Application of Scrap Tires as Earth Reinforcement for Repair of Tropical Residual Soil Slope

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ABSTRACT

The need to recycle scrap tires and to design a more environmental friendly, cost effective slope repairs, prompted the study to look into the possibility of using scrap tires as earth reinforcement for slope repair. This paper describes work done on testing for tensile strength of scrap tires where currently there appeared to be no test standard available, design and test of suitable attachment to tie the tire together, and the construction and performance of field trial of the propose scrap tire reinforced earth system. The study showed that scrap tires could easily carry tensile load of 20 kN. Polypropylene rope of 12 mm in diameter could provide the required (matching) strength as joint. Scrap tire reinforced earth system comprising whole tires tied with polypropylene rope stacked on top of each other and backfilled with in-situ cohesive tropical residual soil fill showed excellent performance for repairing slope of up to 5 m high.

KEYWORDS: recycle material, reinforced earth, residual soil, scrap tires, slope failures, slope repair

INTRODUCTION

Huge quantity of unwanted scrap tires is being generated every year and results in major environmental hazards worldwide. The present recycling techniques of the scrap tires may only consume a very small amount of the unwanted tires. The percentage of scrap tire recycled is not compatible with the growth of scrap tire. This has become a serious problem in many countries.

Research into the application of scrap tires for construction purpose has started some years back in the developed countries like America, Australia and Europe (Long 1996). For Civil Engineering applications, scrap tires could be used as subgrade fill and embankments, backfill for wall and bridge abutments, septic system drain fields, beach erosion control, and sound attenuation systems (RMA, 2007). Examples of application of whole tires as construction materials can be found in Long (1996) and Garga & O'Shaughnessy (2000), while those of shredded tires are given by Drescher and Newcomb (1994), Abbott (2001), Amirkhanian (2001), Okba et al. (2001), Ghani et al. (2002) and RMA (2007).

The use of whole scrap tire without shredding is probably more preferable because energy is not wasted in further processing. An example of such application would be to use the tires as a retaining wall (Garga & O'Shaughnessy, 2000). A tire is composed of rubber or polymer materials strongly reinforced with synthetic fibers and high strength steel which produces a material having unique properties such as very high tensile strength, flexibility and high frictional resistance. Its mechanical properties remain available even after its ordinary life as a car wheel element has expired.

Utilization of scrap tires as reinforcement, especially for slope repairs would be particular useful to countries where slope failures (landslides) are common, and scrap tires are abundant. The application of scrap tires for reinforcement requires a good understanding of the physical and mechanical strength properties, and durability of the tire. Currently, there is little information available. There is also apparently no testing standard or guideline that is suitable to test the tensile strength of scrap tire for such an application. In countries like Malaysia, scrap tires are sometimes used as facing elements of a retaining wall, but not as the entire system (Huat et al., 2006).

This paper describes an experimental investigation done on the physical and mechanical strength properties of R12 to R15 tires, being the most commonly used passenger car tires, and the design of attachment to tie the tire together so as to act as an integral unit in a reinforced earth application. The paper also describes the performance of a 5 m high field trial of the proposed scrap tire reinforced earth system using in-situ cohesive tropical residual soil as backfill.

EXPERIMENTAL PROGRAMS

An experimental investigation on the physical and mechanical strength properties of commonly used passenger car tires were carried out. Knowledge of the strength properties of these car tires would enable an evaluation of the potential of scrap tires for earth reinforcement.

In this experimental investigation, tensile test were carried out on 13 scrap tires of commonly available sizes, i.e. R12 to R15. Two types of tensile tests were carried out to study the tensile strength of scrap tires. The first tensile test was carried out on whole tire using universal tensile machine. Universal Tensile Machine manufactured by Nuremberg Works Germany with maximum capacity of 6000 kN, minimum readability of 1 kN (0.1 ton), with some modification of the machine jaw was used for this test. The test included the measurement of load elongation characteristic. The tire was pulled (tensioned) at a constant rate at 50 mm/min until it broke and the maximum tensile strength was recorded. An illustration of the test is shown in Figure 1.

(a) whole tire with side walls removed being stretched until failure

(b) at failure

Figure 1: Tensile test on scrap tire

The mean tensile strength was 55.81 kN, with standard deviation 15.19 kN. Statistical probability analysis carried out on the results of the tensile tests showed that the probability of tensile strength greater than 20 kN was 99.08%. It should also be noted that the strength of scrap tire was apparently independent of tire size. A similar range of values is also reported by Long (1996).

For the second tensile test, 6 samples of the scrap tires were cut into 100 mm width x 300 mm length and tested in accordance to ASTM D4595 standard. The variation of tire width with tensile strength and modulus of elasticity were studied in this case. The tensile properties of the test specimen were calculated from machine scales, dials and interfaced computer. The rate of strain was fixed at 10% per minute. The ASTM D4595 tensile test was originally developed for determination of the tensile properties of geotextiles and related products, using wide-width strip. Since, the function of scrap tire in a reinforced earth system was similar to the application of geosynthetic products, hence the test would be applicable to scrap tire.

The machine used for this test was Zwick / Z-100 Tensile Test Machine manufactured by Zwick Roell Group, Germany. The machine had maximum capacity of maximum tensile capacity of 100 kN. The computerized hydraulic cramp with automatic adjustable cramp pressure to maximum 30 bar or 3000 kPa enabled the specimen to be held firmly through out the tensile test. The test machine was fully computerized. Figure 2 illustrates the typical failure pattern of the scrap tire sample.

Figure 2: Typical failure pattern of the scrap tire after ASTM D4595 tensile test

Tensile strength versus elongation were recorded automatically during the test and plotted in graphs. The maximum tensile strength range from 21.293 to 59.754 kN, with elongation between 9.94 % to 50.10 % at maximum tensile strength. The maximum elastic modulus ranges from 1928.95 N/mm to 3721.90 N/mm. Statistical probability analysis carried out on the results of the ASTM D4595 showed that the probability of tensile strength greater than 20 kN was 88.88%.

Generally the results of ASTM D4595 tensile test on scrap tire were lower compared with the results of general tensile test. It is reasonable to infer that the cutting process of the tire samples induced major disturbances to the designed structure of the tire. The ring structure of a tire is a continuous element that is designed to distribute stress evenly to the whole structure.

Suitable attachment to attach the tires together so as to act as an integral unit was an equally important aspect of the new wall design, and probably was the most delicate. In this study, two attachment systems were considered and tested in laboratory for tension. They were the wire rope and U-clip, and polymer rope of different numbers of wrap and knots (Figure 3). For the wire rope and U-clip system, a 12 mm diameter wire rope with its compatible size U-clip was selected for testing purpose. Whilst for polymer rope, 12 mm diameter polypropylene was chosen for ease of handling and economy. The rope was tightened on the cross beam of tensile machine and pull until the rope rupture. The wire rope had working load of 25kN but the attachment (wire rope and U-clip) could only carry 15 kN. The 12 mm diameter polypropylene rope however could carry load up to 52 kN (Table 1), and was therefore a suitable attachment for scrap tire reinforced earth system.

Table 1: Tensile strength of polypropylene rope attachment

Sample No	Dia. of rope, mm	No of wrap	No of knot	Max. Strength, kN
1	12	1	1	12.0
2	12	1	2	23.0
3	12	2	2	52.0

(a) wire rope and U-clip

(b) polypropylene

Figure 3: Testing the attachment

FIELD TESTS

A full scale field test was carried out to study the performance of the propose scrap tire reinforced earth system. The trial site was a previously failed slope (Figure 4), located within the compound of IKRAM Park, next to University Putra Malaysia campus in Selangor, Malaysia. The proposed system comprised of whole scrap tires tied together to make a mat configuration, backfilled with in-situ cohesive tropical residual soil, and then placed in successive layers so that the resulting structure could functioned as a reinforced earth. This proposed system would maximize the number of tires to be used in a single structure.

Figure 4: Test site in Ikram Park, Selangor

The failed slope was first excavated as shown in Figure 4 above. Scrap tires with one side wall (top side) removed for better soil compaction were tied together with polypropylene rope into mat configuration and staggered layer by layer to form the 7 m wide by 5 m high slope, with slope angle of about 450. Lengths of the reinforcement (tire mats) were 5 m at the base and 3m at the top of the wall. In-situ cohesive tropical residual soil was used as backfilled, and compacted with 1 ton smooth-wheel roller compactor, each layer being compacted to a thickness of about 200 mm, i.e. the thickness of the tire layer. Figure 5 illustrates the construction sequence. A total of 2100 numbers of scrap car tires in 25 layers was used. It only took 5 unskilled workers 20 workings days to complete the structure. Instrumentation like settlement plates and pressure cells were installed to monitor the performance of the trial wall. Figure 6 shows the completed structure.

(*a*) Laying first tires in mat configuration, with each tire tied together with polypropylenes rope

(*b*) Backfilling tire mat layer with in situ cohesive material and compaction

Figure 5: Constructing the trial scrap tire wall

Basic properties of the in-situ cohesive tropical residual soil excavated from the failed slope are given in Table 2 below.

Table 2: Properties of in-situ soil

Soil description	Yellowish brown sandy clay, CL
Soil origin	Weathered meta-sediment (sandstone, quartz, phyllite & shale); weathering grade VI
Atterberg limit: LL	46%
PL	24%
PI	22%
Percentage passing 63μm sieve	74%
Max dry density (modified Proctor)	1.77 Mg/m^3
Optimum moisture content	17.8%
Shear strength parameters (from 60 mm x 60 mm shear box)	$\phi = 32 - 34^o$
Rankine active earth pressure coefficient , K_a (ave.)	0.295

Figure 6: The completed structure

The in-situ (excavated) slope soil would be deemed as unsuitable fill for conventional reinforced earth, but was used in this case to minimize repair cost. For example, FHWA-HI-95-038 recommends backfill material for reinforced earth to have percentage passing 0.075 mm sieve less than 50%, and plasticity index, PI less than 20%.

Field density tests using sand replacement method on compacted fill gave relative compaction of 78% to 89%. The in-situ moisture contents were between 24% and 26 %, which was on the wet of optimum due to construction done during rainy season.

Figure 7 shows a cumulative settlement – time plot of the bottom (ground) layer. Total ground settlements measured were only 14, 26 and 59 mm for markers placed at the bottom (ground), 2nd layer and 10th layer respectively. All three plates recorded almost constant settlements after completion of construction work. The results were apparently good given that the compaction was not at 90% the maximum dry density.

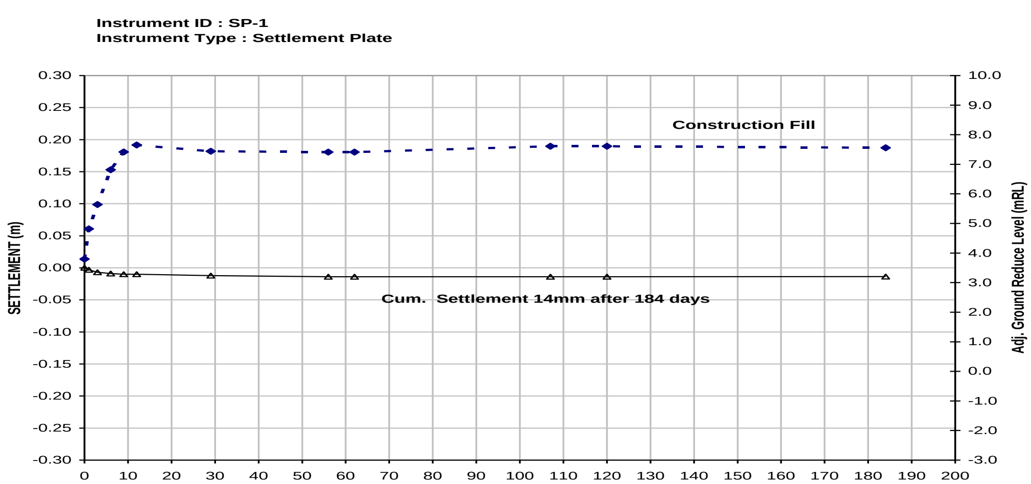

Figure 7: Settlements of the trial wall

Two number of vibrating wire earth pressure cell were installed at depth of 4.835 m (PC1) and 2.825 m (PC2). The comparisons of theoretical and field measured lateral earth pressures were shown in Table 3 below.

Table 3: Comparison of earth pressures

No	Pressure Cell	Depth, m	Ka average	Bulk Unit Weight [average], Mg/m3	Earth Pressure, kPa (Theory)	Earth Pressure, kPa (Measured)
1	PC1	4.835	0.295	1.831	26.12	25.45
2	PC2	2.825	0.295	1.831	1.53	2.06

From the pressure cell monitoring results, it could be concluded that the scrap tire wall was in Rankine's active state.

CONCLUSIONS

From this study, it can be concluded that:

Scrap car tire retained its high tensile strength although its service life as car tire had expired. It offered a 99.08% probability tensile strength greater than 20 kN with its tire thread alone. It is an excellent construction material especially as reinforcement element of a reinforced earth.

Polypropylene rope was the most suitable attachment system to tie the scrap tires to form a mat configuration. It offered a superior strength that was compatible with the scrap tire; it was flexible, and inexpensive. Polymer material is also known to be resistant to chemical, biological attack and free from corrosion.

The performance of scrap tire retaining wall was surprisingly well despite having to use 'unsuitable' in-situ cohesive tropical residual soil fill. It achieved Rankine's active state with minimal vertical settlement.

The significant advantage of the propose scrap tire reinforced earth system would be the reduced cost of materials and construction. Both scrap tires and backfill soils were recycled material. Besides, the construction of the system was relatively simple, it did not require skilled workers and heavy machineries.

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