New Horizons in Earth Reinforcement – Otani, Miyata & Mukunoki (eds)

Tire-chips for geotechnical applications

K. Yasuhara
Department of Urban and Civil Engineering, Ibaraki University, Hitachi1, Ibaraki, Japan

H. Hazarika
Department of Architectural Environmental Systems, Akita Prefectural University, Akita, Japan

Y. Mitarai
Technical Research Center, Toa Corporation, Tokyo, Japan

A.K. Karmokar
Technical Research Center, Bridgestone Corporation, Tokyo, Japan

ABSTRACT: This paper introduces recent Japanese experiences related to scrapped tires for geotechnical applications with a focus placed on tire-chips. Techniques for using tire shreds and chips are classifiable into two categories: tire chips mixed and not mixed with soil. The former techniques include cement-treated clay with tire chips, which possess high ductility and toughness, and the latter describes the cushion effects of tire chips' placement installed close to quay walls which are intended to reduce lateral earth pressures, residual deformations of backfills during earthquakes and ongoing projects of the latter category include tire-chip drains that replace gravel drains as a countermeasure against liquefaction in sand.

1 INTRODUCTION

Scrapped tires provide numerous advantages from the viewpoint of civil engineering practices. They have light weight, high vibration-absorption, high elastic compressibility, high hydraulic conductivity, and temperature-isolation potential. New techniques have emerged to utilize these advantageous characteristics for practical purposes. Mainly, two types of scrapped tire materials are used for civil engineering applications: with and without shredding or cutting into small pieces of several tens of centimeters' or several centimeters' diameter. The former, without shredding, is useful for infrastructural retaining walls and foundations. The material is sometimes reinforced with geosynthetics. On the other hand, in cases with shredding or cutting into pieces of similar size, as with gravel and sand (sometimes called tire-derived aggregate, TDA after Humphrey, 2007), they can be put into practical use for geotechnical application. This latter material type might be more costly than unshredded or uncut material.

Among these possible techniques using the used tires, this paper describes attempts to introduce two possibilities of tire-chips for geotechnical applications. Techniques for using tire-chips are classifiable as cases of tire chips mixed and not mixed with soil. The former techniques include cement-treated clay with tire chips, which possess high ductility and toughness, and non-cement-treated sand mixed with tire chips, which is intended to reduce lateral pressures, lateral displacements and liquefaction potential during earthquakes.

2 UTILIZATION OF USED-TIRE CHIPS WITHOUT ADDITIVES

The tire chips were made from used tires by crushing and subsequent removal of the constituent textiles and metal fibers. The chips therefore have a rough or serrated surface. The specific gravity of tire chips used in this study is 1.15 and the grain size is 2 mm on average. Tire chips are an elastically compressible material, of which Poisson's ratio is nearly 0.5 and the elastic modulus is approximately 4–6 MPa on average, corresponding to 0–15% strain.

2.1 *Application of tire-chips without soil mixing to damage mitigation during earthquakes (Hazarika et al. 2006a, b)*

2.1.1 *Sandwiched backfilling technique*

The environmentally friendly and the cost-effective disaster mitigation technique involve placing a

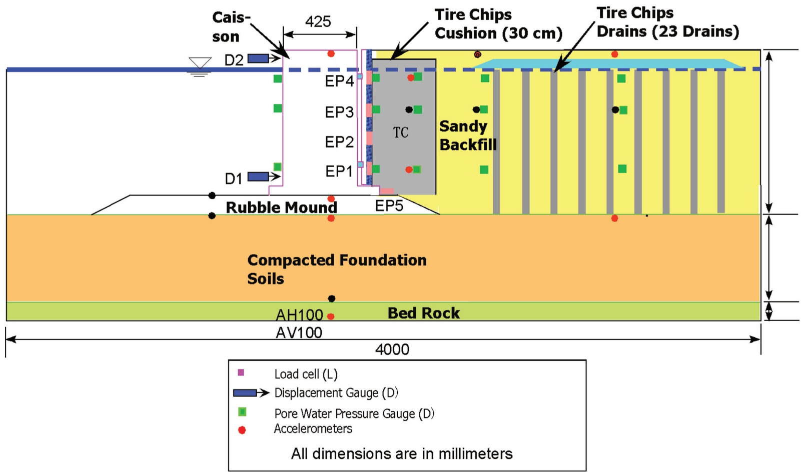


Figure 1. Cross section of the experimental.

cushioning layer of tire chips as a vibration absorber immediately behind the structure. The beneficial effects of such a sandwiched cushioning technique have been described in Hazarika et al. (2006a). In addition, vertical drains made out of tire chips can be installed in the backfill to prevent soil liquefaction. Yasuhara et al. (2004) used tire chips in vertical drains for reducing liquefaction-induced deformation. One function of the cushion is to reduce the load against the structure caused by the energy absorption capacity of the cushion material. Another function is to curtail permanent displacement of the structure attributable to compressible material.

2.1.2 *Underwater shaking-table testing*

Large three-dimensional underwater shaking table assemblies of the Port and Airport Research Institute (PARI) were used in the testing program. The shaking table is circular with 5.65 m diameter; it is installed on a 15 m long × 15 m wide × 2.0 m deep water pool. The details of the shaking table are available in Iai & Sugano (2000).

A caisson-type quay wall (model to prototype ratio of 1/10) was used for testing. Figure 1 shows a cross section of the soil box, the model caisson and the locations of the various measuring devices (load cells, earth pressure cells, pore water pressure cells, accelerometers and displacement gauges). The model caisson (425 mm in breadth) was made of steel plates filled with dry sand and sinker to bring its center of gravity to a stable position. The caisson consists of three parts: the central part (width 500 mm) and two dummy parts (width 350 mm each). All the monitoring devices were installed at the central caisson to eliminate the effect of sidewall friction on the measurements. The soil box was made of a steel container 4.0 m long, 1.25 m wide, and 1.5 m deep. The foundation rubble beneath the caisson was prepared using Grade 4 crushed stone with 13–20 mm particle size. The backfill and the seabed layer were prepared using Sohma sand (No. 5).

The dense foundation sand representing the seabed layer was prepared in two layers. After preparing each layer, the entire assembly was shaken with 300 Gal of vibration starting with a frequency of 5 Hz and increasing up to 50 Hz. Backfill was also prepared in stages using free falling technique; it was then compacted using a manually operated vibrator. After constructing the foundation and the backfill, and setting up of the devices, the pool was filled with water, which gradually elevated the water depth to 1.3 m to saturate the backfill. This submerged condition was maintained for two days so that the backfill can attain a complete saturation stage.

2.1.3 *Test cases*

As was shown in Figure 2, two test cases were examined. In one case (Case A), a caisson with a rubble backfill with conventional sandy backfill behind it was used. In another case (Case B), behind the caisson, a cushion layer of tire chips (average grain size 20 mm) was placed vertically; its thickness was 0.4 times the wall height. In actual practice, the design thickness will depend upon many other factors such as the height and rigidity of the structure, in addition to compressibility and stiffness of the cushion material. In compressible buffer applications, there seems to be an optimum value for the cushion thickness, beyond which increased thickness will not engender a proportionate decrease of the load. The effect of the cushion thickness shaking table test was

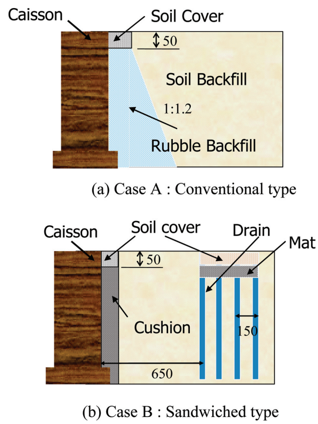


Figure 2. Test cases of backfill.

described using a small-scale model in Hazarika et al. (2006b).

2.1.4 *Test procedures*

The cushion layer was prepared by filling the tire chips (average grain size 10 mm) inside a geotextile bag. Then, the presence of geotextiles prevents flowing of sand particles into the chip structure. The average dry density of the tire chips achieved after filling and tamping was 0.675 t/m^3.The relative densities that were achieved after the backfill preparation were about 50% to 60%, implying that the backfill soil is partly liquefiable. The foundation soils were compacted with a mechanical vibrator to achieve a relative density of about 80%, implying a non-liquefiable foundation deposit. Vertical drains made out of tire chips (average grain size 7.0 mm) were installed in the backfill. They were then installed with a spacing of 150 mm in triangular pattern. The drain diameter was chosen as 50 mm. The tops of all drains were covered with a 50-mm-thick gravel layer underlying a 50-mm-thick soil cover. The purpose of such a cover layer is twofold: one is to allow the free drainage of water and other is to prevent the likely uplifting of the tire chips during shaking because of its lightweight nature. Earthquake loadings of different magnitudes were imparted to the soil-structure system during the tests. The input motions selected were: 1) the Port Island (PI) wave – the strong motion acceleration record at the Port Island, Kobe, Japan during the 1995 Hyogo-ken Nanbu earthquake (M 7.2); and 2) the Ohta Ward (OW) wave – a scenario synthetic earthquake motion assuming an earthquake that is presumed to occur in the southern Kanto region with its epicenter at Ohta ward, Tokyo, Japan. It is noteworthy that the 1995 Hyogo-ken Nanbu earthquake is an intra-plate earthquake, while the scenario earthquake (synthetic)

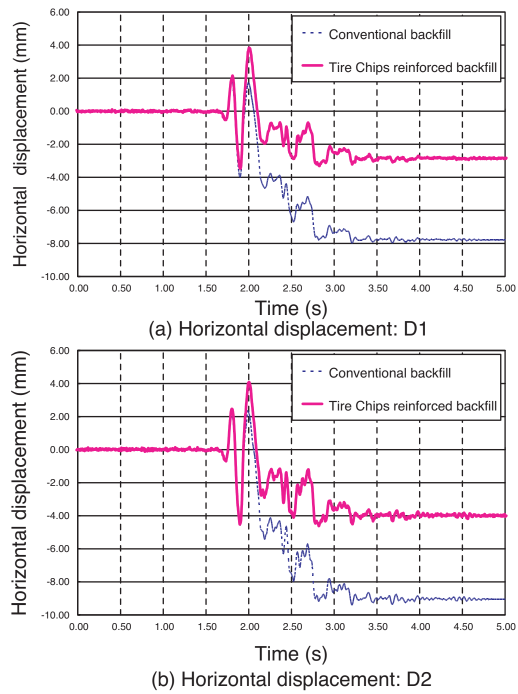


Figure 3. Time history of the caisson displacement.

was constructed assuming an inter-plate earthquake. The loading intensities were varied using the various maximum acceleration ratios (0.5, 1.0, 1.2, and 1.5) of the target acceleration to the actual acceleration. Durations of the shaking in the model testing were based on the time axes of these accelerograms.

2.2 *Test result and discussion*

Various types of earthquake motion with different magnitudes were adopted for this study. However, the discussion here will be mostly limited to series no. 3 (PI 1.0). The PI 1.0 data are the actual recorded data at Port Island, Kobe, with the time axes scaled to fit the model to prototype ratio of 1/10.

The time histories of the horizontal displacements (D1 and D2 in Figure 1) during the loading for the two test cases are compared in Figure 3. Comparisons reveal that the maximum displacement experienced by the quay wall with a tire-chip reinforced caisson (thick continuous line) is toward the backfill, in contrast to the quay wall without any reinforcement (shown in dotted line), for which case it is seaward. The compressibility of the tire chips renders flexibility to the soil-structure system, which allows the quay wall to bounce back under its inertia force; this tendency ultimately (at the end of the loading cycles) aids in preventing the excessive seaward deformation of the wall.

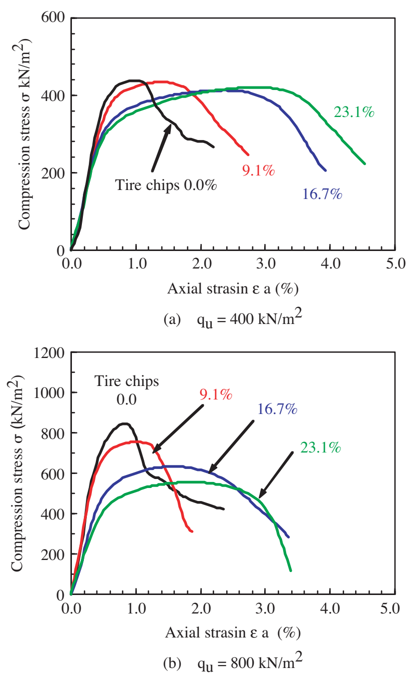


Figure 4. Stress vs. strain curves for unconfined-compression tests on CTCT specimens.

However, the wall with a conventional backfill experiences very high seaward displacements right from the beginning because of its inertia. As a consequence, the structure can not move back to the opposite side and ultimately suffers from a huge permanent seaward displacement.

3 CEMENT-TREATED MARINE CLAY MIXED WITH TIRE-CHIPS (MITARAI ET AL., 2006)

3.1 *Preparation of specimens*

Dredged clay was used to make specimens of the cement-treated clay with addition of tire chips (CTCT). The dredged clay was taken from Tokyo Bay ($\rho s = 2.72$ g/cm^3, $wL = 100\%$ and $Ip = 70$). Its percentage of fine-grained fraction is about 90%. Slurry dredged clay with initial water contents of 250% was mixed with seawater to produce a 1.25 g/cm^3. The cement used was normal Portland cement. The tire chips were made from used tires, and these average grain sizes are 2 mm which particle density is 1.15 g/cm^3. The specimens were prepared to provide two kinds of strength of cement-treated clay, and four kinds of tire chips' contents. The targeted unconfined compressive strength of cement-treated clays were $qu = 400$ or 800 kN/m^2. The mixing conditions of cement-treated clay and the percentage of added tire chips were 0%, 9.1%, 16.7%, and 23.1% within a whole volume of specimen.

3.2 *Undrained behavior*

Figure 4 shows the stress-strain relation of unconfined compressive test (UC-test) on CTCT. These results imply the following; 1) The deformation property of cement-treated clay was changed from brittle into tough, merely by addition of tire chips, 2) The larger the percentage of tire chips in the mixture is, the larger the failure strain becomes. In the case of the cement-treated clay without adding tire chips, the stress-strain relation shows a marked strain-softening behavior. On the other hand, CTCT show strain-hardening behavior, 3) The larger the strength of cement-treated clays is, the smaller the tangent elastic modulus by adding tires chips becomes.

For comparison with the results from UC-tests, undrained triaxial compression tests (TC-test) were conducted under the following condition consolidation stress was 200 kPa (2 hr) and after consolidation, during undrained shear, the confining pressure was maintained constant with 300 kPa. The results from TC-tests were interpreted to investigate the effects of tire-chips contents and hardness of tire chips on toughness improvement. Figures 5 show the stress vs. strain curves for specimens with different contents of tire chips for the target undrained strengths of 400 kN/m^2 and 800 kN/m^2, respectively, although the strain at peak stress for specimens with 800 kN/m^2 is greater than that for specimens with 400 kN/m^2. Figure 5 illustrates a set of comparisons between results in which the target unconfined strength was 800 kN/m^2. Both tests were carried out on three classes of tire-chip contents. This test series was carried out for verifying the effect of confinement on toughness characteristics. It is apparent from comparison between both test results that: 1) the stress and strain curves in triaxial tests exhibit ductile behavior, whereas those in unconfined compression test show brittle behavior, independently of tire-chip content; 2) the ductile behavior in triaxial tests was improved according to the increase in the tire-chip content; 3) as in the ductile behavior improvement, less increase in triaxial undrained strength was observed, even with increasing the tire-chip content, while unconfined compressive strength rather decreases, even with increased tire-chip content.

3.3 *Improvement of hydraulic conductivity*

As shown above, the cement-treated clay shows brittle deformation. Cracks develop with progress of shear deformation; then it is expected that the hydraulic conductivity increases by increasing deformation. But, in

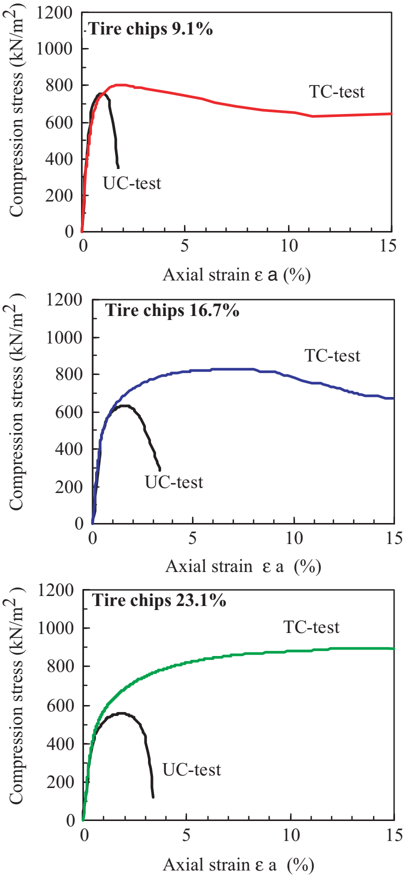


Figure 5. Effect of horizontal stress (Comparison UC-test with TC-test; Target undrained strength of cement treated clay part: qu = 800 kN/m^2).

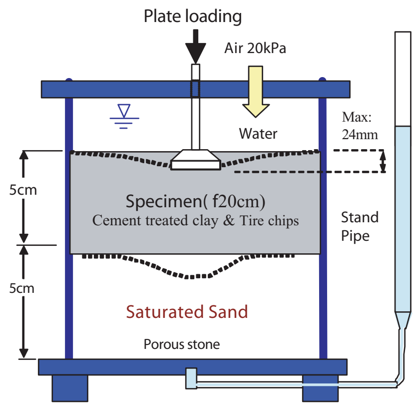


Figure 6. Plate loading tests with measurement of hydraulic conductivity.

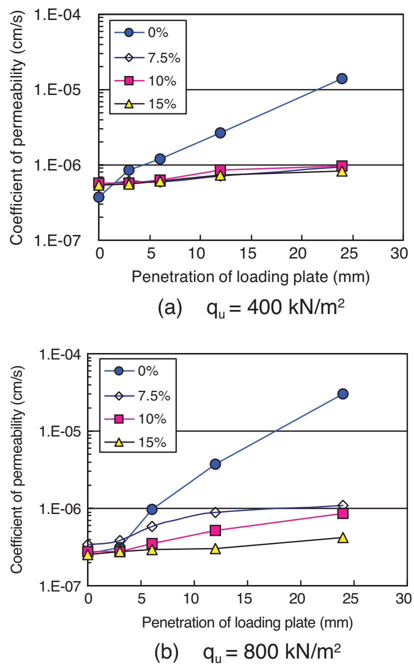
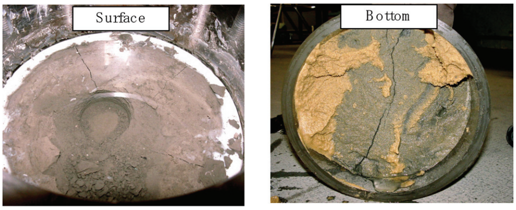
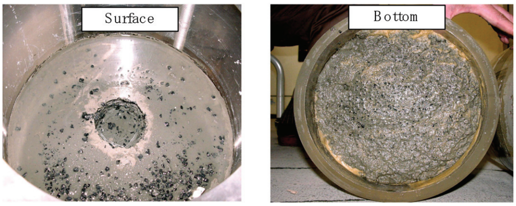


Figure 7. Plate loading tests with measurement of hydraulic conductivity.

the case of adding tire chips, it can be expected that the hydraulic conductivity changes during deformation because the toughness was improved by adding tire chips. To verify that fact, the hydraulic conductivity was measured during shear deformation in the plate loading tests on CTCT. To examine the hydraulic conductivity of a no deformed specimen, we conducted a falling head permeability test. The authors adopted an acrylic fiber cell of 20 cm diameter and 20 cm height, as shown in Figure 7. First, the saturated Toyoura-sand was poured at the bottom of the cell, and then the CTCT was poured on to the sand surface. The thickness of the sand tire and specimen was 5 cm. After the specimen was cured for 7 days under the high moisture condition of more than 95% and constant temperature of 20°C ± 2°C, the falling head permeability test was conducted under the water pressure of 20 kPa applied onto the specimen surface. Figure 7 shows the result of the permeability tests of the cement treated clay. To examine the variations of the hydraulic conductivity of CTCT with deformation in the plate loading tests as shown in Figure 7, we conducted the following examination: the specimen and devices were the same as



(a) With no tire chips addition (at 24 mm peneration)



(b) With 10% tire chips addition (at 24 mm peneration)

Figure 8. Observed appearance of specimens after penetration tests.

above, and the specimen was loaded into the center using a steel loading plate, which had 4 cm diameter. The rate of loading was 15 mm/min.The loading to the specimen was applied gradually, and the permeability test was conducted after unloading. This process was repeated until cracks were readily apparent. In this examination, the loading plate was applied in the center of specimen at a rapid speed; then, the loading plate was penetrated into the specimen. Consequently, the bending deformation was developed in the specimen. Then, it was speculated that the coefficient of permeability might increase by developing some cracks, as compared to that before deformation. Figure 7 shows the relation between the penetration displacement and the coefficients of permeability of CTCT specimen. In this figure, the specimen deformation is shown in the value of penetration by loading plate. As shown in this figure, the change of the coefficient of permeability with deformation was very small in the case of added tire chips (CTCT). On the other hand, the hydraulic conductivity of the cement-treated clay without added tire chips (0% tire-chips) increases with deformation. Figure 8 shows a photograph of the specimen that was taken at 24 mm penetration of the loading plate. It is apparent that the specimen without added tire chips was cracked, but that the specimen of CTCT was not cracked. These observations indicate that the fewer cracks in CTCT are attributable to improving the ductility of cement-treated clay with the added tire chips.

4 CONCLUSIONS

This paper presented descriptions of some recent experiences of the utilization of used tire chips for geotechnical practices. Two techniques were proposed using tire chips that were processed by cutting them into smaller pieces of several centimeters' diameter on average. In one case, a series of model shaking table tests under a 1 *g* gravitational field was conducted to examine the performance of a newly developed sandwiched backfilling technique for earthquake disaster mitigation. In that technique, sandwiched cushions and vertical drains made out of an emerging and smart geomaterial known as tire chips were used as retaining materials behind massive rigid structures such as caisson quay walls. To overcome a salient disadvantage of cement treated clay (CTC), *brittleness*, an attempt was made to mix tire chips with CTC. This technique, abbreviated as CTCT, provided an additional characteristic, toughness or ductility, which was useful for resistance against occurrence of cracks in CTCT during development of shear displacement. This was already put into practice at a disposal yard where CTCT was used as a sealing material to protect leakage of contaminated materials.

ACKNOWLEDGEMENTS

The studies described in this paper have been financially supported by the Grants-in-Aid from the Ministry of Land, Transportation and Infrastructure and the Ministry of Education, Culture, Sports, Science and Education of the Japanese Government. The author is indebted to Drs. Sugano and Yoshiaki Kikuchi of Port and Airport Research Institute, Dr. Takao Kishida of Toa Corp., and Mr. Hideo Takeichi of Bridgestone Corp. for their strong support in carrying out the research project successfully.

REFERENCES

Hazarika, H., Kohama, E., Suzuki, H. & Sugano, T. 2006a. Enhancement of Earthquake Resistance of Structures using Tire chips as Compressible Inclusion. *Report of the Port and Airport Research Institute* 45(1): 1–28.

Hazarika, H., Sugano, T., Kikuchi, Y., Yasuhara, K., Murakami, S., Takeichi, H., Karmokar, A.K., Kishida, T. & Mitarai, Y. 2006b. Evaluation of Recycled Waste as Smart Geomaterial for Earthquake Resistant of Structures. 41*st Annual Conference of Japanese Geotechnical Society, Kagoshima*, pp. 591–592.

Humphrey D.N. 1998. Civil Engineering Applications of Tire Shreds, *Manuscript Prepared for Asphalt Rubber Technology Service*, SC, USA.

Humphrey, D. N., Whetten, N., Weaver, J., Recker, K. & Cosgrove, T. A. 1998. Tire shreds as lightweight fill for embankments and retaining walls. *Recycled Materials in Geotechnical Applications, ASCE, Geotechnical Special Publication* 79: 51–65.

Humphrey, D. N. 2007. Tire derived aggregates as lightweight fill for embankments and retaining walls, Special Invited Lecture, *Proc. International Workshop on Scrap Tires Derived Geomaterials*, pp. 56–79, Yokosuka, Japan.

Iai, S. 1989. Similitude for Shaking Table Tests on Soilstructure- fluid Model in 1 *g* Gravitational Field. *Soils and Foundations* 29(1): 105–118.
Iai, S. & Sugano, T. 2000. Shake Table testing on Seismic Performance of Gravity Quay Walls, *12th World Conference on Earthquake Engineering, WCEE*, Paper No. 2680.
Mitarai, Y. et al. 2006. Application of the cement treated clay with tire-chips added to the sealing materials of coastal waste disposal site. *Proc. 6th International Congress on Environmental Geotechnology*, *Cardiff, UK*, Vol. 1.
Yasuhara, K., Komine, H., Murakami, S., Taoka, K., Ohtsuka, Y. & Masuda, T. 2005. Tire chips drain for mitigation of liquefaction and liquefaction-induced deformation in sand. *Proc. of Symposium on Technology of Using Artificial Geomaterials, Fukuoka, Japan*, pp. 115–118 (in Japanese).
Yasuhara, K., Karmokar, A.K., Kato, Y., Mogi, H. & Fukutake, K. 2006. "Effective utilization technique of used tires for foundations and earth structures." *Kisoko* 34(2): 58–63 (in Japanese).
Yasuhara, K. 2007. Recent Japanese experiences on scrapped tires for geotechnical applications, Keynote Lecture, *Proc. International Workshop on Scrap Tires Derived Geomaterials*, pp. 17–40, Yokosuka, Japan.