Geomechanics and Engineering, *Vol. 8, No. 1 (2015) 1-15*
DOI: http://dx.doi.org/10.12989/gae.2015.8.1.001

Effect of tire crumb and cement addition on triaxial shear behavior of sandy soils

Zuheir Karabash [1,2a] and Ali Firat Cabalar [*1]

[1] *Department of Civil Engineering, University of Gaziantep, 27310, Gaziantep, Turkey*
[2] *College of Engineering, University of Mosul, Mosul, Iraq*

(*Received March 30, 2014, Revised July 11, 2014, Accepted August 21, 2014*)

Abstract. This paper presents a series of conventional undrained triaxial compression tests conducted to determine the effect of both tire crumbs and cement addition on Narli sand specimens. The tire crumb contents and cement contents were 3%, 7%, 15%; and 1%, 3%, 5% by dry weight of the sand specimens respectively. Specimens were prepared at about 35% relative density, cured during overnight (about 17 hours) for artificially bonding under a 100 kPa effective stress (confining pressure of 500 kPa with a back pressure of 400 kPa), and then sheared. Deviatoric stress-axial strain, pore water pressure-axial strain behavior, and Young's modulus of the specimens at various mixture ratios of tire crumb/cement/sand were measured. Test results indicated that the addition of tire crumb to sand decreases Young's modulus, deviatoric stress and brittleness, and increase pore water pressure generation. The addition of cement to sand with tire crumbs increases deviatoric stress, Young's modulus, and changes its ductile behavior to a more brittle one. The results suggest that specimen formation in the way used here could reduce the tire disposal problem in not only economically, and environmentally, but also more effectively beneficial way for some geotechnical applications.

Keywords: sand; tire crumbs; cement; triaxial testing

1. Introduction

The ground improvement techniques in the geotechnical engineering practice are tools applied for fixing the problems of soils that do not fulfill the requirements of an earthwork project. Over the last century, various soil improvement methods have been developed, and today many of them are widely used in earthwork projects. It is appropriate to classify the wide variety of soil treatment methods in the following ways: densification, consolidation/dewatering, chemical additives, heating/freezing. The basic principles of these techniques have not changed since the early part of the twentieth century. The practices, however, have been changing with time mainly because of the development of new materials, new machinery and new technologies. One of the attempts to increase soil strength is to mix it with other materials, such as grouting and artificial cementation. The effects of cementation on the stress-strain behaviour of naturally and artificially cemented soils have been investigated by many authors (Saxena and Lastrico 1978, Clough *et al.* 1979, 1981,

---

*Corresponding author, Associate Professor, E-mail: cabalar@gantep.edu.tr
[a] Ph.D. Student, E-mail: zuheirkra@gmail.com

http://www.techno-press.org/?journal=gae&subpage=7 ISSN: 2005-307X (Print), 2092-6219 (Online)

Acar and El-Tahir 1986, Coop and Atkinson 1993, Cuccovillo and Coop 1999, Huang and Airey 1998, Ismail *et al*. 2000, 2002b, Consoli *et al*. 2009). In almost all the experimental programs given in the literature, artificially cemented specimens have been used either for a greater understanding of fundamental soil behaviour or to study a ground improvement technique. Cementation reinforces the links between soil particles, and so increases stiffness and peak strength. Clough *et al*. (1981) and Ismail *et al*. (2002a), for example, suggest that the type and amount of cement, density, gradation, and effective confining stress are the governing variables. It has also been suggested that soil behaviour is affected by geological and stress-strain history, temperature and principal stress direction (Gens and Nova 1993). Schnaid *et al*. (2001) investigated the stress-strain-strength behaviour of an artificially cemented sandy soil produced through the addition of Portland cement. For cemented sands, they used the unconfined compressive strength as a direct measurement of the degree of cementation. The effects of cementation on soil behaviour were similar to those seen in terms of over consolidated clays. Basically, it comprises an initial stiff behaviour followed by plastic deformation as the soil approaches failure. Accordingly, cemented soils have a very stiff behaviour before yielding. The brittle behaviour changes to a ductile soil response as the stress level changes from low to high. Leroueil and Vaughan (1990) showed that the stress-strain behaviour of soils is dependent on the critical state line of the non-structured remoulded soil, initial state and its position in relation to the yield curve. From the same concept, Coop and Atkinson (1993) idealized the behaviour of cemented soil into three different categorizes. The first occurs when the soil reaches its yield stress during isotropic compression. The second occurs during intermediate stress applications. In this category, it is proposed that bonds are broken during shearing and the strength is mainly controlled by the frictional constituents of the soil. In the third category, the soil is sheared at lower confining stresses, comparing to the strength of bond material. A sharp peak in the stress-strain curve occurs at small strain levels and for stresses outside the limit state surface of the equivalent remoulded soil.

It has been long understood that waste tires are used in some engineering applications and thereby reduce the potential impact on the environment. Millions of scrap tires are discarded annually and even larger numbers are currently stockpiled all around the world. Besides the economical and environmental benefits, tire wastes have unique properties for many geotechnical applications. Tire wastes can be used in highway and earthwork constructions as lightweight fill material for retaining wall backfills and embankments, or in landfill applications as drainage material. Properties of tire wastes such as durability, strength, resiliency, and high frictional resistance are of significant value for the design of highway embankments (Moon-Young *et al*. 2003, Edincliler *et al*. 2012). Such as Ahmed (1993) reported that adding tire chips increases the shear strength of sand, with angle of friction up to 65 obtained for dense sand with 30% tire chips. Masad *et al*. (1996) concluded that the shreded tires and Ottowa sand mixtures have a potential to be used as a lightweight fill material in highway embankments over compressible soils. Tire shreds have been used as lightweight fill material in many embankments and retaining structures (Bosscher *et al*. 1997, Humphrey and Manion 1992, Tweedie *et al*. 1998, Lee *et al*. 1999, Dickson *et al*. 2001, Zornberg *et al*. 2004). The investigations show that the use of waste tire-soil mixtures have lower compressibility and higher shear strength and thus perform better than only waste tire shreds. Embankments constructed with waste tires- soil mixtures can potentially have steeper slopes because the backfill has higher shear strength and lower unit weight. Also, because of using lightweight material, settlement of underlying soil is reduced (Tatlisoz *et al*. 1997). Edil and Bosscher (1994) reported that placing tire shreds in sand vertically led to higher shear strength on the plane perpendicular to the shred.

The purpose of this study is to investigate the applicability of both cement and waste tires in a sand using a triaxial testing apparatus. The higher brittle and dilative behaviour of soils because of adding cement can be controlled by application of waste tires. The tire crumbs (as a type of waste tires) and sands with certain particle characteristics have been used during the experimental study. The experimental programme aimed to examine the influence of various mixture ratios of tire crumbs and cement on some mechanical properties of a sand that was artificially bonded under an effective stress. The study focus on the influences of the ratio between tire crumb content and cement quantity on deviatoric stress/pore water pressure- axial strain behaviour, and the secant Young's modulus values of this new composite material.

2. Experimental study

The experimental work has been directed mainly towards an investigation of the influence of relatively small proportions of cement on the behavior of a sand with different tire crumb contents in a conventional triaxial compression testing equipment. Following the specimen preparation, a series of consolidated undrained (CU) tests were performed to understand the effect of the tire crumb contents on the triaxial behavior of the sand, and then improve its response by cement. The amounts of the tire crumbs used in the experimental study were 0%, 3%, 7%, and 15% by dry weight of the mixture. 0%, 1%, 3%, and 5% cement by dry weight of the mixtures were used as an addition to sand with tire crumbs at 15% mix ratio. 3% cement by dry weight of the mixtures was also added to sand with tire crumbs at all percentages.

2.1 Materials and methods

The materials used during the tests described in this paper were Narli sand, tire crumbs, and cement.

2.1.1 Narli sand

The material used in the experimental study is a river sand obtained from Narli, near Gaziantep city, Turkey. The gradation of the sands falling between 0.6 mm and 1.18 mm were artificially selected to provide uniform specimens for visual classification purposes (Fig. 1). D10, D30 and D60 sizes are around 0.67, 0.78, and 0.92 respectively. Thus, the coefficient of curvature (Cc) and the coefficient of uniformity (Cu) have been calculated as 0.987 and 1.373, respectively. The specific gravity of the grains, classified as poorly graded sand (SP) according to the Unified Soil Classification System (USCS), was found to be 2.64. The sand has minimum and maximum voids ratios of 0.62 and 0.85, respectively. Roundness (R) and sphericity (S) estimations based on the study by Muszynski *et al*. (2012) were found to be 0,27 and 0,62, respectively (Fig. 2). Hence, the sand can be described as subangular.

2.1.2 Tire crumb

Commercially available tire crumb used in the experimental study is a granular material obtained by processing of waste tires. As can be seen from the Fig. 1, D10, D30 and D60 sizes were found around 1.2, 1.3, and 1.7 respectively. Thus, the coefficient of curvature (Cc) and the coefficient of uniformity (Cu) have been calculated as 0.828 and 1.42, respectively. Roundness (R) and sphericity (S) estimations (Muszynski *et al*. 2012) were found to be 0,14 and 0,50, respectively (Fig. 2). Thus, the tire crumb can be described as very angular.

2.1.3 Cement

In the experimental study, high-early-strength type (ISIDAC 40) of cement obtained from the CIM(SA) company was used for completion of its setting in a shorter time interval, which was a type of calcium aluminate cement. The cement used has a specific gravity of 3.25 gm/cm^3, a specific surface area of 3000 cm^2/gm, and a compressive strength of a range of 22- 40 MPa in 6 hours. The chemical compositions of the cement are listed in Table 1.

2.1.4 Testing apparatus

Tests were carried out in a 70 mm diameter conventional ELE triaxial loading frame with 50 kN

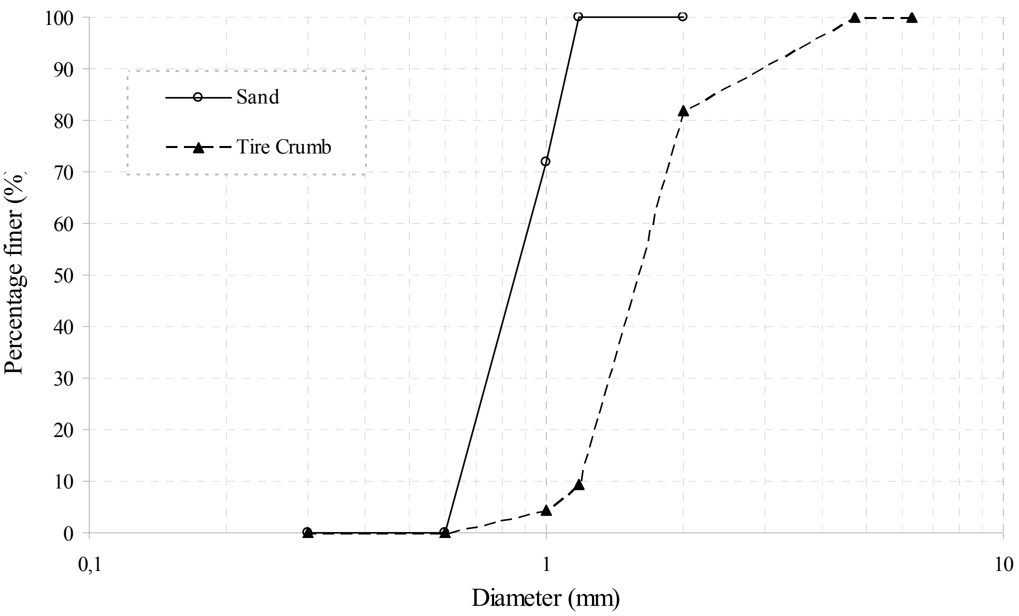


Fig. 1 Grain size distributions of the materials used during experimental study

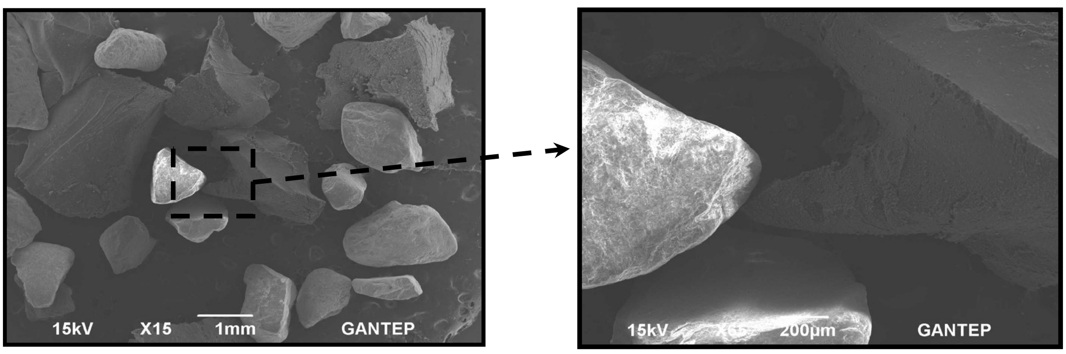


Fig. 2 Scanning electron micrograph (SEM) of the sand tire rubber particles mixture

Table 1 Chemical compositions of the cement use in this study (CIMSA)

Chemicals	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Loss on ignition	Na_2Eq	Chloride (CI-)	S (Sulphur)
Percentages (%)	3,60	39,80	17,05	36,20	0,65	0,04	0,3	0,16	0,0090	0,01

loading capacity. The apparatus was equipped with a 4.5 kN load cell, an external linear displacement sensor (LDS) with a range of 0-25 mm, and pressure transducers with a range of 0-1,000 kPa for the measurement of cell pressure and pore pressure. The specimens were prepared in a 70 mm diameter 140 mm high split mould.

2.1.5 Specimen preparation

The specimens were approximately 70 mm in diameter by 140 mm height. A membrane was attached to the pedestal using o-rings and two-part split mould was then placed around the pedestal. The membrane was stretched inside the mould, and two folded at the top. The triaxial test specimens were prepared using air-pluviation method. At the beginning, the required amount of Narli sand, tire crumbs, and cement were weighed, mixed, and poured via a funnel into the mould. When the mould was completely filled, the membrane was stretched over top platen, and attached with o-rings. Then, de-aired water was flushed from bottom to the top of the specimen for saturation and hydration of the cement. A small suction (of the order of 10 kPa) was applied to the specimen, after stripping the specimen mould, installing the triaxial cell onto its base, and filling the cell with de-aired water. The vacuum applied to the specimen was then reduced while gradually increasing the confining cell pressure until the desired starting values of total and effective stress were achieved (500 kPa confining pressure with a back pressure of 400 kPa). The specimens were kept under pressure for consolidation and curing during overnight, which was about 17 hours. The specimen formation in the way described here could result in cement hydration during saturation phase, and cementation under a consolidation pressure.

2.1.6 Testing procedure

Specimens were isotropically consolidated to 100 kPa effective stress, with a back pressure of 400 kPa, before being sheared in undrained condition. A minimum B-value of 0.95 was obtained before shear. A standard machine rate of displacement, equivalent to 0.15 mm/min, was used throughout the testing. During shear, measurements of deviatoric load, external axial deformation, and base pore pressure were made at approximately 10 sec intervals.

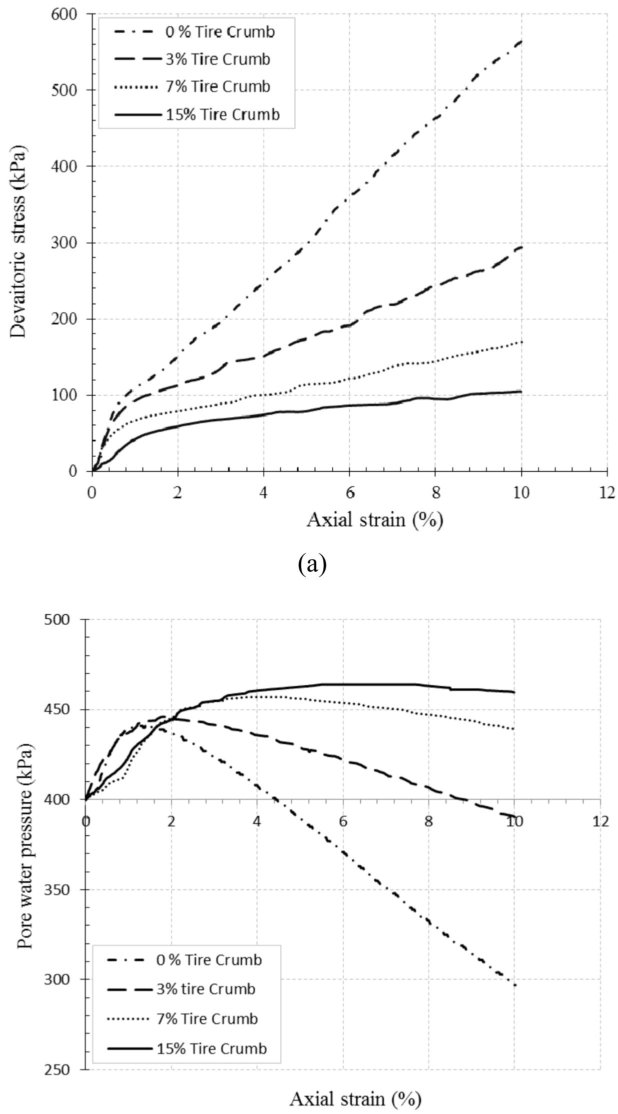
3. Results and discussion

The effect of tire crumbs with small amount of cement on the stiffness, strength, and pore pressure characteristics of sand was investigated to assess the contributions to overall behaviour of the mixture. First, the influence of tire crumbs only on the behaviour of sand was assessed by studying effects of the change in amount of tire crumbs. Specimens contract or dilate substantially under tests in accordance with the relative density values (Vesic and Clough 1968). Some of the engineering properties, including shear strength, compressibility, and permeability of a given soil depend on the relative density. Therefore, the relative density values here in this investigation were aimed to be kept at a constant range (loose to medium). Dry densities of the specimens tested were calculated as 14.45 kN/m^3 for clean sand, 14.10 kN/m^3 for sand with 3% tire crumb, 13.21 kN/m^3 for sand with 7% tire crumb, and 11.99 kN/m^3 for 15% tire crumb. Comparing the relative density of the specimen prepared in de-aired water with those proposed by Terzaghi and Peck (1962), it can be seen that the materials tested could almost exclusively be classified as loose to medium dense.

The untreated specimen (clean sand) responses to triaxial loading served as a benchmark from which the treatment in shear response by adding tire crumbs and cement could be assessed. The deviatoric stress vs. axial strain, and pore pressure generation vs. axial strain behaviors of the specimens with the amount of tire crumbs added to the sand. The Narli sand particles are assumed to be in clean contact with each other in the specimen tested without tire crumbs, and hence the mechanical behaviour of this specimen was governed by the sand particles only. As the amount of tire crumbs increase, the contacts between the sand particles reduce, and the behavior of the specimens are controlled by the tire crumbs. Actually, sand and tire crumbs particles can rearrange themselves into various modes depending on the initial conditions and applied stress. When such a sandy soil- tire crumbs mixture at various ratios is examined, the volume of the voids can be thought as voids due to the sand grains (which is intergranular void ratio, es) and voids due to the tire crumb grains. Thus, intergranular void ratio (es) can be described as the ratio of volume of the intergranular voids to the volume of the sand grains. From the studies by Thevanayagam (1998), Monkul and Ozden (2007), and Cabalar (2010), establishment of direct grain contacts of the sand grain matrix can be assumed to be initiated when the intergranular void ratio of the mixture becomes equal to the maximum void ratio of the host granular material, which is the Narli sand in this study (i.e., es = emax). The tire crumbs content, at which this condition occurs, can be named as ‘transition tire crumb content’. From the studies mentioned above, the transition tire crumb content was found to be about 4.4%. However, it seems to be beyond the scope of this study to provide a detailed discussion on the transition tire crumb content, since the experimental study was directed mainly towards an investigation of the effect of small proportions of cement on the behavior of sand with different tire crumb contents.

Fig. 3 shows deviatoric stress vs. axial strain, and pore pressure generation with axial strain for the clean Narli sand, and that with different amount of tire crumbs at 100 kPa effective consolidation pressure. Fig. 3 presents result of four different experiments, which are the (i) clean Narli sand specimens, and sand with (ii) 3% tire crumb, (iii) 7% tire crumb, (iv) 15% tire crumb. All the tests in this series were performed using de-aired water. As can be seen from Fig. 3(a), deviatoric stress decreases as the tire crumb content increases within the measured strain level. No peak shear stress values are observed for all the specimens, and the deviatoric stress continues to increase with increasing axial strain. Fig. 3(b) presents the pore water pressure generation corresponding to the tests described in Fig. 3(a). It is seen that the pore water pressure in the clean sand generates at the lower strain level. In addition, the generation of the pore water pressure decreases as the tire crumb content increases. Although a clear dilation can be observed in the specimen tested using clean sand, the tests on the sand with tire crumbs do not show dilation within the measured strain range. In addition, stress path results were given in Fig. 4, where the deviatoric stress and mean effective confining stress values were represented by q and p’, respectively. The most striking point in these plots is that the contraction increases as the tire crumbs content increases.

The ductile and contractive behaviour of sand with tire crumbs can be controlled by application



(a)

(b)

Fig. 3 (a) Stress strain curves; and (b) pore water pressure for sand with different proportions of tire crumbs

of cement bonding. The fact is that, investigations into the 'bonding' and bonded soils provide one of the major challenges for geotechnical engineering. It has often been noted that there is a lack of framework to integrate the behaviour of such materials in a consistent way. Such investigations have involved laboratory testing either of artificially bonded soils or of high quality samples. In the past 30 years, many authors have made significant researches in this field presenting various behaviors for such type of soils (e.g., Saxena and Lastrico 1978, Clough *et al*. 1979, 1981, Acar and El-Tahir 1986, Maccarini 1987, Bressani 1990, Leroueil and Vaughan 1990, Gens and Nova 1993, Coop and Atkinson 1993, Malandraki 1994, Cuccovillo and Coop 1999, Liu and Carter

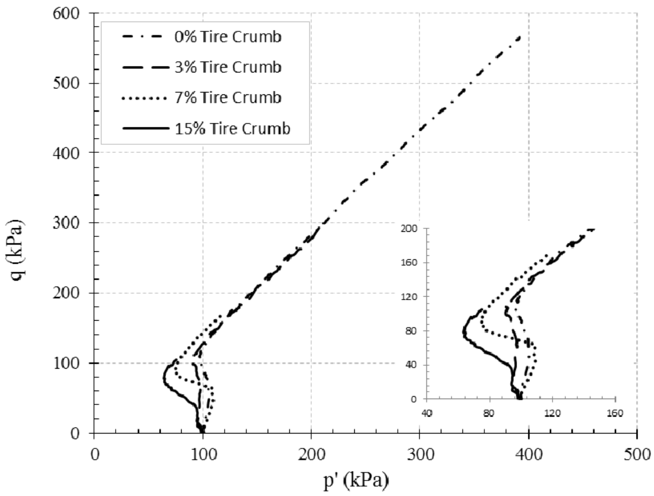
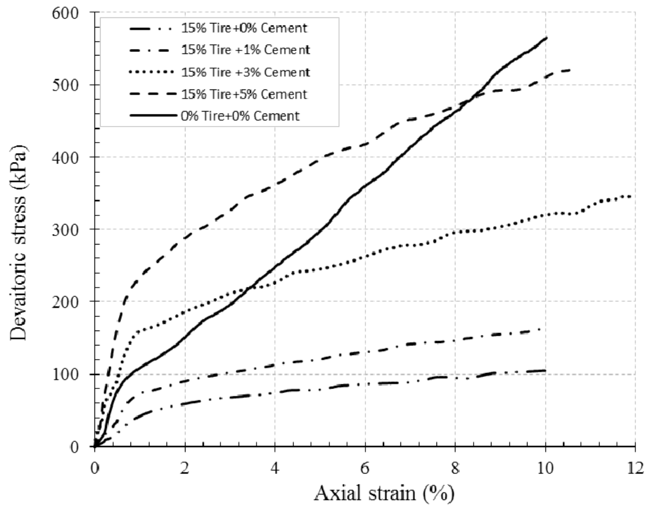


Fig. 4 Effective stress paths for sand samples with different proportions of tire crumbs

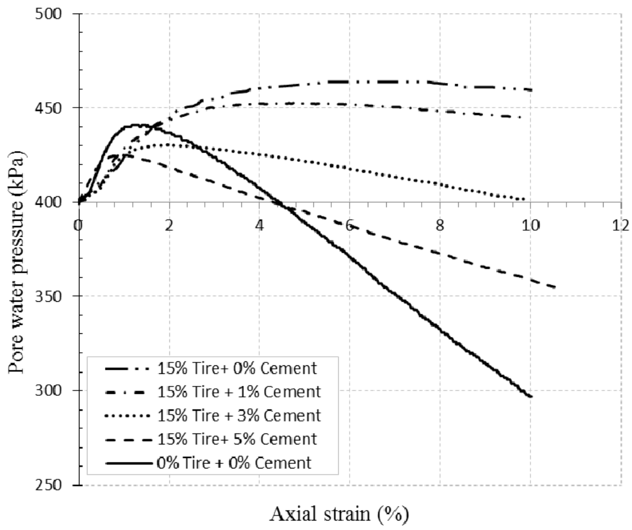
1999, 2000, Ismail *et al*. 2000, Malandraki and Toll 2001). However, in this study, relatively small amount of cement additions (0%, 1%, 3%, and 5%) have been used to improve shear strength of the sand with tire crumb at highest content (15%), which was selected as a worst case (the lowest stress value). The effect of cement content at various ratios on the deviatoric stress- axial strain, and pore water pressure- axial strain responses of the sand was shown in Fig. 5. Similarly to the tested specimens with tire crumbs only, the specimens with both tire crumbs and cement has no observed peak deviatoric stress value within the measured axial strain level (Fig. 5(a)). The type of the failure in the cemented sand/ tire crumb mixture was barrelling type without a distinct failure plane. It is seen that 3% and 5% cement contents have a significant effect on the deviatoric stress. As the cement content increases, the deviatoric stress values, and the energy absorption increase. Energy absorption indicates the amount of energy needed to deformation in a material. This can be found by calculating the area below the stress- axial strain curve (Hamidi and Hooresfand 2013). As shown in Fig. 5(a), energy absorption has higher values within relatively small strain levels. The authors interpreted that this behavior might be attributed to an artificial bonding between the sand grains and tire crumb particles because of the hydrated cement during curing (17 hrs). It is considered that the hydrated cement covers the tire crumbs particles as well as sand grains, and reduces their size and compressibility characteristics, while it is being kept under a 100 kPa effective stress. Fig. 5(b) presents the effect of the cement content to the generation of the pore water pressure for the sand/tire crumb mixtures. It is observed that the pore water generation during shear reduces as the cement content increase in the mixture. The scanning electron micrograph (SEM) pictures indicates the cementation through the sand and tire crumb particles (Fig. 6). Furthermore, to generate more understanding of the deformation behaviour of soils at small strains (< 0.01%), which is dependent on many factors including stress state, stress history, soil fabric, aging and bonding, practitioners must also take account of yielding, plasticity, linear and non-linear ranges as well as anisotropy, fabric and bonding. Since yielding occurs at small strain levels, the significance of the development of local displacement transducers can be seen. Local strain instrumentation with high accuracy and precision in laboratory testing techniques has shed new light on soil behaviour at small strains (e.g., Burland and Symes 1982, Jardine *et al*.

1984, Clayton and Khatrush 1986, Heymann *et al*. 1997, Clayton and Heymann 2001).

Fig. 5(b) presents the pore water pressure generation corresponding to the tests described in Fig. 5(a). The tests on the specimens with less amount of cement exhibit a higher pore water generation, in particularly at larger strain levels. Fig. 7 shows the stress path for the cemented sand/tire crumb mixtures at various ratios. it is observed that the dilatancy increases as the cement content increases. The authors consider that it bonding (cementation) could result in a lower ductility. Fig. 8 indicates the behavior of sand and various content (0%, 3%, 7%, 15%) tire crumbs mixtures with (3%) and without cement additions. Considering the overall testing result, the authors have



(a)



(b)

Fig. 5 (a) Stress strain curves; and (b) pore water pressure for sand/ tire crumbs with different proportions of the cement

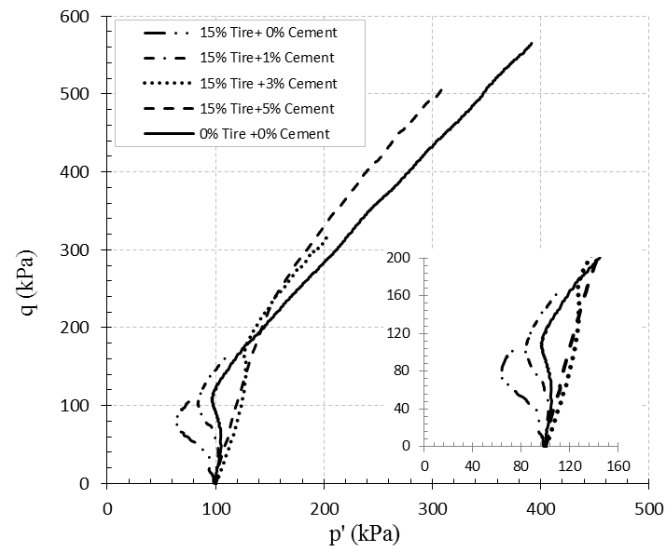


Fig. 6 Effective stress paths for sand/tire crumb mixture samples with different proportions of cement

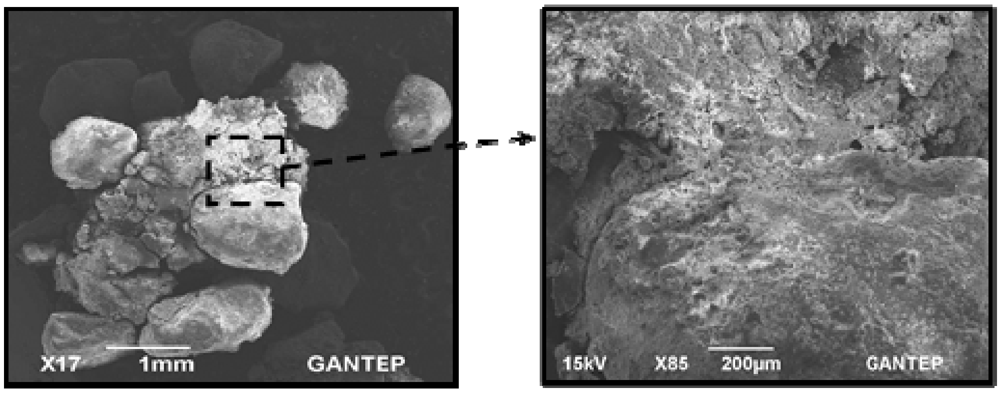
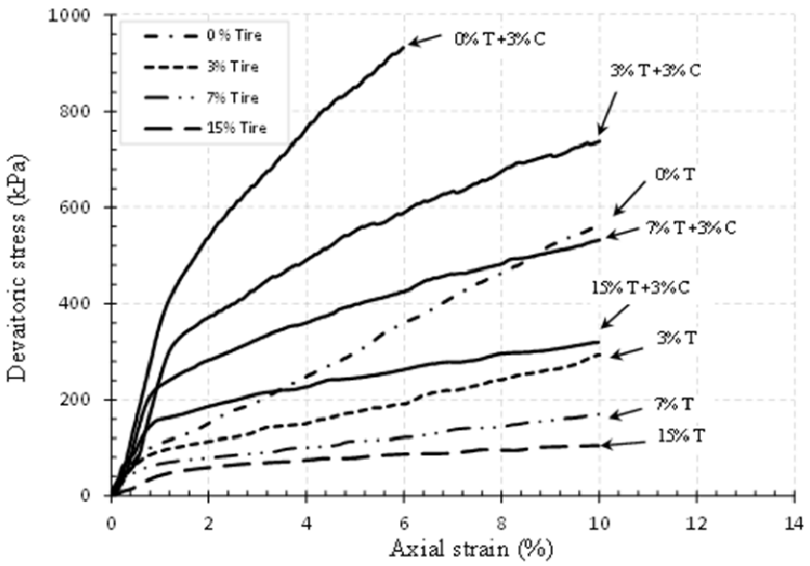


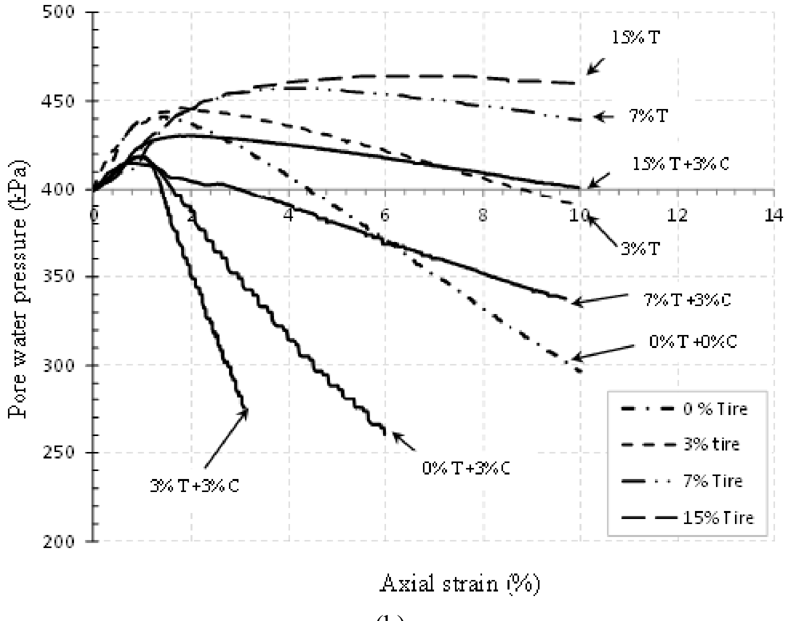
Fig. 7 Scanning electron micrograph (SEM) of cemented sand/ tire crumb mixture

preferred to use 3% cement content in sand with various contents of tire crumbs. Because, the authors interpreted that such cement content could be an optimum value to modify effectively the behavior of various sand- tire crumb mixtures. It can be seen from the Fig. 8(a), the deviatoric stress values for the specimens with 3% cement increase as the tire crumb content reduces. Fig. 8(b) shows the pore water pressure generation corresponding to the tests described in Fig. 8(a). It is observed that the tests on the specimens with less tire crumb content exhibit a lower pore water generation with peak at a smaller strain levels (at about 1%).

The influence of tire crumbs at different concentrations on the stiffness of sand was investigated by considering secant Young's modulus. In order to have an understanding if the Young's modulus of the specimens was a function of tire crumbs, the results were compared at the range of 0.1% to 10% strain levels (Fig. 9). The secant Young's modulus of the specimens decreased with adding tire crumbs. As can be seen from the Fig. 9, the stiffness values for the



(a)



(b)

Fig. 8 Behavior of sand and various content tire crumbs mixtures with/without cement additions, (a) deviatoric stress-axial strain; (b) pore water pressure- axial strain

specimens tested using various tire crumbs contents are fairly close to each other at strain level after the 2% strain level. However, the secant Young's modulus result of the sand- tire crumb specimens differed from each other at relatively smaller strains, in particular; before the 1% strain

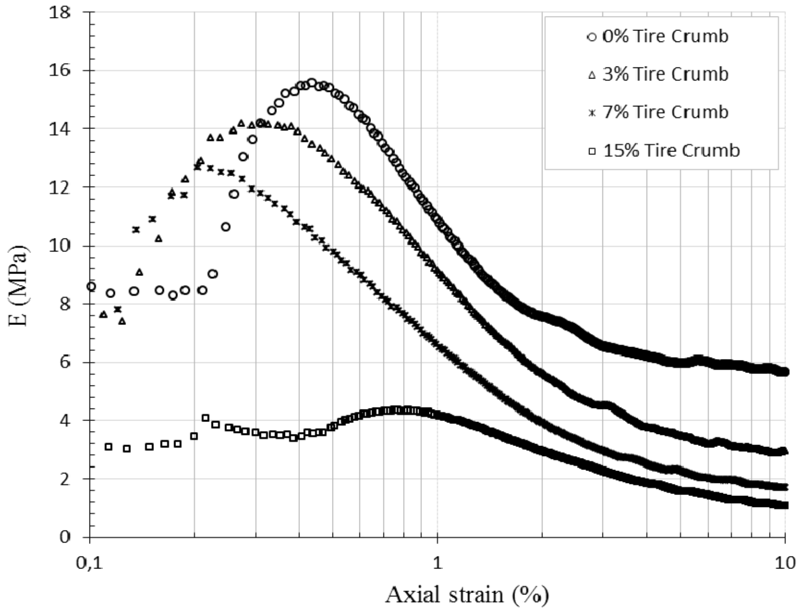


Fig. 9 Variation of the stiffness with tire crumb content

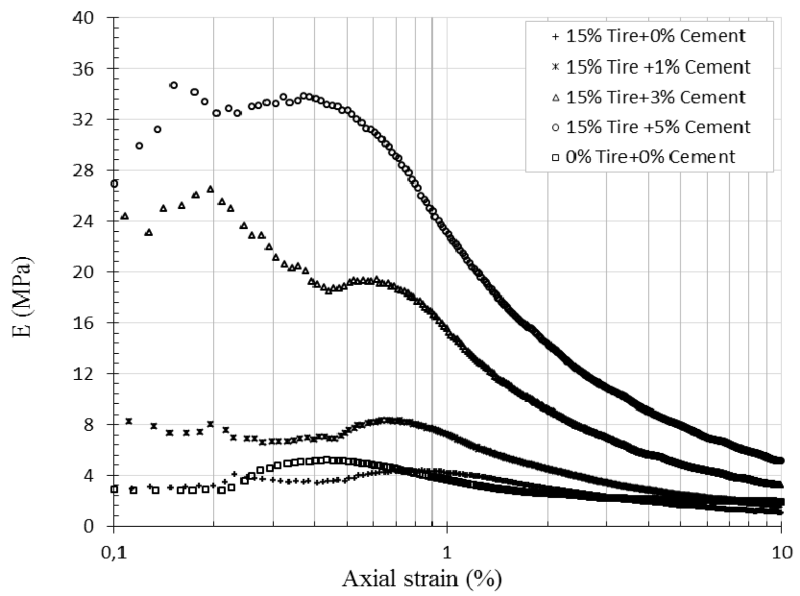


Fig. 10 Variation of the stiffness of the sand/ tire crumb mixture with the cement content

level, characteristics of the plots for the specimens with tire crumbs considerably change. Also, the influence of cement at different concentrations on the stiffness of sand with 15% tire crumbs was investigated by considering secant Young's modulus (Fig. 10). The secant Young's modulus of the specimens increased with adding cement. It is observed that, the stiffness values for all the specimens tested using various cement ratios are fairly close to each other at strain level after the 2% strain level. On the other hand, the secant Young's modulus result of the sand/tire crumb specimens with cement differed from each other at relatively smaller strains, in particular; before the 1% strain level. The modulus of the mixture increases with increasing cement content.

4. Conclusions

Triaxial behaviour sands- tire crumbs- cement mixtures was examined. The common aspect of the published waste tire applications is the determination of a relationship between type, aspect ratio, content of waste tires and their contribution on the behaviour of soils. The use of waste tires in civil engineering applications can reduce the tire disposal problem in an economically and environmentally beneficial way. However, use of waste tires cannot yield desired properties for some geotechnical applications always. Therefore, this paper has attempted to present an investigation carried out to increase the effectiveness of waste tires use in geotechnical applications by creating artificially bonding with a relatively small amount of cement. The paper reports what are thought to be the first investigation ever carried out to test the effect of cementation on a specimen artificially bonded under 100 kPa effective stress by five new facets of behaviour:

- As the cement content in a sand with tire crumb increases, the deviatoric stress values, and the energy absorption increase.
- The sand- tire crumbs specimens with smaller amount of cement exhibit a higher pore water generation, in particularly at larger axial strain levels.
- Hydrated cement particles cover the tire crumbs grains and sand grains, thereby, reduces tire crumbs' size and compressibility characteristics, while it is being kept under a 100 kPa effective stress.
- Ductile and contractive behaviour of sand with tire crumbs can be controlled by application of cement bonding. Dilatancy of the sand- tire crumbs mixtures increases as the cement content increases.
- The secant Young's modulus of the sand- tire crumb specimens, decreased with adding tire crumbs, increased with adding cement.

The results suggest that specimen formation in the way used here could reduce the tire disposal problem not only in economically and environmentally, but also in a more effectively beneficial way for some geotechnical application. It is important to bear in mind that the observations herein are relevant for the type of soil, cement, and tire crumbs used in the present research, and that further studies are required to generalize such findings.

References

Acar, B.Y. and El-Tahir, A.E. (1986), "Low strain dynamic properties of artificially cemented sands", *J. Geotech. Eng. Div.*, *ASCE*, **112**(11), 1001-1015.

Ahmad, I. (1993), "Laboratory study on properties on rubber soils", Report No. FHWA/IN/JHRP-93/4, Joint Highway Research Project, Indiana Department of Transportation, USA.

Bosscher, P.J., Edil, T. and Kuraoka, S. (1997), "Designof highway embankments using tire chips", *J Geotech. Geoenviron. Eng.*, *ASCE*, **123**(4), 295-304.

Bressani, L.A. (1990), “Experimental properties ofbonded soils”, Ph.D. Thesis, University of London, London, UK.

Burland, J.B. and Symes, M. (1982), “A simple axial displacement gauge for use in the triaxial apparatus”, *Géotechnique*, **32**(1), 62-65.

Cabalar, A.F. (2010), “Applications of the triaxial, resonant column and oedometer tests to the study of micaceous sands”, *Eng. Geol.*, **112**(1-4), 21-28.

Clayton, C.R.I. and Heymann, G. (2001), “Stiffness of geomaterials at very small strains”, *Géotechnique*, **51**(3), 245-255.

Clayton, C.R.I. and Khatrush, S.A. (1986), “A new device for measuring local axial strains on triaxial specimens”, *Géotechnique*, **36**(4), 593-597.

Clough, G.W., Kuck, W.M. and Kasali, G. (1979), “Silicate-stabilized sands”, *J. Geotech. Eng. Div., ASCE*, **105**(1), 65-82.

Clough, G.W., Sitar, N., Bachus, R.C. and Shaffi Rad, N. (1981), “Cemented sands under static loading”, *J. Geotech. Eng. Div., ASCE*, **107**(6), 799-817.

Consoli, N.C., Vendruscolo, M.A., Fonini, A. and Rosa, F.D. (2009), “Fiber reinforcement effects on sand considering a wide cementation range”, *Geotext. Geomembr.*, **27**(3), 196-203.

Coop, M.R. and Atkinson, J.H. (1993), “The mechanics of cemented carbonate sands”, *Géotechnique*, **43**(1), 53-67.

Cuccovillo, T. and Coop, M.R. (1999), “On the mechanics of structured sands”, *Géotechnique*, **49**(6), 741-760.

Dickson, T.H., Dwyer, D.F. and Humphrey, D.N. (2001), “Prototypes tire-shred embankment construction”, Transportation research record 1755, TRB, National Reserach Council, Washington, D.C., USA, pp. 160-167.

Edil, T. and Bosscher, P. (1994), “Engineering properties of tire chips and soil mixtures”, *Geotech. Test. J.*, **17**(4), 453-464.

Edincliler, A., Cabalar, A.F., Cagaty, A. and Cevik, A. (2012), “Triaxial compression behavior of sand and tire wastes using neural networks”, *Neural. Comput. Appl.*, **21**(3), 441-452.

Gens, A. and Nova, R. (1993), “Conceptual bases for a constitutive model for model for bonded soils andweak rocks”, In: *Geotechnical Engineering of Hard Soils-Soft Rocks*, (A. Anagnostopoulos, R. Frank, Ni. Kalteziotis and F. Schlosser Eds.), Balkema, Rotterdam, The Netherlands, pp. 485-494.

Hamidi, A. and Hooresfand, M. (2013), “Effect of fiber reinforcement on triaxial shear behaviour of cement treated sand”, *Geotext. Geomembr.*, **36**, 1-9.

Heymann, G., Clayton, C.R.I. and Reed, G.T. (1997), “Laser interferometry to evaluate the performanceof local displacement transducers”, *Géotechnique*, **47**(3), 399-405.

Huang, J.T. and Airey, D.W. (1998), “Properties of artificially cemented carbonate sand”, *J. Geotech. Geoenvir. Eng. Div., ASCE*, **124**(6), 492-499.

Humphrey, D. and Manion, W. (1992), “Properties of tire chips for lightweight fill”, *Grouting Soil Improv. Geosynth*, **2**, 1344-1355.

Ismail, M.A., Joer, H.A. and Randolph, M.F. (2000), “Sample preparation technique for artificially cemented sands”, *Geotech. Test. J., ASTM.*, **23**(1), 141-157.

Ismail, M.A., Joer, H.A., Randolph, M.F. and Meritt, A. (2002a), “Cementation of porous materials using calcite”, *Géotechnique*, **52**(5), 313-324.

Ismail, M.A., Joer, H.A., Sim, W.E. and Randolph, M.F. (2002b), “Effect of cement type on shear behaviour of cemented calcareous soil”, *J. Geotech. Geoenviron. Eng.*, **128**(6), 520-529.

Jardine, R.J., Symes, M.J. and Burland, J.B. (1984), “The measurement of soil stiffness in the triaxial apparatus”, *Géotechnique*, **34**(3), 323-340.

Lee, J.H., Saigado, R., Bernal, A. and Lovell, C.W. (1999), “Shredded tires and rubber-sand as lightweight backfill”, *J Geotech Geoenviron Eng*, **125**, 132-141.

Leroueil, S. and Vaughan, P.R. (1990), “The generaland congruent effects of structure in natural soils and weak rocks”, *Géotechnique*, **40**(3), 467-488.

Liu, M.D. and Carter, J.P. (1999), “Virgin compression of structured soils”, *Géotechnique*, **49**(1), 43-57.

Liu, M.D. and Carter, J.P. (2000), "Modelling the destructuring of soils during virgin compression", *Géotechnique*, **50**(4), 479-483.

Maccarini, M. (1987), "Laboratory studies of weakly bonded artificial soil", Ph.D. Thesis, University of London, London, UK.

Malandraki, V. (1994), "The engineering behaviour of a weakly bonded artificial soil", Ph.D. Thesis, University of Durham, Durham, UK.

Malandraki, V. and Toll, D.G. (2001), "Triaxial tests on weakly bonded soil with changes in stress path", *J. Geotech. Geoenviron. Eng.*, **127**(3), 282-291.

Masad, E., Taha, R., Ho, C. and Papagiannakis, T. (1996), "Engineering properties of tire/soil mixtures as a lightweight fill material", *Geotech.Test. J.*, **19**(3), 297-304.

Monkul, M.M. and Ozden, G. (2007), "Compressional behavior of clayey sand and transition fines content", *Eng. Geol.*, **89**(3-4), 195-205.

Moo-Young H., Sellasie, K., Zeroka, D. and Sabnis, G. (2003), "Physical and chemical properties of recycled tire shreds for use in construction", *J. Geotech. Geoenviron. Eng., ASCE*, **129**(10), 921-929.

Muszynski, M.R. and Stanley, J.V. (2012), "Particle shape estimates of uniform sands: visual and automated methods comparison", *J. Mater. Civ. Eng.*, **24**(2), 194-206.

Saxena, S.K. and Lastrico, R.M. (1978), "Static properties of lightly cemented sand", *J. Geotech. Eng. Div., ASCE*, **104**(12), 1449-1464.

Schnaid, F., Prietto, P.D. and Consoli, N.C. (2001), "Characterization of cemented sand in triaxial compression", *J. Geotech. Geoenviron. Eng., ASCE*, **127**(10), 857-868.

Tatlisoz, N., Benson, C.H. and Edil, T. (1997), "Effect of fines on mechanical properties of soil-tire chip mixtures", In: *Testing Soil Mixed with Waste or Recycled Materials*, (Edited by M.A. Wasemiller and K.B. Hoddinott), ASTM International, pp. 93-108.

Terzaghi, K. and Peck, R.B. (1962), *Soil Mechanics in Engineering Practice*, John Wiley & Sons Inc., (12th Edition), USA.

Thevanayagam, S. (1998), "Effect of fines on confining stress on undrained shear strength of silty sands", *J. Geotech. Geoenviron. Eng., ASCE*, **124**(6), 479-491.

Tweedie, J.J., Humphrey, D.N. and Sandford, T.C. (1998), "Full scale field trials of tire shreds as lightweight retaining wall backfill, at-rest conditions", *Transp. Res. Rec.*, **1619**, 64-71.

Vesic, AB. and Clough, G.W. (1968), "Behaviour of granular materials under high stresses", *J. SMFE, ASCE*, **94**(8M-3), 661-688.

Zornberg, J.G., Cabral, A.R. and Viratjandr, C. (2004), "Behaviour of tire shred-sand mixtures", *Can. Geotech. J.*, **41**(2), 227-241.

CC