The P-wave velocities obtained for the PET mixtures were found lower than the pure clayey silt soil. For clayey silt soil P-wave velocities was obtained 626 m/s. For 15 %, 30 %, 45, and 60% coarse PET aggregate mixing ratios, P-wave velocities were obtained as 517, 383, 412, and 400 m/s, respectively. For 15 %, 30 %, 45, and 60% fine PET aggregate mixing ratios, P-wave velocities were obtained 594, 476, 471, and 410 m/s, respectively (Figs. 7a-7b).

### *3.4. UCS test*

The uniaxial compressive strength (UCS) experiments were made on pure clayey silt soil, and fine and coarse PET aggregate mixture samples, which were prepared at optimum moisture content ($w_{opt}$) and the maximum dry unit weight ($\gamma_{max}$). The soil strength obtained from PET mixture was found greater than the pure clayey silt soil. (Figs. 7c-7d). For the 15 %, 30 %, 45, and 60% coarse PET aggregate mix ratios, shear strengths were obtained as 2122, 2548, 2317, and 2531 kPa, respectively. For 15 %, 30 %, 45, and 60% fine PET aggregate mix ratios, strengths were obtained 2572, 2024, 2840, and 2269 kPa, respectively.

### *3.5. Shear box test*

The shear stress-normal stress graphics (failure envelopes) were plotted which were used to find cohesion (c) and internal friction angle values ϕ) for the pure clayey soil, pure PET aggregates (both fine and coarse) and the samples with varying mix ratios. Tests were performed under various normal pressures (27.24 kPa, 55.49 kPa and 81.72 kPa) (Figs. 8a-8b). Internal friction angle values (ϕ) were obtained approximately $22^0$ for pure clayey, fine and coarse PET aggregate mixture.

Cohesion values (c) were obtained 8 kPa, 12 kPa, 9 kPa, 16 kPa, and 17 kPa for pure clayey soil, %15, %30, %45, and %60 for the fine PET aggregate mixtures, respectively. Internal friction angle values (ϕ) were obtained 8 kPa, 12 kPa, 16 kPa, 13 kPa, and 28 kPa for pure clayey, 15 %, 30 %, 45 %, and 60 % coarse PET aggregate mixture, respectively.

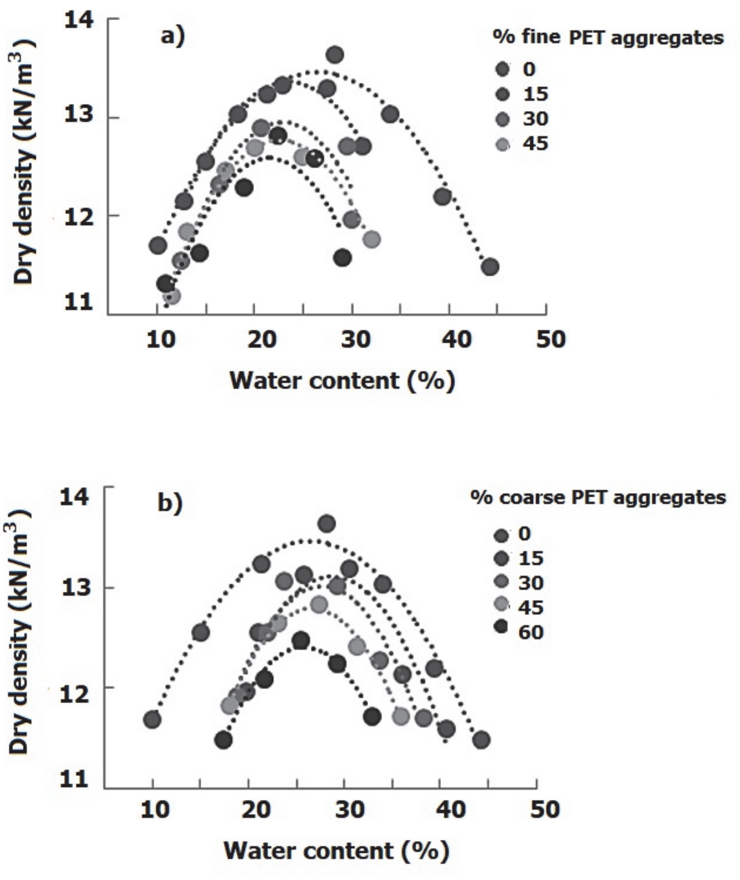



**Fig. 6.** Comparison compaction curve's of obtained clayey silt and fine (a)-coarse (b) PET mixtures

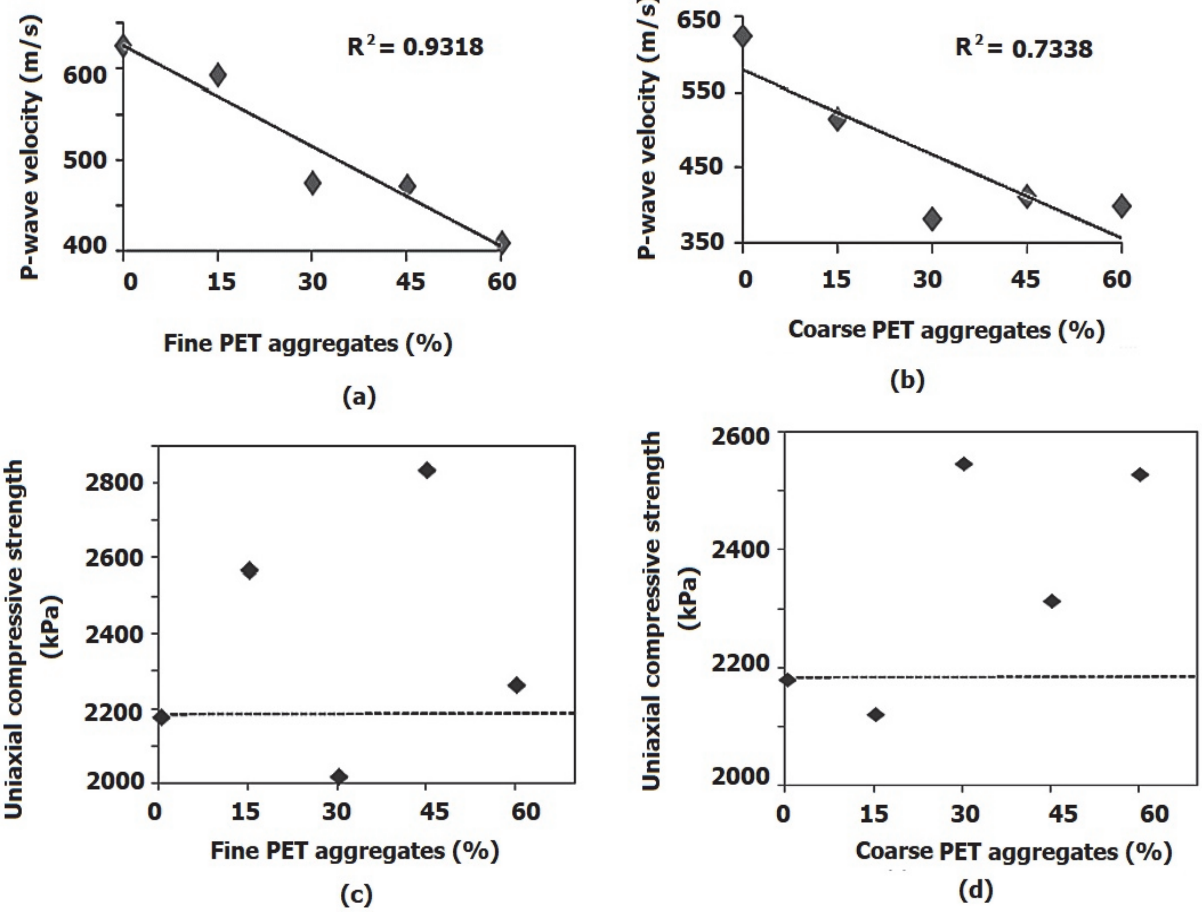
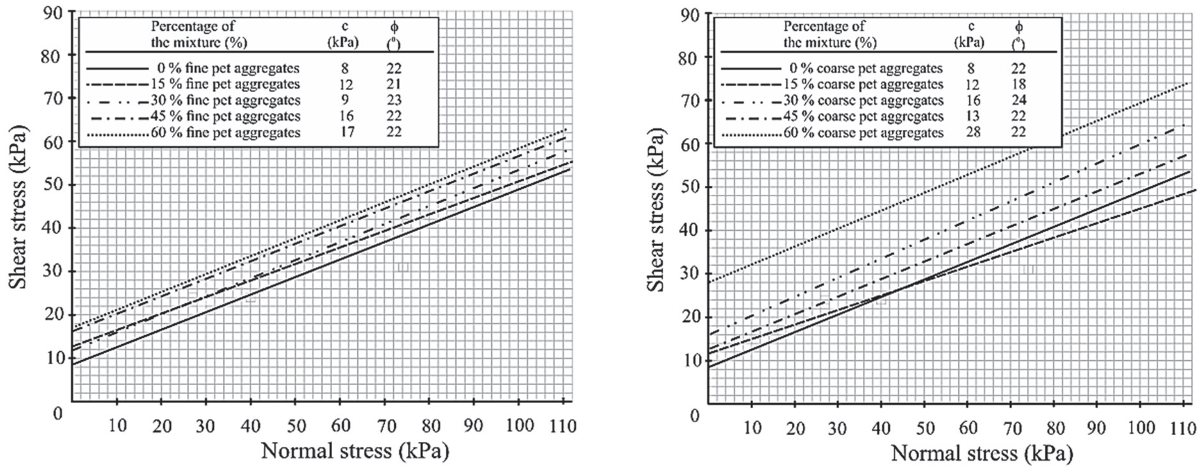



**Fig. 7.** P-wave velocity measurements (a-b) and Uniaxial compressive strengths (c-d) obtained with fine and coarse PET aggregate mixtures




(a) (b)

**Fig. 8.** Failure envelopes of fine and coarse PET aggregates mixed and pure soils

## 4. Conclusions

Recycled Polyethylene Terephthalate grains were tested as filling material for-soils. To generate this material, low specific weight PET plastic (1.27 g/cm$^3$) was mixed with soil of 2.69 g/cm$^3$ specific weight. After the compaction tests, the maximum dry unit weight, and optimum moisture content of pure soil were found 13.53 kN/m$^3$, and 26%, respectively. The lower moisture content, and the lower dry density coarse and fine PET tests were performed for both waste-soil mixtures and for PET. The opposite decreasing relation was found between P-wave velocity measurements and mixing ratios of PET aggregates (for fine PET aggregate mixtures, $R^2$= 0.93; for coarse PET aggregate mixtures, $R^2$ =0.73).

In order to determine the shear strength characteristic of the light filling material, uniaxial compression tests were carried out. The uniaxial strength of fine PET waste-soil mixture was measured as 2181 kPa, excepting the result of 30% PET waste - soil ratio. However, the strength of coarse PET waste-soil mixture was measured as 2840 kPa, except 15% PET waste-soil ratio. Shear tests conducted to examine the strength of light filling materials showed that angles of the internal friction remained approximately constant ($22^0$), although the cohesion values increased with increasing PET aggregate ratios in the mixture except for obtained 30 % fine PET waste ratio, and 45% coarse pet waste ratio. The reason of decline is being able to reflect as corresponding pet aggregates on cutting surface.

As an environmental approach, based on these results, the problem of ultimate strength PET waste aggregates as light filling material was found to be a proper solution. It was determined that PET waste mixing ratios can be used up to 45%. Higher PET waste mixing ratios will generate problems on the filled soil. In future studies, after the strength test of improved soil examples is carried out, the image analysis of thin sections shall be performed. This analysis will provide important contributions for uncovering relationship between the PET waste and soil on failure surfaces.

**Acknowledgements**

The authors are grateful to Nigde University Research Fund (FEB 2009/23) for the financial support. We would also like to thank for contributions of Dr. Mustafa FENER and Dr. Semiha AKCAOZOGLU at the project of Research Fund (FEB 2009/23).

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