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APPLICATIONS OF PERMEABILITY, OEDOMETER AND DIRECT SHEAR TESTS TO THE SAND MIXED WITH WASTE TIRE CRUMB

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Abstract. The amount of the used waste rubbers in the world has been increasing every year, and their utilization, become a major environmental problem worldwide. The present experimental work has been performed to investigate the influence of rubber inclusion on the behavior of a sand. Geotechnical properties of the sand, and sand with tire crumb at various ratios mixtures (0, 2.5, 7.5, and 15%) were investigated through a series of mechanical tests, which are sieving, permeability, direct shear and consolidation. From the results of conducted tests, it is revealed that the addition of tire crumb grains increased both the permeability and the compressional characteristics of the sand. Besides, in this work, intergranular void ratio (e_s) was employed as an alternative parameter to express the compressive response of sand-tire crumb mixtures. It is seen that intergranular void ratio concept is a good indicator for understanding the behavior of sands with waste tire crumb.

Key words: Sand, tire crumb, permeability, oedometer, direct shear, intergranular void ratio.

INTRODUCTION

The disposal of scrap tires has become a major environmental problem all over the world. Each year, millions of waste tires are disposed in large piles across the countryside or dumped in landfills in huge volumes. These tire stocks not only generate environmental pollution but might also pose fire and health hazards. Therefore, some of the America's states have prohibited the disposal of waste tires in the field [Masad et al. 1996]. As rainwater tends to gather in stockpiled tires, it may become a breeding place for mosquitoes, which can carry dangerous diseases including encephalitis and malaria.

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Waste granular rubber, are usually produced in every society and utilized in some engineering implementation to reduce the potential impact on the environment. According to Humphrey [2000], the use of tire crumb in geotechnical engineering applications is advisable, since it has a low density, high durability, high thermal insulation and what is more in many cases, it occurred to be cost effective when compared to other fill materials.

There are some previous studies that have determined engineering properties of pure tire chips and its various mixtures with sandy soils as a light fill material [Wu et al. 1997, Lee et al. 1999, Yang et al. 2002, Youwai and Bergado 2003]. They decided that rubber chips and its mixtures with sand can be applied as a possible fill material in bridge abutments, highway embankments and also as backfills in retaining structures. Large amounts of rubber mixtures can be consumed especially in highway embankments. The behavior of a saturated embankment is mainly affected by the hydraulic characteristics of the used material [Cedergren 1989]. The increment of excess pore water pressures while loading of fill might be prevented by the use of a permeable material. It will also improve the structure stability by providing a drainage path for underlying low permeable soils and that give a great possibility of rubber waste usage. Recently, many experimental researches on the soil reinforcement have been made, including the usage of natural and synthetic fiber materials [Yetimoglu and Salbas 2003].

The objective of the present study is to examine the permeability, compressional characteristics and shear strength behavior of a pure sand and sand mixed with three different percentages of crumb, which are 2.5, 7.5 and 15% by dry weight. For that reason, permeability, oedometer and direct shear tests have been carried out.

MATERIALS AND METHODS

Sample preparation

The grain size distribution curves of sand and tire crumbs are given in Figure 1. Soil contains rounded, river washed grains with coefficient of uniformity c_u = 3.48 and coefficient of curvature c_c = 0.55. Grain sizes range between 0.075 mm (No. 200 sieve) and 4.00 mm (No. 5 sieve). Rubber particles range between 0.60 mm and 4.00 mm, with more rectangular shape. Crumb has a size distribution a little more course than sand. Samples were prepared by mixing sand with the tire crumb at dry case.

Four different mixtures were prepared, containing respectively 0, 2.5, 7.5 and 15% of tire crumb. The sand was obtained from Narli river in southern-central Turkey, and the waste material was possessed from a tire manufacturing company in Adana, Turkey. When the cars tire gets more used, it is cheaper to trim off the old tread and recover it, than to buy a brand new one. The tire is trimmed off to 200 mm and less by a sharp rotating disc, later those strips are ground into a crumb rubber [Pierce and Blackwell 2003]. Tire crumb size used in this studies range between 0.3 mm (No. 50 sieve) and 4,00 mm (No. 5 sieve). The required amount of sand and waste tire crumb were blended together at dry condition. Firstly sand was washed and dried in an oven at approximately 105°C. Effects of tire crumb on the geotechnical properties of the sand were investigated through a series of soil mechanics tests. All the testing samples were prepared at relative density of 35%.

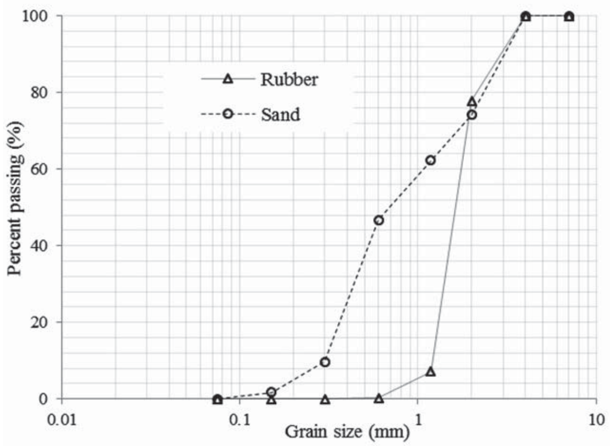

Fig. 1. Particle size distribution curves for the sandy soil and rubber chips

Permeability testing

The behavior of embankment or retaining structure fillings under saturated conditions is generally influenced by drainage capacity of the filling material used [Cedergren 1989]. Therefore, according to ASTM D2334, series of constant head tests were performed. Four samples at a specified tire crumb content were conducted in a cylindrical permeability cell, with a 8 cm diameter and 22 cm height. All the specimens were made fully saturated before testing.

Consolidation test

During the research, values of intergranular void ratio (e_s) and vertical displacement were determined from oedometer tests in accordance with ASTM 2435-96. The incremental loading was to apply daily increments of vertical load to a submerged container in a rigid ring, with draining permitted through porous stones at the bottom and top. Oedometer samples were tested in 5 cm diameter rings. Loadings were initiated from 1 kg (5 kPa), and were doubled each day, that is the ratio of load increment to existing load is usually 1. In introduction of void ratio definition, a term "volume of voids" describes the space in the soil, which is not occupied by mineral grains. In sand or its mixture with different elements, the volume of void can be represented by two ways; voids due to skeleton particles (in this study sand grains) and voids due to different elements (tire crumb in this case) [Monkul and Ozden 2005].

According to Monkul and Ozden (2006) intergranular void ratio (e_s) can be estimated as the ratio of volume of the intergranular voids to the volume of granular solids:

$$e_s = \frac{(V_v + V_r)}{V_s} \tag{1}$$

where: V_v, V_r, V_s are the volume of voids, rubber, sand and $V_v + V_r$ represents the volume of intergranular void space.

Direct shear test

In order to determine the shear strength parameters of the samples, a series of shear box tests was carried out in accordance with ASTM D 3080. For these tests, the samples were placed in the standard shear box apparatus with 60 mm in width and length and 27 mm in height at the relative density of 35%.

RESULTS AND DISCUSSIONS

Permeability

Permeability, which is the capacity of a soil to conduct liquid or gas, affects leachate flow and landfill gas migration). The increment of excess pore water pressures while loading of fill might be prevented by the usage of a well-drained material. It will also improve the structure stability by providing a drainage path for underlying low permeable soils.

The permeability tests were conducted on the clean sands and its three different mixtures with tire crumbs. All samples were made fully saturated from the bottom up. The permeability values range from 0.0326 cm·s^{-1} to 0.1244 cm·s^{-1} for that type of soil. As the effect of the tire crumbs inclusion, stable permeability increase was observed as shown in Figure 2. For the clean sand and its mixture with 15% tire chips a permeability value has increased almost four times. It indicates a possible use of that waste material. Results show that the mixtures can be used where high permeability and low density (or loading) are needed in fills on weak foundation material such as alluvium. They might be used where drainage is needed to prevent the development of pore pressures during loading of fills under saturated conditions.

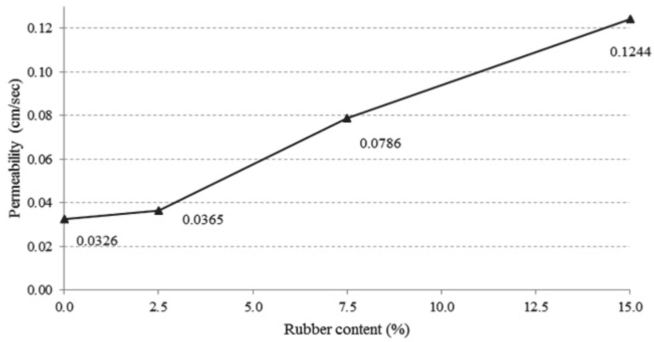

Fig. 2. Changes of the permeability values as the content of tire crumb increases

In the literature, when tire crumbs mixed with clean uniform sand or fine glacial till an increase in permeability was found [Ahmed and Lovell 1993; Edil and Bosscher, 1994]. Furthermore and Humphrey [2000] observed that values of permeability for tire crump were greater than those of most granular aggregate. Hence, it makes rubber useful in drainage layers in landfills.

Consolidation

Consolidation might be most significant property of the soil when it is subjected to high compressive stresses. The usage of tire crumb and its soil mixtures increases specimen compression when the stress level increases [Humphrey et al. 1993]. In the literature, compression of tire crumb-sand mixtures was observed to increase significantly, when tire crumb content was greater than 30% by weight of sand [Edil et al. 1990]. The influence of either tire crumb or sand grains on the periphrastic behavior of the sample, vary during the one dimensional compression. This intersperse the impact expressed by the intergranular void ratio concept.

Intergranular void ratio values were determined using equation (2), which was established on the basis of equation (1) [Monkul 2005]:

$$e_s = \frac{e + \dfrac{G \cdot RC}{G_r \cdot 100}}{\dfrac{G}{G_s} \cdot \left(1 - \dfrac{RC}{100}\right)} \tag{2}$$

where: G_r and G_s represent the specific gravity of rubber and sand grains, respectively, G is the value of specific gravity for the soil itself and RC indicates the amount of rubber composition.

In the intergranular void ratio concept, it is adopted that the tire crumb grains do not actively contribute to the force resistance, they may support it marginally only. The coarser sand grains are the major force transfer means [Thevanayagam and Mohan 1998]. The variation of intergranular and regular void ratios with tire crumb content under different oedometer stresses is shown in Figure 3. When tire crumb content in the specimen increases, the void ratio is observed to reach higher values as well, it is even more significant considering the intergranular void ratio. Sand samples with various tire crumb content were compressed at five different effective stresses reaching from 50 to 800 kPa.

Compression test data converted according to the intergranular void ratio concept (Fig. 3b) allows presenting clearer and more understandable results. The inclusion of tire crumb grains to sand results in the occurrence of more elastic behavior of the specimen. As can be observed displacement reaches greater values, when tire crump content increases for the same stress applied to the sample. This phenomenon is also noticed in unloading process in Figure 4. when the rebound of soil mixture extents while tire crumb ratio increases. For ratio 0% it is equal to 0.09 mm, when for ratio of 15% it reaches 0.545 mm, which is 6 times more.

The maximum void ratio of the clean sand was determined as 0.6272 and it describes the loosest state of the sample. Hence, when the value of intergranular void ratio (e_s) becomes equal to this value (e_{max}), we can assume that the sand grains start to touch each other, be in contact. The amount of tire crumb content, at which the contact taking place is named “transition rubber content” RC_t. Intergranular void ratio values at different stresses applied with various tire crumb content are presented in Figure 5. From the graph, transition tire crumb content can be estimated by intersecting e_{max} dashed line with the curves. Results are given in Table 1.

a

b

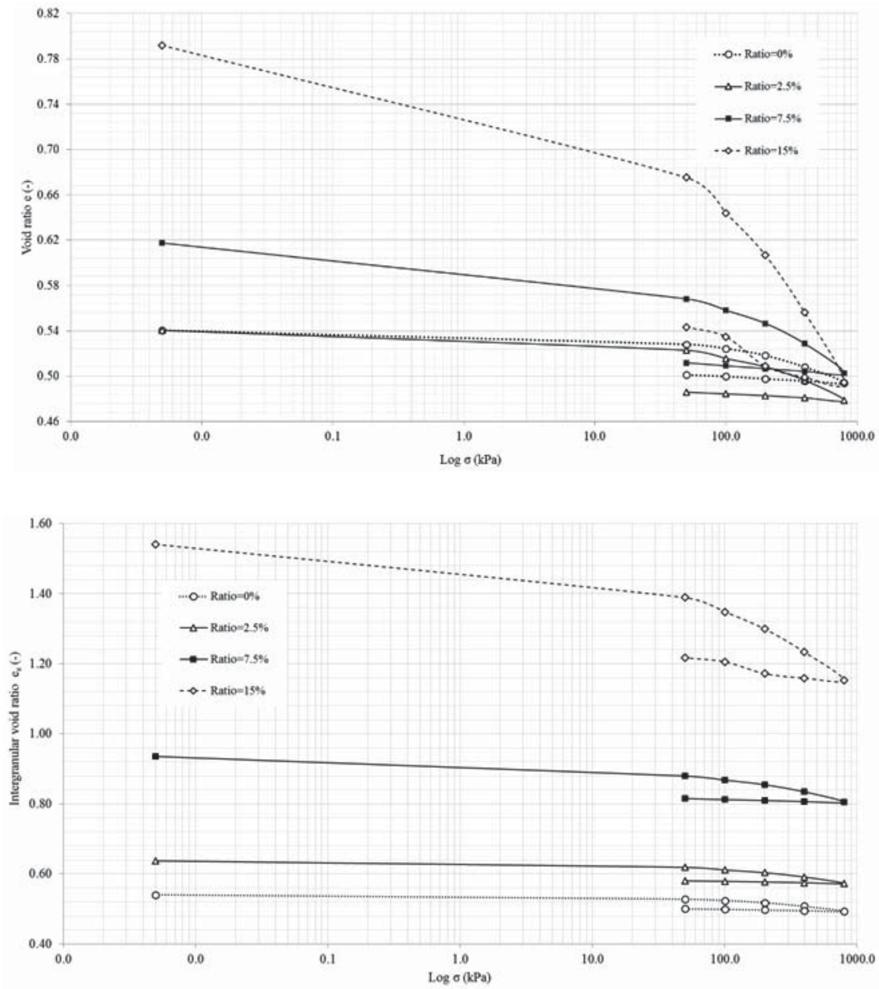

Fig. 3. Variation of a) global and b) intergranular void ratio with rubber content under different oedometer stresses

Table 1. Transition rubber content under different oedometer stresses

Effective stress σ′ [kPa]	*RCt* [%]
0	2.30
50	2.68
100	2.84
200	3.02
400	3.30
800	3.73

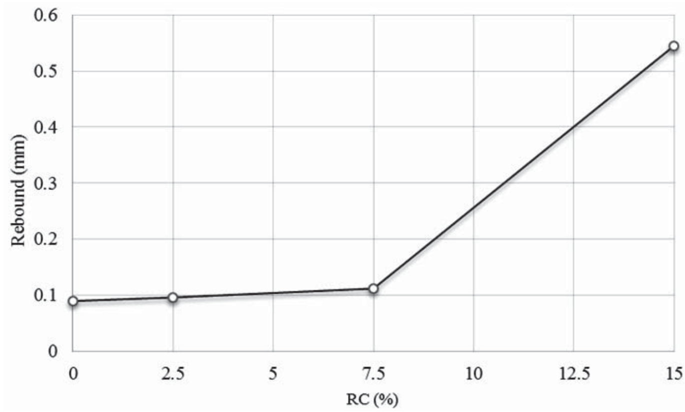

Fig. 4. Rebound of the specimen while unloading process

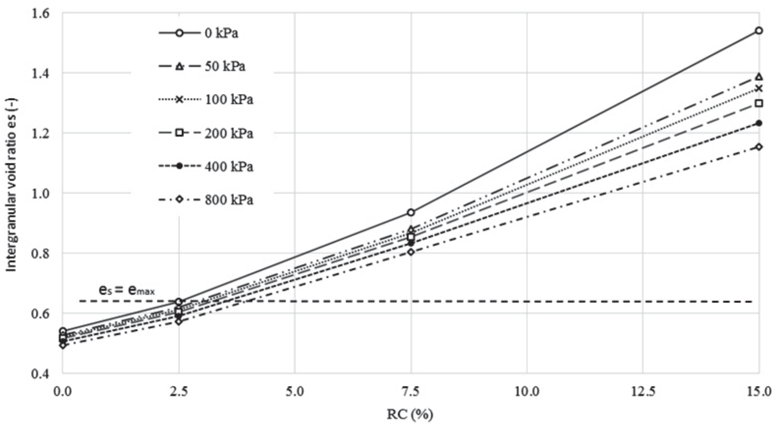

Fig. 5. Variations of intergranular void ratio with tire crump under different effective stresses

The transition tire crumb content increases with an increase in effective stress applied, for mixtures used in the test RC_t values range from 2.3 to 3.7%. At initial conditions volume of all the samples was found to be same, therefore when tire crumb content increases, the amount of sand grains in the mixture decreases, so grains are placed in a looser state. That means more energy, stress is required to reorganize and form the contact between the grains.

For the samples with 7.5 and 15% of tire crumb content, the contact between the sand grain matrixes does not occur, a higher stress would be necessary. The specimen with only clean sand grains in Figure 5. was located below the dashed line, which means, the void ratio is lower than e_{max} for initial condition, it is a result of relative density 35% at which all the samples were prepared.

For better understanding of the sand grains rearrangement, granular compression index ($c_{c\text{-}s}$) is presented. Definition of this parameter is based on the compression index theory ($c_c = \Delta e / \Delta \log \sigma'$), though as shown in equation (3) $c_{c\text{-}s}$ consists of the intergranular void ratio decrease with the effective stress increment [Monkul and Ozden 2005]:

$$c_{c-s} = \frac{\Delta e_s}{\Delta \log \sigma'} \tag{3}$$

The variations of granular compression index ($c_{c\text{-}s}$) and global compression index (c_c) of the samples with rubber mixtures are presented in Figure 6. The $c_{c\text{-}s}$ and c_c values are estimated in a range of pressure from 245 to 295 kPa. Compressional behavior of the sand-tire crumb mixtures can be discussed in three stages. The transition area between dashed lines represents the RC_t values at the beginning and at the end of the pressure range used in the compression indexes estimation. In the first stage (Area 1) sand grains are adopted to be in contact with each other and rubber particles only fill the intergranular voids. Thus, low compression was observed and mainly controlled by the sand grains. When more tire crumb is added to soil grains matrix organize in a looser state. At the start of transition area soil grain's contact begins to reduce and further, in Area 2 a sharp increase in compression index can be observed, as the sand matrix becomes more dispersed. At this stage compressibility is mostly controlled by the tire crump particles, most of the sand grains are surrounded by tire crumb grains.

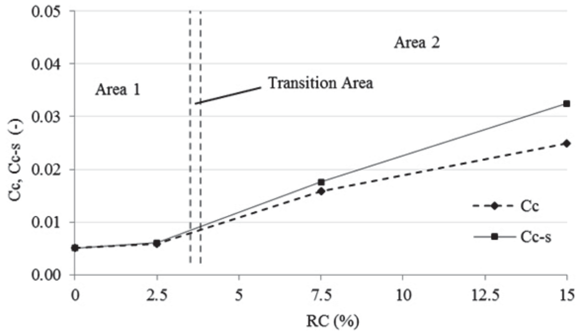

Fig. 6. Alteration of granular compression index ($c_{c\text{-}s}$) and global compression index (c_c) with rubber content

Direct shear box test

As to determine the shear strength parameters of sand with tire crumb grains rubber, a series of shear box tests was performed at different normal stresses in accordance with ASTM D 3080. For these tests, samples were placed in the standard shear box apparatus with 60 mm in width and length and 27 mm in height at 35% of relative density. The shear strength of the sand with tire crumb grains was measured by conducting direct shear test at 26, 40 and 67 kPa normal stresses. Figure 7 presents the shear stress-strain curves for clean sand and sand with various tire crumb grains (2.5, 7.5 and 15%) at 26, 40 and 67 kPa vertical stresses. As an overall view Figure 8 shows the variation of maximum shear stress with tire crumb content. However in Figure 9 shear stress and normal stress relation was presented. The shear box tests show that while increasing up to 2.5% tire

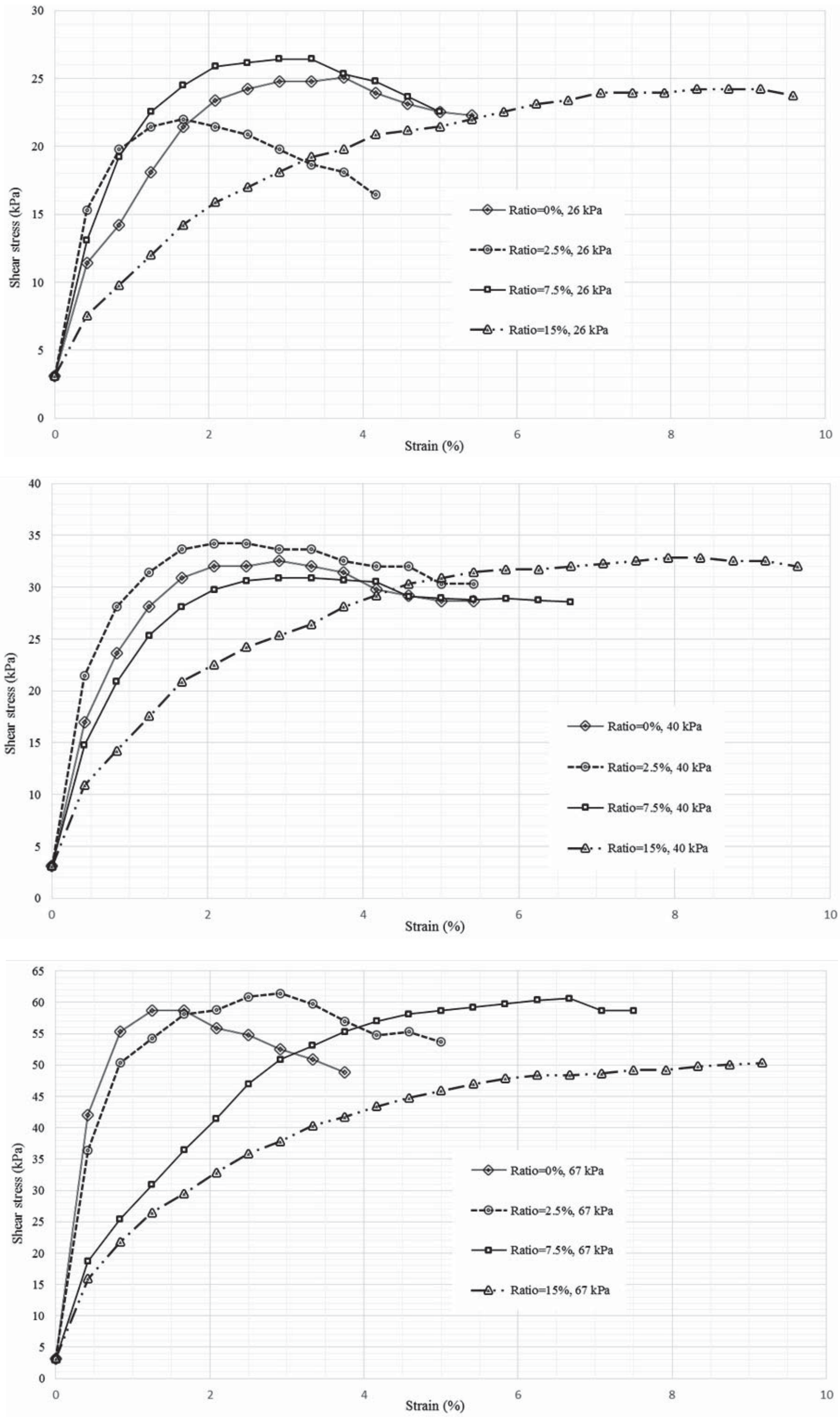

Fig. 7. Shear stress-strain curves for sand with various mix ratios at different vertical stresses

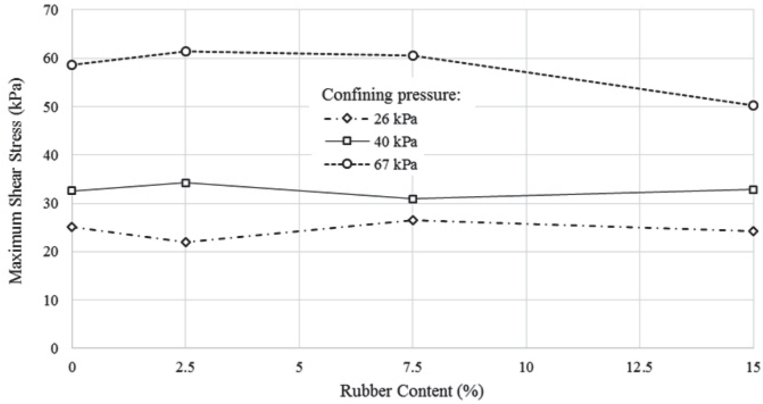

Fig. 8. Effect of rubber particles on the maximum shear stress for sand

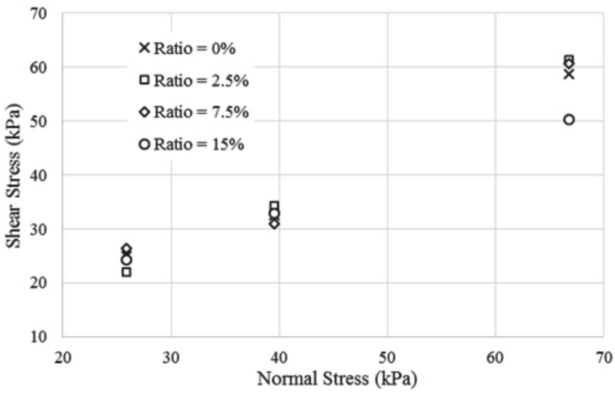

Fig. 9. Shear stress-normal stress curve for sand with mix ratios

rubber, the internal friction angle values increases, but when more rubber was added the friction angle started to decrease, which is show in Figure 10 and can be explained by the tire crumb transition content concept.

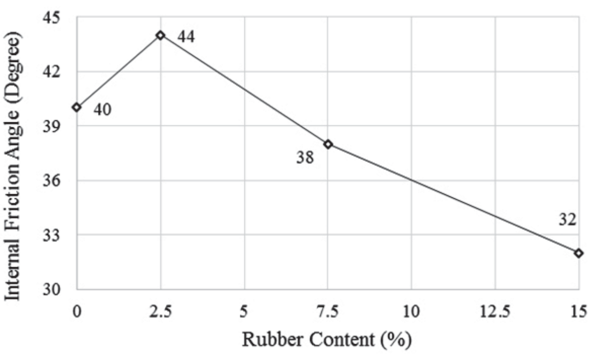

Fig. 10. Effect of rubber particles on the internal friction angle for sand

Brittleness index introduced by Consoli et al. [1998] was determined to investigate the brittle behavior of soil mixtures:

$$I_B = \frac{q_{\max}}{q_{\text{res}}} - 1 \tag{4}$$

where: I_b is the brittleness index, $q_{\max}$ and q_{res} are the peak and residual shear stresses, respectively.

Determined values of the shear stress at failure, residual stress and brittleness index under different confining pressures are summarized in Table 2. Curves of the brittleness index according to confining pressures are shown in Figure 11.

Table 2. Direct shear test results with brittleness index

Confining pressure	26 kPa			40 kPa			67 kPa		
Rubber content [%]	Shear stress [kPa]		Brittleness index	Shear stress [kPa]		Brittleness index	Shear stress [kPa]		Brittleness index
	at failure	residual		at failure	residual		at failure	residual	
0	25.056	22.278	0.125	32.556	28.667	0.136	58.667	50.889	0.153
2.5	22.000	16.444	0.338	34.222	30.333	0.128	61.444	53.667	0.145
7.5	26.444	22.556	0.172	30.889	28.567	0.081	60.611	55.889	0.084
15	24.222	22.000	0.101	33.667	31.722	0.061	50.333	49.222	0.023

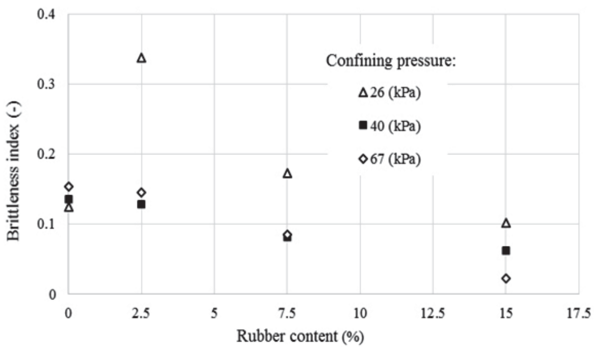

Fig. 11. Variation of brittleness index with rubber content for different confining pressures

The amount of energy needed to generate deformations in the soil mixtures is described as energy absorption. It is estimated by calculating the area under the stress-strain curve. In this study, energy absorption was determined for an axial strain of 3.75% for all the tests. The variation of energy absorption capacity with rubber content under different confining pressures is given in Figure 12.

CONCLUSIONS

The purpose of the present study was to investigate the compressional behavior of sand and its various mixtures with rubber in the perspective of intergranular void ratio concept by defining the transition tire crumb content and granular compression index

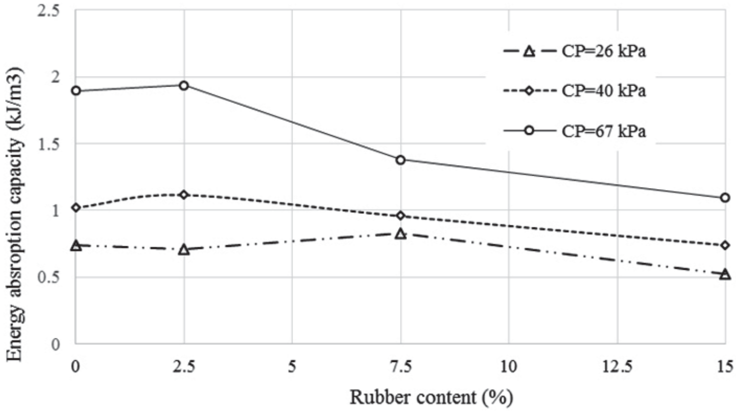

Fig. 12. Variation of energy absorption capacity with rubber content

parameters. Influence of the tire crumb content and stress conditions on this interaction has been studied by means of permeability, oedometer and direct shear tests. Rubber inclusion may improve the hydraulic properties of the material (however it highly depends on the grain sizes), it also increased the compression range and made material behave more elastic. Application does not reduce the maximum shear resistance, small rubber addition increased the friction angle, but great addition may have an opposite effect. Conducted research presents some potential usage of tire crumbs, which could help to save the environment and solve the wastes problem. Further studies are needed for better understanding of applications of different tire crumb sizes and percentages with various types of soils to develop future field implementation methods.

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ZASTOSOWANIE BADANIA FILTRACJI, EDOMETRU ORAZ APARATU BEZPOŚREDNIEGO ŚCINANIA DO WYZNACZENIA WŁAŚCIWOŚCI MIESZANINY PIASKU Z KAWAŁKAMI POCIĘTYCH OPON

Streszczenie. Ilość materiałów gumowych stosowanych na świecie rośnie z roku na rok, a ich utylizacja stała się głównym problemem dla środowiska naturalnego na całym świecie. Niniejsze prace eksperymentalne zostały przeprowadzone w celu zbadania wpływu dodatku gumy pochodzącej z opon samochodowych na zachowanie piasku oraz określenia możliwego zastosowania. Właściwości geotechniczne piasku i mieszaniny piasku z różną zawartością kawałków pociętej opony (0, 2,5, 7,5 i 15%) były badane za pomocą szeregu testów mechanicznych, przesiewania, filtracji, jednoosiowej konsolidacji i bezpośredniego ścinania. Na podstawie wyników przeprowadzonych prób okazuje się, że dodanie fragmentów opony zwiększa zarówno przepuszczalność, jak i kompresyjne właściwości piasku. Poza tym w pracy wykorzystany został koncept międzycząsteczkowego wskaźnika porowatości (e_s) jako alternatywnego parametru do określania charakterystyki ściśliwości mieszaniny piasku z kawałkami opon. Okazał się on być dobrym wskaźnikiem dla zrozumienia zachowania tego typu mieszaniny.

Słowa kluczowe: filtracja, edometr, aparat skrzynkowy, piasek, opony, utylizacja odpadów

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