PennDOT RECYCLING FACT SHEET

Scrap Tire and Tire-Rubber

Introduction and Background

According to the Scrap Tire Management Council, approximately 280 million tires are discarded each year by consumers. Around 30 million of these tires are retreaded or reused, leaving roughly 250 million scrap tires to be managed annually. Still, it has been estimated that there may be as many as 2 to 3 billion tires that have accumulated over the years and are contained in numerous stockpiles. 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.

The most predominant single use of scrap tires is use as tire-derived fuels for power plants, cement plants, pulp and paper mill boilers, utility boilers, and other industrial boilers. Other uses of scrap tires are production of various new products. In 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 are: embankment lightweight fill (tire shreds), retaining walls (whole or slit tires), channel slope stabilization and protection (whole tires).

This fact sheet provides information on the recycling of scrap tires in its various forms, including the material and engineering properties, and select applications for use in civil engineering applications, including materials provided by the Federal Highway Administration website. The fact sheet is divided into the following sections:

Material Properties – describes the physical properties and engineering parameters,
Applications – describes embankment fill and asphalt paving, and
Specifications – present existing PennDOT specifications.

Material Physical & Engineering Properties[1]

The principal chemical component of tires is a blend of natural and synthetic rubber, but additional components include carbon black, sulfur, polymers, oil, paraffins, pigments, fabrics, and bead or belt materials. The following table list production methods and typical material properties per type of recycled tire product:

Scrap Tire Product	**Production method**	**Material Sizes and Properties**
Slit tires <u>Description:</u> Full size tire pieces.	Slit Tires 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 <u>Description:</u> Basically flat, irregular shaped tire chunks with jagged edges that may or may not 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 effectively cuts or shreds tires as they are fed into the machine.	The size of the tire shreds produced in the primary shredding process can vary from as large as 300 to 460 mm (12 to 18 in) long by 100 to 230 mm (4 to 9 in) as wide, down to as small as 100 to 150 mm (4 to 6 in) in length, depending on the manufacturer, model, and condition of the cutting edges. The shredding process results in exposure of steel belt fragments along the edges of the tire shreds.[3] <u>Key Properties:</u> Average loose density: 24-33 lbs/CF Average compacted density: 40-52 lbs/CF <u>Chemical properties:</u> non-reactive under normal environmental conditions. Internal friction angles: 19°-26° Cohesion values: 90-240 lbs/CF Permeability coefficient: 1.5-15 cm/sec.
Tire Chips <u>Description:</u> Basically 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 results generally in larger tire shred pieces. Secondary shredding results in the production of chips that are more equidimensional.	Tire chips are normally sized from 76 mm (3 in) down to 13 mm (1/2 in), based on primary or secondary shredding operations. Exposed steel fragments will still occur along the edges of the chips.[3] <u>Key Properties:</u> Average loose density: 20-30 lbs/CF (320-490 kg/m3) Average compacted density: 40-52 lbs/CF (570-730 kg/m3)

		Absorption values range: 2.0-3.8% Chemical properties: non-reactive under normal environmental conditions. Internal friction angles: 19°-26° Cohesion values: 90-240 lbs/CF (4.3-11.5 kPa) Permeability coefficient: 1.5-15 cm/sec.
Ground Rubber or Crumb Rubber Description: 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, hammer mills, 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.[4]	Ground Rubber may be sized from particles as large as 19 mm (3/4 in) to as fine as 0.15 mm (No. 100 sieve) depending on the type of size reduction equipment and the intended application. 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). Specific gravity: ~1.15 Key Properties: Specific gravity: ~1.15 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] www.FHWA.dot

Embankment or Fill with Scrap Tires

Tire shreds and tire chips, also known as tire derived aggregate (TDA), when processed, have both been used as lightweight fill materials for roadway embankments and backfills behind retaining walls. TDA is an excellent lightweight embankment fill material, and have compacted weights significant less than ordinary soils (~ 50 lbs/CF vs. 120 lbs/CF). Additionally, TDA offers good thermal characteristics in resisting frost penetration and have good drainage characteristics, being as permeable as a coarse granular soil. TDA may be used by themselves 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.

PennDOT has developed specifications for the use of TDA in embankment fills, and for the production of TDA aggregates in embankments, as listed below:

- ***Special Provision (SP), Item 9203-0100 - Select Borrow Excavation, Structure Backfill, Tire Derived Aggregate***

- ***Special Provision (SP), Item 9703-0100 – Production of Tire Derived Aggregate for Embankment and Backfills***

SP TDA Gradation Requirements:				
Sieve Size	8 inch	3 inch	1.5 inch	No. 4
Percent Passing	75-100%	50% max.	25% max	1% max

Other SP requirements include:

- Length: No more than 1% & 10% (by weight) having max. dimension > than 18 inches & 12 inches, respectively.
- Exposed Metal: At least 76% and 90% (by weight) of tire shreds with metal fragments encased in rubber that do not protrude > 1 inch & 2 inches from edge of tires, respectively.
- Free Steel: less than 1% by weight of metal fragments
- Deleterious Materials restricted: oils, gasoline, diesel fuel, hydraulic fluid, grease, ice, snow, burnt tires.

Other Considerations:
The site of the embankment should be prepared in essentially the same manner as though common earth were being used for fill material. Tire shreds (layers) shall be encapsulated with geotextile. Maximum height of tire shred layers is 10 feet. Designs of higher embankments require multiple tire shred layers. A 3 feet minimum distance between two adjacent tire shreds layers is required.

Bituminous Pavements with Crumb Rubber.[1]

Scrap tire rubber can be incorporated into bituminous pavement mix-designs using two different methods referred to as the wet process and the dry process. In the wet process, crumb rubber acts as an asphalt cement modifier, while in the dry process, granulated or ground rubber and/or crumb rubber is used as a portion of the fine aggregate. 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 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 hot mix asphalt, the chip seal is referred to as a stress-absorbing membrane interlayer (SAMI).

In the wet process, crumb rubber is blended with asphalt cement (usually in the range of 18 to 25 percent rubber) before the binder is added to the aggregate. 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 18 percent. Structural Design Conventional 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.

Material Properties:

Some of the engineering properties that are of particular interest when rubber is incorporated in asphalt concrete (wet process) include asphalt viscosity, asphalt softening point, resilient modulus, permanent deformation, thermal cracking, and resistance to aging.

- Viscosity: Adding crumb rubber to asphalt cement can dramatically increase the viscosity of the resultant asphalt-rubber binder. Various quantities of kerosene or other diluents can be used to adjust the viscosity. Viscosity increases can occur after the addition of diluents, but higher percentages of diluent usually result in lowered viscosity increases. Reaction temperatures also affect these relationships. The benefit of increased viscosity of the asphalt-rubber binder is that additional binder can be used in the asphalt mix to reduce reflective cracking, stripping, and rutting, while improving the binder's response to temperature change and long-term durability, as well as its ability to adhere to the aggregate particles in the mix and to resist aging.

- Softening Point: In addition to modifying binder viscosity, asphalt-rubber binders used in seal coats and hot mix asphalt show an increase in the softening point of the binder by 11°C (20°F) to 14°C (25°F), resulting in reduced rutting or shoving of the asphalt-rubber products at elevated temperatures. Modification of asphalt cement with ground tire rubber greatly increases binder elasticity compared with unmodified asphalt cement, thus providing asphalt-rubber pavement systems with increased resistance to deformation and cracking.

- Resilient Modulus: Resilient modulus values for mixtures containing conventional aggregate and asphalt-rubber binder are generally lower than the resilient modulus values for similar mixtures in which conventional asphalt cement are used. The higher the temperature, the greater the difference between the resilient modulus of the conventional mix and the asphalt-rubber mix. Permanent Deformation: The permanent deformation properties of dense-graded asphalt-rubber mixtures are within the range of properties normally associated with conventional hot mix asphalt paving mixtures, although asphalt-rubber mixtures may be somewhat less resistant to permanent deformation.

- Thermal Cracking: Asphalt-rubber binders also exhibit reduced fracture temperatures compared with conventional asphalt cement, usually 5.5°C (10°F) to 8.3°C (15°F) lower, meaning that asphalt-rubber products are less brittle and more resistant to cracking at lower temperatures than conventional chip seals or hot mix asphalt paving. Isolated fatigue studies have also indicated greater resistance to low temperature thermal cracking. In summary, asphalt-rubber is more elastic than asphalt cement and remains elastic at lower temperatures.

- Resistance to Aging: Laboratory data also indicate that asphalt-rubber mixtures are somewhat more resistant to aging than normal asphalt mixtures. Aging studies performed in asphalt-rubber binders placed in northern and central Arizona pavements indicate that asphalt-rubber binders have an increased resistance to hardening.

- ***PennDOT Standard Provision, c04491 Item 9449- Wet Processed Treated Crumb Rubber Modified Bituminous Concrete Wearing Binder, Leveling, and Scratch Courses allows for the use of 9% total weight of binder treated CFM to produce a nominal binder grade of PG-70-22.***

<u>Bituminous Pavements with Crumb Rubber (Wet Process)</u>

Crumb rubber material in the dry process can be used for hot mix asphalt 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 hot mix asphalt concrete, the resultant product is sometimes referred to as rubber-modified asphalt concrete. Predominantly, dry process uses from 1 to 3 percent granulated crumb rubber by weight of the total mix is added to the paving mix. Additionally, the dry process technology can produce dense-graded hot mixtures, where both coarse and fine crumb rubber to match aggregate gradations and to 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 its gradation, particle shape, and reaction time.

- *Viscosity*: Adding crumb rubber to asphalt cement can dramatically increase the viscosity of the resultant asphalt-rubber binder. Various quantities of kerosene or other diluents can be used to adjust the viscosity. Viscosity increases can occur after the addition of diluents, but higher percentages of diluent usually result in lowered viscosity increases. Reaction temperatures also affect these relationships. The benefit of increased viscosity of the asphalt-rubber binder is that additional binder can be used in the asphalt mix to reduce reflective cracking, stripping, and rutting, while improving the binder's response to temperature change and long-term durability, as well as its ability to adhere to the aggregate particles in the mix and to resist aging.

- *Softening Point*: In addition to modifying binder viscosity, asphalt-rubber binders used in seal coats and hot mix asphalt show an increase in the softening point of the binder by 11°C (20°F) to 14°C (25°F), resulting in reduced rutting or shoving of the asphalt-rubber products at elevated temperatures. Modification of asphalt cement with ground tire rubber greatly increases binder elasticity compared with unmodified asphalt cement, thus providing asphalt-rubber pavement systems with increased resistance to deformation and cracking.

- *Resilient Modulus*: Resilient modulus values for mixtures containing conventional aggregate and asphalt-rubber binder are generally lower than the resilient modulus values for similar mixtures in which conventional asphalt cement are used. The higher the temperature, the greater the difference between the resilient modulus of the conventional mix and the asphalt-rubber mix.

- *Permanent Deformation*: The permanent deformation properties of dense-graded asphalt-rubber mixtures are within the range of properties normally associated with conventional hot mix asphalt paving mixtures, although asphalt-rubber mixtures may be somewhat less resistant to permanent deformation.

- *Thermal Cracking*: Asphalt-rubber binders also exhibit reduced fracture temperatures compared with conventional asphalt cement, usually 5.5°C (10°F) to 8.3°C (15°F) lower, meaning that asphalt-rubber products are less brittle and more resistant to cracking at lower temperatures than conventional chip seals or hot mix asphalt paving. Isolated fatigue studies have also indicated greater resistance to low temperature thermal cracking. In summary, asphalt-rubber is more elastic than asphalt cement and remains elastic at lower temperatures.

- *Resistance to Aging*: Laboratory data also indicate that asphalt-rubber mixtures are somewhat more resistant to aging than normal asphalt mixtures. Aging studies performed in asphalt-rubber binders placed in northern and central Arizona pavements indicate that asphalt-rubber binders have an increased resistance to hardening. When crumb rubber is added to asphalt cement, fatigue life is improved.

It is recommended that compacted mixes be sampled according to AASHTO T168, and tested for specific gravity in accordance with ASTM D2726 and in-place density in accordance with ASTM D2950.

- ***PennDOT Standard Provision (SP), c04491 Item 9448- Dry Processed Treated Crumb Rubber Modified Bitumimous Concrete Wearing Binder, Leveling, and Scratch Courses allows for the use CRM to 0.5% of the total mix weight.***

Other Considerations:

To summarize, based on a study of projects in participating states, the overall results of these performance investigations suggest the following:

- Precoated chips must be used and are effective in reducing, but not eliminating, reflective cracking, especially in warmer climates.
- Asphalt-Rubber Hot Mix Overlays. Improved performance was observed compared with conventional hot mix overlays using the wet process in most climates. Dense-graded asphalt-rubber overlays may be effective at reduced thicknesses, compared with conventional overlays. Open-graded asphalt-rubber friction courses exhibit improved durability in warmer climates, compared with conventional friction courses.
- The overall consensus is that crumb rubber modified asphalt pavements may cost 1.5 to 2 times as much as conventional asphalt. Many states have questioned the cost effectiveness of CRM in hot mix asphalt.
- The reported performance of rubber-modified asphalt concrete pavements has varied widely in different sections of the United States. Performance of rubber-modified asphalt using the dry process has been mixed, with some early failures.