PennDOT RECYCLING MATERIAL BRIEF

Scrap Tire and Tire-Rubber

Introduction and Background

Since the early 1990's the uses of waste scrap tire have grown exponentially. According to the Scrap Tire Management Council, approximately 250 million tires are discarded each year by consumers. In 1990 approximately 11 percent of all waste scrap tires generated were beneficially reused, in 2017 the end-use markets consumed over 81 percent of waste scrap tires. Scrap tires can be recycled in various forms, such as whole tire, a slit tire, a shredded or chipped tire, as ground or crumb rubber product. Tire shreds and chips are normally available from tire shredder operations, while ground crumb rubber would normally be available from scrap tire processors.

Historically, scrap or waste tires were primarily landfilled or used as a fuel alternative to coal in cement kilns, pulp and paper mills, and electric utility boilers. Other uses of scrap tires include the production of new products for various markets. Pertaining to highway applications, the largest use of scrap tires is in ground rubber form as a fine aggregate in asphalt courses, and as a modifier in hot mix asphalt pavements. Other highway applications of scrap tires include embankment lightweight fill (tire shreds), retaining walls (whole or slit tires), slope stabilization and protection (whole tires).

This fact sheet provides information on the material properties of waste tire-derived products, use applications, and approved PennDOT Specifications for products generated using waste tires.

Example of a Crumb Rubber Material

Stockpile of Tire Derived Aggregate

Material Physical & Engineering Properties(1)

The principal chemical components of tires is a blend of natural and synthetic rubber. Additionally, components include carbon black, sulfur, polymers, oil, paraffins, pigments, fabrics, and bead or belt materials. The production methods and material sizes/properties of scrap tire materials range by product type, see the table below for detailed information:

Scrap Tire Product	Production method	Material Sizes and Properties
Slit tires Full size tire pieces.	Slit tires are produced in tire cutting machines. These cutting machines can slit the tire into two halves or can separate the sidewalls from the tread of the tire.	Size based on original tire (automobile, truck or other).
***Tire Shreds** Flat, irregular shaped tire masses with jagged edges that may contain protruding, sharp pieces of metals (parts of steel belts or beads).	Typical production of tire shreds involves primary shredding. A tire shredder is a machine with a series of oscillating or reciprocating cutting edges, moving back and forth in opposite directions to create a shearing motion, that cuts or shreds tires as they are fed into the machine.	Based on the manufacturer, model, and condition of the cutting edges, the size of the tire shreds produced in the shredding process varies from 300 to 460 mm (12 to 18 in) long by 100 to 230 mm (4 to 9 in) wide, down to as small as 100 to 150 mm (4 to 6 in) in length. The shredding process results in exposure of steel belt fragments along the edges of the tire shreds.
***Tire Chips** Flat, irregular tire pieces, more finely and uniformly sized than tire shreds.	Production of tire chips, requires two-stage processing of the tire shreds (i.e., primary and secondary shredding) to achieve adequate size reduction. Primary shredding generally results in larger tire shred pieces. Secondary shredding results in the production of chips that are more equidimensional.	Based on primary or secondary shredding operations, tire chips normally range in size from 76 mm (3 in) to 13 mm (1/2 in). Exposed steel fragments will still occur along the edges of the tire chips.
Ground Rubber or Crumb Rubber Ground rubber particles are intermediate in size between tire chips and crumb rubber. Crumb rubber is finer particles than ground rubber particles.	The production of ground rubber is achieved by granulators, hammermills, or fine grinding machines. Granulators typically produce particles that are regularly shaped and cubical with a comparatively low-surface area. The steel belt fragments are removed by a magnetic separator. Fiberglass belts or fibers are separated from the finer rubber particles, usually by an air separator. Ground rubber particles are subjected to a dual cycle of magnetic separation, then screened and recovered in various size fractions.	Based on the type of size reduction equipment and the intended application, **Ground Rubber** particles may be as large as 19 mm (3/4 in) to as fine as 0.15 mm (No. 100 sieve) **Crumb Rubber** usually consists of particles ranging in size from 4.75 mm (No. 4 sieve) to less than 0.075 mm (No. 200 sieve). Most processes that incorporate crumb rubber as an asphalt modifier use particles ranging in size from 0.6 mm to 0.15 mm (No. 30 to No. 100 sieve)

(1) Source: https://www.fhwa.dot.gov/publications/research/infrastructure/structures/97148/st1.cfm
* Tire shreds and tire chips are also known as tire derived aggregate (TDA)

Applications

Tire Derived Aggregate (TDA)

TDA can be used for a wide range of civil engineering applications including lightweight embankment fill, landslide repair/slope stabilization, various landfill applications, retaining wall backfill, sound wall fill material, and more. TDA compacts weight significantly less than ordinary soils, offers good thermal characteristics (resisting frost penetration), and has good drainage characteristics, being as permeable as a coarse granular soil. TDA may be used by itself or blended with soil.

Embankments containing tire shreds are constructed by completely surrounding the shreds or chips with a geotextile fabric and placing at least 0.9 m (3 ft) of natural soil between the top of the scrap tires and the roadway. Using TDA when designing a retaining wall will provide many benefits; specifically, it is lighter than soil, is free draining, and has a high internal angle of friction, which results in significant pressure reduction on the wall. When a road landslide occurs, it might be necessary to excavate the sliding road material down to stable soil and rebuild the slope and road in compacted layers of soil called lifts. Drainage networks are typically installed so that hydrostatic pressure does not build up behind the fill, causing potential instability. By using TDA as a lightweight backfill material, less excavation is necessary and TDA's free-draining properties allow for a more cost effective design.[(2)]

Historically, PennDOT created Special Provisions and performed a demonstration project using TDA. Specifically, from 2002 to 2005, PennDOT District 10 collected and processed over 5,600 passenger tires into TDA to use as lightweight embankment fill on two bridge approaches along State Route 4023, Section 150. Following completion of the project, some differential settlement occurred. However, the settlement was resolved and the bridge returned to normal operation. To date the embankment has performed as expected with no additional impediments occurring.

Crumb Rubber

Crumb Rubber can be incorporated into bituminous pavement mix-designs using two different methods referred to as the wet process and the dry process. In both cases, crumb rubber is sometimes referred to as crumb rubber modifier (CRM) because its use modifies the properties of the resultant hot mix asphalt concrete product.

Bituminous Pavements with Crumb Rubber (Wet Process)

The wet process can be used for hot mix asphalt paving mixtures, as well as chip seals or surface treatments. The wet process can also be used to prepare rubberized joint and crack sealants; when CRM is blended with asphalt cement in the wet process, the modified binder is referred to as asphalt-rubber. Asphalt-rubber binders are used in chip-seal coats as well as hot mix asphalt (HMA) paving. Chip-seal coat applications using asphalt-rubber binders have become known as stress-absorbing membranes (SAM). When an asphalt-rubber chip seal or SAM is overlaid with HMA, the chip seal is referred to as a stress-absorbing membrane interlayer (SAMI).

Before the binder is added to the aggregate, crumb rubber is blended with asphalt cement (usually in the range of 18 to 25 percent rubber). When asphalt cement and CRM are blended together, the CRM reacting with the asphalt cement swells and softens. This reaction is influenced by the temperature at which the blending occurs, the length of time the temperature remains elevated, the type and amount of mechanical mixing, the size and texture of the CRM, and the aromatic component of the asphalt cement. The reaction itself involves the absorption of aromatic oils from the asphalt cement into the polymer chains that comprise the major structural components of natural and synthetic rubber in CRM. In the design mix, air voids and aggregate gradation depend on the CRM content. Most wet processes use CRM particles ranging in size from 0.6 mm (No. 30 sieve) to 0.15 mm (No. 100 sieve). The CRM percentage by weight can range from 5 to 25 percent of the binder but is typically around 18 percent. Structural Design Conventional American Association of State Highway and Transportation Officials (AASHTO) design procedures for flexible pavements are typically used for pavements containing wet process CRM.

To ensure proper quality control of the CRM binder, the crumb rubber particle size, the rate of addition of crumb rubber, the mixing temperature and the time of blending and reaction must all be carefully monitored. Placing and compacting placement of hot mix asphalt paving material with wet-process CRM binder can be accomplished using standard paving machinery.

Some of the engineering properties that are of particular interest when rubber is incorporated in asphalt concrete (wet process) include; increased asphalt viscosity of the binder, increased asphalt softening point, lower resilient modulus values, no significant changes to permanent deformation, increased resistance to thermal cracking, and added resistance to aging.

Bituminous Pavements with Crumb Rubber (Dry Process)

Crumb rubber material in the dry process can be used for HMA paving in dense-graded, open-graded, or gap-graded mixtures. It cannot be used in other asphalt paving applications, such as cold mix and chip seals or surface treatments. In the dry process, granulated or ground rubber and/or crumb rubber is used as a substitute for a small portion of the fine aggregate (usually 1 to 3 percent by weight of the total aggregate in the mix). The rubber particles are blended with the aggregate prior to the addition of the asphalt cement. When tire rubber is used as a portion of the aggregate in HMA concrete, the resultant product is sometimes referred to as rubber-modified asphalt concrete. Predominantly, the dry process uses from 1 to 3 percent granulated crumb rubber by weight of the total mix. Additionally, the dry process technology can produce dense-graded hot mixtures, where both coarse and fine crumb rubber match aggregate gradations and achieve improved binder modification. The crumb rubber may need a pre-reaction or pretreatment with a catalyst to achieve optimum particle swelling. In this system, rubber content does not exceed 2 percent by weight of total mixture for surface courses.

Both batch and drum-dryer plants have been used to produce the asphalt rubber mix. The reclaimed granulated rubber is usually packed and stored in 110 kg (50 lb) plastic bags.   Additional manual labor and conveying equipment, such as work platforms, are needed in order to introduce the granulated rubber into the paving mix, regardless of the type of mixing plant used. For both batch and drum-dryer plants the addition of rubber normally requires that the mixing time and temperature be increased. Batch plants require a dry mix cycle to ensure that the heated aggregate is mixed with the crumb rubber before the asphalt cement application.

Some of the engineering properties of granulated or ground rubber that are of particular interest when used in asphalt concrete (dry process) include those that are also recognized through the dry processes as well as its gradation, particle shape, and reaction time.

The use of any new material does not come without obstacles that must be addressed, as state DOTs and contractors have experienced the incorporation of crumb rubber in asphalt mixture can make the mixture sticky and hard to control which is proven to make it difficult to be placed on the roadway surface. However, as contactors continue to use the material and gain a better sense of its characteristics, the placement of this material has become easier. Additionally, the cost to include crumb rubber in asphalt mixtures is initially higher than virgin material, which has proven to be a major deterrent when considering its use. But what is not considered in initial costs is the reduction in roadway maintenance that is required for crumb rubber asphalt, which reduces the overall Life Cycle Cost of the roadway.

Specifications

In PennDOT’s Publication 408 – Construction Specifications, waste tire material is approved for use in asphalt mixtures, pervious pavement systems, joint materials, traffic control devices and within noise walls. The following table is a listing of all Publication 408 – Construction Specifications approved uses for waste tire material:

Section	Application
412	Superpave Mixture Designs, Construction of Plant-Mixed 6.3 millimeter (mm) Thin Asphalt Overlay Courses
413	Superpave Mixture Design, Standard and RPS Construction of Plant-Mixed Asphalt Courses with Percent Within Limits and LTS Testing (PWL-LTS)
419	Stone Matrix Asphalt Mixture Design, RPS Construction of Plant-Mixed Wearing Courses
420	Pervious Asphalt Pavement System
705	Joint Material
901	Traffic Accommodation and Control - Material (Drum Rubber Tire Bases)
1086	Noise Wall - Whisper Wall

Special Provisions

The below table provides a listing of Special Provisions that have been approved for the usage of waste tire material. Copies of these Special Provisions are available on PennDOT's Engineering and Construction Management Website (ECMS).

Special Provision Number	Use
c04481 Item 9448[1]	Dry Processed Treated Crumb Rubber Modified Bituminous Concrete Wearing, Binder, Leveling, and Scratch Courses
c04491 Item 9449[2]	Wet Processed Treated Crumb Rubber Modified Bituminous Concrete Wearing, Binder, Leveling, and Scratch Courses
C04493	Superpave Mixture Design, Standard and RPS Construction of Plant-Mixed HMA or WMA Courses Using Asphalt Rubber Binder
C02031 Item 9203-0100	Select Borrow Excavation, Structure Backfill, Tire Derived Aggregate
C07031 Item 9606-2050	Production of Tire Derived Aggregate for Embankments and Backfills
C06061 Item 9606-2050	Grade adjustment of existing inlets using recycled rubber
c00006 Item 9000-5001[3]	Rubberized Asphalt Seal Coat (RASC)
T031300 Item 9000-0007	36” x 72” Recycled Tire Mats

[1] – Also identified under ECMS number c00004 (active) and c04091 (inactive).
[2] – Also identified under ECMS number c00005 (active) and c04092 (inactive).
[3] – Also identified under ECMS numbers: c04721 item 9472-2001 (item 9472-001), item 9472-2002 (item 9472-0002) Coarse Aggregate, and item 9472-2003 (item 9472-0003) Bituminous Materials.

Conclusions

Rubber generated from waste tires has many beneficial applications in transportation and civil engineering projects, because of this efforts by manufactures/scientists/engineers are continuous to improve the existing ways they are used as well as identifying new ways.

If there is a project opportunity where waste scrap tires may appear to be an applicable substitute for a virgin material in a method that is not described above, contact PennDOT's Strategic recycling Program (SRP) at PennDOTSRP@pa.gov.

Resources:

(1) FHWA, last modified 2016. User Guidelines for Waste and Byproduct Materials in Pavement Construction, Scrap Tires (https://www.fhwa.dot.gov/publications/research/infrastructure/structures/97148/st1.cfm).

(2) CalRecycle, last modified 2020. Uses Tire-Derived Aggregate (https://www.calrecycle.ca.gov/tires/tda/uses#:~:text=Tire%20derived%20aggregate%20(TDA)%20is,%2C%20vibration%20mitigation%2C%20and%20more).