Designation: D 6270 – 98

Standard Practice for
Use of Scrap Tires in Civil Engineering Applications[1]

This standard is issued under the fixed designation D 6270; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice provides guidance for testing the physical properties and gives data for assessment of the leachate generation potential of processed or whole scrap tires in lieu of conventional civil engineering materials, such as stone, gravel, soil, sand, or other fill materials. In addition, typical construction practices are outlined.

2. Referenced Documents

2.1 *ASTM Standards:*

C 127 Test Method for Specific Gravity and Absorption of Coarse Aggregate[2]

D 422 Test Method for Particle-Size Analysis of Soils[3]

D 698 Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3 (600 kN-m/m^3))[3]

D 1557 Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3))[3]

D 2434 Test Method for Permeability of Granular Soils (Constant Head)[3]

D 3080 Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions[3]

D 4253 Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table[3]

2.2 *AASHTO Standard:*

T 274 Standard Method of Test for Resilient Modulus of Subgrade Soils[4]

2.3 *USEPA Standard:*

Method 1311 Toxicity Characteristics Leaching Procedure[5]

3. Terminology

3.1 *Definitions:*

3.1.1 *baling, n*—a method of volume reduction whereby tires are compressed into bales.

3.1.2 *bead, n*—the anchoring part of the tire which is shaped to fit the rim and is constructed of bead wire wrapped by the plies.

3.1.3 *bead wire, n*—a high tensile steel wire surrounded by rubber, which forms the bead of a tire that provides a firm contact to the rim.

3.1.4 *belt wire, n*—a brass plated high tensile steel wire cord used in steel belts.

3.1.5 *buffing rubber, n*—vulcanized rubber usually obtained from a worn or used tire in the process of removing the old tread in preparation for retreading.

3.1.6 *carcass, n*—see **casing**.

3.1.7 *casing, n*—the basic tire structure excluding the tread (Syn. *carcass*).

3.1.8 *granulated rubber, n*—particulate rubber composed of mainly nonspherical particles that span a broad range of maximum particle dimension, from below 425 µm (40 mesh) to 12 mm (also refer to **particulate rubber**).[6]

3.1.9 *ground rubber, n*—particulate rubber composed of mainly nonspherical particles that span a range of maximum particle dimensions, from below 425 µm (40 mesh) to 2 mm (also refer to **particulate rubber**).[6]

3.1.10 *nominal size, n*—the average size product (chip) that comprises 50 % or more of the through put in a scrap tire processing operation; scrap tire processing operations generate products (chips) above and below the nominal size.

3.1.11 *particulate rubber, n*—raw, uncured, compounded or vulcanized rubber that has been transformed by means of a mechanical size reduction process into a collection of particles, with or without a coating of a partitioning agent to prevent agglomeration during production, transportation, or storage (also see definition of **buffing rubber, granulated rubber, ground rubber,** and **powdered rubber**).[6]

3.1.12 *passenger car tire, n*—a tire with less than a 457-mm rim diameter for use on cars only.

3.1.13 *powdered rubber, n*—particulate rubber composed of mainly nonspherical particles that have a maximum particle dimension equal to or below 425 µm (40 mesh) (also refer to **particulate rubber**).[6]

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[1] This practice is under the jurisdiction of ASTM Committee D-34 on Biotechnology and is the direct responsibility of Subcommittee D34.06 on Recovery and Reuse.

Current edition approved June 10, 1998. Published August 1998.

[2] *Annual Book of ASTM Standards*, Vol 04.02.

[3] *Annual Book of ASTM Standards*, Vol 04.08.

[4] *Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Part II: Methods of Sampling and Testing*, American Association of State Highway and Transportation Officials, Washington, D.C.

[5] *Test Methods for Evaluating Solid Waste: Physical/Chemical Methods*, 3rd ed., Report No. EPA 530/SW-846, U.S. Environmental Protection Agency, Washington, D.C.

[6] The defined term is the responsibility of Committee D-11 on Rubber.

3.1.14 *rough shred, n*—a piece of a shredded tire that is larger than 50 mm by 50 mm by 50 mm, but smaller than 762 mm by 50 mm by 100 mm.

3.1.15 *rubber fines, n*—small particles of ground rubber that result as a by-product of producing shredded rubber.

3.1.16 *scrap tire, n*—a tire, which can no longer be used for its original purpose due to wear or damage.

3.1.17 *shred sizing, n*—a term which generally refers to the process of particles passing through a rated screen opening rather than those which are retained on the screen.

3.1.18 *shredded tire, n*—a size reduced scrap tire where the reduction in size was accomplished by a mechanical processing device, commonly referred to as a shredder.

3.1.19 *shredded rubber, n*—pieces of scrap tires resulting from mechanical processing.

3.1.20 *sidewall, n*—the side of a tire between the tread shoulder and the rim bead.

3.1.21 *single pass shred, n*—a shredded tire that has been processed by one pass through a shear type shredder and the resulting pieces have not been classified by size.

3.1.22 *steel belt, n*—rubber coated steel cords that run diagonally under the tread of steel radial tires and extend across the tire approximately the width of the tread.

3.1.23 *tire chips, n*—Pieces of scrap tires that have a basic geometrical shape and are generally between 12 mm and 50 mm in size and have most of the wire removed (Syn. *chipped tire*).

3.1.24 *tire shreds, n*—Pieces of scrap tires that have a basic geometrical shape and are generally between 50 mm and 305 mm in size.

3.1.25 *tread, n*—that portion of the tire which contacts the road.

3.1.26 *truck tire, n*—a tire with a rim diameter of 500 mm or larger.

3.1.27 *waste tire, n*—a tire which is no longer capable of being used for its original purpose but which has been disposed of in such a manner that it cannot be used for any other purpose.

3.1.28 *whole tire, n*—a scrap tire that has been removed from a rim but which has not been processed.

3.1.29 *x-mm minus, n*—pieces of classified, size reduced scrap tires where the maximum size of 95 % of the pieces is less than x-mm in any dimension (that is, 25-mm minus; 50-mm minus; 75-mm minus, etc).

4. Significance and Use

4.1 This practice is intended for use of scrap tires including tire chips or tire shreds comprised of pieces of scrap tires, tire chip/soil mixtures, tire sidewalls, and whole scarp tires in civil engineering applications. This practice includes the use of tire chips, tire shreds, and tire chip/soil mixtures as lightweight embankment fill, lightweight retaining wall backfill, drainage layers, thermal insulation to limit frost penetration beneath roads, insulating backfill to limit heat loss from buildings, and replacement for soil or rock in other fill applications. Use of whole scrap tires and tire sidewalls includes construction of retaining walls and drainage culverts, as well as use as fill when whole tires have been compressed into bales. It is the responsibility of the design engineer to determine the appropriateness of using scrap tires in a particular application and to select applicable tests and specifications to facilitate construction and environmental protection. This practice is intended to encourage wider utilization of scrap tires in civil engineering applications.

4.2 Three tire shred fills with thicknesses in excess of 7 m have experienced a serious heating reaction; however, more than 70 fills with a thickness less than 3 m have been constructed with no evidence of a deleterious heating reaction (**1**)[7]. Guidelines have been developed to minimize internal heating of tire shred fills (**2**) as discussed in 6.10. The guidelines are applicable to fills less than 3 m thick; thus, this practice should be applied only to tire shred fills less than 3 m thick.

5. Material Characterization

5.1 The specific gravity and water absorption capacity of tire shreds should be determined in accordance with Test Method C 127; however, the specific gravity of tire shreds is less than half the value obtained for common earthen coarse aggregate, so it is permissible to use a minimum weight of test sample that is half of the specified value. The particle density or density of solids of tire shreds (ρ_s) may be determined from the apparent specific gravity using the following equation:

$$\rho_s = S_a(\rho_w) \qquad (1)$$

where:

S_a = apparent specific gravity, and
ρ_w = density of water.

5.2 The gradation of tires shreds should be determined in accordance with Test Method D 422; however, the specific gravity of tire shreds is less than half the values obtained for common earthen materials so it is permissible to use a minimum weight of test sample that is half of the specified value.

5.3 The laboratory compacted dry density, or bulk density, of tire chips and tire chip/soil mixtures with less than 30 % retained on the 19.0-mm sieve can be determined in accordance with Test Method D 698 or D 1557. Tire Shred and tire shred/soil mixtures used for civil engineering applications, however, almost always have more than 30 % retained on the 19.0-mm sieve, so these methods generally are not applicable. A larger compaction mold should be used to accommodate the larger size of the tire shreds. The sizes of typical compaction molds are summarized in Table 1. The larger mold requires that the number of layers, or the number of blows of the rammer/layer, or both, be increased to produce the desired compactive

TABLE 1 Size of Compaction Molds Used to Determine Dry Density of Tire Shreds

Maximum Particle Size (mm)	Mold Diameter (mm)	Mold Volume (m^3)	Reference
75	254	0.0125	(**3**)
75	305	0.0146	(**4**)
51	203 and 305	N.R.[A]	(**5**)

[A] N.R. = not reported.

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[7] The boldface numbers in parentheses refer to the list of references at the end of this standard.

energy/unit volume. Compactive energies ranging from 60 % of Test Method D 698 (60 % × 600 kN-m/m^3 = 360 kN-m/m^3) to 100 % of Test Method D 1557 (2,700 kN-m/m^3) have been used. Compaction energy only has a small effect on the resulting dry density (**3**); thus, for most applications it is permissible to use a compactive energy equivalent to 60 % of Test Method D 698. To achieve this energy with a mold volume of 0.0125 m^3 would require that the sample be compacted in five layers with 44 blows/layer with a 44.5 N rammer falling 457 mm. The water content of the sample only has a small effect on the compacted dry density (**3**) so it is permissible to perform compaction tests on air or oven-dried samples.

5.3.1 The dry densities for tire shreds loosely dumped into a compaction mold and tire shreds compacted by vibratory methods (similar to Test Method D 4253) are about the same (**4, 5, 6**); thus, vibratory compaction of tire shreds in the laboratory (see Test Method D 4253) should not be used.

5.3.2 When estimating an in-place density for use in design, the compression of a tire shred layer under its own self-weight and under the weight of any overlying material must be considered. The dry density determined as discussed in 5.3 are uncompressed values. In addition, short-term time dependent settlement of tire shreds should be accounted for when estimating the final in-place density (**7**).

5.4 The compressibility of tire shreds and tire shred/soil mixtures can be measured by placing tire shreds in a rigid cylinder with a diameter several times greater than the largest particle size and then measuring the vertical strain caused by an increasing vertical stress. If it is desired to calculate the coefficient of lateral earth pressure at rest K_O, the cylinder can be instrumented to measure the horizontal stress of the tire shreds acting on the wall of the cylinder.

5.4.1 The high compressibility of tire shreds necessitates the use of a relatively thick sample. In general, the ratio of the initial specimen thickness to sample diameter should be greater than one. This leads to concerns that a significant portion of the applied vertical stress could be transferred to the walls of the cylinder by friction. If the stress transferred to the walls of the cylinder is not accounted for, the compressibility of the tire shreds will be underestimated. For all compressibility tests, the inside of the container should be lubricated to reduce the portion of the applied load that is transmitted by side friction from the sample to the walls of the cylinder. For testing where a high level of accuracy is desired, the vertical stress at the top and the bottom of the sample should be measured so that the average vertical stress in the sample can be computed. A test apparatus designed for this purpose is illustrated in Fig. 1 (**8**).

5.5 The resilient modulus (M_R) of subgrade soils can be expressed as:

$$M_R = A\Theta^B \tag{2}$$

where:

Θ = first invariant of stress (sum of the three principal stresses),
A = experimentally determined parameter, and
B = experimentally determined parameter.

Tests for the parameters A and B can be conducted according to AASHTO T 274. The maximum particle size typically is limited to 19 mm by the testing apparatus, which precludes the

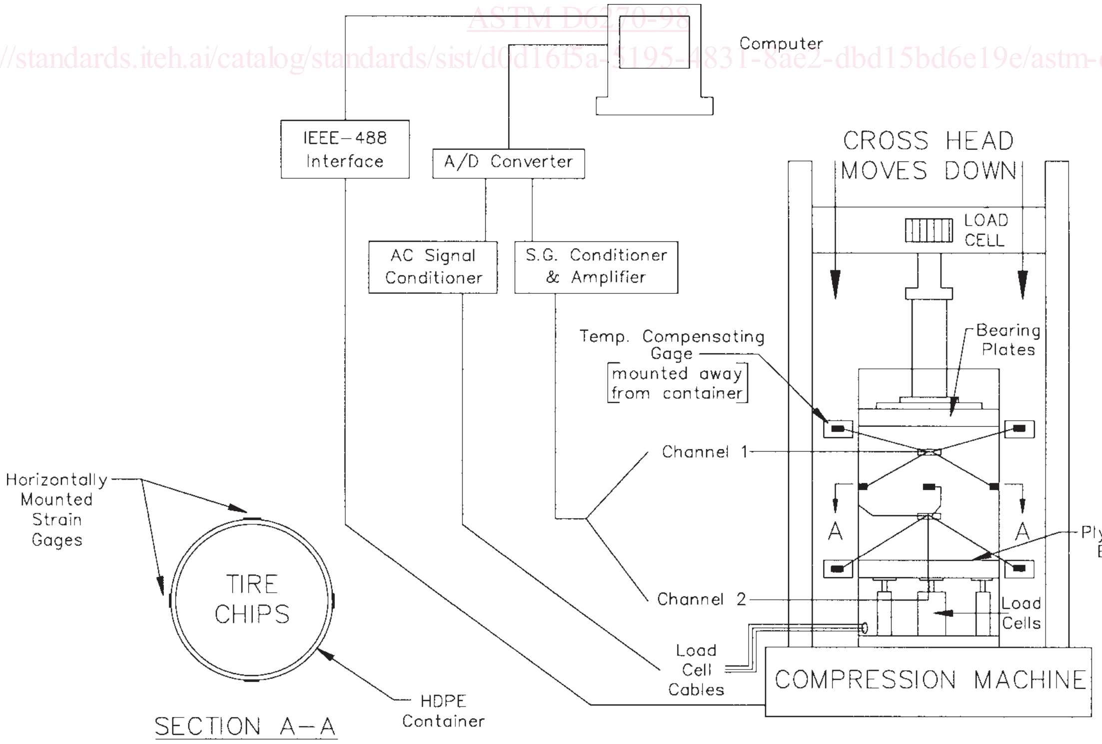

FIG. 1 Compressibility Apparatus for Tire Shreds Designed to Measured Lateral Stress and the Portion of the Vertical Load Transferred by Friction from Tire Shreds to Container (8)

general applicability of this procedure to the larger size tire chips and shreds typically used for civil engineering applications.

5.6 The coefficient of lateral earth pressure at rest K_O and Poisson's ratio μ can be determined from the results of confined compression tests where the horizontal stresses were measured. A test apparatus designed for this purpose is shown in Fig. 1 K_O and μ are calculated from:

$$K_O = \sigma_h / \sigma_v \tag{3}$$

$$\mu = K_O / (1 + K_O) \tag{4}$$

where:

σ_h = measured horizontal stress, and
σ_v = measured vertical stress.

5.7 The shear strength of tire shreds may be determined in a direct shear apparatus in accordance with Test Method D 3080 or using a triaxial shear apparatus. The large size of tire shreds typically used for civil engineering applications requires that specimen sizes be several times greater than used for common soils. Because of the limited availability of large triaxial shear apparatus, this method is generally restricted to tire chips 25 mm in size and smaller. Extrapolation of results on small size pieces to the 75-mm and larger size shreds used for civil engineering applications is uncertain since small pieces are nearly equidimensional while larger tire chips and shreds tend to be long and flat. Furthermore, the triaxial shear apparatus generally is not suitable for tire shreds that have steel belts protruding from the cut edges of the shreds since the wires would puncture the membrane used to surround the specimen. The interface strength between tire shreds and geomembrane can be measured in a large scale direct shear test apparatus (**9**).

5.8 The hydraulic conductivity (permeability) of tire shreds and tire shred/soils mixtures should be measured with a constant head permeameter with a diameter several times greater than the maximum particle size. Tire chips with a maximum size smaller than 19 mm can be determined in accordance with Test Method D 2434; however, tire shreds and tire shred/soil mixtures used for civil engineering applications almost always have a majority of their particles larger than 19 mm so this method is generally not applicable. Samples should be tested at a void ratio comparable to the value expected in the field. This may require a permeameter capable of appling a vertical stress to the sample to simulate the compression that would occur under the weight of overlying material. The high hydraulic conductivity of tire shreds should be accounted for in design of the permeameter. The design shall include provisions for an adequate supply of water and measuring the head loss across the sample using standpipes mounted on the body of the permeameter. An apparatus designed taking these factors into account is shown in Fig. 2 (**10).**

5.9 The thermal conductivity of tire shreds is significantly lower than for common soils. For tire chips smaller than 25 mm in size, the thermal conductivity can be measured using commercially available guarded hot plate apparatus. For tire shreds larger than 25 mm, it is necessary to construct a large

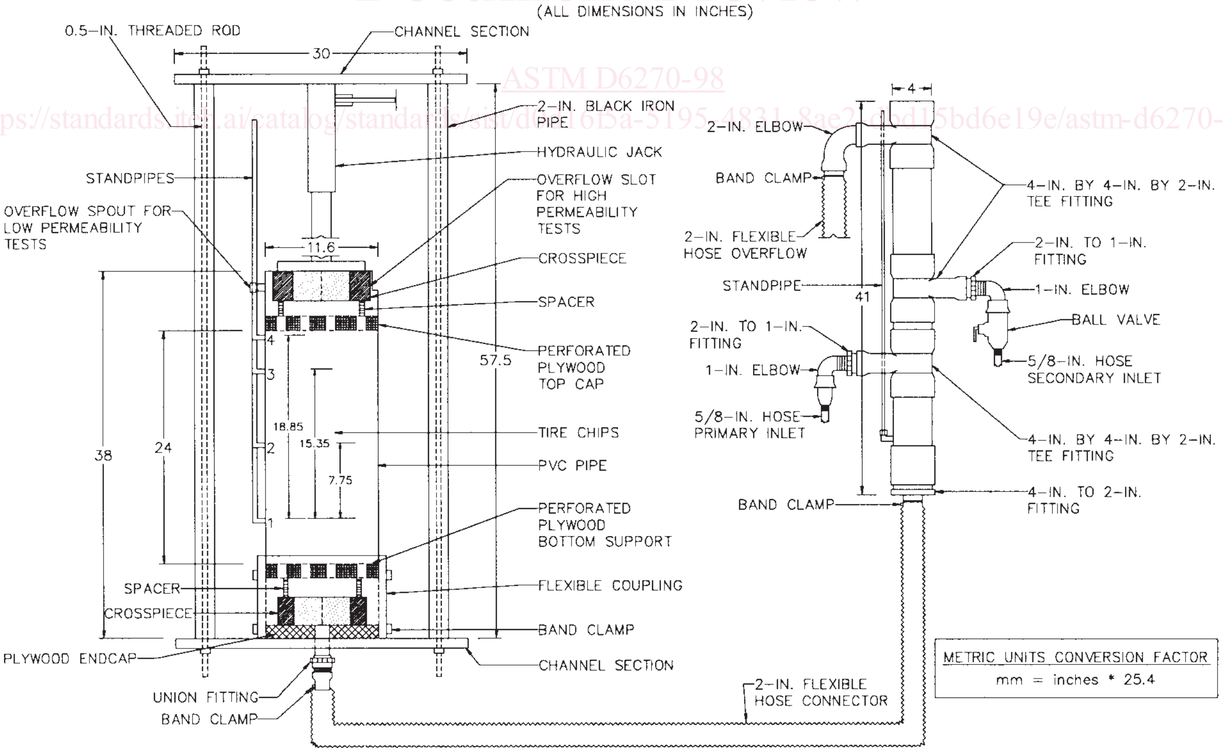

FIG. 2 Hydraulic Conductivity Apparatus for Tire Shreds with Provisions for Application of Vertical Stress (10)

scale hot plate apparatus (**11**). The thermal conductivity of tire shreds also can be backcalculated from field measurements (**11**).

6. Construction Practices

6.1 Tire shreds have a compacted dry density that is one-third to one-half of the compacted dry density of typical soil. This makes them an attractive lightweight fill for embankment construction on weak, compressible soils where slope stability or excessive settlement are a concern.

6.2 The thermal resistivity of tire shreds is approximately eight times greater than for typical granular soil. For this reason, tire shreds can be used as a 150 to 450-mm thick insulating layer to limit the depth of frost penetration beneath roads. This reduces frost heave in the winter and improves subgrade support during the spring thaw. In addition, tire shreds can be used as backfill around basements to limit heat lost through basement walls, thereby reducing heating costs.

6.3 The low-compacted dry density, high-hydraulic conductivity, and low-thermal conductivity makes tire shreds very attractive for use as retaining wall backfill. Lateral earth pressures for tire shred backfill can be about 50 % of values obtained for soil backfill (**7**). Tire shreds also can be used as backfill for geosynthetic-reinforced retaining walls.

6.4 The high hydraulic conductivity of tire shreds, generally greater than 1 cm/s, makes them suitable for many drainage applications, including French drains, drainage layers in landfill liner and cover systems, and leach fields for on-site sewage disposal systems.

6.5 Two different sizes of tire shreds commonly are used for the applications discussed above. One has a maximum size of 75 mm and the other has a maximum size of 300 mm. Rough shreds also can been used for some applications provided all tires are shredded such that the largest shred is the lesser of one-quarter circle in shape or 600 mm in length. In all cases, at least one side wall should be severed from the tread.

6.6 Tire shreds with a maximum size of 75 mm or 300 mm generally are placed in 300-mm thick lifts and compacted by a tracked bulldozer, sheepsfoot roller, or smooth drum vibratory roller with a minimum operating weight of 90 kN. Rough shreds generally are placed in 900-mm thick lifts and compacted by a tracked bulldozer. For most applications, a minimum of six passes of the compaction equipment should be used.

6.7 Tire shreds should be covered with a sufficient thickness of soil to limit deflections of overlying pavement caused by traffic loading. Soil cover thicknesses as low as 0.8 m may be suitable for roads with light traffic. For roads with heavy traffic, 1 to 2 m of soil cover may be required. For unpaved applications, 0.3 to 0.5 m of soil cover may be suitable depending on the traffic loading. The designer should assess the actual thickness of soil cover needed based on the loading conditions, tire-shred layer thickness, pavement thickness, and other conditions as appropriate for particular project. Regardless of the application, the tire shreds should be covered with soil to prevent contact between the public and the tire shreds, which may have exposed steel belts.

6.8 In applications where pavement will be placed over the tire shred layer and in drainage applications, the tire shred layer should be wrapped completely in a layer of nonwoven or woven geotextile to minimize infiltration of soil particles into the voids between the tire shreds.

6.9 Whole tires and tire sidewalls that have been cut from the tire carcass can be used to construct retaining walls and bound together to form drainage culverts.

6.10 Tire shred fills should be designed to minimize the possibility of an internal heating reaction (**2**). Possible causes of the reaction are oxidation of the exposed steel belts and oxidation of the rubber. Microbes may play a role in both reactions. Although details of the reaction are under study, the following factors are thought to create conditions favorable for oxidation of exposed steel, or rubber, or both; free access to air; free access to water; retention of heat caused by the high insulating value of tire shreds in combination with a large fill thickness; large amounts of exposed steel belts; smaller tire shred sizes and excessive amounts of granulated rubber particles; and, the presence of inorganic and organic nutrients that would enhance microbial action.

6.10.1 The design guidelines given in the following sections have been developed to minimize the possibility for heating of tire shred fills by minimizing factors that could possibly create conditions favorable for this reaction. As more is learned about the causes of the reaction, it may be possible to ease some of the guidelines. In developing these guidelines, the insulating effect caused by increasing fill thickness and the favorable performance of projects with tire shred fills less than 4-m thick have been considered; thus, design guidelines are less stringent for projects with thinner tire shred layers. The guidelines are divided into two classes; Class I Fills with tire shred layers less than 1-m thick, and Class II Fills with tire shred layers in the range of 1-m to 3-m thick. Although there have been no projects with less than 4-m of tire shred fill that have experienced a catastrophic heating reaction, to be conservative, tire shred layers greater than 3-m thick are not recommended. In addition to the guidelines given below, the designer must choose the maximum tire shred size, thickness of overlying soil cover, etc., to meet the requirements imposed by the engineering performance of the project. These guidelines are for use in designing tire shred fills. Design of fills that are mixtures or alternating layers of tire shreds and mineral soil that is free from organic matter should be handled on a case by case basis.

6.10.2 For both Class I and II Fills, the tire shreds shall be free of all contaminants, such as oil, grease, gasoline, diesel fuel, etc., that could create a fire hazard. In no case shall the tire shreds contain the remains of tires that have been subjected to a fire because the heat of a fire may liberate liquid petroleum products from the tire that could create a fire hazard when the shreds are placed in a fill.

6.10.3 For Class I Fills, the tire shreds shall have a maximum of 50 % (by weight) passing the 38-mm sieve and a maximum of 5 % (by weight) passing the 4.75-mm sieve. No special design features are required to minimize heating of Class I Fills.

6.10.4 For Class II Fills, the tire shreds shall have a maximum of 25 % (by weight) passing the 38-mm sieve and a maximum of 1 % (by weight) passing the 4.75-mm sieve. The tire shreds shall be free from fragments of wood, wood chips, and other fibrous organic matter. The tire shreds shall have less than 1 % (by weight) of metal fragments, which are not at least partially encased in rubber. Metal fragments that are encased partially in rubber shall protrude no more than 25 mm from the cut edge of the tire shred on 75 % of the pieces and no more than 50 mm on 100 % of the pieces.

6.10.5 Class II Fills shall be constructed in such a way that infiltration of water and air is minimized; moreover, there shall be no direct contact between tire shreds and soil containing organic matter, such as topsoil. One possible way to accomplish this is to cover the top and sides of the fill will a 0.5-m thick layer of compacted mineral soil with a minimum of 30 % fines. The mineral soil should be free from organic matter and should be separated from the tire shreds with a geotexile. The top of the mineral soil layer should be sloped so that water will drain away from the tire shred fill. Additional fill may be placed on top of the mineral soil layer as needed to meet the overall design of the project. If the project will be paved, it is recommended that the pavement extend to the shoulder of the embankment or that other measures be taken to minimize infiltration at the edge of the pavement.

6.10.6 For Class II Fills, use of drainage features located at the bottom of the fill that could provide free access to air should be avoided. Use of drainage features includes, but is not limited to, open graded drainage layers daylighting on the side of the fill and drainage holes in walls. Under some conditions, it may be possible to use a well graded granular soil as a drainage layer. The thickness of the drainage layer at the point where it daylights on the side of the fill should be minimized. For tire shred fills placed against walls, it is recommended that the drainage holes in the wall be covered with well graded granular soil. The granular soil should be separated from the tire shreds with geotextile.

7. Leachate

7.1 The Toxicity Characteristics Leaching Procedure (TCLP) (USEPA Method 1311) is used to determine if a waste is a hazardous waste, thereby posing a significant hazard to human health due to leaching of toxic compounds. The TCLP test represents the worst case scenario of acid rain percolating through the waste and exiting as leachate. For all regulated metals and organics, the results for tire shreds are well below the TCLP regulatory limits (**12, 13, 14**); therefore, tire shreds are not classified as a hazardous waste.

7.2 In addition to TCLP tests, laboratory leaching studies have been performed following several test protocols. Results show that metals are leached most readily at low pH and that organics are leached most readily at high pH (**14, 15**); thus, it is preferable to use tire shreds in environments with a near neutral pH.

7.3 Field studies of tire shred fills located above the ground water table show that tire shreds tend to leach manganese, and under some circumstances, iron at levels above their secondary drinking water standard (**4, 16**). Since secondary standards are based on aesthetic factors, such as color, odor, and taste, rather than health concerns, release of manganese and iron from tire shreds is not a significant concern. Release of organics from tire shreds placed above the water table generally is below test method detection limits (**16**); thus, release of organics from tire shreds placed above the water table is not a significant concern.

7.4 For tire shreds placed below the water table, tire shreds release levels of manganese and iron that are significantly above their secondary drinking water standards (**14**); thus, tire shreds should be used below the water table only where the aesthetic concerns raised by elevated levels of manganese and iron have been examined. Tire shreds placed below the water table leach low levels of a few organic compounds into the ground water (**14**). Further study is needed to determine if these levels are high enough to be of concern. Pending continued studies of the effect of tire shreds placed below the water table on organic levels, the use of tire shreds should be limited to above water table applications.

8. Keywords

8.1 construction practices; landfills; leachate; lightweight fill; retaining walls; roads; scrap tires

APPENDIX

(Nonmandatory Information)

X1. Typical Material Properties

X1.1 This appendix contains typical properties of tire chips and shreds to aid in the selection of values for preliminary designs and to provide a basis for comparison for test results.

X1.2 Values of specific gravity and water absorption capacity reported in the literature are summarized in Table X1.1. Table X1.2 summarizes the compacted and uncompacted dry density of tire shreds. Compaction results for mixtures of tire shreds and soil also are available (**4, 5, 6, 17**). The results from one study are summarized in Fig. X1.1.

X1.3 Typical compressibility results are summarized in Table X1.3. A measure of compressibility applicable to vehicle loads is resilient modulus. Results determined by Ahmed (**5**) using AASHTO T 274-82 for mixtures of tire chips and soil are summarized in Table X1.4. The parameter A, and therefore M_R, decreases as the percent tire sheds by dry weight of the mix increases. Results determined by Edil and Bosscher (**4, 17**) for mixtures of tire shreds and sand are summarized in Fig. X1.2. Shao et al (**18**) performed resilient modulus tests on crumb rubber (7-mm maximum size) and rubber buffings (1-mm maximum size). The resilient modulus values ranged from 700 to 1700 kPa.

TABLE X1.1 Summary of Specific Gravity and Water Absorption Capacity

Tire Shred Type	Specific Gravity			Water Absorption Capacity (%)	Reference
	Bulk	Saturated Surface Dry	Apparent		
Glass belted (F and B)	- - - -	- - - -	1.14	3.8	(**21**)
Glass belted	0.98	1.02	1.02	4	(**26**)
Steel belted	1.06	1.01	1.10	4	(**26**)
Mixture	1.06	1.16	1.18	9.5	(**19**)
Mixture (Pine State)	- - - -	- - - -	1.24	2	(**21**)
Mixture (Palmer)	- - - -	- - - -	1.27	2	(**21**)
Mixture (Sawyer)	- - - -	- - - -	1.23	4.3	(**21**)
Mixture	1.01	1.05	1.05	4	(**26**)
Mixture (12.7 mm to 50.8 mm)	- - - -	0.88 to 1.13	- - - -	- - - -	(**5**)

TABLE X1.2 Summary of Laboratory Dry Densities of Tire Shreds

Compaction Method[A]	Particle Size Range (mm)	Tire Shred Type	Source of Tire Shreds	Dry Density (kg/m^3)	(Reference)
Loose	2 to 75	Mixed	Palmer Shredding	341	(**21, 22**)
Loose	2 to 51	Mixed	Pine State Recycling	482	(**21, 22**)
Loose	2 to 25	Glass	F and B Enterprises	495	(**21, 22**)
Loose	2 to 51	Mixed	Sawyer Environmental	409	(**3, 26**)
Loose	51 max	Mixed	- - - -	466	(**5, 6**)
Loose	25 max	Mixed	- - - -	489	(**5, 6**)
Vibration	25 max	Mixed	- - - -	496	(**5, 6**)
Vibration	13 max	Mixed	- - - -	473	(**5, 6**)
50 % Standard	51 max	Mixed	- - - -	614	(**5, 6**)
50 % Standard	25 max	Mixed	- - - -	641	(**5, 6**)
60 % Standard	2 to 75	Mixed	Palmer Shredding	620	(**21, 22**)
60 % Standard	2 to 51	Mixed	Pine State Recycling	643	(**21, 22**)
60 % Standard	2 to 25	Glass	F and B Enterprises	618	(**21, 22**)
60 % Standard	2 to 51	Mixed	Sawyer Environmental	625	(**3, 26**)
Standard	2 to 51	Mixed	Sawyer Environmental	640	(**3, 26**)
Standard	51 max	Mixed	- - - -	635	(**5, 6**)
Standard	38 max	Mixed	- - - -	645	(**5, 6**)
Standard	25 max	Mixed	- - - -	653	(**5, 6**)
Standard	13 max	Mixed	- - - -	633	(**5, 6**)
Standard	20 to 75	- - - -	Rodefeld	594[B]	(**4, 17**)
Standard	20 to 75	- - - -	Rodefeld	560[C]	(**4, 17**)
Modified	2 to 51	Mixed	Sawyer Environmental	660	(**3, 26**)
Modified	51 max	Mixed	- - - -	668	(**5, 6**)
Modified	25 max	Mixed	- - - -	685	(**5, 6**)
- - - -	50.8	Mixed	- - - -	410 to 570	(**19**)

[A] Compaction methods:

Loose = no compaction; tire shreds loosely dumped into compaction mold
Vibration = Test Method D 4253
50 % Standard = Impact compaction with compaction energy of 296.4 kJ/m^3.
60 % Standard = Impact compaction with compaction energy of 355.6 kJ/m^3.
Standard = Impact compaction with compaction energy of 296.4 kJ/m^3.
Modified = Impact compaction with compaction energy of 2693 kJ/m^3.

[B] 152-mm diameter mold compacted by 4.54 kg rammer falling 305 mm.

[C] 305-mm diameter mold compacted by 27.4 kg rammer falling 457 mm.

X1.4 Typical values of coefficient of lateral earth pressure at rest and Poisson's ratio, measured as part of vertical compression tests, are presented in Table X1.5.

X1.5 The shear strength of tire shreds has been measured using triaxial shear (**5, 19, 20**) and using direct shear (**9, 21, 23**). Failure envelopes for tests conducted at low stress levels (less than about 100 kPa) are compared in Fig. X1.3. The failure envelopes are non-liner and concave down, so when fitting a linear failure envelope to the data, it is important that this be done over the range of stresses that will occur in the field.

X1.6 The shear strength of tire shred/soil mixtures has been measured using triaxial shear (**4, 24**) and direct shear (**4, 25**). Table X1.6 and Table X1.7 summarize the results from Ahmed (**5**). Edil and Bosscher (**4**), and Benson and Khire (**25**) are interested primarily in the reinforcing effect of tire shreds when added to a sand. Under some circumstances, the shear strength is increased by adding tire shreds.

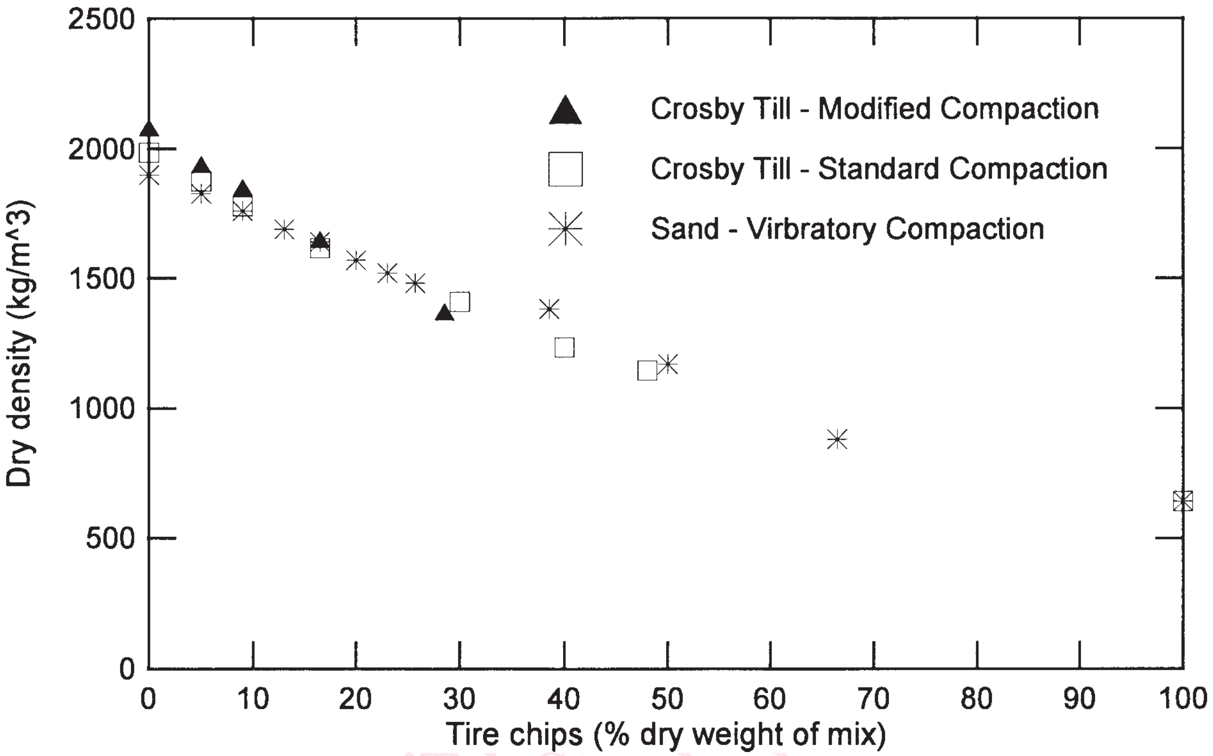

FIG. X1.1 Comparison of Compacted Dry-Density of Mixtures of Tire Shreds with Ottawa Sand and Crosby Till (5)

TABLE X1.3 Compressibility on Initial Loading

Particle Size Range (mm)	Tire Shred Type	Tire Shred Source	Initial Dry Density (kg/m^3)	Vertical Strain (%) at Indicated Vertical Stress (kPa)					Reference
				10	25	50	100	200	
2 to 75	Mixed	Palmer	Compacted	7 to 11	16 to 21	23 to 27	30 to 34	38 to 41	**(26)**
2 to 51	Mixed	Pine State	Compacted	8 to 14	15 to 20	21 to 26	27 to 32	33 to 37	**(21)**
2 to 25	Glass	F and B	Compacted	5 to 10	11 to 16	18 to 22	26 to 28	33 to 35	**(21)**
2 to 51	Mixed	Sawyer	Compacted	5 to 10	13 to 18	17 to 23	22 to 30	29 to 37	**(26)**
	Mixed		Compacted	4 to 5	8 to 11	13 to 16	18 to 23	27	**(5)**
75 max	Mixed	Pine State	510 to 670	12 to 20	18 to 28	- - - -	- - - -	- - - -	**(8)**
2 to 51	Mixed	Pine State	Loose	18	34	41	46	52	**(21)**
2 to 25	Mixed	F and B	Loose	8	18	28	37	45	**(21)**
	- - - -		Loose	9	12 to 17	17 to 24	24 to 31	30 to 38	**(27)**

X1.7 Typical hydraulic conductivities for tire shreds and mixtures of tire shreds and soil are reported in Table X1.8 and Table X1.9 and Fig. X1.4.

X1.8 Measured thermal conductivities ranged from 0.0838 Cal/m-hr-°C for 1-mm particles tested in a thawed state with a water content less than 1 % and with low compaction to 0.147 Cal/m-hr-°C for 25 mm tire shreds tested in a frozen state with a water content of 5 % and high compaction (**18**). The thermal conductivity increased with increasing particle size, increased water content, and increased compaction. The thermal conductivity was higher for tire shreds tested under frozen conditions than when tested under thawed conditions. A thermal conductivity of 0.2 Cal/m-hr-°C was backcalculated from a field trial constructed using tire shreds with a maximum size of 51 mm (**11**). It is reasonable that the back calculated thermal conductivity is higher than found by Shao et al (**18**) since the tire shreds for the former were larger and contained more steel bead wire and steel belt.

X1.9 The results of TCLP tests for regulated metals are summarized in Table X1.10. Results of field studies of the effect of tire chips on water quality are summarized in Table X1.11 and Table X1.12, as well as Fig. X1.5 and Fig. X1.6.

X1.10 A typical material safety data sheet for whole scrap tires is included in Fig. X1.7.

TABLE X1.4 Resilient Modulus of Tire Shreds and Tire Shred/Soil Mixtures (5)

NOTE 1—Constants A and B are the constants for the regression equation and r^2 is the regression coefficient.
NOTE 2—Standard = Standard Proctor Energy = 296.4 kJ/m^3.
NOTE 3—The constants A and B assume the units for θ and M_R are psi (1 psi = 6.89 kPa).

Test No.	Tire Shred Maximum Size (mm)	Sample Preparation	% tire Shreds Based on Total Weight	Soil Type	Constant A	Constant B	r^2
AH01	No. shreds	Vibratory	No shreds	Sand	1071.5	0.84	0.95
AH02	13	Vibratory	15	Sand	524.8	0.83	0.95
AH03	13	Vibratory	30	Sand	269.2	0.90	0.67
AH04	13	Vibratory	38	Sand	42.7	1.15	0.89
AH05	13	Vibratory	50	Sand	38.9	0.83	0.84
AH06	13	Vibratory	100	Sand	36.3	0.55	0.74
AH07	19	Vibratory	38	Sand	34.7	1.21	0.92
AH08	No shreds	Standard	No shreds	Crosby Till	3162.3	0.49	0.83
AH09	13	Standard	15	Crosby Till	53.7	1.15	0.91
AH10	13	Standard	29	Crosby Till	61.7	0.91	0.94
AH11	13	Standard	38	Crosby Till	55.0	0.67	0.95

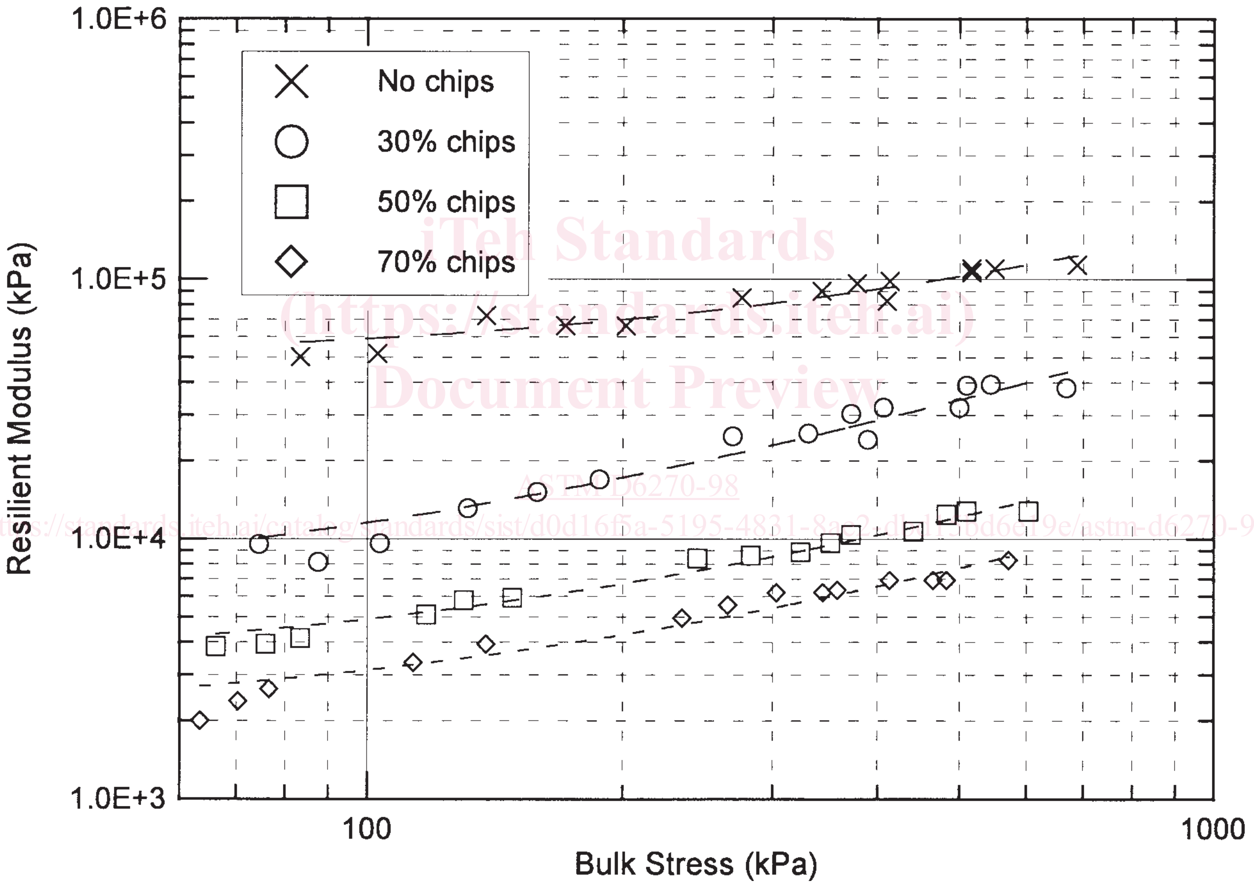

FIG. X1.2 Resilient Modulus of Mixtures of Tire Shreds and Clean Sand (4)

TABLE X1.5 Summary of Coefficient of Lateral Earth Pressure at Rest and Poisson's Ratio

Particle Size Range (mm)	Tire Shred Type	Source of Tire Shreds	K_O	-µ	References
2 to 51	Mixed	Sawyer Environmental	0.44	0.30	**(3, 26)**
2 to 75	Mixed	Palmer Shredding	0.26	0.20	**(21, 22)**
2 to 51	Mixed	Pine State Recycling	0.41	0.28	**(21, 22)**
2 to 25	Glass	F and B Enterprises	0.47	0.32	**(21, 22)**
- - - -	- - - -	- - - -	- - - -	0.3 to 0.17	**(4, 17)**
13 to 51	Mixed	Maust Tire Recyclers	0.4^A	0.3	**(27)**

[A] For vertical stress less than 172 kPa.

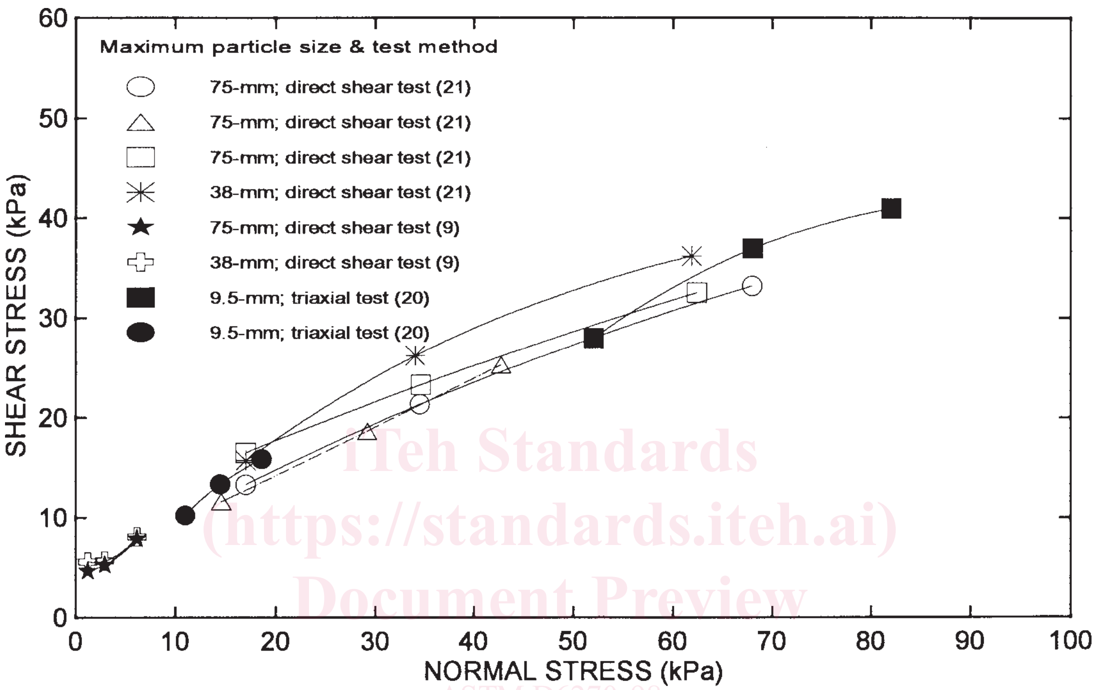

FIG. X1.3 Comparison of Failure Envelops of Tire Shreds at Low Stress Levels