Shear Strength Behaviour of Tire Derived Aggregate – Lateritic Soil Mixtures

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ABSTRACT
Use of tire derived aggregate (TDA) – soil mixtures in embankment construction is becoming an accepted technique among the alternative technologies for environmentally correct disposal of scrap tires. Applications of TDA in tropical soils require knowledge on the mechanical response of the resulting mixtures. In this paper, an experimental testing program was carried out using a direct shear apparatus in order to examine the shear strength behaviour of mixtures of TDA (tire buffings) and a lateritic soil. For the range of confinement levels considered in this study, TDA was found to considerably increase the shear strength of the mixture. The reinforcement provided by the TDA in the soil is maximum for a TDA content of 40% by weight. The contribution of the TDA to reinforcement mechanisms was comparatively less significant at low strains.

RESUMEN
El uso de mezclas de agregados derivados de neumáticos y suelo para la construcción de rellenos se está convirtiendo en una práctica común entre las alternativas tecnológicas para la eliminación correcta de los neumáticos de desecho. Aplicaciones de agregados de neumáticos en los suelos tropicales necesitan de conocimientos previos sobre la respuesta mecánica de la mezcla resultante. En este trabajo, un programa experimental fue desarrollado a través de ensayos de corte directo a fin de examinar la resistencia al corte de las mezclas de agregados de neumáticos y un suelo laterítico. Para los niveles de confinamiento utilizados, se encontró que el agregado de neumáticos aumenta considerablemente la resistencia al corte de la mezcla. El refuerzo proporcionado por la adición de neumáticos es máximo para un contenido de neumáticos de 40% en peso. La contribución del agregado de neumático como refuerzo para la mezcla fue menos importante en bajas deformaciones.

1 INTRODUCTION

Tire demand in the world is growing in line with the economic development of the developing countries. In Brazil, more than 65 million tires are manufactured annually (ANIP 2010). A large quantity of tires is also imported to the country. Unfortunately, most of the used tires are not adequately discarded. Scrap tires are illegally dumped in landfills, rivers, valleys, abandoned properties, and other inappropriate locations. Estimates indicate that there are more than 100 million tires stockpiled across the country (Lopes et al. 2002).

In an attempt to reduce depletion of natural resources, specific environmental legislation on the destination of used tires has been put forward in Brazil. Tire manufacturers and importers are now responsible for the complete lifecycle of the product. For each new tire put on the market, one discarded tire must be collected and given an environmentally adequate end use (Conama, 2009). Brazilian legislation also forbids the import of retreaded tires and tire waste. Manufacturers and importers of tires are required to support research and development on techniques for reusing and recycling of scrap tires.

One adequate final destination of scrap tires consists of using pieces of tires, pure or mixed with soil, as fill of backfill. This material is known as tire derived aggregate (TDA) according to ASTM D 6270 (ASTM 2008).

The use of TDA presents several advantages. TDA have low unit weight, high durability, and do not cause adverse effects on groundwater (Bosscher et al. 1992). TDA within the soil mass may induce reinforcement mechanisms, increasing the shear strength of the mixture (Zornberg et al. 2004a, Cetin et al. 2006). In addition, the potential for exothermic reaction of TDA is drastically reduced when mixed in the soil, thus solving the problem of spontaneous ignition in stockpiles and in pure tire residue fills (Humphrey 1996, Gacke et al. 1997).

Several applications with TDA have been proposed, such as the construction of road embankment fills (Bosscher et al. 1992, Dickson et al. 2001, Zornberg et al., 2004b).

Although past studies have shown evidence of the beneficial effect of TDA when mixed with soil, the behaviour of mixtures of TDA and tropical soils still remains virtually unknown. Lateritic soil deposits cover more than 75% of Brazil, and are often required for highway embankment construction due to their comparatively good mechanical and hydraulic performance (Nogami and Villibor, 1995, Villibor et al. 2000). Even soils with higher contents of fines show good behaviour after compaction and are used regularly in the construction of vicinal road embankments. The use of TDA – lateritic soil mixtures for geotechnical purposes may be a promising technique in tropical environments, but requires an awareness of the properties and limitations of these materials.

A preliminary assessment of the shear strength behaviour of pure TDA and mixtures of this material with a lateritic soil is presented in this paper. An experimental program including direct shear tests was undertaken. Emphasis was placed on the influence of TDA content and confining stress level on material behaviour.

2 MATERIAL PROPERTIES AND TESTING PROCEDURE

The soil used in this study was locally obtained from a site at the City of Natal, located in the northeast region of Brazil. It is a lateritic, reddish soil, which belongs to the Barreiras Formation of the Miocene age (Santos Jr. and Chaves, 2005). The soil has specific gravity of 2.72, liquid limit of 21% and plasticity index of 7%. It classifies as SC (clayey sand) according to the Unified Soil Classification System. The grain size distribution curve of the test soil is shown in Figure 1. The soil has a silica-sesquioxide ratio of 1.52, which is within the typical range for lateritic soils (Winterkorn and Chandrasckharan, 1951).

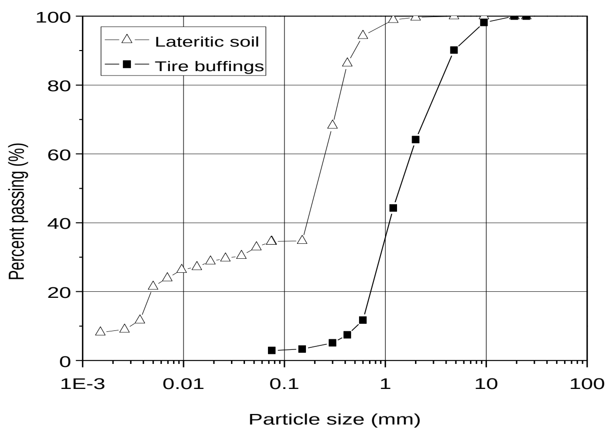

Figure 1. Particle size distribution curves for the lateritic soil and the tire buffings

The TDA used in this study are tire buffings with no steel belts, obtained at a local retread facility. Tire buffings are the by-product of the tire retreading process (ASTM D 6270 2008). The particle size distribution of the tire buffings is shown in Figure 1. The average particle size of the tire buffings (D_{50}) is equal to 1.4 mm. It has specific gravity of 1.11, and water absorption obtained after soaking during 6 days is 5.5%. A view of the tire buffings used in this study is presented in Figure 2.

Figure 2. View of the tire buffings used in this study

Direct shear specimens were prepared using pure soil, pure tire buffings, and mixtures of these two materials. Tire buffing content (χ) was defined as (Zornberg et al. 2004a):

$$\chi = \frac{w_{tb}}{w_{tb} + w_s} \quad [1]$$

where w_{tb} is the weight of tire buffing, and w_s is the dry weight of the soil. The following tire buffing contents (χ) were used: 0% (pure soil), 10%, 20%, 40%, 50% and 100% (pure tire buffings). Due to potential boundary effects,

The specimens were prepared by placing the material in a cylindrical mould with 50 mm in diameter and 20 mm in height. The soil – tire buffing mixtures were thoroughly homogenized and allowed to rest overnight before compaction. The tire buffings used in the direct shear tests were limited to a maximum size of 10 mm due to the reduced size of the specimens. The material was statically compacted in three equal layers with a steel rod until it reached the target compaction degree. All specimens were compacted with optimum water content (w_{ot}) and maximum dry unit weight (γ_{dmax}), defined from standard Proctor tests (Figure 3). The maximum bulk dry unit weight reached by pure tire shred specimens compacted in the same mode as of pure soil and soil – tire buffing specimens was approximately 7 kN/m^3. This value remained virtually the same for different water contents.

A total of 6 series of direct shear tests were carried out as part of this investigation. The tests were conducted in accordance with ASTM standard test method D 3080 (ASTM 2004). Each series corresponded to one buffing content (χ) and included normal stresses (σ_n) of 50, 100, and 200 kPa. The horizontal and vertical displacements of the shear box were measured using dial gages with a resolution of 0.01 mm and maximum stroke of 20 mm. The lateral force needed to hold the top half of the stationary shearbox was measured using a proving ring. The specimens were sheared under a constant shear rate of 0.05 mm/min, and in “dry” conditions, i.e., with moulding water content.

A summary of the Mohr-Coulomb compaction and shear strength parameters is provided in Table 1. Once the tests were carried out with dry specimens, friction angle (ϕ) and cohesion intercept (c) refer to effective parameters.

Table 1. Summary of compaction and shear strength parameters

Series	χ (%)	w_{ot} (%)	γ_{dmax} (kN/m^3)	ϕ (^{0})	c (kPa)	R^2
1	0	12.6	18.8	30.4	8.1	0.99
2	10	12.5	17.5	35.2	7.9	0.99
3	20	11.2	16.0	31.6	11.8	0.99
4	40	12.7	14.3	33.9	32.2	0.88
5	50	10.5	12.2	31.7	15.5	0.97
6	100	-	7.0	24.9	0.0	0.99

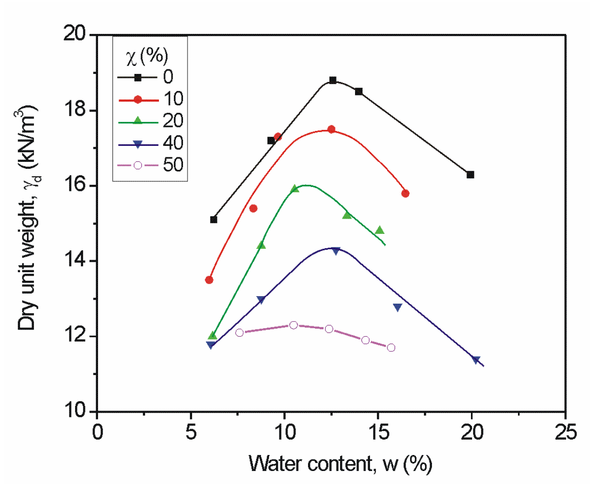

Figure 3. Standard Proctor test results for selected tire buffing contents

3 RESULTS AND DISCUSSION

Figure 3 show shear stress and volumetric strain versus horizontal displacement curves for the selected tire buffing contents (χ) and normal stresses. Soil dilation is taken as negative for the volumetric strain curves.

Pure lateritic soil specimens (χ = 0%) compacted at optimum water content and maximum dry unit weight show no defined peak shear strength for the normal stress levels used in this investigation (Figure 3a). Instead, shear stress stabilizes at increasing levels of axial displacements. The volumetric strain behaviour is dilatant under lower stress levels and contractive under higher stress levels.

On the other hand, the stress-strain behaviour of pure tire buffing specimens (χ = 100%) is nearly linear with increasing shear stress under increasing axial displacements (Figure 3f). The volumetric strain behaviour is fully contractive. The volume change is linear at low horizontal displacements, and is in agreement with results from tests reported elsewhere (Lee et al., 1999, Zornberg et al., 2004a). A shift in the tendency to decrease in volume for larger horizontal displacements is observed at σ_n = 50 kPa normal stress.

Similarly to pure soil, and pure tire buffings, the soil – tire buffing mixtures do not show a defined peak shear strength either (Figure 3b-e). The required horizontal displacement for shear stress stabilization increases with increasing tire buffing content (χ). At lower normal stress levels, the mixtures show an initial compressive behaviour followed by a dilatant behaviour at larger horizontal displacements. The horizontal displacements at which compression develops increases with increasing tire buffing content. A fully compressive behaviour is observed only for χ = 100% (Figure 3f). On the other hand, at high normal stress (σ_n = 200 kPa) the behaviour of the mixtures is fully compressive irrespective to tire buffing content. Compression reduces with increasing horizontal displacements.

The compressive behaviour of the mixtures increases with increasing tire buffing content. Compression is minimum with χ = 10% and maximum with χ = 100%.

Figure 4 shows the Mohr-Coulomb shear strength envelopes obtained for pure lateritic soil specimens, pure tire buffing specimens and soil-tire buffing specimens. Once a clear peak shear strength could not be identified in the tests (Figure 3), failure was defined as the maximum achieved shear stress or the shear stress corresponding to 10% horizontal strain, whichever occurred first at the test (ASTM D3080 2004).

The shear strength envelope of pure tire buffings is characterized by a linear envelope with internal friction angle of 24.9^0 and zero cohesion intercept. Cecich et al. (1996) reported friction angles of 27^0 and cohesion intercept of 7 kPa for pure shredded tire specimens with particle sizes ranging from 5 to 15 mm. Black and Shakoon (1994) reported friction angles of 27 to 31^0 and cohesion intercepts of 3 to 6 kPa for pure shredded tire specimens with particle sizes smaller than 7 mm.

Results shown in Figure 4 also indicate that shear strength increases with increasing tire buffing content, reaches a maximum value for tire buffing content of 40%, and then reduces for tire buffing contents beyond this value. Zornberg et al. (2004a) have found that a tire shred content value in the vicinity of 35% leads to the maximum shear strength in mixtures of pure sand and tire shreds. Cetin et al. (2006) obtained maximum shear strength of 20% for coarse grained tire chips and 30% for fine grained tire chips mixed with a clayey soil.

A defined trend was not observed for the variation of the internal friction angle of the tire buffing – soil mixtures with tire buffing content (see Table 3 and Figure 4). Nonetheless, the friction angle of the mixtures was larger than that of pure soil and pure tire buffings. The friction angle of pure tire buffing specimens was dramatically smaller than the range of variation of the friction angle of pure soil and tire buffing – soil mixtures.

Cohesion intercept, on the other hand, showed a defined trend with the variation of tire buffing content (see Table 3 and Figure 4). Cohesion increases with increasing tire buffing content, reaches a peak for the optimum content (χ = 40%), and then reduces for tire buffing contents beyond this value.

Figure 5 shows the shear strength as a function of tire buffing content for each individual normal stress used in the testing program. In the figure, the line connecting the shear strengths of pure soil (χ = 0%) and pure tire buffings (χ = 100%) represents the contribution of internal shear mechanisms to the mixture shear strength, as defined by Zornberg et al. (2004a). The shear strength above this line results from the contribution of reinforcement mechanisms to the mixture shear strength. This occurs due to tensile forces mobilized within the tire buffings. It is noted that the reinforcement provided by the tire buffings improves significantly the shear strength of the mixtures, in all confinement levels investigated in this study.

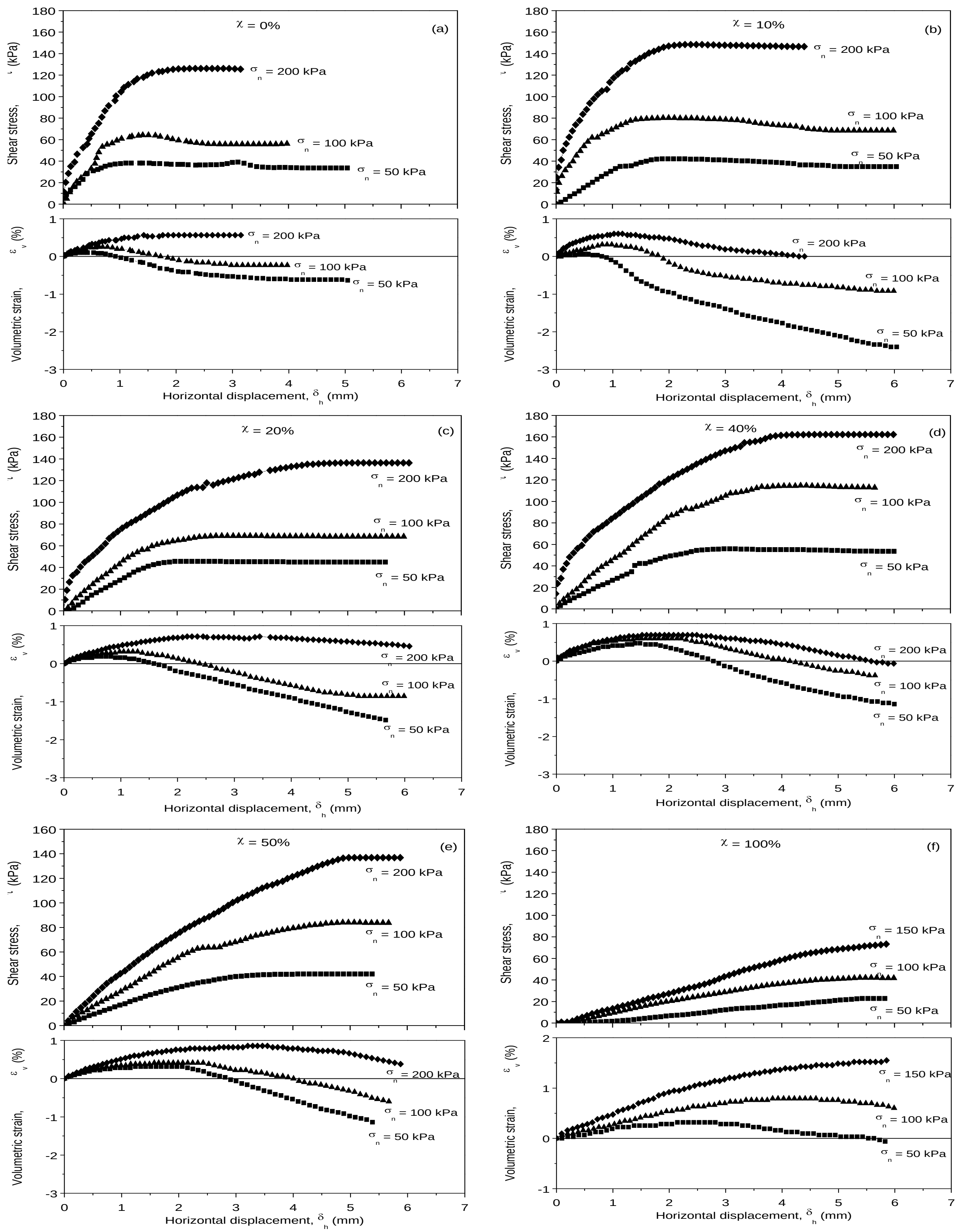

Figure 3. Shear stress and volumetric strain behaviour for pure soil, pure tire buffings and tire buffing – soil specimens

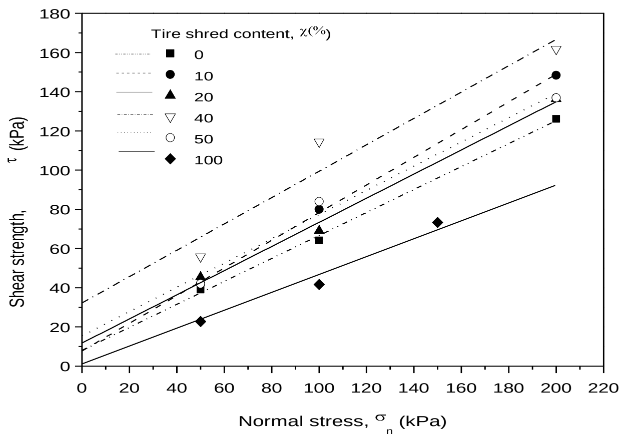

Figure 4. Shear strength envelopes for different tire buffing contents

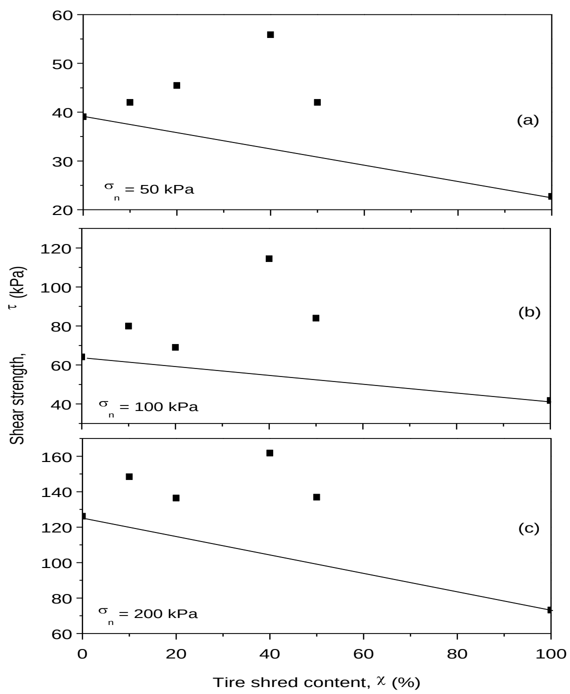

Figure 5. Shear strength versus tire buffing content

Figure 6 shows the influence of tire buffing content on the shear stress mobilized at a horizontal strain of 2% ($\tau_{2\%}$), for the normal stress levels used in this investigation. The reinforcement contribution of the tire buffings to the mixture shear strength is either small as compared to that at larger strains or not present.

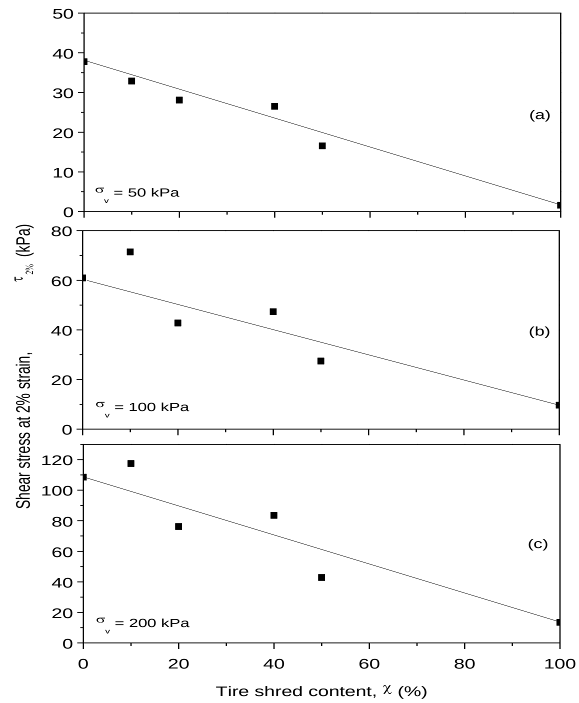

Figure 6.Shear stress at 2% horizontal strain versus tire buffing content

CONCLUSIONS

The shear strength and volumetric strain behaviour of tire derived aggregate (TDA) – lateritic soil mixtures was evaluated through an experimental program involving a series of direct shear tests. Although the behaviour of TDA – granular soil mixtures is well documented, there is a lack of information on the use of TDA with lateritic soils. Focus was placed on the influence of TDA content and on confinement level. The TDA used in this study were tire buffings with an average particle size of 1.4 mm.

The analysis of the data collected as part of this investigation showed that shear strength increases with increasing tire buffing content, reaches a maximum value for tire buffing content of 40% by weight, and then reduces for tire buffing contents beyond this value. The optimum dosage for the lateritic soil investigated in this study is, therefore, about 40%. The reinforcement gain provided by the tire buffings takes place at all investigated confinement levels.

At low strains, however, the reinforcement contribution of the tire buffings to the mixture shear strength is either small as compared to that at larger strains or not present. In practice, this means that earth embankment fills constructed with TDA – lateritic soils may take advantage from the reinforcement provided by the TDA if they are allowed to undergo moderate to larger deformations. Although further analyses on the use of TDA in lateritic soils are required, this aspect should be taken into consideration in the design of embankment fills using TDA – lateritic soil mixtures.

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