The Direct Shear Strength of Sand -Tyre Shred Mixtures

J. S.Vinod, N. Sheikh, D. Mastello, B. Indraratna and M.S. Mashiri

School of Civil, Mining & Environmental Engineering, University of Wollongong, Wollongong, NSW 2522, Australia

ABSTRACT: Waste tyres are currently being stockpiled in large quantities around the world causing adverse environmental impact. Significant research is currently underway to investigate possible options for the reuse of waste tyre, particularly in civil engineering applications. One such option is to utilise waste tyre (in the form of tyre shreds) and sand mixture as a lightweight fill material in infrastructure constructions. Utilising waste tyre in civil engineering projects has multiple benefits, including effective recycling of the waste tyre easing the strain on natural fills, reducing material costs and enhancing the geotechnical properties of the soil. Understanding the shear and volume change behaviours of waste tyre and sand mixture is critical before recommending the mixture as an appropriate lightweight-reinforcing structural fill. Therefore, the objective of this study is to investigate the effect of tyre shreds on the shear behaviours of sand using large scale direct shear apparatus. The effect of tyre shreds on the vertical strain (volume change) behaviour of sand has also been investigated. It has been observed that tyre shreds have significant influence on the shear and vertical strain behaviours of sand. The findings of this study demonstrate that overall improvements in the soil characteristics, such as enhanced shear strength, can be achieved by the addition of tyre shreds

1 INTRODUCTION

Australia, like many other countries, is in danger of being overrun by scrap tyres. For instance, during 2007-2008, about 52.5 million pneumatic passenger car tyres were discarded. Approximately 70% of these scrap tyres went in the landfill or were illegally dumped or stockpiled (Australian Government, 2010). If this trend continues, within next 20 years, 680 million waste tyres may end up in the landfill. The current practice of placing waste tyres in the landfill and stockpiling is ultimately unsustainable, and hence effective recycling solutions may urgently need to be explored and implemented (Australian Government 2010). Existing techniques of scrap tyre recycling include reclamation of the original synthetic through devulcanization, re-utilisation as a low-grade rubber replacement, and combustion as an energy source in concrete kilns, paper mills and boilers. Recently, a lot of research studies have been carried out on the potential use of scrap tyre in engineering applications. Nevertheless, only a limited amount of scrap tyres are used in some civil engineering applications, which include rubber-modified asphalt, concrete filler/aggregate, lightweight structural fill, slope stabilisation, earthquake damping, control of ground erosion, and soil reinforcement (Edeskar, 2004).

In the recent past, a lot of research studies have been reported on the properties of scrap tyres including its potential engineering applications (e.g. Edil and Bosscher 1994; Foose et al. 1996; Masad et al. 1996; Tatlisoz et al., 1998; Lee et al., 1999; Youwai and Bergado 2003;Ghazavi and Sakhi, 2005; Zornberg et al., 2004; Hataf and Rahimi, 2005; Rao and Dutta 2006; Lee et al. 2007; Sheikh et al., 2013; Mashiri et al., 2015a and Mashiri et al., 2015b). Few studies have reported that the addition of tyre crumbs (granulated rubber) in sand has been found to reduce the shear strength of sand (e.g. Masad et al., 1996; Youwai and Bergado, 2003; Sheikh et al., 2012). Ahmed (1993) and Zornberg (2004) observed that the behaviour of sand-tyre mixture varied from sand-like to rubber-like with increasing amount of tyres in the mixture. Foose et al., (1996) carried out large scale ring shear test to evaluate the effect of shredded tyre fragments in reinforcing the sand. They have concluded that shear strength of sand depends on the normal stress, shred content and sand matrix unit weight. Rao and Dutta (2006) reported an increase in the apparent cohesion with increase in the shred content based on triaxial testing. Mashiri et al., (2015a) highlighted significant shear strength improvement together with the reduction of dilatancy of sand with the inclusion of tyre chips, especially in sand-rubber behaviour zone where both sand and tyre chips form the skeleton of the matrix material.

This study evaluates the shear behaviour of sand-tyre shred mixtures, using large scale direct shear testing to evaluate the possible benefits of replacing virgin soil with scrap tyre-soil mixtures.

In order for the tyre shreds to be an effective light-weight fill and reinforcing material, it must provide increased shear strength to sand without incurring any significant adverse volume change, such as excessive compression or dilation.

2 MATERIALS AND METHODS

In this study, experimental investigations have been carried out in a large scale direct shear box with 300 mm x 300 mm cross-section and 190 mm height. The particle size distribution of the beach sand used for the study is shown in Fig.1. The specific gravity of the sand was measures as 2.67. The minimum and maximum dry unit weights of sand were 14.60 kN/m^3 and 16.41 kN/m^3, respectively. The scrap tyres in the form of tyre shreds are used for the testing program (see inset of Fig. 1). The size distribution of scrap tyre is presented in Fig.1. The specific gravity of the tyre shreds was measured as 1.13. This is within range of the specific gravities of scrap tyres (1.02 to 1.30) reported by different investigators (e.g., Humphrey et al. 1993;

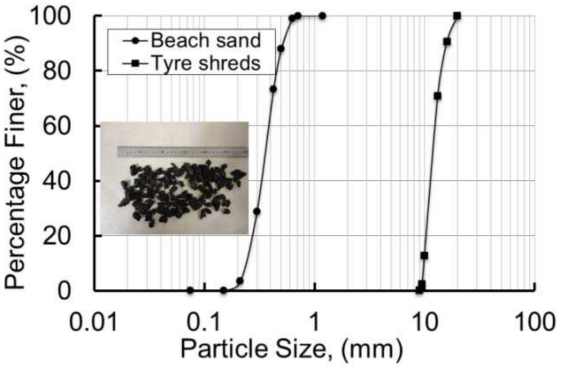

Fig. 1 Particle size distributions of Sand and Tyre Shreds.

Edil and Bosscher, 1994; Foose et al. 1996; Ghazavi and Sakhi, 2005). The sand and tyre shred samples were prepared by thoroughly mixing and placing three layers of sand and tyre shred (equal mass) in the shear box. Each layer of sand-tyre shred (S-TS) mixture was compacted in the shear box to achieve the required sand matrix unit weight. The S-TS mixtures were prepared at a relative density of 75%, corresponding to a sand matrix unit weight of 15.91 kN/m^3. The sand matrix unit weight (γ_m)is defined as:

$$\gamma_m = m_s g/(V_s + V_{vTS}) \quad (1)$$

where, m_s is the mass of sand in t, g is acceleration due to gravity (9.81 m/s^2), V_s is the volume of sand particles (m^3) and V_{vTS} is the volume of voids of TS (m^3). The tests have been carried out on S-TS mixtures with different gravimetric percentages of TS (e.g., 0%, 10% and 30%). The gravimetric percentage of TS is defined as the ratio of the mass of tyre shreds to the total mass of sand and tyre shreds. The S-TS mixtures were sheared at a constant horizontal strain rate of 0.367 mm/min.

3 RESULTS AND DISCUSSIONS

3.1 *Influence of the percentage of tyre shred (TS)*

Fig. 2 shows the variation of shear stress with the horizontal strain for different percentages of TS. It is evident from the Fig. 2 that TS have a significant influence on the shear behaviour of sand. The shear stress increases with the increase in the percentage of TS. The increase in the shear stress with TS content is a result of the increased interlocking between sand/tyre shred and tyre shred/tyre shred fragments.

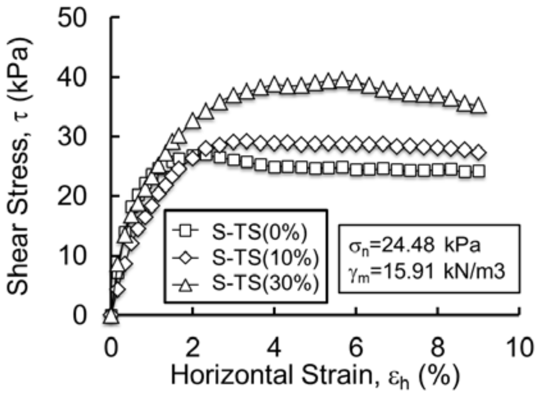

Fig. 2 Variation of shear stresswith horizontal strain for different amounts of TS.

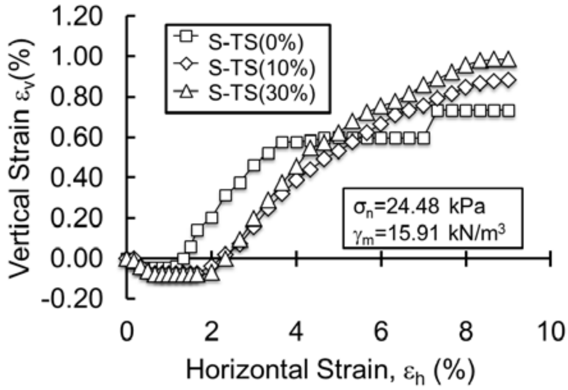

Fig. 3 Variation of vertical strain with horizontal strain for different amounts of TS.

Fig. 3 shows the variation of the vertical strain with the horizontal strain of sand for various percentages of TS. It is shown that all the samples show initial compression at early stages of shearing followed by vertical expansions at higher horizontal strains. It is noted that S-TS mixtures shows a higher value of ε_v for ε_h>4%.

3.2 *Effect of the normal stress (σ_n)*

Figs. 4 & 5 show the influence of normal stress on the shear behaviour of S-TS(30%) mixture. As expected, the shear stress and initial stiffness increase with increase in the normal stress (Fig.4). In addition, the horizontal shear strain corresponding to peak shear stress increases with the increase in the normal stress. It can be noticed that a distinct peak shear stress becomes less prominent with the increase in the normal stress. Fig.5 shows the effect of normal stress on the vertical strain for S-TS(30%) mixture. It is shown that the vertical strain decreases with the increase in the normal stress. In other words, dilation of the mixture decreases with the increase in the normal stress.

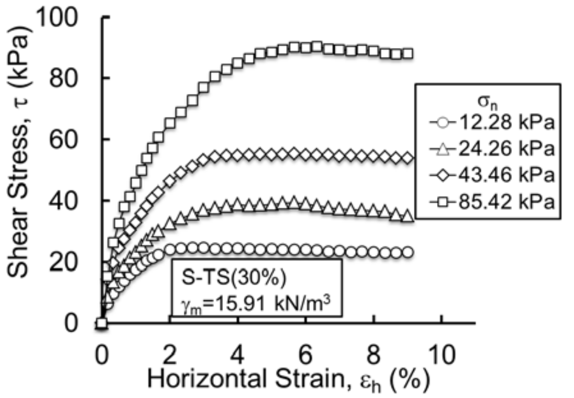

Fig.4 Variation of shear stress with horizontal strain for different normal stress.

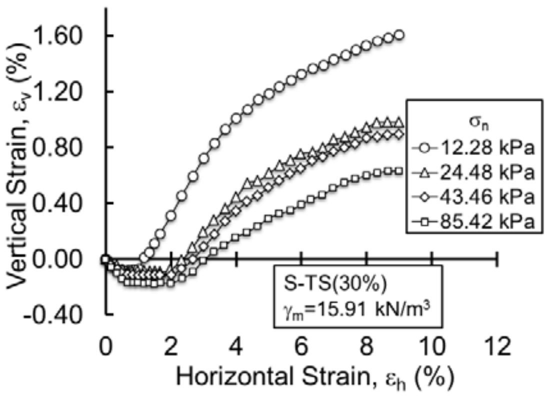

Fig.5 Variation of vertical strain with horizontal strain for different normal stress.

Fig. 6 shows the variation of peak shear stress with normal stress for S-TS(10%) and S-TS(30%). Also, the results of sand-tyre shred mixtures (S-TS) at γ_m=16.8 kN/m^3 in Foose et al. (1996) are presented in Fig.6 for comparison. It is evident from the Fig.6 that results of the current study compare well with the experimental results of Foose et al. (1996). It is noted that S-TS mixture shows a trend of bilinear shear envelope very similar to Foose et al. (1996). For instance, S-TS (30%) shows two distinct friction angles before and after a normal stress of 24.48 kPa. However, a detailed experimental investigation has to be carried out at low normal stress to confirm the bilinear trend for higher percentages of TS. Moreover, the friction angle increases with the increase in the percentage of TS in the mixtures. The increase in the friction angle of the S-TS mixtures is due to the mobilized interactions between sand-shred, shred-shred and sand-sand as reported by Al-Refeai (1990).

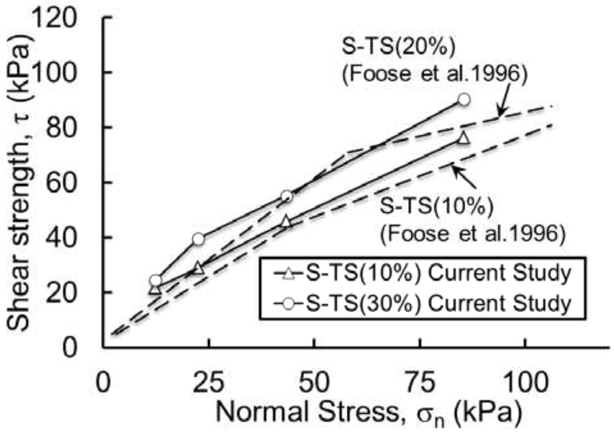

Fig. 6 Variation of shear stress with normal stress for sand-tyre shred (S-TS) mixtures

3.3 *Influence of the sand matrix unit weight (γ_m)*

Figs. 7 & 8show the influence of the sand matrix unit weight on the shear strength and vertical strain behaviour of S-TS mixtures at σ_n=43.46 kPa. It is evident from Figs. 7 & 8 that matrix unit weight has a significant influence on the shear and vertical strain behaviour of S-TS mixtures. The peak shear stress and the vertical strain are significantly reduced with the reduction of sand matrix unit weight for S-TS(0%). On the other hand, the peak shear strength of S-TS(10%) and S-TS(30%) is not significantly affected by the reduction in γ_m. However, both the mixtures have shown significant increase in initial stiffness and ductility (softening behaviour of S-TS(0%) decreased) at high strain level. The vertical strain behaviour of S-TS mixtures was significantly reduced by the reduction of the dry unit weight (Fig. 8) without affecting the peak shear stress.

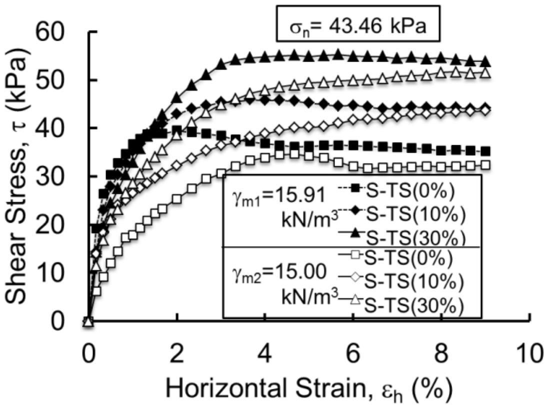

Fig.7 Variation of shear stress with horizontal strain for different sand matrix unit weight.

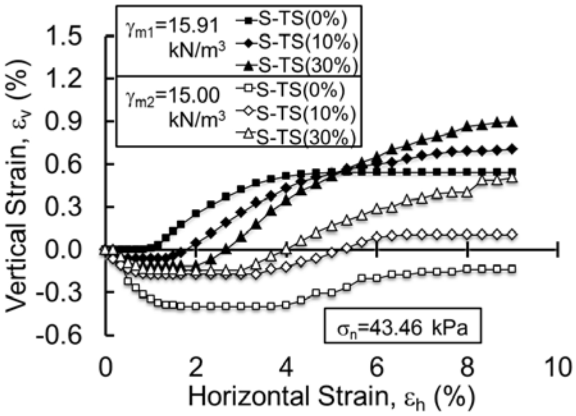

Fig.8 Variation of vertical strain with horizontal strain for different sand matrix unit weight.

4 CONCLUSIONS

This paper has presented the laboratory test results on the shear and vertical strain behaviour of sand-tyre shred (S-TS) mixtures. It was found that the tyre shreds (TS) have a significant influence on the shear and vertical strain behaviour of sand. The shear stress of sand increases with the increase in TS. For example, a 47% increase in peak shear stress was observed with the addition of TS =30% at σ_n= 24.48 kPa. A more ductile behaviour was observed with the addition of TS. S-TS mixtures exhibit compressive behaviour at low horizontal strain, but show a higher value at large horizontal strain compared to S-TS(0%). Moreover, the friction angle increases with the increase in TS. A bi-linear shear envelope has been observed for the S-TS(30%), however, requires more data for validation. S-TS mixtures show higher shear stress and vertical strain with the increase in sand matrix unit weight. It is important to note that lower sand matrix unit weight significantly reduces the dilatancy without affecting the peak shear strength of the S-TS mixtures. Moreover, the results of this study are in agreement with the findings of the earlier investigators (e.g. Fooseet et al., 1996 & Rao and Dutta, 2006).

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