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USE OF SHREDDED TIRES AS LIGHTWEIGHT FILL IN ROADWAY CONSTRUCTION

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Use:

- Lightweight fill (350 to 700 kg/m^3)
  - → Floating embankments
  - → Slope stability application
  - → Behind retaining walls
- Thermal insulation layer

Restrictions:

- Must be above water table
- Use must be authorized by permit from the Minnesota Pollution Control Agency (MPCA)
- Engineer review required

Cautions:

- Combustible, may ignite spontaneously
- Leachate concerns
  - → Metals from wire reinforcement
  - → Hydrocarbon in groundwater runoff
- Shreds must be free of contaminants and small or fine rubber particles
- Placement should be encapsulated with a geosynthetic to prevent soil contamination

INTRODUCTION

Weak soils, such as peat and muck, have been a problem for engineers for as long as people have been building roads. In the past the most commonly selected alternatives when encountering weak soils was to go around the area, float an embankment over the weak soils, or remove the weak soils and replace them with a suitable material. Current economics and/or land restrictions result in highway departments too often traversing areas of weak soils without the funds to avoid or remove the weak soils. In situations where the in-place weak soils must be traversed, an available alternative may involve "floating" a road structure with a lightweight fill material for the road embankment.

In 1992, automotive waste tires were discarded at a rate of four million tires per year, including 84,106 m^3 of tires (110,000 yd^3) annually in the state of Minnesota. (1) In 1985, a recycling firm and a logging contractor contacted the Minnesota Pollution Control Agency (MPCA) regarding the use of waste tires to construct forest roads. In 1986 the Hedbom Forest Road in Floodwood, Minnesota, was constructed using waste tires. The tires were placed below the base material using nine different placement strategies. (2) These placements ranged from tying whole tires together to spreading shredded tires as a base material. As of the last review in 1989, all test sections performed exceptionally well. This study prompted the MPCA to conduct testing to establish some guidelines for the use of waste tires as a fill material. The MPCA has expressed concern about tires below the water level releasing heavy metals, leachates, and hydrocarbons. Independent research by the Minnesota Department of Transportation (Mn/DOT) and others has shown only minor concern. (3)

This Research Implementation Series (RIS) presents and discusses the concept of using shredded tires as a lightweight fill material, following the suggestions in the LRRB report of "Lightweight Fill Materials for Road Construction." (4) This RIS includes the methods now used throughout the United States, major application problems and solutions, current practices in Minnesota and the environmental implications and restrictions now in place within the state of Minnesota.

BACKGROUND

Weak subgrade soils have low bearing capacities that call for either special subgrade designs or special cases of conventional designs. When less than satisfactory foundation conditions exist, the embankment may fail during or after construction by excessive settlement, sliding, local rotational failure, or lateral movement. For such adverse foundation conditions, various design alternatives exist: preloading/staged construction; construction with a lightweight fill; excavation and replacement of all or part of the weak soils; geosynthetic reinforced embankments; or bridging the area with a piled structure.

Conventional designs either call for removal and replacement of the soft subgrade soils or overfilling for planned settlement with or without a counterbalance. In some cases, these designs cannot be constructed over a soft foundation or may not be cost effective. As an alternative, shredded tires provide a lightweight platform for construction when properly placed over the soft soils.

LEGISLATIVE CHANGES AND THE PERMITTING PROCESS

As stated in Minnesota Statute 1996, the disposal of waste tires in the land is prohibited after July 1, 1985. (5) The MPCA created and administers Minnesota's Waste Tire Program, a total waste management system for waste tires. The program requires that waste tire generators keep disposal records, and transporters receive an MPCA Identification Number authorizing them to haul waste tires. (6) With an identification number or an exemption from the identification number requirement, waste-tire transporters must keep all shipment records and submit quarterly statements to the MPCA. The statements must include location, date, and quantity of collection and disposition. A current listing of authorized transporters can be requested from the MPCA. (7)

The MPCA has permit requirements for the proper storage and processing of waste tires, as well as for waste tire transfer stations that store waste tires temporarily. Any owner or operator of a business that intends to accumulate whole waste tires or tire-derived products as part of a business activity must obtain a permit from the MPCA. In general the permitting process involves application and operational requirements such as stockpile size, fire lane, mosquito and rodent control, closure plan, financial assurance for cleanup, and annual report. (8)

When shredded tires are used as lightweight fill materials, the MPCA prohibits their use in areas where they will be in contact with ground water. The MPCA developed guidelines applicable to road repair and construction above the water table. These guidelines help reduce water infiltration and promote surface water drainage. To determine if the proposed project meets the guidelines, the proposal should be submitted to the MPCA for technical review. The proposal should include construction methods, number and type of tires to be used, depth to the water table, and soil data. Also required are maps, diagrams, and cross-sections to show construction details. (9)

In 1997 Minnesota Statute 1996, Chapter 115A, 115A.912 was amended to include four subdivisions. Subdivision 4 adds the requirement that a professional engineer in the geotechnical field prepare a construction plan of a waste tire fill. The plan should at least include the location, duration, and length of the project, the depth of fill and cover, tire chip sizes, and fire protection. (10)

MATERIAL PROPERTIES

As a lightweight fill material, shredded tires have their own material properties, which differ from and are compared to another lightweight material, wood chips. Vehicle tires today contain metal additives plus metal belts and bead wire, as well as petroleum. On the other hand, wood is a solid fibrous substance. Tables 1 and 2 list typical physical and chemical constituents of tires. The different tire shredding operations may result in different particle sizes: 25 mm x 51 mm, 51 mm x 76 mm, 102 mm x 152 mm, 102 mm x 457 mm (1 x 2 in, 2 x 3 in, 4 x 6 in, 4 x 18 in, etc.). (11) The wood chipping operation can be conducted to provide uniformity of the particle size. (12) As a result, the gradation of shredded tires tends to be random to uniformly graded while that of wood chips may be poorly graded, as shown in Table 3.

Table 1. Physical Constituents of Tires

Physical Constituents	Percent by Weight		Percent by Weight
Fabric	10		
Bead Wire	4		
Rubber Compound	86	Rubber Polymer	47
		Carbon Black	30
		Oil	18
		Chemicals	3
		Zinc Oxide	2
		Total	100
Total	100		

Table 2. Chemical Constituents of Tires

Chemical Constituents	Carbon	Hydrogen	Nitrogen Oxygen Sulfur	Total
Percent by Weight	83	7	10	100

Table 3. Engineering Properties of Tire Chips and Wood Chips

Engineering Property	Tire chips	Wood chips	Remarks
Gradation	0.2"-20"	0.2"-2"	
Specific Gravity	1.06-1.15	0.15-0.46	
Bulk Unit Weight kg/m^3	356.78 (14-22)		truck measure
	22	237 (14)	field compaction
	405.43-567.60 (25-35)		lab compaction
Thermal Conductivity	0.38	0.18	
Permeability cm/sec	3.53 (10,000)		
Internal Friction Angle	18°		
Cohesion kPa	28.74 (4.2)		
Angle of Repose	45°		design parameter
Young's Modulus MPa	.04-1.02 (9-148)	6.81 (1,000)	secant of 10% strain
Shear Modulus MPa	2.70 (390)	15.46 (2,240)	
Poisson's Ratio	0.3-0.5		
CBR (%)	0.55	3.07	
Compressibility Index	0.50	0.35	
Swelling Index	0.27	0.03	

Table 3 also includes other engineering properties of shredded tires as compared to those of wood chips. There is a large range of truck measured bulk unit weights of shredded tires, from 224.14 kg/m^3 to 352.22 kg/m^3 (14 pcf to 22 pcf). In the laboratory, the minimum bulk unit weight may be 400.25 kg/m^3 (25 pcf) and the maximum may be 560.35 kg/m^3 (35 pcf). In the field, the maximum compacted bulk unit weight may be 352.22 kg/m^3 (22 pcf) after a number of dozer passes for multiple 0.9 m (3-ft) layers. On the other hand, the maximum bulk unit weight of wood chips is about 224.14 kg/m^3 (14 pcf). When wood chips are submerged in water, the maximum unit weight could be doubled to 464.29 kg/m^3 (29 pcf). Therefore, shredded tires are heavier than wood chips in dry conditions even though both chips are lightweight materials. In situ densities of shredded tires in a completed project may approach 730 kg/m^3 (45 pcf) after compaction. After surcharge and one year compression, final density approaches 860 kg/m^3 (53 pcf). (13) The laboratory tests on the deformation of shredded tires under load indicated the existence of creep in the first two years that should be accounted for in the design. (14)

Other material properties include:

- shredded tires are more compressible than wood chips;
- both tire and wood chips have very high permeability; and
- both chip fills can result in less frost heave and limit the depth of frost penetration and heat loss.

Shredded tires have a greater thermal conductivity than wood chips and shredded tires are eight times better than soil as an insulator. In one study, wood chips were stronger than shredded tires in terms of either compression or shear modulus. (12)

APPLICATION PROBLEMS AND SOLUTIONS

Application of shredded tires as lightweight fill materials to road construction has resulted in two major concerns — environmental and fire hazards.

Ground Water Contamination

Based on chemical analysis of the leachate and a comparison of the analytical results to drinking water standards (Table 4), current MPCA policy does not allow shredded tires to be placed below the water table. The drinking water standards may be exceeded in the laboratory under "worst-case" conditions for zinc, which can appear at low pH (acid) conditions or at $pH < 3.5$. Some concerns exist about other heavy metals and organics, but the tests did not show any other items exceeded drinking water standards. Mn/DOT has evaluated chemical leachate, along with biological effect leachate, using a comparative risk bioassay method to determine the comparative toxicity of wood chips and their proposed replacement material, shredded tires. (3) As shown in Table 5, both the wood chip and shredded tire leachate produce acute and chronic toxicity that affects three out of five selected species of organisms, algae, water fleas, and minnows. In both the water fleas and the minnows, the toxicities are greater from shredded tires than wood chips in both the acute and growth/reproductive tests. Lettuce, another organism, demonstrated increased growth from both leachates while compost earthworms showed no effect from either leachate.

The chemical results and the biological effects presented above were obtained in laboratory tests. A field study in Wisconsin indicated that most leachates stayed within acceptable limits. Also, in Maine, Dr. Dana Humphrey has not observed metals exceeding drinking water standards in the field. Therefore, it seems appropriate that field testing of the ground water occurs before proposing construction of a tire chip lightweight fill. Furthermore, shredded tires must be clean and free of oils and grease to avoid ground water and soil contamination. The cleanliness can be maintained by using a synthetic geotextile fabric above and below tire chip fills. The shredded tires should be placed above the water table and not in contact with ground water, as stated in MPCA guidelines.

The use of shredded tires as lightweight fill beneath the water table requires the removal and/or permanent stabilization of zinc from shredded tires to provide sufficient decreases in zinc levels.

Table 4. Chemical Parameters That Exceeded the Health Risk Limits[a] (HRL) Limits for Groundwater

Parameter	HRL	Tire Chips	Wood Chips
2-Methylphenol (ug/l)	30	<3	34
Zinc (ug/l)	2000	2950	284

[a] Set by the Minnesota Department of Health

Table 5. Biological Effects of Chemical Leached

Organism	Test	% of Leachate Used to produce Results	
		Tire Chips	Wood Chips
Algae	Acute Effect on Cell Density (EC50)	<6.3	<6.3
	No Acute Effect on Cell Density	<6.3	<6.3
Water Flea	Reproduction Effects	<1.6	13
	No Acute Effect on Survival	3.1	25
	Acute Toxicity (LC50)	6.3	34
Minnow	Growth Effects	6.3	13
	Acute Toxicity (LC50)	8.9	25
	No Effect on Survival	6.3	13

Fire Hazards

Nationwide, three isolated tire chip fill locations have been documented to exhibit exothermic reactions. These locations had similar conditions: use of many steel-belted and fine-crumbed shredded tires, access to oxygen, relative thick fills, and hydroseeded topsoil contact directly on the top of the shredded tires. Steel generates heat when it rusts. Organic materials -- including fertilizers in water runoff -- oxygen access, and moisture conditions enhance the rusting of the exposed steel belts. The significant content of crumbed rubber in the tire chip fill provides a source of sulfur, reducing the pH and increasing corrosion rate.

The solutions to fire problems involve minimizing the aggravating factors such as free access of the fill to oxygen, organic matter leached into the tire chip fill, fertilizer washed into the fill, significant amounts of exposed steel belts, and possible accumulations of fine-crumbed rubber. The gradation of shredded tires should be specified to control the content of fine-crumbed rubber and to ensure the complete compaction. The confinement by a geotextile fabric can minimize organic matter in topsoil from coming into contact with the fill. Proper sizing and magnetic removing can help by reducing amounts of the exposed steel belts. For example, the shreds produced by a shearing process have a smaller surface area than the shreds produced by a hammer-mill process.

CURRENT PRACTICE OF MN/DOT

In 1985 Minnesota began using shredded tires as a lightweight fill material on logging roads through areas with weak soils. Through 1991, the MPCA documented 23 sites out of 28 sites statewide that have used more than 61,000 m^3 (80,000 yd^3) of shredded tires or approximately 2.2 million tires. Most shredded tire fill was used on either private driveways, county roads, or city streets. (15) These projects had similar engineering features, including a relatively larger shred size, 0.9 m (3-ft) fill lift, encapsulation of geotextile fabric, 0.6 m (2 ft) or more mineral soil cover, 0.3 m (1 ft) above the water table, and wood chip continuation into the ground water. A wide range of applications for shredded tires as lightweight fill materials includes embankments, bridge approaches, paved and unpaved roads, parking and highway ramps, driveways, and streets over soft soils such as peat, loam, muck, and organic soils. These projects demonstrate a successful track record with no reporting of either fires or ground water contaminations in the past 13 years.

As reported in a Federal Highway Administration (FHWA) nationwide survey through 1996, about 59 out of 70 -- or 84 percent -- projects that used whole or shredded tires as lightweight fill in the United States occurred in Minnesota. (15) Thickness of the shredded tire fill ranged from 0.6 to 2.4 m (2 to 8 ft) with exceptions of two 4.6 m (15-ft) thick fills. To date, none of these projects have exhibited an exothermic reaction. The specification by Mn/DOT for an interstate freeway exit ramp embankment reflects Mn/DOT's current successful practices. (1)

Some variation is appropriate depending on the project's size, location, and importance. Undisturbed soil borings are recommended for settlement estimates and other uses. The pH readings of surrounding soil and water are taken to verify a range between five and nine. In most cases a geotextile encapsulation layer is recommended to isolate the shreds, to prevent sinkholes from forming in the overlying cover material, and, in some cases, to help shed or filter water.

Adequate cover and time is needed to consolidate the shreds and ensure a high enough subgrade modulus for pavement durability. Settlement plates are often helpful. For major roads, 1.5 to 1.8 m (5 to 6 ft) of cover has worked well. Low volume unpaved roads have been built with 460 mm (18 in.) of cover, but with no conclusive evidence on performance. In any case, a waiting period of one month is helpful.

Shredded tire stockpiles and the embankment itself should have a fire control plan that requires covering the material within two weeks or enclosing it in a chain link fence. For large stockpiles, fire lanes and smaller piles are recommended.

STATE OF PRACTICE

The following unique properties make shredded tires particularly useful for road construction: low compacted density or lightweight, low lateral earth pressure, low thermal conductivity, and high permeability. Each cubic meter of shredded tire fill may use from 50 to 100 scrap tires (35-75 tires/yd^3). Tire shreds cost \$2-13/m^3 (\$1.50-10.00/yd^3). The use of tire shreds for highway construction nationwide offers the potential for disposal of two billion scrap tires yearly. (18)

Lightweight Fill for Slope Repairs

Because they are lightweight with interlocking properties, shredded tires are an ideal fill material to stabilize embankments that have experienced slide failures. Colorado completed such a project. (13)

This project used the Minnesota gradation for shredded tires that requires 100 passing the 610 mm (24-in.) sieve, 80 percent passing the 200 mm (8-in.) sieve, and 50 percent retained in the 100 mm (4-in.) sieve. All material passing the 50 mm (2-in.) sieve was removed and used as a low-grade fuel. The shredded tire fill height was 3.6 m (12 ft), and it was encapsulated with a geotextile to prevent soil intrusion. A 0.9 m (3-ft) soil cap was placed over the shredded tires.

Lightweight Fill Behind Retaining Walls
The low-unit weight, high-shear strength, and high permeability of shredded tires make them an effective retaining wall backfill. A test wall constructed in Maine showed that the at-rest horizontal stress at the base of tire chip fill 4.3 m (14 ft) high with 36 kPa (5.22 psi) surcharge was 45 percent less than that for a typical granular fill. (17) The test wall -- 4.9 m (16 ft) high and 4.6 m (15 ft) by 4.6 m (15 ft) in plan -- consists of four walls and a reinforced concrete foundation, forming a rigid confinement. Two sizes of tire chips were investigated: one was long and flat containing many exposed belts with a maximum size of 40 mm (1.5 in.); the other was equidimentional with few exposed steel belts and a maximum size of 76 mm (3 in.). Shredded tires were placed in 200 mm (8 in.) lifts. If the surcharge was less than 24 kPa (3.48 psi), the static coefficient of lateral pressure was found to be independent of chip size and the amount of steel belts decreased with depth. The angle of wall friction between concrete and shredded tires ranges from 30° to 32°. As a result, the lower pressures would allow the construction of thinner walls.

Lightweight Fill for Embankments over Soft Soils
Because shredded tires are lightweight and non-biodegradable, they may be used to float a road across the soft soil area as long as they are not placed below the water table. They also are often used in embankments for bridge approaches and interchange ramps. Concerning the effect of a compressible tire-chip layer on pavement life, two projects showed that placing 1.8 m (6 ft) of soil cover over 0.6 m (2 ft) of shredded tires yielded the same tensile strains at the bottom of the test pavement as for a control section with no shredded tires. Even for soil covers as shallow as 0.8 m (2.5 ft), the tensile strains at the pavement's bottom were only 40 percent greater than those in the control section. Another test road project showed that there could be a size range for less compressibility, 102 to 203 mm (4 to 8 in.), and premixing of soil and shredded tires provided a better placement condition than placing layers of each material separately. (18) With shredded tires, tire/soil mixes, or tire/soil interlayers confined in geotextile fabric and placed above the ground water table and in a neutral soil (pH=6.9), the project indicated little or no likelihood of detrimental effects on ground water.

Fill as Roadbed Insulators
Shredded tires also are a good thermal insulator limiting frost penetration depth and reducing problems from frost heave. Their thermal resistance is approximately eight times higher than that of gravel. A field test project in Maine indicated there was less frost penetration by using shredded tires enclosed in a geotextile. Another field test project on a gravel road showed that 300 mm (1 ft) of shredded tires reduced frost penetration depth by 40 percent. (16) The project uses shredded tires that have been cut into 51-mm (2-in.) pieces. They offer an attractive alternative to conventional insulation boards because they have moderate thermal resistance and are durable, free-draining, and low cost. Constructed in August 1992, the project is 228.6 m (750 ft) long, consisting of five sections with different thicknesses of shredded tires and overlying soil cover and two control sections. The thickness of the tire chip layers ranges from 152 to 305 mm (6 to 12 in.), while the thickness of the granular soil cover ranges from 305 to 610 mm (12 to 24 in.). The project is instrumented with thermocouples, resistivity gauges, ground water monitoring wells, and a weather station. In addition, the strength of the road surface is periodically measured with a heavy-weight deflectometer. Results from the first year of service show that a 152-mm (6-in.) tire chip layer can reduce frost penetration by

up to 25 percent and the gravel cover should be 305 to 457 mm (12 to 18 in.) thick to provide a stable riding surface.

MINNESOTA CASE STUDY EXAMPLE

Near Pine City, Minnesota, approximately 23,000 m^3 (30,000 yd^3), or about 900,000 shredded tires, were used to construct a 300 m (1,000 ft) section of an interstate freeway exit ramp embankment. Designed by Mn/DOT, the project is located at the northwest quadrant of C.S.A.H. 11 and I-35. The construction of the shredded tire embankment, with a maximum height of 4.6 m (15 ft) compacted shredded tires, began in fall 1992 and was completed in August 1993. The unit cost of the shredded tire fill placement was \$1.57/m^3 (\$1.20/yd^3). The specification included the following:

1. Both the maximum desired size and 90 percent passing shall be 203 mm (8 in.), with 50 percent retaining at 101 mm (4 in.).
2. All pieces shall have at least one of the sidewalls removed
3. All metal shall be 95 percent embedded in the pieces and no free metal pieces shall be allowed in the fill.
4. The density shall be 360 kg/m^3 (22.5 lbs/ft^3) in loose conditions.
5. A representative sample shall be submitted to the Project Engineer for approval before delivery.

Construction began with the placement of geotextile fabric on a 300 mm (1 ft) thick granular layer construction platform. The shredded tires were then placed and compacted with a dozer to a maximum height of 4.6 m (15 ft). Completed construction included the addition of another geotextile layer and about 1.8 m (6 ft) of granular material. It took about 1.2 m (4 ft) of granular fill before the surface was stable enough to operate equipment. The pavement consisted of 203 mm (8 in.) thick doweled, jointed plain concrete. Mn/DOT reports no performance problems on this section to date.

SUMMARY

Minnesota has prohibited the disposal of waste tires below the water table since July 1, 1985. Based on chemical leachate laboratory analysis, the MPCA discovered that zinc exceeds the drinking water limits. As a result, the MPCA requires a permit for road repair and construction using waste tires. Also based on the biological effect of leachate analysis in the laboratory, Mn/DOT discovered that waste tires and wood chips produce acute and chronic toxicity on water fleas and minnows and presently recommends not using shredded tires in applications under the water table. These findings have not been verified in field testing.

As indicated by past successful projects, shredded tires should be clean and free of dirt and loose wires before application. The geotextile encapsulation also is important for isolation of the tire shreds from surrounding soils, for prevention of sinkholes in the cover material and, in some cases, for the shedding or filtration of water. Compaction and consolidation should be achieved to ensure an adequate subgrade modulus and reduce long-term settlement.

Waste tire shreds have been applied successfully as lightweight materials to repair failed slopes, to backfill retaining walls, and to construct embankments over soft soils. Waste tire shreds also have proven effective in reducing frost penetration when used as thermal insulation.

Using waste tires in highway construction provides a cost-effective alternative where lightweight fills are required and reduces used tire storage requirements. The use of waste tires in highway construction should not cause environmental and safety problems as long as necessary measures are taken to keep the tires above the water table and to control exothermic reactions. Waste tires offer the advantage of unique engineering properties such as a low unit weight and thermal insulation qualities. A professional engineer in the geotechnical field should prepare a work plan which considers both the environmental and engineering merits.

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