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EFFECTS OF GEOSYNTHETIC REINFORCEMENT ON THE MECHANICAL BEHAVIOUR OF COMPOSITE MATERIALS FOR VIBRATION ISOLATION

D.R. Manohar
Research Scholar, Department of Civil Engineering, Indian Institute of Science, Bangalore, 560012, India. manohardr@civil.iisc.ernet.in

P. Anbazhagan*
Assistant Professor, Department of Civil Engineering, Indian Institute of Science, Bangalore, 560012, India. anbazhagan@civil.iisc.ernet.in (Corresponding Author)

M. Neaz Sheikh
Senior Lecturer, School of Civil, Mining and Environmental Engineering, University of Wollongong, NSW, Australia. msheikh@uow.edu.au

Hing-Ho Tsang
Senior Lecturer, Faculty of Science, Engineering and Technology, Swinburne University of Technology, Melbourne, Australia. htsang@swin.edu.au

ABSTRACT

This study investigates the mechanical behavior of geosynthetic-reinforced composite materials, Sand-Tyre Crumb Mixtures (STCM) by conducting Unconsolidated Undrained (UU) triaxial tests. The main objective of this study is to evaluate the stress-strain characteristics of STCM in geosynthetic-reinforced works. The mechanical behavior of geosynthetic-reinforced STCM has been investigated by varying proportions of tyre crumbs (50% and 75% tyre crumbs by volume), type of geosynthetic (geotextile, geogrid and geonets), number of geosynthetic layers (1 to 4 layers) and confining pressure. A series of UU triaxial tests has been carried out to select the optimum size of tyre crumb. Tyre crumb that provides comparatively higher stiffness is considered as the optimal size and has been used in the investigation on geosynthetic-reinforced STCM. The results demonstrate that STCM reinforced by geotextile has enhanced peak strength, axial strain at failure, energy absorption and ductility capacity. Also, it has been found that the type of geosynthetic significantly influences the shear strength of STCM.

KEYWORDS

Geosynthetic, reinforcement, composite materials, stress-strain.

INTRODUCTION

Natural and man-made vibrations are undesirable for structures, as structural stability, durability, and performance are affected considerably. Vibration reduction can be attained either by increasing the damping capacity or by increasing stiffness of the structure and the construction materials. Rubber is commonly used as a vibration damping material due to its viscoelasticity (Ganeriwala, 1995; Tsang, 2008; Tsang et al., 2012). The damping properties of the rubber crumbs derived from the waste tyres are yet to be exploited to use them effectively in common civil engineering applications. Scrap tyre derived recycled products (such as tyre chips and tyre shreds) has been called "smart-geomaterial," due to their good permeability, high strength, compressibility, and the absence of strain localization (Hazarika et al., 2008; Sheikh et al., 2013).

On an average, scrap tyres are generated one per capita annually in many countries (Edil & Bosscher, 1994), and the amount of disposal has been increasing rapidly particularly in developing countries. It is challenging and expensive to dispose them safely without any threat to human health and the environment, and it also represents a possibility of fire and health hazards. Hence, there is an urgent need to find a new beneficial ways of recycling the waste tyres. Over the last few years, recycling of waste tyres as construction materials has been considered important to solve economical and technical problems for a sustainable environment. Utilizing rubber tyres in vibration mitigation due to its high energy absorption capacity can be a viable approach of resolving the chronic problems associated with disposal of waste tyres.

High-damping composite materials, such as Sand-Tyre Crumb Mixtures (STCM), have proven to be suitable for vibration isolation. However, the compressible STCM may be unfavorable for carrying the gravity loads. This paper investigates the effect of geosynthetic reinforcement on the strength of STCM through triaxial compression test. Three types of geosynthetics (geogrid, geonets and geotextile) were used for reinforcing STCM in layered form. A series of UU triaxial tests has been carried out to select the optimum size of tyre crumbs, from tyre crumb sizes of 2.00 – 1.00 mm (passing the 2.0 mm sieve and retained on 1.00 mm sieve, designated as A), 4.75 – 2.00 mm (B), 5.60 – 4.75 mm (C), 8.00 – 5.60 mm (D), 9.50 – 8.00 mm (E), 12.50 – 9.50 mm (F), and 20.00 mm – 12.50 mm (G). The tyre crumb size that provides comparatively higher stiffness and energy absorption capacity is considered as the optimal size and has been used in the investigation on geosynthetic-reinforced STCM. The main objective of this paper is to evaluate the stress-strain characteristics of STCM in geosynthetic-reinforced works. The mechanical behavior of geosynthetic-reinforced STCM has been investigated by varying proportions of tyre crumbs (50% and 75%), type of geosynthetic (geotextile, geogrid and geonets), number of geosynthetic layers (1 to 4 layers), and confining pressure (20, 60 and 100 kPa).

MATERIALS USED FOR TESTING

Sand and Rubber

In the present study, sand and manufactured scrap tyres in Bangalore India were used. The soil particles used in the present study were granular passing through a 4.75 mm sieve and retained on 0.075 mm. The specific gravity of the sand is 2.65, estimated as per ASTM D854 (2010). The sand is classified as uniformly graded sand according to the unified classification system, ASTM D2487 (2003). Other details of sand are presented in Table 1. Tyre crumb were prepared with special machinery where scrap tyres were crushed into pieces and powdered after removing steel belts. The processed tyre crumbs obtained from industry were sieved into groups of seven different sizes from A to G, as mentioned above. The specific gravity and water absorption values of tyre crumbs are determined in accordance with ASTM D854 (2010) and ASTM C128 (2007), except that the specimens were air dried rather than oven dried at the beginning of the test. The obtained specific gravity and water absorption were found to be 1.14 and 3.85.

Geosynthetics

Three types of geosynthetics have been adopted for reinforcement, namely geotextile, geonets and geogrids. The physical and mechanical properties of geosynthetics are presented in Table 2. The load elongation behavior of the geosynthetics in the wide width tension test is shown in Figure 1. The beneficial effect of geosynthetic material is largely dependent on the type of material used as reinforcement.

SAMPLE PREPARATION AND TESTING PROCEDURE

The amount of sand and tyre crumb required for each percentage composition was estimated for all the crumb sizes. Tyre crumb specimens were prepared by hand mixing with dry sand. The sand-tyre crumbs were transferred into the mould in layers with uniform mix to avoid segregation during the sample preparation. The UU triaxial tests were carried out on sample size of 50 x 100 mm for crumb sizes A to D, and 100 x 200 mm for crumb size of E to G for the respective densities of STCM and for effective confining pressures of 20, 60 and 100 kPa to select the optimum size of tyre crumb. The samples were tested according to ASTM-D2850 (2007). The prepared STCM samples were poured into vacuum split mould in 4 to 5 layers to achieve uniform mix, and were slightly compacted for a higher percentage of rubber. Triaxial tests were carried out on STCM at a constant strain rate of 1.25 mm/min.

Table 1. Properties of sand used in the study

Description	Value
Effective size, D_{10}	0.2 mm
D_{30}	0.4 mm
Mean size, D_{50}	0.6 mm
D_{60}	0.71 mm
Uniformity coefficient (*Cu*)	3.50
Curvature coefficient (*Cc*)	1.14
Specific Gravity	2.65
Maximum dry density	1.786 g/cc
Minimum dry density	1.434 g/cc
Relative density adopted	80 %
Friction angle	35^o

Table 2. Mechanical properties of geosynthetic material

Type of geosynthetic material	Mass (g/m^2)	Thickness (mm)	Effective opening size (mm)	Ultimate tensile strength (kN\m)	Axial strain at failure (%)	Secant modulus at 5% strain
Geogrid	39.2	1.0	9.0	1.60	14.47	40
Geonet	74.4	1.5	8.0	5.95	47.37	50
Geotextile	21.4	0.3	1.0	9.50	107.89	60

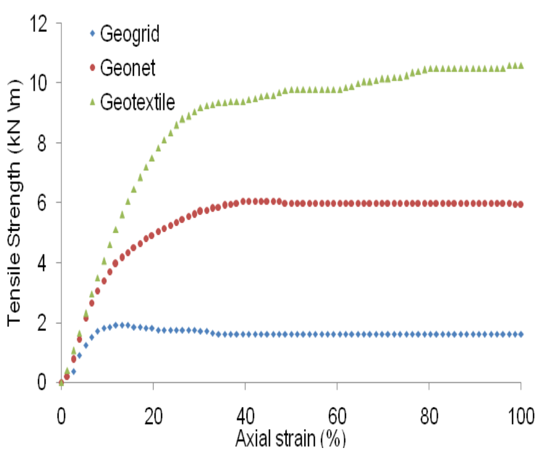

Figure 1. Load elongation behavior of geosynthetics

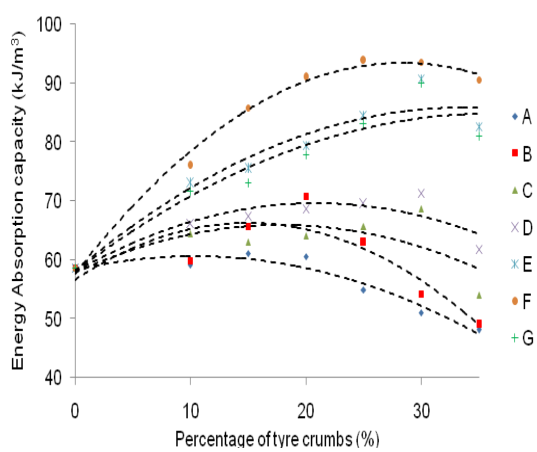

Figure 2. Typical plot of energy absorption capacity for different crumb sizes and contents for confining pressure of 100 kPa.

For the selected optimum size of tyre crumb, the effects of reinforcement on mechanical behavior of STCM were investigated. All reinforcement tests were conducted with a sample size of 100 x 200 mm with geosynthetics arranged in horizontal layers where each layer was arranged with equal space (geosynthetic placed at H/2 for 1-layer, H/3 for 2-layers, H/4 for 3-layers, and H/5 for 4-layers, where H is the height of the sample). Geosynthetics were arranged in horizontal layers, as this could improve the strength mainly by friction, and interlocking between soil and the reinforcement (Madhavi and Vidya, 2007). The diameter of reinforcement was slightly less than that of the sample. UU triaxial tests on geosynthetic reinforced STCM were carried at the strain rate of 1.25 mm/min. Most of the tests were carried out up to strain level of 20%. All the necessary corrections were considered and applied.

RESULTS AND DISCUSSION

The effects of energy absorption and strength characteristics of the composite materials were examined through Unconsolidated Undrained (UU) triaxial test in order to select the optimum size of tyre crumb from different size range (A to G). The higher the rubber content in STCM, the higher will be the viscoelasticity of the material, but the lower will be the load carrying capacity. To enhance the shear properties of compressible STCM, reinforcement study was carried out. The results of the geosynthetic reinforcement with STCM through laboratory tests are presented with discussion highlighting the effects of various parameters.

Influence of Tyre Crumb Size

Many researchers have reported that the difference in chips/crumb sizes may result in different stiffness. To study the effect of crumb size on shear properties of STCM, a series of UU tests was carried out. Shear strength of STCM increases with increasing tyre crumb size from A to F, and it decreases thereafter (G). The optimum percentage mix of tyre crumbs for enhanced shear strength of STCM varies for different sizes of crumbs (A to G). In this study, the shear properties of sand were increased with the addition of tyre crumbs, which might be due to the influence of tyre crumb length, aspect ratio (length/diameter), stiffness of tyre crumbs, orientation of tyre crumbs, sand friction angle and confinig stress (Gray and Ohashi, 1983). Typical plot of energy absorption capacity for different crumb sizes and composition (A to G) for confining pressure of 100 kPa is shown in Figure 2. The area under the stress-strain curve up to a given value of strain is the total mechanical energy per unit volume consumed by the material while straining it to that value (Roylance, 2001).

The results demonstrated that the crumb size tended to be more effective in increasing the shear properties of STCM. Shear strength increases with increase in crumb size up to crumb size F, but for larger crumb size G, shear strength was found lower than that for crumb size F. Considering all the crumb sizes, crumb size F provides comparatively higher energy absorption capacity and stiffness. Hence crumb size F is considered as an optimum mix, and is further used for geosynthetic reinforcement study with a higher percentage of rubber in STCM (50% and 75% tyre crumbs by volume).

Influence of Geosynthetic Reinforcement

Reinforcement studies were carried out for a higher percentage of rubber i.e., 50% and 75% rubber by volume with the selected optimum size of F. Stress-Strain plot for 50% and 75% STCM compared with sand is shown in Figure 3. The maximum shear strength of 50% STCM were close to that of sand, but for 75% crumb mixtures, the maximum shear strength was found lower than that of sand. Energy absorption capacity of sand, 50% of STCM and 75% of STCM were 59, 55.65 and 46.11 kJ/m^3 respectively. Hence the present study is carried out to increase the shear strength properties of STCM through geosynthetic reinforcement for a higher percentage of rubber in STCM for the selected crumb size of F.

Typical stress-strain curves for reinforced STCM (50% STCM) with different types of geosynthetics and with different number of geotextile layers for confining pressure of 100 kPa is shown in Figure 4 and Figure 5, respectively. These figures indicate that geosynthetic inclusion increases the failure and ultimate strength significantly. Also, increase in strength varies with different types of geosynthetics which can be clearly seen from Figure 4. Results indicated that for 50% STCM, STCM reinforced with geotextile resulted in the largest increase in strength, whereas for 75% STCM, geonets led to the highest strength. Meanwhile,the reinforced STCM exhibited higher axial strain at failure compared to that of unreinforced STCM for both 50% and 75% tyre crumbs by volume, which depends on the type of reinforcement and number of layers.

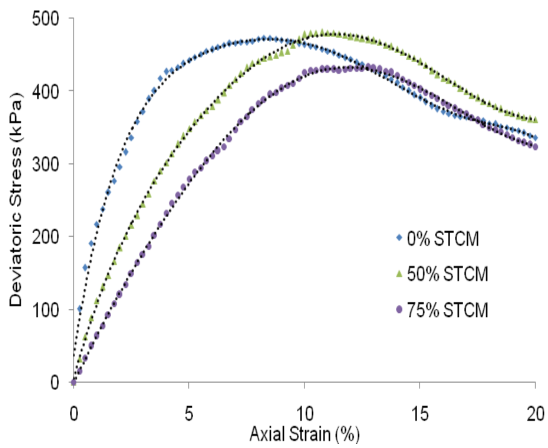

Figure 3. Stress-Strain plot for unreinforced STCM for tyre crumb size F

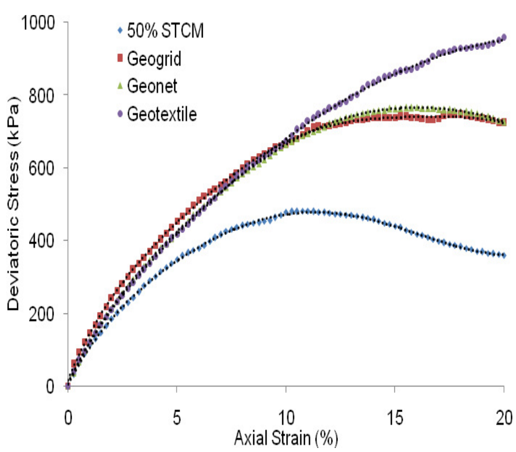

Figure 4. Stress-Strain curve for different types of reinforcement for 50% STCM with confining pressure of 100 kPa

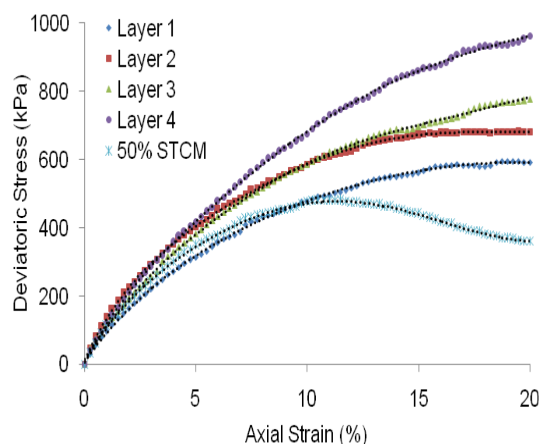

Figure 5. Stress-Strain curve for different layering of geotextile for 50% STCM with confining pressure of 100 kPa

The results demonstrated that with the increase in the layers of reinforcement, the peak and failure strengths increase significantly with a corresponding increase in axial strain. As it can be seen from Figure 5, geotextile reinforced with 50% STCM exhibits twice the increase in shear strength for 4-layer reinforcement compared to unreinforced STCM. Geotextile inclusion increased the energy absorption capacity and reduced the brittleness index (a measure of ductility capacity was based on the brittleness index (I_B), which is a function of q_f and q_{ult}, as the brittleness index decreases towards zero, failure mechanism becomes more ductile) values close to zero. In fact, increasing the number of geosynthetic layers resulted in higher energy absorption capacity and less brittleness index value, which resulted in STCM being more ductile. The energy absorption capacity increases by more than two times, for 50% STCM reinforced with 4-layer of geotextile, and 75% STCM reinforced with 4-layer of geonets. The brittleness index values as low as 0.01 is noted in the above mentioned cases. The stiffness of the geosynthetic reinforced STCM increases when compared to unreinforced STCM.

Stiffness also increases with an increase in the layer of reinforcement and confining pressure. With the effects of reinforcement on STCM, it becomes more capable and reliable for carrying gravity loads and it also becomes more ductile for vibration isolation.

CONCLUSIONS

This paper presents the results of experimental investigations on geosynthetic reinforced STCM. A series of Unconsolidated Undrained (UU) triaxial tests has been carried out for selecting the optimum size of tyre crumb. The Crumb size that provides the highest stiffness and energy absorption capacity compared to other crumb size has been considered as the optimal size (crumb size F) and was used in the subsequent investigation on geosynthetic-reinforced STCM. All reinforced STCM demonstrated significantly different stress-strain relationship as compared to unreinforced STCM. It is shown that the reinforcement has enhanced the peak and ultimate stresses and were associated with a larger axial strain. Strength improvement is significantly affected by the type of reinforcement (geogrid, geonet and geotextile), layer of reinforcement (1 to 4) and confining pressure. 50% of STCM reinforced by geotextile with 4 layers demonstrated a maximum increase in shear strength, but 75% STCM reinforced by geonets with 4 layers led to a maximum increase in shear strength properties. Geosynthetic reinforcement increased the energy absorption capacity by 2 times for both STCM's, and reduced the brittleness index values to as close as zero when compared to unreinforced STCM.

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