

**Producing Ground Scrap Tire Rubber: A Comparison Between Ambient and
Cryogenic Technologies:**

M. H. Blumenthal
Executive Director, Scrap Tire Management Council
1400 K Street, NW
Washington, D.C.
20005

In 1985, the scrap tire industry was created when Minnesota became the first state to develop specific legislation and regulations for scrap tires. Up to that time, many scrap tires, like most solid and household wastes, went into the municipal dump. Those tires not placed in the dump went into stock piles, some of which still exist today. Prior to 1985, few, if any scrap tires were processed. The Minnesota program changed all that.

The equipment first introduced to process scrap tires consisted of redesigned wood or metal shredders. The performance of these systems left much to be desired. In the past 10 years, many companies and equipment systems, designed especially for scrap tires, have come into existence. Until recently, scrap tires were typically processed by "ambient" systems. These systems consist of a mechanical process, which

cuts and or grinds whole tire rubber into the desired sized particle at room (ambient) temperatures.

Historically, producing ground rubber, like all other rubber processing, was done by an ambient (room temperature) processing system. Within the last several years, cryogenic processing of scrap tires has been introduced for the preparation of ground rubber. In the cryogenic process, rubber is introduced into a bath of liquid nitrogen, instantly freezing the rubber. Once embrittled, the rubber is struck with an impact devise, effective shattering the rubber.

Markets for Scrap Tires

In 1990, 11 percent of the annually generated scrap tires had markets. The primary market was tire-derived fuel (TDF), which was generally a roughly shredded piece of scrap tire. Today, almost 60 percent of the 253 millions scrap tires generated annually have markets. While TDF continues to be the largest single market for scrap tires, the market place now generally requires a fuel chip, none of its dimensions larger than two inches (5.08 cm). Furthermore, new market applications are emerging. One market in particular, the ground rubber market, requires comparatively more processing than any other market application for scrap tires, since the particles formed can be reduced to 80 mesh (180 microns).

Ambient Processing Systems

There is no one, universally accepted way to ambiently size reduce scrap tires. Many processors of ground rubber and equipment manufacturers may argue over the placement of each piece of equipment and what piece of equipment is the most efficient and cost effective to use in each stage or process. It is not the intent of this paper to discuss the arguments made nor to suggest how to process the rubber. Rather, this section defines the equipment that can be used.

Equipment Description

As a starting point, it is presumed that the scrap tires have already been ambiently reduced to two inch minus (-5 cm) in size and that the bead steel has been removed (for information on processing whole scrap

tires to the two inch minus (-5 cm) size, refer to Processing of Scrap Tire: Technology and Market Applications, by the same author, given at the June 19-25, 1994 ASME Conference). From this point, the scrap tire particle can be further reduced to one of three general sizing grades; (1) Coarse Ground Sizing; (2) Fine Ground Sizing; (3) Ultra Fine Power Sizing.

Producing Course Ground Material

Course ground material is generally classified as material in the one half (1.27 cm) to one eighth inch (0.3175 cm) size range. This sized materials is referred to as granulate or crumbed rubber, since their appearance is granular. This material is produced by feeding the two inch minus (-5 cm) particles into a primary granulator.

Granulators can be categorized as medium to high speed (100-1200 revolutions per minute) processing systems. They utilize a rotor in which fly knives are attached. These fly knives pass in close proximity with stationary knives which cause a cutting and shearing action. Product size is controlled by a screen within the machine. Screens, which are used to sort the particles by size, can be changed to vary end product size.

Upon exiting the primary granulator, all product passes through a magnetic separation system where the vast majority of the belt wire steel is separated. The material is then fed to air gravity separation table where the majority of fiber is removed.

Producing Fine Grind Material

Upon exiting the primary granulator, the material is sent to a secondary crackermill. Primary and secondary crackermills are very similar and operate on basically the same principle, however the roll configurations are what make them different. Secondary crackermills can be categorized as low speed processing systems, operating at 30-50 RPM. They use two large counter rotating rollers with serrations cut in one or both of them. These rollers operate face to face in a close tolerance. Each roller operates at different speeds. This causes a rolling, cracking or grinding action. Product size is controlled by the clearance between the rollers which is also called the nip. Rubber particles leaving this system can be in the 10 (2 mm) to 30 mesh (600 microns) range.

Once the rubber particles are processed to the desired size, the product is sent through a second magnetic separation system. At this stage, all remaining steel is removed. The product is then screened and all 1/8 inch (0.3175 cm) or larger product is returned to the secondary crackermill for further reduction. The product which is smaller than 1/8 inch (0.3175) is fed to a second air gravity separation system where the remaining fiber is removed.

Before the final rubber particles leave the processing system, the material passes through a finishing mill for final sizing. All product is then sent through a system designed to remove any stones, rock, or other types of heavy contamination. Final product is then screened into its respective product size ranges and bagged and weighed.

Producing Ultra Fine Material

Micromills or micromilling, also called the wet process, is a patented grinding process for ultra fine grinding. It reduces particle size by grinding in a liquid medium, usually water. Grinding is performed between two closely spaced grinding wheels. Product size is controlled by the time spent in the micromill. If a particle smaller than 30 mesh (600 micron) is required in any quantities, the micromill or wet process could be incorporated into the system. However, this is a patented process and its use is limited to its patent holders

Cryogenic Processing Systems

Once again, we start with a piece of shredded scrap tire, in the 1- to 3-inch (2.54-7.62) size range. These initial pieces are size reduced by an ambient processing system. The tire pieces are chilled with liquid nitrogen, ground a mill. Afterwards, in a separate process, the fiber and metal are separated from the rubber particles. Finally, the ground rubber is sorted according to size. In this process, 70 to 80 percent of the ground rubber produced is smaller than 10 mesh (2 mm).

A variation on this approach involves shredding the tires with one or more shredders, coarse grinding the chunks with multiple ambient temperature granulators, separating the metal and fiber, then pre-cooling the chip. This is followed by placing the chip into the liquid nitrogen, processing the material and then sorting the particles by size. This produces rubber that is all substantially smaller than 30 mesh (600 micron).

For many applications a finer crumb, 30 mesh (600 micron) or smaller, is required and producing it calls for secondary cryogenic processing. In cases like this, the process starts with the 4- to 10-mesh (4.75 mm-2 mm) ground rubber produced in one of the primary grinding systems just described, pre-cool the material, cryogenically grind it, and sort the product by particle size. Conventional technology can be utilized to obtain particle size distributions with over 40 percent smaller than 80 mesh (180 micron).

Liquid Nitrogen

The one necessary ingredient for cryogenic grinding is liquid nitrogen. Nitrogen is non-toxic and relatively non-reactive. It boils at -195.8°C (-320.4°F). The liquid is somewhat less dense than water. It weighs 0.81 kg/l (50.5 lb/cu ft). An efficient way to minimize temperature loss is to use a counter current heat exchanger in which virtually all the cooling energy of the nitrogen is extracted before the frozen rubber is introduced into the grinding mill.

Liquid nitrogen is produced in air separation plants. Air is purified, compressed, and liquefied. Then through fractional distillation, nitrogen is separated from oxygen, argon, and other impurities in a tall distillation column. Air separation plants range in size from about 200 metric tons per day to 2,000 metric tons per day. Currently, there a facility is being constructed, which will be the world's largest air separation plant, generating 2,500 metric tons (2,700 tons) per day.

Cryogenic Grinding Equipment

The equipment for pre-cooling and cryogenic grinding is highly varied. Typically, the choice depends on your particular circumstances, such as your existing equipment, starting rubber size, and capital vs. operating cost trade-off. One of the common pre-coolers is the rotary kiln type. As the chunk or ground rubber moves forward through the rotating cylinder, it is sprayed with liquid nitrogen and chilled to at least -73°C . (-100°F .) before passing into the processing mill.

Paddle-type conveyors can also be used for the pre-cooling process. As with all the pre-coolers, the material to be processed is sprayed with liquid nitrogen. The paddle-type unit has the advantage in that the speed and pitch of the paddles can be independently varied, thus permitting optimization of particle residence time and "wind chill" factor. The screw-type pre-cooler is a less flexible variation of the paddle-type pre-cooler. Belt-type or vibratory pre-coolers can also be used. Liquid nitrogen is sprayed on the rubber as it moves through the pre-cooler toward the mill. An efficient system will extract 90-95 percent of the (theoretical) cooling energy from the liquid nitrogen.

A somewhat different type of pre-cooler is the immersion bath. In this system, the rubber material is totally immersed in liquid nitrogen. This system is different from the others in that there is no provision for using the 196°C (-320°F) vaporized nitrogen for cooling the rubber. The cold gas can be drawn into the mill where it affords some cooling or

fed into an additional heat exchanger where it pre-cools warm rubber.

Following the pre-cooling, the rubber is typically pulverized in an impact type mill such as a hammer mill. In this impact mill, the rubber also can be sprayed with liquid nitrogen to lower the temperature to that needed for effective cryogenic grinding. Usually, liquid nitrogen injection into a mill is only required for fine particle sizes where multiple impacts must occur. A hammer mill can have either fixed or swinging hammers to shatter the frozen rubber.

Comparisons of Processing Technologies

Cryogenic processing systems do offer several advantages over ambient processing systems. For example, cryogenically frozen rubber pulverizes much more easily than rubber at ambient temperatures, requiring less power to produce the final product of the same size. There is, however, a trade-off to the advantage of ambient systems. This is the cost of the liquid nitrogen which is obviously needed in a cryogenic system. Nitrogen costs are typically \$0.02 to \$0.06 per pound of rubber, depending on the degree of particle fineness required and quantity of nitrogen purchased. The former number typically takes you from 2-inch (5 cm) TDF to 80 percent 10 mesh (2 mm). The latter from 2-inch (5 cm) chips to 99 percent minus 30 mesh (600 micron).

Because cryogenically frozen rubber pulverizes more easily than rubber at ambient temperatures, there is less wear and tear on machinery and maintenance costs are

usually significantly reduced. Moreover, maintaining sharp cutting edges is much less important in a cryogenic system as opposed to an ambient system.

Finally, there tends to be less equipment required for a given throughput rate in a cryogenic system, as compared to the ambient systems, thereby requiring less space than that needed for an ambient system.

Particle Comparison

The major difference between particles of rubber generated by ambient and cryogenic processing systems is their shape. Particles derived from the cryogenic process have a smooth surface, akin to shattered glass. Particles derived from the ambient process have a rough surface, giving it greater surface area relative to the cryogenically produced particle.

To a large degree, the advantages or disadvantages of a material derived from a given processing system is a function of the market application. Another way to state this is that there are market applications where cryogenically reduced rubber is preferred, and market applications where ambiently generated material is preferred. To confuse matters further, there are market applications (i.e., rubber modified asphalt) where either type of ground rubber can be used. The deciding factor in these cases is more a function of the manner in which the rubber is used.

Value Added Applications

The markets for ground rubber can be divided into two general categories; rubber modified asphalt (RMA) and new

products. In 1994, the market place consumed some 240 million pounds of ground rubber. Sixty seven percent of the 240 million pounds come from tire buffing (or buffing dust), a by-product of the retreading industry, the remainder was derived from scrap tires. Of the material that is derived from scrap tires, the majority is processed ambiently.

Rubber Modified Asphalt (RMA) is a general term used to describe all the technologies which incorporate an element of ground rubber into asphalt pavement. The Federal Highway Administration (FHWA) uses the Crumb Rubber Modifier (CRM). These terms are the same.

The use of ground rubber in asphalt paving is used to enhance certain properties and characteristics of the asphalt. Tire rubber can be utilized in asphalt in two ways: asphalt-rubber (also known as the Arizona or "wet" process), which is typically used as a sealant or as a relatively thin over-layer; and as rubber modified asphalt (also known as "SUMAC", the "dry" process, or PLUSRIDE™), in which rubber chips replace part of the aggregate in the paving mix.

In this market application, the type of ground rubber is a function of the paving technology and particle size. For example, if the continuous blend technology is used (a variation of the wet process), 80 to 100 mesh rubber (180 micron to 150 micron) is used. Whether the particle was produced by a cryogenic or ambient process is secondary, since both particles have a similar reaction in asphalt at that size. More often than not the deciding factors

are a function of the contractors experiences and the price differential.

In the conventional wet and/or dry processes, ambiently ground rubber is preferred, due primarily to the surface area available in this type of rubber. In crack sealants and interliner sprays, once again, smaller sized rubber (80 to 100 mesh or 180 to 150 micron) is used. The selection criteria can once again be a question of price and availability of product.

The second segment for ground rubber is in the manufacturing of new products. This is still an emerging industry. Of the total 240 million pounds, 42 percent goes into rubber modified asphalt, with the remaining 58 percent going into the manufacturing of these new products.

The breakdown of the market segments for the non-RMA ground rubber (total of 116 million tons) are listed in Table 1:

Table 1

Molded Products.....	8%
Rubber/Plastic.....	8%
Friction Brakes.....	8%
Bound Products.....	21%
Tires.....	30%
Athletic Fields.....	25%

The type of rubber used (ambient or cryogenically produced) in these applications is typically a function of the role rubber has to play. In Athletic field and friction brake material, ambiently produced rubber has used. It is highly likely that ambiently ground rubber will continue to be used in these applications.

Size reduced rubber used in new tire applications is typically 80 mesh (180 micron) or smaller. The major generators of this material use an ambient, wet process (referred to as either a wet grind or micro milling) to produce this sized material. The source material used in this process can come from either processing systems. To date, there are no cryogenic processing facilities in the United States generating minus 80 mesh (180 micron) rubber.

The rubber used in bound rubber products, molded or rubber/plastic products is a function of the product itself. For example, mats and soaker hoses prefer ambiently produced material, while products using a surface modified rubber prefer cryogenically produced rubber.

At present, the products with the more favorable market forecast are the athletic applications (mats, athletic fields and playground cover material) and bound rubber products. The long-term market potential, however, appears brighter for molded or extruded products, assuming certain technical issues can be overcome.

Emerging Technologies

There are two, emerging technical applications for size reduced scrap tire rubber that could significantly impact the demand for this material. The first is surface activation, the second is a process which will devulcanize/re-link scrap rubber.

Surface modification is a process where size reduced rubber is exposed to either fluoride or bromide gas. The gas will

“activate” the surface of the rubber, allowing the material to bond with other polymers, usually urethane. The resultant, composite polymer is then used either as a substitute or in addition to urethane. The benefits of this material are that it is less costly than pure urethane and has similar or enhanced properties. The preferred scrap tire rubber used is a cryogenically size reduced particle since a smooth particle surface is desired.

The second emerging technology of interest is a devulcanization process (De-Link), which reportedly can sever the carbon-sulfur bonds of rubber. Once these bonds are broken, the material (De-Vulc) can be recombined with polymers in a greater percentage than is currently possible. This process also has a preference for cryogenically size reduced rubber.

Ground Rubber Pricing

To place the market value of ground rubber into perspective, it may be useful to give price ranges for the various gradations of ground rubber. The information supplied in Table 2 should be used only as a basis for comparison, since prices do vary depending on the availability, location, cleanliness, volume, and packaging, as well as particle size.

Table 2

Rubber Size Price Range (Mesh)	(\$/lb)
4 (4.75 mm)	0.07-0.09

10	(2.00 mm) 0.10-0.12
30	(600 Micron) 0.17-0.19
40	(425 Micron) 0.19-0.25
80	(180 Micron) 0.33-0.40

a fine ground material (minus 80 mesh or 180 micron).

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Conclusions

There have been advancements in both the markets for scrap tires and the technology capable of process them. While ambient process systems were the original systems introduced to scrap tire processing, recently, cryogenic processing systems were introduced and are finding their way into the market place.

While both system offer advantages, the main issue is not which is the better system, but which type of rubber can meet the end-users specification. Currently, the majority of ground rubber which comes from whole scrap tires is processed by ambient systems. This is due to the fact that this technology has been on the market longer and those companies that first started generating ground rubber could only do so with an ambient system.

Whether the number of processor using the cryogenic process exceeds the number of ambient processor will depend on several factors. These factors include, but are not limited to expansion of certain markets for ground rubber, the cost to produce cryogenic ground rubber, the willingness of the end user market to accept cryogenically produced rubber and the introduction of new technologies that will allow for the use of