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Field Trial of Tire Shreds as Insulation for Paved Roads

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ABSTRACT

This paper discusses the use of tire shreds and tire shred/soil mixtures to improve the performance of paved roads in seasonally cold regions. Tire shreds and tire shred/soil mixtures accomplish this by acting as an insulating layer and free-draining subbase. In addition, this application could use approximately 370,000 tires per kilometer (585,000 tires per mile) for a typical two lane highway. This paper describes the construction of a field trial in Orono, Maine using tire shreds and tire shred/soil mixtures as insulation and a high permeability subbase as well as the performance of the field trial through the winter of 1996-97. The field trial incorporated 152-mm (6-in.) to 305-mm (12-in.) thick layers of tire shreds or tire shred/soil mixtures overlain by 330 mm (13 in.) to 483 mm (19 in.) of gravel base. Tire shreds generally had a 76-mm (3-in.) maximum size. The field trial showed that tire shreds reduced frost penetration by up to 47 percent and reduced frost heave by up to 74 percent. A mixture of 67% tire shreds/33% soil reduced frost penetration by 23 percent and frost heave by 23 percent. A mixture of 33% tire shreds/67% soil reduced frost penetration and frost heave only marginally. The values of thermal conductivity (K) measured in a companion laboratory study were slightly higher than those backcalculated from the field trial. The backcalculated values were about 0.17

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W/m•°C (0.10 Btu/hr•ft•°F) for tire shreds to 0.21 W/m•°C (0.12 Btu/hr•ft•°F) for a mixture containing 67% tire shreds/33% soil to 0.54 W/m•°C (0.31 Btu/hr•ft•°F) for a mixture containing 33% tire shreds/67% soil. For comparison, a value of 1.60 W/m•°C (0.94 Btu/hr•ft•°F) was measured in the companion laboratory study for the gravel base used in this field trial. Pavement performance measurements showed that 330 mm (13 in.) of soil cover over a 305-mm (12-in.) tire shred layer would lead to premature cracking but that 483 mm (19 in.) of soil cover could be used with only a small effect on pavement life.

INTRODUCTION

This paper describes a field trial using tire shreds and tire shred/soil mixtures to improve the performance of paved roads in seasonally cold regions. An earlier study investigated gravel surfaced roads (Humphrey and Eaton, 1995). The primary goals were to determine the thickness of tire shreds and thickness of soil cover needed to effectively insulate and protect paved roads. Another goal was to determine the effects of placing tire shreds as underdrain backfill on the drainage of pavement sections. Material properties and construction considerations are also discussed. A companion study measured the thermal and hydraulic conductivity of tire shreds in the laboratory (Lawrence, et al., 1998).

SITE DESCRIPTION

The test site is located on a dead-end road leading to the University of Maine's Whitter Farm. The portion of the road used for the 77.7-m (255-ft) long trial section was originally gravel surfaced. The road runs from west to east. A wooded area lies to the south of the road and a farm pasture lies to the north. The overall topography slopes gently from north to south. The road is used primarily by farm vehicles and a small number of passenger vehicles. Since very few vehicles travel this road, non-destructive pavement performance measurements were used to estimate the useful life of the pavement under heavier traffic conditions. Native soils beneath the existing gravel-surfaced road ranged from brownish-gray silty clay to sandy silty clay. The subgrade soils were classified as frost susceptible.

TEST SITE CONFIGURATION

The test site is broken up into five tire shred/soil test sections and a control section. The five tire shred/soil test sections are designated 1 through 5. A typical cross-section is shown in Figure 1. Table 1 lists the test section configurations. Both 305-mm (12-in.) and 152-mm (6-in.) thicknesses of tire shred/soil mixtures were used to determine the thickness of insulation needed to reduce frost penetration. Three percentages (100%, 67%, and 33%) of tire shreds were investigated. The percent tire shreds was based on volume. Soil cover of either 483 mm (19 in.) or 330 mm (13 in.) was used to investigate minimum cover requirements for tire shred sections.

Figure 1 Typical tire shred cross-section

Table 1 Summary of test section configuration

Section	Depth of excavation (mm)	Thickness of layer (mm)		
		Tire shred/soil Mixtures	Gravel fill	Paved surface
1	914	326 (33% t.s.)	483	127
2	914	288 (67% t.s.)	483	127
3	914	259 (100% t.s.)	483	127
4	762	154 (100% t.s.)	483	127
5	762	305 (100% t.s.)	330	127
Control	762	----	635	127

25.4 mm = 1 in.

MATERIALS

The tire shreds were left over from a previous research project and were stockpiled on campus (Tweedie, et al., 1998). They were obtained from Palmer Shredding of North Ferrisburg, Vermont and Pine State Recycling of Nobleboro, Maine. They met Maine Department of Transportation (MDOT) specifications for Type A tire shreds and generally had a 76-mm (3-in.) maximum size. A few pieces that were obviously larger than 76 mm (3 in.) were removed by hand as they were placed.

The granular subbase was 102-mm (4-in.) maximum size processed gravel and met MDOT Specification 703.06, Type D (152-mm (6-in.) maximum size, 25 to 70% passing the 6.4 mm (1/4-in.), 30% maximum passing the No. 40, and 7% maximum fines). This material was used for subbase over the tire shreds and tire shred/soil mixtures as well as for the subbase course in the Control Section. Similar material was also used for the edge drain in the Control Section and for the tire shred/soil mixtures.

Bituminous pavement aggregate met MDOT specification 703.09 for Types B (100% passing the 25-mm (1-in.) sieve, 50 to 85% passing the 13-mm (0.5-in.) sieve, 14 to 39% passing the No. 16 sieve, and 1 to 8% passing the No. 200) and

Type C (100% passing the 19-mm (0.75-in.) sieve, 80 to 100% passing the 13-mm (0.5-in.) sieve, 17 to 40% passing the No. 16 sieve, and 2 to 7% passing the No. 200 sieve).

The subgrade soil had an average specific gravity of 2.65. Natural water content ranged from 14.4 to 32.8. The average liquid limit was 31 and the average plastic limit was 22. Approximately 73 to 100% passed the #200 sieve. For frost considerations, this soil is classified as an F4 soil with low to very high frost susceptibility according to the US Army Corps of Engineers classification system (Chamberlain, 1981).

CONSTRUCTION

Excavation of the road took place on September 9, 1996. Sections 1, 2, and 3 were excavated to 0.91 m (36 in.) below final grade and Sections 4, 5, and control were excavated to 0.76 m (30 in.) below final grade. As the left side of the road was being excavated with a tracked excavator, a backhoe equipped with a 0.6-m (24-in.) wide bucket excavated a trench for the edge drain. The trench was excavated to 1.07 m (3.5 ft) below the subgrade elevation. Since the entire road was excavated in one day and the exposed subgrade would be impassable to traffic for about one month, a temporary passing lane was built utilizing some of the excavated soil.

Tire shreds were loaded into a 4.6-m^3 (6-yd^3) dump trailer by a small tractor outfitted with a front-end loader bucket. Tire shred/soil mixtures were made by dumping a ratio of two buckets of tire shreds to one bucket of soil for the 67% tire shred / 33% soil mixture, and two buckets of tire shreds to three buckets of soil for the 33% tire shred / 67% soil mixture. The latter ratio was necessary to obtain the desired 2 to 1 ratio based on percent of solids volume. After mixing in the trailer with shovels and rakes, the mixture was transported to the construction site. It was difficult to maintain a homogeneous mixture of tire shreds and soil for Sections 1 and 2 because the mixtures would tend to segregate when dumped and spread. This was especially evident for the 67% tire shred/33% soil mixture in Section 2.

Geotextile lined the bottom and sides of the trench. Trenches were filled with the same ratio of tire shreds to soil as their adjacent subbase section. A perforated 102-mm (4-in.) diameter ADS drainage pipe was placed 152 mm (6 in.) above the base of the trench.

After a lift was in place, it was compacted by “dynamic compaction” with ten drops of a 354 kg (780 lb) concrete block lifted with the front bucket of a tractor. This procedure was necessary since previous research indicated that vibratory plate compactors could not successfully compact tire shreds (Tweedie, et al., 1998) and the researchers could not find a walk-behind roller that was narrow enough to fit in the trench. Since the trench was wider near the top, the researchers were able to use a walk-behind compactor with a width of 838-mm (33-in.) and an operating weight of 1,315 kg (2,900 lb.) to compact the upper portion of the trench. The walk-behind compactor made a minimum of six passes for each lift. Roadbed tire shreds and tire shred/soil mixtures were transported and placed in similar fashion. Compaction was achieved with a minimum of six passes of a smooth drum vibratory roller with an operating weight of 10.9 metric tons (12.0 tons).

As with the trench, the tire shred/soil mixtures were completely encased with non-woven drainage geotextile (Synthetic Industries Type 701) to prevent migration of fines into the tire shred/soil layers. Seams were overlapped 457-mm (18 in.).

The base course gravel was dumped and spread with the tractor over the tire shred/soil mixtures. Placement of the subbase material was completed on October 5, 1996. At this point the temporary passing lane was closed and traffic was allowed to drive on the road.

Field density tests were performed by digging to a depth of at least 20 mm (8 in.) in the base course gravel and performing sand-cone tests. The optimum water content was 7.1 percent and the maximum dry density was 2.25 Mg/m^3 (140 lb/ft^3). In-place water contents ranged from 2.5 to 3.6 and relative compaction ranged from 92 to 105 percent.

Tire shreds need time to settle before paving because they exhibit some time dependent settlement (Tweedie, et al., 1998). The time between completion of subbase placement and paving was 40 days. Fine grading to +/- 10 mm (3/8 in.) was performed on November 13, 1996 with a road grader. The road section was paved on November 14, 1996.

INSTRUMENTATION AND MONITORING

A monitoring program was undertaken to evaluate the thermal behavior, heave, settlement, and groundwater levels. Instrumentation and monitoring devices included ten settlement plates to measure the compacted thickness of each tire shred/soil layer, thermocouples, two frost free elevation benchmarks, and three groundwater wells.

One thermocouple string was installed in the center of each section. Each string contained from twelve to twenty 20-gage copper-constantan (Type T) thermocouples. Thermocouples were installed in 102-mm (4-in.) diameter holes. The U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory mounted the thermocouple pairs on 25-mm (1-in.) diameter wooden dowels. The string of thermocouples was then placed in the hole and the hole was filled with the soil removed from the hole.

PERFORMANCE

Thermal Behavior

The coldness of a winter is estimated by the freezing index. For the winter of 1996/97 the freezing season lasted from December 19, 1996 to March 24, 1997 and the freezing index was 461 °C-days (829 °F-days). The average freezing index for Orono is about 714 °C-days (1285 °F-days) (Bigelow, 1969). Thus, the winter of 1996-1997 was much warmer than an average winter.

Figure 2 shows frost depth versus date for each section. Behavior of Section 1 (33% tire shreds) and the Control Section were similar. The frost penetration in these two sections was initially slower than the frost penetration in Sections 2 and 3. This was most likely caused by the insulating value of the tire shreds in Sections 2 and 3 preventing heat stored in the ground from warming the near surface granular soil above the tire shreds. However, by mid-winter the Control Section and Section 1 had the greatest depth of frost penetration.

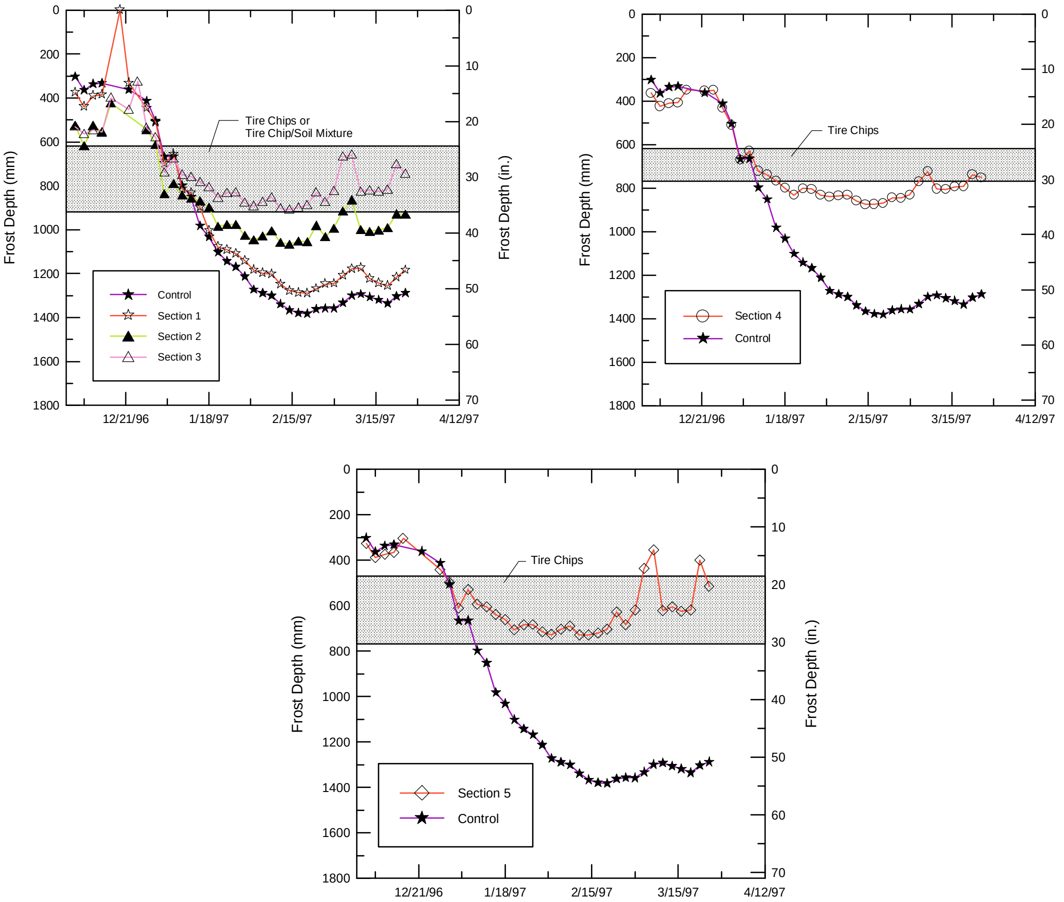

Figure 2. Frost Depth vs. Date

Freezing fronts of Sections 1, 2, and 3, and the Control Section passed through a depth of 610 mm (24 in.), which corresponds to the top of the tire shreds or tire shred/soil mixtures, on nearly the same date (Figure 2). The freezing front in Section 3 diverged from the others at about mid-depth in the tire shred layer and remained in the tire shred layer for the entire winter. In Section 2 the freezing front diverged from Section 1 and the Control Section when it passed the bottom of the tire shred/soil layer. In Section 1 the freezing front diverged from the Control Section at a depth of about 1100 mm (43 in.).

Maximum depth of frost penetration for each section is shown in Figure 3. The 33% tire shreds/67% soil in Section 1 reduced the frost penetration by only 7 percent compared to the Control Section. The frost penetration in Section 2 was reduced 23 percent, Section 3 was reduced 34 percent, and Section 4 was reduced 36 percent. Section 5 had the smallest depth of frost penetration at 730 mm (29 in.), which was a 47 percent reduction. Frost did not penetrate into the subgrade in Sections 3 and 5. The maximum depth of frost penetration was less than the elevation of the groundwater table in every section except the Control Section, where the maximum depth of frost penetration was 510 mm (20 in.) below the groundwater table. Groundwater table elevations were interpolated at the center of each section based on readings taken in April and May from the three groundwater wells located beyond the shoulders of the road.

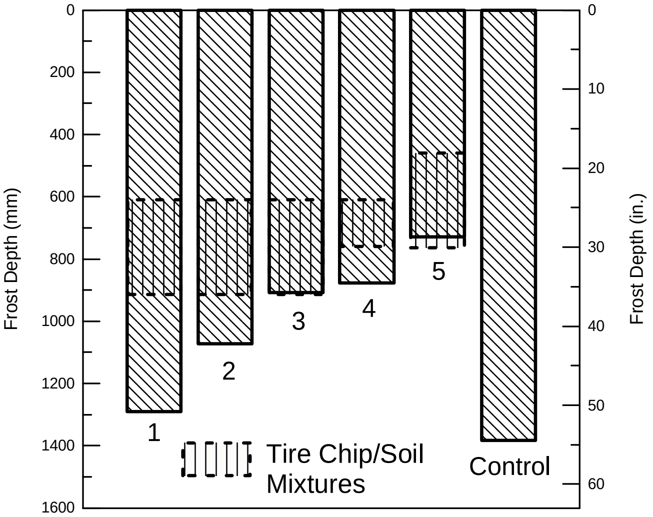

Figure 3. Maximum Depths of Frost Penetration

The profiles of temperature versus depth show the insulating effects of tire shreds and tire shred/soil mixtures. The profiles in Figure 3 display temperature vs. depth on February 14, 1997. This date marks the end of a 47-day cold period from December 30, 1996 to February 14, 1997. This day was also on or close to the dates of maximum frost penetration for each section, as can be seen in Figure 2. Figure 3 shows that there were sharp changes in the slopes of temperature lines as they crossed the top of the tire shred or tire shred/soil layers. Another sharp change in slope occurred as they crossed the bottom of the tire shred or tire shred/soil mixtures into the subgrade.

The temperature profiles of Sections 1, 2, and 3 show that temperatures above the tire shred or tire shred/soil mixtures decreased with an increase in the percentage of tire shreds. This was due to the higher thermal resistivity of materials with higher proportions of tire shreds that impeded heat flow to the soil above the

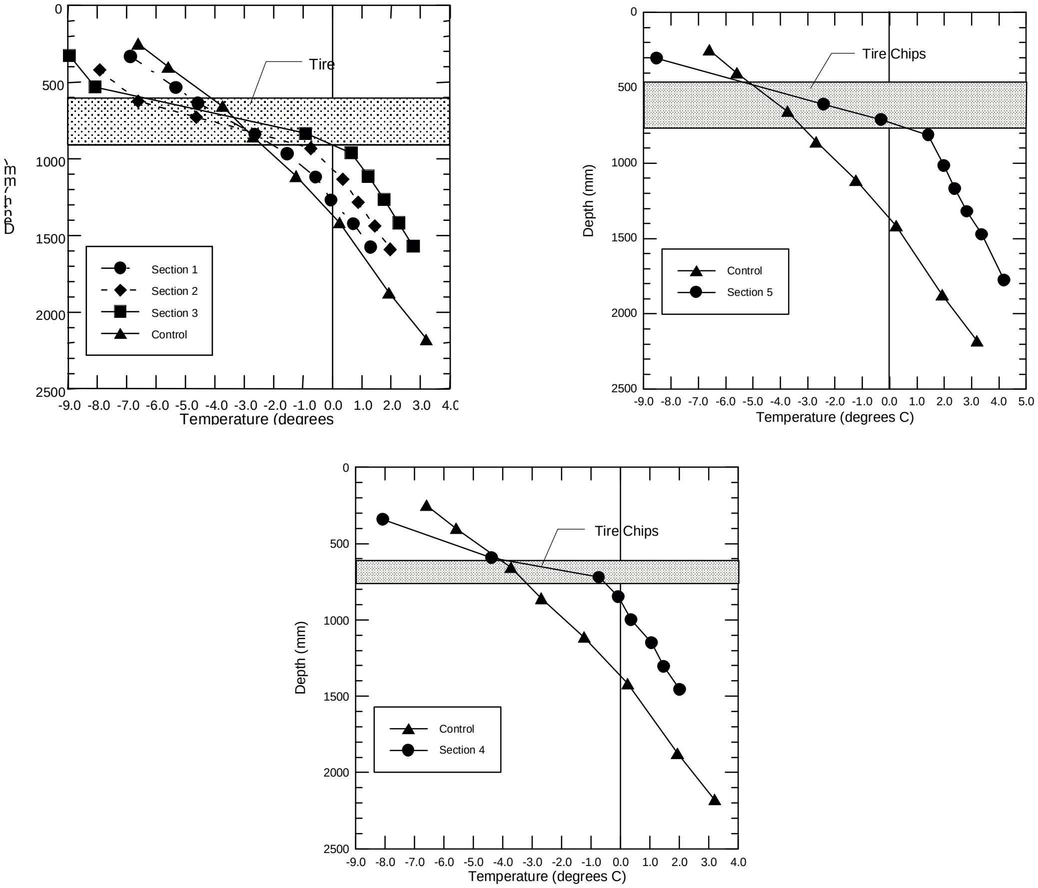

Figure 4. Temperature Profile on February 14, 1996

tire shred/soil layers, resulting in lower temperatures in these regions. Temperatures below the tire shred/soil layers were higher in sections with greater percent tire shreds for the same reason.

Frost heave was measured at 96 points located on the left outside, left inside, right outside, and right inside wheel paths. Comparisons were made between the test sections to determine the effect on heave of percent tire shreds, tire shred layer thickness, and depth to top of tire shred layer. Sections 1, 2, and 3 had the same layer thickness and depth to the top of the tire shred layer but different percentages of tire shreds. Comparison of the heave in Sections 1, 2, and 3 gives an approximate relationship between frost heave and percent tire shreds. This relationship is shown graphically in Figure 4. There is essentially no benefit in using 33% tire shreds/67% gravel to reduce heave.

Backcalculated Thermal Conductivity

Two methods were used to backcalculate the approximate thermal conductivities of tire shreds and tire shred/soil mixtures (Humphrey, et al., 1996). The first method was a steady state heat flow equation, which was used to calculate the thermal conductivity of tire shred and tire shred/soil layers relative to the subgrade. The subgrade thermal conductivity was estimated from charts by Kersten (1949). The second method was based on the modified Berggren equation (Aldrich, 1956). Reasonable agreement was obtained between the measured and calculated frost depth which means that the backcalculated value of K is reasonably accurate.

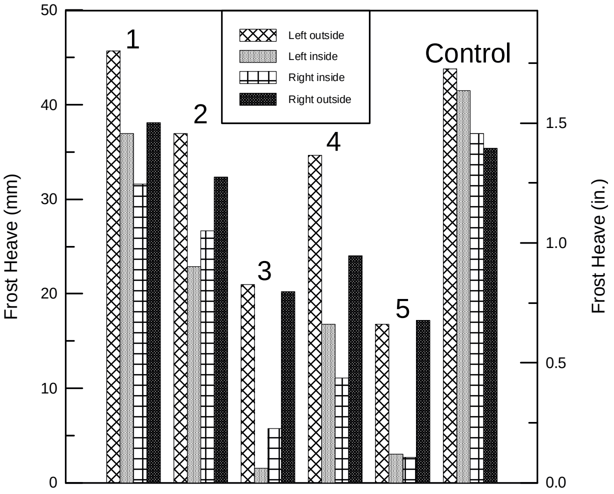

Figure 5. Average Frost Heave in Individual Wheel Paths

For sections with 100% tire shreds, the backcalculated K was 0.16 W/m·°C (0.09 Btu/hr·ft·°F) in Section 3, 0.17 W/m·°C (0.10 Btu/hr·ft·°F) in Section 4, and 0.18 W/m·°C (0.10 Btu/hr·ft·°F) in Section 5. Thus, the backcalculated K values of tire shreds fall in a narrow range. The K values of mixtures increased with a decrease in percent tire shreds. Section 2, with 305 mm (12 in.) of 67% tire shreds/33% gravel and 483 mm (19 in.) of cover, had a K of 0.21 W/m·°C (0.12 Btu/hr·ft·°F), and Section 1, with 305 mm (12 in.) of 33% tire shreds/67% gravel and 483 mm (19 in.) of cover, had a K of 0.54 W/m·°C (0.31 Btu/hr·ft·°F).

Field backcalculated thermal conductivities were compared to values determined in a companion laboratory study (Lawrence, et al., 1998). The laboratory values were higher than those calculated in the field. The range of differences for tire shreds was 28 percent to 44 percent. The difference for 67% tire shreds was 95 percent, and the difference for 33% tire shreds was 56 percent. The large percent difference in Section 2 could be due partly to differences between the assumed percentage of tire shreds in Section 2 and the actual percentage, differences between field and lab moisture contents, and/or differences in the thermal conductivity of frozen and unfrozen material. There is also the possibility that the many freeze-thaw cycles throughout the winter made backcalculation of thermal conductivity difficult. For design purposes, use of the laboratory K would give conservative estimates of frost penetration.

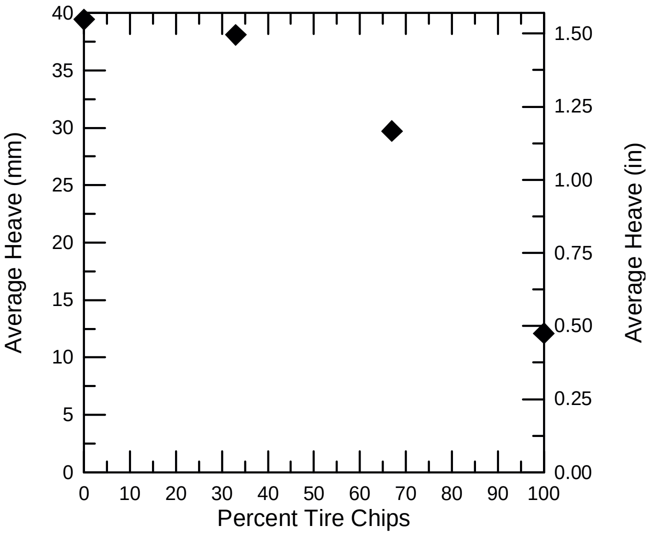

Figure 6. Average Frost Heave vs. Percent Tire Shreds

Pavement Performance

Modified Benkelman Beam (MBB) tests were performed in April 1997 and August 1997 and Heavy Weight Deflectometer (HWD) tests were performed in November 1996 and April 1997. An additional set of Falling Weight Deflectometer (FWD) tests was done in August, 1997. August pavement deflections were significantly higher than April deflections in the 305-mm (12-in.) thick tire shred sections. The deflection basins for the mixtures, the 152-mm (6-in.) tire shred section, and the Control were about the same in April and August. A possible explanation for this is that the colder, and therefore stiffer, pavement in April combined with the good drainage provided by the 305 mm (12 in.) of tire shreds resulted in lower deflections in April. Overall, MBB deflection basins responded as expected, with the centerline deflection and radius of the deflection basin increasing as the percentage of tire shreds increased and/or the amount of soil cover decreased.

The computer program KENLAYER (Huang, 1993) was used to estimate deflection basins and strains at the base of the pavement. KENLAYER is a computer program based on the solution for an elastic multilayer system under a circular loaded area. The tensile strain in each section was divided by the tensile strain in the Control Section to give normalized strains.

Huang (1993) presents a formula relating tensile strain at the base of the pavement to pavement life. Normalized strains were calculated for each tire shred and tire shred/soil layer and used in conjunction with this formula to calculate a range of pavement life ratios in each section. This ratio is the pavement life of a section divided by the pavement life of the Control Section. Normalized strains of tire shreds ranged from 1.022 in Section 3 to 1.323 in Section 5 (See Table ?). Thus, the pavement life ratios were lowest in Section 5 and ranged from 0.20 to 0.40, while pavement life ratios were highest in Section 3 and ranged from 0.88 to 0.93. This means that in a qualitative sense Section 3, which has 483 mm (19 in.) of soil cover and 305 mm (12 in.) of tire shreds, would lose very little pavement life due to the compressibility of the tire shreds compared to Section 5, which has 330 mm (13 in.) of soil cover and 305 mm (12 in.) of tire shreds. Thus, the configuration of Section 5 would lose a significant amount of its life and would not be acceptable for design in most circumstances. This is supported by visual inspection of the road surface, which exhibited fatigue cracking in Section 5 within 1 year of construction. Overall, the calculated reduction in pavement life gives a qualitative sense of the performance of pavement in tire shred and tire shred/soil mixture sections. Other sections have not yet shown visible signs of fatigue. It was possible only to estimate the effect of tensile strain on pavement life. It was not possible to quantitatively assess the effect of improved drainage and reduced frost heave on increasing pavement life.

Table 2. Computation of strain at base of pavement in KENLAYER

KENLAYER Results				
Section	Soil Cover (mm)	Percent Tire Chips	Minor Principal Strain (x10^{-2}%)	Normalized Strain
1	483	33	-5.149	1.053
2	483	67	-5.083	1.039
3	483	100	-4.998	1.022
4	330	100	-5.071	1.037
5	483	100	-6.473	1.323
Control	635	-	-4.891	-

CONCLUSION

This full-scale field trial shows that some combinations of tire shreds, and overlying aggregate can be used as insulation and a free-draining layer beneath paved roads. Tire shred/soil mixtures tend to segregate during placement so it is preferable to use 100% tire shreds. Tire shreds reduced frost penetration depth by up to 47 percent and frost heave by up to 74 percent. The laboratory thermal conductivity of tire shreds and tire shred/soil mixtures was typically higher than estimated in the field trial. Thus, use of the laboratory values of thermal conductivity would be conservative. The backcalculated K of tire shreds ranged from 0.16 W/m•°C (0.09 Btu/hr•ft•°F) to 0.18 W/m•°C (0.10 Btu/hr•ft•°F). The backcalculated K of 67% tire shreds was 0.21 W/m•°C (0.12 Btu/hr•ft•°F), and the bcackcalculated K of 33% tire shreds was 0.54 W/m•°C (0.31 Btu/hr•ft•°F). A minimum of 483 mm (19 in.) of soil cover over 305 mm (12 in.) of tire shreds can be used on low volume roads with only a small effect on pavement life.

Acknowledgments

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