USE OF SCRAP TIRES IN ROAD CONSTRUCTION

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ABSTRACT: Growing piles of discarded tires create fire and health hazards. Current disposal methods are wasteful and costly. This paper presents the results of an investigation into the potential of shredded tires as fill material in road construction. A test road was built to study the constructability, durability, and performance of tire chips as a new construction material. The road was made up of six sections to examine the effects of (1) Tire-chip size; (2) method of placement; and (3) soil-cap thickness on road performance. The field operation proved that use of shredded tires in road construction poses no major handling or placement problems. However, the high compressibility of tire chips and their tendency to shift laterally under compaction equipment need to be noted. The performance of the test road was monitored under freeze-thaw conditions and under service loads. The road showed acceptable performance with moderate maintenance requirements and minimum undesirable effects on ground water quality under the tested conditions.

INTRODUCTION

Disposal of worn-out tires has become a national problem. It is estimated that more than 200,000,000 automobile tires and 40,000,000 truck tires are discarded in the United States each year (*Guidelines* 1987; *State* 1987). The growing stockpiles of discarded tires create potential fire and health hazards.

Because of their chemical composition, stockpiles of tires, once ignited, burn at high temperatures and produce excessive volumes of thick black smoke due to incomplete combustion. The melting tires also generate large quantities of oil that not only add to the fire itself but also, through the runoff, contaminate soil and ground water. Large stockpile fires cause environmental damage and create unnecessary expenses for taxpayers. The Hagersville fire, for example, took 200 firefighters 17 days to extinguish and cost taxpayers approximately $1,000,000 for only essential site cleanup and limited environmental testing (*Scrap* 1990).

In addition to the fire hazard, improper storage of used tires poses a direct threat to public health. Discarded tires, when allowed to collect water and organic debris, become an optimal breeding habitat for four of the most important disease-carrying mosquitoes in the United States. Epidemiological studies have correlated fatal epidemics to the existence of scrap-tire stockpiles. It has been concluded that epidemics in certain localities were a result of the artificially enlarged population of these disease-carrying mosquitoes due to the optimum environment created by tire stockpiles (Thompson 1984, *Used* 1987).

This paper describes a phase of an ongoing investigation aimed at solving the tire disposal problem in the state of Wisconsin by seeking new and innovative applications for scrap tires. This phase focuses on determining the performance of tire chips when used as fill material in road construction.

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The study examines the correlation between road performance and the size, percentage, and method of placement of the tire chips used. This application was selected because of its high potential for consuming a large volume of existing and future scrap tires nationwide.

Background Information

The problem of scrap-tire disposal, however, is not new. It has challenged rubber manufacturers since the use of tires became significant. Initially, tires were made of natural rubber, and reclaiming the rubber from used tires was the practice in the rubber industry. As synthetic elastomers were developed to replace natural rubber, the reclaim process became much more costly and complex. The development of glass and steel-belted tires added more difficulty to the processes and made the reclaim operations, using current technology, economically prohibitive.

Currently, 75–80% of scrap tires are buried in landfills. Burying scrap tires in landfills is not only wasteful but also costly. Disposal of whole tires has been banned in the majority of landfill operations because of the bulkiness of the tires and their tendency to float to the surface with time. Thus, tires must be shredded before they are accepted in most landfills; shredding costs about $65–$85 per ton. To offset added disposal costs and to deter customers from bringing in tires, many landfills in the Midwest are currently charging $200 per ton (approximately 100 automobile tires) tipping fees for accepting whole tires (*Compressed* 1988).

A literature survey shows that only limited research has been carried out in the area of tire recycling and innovative disposal. Most such research efforts have been initiated by government agencies and driven by legislation. Findings have been published in reports available to the public. The first reported study was conducted by the Federal Bureau of Solid Waste Management in 1968 (Pettigrew et al. 1970). Further studies were initiated and funded by state agencies (*Scrap* 1985; *Used* 1987; *Guidelines* 1987; *State* 1987; *Waste* 1990). These studies, however, focused primarily on estimating the volume of existing scrap tire in a particular state, listing possible applications, citing the small number of case studies involving use of scrap tires, and performing preliminary evaluation of environmental impacts. To date, no reported investigation has addressed one solution/application in depth.

Major tire manufacturing companies also have participated in a limited number of research projects. Most of these efforts have been coordinated through organizations such as the Rubber Subcommittee of the National Industrial Pollution Control Council, the Rubber Manufacturing Association, and conferences and exhibitions. To date, the tire manufacturers' research efforts have generally focused on developing and improving pyrolysis processes and techniques in an attempt to recover synthetic rubber compounds (Beckman et al. 1974; Wolfson et al. 1969). It was also noticeable in the literature search that very little has been done by scrap-tire processors in terms of funded research or publications, perhaps because of their typically small operations and narrow profit margins. Also, very limited research has been done by research institutes (Higgins et al. 1986; Rowley et al. 1984; Ravella et al. 1987).

Potential Applications

As a result of the research discussed previously, a variety of applications for scrap tires have been proposed. Following is a list of the major appli-

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cations grouped under three categories: whole tires, chemically/thermally processed tires, and mechanically processed tires.

Whole Tire Applications

Scrap whole tires can be used in building artificial reefs, breakwaters, dock bumpers, soil erosion control mats, and playground equipment by various fabrication processes. Case studies of some of these applications were reported by California Department of Transportation (*Guidelines* 1987). However, these applications can be labor-intensive and their potential in solving the nation's tire disposal problem is limited.

Chemical- and Thermal-Processed Tire Applications

Many researchers and manufacturers have investigated the reclaiming of rubber from old tires by pyrolysis processes (Barbooti et al. 1989, Bouvier et al. 1987, Kaminsky 1985, Beckman et al. 1973, Wolfson et al. 1969). However, with the current technology, the process is still costly. No significant changes are expected without technological advances in the reclaiming processes to allow for lower production costs and increased demand for the recycled tire products. Other applications include use of whole or shredded tires as a tire-derived fuel (TDF) in cement kilns and steam-generating plants. Although the TDF has some advantages compared to other conventional energy sources, considerable capital investment is required for modifying the fuel handling and feeding system.

Mechanically Processed Tire Applications

Volume reduction of scrap tires to any required size can be achieved by cryogenic or mechanical grinding. The cryogenic procedure consists of cooling scrap rubber below its glass transition temperature and then pulverizing the brittle material. The cooling is usually realized by exposure to liquid nitrogen. Cryogenic grinding is an appropriate means for obtaining steel and fabric-free finely ground (down to powder size) rubber particles, but this product comes at a premium. Mechanical grinding, on the other hand, is a much cheaper means to grind (shred) scrap tires including beads and steel belts to particle sizes ranging from several inches to fractions of an inch. In Fig. 1, the shape and size of the tire chips are contrasted with those of the rubber particles obtained by cryogenic grinding.

Mechanically ground tires (tire chips) are suitable for a number of applications related to fabricated goods and construction materials as well as tire-derived fuel (TDF). Examples of these applications include floor mats, truck mats, carpet tiles, gaskets, engine seats, crack sealants, friction break material, molded rubber goods, athletic surfaces, rubberized asphalt pavement, fill substitute in road construction, aggregate substitute in concrete mixes, and wood chips substitute in sludge composting.

A full picture of the economics of tire recycling would complement this study. However, it should be noted that many applications for scrap tires are not proposed because of the savings realized through use of recycled tires as opposed to conventional materials. Often, use of recycled tires is proposed as a solution to the problem of scrap-tire disposal which is continuing to cost taxpayers millions of dollars every year and continuing to pose environmental threats on which placing a monetary value is very difficult. The severity of the problem has recently forced many states to mandate additional taxes on the purchase of new tires and on auto registration to raise funds for disposal costs. Also, many states have realized the need

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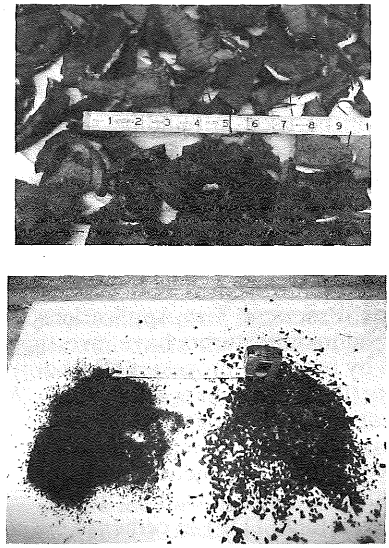

FIG. 1. Typical Size and Shape of Mechanically and Cryogenically Ground Tires

for developing incentives/subsidy programs to encourage use and disposal innovations that reduce disposal in landfills, $20 per ton is paid to scrap-tire users in Idaho, Oregon, Utah, and Wisconsin. A current tire disposal project in the state of Wisconsin is costing $200 per ton. In addition to the direct costs of disposal, we are wasting landfill sites that are becoming more and more scarce and valuable. The effort to find less costly or environmentally safer applications may, thus, be worthwhile even if it is not appealing from the standpoint of conventional economic analysis. The topic of the economics of tire recycling and disposal is covered in another publication that is currently being prepared by the principal writer.

Design of Test Road

A test road 16 ft wide, 6 ft high, and approximately 200 ft long was built from shredded tires so that its performance under service conditions could be studied. The road was built in sections to permit examination of a number of test variables including size, percentage, and placement conditions of tire chips, as well as thickness of soil cap. Table 1 and Fig. 2 summarize the experimental design.

Prior to the construction of the test road, a laboratory investigation was conducted to guide the selection of test variables for the test road. The lab tests, involving seven samples collected from different processors, included visual inspection, classification, and compressibility. Since compressibility of tire chips was a major concern, measurement of vertical displacement response under cyclic loading with and without vibration (simulating field compaction) was done in the lab to evaluate the compressibility of tire chips. Details of the laboratory investigation are provided elsewhere (Edil et al. 1990). To summarize, lab results indicated that major compression took place in the first loading cycle. Less compression was observed in subsequent cycles with some persisting rebound upon unloading. This was true for all

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TABLE 1. Experimental Design

Section number (1)	Chip size (in.) (2)	Percent by volume (3)	Soil-gap thickness (ft) (4)	Placement condition (5)
1	4	50	1	layered (tire chips/soil, 1 ft per layer)
2	4	100	1	tire chips only in 1-ft lifts
3	4	100	3	tire chips only in 1-ft lifts
4	8	100	3	tire chips only in 1-ft lifts
5	2	100	1	tire chips only in 1-ft lifts
6	4	50	1	premixed (tire chips and soil, 1-ft lifts)

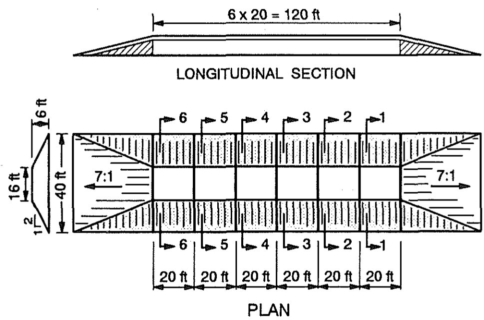

FIG. 2. Layout of Test Road

tire chip sizes tested, with some minor variations in displacement magnitude. It was also observed that the magnitude of displacement did not seem to change when the mold was vibrated during loading and unloading cycles.

The compressibility tests were repeated using mixtures of tire chips and sand at various mixing ratios. Results similar to those described previously were obtained with some increase in the mixture's bulk density due to the vibration effect on sand. An average initial loose dry unit weight by about 25 pcf and an average final dry unit weight ranging between 35 and 45 pcf were typical. When various mixing ratios were tried, a significant increase in compressibility occurred at ratios (tire chips to sand) exceeding 50% on volume basis.

Since the preliminary laboratory tests did not favor a particular size of tire chips, the 4-in. nominal size was selected as the principal size tested because of its availability in the vicinity of the project site. On the basis of the laboratory results, the tire chips were mixed with a granular silty soil available near the project site at a mixing ratio of 50% by volume. Two methods of placement (layered and premixed conditions) were tested in sections 1 and 6, as shown in Fig. 3. If the performance of both sections proved acceptable, the layered placement would be preferable from the construction procedure standpoint. Use of distributors/dump trucks with adjustable tailgates and pulverizers for placement of material and in situ mixing involves less material handling than premixing followed by placement operations.

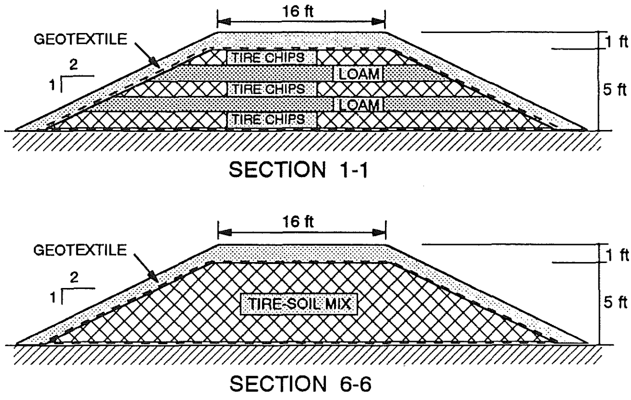

FIG. 3. Design of Sections 1 and 6 of Test Road

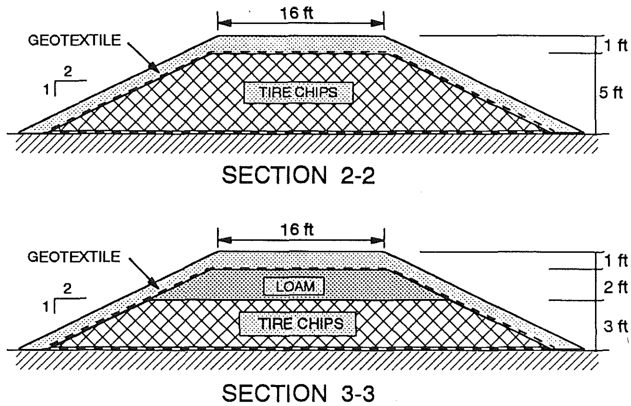

FIG. 4. Design of Sections 2 and 3 of Test Road

So that the full potential of shredded tires in road construction could be studied, two more sections were built of 100% tire chips, 4-in. nominal size. In sections 2 and 3, Fig. 4, two soil cap thicknesses (1 and 3 foot) were used to examine the effect of cap thickness on the performance of tire-chip underlayers.

So that data on handling and placement of various chip sizes could be collected and size effects under field conditions examined, two additional sections (4 and 5) were built using 2-in. and 8-in. nominal size tire chips as shown in Fig. 5. A 3-ft thick soil cap and a 1-ft cap were also used in the 8-in. section and the 2-in. section, respectively.

A geotextile fabric was used as a separator between the tire chips and the soil above and below. Two ramps were built to provide access for traffic. The test road (all sections and access ramps) was surfaced using a typical 1-ft thick base course of 6-in. maximum size well-graded crushed stone. To maximize the area through which rain water might percolate through the tire chips before it was collected in the leachate lysimeters, the roadway was not paved.

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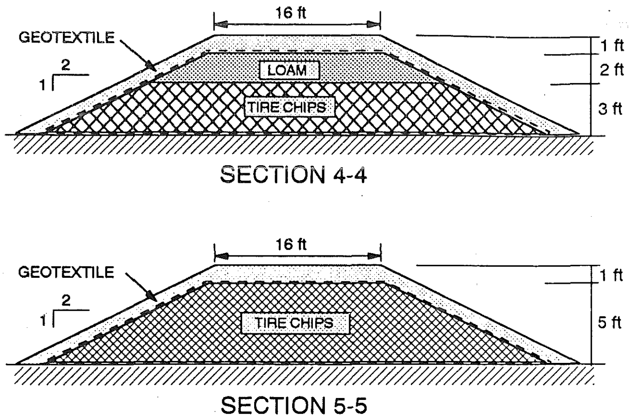

FIG. 5. Design of Sections 4 and 5 of Test Road

Construction of Test Road

After the experimental design concept for the test road was developed, design plans and specifications were completed. Dane County Highway and Transportation Department was given the responsibility of building the test road. The construction crew consisted of five crewmen. A front-end loader, a backhoe, a scraper, a grader, a vibratory sheepsfoot roller, and two dump trucks were assigned to the project for the construction duration. With the cooperation of the Dane County Department of Public Works, county landfill number 2 was selected as the project site. It was decided that the test road should be built parallel to the landfill access road, making it feasible to divert a known quantity of traffic onto the test road as desired. Heavy trucks and other vehicles are routinely weighed as they bring refuse to the landfill.

Construction began in early December 1989. Weather conditions caused slowdowns on a number of occasions but did not shut down construction activities on any single day. The construction of the test road cost approximately $21,000 and took about three weeks to complete. These steps were followed in the construction procedure:

1. The top soil was removed and preserved on-site for reuse on the side slopes after construction was complete. The top underlying 18 in. were replaced by granular silty soil available in the vicinity of the site. The soil was placed in two lifts, compacted, and graded to the required elevations.
2. In each of sections 2 and 5, a leachate collection lysimeter was installed according to the manufacturer's instructions as will be described in the following section.
3. Two 20-ft wide rolls of geotextile fabric (Synthetic Industries, style 970) were sewn together and placed on grade to provide a separator between the road materials and the underlayer. The fabric was cut to expose the full area of each lysimeter.
4. The construction materials (tire chips and soil) were arranged in each section as shown in Figs. 3, 4, and 5. Dump trucks were used to transport the designated materials to each section. The grader was used at first to spread the materials, but it was soon replaced by a backhoe, which was

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more efficient in this operation. Materials were installed in 1-ft lifts in all sections and compacted thoroughly with five passes per layer. After the completion of the top lift in each section, geotextile fabric was installed to provide a separator between the tire chips and the soil cap above.

5. Upon reaching the design height for each section, the roadway was surfaced with a well-graded crushed-stone base course of 1 ft typical thickness that was compacted and graded to the required elevations. The test road was closed to traffic through the winter season.

6. In the spring of 1990, the test road was examined and surveyed. A few longitudinal cracks and surface depressions were apparent. The cracks were approximately 2 in. wide, 12–16 in. deep, and 8–12 ft long. The depressions were of about 2–3 ft radius and 4–6 in. deep. In late April 1990, the construction crew went back to prepare the test road for traffic. Additional base-course material was added to fill the cracks and depressions, then compacted and graded. The preserved top soil was placed on the side slopes and finished to 2:1 inclination.

Instrumentation of Test Road

Two lysimeters were installed, one in section 2 and one in section 5, to collect leachate samples as rain water percolated down through the tire chips. Each lysimeter consisted of a 30-mil thick, 10-ft wide by 12-ft long by 1-ft high polyvinyl chloride (PVC) impervious liner, Fig. 6. The liner was also fitted with a 4-in. pipe boot designed to receive a 4-in. PVC drain pipe leading to a collection well. The liner was squared in a hole of the same dimensions excavated under the section. The soil underneath the liner was sloped to the center in the direction of the drain pipe. The liner was filled with 1/4 in. washed pea gravel to form a collection basin. A filter cloth was placed on top of the gravel to prevent clogging of the collection system. The drain pipe conducted the collected leachate to the south side of the test road into a collection well consisting of a vertical cylindrical PVC container of 10-in. diameter and 5 ft deep. The top of the well was fitted with a protective cap that could be easily removed during sampling. All pipes and fittings were assembled using manufacturer's epoxy.

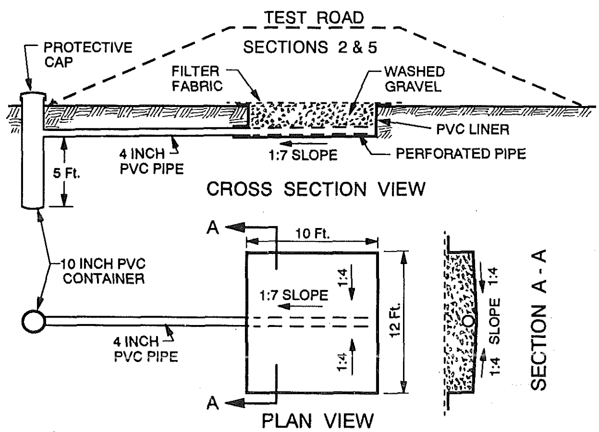

FIG. 6. Schematic of Leachate Collection Lysimeter

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Eight settlement plates were installed during the construction of the test road. These were the standard Wisconsin Department of Transportation plates consisting of a 2-ft square steel plate with a 6-ft rod welded in the center and a shielding pipe to eliminate friction between soil and the road. Six plates were placed roughly in the midheight of the road (top of the third layer above grade) in each section. Two additional settlement plates were installed, one on grade in section 4 and another on top of the first layer in section 1.

Three survey markers were placed on the roadway in each section as shown in Fig. 7. A survey marker consisted of a 2-in. square, 1/4-in. thick steel plate with a 10-in. long number 4-bar anchor welded to its center. The initial elevations of these markers were recorded to establish measuring surface deformation of the test road under service conditions.

Construction Observations

Both before and after compaction of each lift, unevenness and roughness of the tire-chip surface were obvious. These surface characteristics, resulting from the nature of tire chips, their tendency to rebound, and their ability to retain their shape, made it difficult to determine accurately the surface elevations of each lift and allowed only approximate measurements. Elevations were, therefore, measured on a 2-ft square steel plate placed on the top of the lift in the center of the section. The plates provided a stable surface for the surveying road, preventing penetration into the tire-chip layers, and offered consistency in the taking of readings.

Balling-up of the large-size tire chips, the 8-in. nominal size, was another field problem. Spreading this material required more effort and took twice the time needed to spread the smaller sizes. Smooth dumping and distribution of this nonconventional construction material may require equipment modifications. For all sizes of tire chips, a backhoe seemed more capable of spreading the tire chips more evenly and efficiently than a grader or a front-end loader.

Tracked equipment had no trouble maneuvering over the shredded-tire fill, but trucks sank in and had to be pulled out once the tire chips were over 3 ft thick. The average gross weight of the trucks ranged from 20 to 25 ton.

The 12-ton sheepsfoot vibratory roller used to compact the tire chips was adequate. During the compaction of the first layer, the northern half of each section was compacted with vibratory action, whereas the southern half was subjected to no vibration. Unit weights after compaction for both halves were computed from the weight of material placed and section's dimensions. The data indicated that vibratory action did not improve compaction of tire chips and, therefore, use of vibration was stopped for the subsequent layers. Although the chips compacted steadily, there was an apparent partial rebound manifested in an upheaval wave that could be

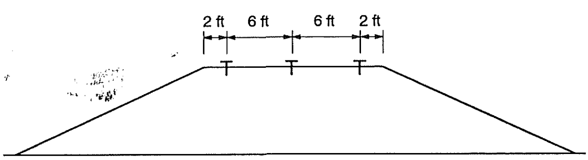

FIG. 7. Positions of Surveying Markers

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easily seen right behind the roller drum. This is attributable to the resilience of the tire chips.

Attaining the desired side slopes and compacting the edges of the roadway were difficult once the tire chips were over 3 ft high. The chips tended to stick together and then abruptly shift laterally in bundles. This caused one minor accident as the roller turned over while compacting the edge of the fourth lift in section 5. No one was hurt, but it was an unpleasant surprise. These problems were resolved by using a tracked backhoe for shaping and compacting the sides and a slow-speed roller for roadway compaction. The roller operator was instructed to stay on a straight path and to refrain from maneuvering near the edges.

The ability of tire chips to absorb and prevent the transmission of vibrations was also very noticeable. One could easily feel the ground shaking when the vibratory roller was compacting the approaches built of soil. Less vibration was felt when the roller traveled on the soil-tire mixture, and almost no vibration was felt during compaction of the sections built of tire chips only. This ability to control vibration could prove valuable, especially for building roads on sensitive soils where reduction of vibration is desirable. It is speculated that use of shredded tires will also be advantageous in building sound barriers in metropolitan areas where reduction of traffic noise from a nearby highway is desirable.

Field Data

By the end of May 1990, the initial survey of the markers and settlement plates was completed and the final dimensions of the test road were determined. In June 1990, the road was opened to traffic; it remained open until the end of September with occasional interruptions for surface maintenance. During this period, a daily average of 166 vehicles totalling approximately 885 tons were passing over the test road. Table 2 provides the monthly data showing number of vehicles and cumulative total load. It should be noted, however, that vehicles varied from small passenger cars (few hundred pounds axial load) to large-size 40-ton trucks (20 ton per axial). The daily log of the landfill shows that, on average, four trucks of the 40-ton size drove over the test road daily.

Surface depressions reoccurred during these months, requiring periodic maintenance to keep driving conditions safe. After about three months of service, the roadway markers were surveyed again and the readings were compared to the initial readings as shown in Table 3.

Leachate samples were gathered monthly from the collection wells of the two lysimeters installed in sections 2 and 5. The samples were tested for barium (Ba), calcium (Ca), iron (Fe), lead (Pb), magnesium (Mg), manganese (Mn), sodium (Na), zinc (Zn), chloride (Cl), and sulfate (SO_4). The analysis also included determination of the pH, alkalinity, hardness, biological oxygen demand (BOD), and chemical oxygen demand (COD) of the samples. Table 4 summarizes the test results.

TABLE 2. Daily Average Number of Trucks and Tonnage

Daily average (1)	June (2)	July (3)	August (4)	September (5)
Number of trucks	163	171	166	163
Total tonnage	839	900	939	851

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TABLE 3. Surface Deformation Data

Section number (1)	Original elevation (2)	Final elevation (3)	Deformation (in.) (4)
1	14.26	13.94	3.80
2	14.54	14.42	1.48
3	14.86	14.72	1.68
4	15.13	14.99	1.68
5	15.47	15.28	2.28
6	15.67	15.44	2.68

ANALYSIS

The limited field data suggest that the size of tire chips may affect road performance. Comparisons of surface deformation in sections 2 and 5 indicate that the 4-in. nominal size tire chip showed less compressibility under service loads than the 2-in. These two sections were built of 100% tire chips, under 1-ft soil cap, and above collection lysimeters. However, comparison between the 4-in. size and the 8-in. size in sections 3 and 4 does not reveal the same size effect on performance. Again, the only apparent difference between these two sections was the size of the tire chips. Although a full conclusion cannot be drawn from these limited observations, the results indicate that there could be a size range that provides better performance than others. Among the sizes tested, that range would be 4–8 in. Of course, additional data are needed to support this claim. Moreover, it might be helpful to use an evaluation criteria based on more elements than just monitoring surface displacement. Perhaps criteria related to surface conditions and maintenance requirements would be more appropriate because of the reoccurring surface cracks and depressions that are not apparent in the presented data.

Premixing of soil and tire chips provided a better placement condition than placing layers of each material separately. Section 6, under premixed conditions, showed less deformation under service loads than section 1.

A review of the designs of the few experimental forestry roads built with tire chips (Geisler et al. 1989) shows that soil caps ranging from 1 to 4 ft thick were used. However, no design criteria for soil-cap thickness were recommended in these case studies. In the test road, a 1-ft thick and a 3-ft thick soil cap were used to examine the effect of soil-cap thickness on deformation of the underlayers of tire chips. Comparison of data from sections 2 and 3 suggests that performance of tire-chip underlayers may not be sensitive to soil-cap thickness in the range tested.

Preliminary evaluation of the potential environmental impact of using tire chips was done through periodic analysis of specimens from the leachate collecting lysimeters. As shown in Table 4, chemical analysis of the field samples indicated that the enforcement standard limits (hazardous limits) for Ba and Pb were not exceeded. However, Ba concentration somewhat exceeded the preventive action limits (PAL). Concentration of Pb, on the other hand, was well below the PAL in section 2 (i.e., 4-in. tire chips) and at or slightly above in section 5 (i.e., 2-inch tire chips). Perhaps this was due to the size effect (smaller tire chips having a higher surface area) or due to some contamination from the landfill. More investigation is necessary to determine the actual cause for the consistent

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TABLE 4. Leachate Chemical Analysis

Element tested (1)	Unit (2)	Lysimeters in Section 2						Lysimeters in Section 5						Wisconsin limits[a]
		April (3)	May (4)	June (5)	July (6)	August (7)	September (8)	April (9)	May (10)	June (11)	July (12)	August (13)	September (14)	
Barium	μg/L	240	240	230	210	360	472	220	210	240	190	270	300	1,000/20
Calcium	mg/L	190	180	160	140	120	114	200	170	180	110	130	143	/25
Iron	mg/L	0.05	0.05	0.24	0.57	0.26	0.39	1.3	0.05	0.12	0.54	0.53	0.36	/0
Lead	μg/L	3	3	3	3	3	3	9	3	5	4	15	6	50/5
Magnesium	mg/L	190	160	150	130	120	132	200	150	150	96	110	121	/25
Manganese	μg/L	170	200	220	350	2,500	2,060	230	270	300	200	1,700	2,310	/50
Sodium	mg/L	330	290	220	130	86	89	280	220	260	98	120	137	/10
Zinc	μg/L	19	12	17	16	12	—	84	46	44	540	560	119	5,000/25
Chloride	mg/L	—	770	570	300	230	120	—	460	300	130	170	200	/25
Sulfate	mg/L	130	97	130	150	140	110	—	140	140	92	150	180	/25
pH	su	7.6	7.5	7.6	7.9	7.3	7.5	—	7.7	7.4	7.8	7.5	7.3	—
Alkalinity	mg/L	381	557	656	722	710	726	—	533	567	625	671	705	/10
Hardness	mg/L	1,300	1,100	1,000	900	794	828	1,300	1,100	1,100	660	777	855	—
BOD	mg/L	41	15	6	5.2	17	40	—	14	10	39	75	57	/25
COD	mg/L	200	110	84	120	140	230	280	170	220	320	290	390	/25

[a]Limits are taken from Wisconsin Administrative Code, October 1990, Chapter NR 140, 682–686. The figures represent hazardous/preventive limits.

difference in the data collected from both lysimeters. Fe seemed to fluctuate around the PAL with no consistent trend from one lysimeter to the other. Ca, Mg, Mn, and Na all well exceeded the PAL. Although SO_4 also exceeded the PAL, its concentration seemed to be decreasing with time and to be approaching levels below the desired limits. Alkalinity, hardness, BOD, and COD also were well above the recommended PAL. It is speculated that the high concentrations of Ca and Mg may have contributed to sample hardness.

It should be noted here that the concentrations measured from the leachate should not be misinterpreted. Pollution limits are enforced at a property's boundaries that are, for a highway, at some distance from the roadway itself. At this distance, the measured concentrations will be lower due to natural diffusion. Further reduction in the measured concentrations, coming from a finite source, is to be expected as the leachate gets diluted in the large body of ground water. Although the recommended PAL represent the target concentrations, PAL are meant to provide an early warning to the enforcing agencies and to leave to their discretion on a case-by-case basis whether an action should be taken.

Analysis of variance (ANOVA) for the measured elements indicated no significant size effect on the concentrations of the leaching elements, but a relatively strong time effect on the concentrations of Mg, Mn, and Na. It also indicated a weak time effect on Ca and Ba as shown in Table 5. A correlation analysis was also done to examine the concentration variation of the leaching substances over time, Table 6. A significant positive correlation with time was found for Mn and a significant negative correlation with time for Na and Mg. A very significant negative correlation for Ca was found in the west lysimeter and a weaker negative correlation in the east lysimeter. The other elements did not show any significant correlation with time.

TABLE 5. Analysis of Variance for Leaching Elements

Metal (1)	Source (2)	Degrees of freedom (3)	Type II Sum of squares (4)	Mean Square (5)	*F* Value (6)	*P* Value (7)
Ba	size	1	8216.33	8,216.33	4.03	0.1008
Ba	time	5	10,428.33	10,428.33	5.12	0.0487
Ca	size	1	70.08	70.08	0.30	0.6048
Ca	time	5	9,410.42	1,882.08	8.18	0.0188
Fe	size	1	0.11	0.11	0.07	0.8004
Fe	time	5	5.27	1.05	0.69	0.6520
Pb	size	1	48.00	48.00	4.90	0.0778
Pb	time	5	49.00	9.80	1.00	0.5000
Mg	size	1	252.08	252.08	2.35	0.1859
Mg	time	5	9,702.42	1,940.48	18.09	0.0032
Mn	size	1	21,675.00	21,675.00	0.16	0.7099
Mn	time	5	88,555,341.67	1,771,068.33	12.68	0.0072
Na	size	1	75.00	75.00	0.06	0.8219
Na	time	5	78,414.67	15,682.93	11.76	0.0086
Zn	size	1	60,372.90	60,372.90	2.51	0.1886
Zn	time	5	210,725.03	42,145.01	1.75	0.3040

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TABLE 6. Correlation of Concentration with Time

Element detected (1)	West lysimeter section 2 (2)	East lysimeter section 5 (3)
Barium	0.78	0.70
Calcium	−0.99[b]	−0.75
Iron	0.71	−0.43
Lead	Cste over time	0.29
Magnesium	−0.90[a]	−0.81[a]
Manganese	0.82[a]	0.95[b]
Sodium	−0.97[b]	−0.81[a]
Zinc	−0.48	0.48

[a]1% level.
[b]5% level.
Observed level of significance was not adjusted for multiple comparisons.

Environmental Concern

A recent study by Minnesota Pollution Control Agency (MPCA) suggested potential environmental concerns regarding the use of scrap tires in extreme acidic or basic environments (*Waste* 1990). The MPCA study reported that excessive barium, cadmium, chromium, lead, cesium, and zinc were released at pH of 3.5 to 5. It also indicated that certain types of hydrocarbons may be released at a pH of 8.0.

Use and recycling of solid wastes, including scrap tires, require assurance of environmental safety. In the test road, two lysimeters were installed to assess the environmental impact of scrap tires on ground-water quality. The tire chips were placed well above the ground-water table and in a neutral soil (pH 6.9). From the limited environmental data currently available, use of tire chips in environments similar to that of the test road should have no excessive undesirable effects on ground-water quality. However, it is evident that extensive laboratory and field studies are still needed. These studies should lead to the development of engineering and environmental specifications for the safe use of scrap tires as a construction material.

Conclusion

This paper summarizes the findings of research conducted to evaluate the potential for using waste tires in building roads and highways. A 16-ft wide, 6-ft high, and 200-ft long test road was built from shredded tires to determine the effect of tire-chip size, method of placement, and soil-cap thickness on road performance. Valuable information was collected on material handling, compaction of tire chips, and the environmental impact of this application.

The available data indicate that the use of shredded tires does not present major handling and placement problems in road construction. However, control of compressibility appears to be somewhat problematic. The test road required periodic moderate surface maintenance under the service loads during the first three months. This suggests that performance evaluation criteria other than surface displacement, related to surface conditions and maintainability of the road, will be advantageous. Chemical analysis of leachate indicated little or no likelihood of detrimental effects on ground water in the tested environment. Further research is strongly recommended to provide statistical validation of the data presented here.

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