Designation: D6270 – 08[ε1]

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

This standard is issued under the fixed designation D6270; 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.

ε[1] NOTE—Fig 1, Fig. 2 and Fig. X1.3 were improved and editorial changes were made throughout in July 2009.

1. Scope

1.1 This practice provides guidance for testing the physical properties, design considerations, construction practices, and leachate generation potential of processed or whole scrap tires in lieu of conventional civil engineering materials, such as stone, gravel, soil, sand, lightweight aggregate, or other fill materials.

1.2 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

2. Referenced Documents

2.1 *ASTM Standards:*[2]
C127 Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate
C136 Test Method for Sieve Analysis of Fine and Coarse Aggregates
D698 Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft^3 (600 kN-m/m^3))
D1557 Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3))
D2434 Test Method for Permeability of Granular Soils (Constant Head)
D3080 Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions
D4253 Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table
D2974 Test Methods for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils

2.2 *American Association of State Highway and Transportation Officials Standard:*
T 274 Standard Method of Test for Resilient Modulus of Subgrade Soils[3]
M 288 Standard Specification for Geotextiles[4]
2.3 *U.S. Environmental Protection Agency 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 *chipped tire, n*—see *tire chip.*

3.1.9 *chopped tire, n*—a scrap tire that is cut into relatively large pieces of unspecified dimensions.

3.1.10 *granulated rubber, n*—particulate rubber composed of mainly non-spherical particles that span a broad range of

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maximum particle dimension, from below 425 μm (40 mesh) to 12 mm (also refer to *particulate rubber*).[6]

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

3.1.12 *mineral soil, n*—soil containing less than 5 % organic matter as determined by a loss on ignition test (D2974).

3.1.13 *nominal size, n*—the average size product that comprises 50 % or more of the throughput in a scrap tire processing operation; scrap tire processing operations generate products above and below the nominal size.

3.1.14 *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]

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

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

3.1.17 *preliminary remediation guideline, n*—risk-based concentrations that the USEPA considers to be protective for lifetime exposure to humans.

3.1.18 *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.

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

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

3.1.21 *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.

3.1.22 *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.

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

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

3.1.25 *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.

3.1.26 *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.

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

3.1.28 *tire derived aggregate (TDA), n*—pieces of scrap tires that have a basic geometrical shape and are generally between 12 and 305 mm in size and are intended for use in civil engineering applications. Also see definition of *tire chips* and *tire shreds*.

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

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

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

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

3.1.33 *x-mm minus, n*—pieces of classified, size-reduced scrap tires where a minimum of 95 % by weight passes through a standard sieve with an x-mm opening size (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 derived aggregate (TDA) comprised of pieces of scrap tires, TDA/soil mixtures, tire sidewalls, and whole scrap tires in civil engineering applications. This includes use of TDA and TDA/soil mixtures as lightweight embankment fill, lightweight retaining wall backfill, drainage layers for roads, landfills and other applications, thermal insulation to limit frost penetration beneath roads, insulating backfill to limit heat loss from buildings, vibration damping layers for rail lines, and replacement for soil or rock in other fill applications. Use of whole scrap tires and tire sidewalls includes construction of retaining walls, drainage culverts, road-base reinforcement, and erosion protection, 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 TDA fills with thicknesses in excess of 7 m have experienced a serious heating reaction. However, more than 100 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 TDA fills (**2**) as discussed in 6.11. The guidelines are applicable to fills less than 3 m thick. Thus, this practice should be applied only to TDA fills less than 3 m thick.

5. Material Characterization

5.1 The specific gravity and water absorption capacity of TDA should be determined in accordance with Test Method

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[6] The defined term is the responsibility of Committee D11 on Rubber.

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

C127. However, the specific gravity of TDA 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 TDA (ρ_s) may be determined from the apparent specific gravity using the following equation:

$$\rho_s = S_a(\rho_w) \tag{1}$$

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

5.2 The gradation of TDA should be determined in accordance with Test Method C136. However, the specific gravity of TDA 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 TDA and TDA/soil mixtures with less than 30 % retained on the 19.0-mm sieve can be determined in accordance with Test Method D698 or D1557. However, TDA and TDA/soil mixtures used for civil engineering applications 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 TDA. 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 per layer, or both, be increased to produce the desired compactive energy per unit volume. Compactive energies ranging from 60 % of Test Method D698 (60 % × 600 kN-m/m^3 = 360 kN-m/m^3) to 100 % of Test Method D1557 (2700 kN-m/m^3) have been used. Compaction energy has only 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 D698. To achieve this energy with a mold volume of 0.0125 m^3 would require that the sample be compacted in 5 layers with 44 blows per layer with a 44.5 N rammer falling 457 mm. The water content of the sample has only 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 TDA loosely dumped into a compaction mold and TDA compacted by vibratory methods (similar to Test Method D4253) are about the same (4, 5, 6). Thus, vibratory compaction of TDA in the laboratory (see Test Method D4253) should not be used.

5.3.2 When estimating an in-place density for use in design, the compression of a TDA 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 TDA should be accounted for when estimating the final in-place density (7).

5.4 The compressibility of TDA and TDA/soil mixtures can be measured by placing TDA 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 TDA acting on the wall of the cylinder.

5.4.1 The high compressibility of TDA 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 TDA 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.

5.5.1 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 general applicability of this procedure to the larger size TDA 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:

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

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

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

TABLE 1 Size of Compaction Molds Used to Determine Dry Density of TDA

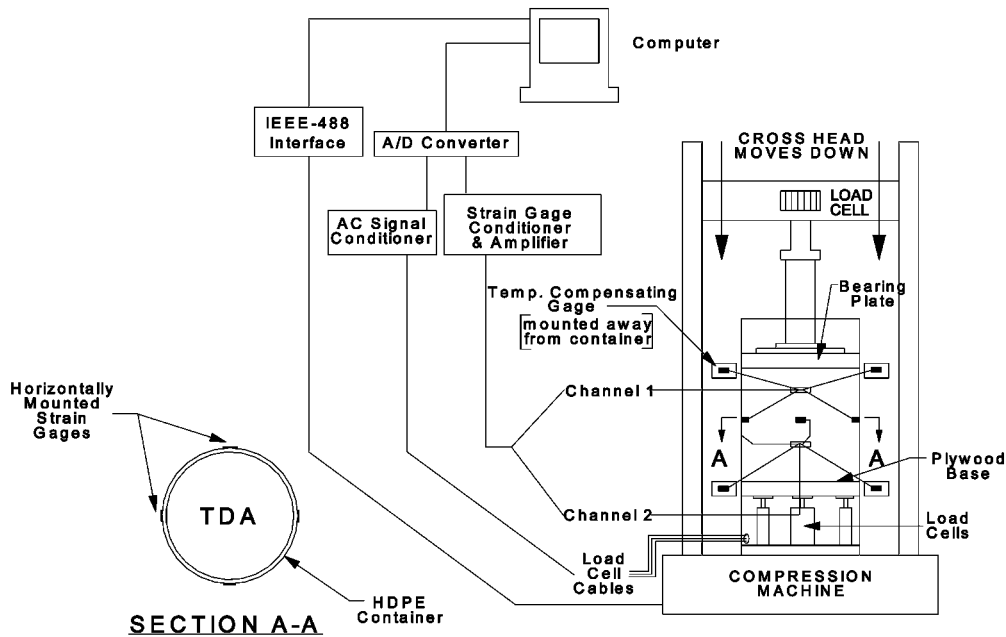| Maximum Particle Size (mm)	Mold Diameter (mm)	Mold Volume (m³)	Reference
75	254	0.0125	(3)
75	305	0.0146	(4)
51	203 and 305	N.R.^{A}	(5)

^{A} N.R. = not reported.

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FIG. 1 Compressibility Apparatus for TDA Designed to Measured Lateral Stress and the Portion of the Vertical Load Transferred by Friction from TDA to Container (10)

5.7 The shear strength of TDA may be determined in a direct shear apparatus in accordance with Test Method D3080 or using a triaxial shear apparatus. The large size of TDA 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 TDA 25 mm in size and smaller. The interface strength between TDA and geomembrane can be measured in a large scale direct shear test apparatus (9).

5.8 The hydraulic conductivity (permeability) of TDA and TDA/soils mixtures should be measured with a constant head permeameter with a diameter several times greater than the maximum particle size. TDA with a maximum size smaller than 19 mm can be determined in accordance with Test Method D2434. However, TDA and TDA/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 applying a vertical stress to the sample to simulate the compression that would occur under the weight of overlying material. The high hydraulic conductivity of TDA should be accounted for in design of the permeameter. This includes 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 that takes these factors into account is shown in Fig. 2 (10).

5.9 The thermal conductivity of TDA is significantly lower than for common soils. For TDA smaller than 25 mm in size, the thermal conductivity can be measured using commercially available guarded hot plate apparatus. For TDA larger than 25 mm, it is necessary to construct a large scale hot plate apparatus (11). The thermal conductivity of TDA also can be back-calculated from field measurements (11).

6. Construction Practices

6.1 TDA 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 embankments constructed on weak, compressible soils where slope stability or excessive settlement are a concern, as well as landslide repair.

6.2 The thermal resistivity of TDA is approximately eight times greater than for typical granular soil. For this reason, TDA 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, TDA 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 TDA very attractive for use as retaining wall backfill. Lateral earth pressures for TDA backfill can be about 50 % of values obtained for soil backfill (7, 8, 9). TDA can also be used as backfill for geosynthetic-reinforced retaining walls.

6.4 The hydraulic conductivity of TDA 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. For applications with a
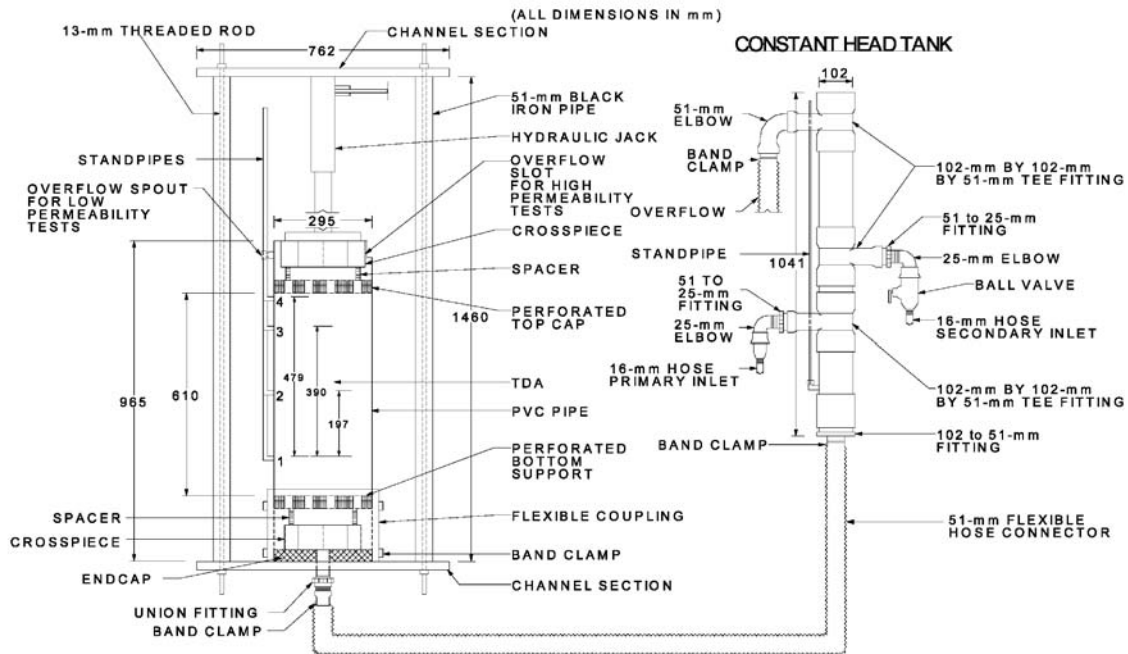
FIG. 2 Hydraulic Conductivity Apparatus for TDA with Provisions for Application of Vertical Stress (12)

vertical stress less than 50 kPa, the hydraulic conductivity of TDA is generally greater than 1 cm/s, which is comparable to conventional uniformly graded aggregate. When TDA is used as a component of landfill leachate collection and removal systems, and other applications where the vertical stress would be greater than 50 kPa, the hydraulic conductivity and void ratio under the final design vertical stress should be considered. The hydraulic conductivity must meet applicable regulatory requirements and the void ratio must be sufficient to minimize clogging.

6.5 TDA can be used as a vibration damping layer beneath rail lines to reduce the impact of ground bourn vibrations on residences and businesses adjoining the tracks. In this application, a 300-mm thick layer of 75-mm maximum size TDA is placed beneath the conventional ballast/subballast system (**13**).

6.6 Two different sizes of TDA are commonly 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 can also be 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.

6.7 TDA with a maximum size of 75 mm or 300 mm are generally 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 are generally 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.

6.8 TDA 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 paved roads with light traffic. For paved 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, TDA layer thickness, pavement thickness, and other conditions as appropriate for a particular project. Regardless of the application, the TDA should be covered with soil to prevent contact between the public and the TDA which may have exposed steel belts.

6.9 In applications where pavement will be placed over the TDA layer, highway drainage applications, and retaining wall backfill, the TDA layer should be completely wrapped in a layer of non-woven or woven geotextile to minimize infiltration of soil particles into the voids between the TDA. AASHTO M 288 should be used for guidance on geotextile selection.

6.10 Whole tires and tire sidewalls that have been cut from the tire carcass can be used to construct retaining walls, reinforcing mats beneath roads constructed on weak ground, and erosion protection layers.

6.11 TDA 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. Factors thought to create conditions favorable for oxidation of exposed steel, or rubber, or both, include; free access to air; free access to water; retention of heat caused by the high insulating value of TDA in combination with a large fill

thickness; large amounts of exposed steel belts; smaller TDA sizes and excessive amounts of granulated rubber particles; and the presence of inorganic and organic nutrients that would enhance microbial action.

6.11.1 The design guidelines given in the following sections were developed to minimize the possibility for heating of TDA fills by minimizing factors that could create conditions favorable for this reaction. In developing these guidelines, the insulating effect caused by increasing fill thickness and the favorable performance of projects with TDA fills less than 4-m thick have been considered Thus, design guidelines are less stringent for projects with thinner TDA layers. The guidelines are divided into two classes: Class I Fills with TDA layers less than 1-m thick, and Class II Fills with TDA layers in the range of 1 to 3-m thick. Although there have been no projects with less than 4 m of TDA fill that have experienced a catastrophic heating reaction, to be conservative, TDA layers greater than 3-m thick are not recommended. The guidelines are for use in designing TDA fills. Design of fills that are mixtures or alternating layers of TDA and mineral soil should be handled on a case by case basis.

6.11.2 For Class I Fills, the material shall meet the material requirements for Type A TDA given in 7.1.1 and 7.1.2. No special design features are required to minimize heating of Class I Fills.

6.11.3 For Class II Fills, the material shall meet the material requirements for Type B TDA given in 7.1.1 and 7.1.3.

6.11.4 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 TDA and soil containing organic matter, such as topsoil. One possible way to accomplish this is to cover the top and sides of the fill with a 0.5-m thick layer of compacted mineral soil with a minimum of 30 % fines. The mineral soil should be separated from the TDA with a geotextile. The top of the mineral soil layer should be sloped so that water will drain away from the TDA 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.

6.11.5 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. This includes, but is not limited to, open graded drainage layers daylighting on the side of the fill. 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 TDA 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 TDA with geotextile.

6.11.6 Embankments constructed in accordance with the guidelines have shown no evidence of self heating (14).

7. Material Specifications

7.1 The material specifications for TDA that are presented below take into consideration the need to limit internal heating of TDA fills as discussed in 6.11, producing a material that can be placed and compacted with conventional construction equipment, and limiting exposed steel belts to allow for rubber to rubber contacts between the pieces when placed in a fill. Moreover, TDA meeting the specifications can be produced with reasonably well-maintained processing equipment that has been properly selected for the size product being produced. Specifications are provided for two size ranges. The first is termed Type A and is suitable for many drainage, vibration damping, and insulation applications. The second is larger and is termed Type B. It is suitable for use as lightweight embankment fill, wall backfill, and some landfill drainage and gas collection applications.

7.1.1 The TDA shall be made from scrap tires which shall be shredded into the sizes specified in 7.1.2 for Type A TDA or 7.1.3 for Type B TDA. They shall be produced by a shearing process. TDA produced by a hammer mill will not be allowed. The TDA shall be free of all contaminants including but not limited to oil, grease, gasoline, and diesel fuel that could leach into the groundwater or create a fire hazard. In no case shall the TDA 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 TDA are placed in a fill. The TDA shall be free from fragments of wood, wood chips, and other fibrous organic matter. The TDA shall have less than 1 % (by weight) of metal fragments that are not at least partially encased in rubber. Metal fragments that are partially encased in rubber shall protrude no more than 25 mm from the cut edge of the TDA on 75 % of the pieces (by weight) and no more than 50 mm on 90 % of the pieces (by weight). The gradation shall be measured in accordance with Test Method C136, except that the minimum sample size shall be 6 to 12 kg for Type A TDA and 16 to 23 kg for Type B TDA.

7.1.2 Type A TDA shall have a maximum dimension, measured in any direction, of 200 mm. In addition, Type A TDA shall have 100 % passing the 100-mm square mesh sieve, a minimum of 95 % passing (by weight) the 75-mm square mesh sieve, a maximum of 50 % passing (by weight) the 38-mm square mesh sieve, and a maximum of 5 % passing (by weight) the 4.75-mm sieve.

7.1.3 Type B TDA shall have a minimum of 90 % (by weight) with a maximum dimension, measured in any direction, of 300 mm and 100 % with a maximum dimension, measured in any direction, of 450 mm. At least one side wall shall be removed from the tread of each tire. The side wall will be considered removed if the bead wire has been completely severed from the side wall. A minimum of 75 % (by weight) shall pass the 200-mm square mesh sieve, a maximum of 50 % (by weight) shall pass the 75-mm square mesh sieve, a maximum of 25 % (by weight) shall pass the 38-mm square mesh sieve, and a maximum of 1 % (by weight) shall pass the 4.75-mm sieve.

8. Leachate

8.1 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 scenario of acid rain percolating through the waste and exiting as leachate. For all regulated metals and organics, the results for TDA are well below the TCLP regulatory limits (**15, 16, 17**); therefore, TDA are not classified as a hazardous waste.

8.2 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 (**17, 18**). Thus, it is preferable to use TDA in environments with a near neutral pH.

8.3 The potential of TDA to generate leachate has been examined in field studies for both above and below groundwater table applications. The results have been compared to primary drinking water standards, secondary (aesthetic) drinking water standards, and USEPA preliminary remediation goals (PRG) (**19**). PRG are risk-based concentrations that the USEPA considers to be protective for lifetime exposure to humans (**19**). Freshwater aquatic toxicity has also been evaluated. These results were summarized in a literature review and statistical analysis performed for the USEPA Resource Conservation Challenge (**20**).

8.4 In above groundwater table applications the TDA is placed above the water table and are subjected to water from infiltration. Seven field studies have examined this category of applications (**21, 22, 23, 24, 25, 26, 27, 28**). A statistical comparison was performed (**20**) using procedures for censored environmental data recommended by Helsel (**29**).

8.4.1 The preponderance of evidence shows that TDA used above the water table does not cause the primary drinking water standards for metals to be exceeded. Moreover, a statistical comparison shows that TDA is unlikely to increase levels of metals with primary drinking water standards above naturally occurring background levels (**20**).

8.4.2 For above groundwater table applications, it is likely that TDA would increase the concentrations of iron and manganese, which have secondary drinking water standards. At the point where water emerges from a TDA fill, it is likely that the levels of iron and manganese will exceed secondary drinking water standards, and the PRG for tap water for manganese will also be exceeded. However, for two of three projects where samples were taken from wells adjacent to the TDA fills, the iron and manganese levels were about the same as background levels. The prevalence of manganese in groundwater is shown by the naturally occurring concentrations at three projects being above the secondary drinking water standard and PRG. For other chemicals with secondary drinking water standards, a statistical comparison shows that there is no evidence that TDA affects naturally occurring background levels (**20**).

8.4.3 Volatile and semivolatile organics have been monitored on two projects where TDA was placed above the water table (**22, 23, 24**). Substances are generally below detection limits. Moreover, for those substances with drinking water standards, the levels were below the standards. The concentrations were also below the applicable PRG (**20**). A few substances were occasionally found above the test method

detection limit; however, the highest concentrations were found in a control section located uphill from the TDA (**22**), suggesting a source associated with active roadways. There are also laboratory studies showing that TDA has the ability to absorb some organic compounds (**30**).

8.4.4 Aquatic toxicity tests were performed on samples taken from one above groundwater table project. The results showed that water collected directly from TDA fills had no effect on survival, growth, and reproduction of two standard test species (fathead minnows and a small crustacean (*Ceriodaphnia dubia*) (**20, 23**).

8.5 TDA placed below the water table has been studied at three different sites (**31**). A statistical comparison was performed (**20**) using procedures for censored environmental data recommended by Helsel (**29**).

8.5.1 A statistical analysis of the data at these sites showed that use of TDA did not cause primary drinking water standards for metals to be exceeded. Moreover, the data shows that TDA was unlikely to increase levels of metals with primary drinking water standards above naturally occurring background levels (**20**).

8.5.2 For chemicals with secondary drinking water standards, it is likely that TDA below the groundwater table would increase the concentrations of iron, manganese, and zinc. For water that is collected directly from TDA fill below the groundwater table, it is likely that the concentrations of manganese and iron will exceed their secondary drinking water standards and PRG for tap water. The secondary drinking water standards and PRG for zinc were not exceeded even for water in direct contact with TDA. The concentration of iron, manganese, and zinc decreases to near background levels by flowing only a short distance though soil (0.6 to 3.3 m). For other chemicals with secondary drinking water standards, a statistical comparison showed little likelihood that TDA placed below the water table alters naturally occurring background levels (**20**).

8.5.3 Trace levels of a few volatile and semivolatile organics were found from water taken directly from TDA-filled trenches. The concentration of benzene, chloroethane, cis-1,2-dichloroethene, and aniline for water in direct contact with TDA are above their respective PRG for tap water. However, chloroethane, cis-1,2-dichloroethene, and aniline concentrations were below the PRG for all samples taken from wells 0.6 and 3.3 m downgradient. Moreover, the concentrations were below the detection limits for virtually all samples, indicating that these substances have limited downgradient mobility (**17**).

8.5.4 The data on benzene deserves additional discussion. The primary drinking water standard for benzene is 5 µg/L and its PRG is 0.35 µg/L. For six sample dates, the detection limit reported by the laboratory was 0.5 µg/L, slightly above the PRG. For the remaining four sample dates the detection limit was 5 µg/L. Focusing on the data from samples with a detection limit of 0.5 µg/L, the benzene concentration was below the detection limit in downgradient wells for all but one well, on a single date, when the concentration was 1 µg/L. This data shows that benzene also has limited downgradient mobility (**17**).

8.5.5 Aquatic toxicity tests were performed on samples taken on two dates. The results showed that water collected directly from TDA filled trenches had no effect on survival, and growth of fathead minnows. While there were some toxic effects of TDA placed below the groundwater table on *Ceriodaphnia dubia*, a small amount of dilution (up to 3-fold) as the groundwater flowed downgradient or when it entered a surface body of water would remove the toxic effects (**20, 23**).

8.5.6 In summary, TDA placed below the water table would be expected to have a negligible off-site effect on water quality (**20**).

9. Keywords

9.1 construction practices; landfills; leachate; lightweight fill; rail lines; retaining walls; roads; scrap tires; TDA; tire chips; tire derived aggregate; tire shreds; vibration damping

APPENDIX

(Nonmandatory Information)

X1. TYPICAL MATERIAL PROPERTIES

X1.1 This appendix contains typical properties of TDA 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 TDA. Compaction results for mixtures of TDA and soil also are available (**4, 5, 6, 32**). The results from one study are summarized in Fig. X1.1.

X1.3 Typical compressibility results are summarized in Table X1.3.

X1.4 A measure of compressibility applicable to vehicle loads is resilient modulus. Results determined by Ahmed (**5**) using AASHTO T 274-82 for mixtures of TDA and soil are summarized in Table X1.4. The parameter A, and therefore M_R, decreases as the percent TDA by dry weight of the mix increases. Results determined by Edil and Bosscher (**4, 33**) for mixtures of TDA and sand are summarized in Fig. X1.2. Shao et al (**34**) 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.

X1.5 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.

X1.6 The shear strength of TDA has been measured using triaxial shear (**5, 34, 35**) and using direct shear (**9, 32, 36, 37**). 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.

X1.7 The shear strength of TDA/soil mixtures has been measured using triaxial shear (**5, 38**) and direct shear (**4, 39**). Table X1.6 and Table X1.7 summarize the results from Ahmed (**5**). Edil and Bosscher (**4**), and Benson and Khire (**39**) were primarily interested in the reinforcing effect of TDA when added to a sand. Under some circumstances, the shear strength is increased by adding TDA.

X1.8 Typical hydraulic conductivities for TDA and mixtures of TDA and soil are reported in Tables X1.8 and X1.9, and Fig. X1.4.

X1.9 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 TDA tested in a frozen state with a water content of 5 % and high compaction (**34**). The thermal conductivity increased with increasing particle size, increased water content, and increased compaction. The thermal conductivity was higher for TDA tested under frozen conditions than when tested under thawed conditions. A thermal conductivity

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

TDA Type	Specific Gravity			Water Absorption Capacity (%)	Reference
	Bulk	Saturate Surface Dry	Apparent		
Glass belted (F&B)	- - - -	- - - -	1.14	3.8	(**32**)
Glass belted	0.98	1.02	1.02	4	(**41**)
Steel belted	1.06	1.01	1.10	4	(**41**)
Mixture	1.06	1.16	1.18	9.5	(**35**)
Mixture (Pine State)	- - - -	- - - -	1.24	2	(**32**)
Mixture (Palmer)	- - - -	- - - -	1.27	2	(**32**)
Mixture (Sawyer)	- - - -	- - - -	1.23	4.3	(**32**)
Mixture	1.01	1.05	1.05	4	(**41**)
Mixture (12.7 mm to 50.8 mm)	- - - -	0.88 to 1.13	- - - -	- - - -	(**5**)

TABLE X1.2 Summary of Laboratory Dry Densities of TDA

Compaction Method[A]	Particle Size Range (mm)	TDA Type	Source of TDA	Dry Density (kg/m³)	Reference
Loose	2 to 75	Mixed	Palmer Shredding	341	(32, 36)
Loose	2 to 51	Mixed	Pine State Recycling	482	(32, 36)
Loose	2 to 25	Glass	F&B Enterprises	495	(32, 36)
Loose	2 to 51	Mixed	Sawyer Environmental	409	(3, 41)
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	(32, 36)
60 % Standard	2 to 51	Mixed	Pine State Recycling	643	(32, 36)
60 % Standard	2 to 25	Glass	F&B Enterprises	618	(32, 36)
60 % Standard	2 to 51	Mixed	Sawyer Environmental	625	(3, 41)
Standard	2 to 51	Mixed	Sawyer Environmental	640	(3, 41)
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, 33)
Standard	20 to 75	- - - -	Rodefeld	560[C]	(4, 33)
Modified	2 to 51	Mixed	Sawyer Environmental	660	(3, 41)
Modified	51 max	Mixed	- - - -	668	(5, 6)
Modified	25 max	Mixed	- - - -	685	(5, 6)
- - - -	50.8	Mixed	- - - -	410 to 570	(35)

[A] Compaction methods:
Loose = no compaction; TDA loosely dumped into compaction mold.
Vibration = Test Method D4253.
50 % Standard = Impact compaction with compaction energy of 296.4 kJ/m³ .
60 % Standard = Impact compaction with compaction energy of 355.6 kJ/m³.
Standard = Impact compaction with compaction energy of 296.4 kJ/m³.
Modified = Impact compaction with compaction energy of 2693 kJ/m³.
[B] 152-mm diameter mold compacted by 4.54 kg rammer falling 305 mm.
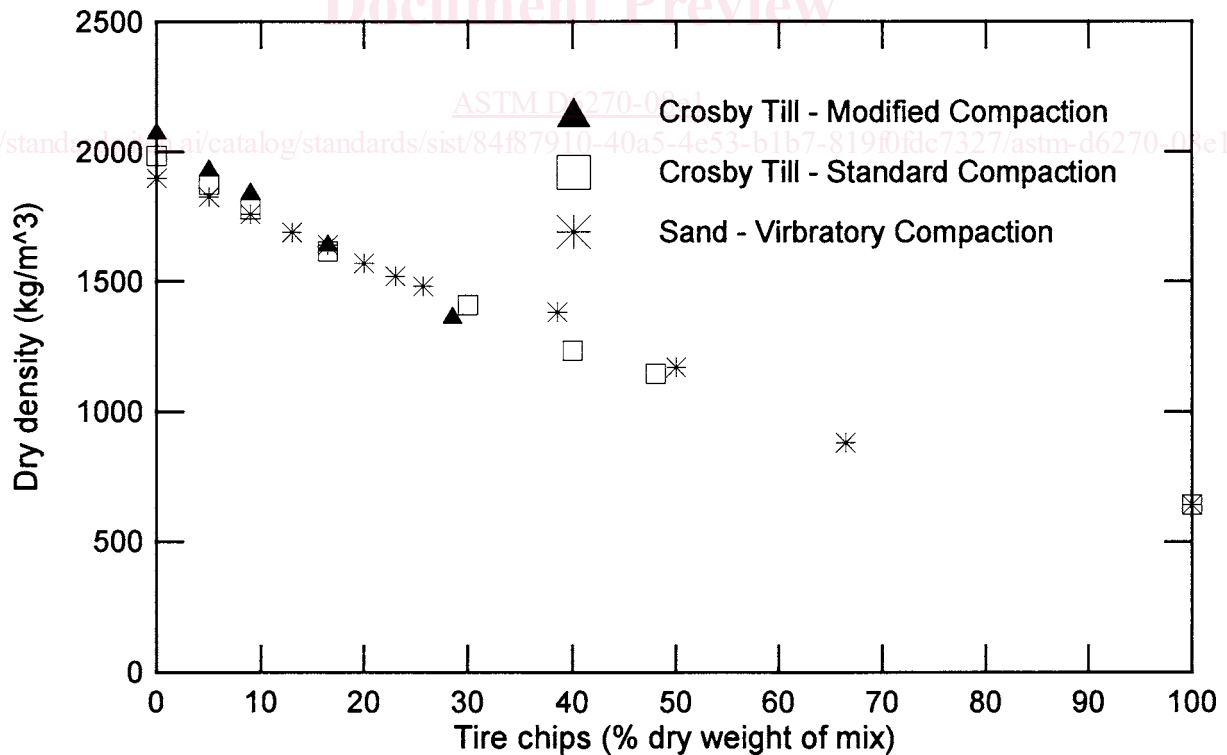[C] 305-mm diameter mold compacted by 27.4 kg rammer falling 457 mm.

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

of 0.2 Cal/m-hr-°C was back-calculated from a field trial constructed using TDA with a maximum size of 51 mm (40).

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TABLE X1.3 Compressibility on Initial Loading

Particle Size Range (mm)	TDA Type	TDA Source	Initial Dry Density (kg/m³)	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	(41)
2 to 51	Mixed	Pine State	Compacted	8 to 14	15 to 20	21 to 26	27 to 32	33 to 37	(32)
2 to 25	Glass	F&B	Compacted	5 to 10	11 to 16	18 to 22	26 to 28	33 to 35	(32)
2 to 51	Mixed	Sawyer	Compacted	5 to 10	13 to 18	17 to 23	22 to 30	29 to 37	(41)
	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	(32)
2 to 25	Mixed	F&B	Loose	8	18	28	37	45	(32)
	- - - -		Loose	9	12 to 17	17 to 24	24 to 31	30 to 38	(42)

TABLE X1.4 Resilient Modulus of TDA and TDA/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/m³.

NOTE 3—The constants A and B assume the units for θ and M_R are psi (1 psi = 6.89 kPa).

Test No.	TDA Max Size (mm)	Sample Preparation	% TDA Based on Total Weight	Soil Type	Constant A	Constant B	r²
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

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

Particle Size Range (mm)	TDA Type	Source of TDA	K_O	-µ	Reference
2 to 51	Mixed	Sawyer Environmental	0.44	0.30	(3, 41)
2 to 75	Mixed	Palmer Shredding	0.26	0.20	(32, 36)
2 to 51	Mixed	Pine State Recycling	0.41	0.28	(32, 36)
2 to 25	Glass	F&B Enterprises	0.47	0.32	(32, 36)
- - - -	- - - -	- - - -	- - - -	0.3 to 0.17	(4, 33)
13 to 51	Mixed	Maust Tire Recyclers	0.4[A]	0.3	(42)

[A] For vertical stress less than 172 kPa.

It is reasonable that the back-calculated thermal conductivity is higher than found by Shao et al (34) since the TDA for the former were larger and contained more steel bead wire and steel belt.

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

X1.11 A typical material safety data sheet for whole scrap tires is included in Fig. X1.7.