Laboratory Characterization of Shredded Tires as Substructure Road Drainage Layer Material

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ABSTRACT

Frost action and sub-structure moisture problems cause losses in road structural integrity in cold climatic areas. The combination of three conditions cause frost heave within road structures: moisture, temperature below freezing, and frost susceptible soils. To mitigate frost heave, one of these three conditions must be eliminated. Shredded tires have been found to provide free drainage and high thermal insulation. Previous research has showed that incorporating shredded tires as a drainage layer material in road test sections has mitigated frost action and moisture infiltration. However, the structural integrity of these test sections was reportedly compromised.

This paper summarizes laboratory characterization of the structural and drainage properties of shredded tires and shredded tire/sand blends. Results from the structural characterization of these materials indicated that shredded tires have low mechanical strength. As the proportion of sand in the blend was increased, this led to an increase in mechanical behaviour. However, the permeability of the mix was compromised as the quantity of sand in the shredded tire layer was increased.

Based on findings of this research, shredded tire/sand blends at a blend ratio of 1:3 by volume provided permeability of 0.0026 cm/s and also provided adequate structural stability, as required for the construction of a drainage layer.

INTRODUCTION

Roads in many urban cities have deteriorated as a result of a number of factors including severe climatic conditions and increased traffic loadings. There has also been a major growth in traffic volumes on many roads in Canada's ageing infrastructure (1). In addition, the cost of road maintenance and rehabilitation has increased significantly in recent years (2, 3). Depletion of high quality virgin aggregates in and around urban centres and increases in high water tables over recent years are factors that have led to increased road construction rehabilitation costs (3).

Field state conditions in northern climates such as Saskatchewan contribute to accelerated pavement deterioration. Frost action causes the heaving of roads when ice lenses form in frost susceptible soils, leaving uneven road surfaces (4, 5). Subsequent thawing of ice lenses within the substructure results in the release of moisture, reducing the bearing capacity of the pavement structure and making it prone to premature pavement distress and failure (4). For instance, a road constructed on a frost susceptible subgrade is likely to require major rehabilitation after 5 years despite having an original design life of 12 to 15 years (5).

In addition, urban cities are faced with the problem of solid waste management. High population growth rates in urban centres have led to an increase in amounts of waste generated. Scrap tires are a waste material that occupies large volumes of air space in many landfills. Saskatchewan alone generates over one million scrap tires every year (6). Scrap tires are non-degradable and bulky, making their disposal costly. Scrap tires also pose a health risk since they serve as breeding places for mosquitoes when disposed in landfills. Due to the combustible nature of scrap tires, tire stockpiles expose landfills to severe fire hazards. For example, a pile of scrap tire caught fire on a landfill in Hagersville, Ontario, costing the province $14 million to extinguish (6).

There is a clear need to adopt more sustainable solutions geared towards mitigating environmental problems caused by the landfill disposal of scrap tire and providing high performance roads at less cost to taxpayers.

Background

Pavement performance in northern climates such as Canada is significantly influenced by field state climatic conditions. Frost action together with substructure moisture problems intensifies the magnitude of road deterioration caused by heavy traffic loading (4). Frost action consists of two mechanisms, namely frost heave and thaw weakening. Frost heave involves the formation of ice lenses within the sub-structure during winter. Thaw weakening involves the melting of ice lenses formed.

Frost heaving involves the interaction of three factors: low field state temperature below freezing, moisture supply, and frost-susceptible soils. Soils that contain three percent or more material finer than 0.02 mm are defined as frost susceptible soils (4, 7). Pavement structures containing frost soils in temperature conditions below freezing are likely to undergo frost heave.
Frost heaving initiates with the formation of ice lenses in the pavement substructure. The formation of ice lenses induces the flow of moisture from unfrozen portions of the substructure, leading to the expansion of the ice lenses. Differential heaving occurs when the pavement

substructure is composed of non-uniform constituent material or contains material of varying soil texture (8). Differential frost heaving leads to the development of uneven driving surfaces and poor rider quality. The subsequent thawing of ice lenses releases moisture into the substructure. When the substructure drainage provided is inefficient, excess water becomes trapped, leading to the development of positive pore pressure within the saturation zone upon the application of heavy traffic loading (4). The development of pore water pressure leads to a drastic reduction in the bearing capacity of the road substructure, leaving the pavement prone to structural failure (2, 3).

In urban environments, roads are typically constructed in a "clay box" which prevents the free lateral drainage provided by rural cross sections. In addition, urban field state conditions typically include lawn watering adjacent to roadways, which often results in water infiltration into the road substructure.

Previous research studies adopted the use of shredded tires as aggregates in road construction to mitigate frost action. Shredded tire provides both efficient drainage and higher thermal insulation than conventional aggregates. However, laboratory characterization carried out in previous research indicates that shredded tire materials are highly compressible when initially loaded (9). Shredded tires provide low structural support to pavement structures as compared to conventional aggregates (9). Field experiments carried out in Maine implemented the use of shredded tire and shredded tire/sand blends in pavement subbase construction to evaluate their performance in paved roads (10). In this evaluation process, sand was blended in different proportions with shredded tire material in individual test sections to provide structural support. A section constructed using 100 percent shredded tire material mitigated frost heave by up to 74 percent whereas the sections with a shredded tire/sand blend only mitigated frost heave by a very small margin (10). As the quantity of sand in the shredded tire/sand blend increased, the structural support was improved but the drainage provided by the layer to mitigate frost damage was highly compromised.

Project Objective

This paper summarizes laboratory research aimed at improving the structural performance of roads constructed using shredded tire as a drainage material in Saskatchewan urban field state conditions.

Project Scope

This paper investigated laboratory characterization of shredded tire material available in the City of Saskatoon blended with "clean" sand. Strength characterization included California Bearing Ratio (CBR) testing and rapid triaxial frequency sweep testing. Free drainage testing was also performed on the CBR-compacted samples. A literature review of the environmental impact of using shredded tire materials was performed; it was found that the use of shredded tire materials did not have a significant effect on the groundwater quality (11, 12, 13). Therefore, environmental impact analysis was outside the scope for this project. The scope of this project was also restricted to a typical City of Saskatoon local street construction in a high water table area with urban cross section.

CHARACTERIZATION OF SHREDDED TIRE/SAND BLENDS

Sample Preparation

Shredded tire materials used for the field construction of drainage layers typically have maximum particle sizes of 50 to 75 mm (10). Due to the small diameter of specimens prepared for laboratory characterization, shredded tires were cut into smaller pieces to limit the ratio of the maximum asperity size of the material particles to the size of the laboratory-created sample (sample size ratio). The effect of sample size becomes negligible as the sample size ratio approaches six (14, 15). Consequently, shredded tire materials were cut into smaller chips of sizes ranging between 10 mm and 25 mm as shown in Figure 1.

Five samples consisting of 100 percent shredded tire material and shredded tire/sand blends with tire to sand mix ratios of 1:1, 1:1.35, 1:2 and 1:3 were characterized to determine drainage and structural mechanical properties. The mix ratios of the shredded tire/sand blends are in proportions by volume of shredded tire and sand. The sand used in the blends was clean sand with no fines and as per the unified soil classification system (USCS) was poorly graded sand (SP). Figure 2 shows a blend of tire chips/sand in the ratio of 1:2.

Gradation Test Results

Figure 3 shows the gradation test results. A uniform gradation for the 100 percent shredded tire material with constituent particles ranging between 12 to 20 mm in nominal dimensions was observed. The clean sand had no material finer than 0.1 mm. As the quantity of shredded tires in each blend increased, the material became coarser than the clean sand.

California Bearing Ratio Test

The California Bearing Ratio (CBR) value is an index used to determine the strength or load bearing capacity of soils used for road construction. This test measures the resistance of a compacted soil sample to penetration under loading, as compared to that of well graded crushed rock. The higher the CBR value of a soil, the higher its bearing capacity. Well graded crushed rock is considered to have a CBR value of 100 percent. An unsoaked CBR test was conducted on compacted specimens prepared using 100 percent shredded tire and shredded tire/sand blends in the ratios 1:1, 1:1.35, 1:2, and 1:3.

The CBR values obtained from this test were used to compare the relative strength of the prepared specimen under similar loading conditions. As seen in Figure 4, the CBR value of the samples created with 100 percent shredded tire material was 1.33 percent. The CBR values of the blends increased progressively as the quantity of sand in the mix increased. The shredded tire/sand blend with a mix ratio of 1:3 had a CBR value of 9.82 percent. By comparison, the control sample of a typical City of Saskatoon conventional granular base had a much higher CBR value of 36.4 percent. The results showed an increase in the strength of the samples when tested using the CBR method with increasing quantities of sand in the mix blend.

Rapid Triaxial Frequency Sweep Test
Rapid triaxial frequency sweep characterization was used to characterize the mechanical response of shredded tires and shredded tire/sand blends to different field state conditions by testing the materials under varying load rate frequencies ranging from 0.5 Hz to 5 Hz and under varying loading stress states. The dynamic modulus of the shredded tire material and shredded tire/sand material with a ratio of 1:1 was measured using the triaxial frequency sweep test. The dynamic modulus is a measure of material stiffness (16,17,18).

The results shown in Figure 5 indicate that the shredded tire material had low dynamic modulus values under all loading conditions relative to the shredded tire/sand blend. Varying load frequencies did not have a significant impact on the dynamic modulus results for both materials tested.

Permeability Test
In order to mitigate frost action and substructure moisture problems in urban field state conditions, providing sufficient drainage for the pavement structure is necessary. This research adopted the use of a free drainage test to measure and compare the permeability of shredded tires and shredded tire/sand blends. The free drainage test measures the permeability of the CBR-compacted specimen as the depth of percolation of water through the material per unit second, as shown in Figure 6. A high permeability reading indicates that the material tested will provide efficient drainage if used for the construction of a drainage layer.

Figure 7 shows the permeability test results. The 100 percent tire material was free draining and displayed the highest permeability, 1.42 cm/s. The permeability value decreased rapidly with increasing shredded tire/sand blend ratio, with a permeability of 0.012 cm/s for the 1:1 mix ratio and 0.0026 cm/s for the 1:3 mix ratio. These results indicate the detrimental effect of sand on the permeability of the blend. As the quantity of sand in the blend was further increased in the blends of ratios 1:35, 1:2 and 1:3, the permeability of the blends did not decrease by a significant margin.

CONCLUSION

Providing efficient drainage for pavement structures is important in mitigating frost action and substructure moisture problems. This paper investigated improving the structural performance of shredded tire road systems without compromising drainage. Laboratory structural and permeability characterization was performed on shredded tire materials and shredded tire/sand blends to determine the optimum amount of sand required in the blend to improve structural support without compromising drainage.

Results from these tests indicated that shredded tire materials are weak in providing structural support. Structural support was improved as the quantity of sand in the shredded tire/sand blends was increased. For example, a CBR reading of 1.33 percent was determined for shredded tire material whereas shredded tires/sand blend in the ratio of 1:3 gave a CBR value of 9.82 percent. Likewise, frequency sweep testing showed that the dynamic modulus increases as the proportion of sand in the blend is increased. However, permeability test results indicated that increasing the quantity of sand in the blend reduced the drainage offered but this effect becomes significantly less pronounced in mixes ranging between 1:1.35 and 1:3 of shredded tire/sand blends with permeability values ranging between 0.0032 cm/s and 0.0026 cm/s.

Based on the results from the tests conducted, using a 1:3 shredded tire and sand blend ratio as drainage layer material is efficient in providing both sufficient structural support and drainage on roads in Canada.

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LIST OF FIGURES

Figure 1. Shredded Tires in Raw State (left) and Cut Into Smaller Pieces (right).

Figure 2. Shredded tire/sand in the mix ratio of 1:2.

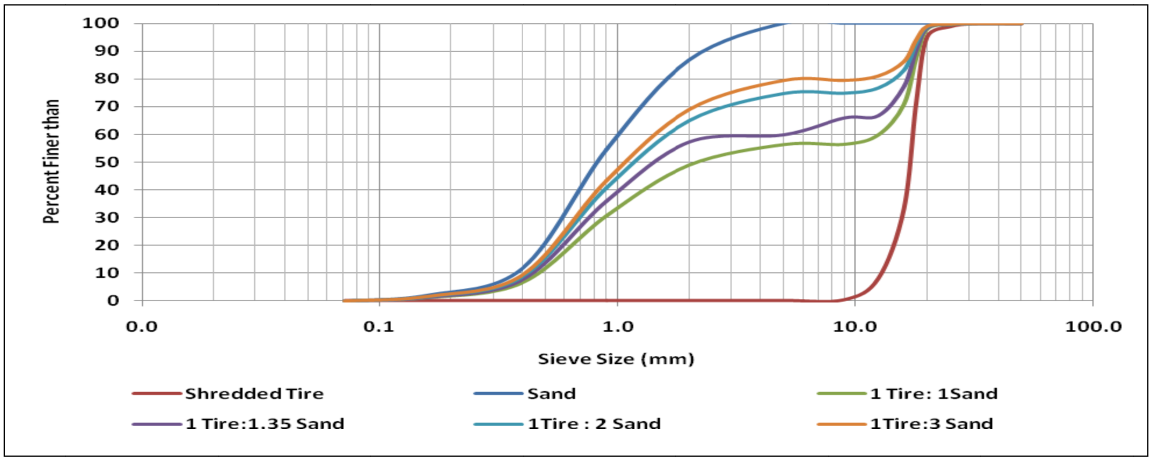

Figure 3. Grain Size Distribution of Shredded Tire and Shredded Tire/Sand Mixes.

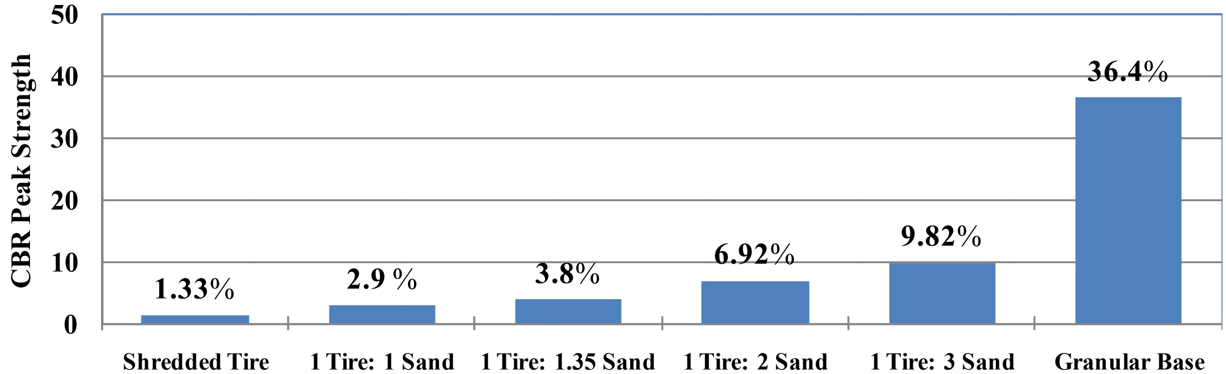

Figure 4. Unsoaked CBR Characterization of Materials.

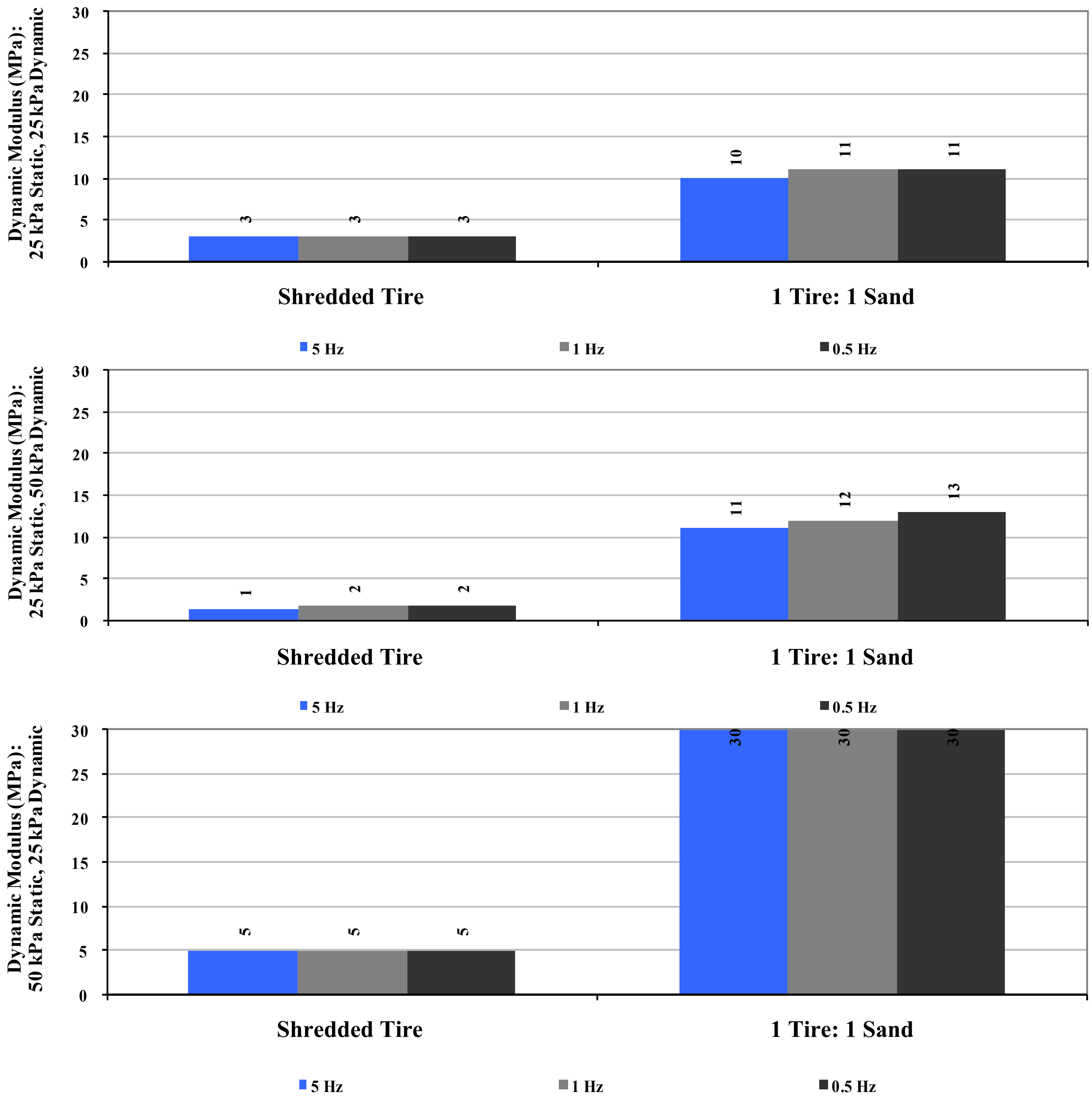

Figure 5. Rapid Triaxial Frequency Sweep Test Results.

Figure 6. Free Drainage Test.

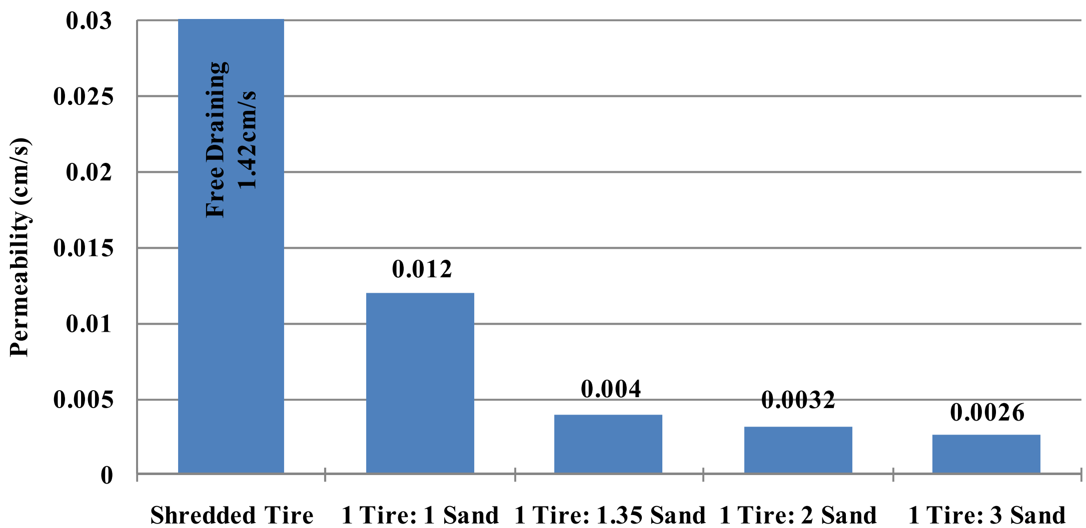

Figure 7. Permeability of Shredded Tire and Sand Blends.