Best Practices in Scrap Tire and Rubber Recycling

The Recycling Technology Assistance Partnership (ReTAP)

A program of the **Clean Washington Center,**

a division of the Washington State Department of Community, Trade & Economic Development

2001 Sixth Avenue, Suite 2700

Seattle, Washington 98121

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ACKNOWLEDGMENTS

The Best Practices in Recycling program is managed by the Clean Washington Center's Recycling Technology Assistance Partnership (ReTAP). ReTAP is an affiliate of the national Manufacturing Extension Partnership (MEP), a program of the U.S. Commerce Department's National Institute of Standards and Technology. ReTAP is also supported by the American Plastics Council and the Environmental Protection Agency.

Principal Authors

This publication is a product of the efforts of many organizations and individuals. The following provided their time, effort, and knowledge as the principal authors of this manual:

1. **William Klingensmith**, Akron Consulting Company, Akron, Ohio.
2. **Krishna Baranwal,** Akron Rubber Development Laboratory, Akron, Ohio.

Individuals or organizations that provided specialized information are acknowledged in the appropriate Best Practice.

The Clean Washington Center

The Clean Washington Center is Washington State's lead agency for recycling market development. The Center is an applied technology center working to increase the capacity of businesses to reduce waste and use recycled materials in manufacturing processes. Focusing on private industry growth opportunities, the Clean Washington Center partners with business, industry, and local governments to:

- Optimize the recycled material use capacity of existing manufacturing facilities and equipment to enhance product performance characteristics, reduce costs, and control product quality;
- Develop new recycled-content product manufacturing capacity, recycled material uses, and commercializable technology;
- Evaluate recycled material markets to strategize product, market, and business growth strategies; and
- Demonstrate product performance advantages and the value added by using recycled materials, and disseminate the information.

The Clean Washington Center's activities support the state of Washington in its efforts to manage solid waste by developing economically viable markets for paper, plastics, glass, compost, tires, and debris from construction, demolition, and land clearing.

Recycling Technology Assistance Partnership (ReTAP). The Recycling Technology Assistance Partnership (ReTAP) is a program of the Clean Washington Center. The mission of ReTAP is to advance industry's use of recycled materials through technology extension services. ReTAP has two components: Industry Services and the ReTAP National Network. Industry Services provides hands-on customized engineering assistance to companies in the state of Washington that want to increase or optimize their use of recycled materials. The ReTAP National Network promotes the development of recycling technical services throughout the nation, and provides this network with resources to support the development of service provider technical expertise, existing recycling technologies, and new technologies.

BEST PRACTICES IN SCRAP TIRE AND RUBBER RECYCLING

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1.0 THE BEST PRACTICES IN RECYCLING PROGRAM

The Clean Washington Center (CWC), through its Recycling Technology Assistance Partnership (ReTAP), is developing commodity-specific Best Practices in Recycling Manuals for glass, HDPE, scrap tires and rubber, PET, and wood waste. Other recycled materials will be considered for the Best Practices program in the future. The manuals are being disseminated through Best Practices Workshops. These workshops and manuals focus on effective uses of recycled materials and effective application of recycling technologies.

Best Practices in Recycling

Best Practices are proven methods and techniques that enable the effective technology applications and materials end uses under certain conditions. "Practices" refer to ways of performing operational activities - either materials sourcing, processing, product manufacturing, or end-use applications - and to methods that help create products that meet customer needs. To be considered "proven," a practice must have been successfully applied in the field or on the shop floor. (A technology application under development, by definition, cannot be a best practice.) An "effective" practice is one that accomplishes or meets all or most of the user's goals or requirements - user requirements are generally measured in terms of cost reduction or performance improvement. An application or materials end use is not considered effective simply because it is convenient, because it is inexpensive to implement, because of personal preference, or because of other non-technical issues.

Best practices range from detailed procedures, such as how to adjust settings on a particular piece of equipment, to general practices, such as how to establish feedstock specifications between a manufacturer and a supplier.

Purpose of the Best Practices Manual

ReTAP collects and disseminates information about recycling technology best practices because this technical know-how offers companies significant benefits. Implementation of best practices can:

- Reduce the cost of processing a recycled material or manufacturing a recycled-content product.
- Add to the performance of a recycled material or recycled -content product.

Access to well-defined best practices reduces the time, effort, and resources required to identify and implement improved processes or techniques. Industries that implement recycling technology best practices will likely improve their competitive position in the marketplace. Within an industry, suppliers and buyers that share best practices are in a better position to meet one another's needs.

Manual Content and Format

Best Practices Manuals contain brief, two-page summaries of industry practices that maximize the cost and performance advantages of recycled feedstocks. Each Best Practices Manual focuses on one recycled commodity or related group of commodities. Each manual consists of four sections - materials sourcing, processing, product manufacturing, and end-use applications. The sections are divided into subsections based on function (e.g., size reduction, washing), process (e.g., injection molding), or application (e.g., construction aggregate, composite filler).

Best Practices descriptions will include:

- Issue addressed by the Best Practice
- Detailed description of the Best Practice
- Suggestions for implementation of the Best Practice
- Benefits associated with the Best Practice
- Sites where the Best Practice has or can be implemented
- References for additional information about the technologies or materials associated with the Best Practice.

Updating the Best Practices Manual

The Best Practices Manuals are designed to be continuously updated as new or more effective best practices are obtained from manufacturers, service providers, and technical experts.

A notice will be sent to all registered holders of the manual indicating those best practices that have been updated or added. Updates will be provided to registered holders of the manual upon request. For information about how to contribute to the Best Practices in Recycling program, please see Section 3.0.

Best Practice Workshops and Information Dissemination

Best practices will be disseminated at workshops presented through a national network of recycling technology service providers. The best practices workshops are a series of commodity-specific regional sessions tailored to meet the needs of manufacturers, technology extension agents, recycling consultants, and market development organizations. Each workshop uses relevant examples from industry. Workshop attendees participate in a series of interactive sessions in which they are encouraged to apply what they have learned to real-world scenarios.

The workshops are a critical step in maintaining industrial competitiveness, advancing industry's use of recovered materials, and strengthening the secondary materials market.

2.0 TECHNOLOGY EXPERT FOCUS GROUP ON SCRAP TIRES AND RUBBER RECYCLING

To help identify potential best practices in glass recycling, ReTAP conducted a Technology Expert Focus Group Meeting. ReTAP invited technical experts from across the nation to participate in the meeting. These people are experienced in materials sourcing, processing, product manufacturing, equipment manufacturing, and research. During two days of facilitated meetings, the participants identified the technology needs of industry, research needs, potential sources of best practices, and potential best practices The meeting facilitators take notes for the meeting.

The Technology Expert Focus Group Meeting on Scrap Tires and Rubber Recycling, held in Greenville, South Carolina on January 18-19, 1995, was made possible through support provided by the U.S. Environmental Protection Agency. The meeting was hosted by Michelin North America at their corporate headquarters.

Twelve people participated in the meeting on scrap tire and rubber recycling. Five people observed the proceedings (i.e., they did not partake in the discussion). The participants included:

- Charles G. Astafan, Sales Manager, Columbus McKinnon Corporation; Sarasota, FL
- Adam T. Baker, Sales and Marketing Manager, Baker Rubber, Inc.; South Bend, IN
- Bernard D. Bauman, Ph.D., President, Composite Particles, Inc.: Allentown, PA
- Gregory Bavington, Vice President, Technology, National Rubber Company; Toronto, Ontario, Canada.
- Douglas L. Bell, Director of Corporate Administration, Michelin North America; Greenville, SC
- Michael H. Blumenthal, Executive Director, Scrap Tire Management Council; Washington, DC
- David L. Forrester, President and Chief Executive Officer, T.I.R.E.S.; Winston-Salem, NC
- Jackson, Applications Consultant, Praxair, Inc.; Danbury, CT

- Jon A. Johnston, Manager, Advanced Materials, Hose and Connector Division, The Gates Rubber Company, Denver, CO

- Michael J. Schnekenburger, P.E., Vice President, Materials-Tire Recycling., National Rubber Company, Inc.; Toronto, Ontario, Canada

- Jack Van Kirk, California Department of Transportation, Engineering Service Center; Sacramento, CA

- Ronald Williams, President, Domal Envirotech, Inc.; Rexdale, Ontario, Canada

The observers included:

- Ted Campbell, Manager, Recycling Market Development Advisory Council, South Carolina Department of Commerce, Columbia, SC

- Diane A. Marlow, Director, South Carolina Clean and Beautiful, South Carolina Department of Parks, Recreation and Tourism, Columbia, SC

- Stephen C. Thomas, Manager, Office of Solid Waste Reduction and Reduction, South Carolina Department of Health and Environmental Control, Columbia, SC

- Alec Vare, Michelin North America, Greenville, SC

- Kevin Wallace, Michelin North America, Greenville, SC

3.0 HOW TO CONTRIBUTE BEST PRACTICES

This Best Practices Manual is a living document. It will only serve its users if the information it contains is constantly reviewed, field-applied, and improvements or additions suggested. Users of the manual are encouraged to contact the Clean Washington Center for information about how to add to existing best practices, or contribute new best practices.

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Instructions for writing and formatting best practices are available, along with a description of the technical criteria by which best practices will be measured for inclusion in the manual.

Please provide any general feedback on the manual by completing the attached feedback form and sending it to "Best Practice Manual Feedback" at the above address.

BEST PRACTICES IN SCRAP TIRE AND RUBBER RECYCLING

Feedback Form

Best Practices Manuals contain proven methods and techniques that enable effective application of recycling technology and materials end uses under certain conditions. Best practices focus on materials sourcing, processing, product manufacturing, or end-use applications.

In order to continually improve the manual, the Clean Washington Center (through its Recycling Technology Assistance Partnership - ReTAP) would like your feedback on the usefulness of the Manual. Please take the time to comment on the manual's overall pluses and minuses, as well as specific recommendations for improvement. Please return the form to the CWC at the address provided below. Thank you for your efforts.

Comments

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Specific Recommendations for Improvement

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"Best Practice Manual Feedback"
Clean Washington Center
Recycling Technology Assistance Partnership
2001 6th Avenue, Suite 2700
Seattle, Washington 98107

4.0 BEST PRACTICES IN SCRAP TIRE AND RUBBER RECYCLING

Material Storage

Material: Recycled Rubber Derived from Tires, Industrial Scrap and Post Consumer Scrap Rubber Products.

Issue: *All recycled rubber chips, crumbs may degrade on storage especially in presence of iron particles and heat.*

Best Practice: This best practice describes precautions that should be taken during the manufacture and storage of whole tires, shredded tires, chips and recycled rubber crumbs. Almost all recycling processes generate heat sometimes as high as 220-240°F, which in presence of oxygen, air, can lead to spontaneous combustion. Also, for natural rubber (NR) compounds presence of iron (Fe) can catalyze the oxidation process causing rubber degradation. This degradation is accelerated with heat. Presence of any metal can also act as conductor of heat in rubber crumbs. During processing and storage volatiles and toxicity chemicals may be generated from hot materials. The moisture content of current recycled rubber in specification is at a maximum of 1%. However, the relative humidity and temperature of the material during storage, shipment and disposition prior to use may cause the moisture content to increase.

Implementation: First the work force in plant and storage areas be trained so that they are aware of the effects of heat and presence of steel (wire) pieces. During the processing and generation of crumbs, etc., the system and materials need to be cooled either by water or air so that temperature is below 200°F to avoid spontaneous combustion. Also, keep recycled rubber free of all metals, especially iron, to avoid conduction of heat and NR degradation. Before the material is stored in bins, piles, etc., make sure that it is cooled and temperature is well below 200°F. Recycled rubber processors should provide MSDS available to their employees and to the end-users. Store materials at ambient temperatures and not in tin sheds or tin-roof warehouses. Store recycled materials in a covered and dry area. There have been reports of fires of shredded and ground rubber being stored when not cooled sufficiently after processing. Be aware of proper cooling requirement, i.e., do not store hot ground rubber.

Benefits: Less safety hazard either during recycling processing or storage of recycled rubber. By eliminating/reducing degradation of crumb, it would impart improved compound properties.

Application Sites: All rubber recyclers during size reduction at various stages and during storage both at processors' and end-users' sites.

Sources/Contacts: Krishna C. Baranwal, Akron Rubber Development Laboratory, Akron, Ohio, Phone 330-794-6600; Fernley Smith, President, ETA, Port Clinton, Ohio; Bill Klingensmith, Akron Consulting Company, Akron, Ohio; and Mike Rouse, Rouse Rubber, Inc., Vicksburg, Mississippi.

References: MSDS sheet example attached in Appendix I, from Vredestein's technical information "Natural Rubber Reclaim, RNR 30/B91."

Issue Date / Update: November 1996

Prepared by the Clean Washington Center. The Clean Washington Center is the Managing Partner of the Recycling Technology Assistance Partnership (ReTAP). ReTAP is an affiliate of the national Manufacturing Extension Partnership (MEP), a program of the U.S. Commerce Department's National Institute of Standards and Technology (NIST). For information on the technology extension services offered through the ReTAP network, or other assistance available at the Clean Washington Center, call Mary Lynch, National Outreach Manager, at (206) 587-4217.

EPA

NIST MEP Environmental Program

Clean Washington Center

VREDESTEIN RUBBER RECYCLING

APPENDIX I

MATERIAL SAFETY DATA

Manufacturer's Name Address:	Vredestein Rubber Recycling B.V. P.O. Box 437, 6200 AK Maastricht
Telephone No:	043 - 290320
Trade Name:	Vredestein RNR 30/B91
Synonyms Chemical Name	Rubber Hydro Carbon

HAZARDOUS INGREDIENTS

MATERIAL		
These products contain MINERAL OIL	less than 20%	
This product is produced from: Truck Tyre Treads		

2. PHYSICAL DATA

Appearance: Slabs.	Odor Characteristics	Specific Gravity 1.110 - 1.240	
Solubility in water	Insoluble		

3. FIRE AND EXPLOSION HAZARD DATA

Extinguishing Media: Water, foam and dry powder

Special Fire Procedures:
To wear self-contained breathing apparatus

Unusual Fire- and Explosion Hazards:
Product does not present explosive hazard.

VREDESTEIN
RUBBER RECYCLING

APPENDIX I

4. PHYSIOLOGICAL EFFECTS

Dermal (skin contact)	Inhalation
none known	none known

Primary route of exposure: dermal contact

Effects of overexposure:

Acute None known or expected.
Ingredients are bound to rubber - so no inhalation problems during handling.
Exposure to volatiles: released during hot processing such a curing may cause respiratory, nose or eye irritation to som people.

Chronic Long term. Inhalation exposure such as concentrated hot pocessing fumes have immediately been reported to reduc long function and cause chronic bronchitis.

5. EMERGENCY AND FIRST-AID PROCEDURES

Remove to fresh air. If not breathing: give artificial respiration or oxygen.
Call a physician at once.

Skin : Compound related effects not expected t require first-aid.

Ingestion: Compound related effects not expected.

6. PHYSICAL HAZARDS

Hazardous. Decomposition products could include carbon-monoxic carbon-dioxid and hydro carbon.

VREDESTEIN RUBBER RECYCLING

APPENDIX I

7. SPECIAL PROTECTION INFORMATION

Ventilation

Good manufactoring practics demand that inhalation of fumes and volatiles from hot processing fumes of rubber compounds must be avoided.
Local ventilation is necessary to prevent routine inhalation of fumes. Not applicable in food- and medical products.

Protective gloves:	Other:

8. CHEMICAL REACTIVITY

Conditions causing instability	: Material is stable
Incompatibility (Materials to avoid):	No known materials to avoid
Hazardous decomposition products carbon	: Carbon monoxid-dioxid sulpheroxid-hydro-
Special sensitivity	: none

9. STORAGE INFORMATION

Precautions to be taken in handling and storage:

- general ventilation advised
- store away from exessive heat and open flame

10. spill, leak and disposal information

Steps to be taken in case material is spilled or released:

- pick- or sweep up material and place in container for disposal or reuse. No precautions necessary.

EPA RCRA ID NUMBER

Flammability

Material *Recycled Rubber from Tires, Industrial Scrap Rubber, and Post-Consumer Scrap Rubber Products*

Issue: *Rubber is a good heat insulator and contains a significant amount of volatile organic material. Under proper conditions (heat and oxygen), it may burn.*

Best Practice: This best practice describes various steps and precautions for minimizing/eliminating recycled rubber combustion and flammability. All automotive rubber products such as hose, mats, and belts must use FMVSS 302 standards. Other specifications that rubbery material must meet are UL 94, ASTM D470, C542 and C864. Release of volatiles upon burning of rubber is of concern.

ASTM D4205-93 describes test methods for determining flammability and combustion properties of rubbery materials. A copy is attached.

Implementation: Process and store materials at ambient temperatures. Avoid build-up of static electricity which may cause combustion. All processing and storage areas should be strictly "non-smoking." Recycled rubber handlers need to have information on volatility of the material from MSDS sheets. A copy of a MSDS sheet, as an example, is attached in "Material Storage" best practice. It is good to avoid static build-up during shredding, grinding and sorting steps. This is best done by properly grounding processing equipment.

Appendix I lists comparative Btu valves of TCF (tire-chip fuel) and TDF (tire-derived fuel) to give an idea regarding the extent of heat generated during burning of these materials.

Benefits: Reduction of fires in manufacturing, storage of recycled rubber and in its use. Also, special care should be taken to remove hot wire during processing to help eliminate any fire.

Application Sites: All recycling manufacturing and recycled rubber storage sites.

Source(s)/Contact: RMA, Washington, D.C.; Fernley Smith, President, ETA, Port Clinton, Ohio; Mike Rouse, Rouse Rubber, Inc., Vicksburg, Mississippi; Krishna C. Baranwal, Akron Rubber Development Laboratory, Akron, Ohio, Phone 330-794-6600.

References: RMA video tape on tire fires; ASTM D470, C542, C864, and D4205; UL 94; FMVSS 302; Best Practice on Material Storage.

Issue Date / Update: November 1996

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APPENDIX I

COMPARATIVE BTU VALUES	
COKE (Petroleum)	13,700 Btu/lb.
WOOD (wet -'Hog Fuel')	4,375 Btu/lb.
BITUMINOUS COAL	12,750 Btu/lb.
SUBBITUMINOUS COAL	10,500 Btu/lb.
LIGNITE COAL	7,300 Btu/lb.
TIRE-CHIP FUEL	14,200 Btu/lb.*
TIRE-DERIVED FUEL	15,500 Btu/lb.*
RUBBER-DERIVED FUEL	16,000 Btu/lb**
NATURAL GAS	1,000 Btu/cu. ft.
OIL - No. 6 Fuel Oil -' Bunker C'	151,000 Btu/gal. 42 gal/bbl

* These values differ depending on the amount wire and fiber contained in the chip.

** Refers to fuel generated from a combination of non-tire and tire-derived rubber.

SOURCE: Rouse Rubber Industries and WRI

Designation: D 4205 – 93 (Reapproved 1994)$^{\epsilon 1}$

Standard Guide for Flammability and Combustion Testing of Rubber and Rubber-Like Materials[1]

This standard is issued under the fixed designation D 4205; 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.

$^{\epsilon 1}$ NOTE—Section 16, Keywords, was revised editorially in December 1994.

1. Scope

1.1 This guide covers the present state-of-the-art test methods for determining the flammability and combustion properties of rubber and rubber-like materials.

1.2 This guide includes standard test methods promulgated by ASTM, NFPA, ANSI, Underwriters's Laboratories, trade associations, and government agencies. It does not include industrial materials specification tests or nonstandard test methods.

1.3 This guide is arranged according to products and systems.

1.4 *This standard should be used to measure and describe the response of materials, products, or assemblies to heat and flame under controlled conditions and should not be used to describe or appraise the fire-hazard or fire-risk of materials, products, or assemblies under actual fire conditions. However, results of these tests may be used as elements of a fire-hazard assessment or a fire-risk assessment which takes into account all the factors which are pertinent to an assessment of the fire hazard or fire risk of a particular end use.*

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For specific precaution statements, see the note in Section 3.

2. Terminology

2.1 The terminology used in the reference test methods is not consistent from test to test. The terms used in a particular test method shall be utilized only in reference to that test method and only in a manner connected with the definition of the terms given in that test method.

3. Significance and Use

3.1 Rubber, like many other materials, is combustible. This guide gives the test methods used in various industries at the present time. These test methods describe the combustibility and burning characteristics of many rubber and rubber-like materials.

3.2 This guide enables the user to select the presently acceptable test methods for the description of the flammability and combustion of his product.

NOTE: **Warning**—During the course of combustion, gases or vapors, or both, are evolved which may be hazardous to personnel. Adequate precautions should be taken to protect the operator.

4. Source

4.1 The source for the test method is given in Annex A1 and referenced by letter designations in the text.

5. Automotive Test Methods

5.1 D 3675 Test Method for Surface Flammability of Flexible Cellular Materials Using a Radiant Heat Energy Source (L4)

5.2 DOT Motor Vehicle Safety Standard No. 302 Flammability of Materials—Passenger Cars, Multipurpose Passenger Vehicles, Trucks and Buses (I)

5.3 SAE J369 Flammability of Automotive Interior Trim Materials (F)

6. Aviation Test Methods

6.1 FAR 14CFR 25.853, Paragraphs (a), (b), and (c) and Appendix F, Airworthiness Standards—Transport Category Airplanes, Compartment Interiors (J)

6.2 SAE-AMS 3851A Fire Resistance Properties for Aircraft Materials (F)

6.3 SAE-AMS 3852A Fire Resistance Properties for Aircraft Materials (F)

6.4 F 501 Test Method for Aerospace Materials Response to Flame with Vertical Test Specimen (for Aerospace Vehicles, Standard Conditions) (L7)

6.5 F 776 Test Method for Resistance of Materials to Horizontal Flame Propagation (for Aerospace Vehicles, Standard Conditions) (L7)

6.6 F 777 Test Method for Resistance of Electrical Wire Insulation Materials to Flame at 60° (L7)

6.7 F 814 Test Method for Specific Optical Density of Smoke Generated by Solid Materials for Aerospace Applications (L7)

6.8 F 828 Test Method for Radiant Heat Resistance of Aircraft Inflatable Evacuation Slide/Slide Raft Materials (L7)

7. Belting Test Methods

7.1 Flame Tests for Conveyor Belting and Hose (K)

7.2 D 378 Methods of Testing Rubber Belting, Flat Type (L4)

[1] This guide is under the jurisdiction of ASTM Committee D-11 on Rubber and is the direct responsibility of Subcommittee D11.17 on Combustibility.

Current edition approved Oct. 15, 1993. Published December 1993. Originally published as D 4205 – 82. Last previous edition D 4205 – 90.

8. Electrical and Power Cable Test Methods

8.1 D 350 Test Method for Testing Flexible Treated Screening Used for Electrical Insulation (L5)

8.2 D 876 Test Method for Testing Nonrigid Vinyl Chloride Polymer Tubing Used for Electrical Insulation (L4, L5)

8.3 D 2633 Testing Thermoplastic Insulations and Jackets for Wire and Cable (L6)

8.4 Bureau of Mines Schedule 2G Electric Motor-Driven Wire Equipment and Accessories (K)

8.5 IEEE 383-1974 Standard for Type Test of Class IE Electric Cable, Field Splices and Connections for Nuclear Power Generating Stations (H)

8.6 MIL-C-7078C General Specification for Cable, Electric Aerospace Vehicle (A)

8.7 SAE J-558 Low Tension Cable Flame Test (F)

8.8 UL-224 Flame-Retardant Properties of FR-1 Tubing (G)

8.9 UL-493 Thermoplastic-Insulated Underground Feeder and Branch-Circuit Cables (G)

8.10 UL-651 Rigid Non-Metallic Conduit Flame-Retardant Properties of Heavy Wall PVC Conduit (G)

8.11 UL-719 Non-Metallic-Sheathed Cables (G)

8.12 UL-854 Service Entrance Cables (G)

8.13 UL-910 Test Method for Fire and Smoke Characteristics of Cables (G)

8.14 UL-1063 Machine-Tool Wires and Cables (G)

8.15 UL-1581 Electrical Wires, Cables, and Flexible Cord (G)

8.16 UL-1666 Test for Flame Propagation Height of Electrical and Optical-Fiber Cables Installed Vertically in Shafts (G)

9. Floor Covering Test Methods

9.1 D 2859 Test Method for Flammability of Finished Textile Floor Covering Materials (L3)

9.2 E 84 (Hill Burton Act) Test Method for Surface Burning Characteristics of Building Materials (L2)

9.3 E 648 Test Method for Critical Radiant Flux of Floor-Covering Systems Using a Radiant Heat Energy Source (L2)

9.4 DOC FF1-70 U. S. Department of Commerce Standard FF 1-70 Standard for Surface Flammability of Carpets and Rugs (A)

9.5 NFPA-253 Test for Critical Radiant Flux of Floor Covering Systems Using a Radiant Heat Energy Source (C)

9.6 UL-992 Flame Propagation Characteristics of Flooring and Floor Covering Materials (G)

10. Hose Test Methods

10.1 Code of Federal Regulations Title 30, Part 18, Section 18.65 "Standard Test Procedures Conveyor Belt and Hose Products Flame Test" Bureau of Mines Schedule 2G (K)

10.2 RMA—CGA Flame Test for Welding Hose (D)

10.3 UL-114 Standard for Safety-Marine Use Flexible Fuel Line (G)

11. Mattress Test Methods

11.1 DOC FF 4-72 Flammability Standard for Mattresses (A)

11.2 California Technical Bulletin No. 121 Flammability Test Procedure for Mattresses for Use in High Risk Occupancies (E)

12. Upholstered Furniture Test Methods

12.1 California Technical Bulletin No. 117 Requirements, Test Procedure and Apparatus for Testing the Flame Retardance of Resilient Filling Materials Used in Upholstered Furniture (E)

12.2 California Technical Bulletin No. 116 Smoldering Test for Flexible Polyurethane Foams Used in Upholstered Furniture (E)

12.3 California Technical Bulletin No. 133, Flammability Test Procedure for Seating Furniture for Use in High Risk and Public Occupancies (E)

12.4 BS 5852 Fire Tests for Furniture (N)

13. Smoke Test Methods

13.1 D 2843 Test Method for Density of Smoke from the Burning or Decomposition of Plastics (L1)

13.2 E 662 Test Method for Specific Optical Density of Smoke Generated by Solid Materials (L1)

13.3 NFPA 258 Test Method for Measuring the Smoke Generated by Solid Materials (C)

14. Toxicity Test Methods

14.1 U. S. Bureau of Mines (MESA) Interim Fire and Toxicity Criteria for Products Taken Into Underground Coal Mines, Draft No. 2, 9-2-76 (K)

15. Miscellaneous Test Methods

15.1 C 542 Specification for Lock-Strip Gaskets (L2, L4)

15.2 C 864 Specification for Dense Elastomeric Compression Seal Gaskets, Setting Blocks, and Spacers (L2, L4)

15.3 D 1929 Test Method for Ignition Properties of Plastics (L1)

15.4 D 2863 Method for Measuring the Minimum Oxygen Concentration to Support Candle-Like Combustion of Plastics (Oxygen Index) (L1)

15.5 E 162 Test Method for Surface Flammability of Materials Using a Radiant Heat Energy Source (L2)

15.6 UL-94 Test for Flammability of Plastic Materials for Parts in Devices and Appliances (G)

15.7 E 906 Test Method for Heat and Visible Smoke Release Rates for Materials and Products (L2)

15.8 ISO 3582 Cellular Plastics and Cellular Rubber Materials—Laboratory Assessment of Horizontal Burning Characteristics of Small Specimens Subjected to a Small Flame (M).

15.9 ISO 9772 Cellular Plastics—Determination of Horizontal Burning Characteristics of Small Specimens Subjected to a Small Flame (M).

16. Keywords

16.1 burning characteristics; combustion; electric cable; fire test; flammability; guide; rubber; smoke; test methods

ANNEX

(Mandatory Information)

A1. REFERENCED DOCUMENTS

A. Superintendent of Documents, U. S. Government Printing Office, Washington, DC 20402

B. Clearing House for Federal Scientific and Technical Information, 5285 Port Royal Road, Springfield, VA 22151

C. National Fire Protection Assn., 470 Atlantic Ave., Boston, MA 02210

D. Rubber Manufacturers Assn., 1901 Pennsylvania Ave., NW, Washington, DC 20006

E. State of California Bureau of Home Furnishings, 3485 Orange Grove Ave., North Highlands, CA 95660

F. Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, PA 15096

G. Underwriters' Laboratories, Inc., Publication Stock, 333 Pfingsten Road, Northbrook, IL 60062

H. IEEE, 345 E. 47th St., New York, NY 10017

I. National Highway Safety Administration, 400 7th St., SW, Washington, DC 20590

J. Standardization Documents, Order Desk, Building 4, Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

K. Mine Enforcement and Safety Administration, 4800 Forbes Ave., Pittsburgh, PA 15213

L. *Annual Book of ASTM Standards*:[2]

L1—Vol 08.02
L2—Vol 04.07
L3—Vol 07.01
L4—Vol 09.02
L5—Vol 10.01
L6—Vol 10.02
L7—Vol 15.03

M. American National Standards Institute, 11 W. 42nd St., 13th Floor, New York, NY 10036.

N. British Standards Institute, 2 Park Street, London, W1A 2B5.

[2] Available from ASTM, 1916 Race St., Philadelphia, PA 19103.

Waste Water Handling (Wet Grind)

Material *Recycled Rubber from Tires, Industrial Scrap Rubber, and Post-Consumer Scrap Rubber Products*

Issue: *The wet grinding process uses a slurry of ground tire or industrial rubber mixed in a water slurry. This technology is proprietary and unique to the wet processes used at Rouse Rubber, Inc., Vicksburg, MS and NRB Materials, Chambersburg, PA. The volume of water used is significant and requires a waste water permit for disposal.*

Best Practice: This best practice covers the handling of the waste water used in the grinding and shredding of recycled rubber produced by wet or solution grinding. The wet grinding technique involves the addition of a fine-mesh ground tire or industrial products rubber between two grinding rolls. The slurry mixture stays between the grinding rolls until it is reduced in particle size to that desired. The final size is controlled by a screen placed over the exit port of the grinder. The water is exposed to all of the organic chemicals, zinc salts, and fine particles of rubber that are in the rubber compound. Most of these have a low solubility in water, but some does get dissolved and/or suspended. Zinc Stearate has a special affinity for dissolving in water.

Implementation: All water used in the grinding portion of the process is contained, cleaned by precipitation of zinc salts, and filtered to remove fine, suspended particles of rubber contaminants in the water. The water is then recirculated and used in other aspects of the plant operation.

Benefits: The major benefit is the elimination of suspended rubber particles, zinc salts, and organic chemicals being discharged into the waste stream.

Application Sites: Rouse Rubber, Inc., Vicksburg, MS and NRB Materials, Chambersburg, PA.

Sources/Contacts: For more information about this Best Practice, contact Mr. Mike Rouse, President, Rouse Rubber, Inc., phone 601-636-7141.

References: "Ultrafine Recycled Rubbers", R.A. Swor, L.W. Jenson, and M. Budzol, Rubber Chemistry and Technology, Vol. 53, 1980, pp. 1215-1225.

"Development and Application of Superfine Tire Powders for Rubber Compounding", Rubber World, June, 1992, 6 pages.

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Sampling Procedures

Material Recycled Rubber from Tires, Industrial Scrap Rubber, and Post-Consumer Scrap Rubber Products

Issue: *From quality point of view, it is important to have consistent and, if possible, uniform procedures for taking samples of crumbs in rubber recycling plants. Those procedures need to be documented and communicated to end-users.*

Best Practice: Each rubber recycling plant may have its own sampling procedures. This best practice describes such a sampling procedure used in some of the plants. Two samples, about 125 gms each, of each skid, about 2,500 lbs., are taken by the bagger at the time of bagging recycled rubber. Random samples are also taken by the laboratory personnel for quality check. Frequency and sampling procedures can be different from these and may be agreed upon between the vendor and customer. High end-use performance product may require more frequent sampling. Customers may use their own sampling procedure to test crumbs received at their plants. For a multi-stage process, samples are taken at the end of each stage. Typically, the recycling industry takes samples of finished crumb just before bagging or shipping into large containers. Field sample size can be as much as one pound because one may have to repeat some tests.

Implementation: Each manufacturing plant must follow a sampling procedure of its own or the one discussed above. Such procedure should be documented and customers be made aware of it. Vendor and customer should agree upon a sampling procedure.

Benefits: Consistent sampling procedures would lead to better quality controls.

Application Sites: Recyclers' and end-users' plants.

Source(s)/Contact: Krishna C. Baranwal, Akron Rubber Development Laboratory, Akron, Ohio, Phone 330-794-6600; Fernley Smith, President, ETA, Port Clinton, Ohio.

References:

- Best Practices on Bulk Density
- ASTM D5603
- Best Practice on Setting Crumb Material Specification

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Sampling & Testing (QA) Plans

Material *Recycled Rubber from Tires, Industrial Scrap Rubber, and Post-Consumer Scrap Rubber Products*

Issue: *Details of sampling procedures are given in the best practice on "Sampling Procedure." After sampling, testing plans need to be established for quality controls.*

Best Practice: After sampling, tests described in ASTM D5603 are run. These tests are: % extractables, ash content, NR and rubber hydrocarbon contents, % heat loss (moisture) and carbon black content. Two samples per truck load (5 skids) are run for percent moisture content and bulk density on randomly selected samples either sampled by a bagger or QC person. Percent ash, carbon black, rubber hydrocarbon, and acetone extract are run once/day per shipment of a truck load. These are done according to ASTM D297. For ambient ground materials, moisture content and bulk density measurements are made on every skid because of possible moisture content variations in feedstock.

Particle size and particle size distribution measurements are made by using the Ro-Tap method (ASTM D5644). Weight percents are plotted as a function of particle size to get the particle size distribution. For higher performance products (e.g., tire carcass compound), variations in particle sizes and distributions are noted. Materials meeting customers' specifications are shipped along with the analysis data for each skid. For lower level performance products (e.g., mats), specification tolerances are much wider and report may be submitted as agreed upon between vendor and customer. At present, there are no test methods for determining fiber and metal contents. In the modified proposal to ASTM, techniques for such tests have been recommended. We are waiting for approval.

Implementation: Recycled rubber processor should develop a quality control plan (if not already in existence) charting actual results and any specification limits. This should be specially done for moisture content, bulk density and particle size distribution.

Benefits: Better quality control.

Application Sites: Recyclers' plant sites and customers' product manufacturing sites.

Source(s)/Contact: Krishna C. Baranwal, Akron Rubber Development Laboratory, Akron, Ohio, Phone 330-794-6600; Fernley Smith, President, ETA, Port Clinton, Ohio.

References: ASTM D5603; ASTM D5644; ASTM D297.

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Determination of Particle Size (PS) and Particle Size Distribution (PSD)

Material Recycled Rubber from Tires, Industrial Scrap Rubber, and Post-Consumer Scrap Rubber Products

Issue: *Recycled rubber crumbs are generally produced by different grinding techniques. Particle size (PS) and size distribution of recycled rubber depends on the end-use of the material and may affect its handling, processing and properties. Therefore, techniques of analyses of particle size and particle size distribution is important for the rubber recycling industry. ASTM D5644 discusses method of determining PS and PSD for crumbs. However, it has been experienced that this technique does not work well for finer (than 100 mesh). A copy of D5644 is attached.*

Best Practice: This best practice briefly describes the ASTM D5644 techniques determining for particle size and particle size distribution. This standard refers to use of Ro-Tap mechanical sieve shaker for determining PS and PSD and gives experimental details of running the test. However, it does not provide specifications for zero and designation screens. Cost per sieve is $40-$60, and automatic vibrator typically runs $1,000-$3,000 with good models available for about $1,500.

The ASTM D11.26 subcommittee has recommended a table listing zero and designation screens for 10, 20, 30, 40, 60, 80 and 100 mesh size materials using the Ro-Tap method, a copy is attached (Table I). Approval by the main ASTM committee is awaited. Final approval may take a minimum of 6 months to a few years.

It is recommended that other techniques be explored for determining PS & PSD for particles finer than 100 mesh. It has been the writer's experience that when Ro-Tap method is used for finer particles (using talcum powder as separating agent) small balls are formed on screens giving higher "apparent" particle sizes that they are. The writer is in the process of evaluating various techniques, and results will be published in a technical journal.

Implementation: The recycling industry should use the current ASTM D5644-94 Ro-Tap method for crumbs. When the main ASTM committee approves ASTM D11.26 subcommittee's recommendations on source sizes and weight percent retentions, it should be used by the industry. Sieves and vibrators are available through most scientific suppliers. However, independent test laboratories such as Akron Rubber Development Laboratory, Akron, Ohio (phone 330-794-6600) routinely perform this test.

Benefits: Standard size and size distribution specification will improve the quality of recycled rubber available in the market. It will also help in more specific definition and characterization of recycled rubber used in rubber products.

Application Sites: At recyclers' and end-users' locations. To our knowledge, most processors conduct these tests themselves. Equipment manufacturers, end-users send out to independent laboratories for testing.

Sources/Contacts: Krishna C. Baranwal, Chairman of the ASTM Subcommittee D11.26, Akron Rubber Development Laboratory, Akron, Ohio 44305, Phone 330-794-6600.

References: ASTM D5644-94; *Particle Size Analysis of Granulated Rubber*, G. W. Holland, B. Hu, and M. A. Smith, Rubber and Plastics News, October 12, 1993.

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TABLE 1 RECYCLED RUBBER

PRODUCT DESIGNATION

Nominal Product Designation	Example ASTM D 5603 Designation[A]	Zero Screen μm	Percent Retained on Zero Screen	Size Designation Screen μm	Maximum Percent Retained on Designation Screen
10 Mesh	Class 10-X	2360 (8 Mesh)	0	2000 (10 Mesh)	5
20 Mesh	Class 20-X	1180 (16 Mesh)	0	850 (20 Mesh)	5
30 Mesh	Class 30-X	850 (20 Mesh)	0	600 (30 Mesh)	10
40 Mesh	Class 40-X	600 (30 Mesh)	0	425 (40 Mesh)	10
60 Mesh	Class 60-X	300 (50 Mesh)	0	250 (60 Mesh)	10
80 Mesh	Class 80-X	250 (60 Mesh)	0	180 (80 Mesh)	10
100 Mesh	Class 100-X	180 (80 Mesh)	0	150 (100 Mesh)	10

[A]When specifying materials replace the X with the proper parent material grade designation code. For example, Class 30-2 would indicate a 600 μm (30 mesh) product made from Grade 2 material, car, truck and bus tread rubber. Class 100-6 would indicate a 150 μm (100 mesh) product made from Grade 6 material, non-tire rubber

Shredding

Material **Recycled Rubber from Tires, Industrial Scrap Rubber, and Post-Consumer Scrap Rubber Products**

Issue: Used rubber articles, especially tires, require size reduction for use in recycled products. This is commonly done using a process called shredding. This best practice will review the major issues concerning shredding of tires.

Best Practice: A paper, #82, presented by Mr. Charles Astafan at the ACS Rubber Division Meeting in Cleveland, Ohio in October 1995 presented an excellent overview of tire shredding. The following description of the process was extracted from the paper with his permission.

There are two basic types of shear shredders used for this application. When comparing all the equipment used for the cutting of whole steel belted passenger car and truck tires, one quickly comes to the conclusion that there are a number of machines that are capable of that task. However, a closer look will reveal that there is one commonly used machine to process scrap tires to specifically sized chips. The rotary shear shredder is used throughout the world for this application.

There are two distinct styles or technologies. The hook and shear type and the Holman type. In developing a comparison of the equipment, it should be noted that this is the most important aspect or difference in the equipment.

Two other aspects of the equipment which are also important and which will be addressed are the screening of the sized and over sized chips and the method used to recirculate, convey, or re-feed material back into the cutting chamber.

The rotary shear shredder consists of two counter rotating shafts which have knives or knife rotors attached to each shaft. These knives overlap on one another and cause a shearing or cutting action. Hook or hook and shear shredders were originally developed by Kurt Roessler, a German engineer, in the 1960's for multipurpose solid processing of bulky material for size or volume reduction. This style of machine uses hexed or keyed shafts. The knife spacers are stacked between the on opposing shafts. The knife spacers between the shafts are used to give appropriate spacing between opposing knives. All knives and knife spacers are stacked on the shafts and locked with a large locking nut which is threaded onto the shaft. There are a number of companies manufacturing these types of machines in the and Europe.

The Holman Patent Shear Shredder was especially designed for processing steel belted scrap tires. It is similar in design to the Hook and Shear Shredder, however it utilizes knife rotors and rotor spacers which are permanently affixed to the shafts by means of heat shrinking. The actual knife is then attached to the rotor by bolting in place. Wear plates or liners are also secured to each side of the rotor to protect against wear.

By permanently affixing each knife and each rotor spacer to the shaft, the tolerances between the knives are predetermined at the factory. These tolerances never change throughout the life of the machine. By utilizing extremely close tolerances of .001-.002 inches between knives, this insures a clean cut of all rubber, steel and fiber cord. This factor is extremely important when screening the chips. Also when using a smaller detachable knife, it is possible to use the highest grade of wear resistant tool steel available to prolong knife wear and reduce operating costs. this knife is 62-63 Rockwell C versus 48-50 on the hook and shear shredder. Close knife to knife tolerance and superior knife materials are the two contributing factors to producing cleanly cut chips with no loose or exposed wire from the chips.

It should be noted that Columbus McKinnon Corporation holds the rights to the Holman patent. It is also important to note that the Holman design uses feeder rollers to align and feed tires to the knives. Unlike the Hook and Shear Shredder which uses hooks on the knives to capture and pull the tire between the knife edged.

The feeder rollers are very simple, highly reliable, inexpensive device. They promote tire feed and reduce the chance for jams when feeding whole tires and eliminate tire bounce.

Once shredded the tires are screened using one of the four following screen types: Single deck screen, Double deck screen, Trommel screen, or Rotary screen. Often a combination of these is used. (See paper #82 for details on screens).

A recirculation drum is used to carry oversized material back into the shredder for additional size reduction.

Implementation: Purchase of a shredder is necessary. See Scrap Tire Directory for sources.

Benefits: The major benefit of the shredder is the reduction of large rubber items into small pieces e.g. 2"x 2" or 1"x 1".

Application Sites: There approximately 250 locations where tire shredding is done in the US.

Sources/Contacts: For more information about this Best Practice, contact Charles Astafan, Columbus McKinnon; Fernley Smith, ETA.

References:

Scrap Tire Directory, published by Recycling Research Institute of Suffield, CT (860) 668-5422.

"Machines for Processing Whole Tires to Specifically Sized Pieces to be Used as Feed Material in Crumb Rubber Processing Systems" , Paper #82, by Charles G. Astafan, ACS Rubber Division Meeting, Cleveland, Ohio October 1995.

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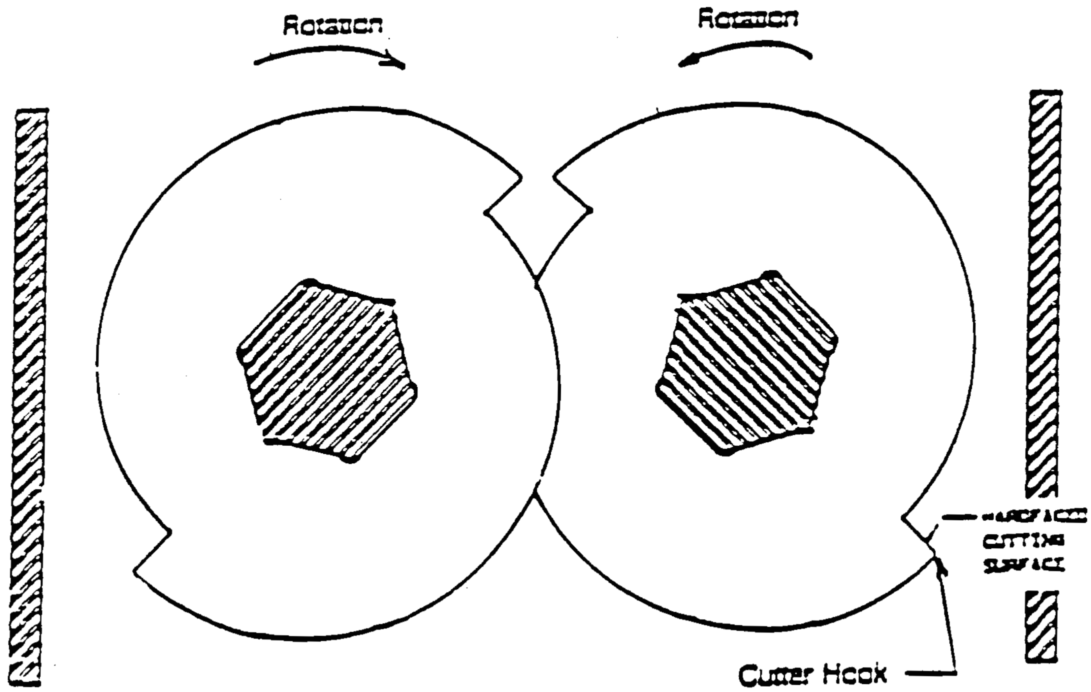
Attachment A

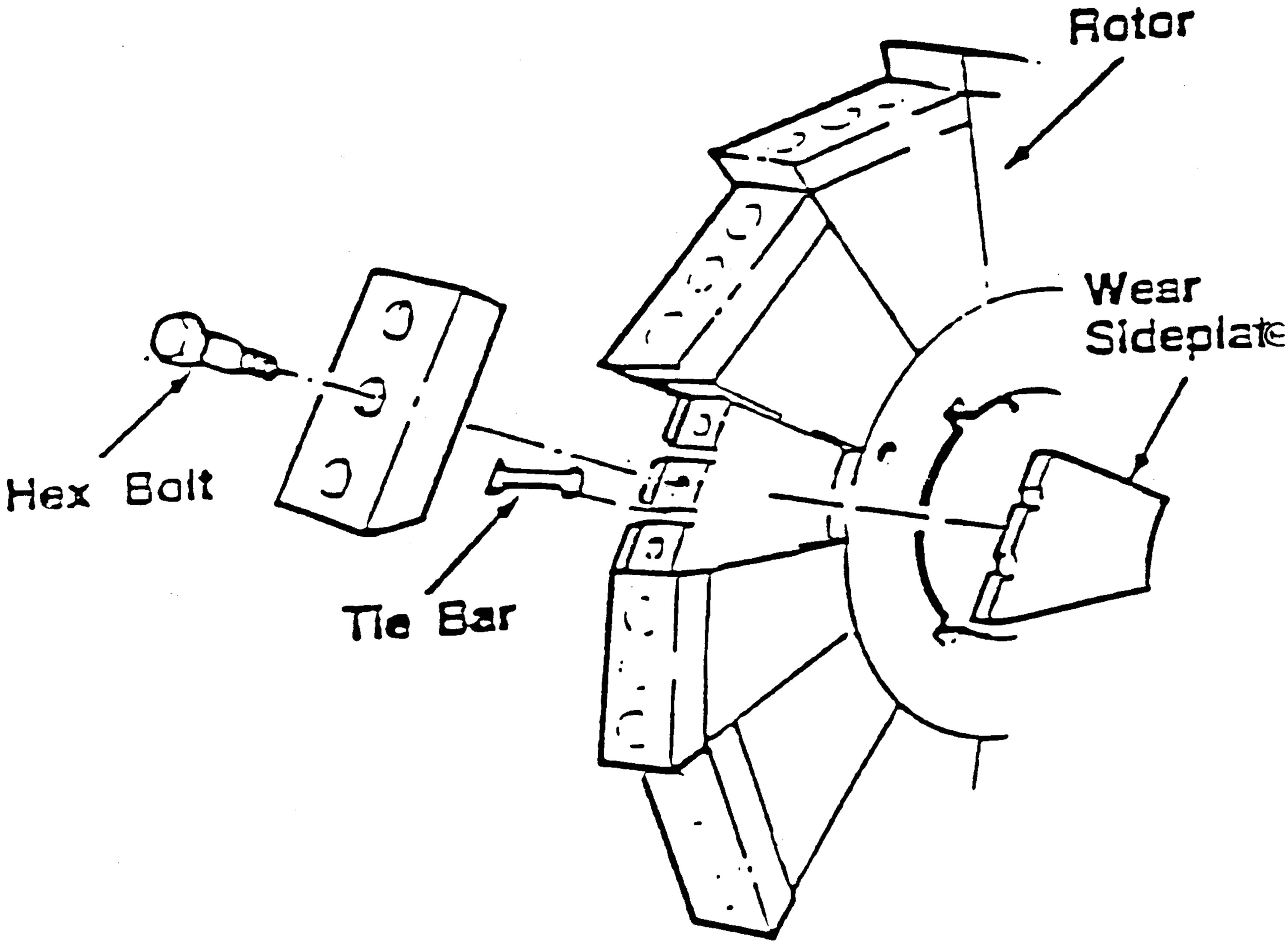
Hook and Shear Type Shredder



ROTARY SHEAR SHREDDER WITH ONE-PIECE KNIVES

Attachment B

Holman Shear Shredder



Grinding Equipment Selection

Material ***Recycled Rubber from Tires, Industrial Scrap Rubber, and Post-Consumer Scrap Rubber Products***

Issue: To produce a crumb rubber, it is usually necessary to reduce the size of the rubber article to particles 10 to 200 mesh in size. This is accomplished by various grinding techniques. The production of fine particle rubber by ambient, cryogenic and wet grinding have been discussed in the Best Practices titled Ambient versus cryogenic grinding, cryogenic grinding, and waste water handling. This Best practice will discuss the preliminary step in producing granulated and coarse ground rubber.

Best Practice: At the ACS Rubber Division Meeting in Cleveland, Ohio in October 1995, Mr. Charles Astafan and Mr. Rudi Kohler presented paper #35 entitled Comparison Scrap Tire Processing Technologies ambient Processing vs. Cryogenic Processing. The information reported here was abstracted from this paper.

"With the processes that I will be discussing, it is presumed that we will be using a raw material derived from whole tire which is two inch minus size and has the bead steel removed. It should also be noted that the systems discussed are the most common systems found in the industry and may not represent all systems being used or produced with the market today. Equipment used for the actual cutting or grinding processes can be divided into eight types. These are (1)Knife Hogs, (2)Primary Granulators, (3)Secondary Granulators, (4)Raspers, (5)Primary Crackermills, (6)Secondary Crackermills, (7)Finishing Mills, (8)Micromills. "

"Knife Hogs, Primary Granulators, Secondary Granulators and Raspers are all very similar and operate on basically the same principle: however their knife configurations are somewhat different. These machines can be categorized as being medium to high speed 100-1200 RPM. They utilize a rotor in which 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 can be changed to vary end product size. (See appendix for grinder cross section.)"

"Primary crackermills , secondary crackermills and finishing mills are all very similar and operate on basically the same principle; however the roll configurations are what make them different. These machines can be categorized as being low speed. They operate at 30-50 RPM. They use two large counter rotating rollers with serration's cut in one or both of them. These rollers operate face to face in 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.
(see Appendix for sketch of crackermill rollers)"

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.

The appendix has a drawing of a crumb rubber system using a granulator and secondary crackermill along with the other necessary machines to produce crumb rubber.

Implementation: One can purchase the equipment necessary to perform grinding from a number of sources. The Scrap Tire Directory published by the Recycling Research Institute of Suffield, CT list the suppliers of grinders and granulators.

Benefits: Grinding and granulating reduces the size of rubber particles down to a size that either makes them useful as is or prepares them for further size reduction.

Application Sites: All the rubber recyclers operating in the US use some type of grinding system. (see Scrap Tire Directory for a listing of their locations).

Sources/Contacts: For more information about this Best Practice, contact Fernley Smith, ETA; Mike Rouse, Rouse Rubber: Dick Shope, Rubber Recovery; JD Jackson, Praxair; Charles Astafan, Columbus McKinnon.

References:

Scrap Tire Directory, published by Recycling Research Institute of Suffield, CT (860) 668-5422.

"Comparison of Scrap Tire Processing Technologies; Ambient Processing vs. Cryogenic Processing", paper #35, by Charles Astafan and Rudi Kohler, ACS Rubber Division Meeting, Cleveland, Ohio, October 1995.

"Machines for Processing Whole Tires to Specifically Sized Pieces to be Used as Feed Material in Crumb Rubber Processing Systems" , Paper #82, by Charles G. Astafan, ACS Rubber Division Meeting, Cleveland, Ohio October 1995.

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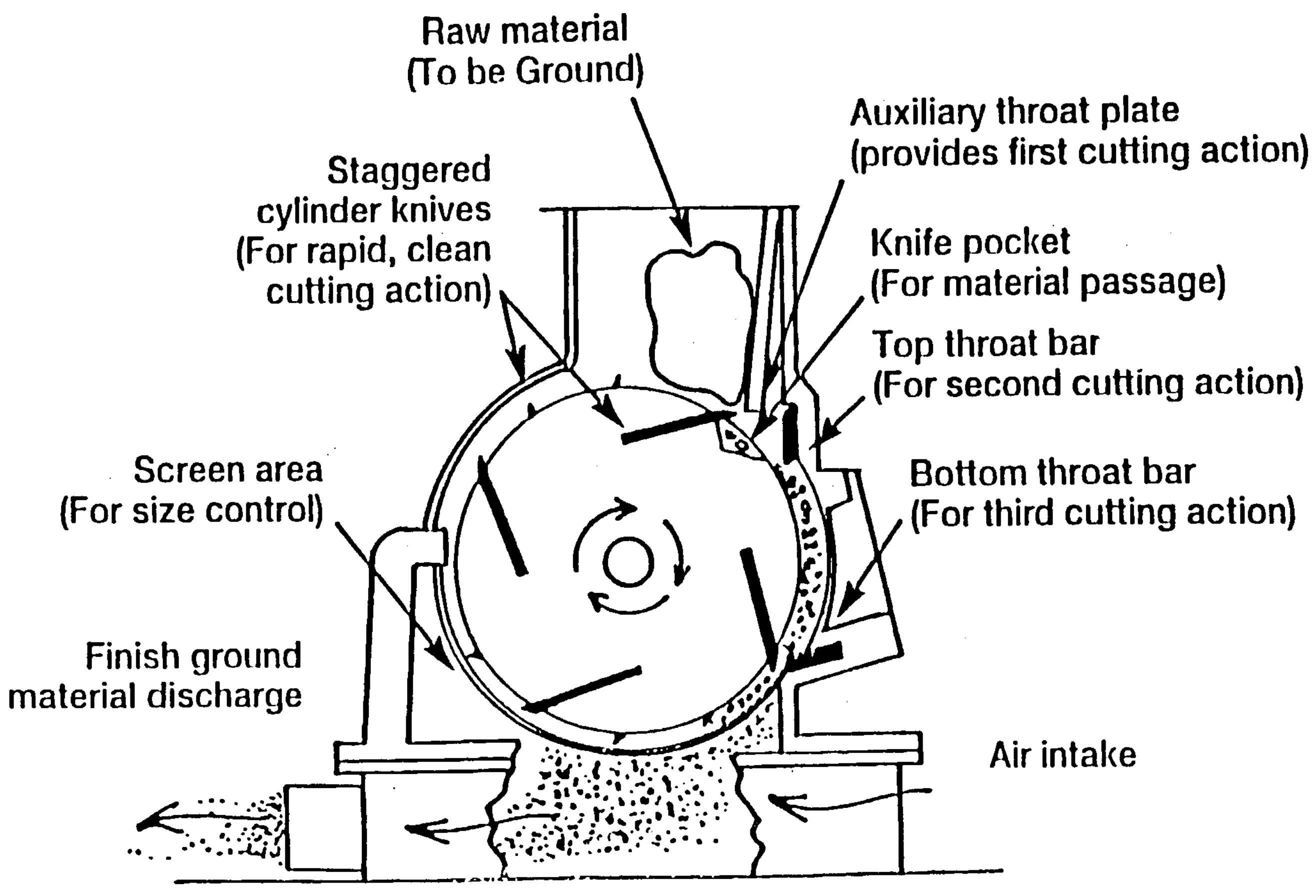
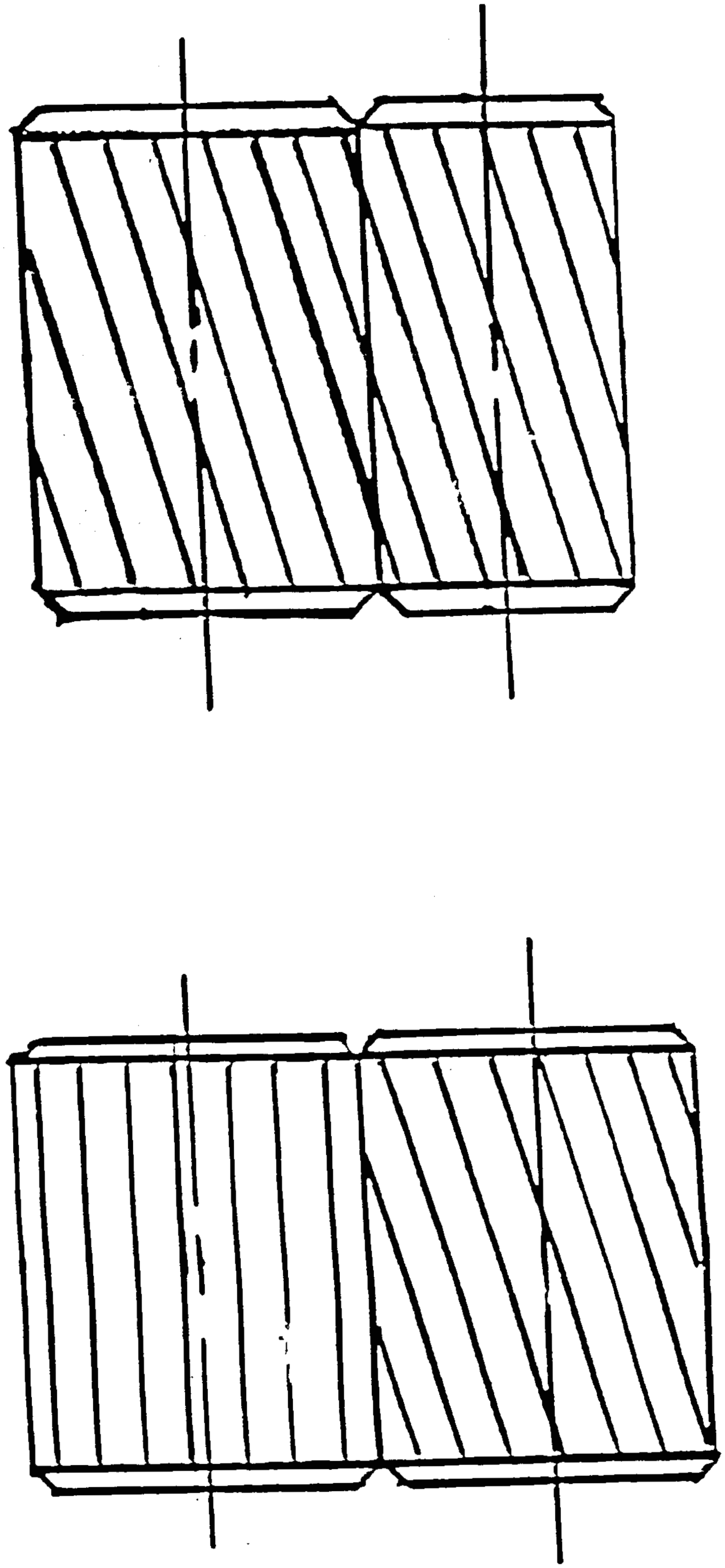
Attachment A

Cross Section of A Grinder or Granulator

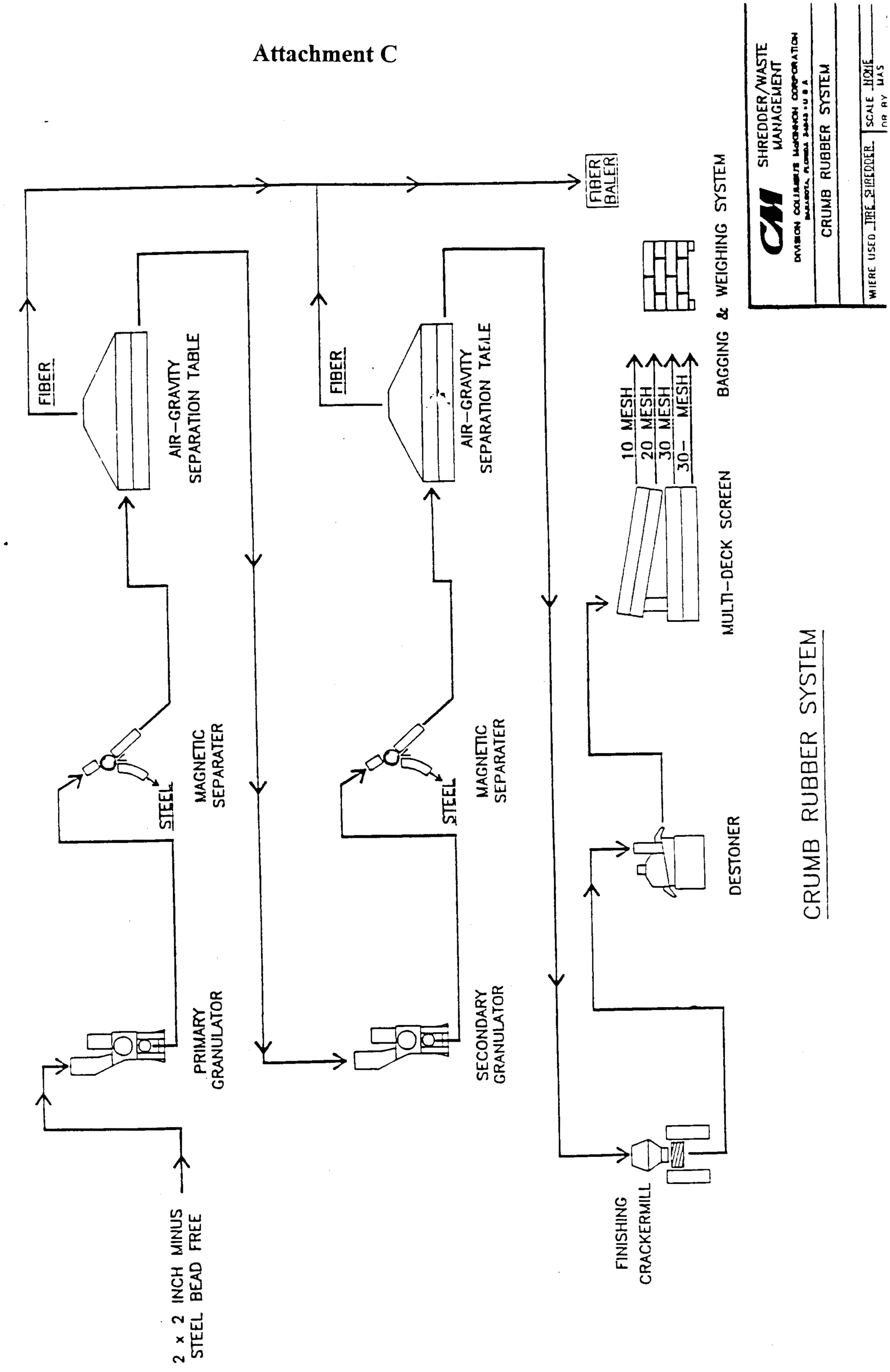


Attachment B



Crackermill Rolls Showing Serrations

Attachment C



Cryogenic Processing

Material *Recycled Rubber from Tires, Industrial Scrap Rubber, and Post-Consumer Scrap Rubber Products*

Issue: *Cryogenic processing employs liquid nitrogen to lower rubber material temperature to well below its freezing point. While frozen, the rubber is shattered with a mill or similar piece of equipment. The resulting material has clean fractured surfaces and low steel and fiber content because of the clean breaks between the fiber, steel, and rubber.*

Best Practice: The temperature of liquid nitrogen is -320°F at atmospheric pressure. Most rubber compounds freeze at their glass transition temperature of about -80°F. At temperatures below the glass transition temperature, the rubber changes from an elastic material to a one that is brittle and easy to grind by impacting it. The use of cryogenic temperatures can be applied at any stage of size reduction of scrap tires. The choice of feed material for a cryogenic stage depends on the feed material available and the characteristics of the desired products. Typically, the size of the feed material is a nominal 2-inch chip or smaller.

The chips are fed at a constant rate into a heat exchanger where they are cooled by direct contact with liquid nitrogen. The most efficient pre-cooler utilizes counter-current heat exchange where the liquid nitrogen is sprayed onto the rubber near the exit end of the pre-cooler. The liquid nitrogen is vaporized as it cools the rubber and the cold nitrogen vapor is passed back toward the feed end where it is further warmed by the rubber. The warm nitrogen gas is vented to a safe location while the cold rubber is fed to the grinding mill.

The temperature of the frozen rubber exiting the pre-cooler is controlled to a temperature ranging from -150°F to -320°F. The choice of temperature depends on the intensity of grinding to be done in the following stage. Typical refrigeration efficiencies for rubber cooled to -150°F is 0.5 pounds of liquid nitrogen for each pound of rubber. Fully pre-cooling to -320°F increases the nitrogen consumption to about 0.75 pounds per pound of rubber. The product particle size is somewhat finer with colder temperatures.

The cold rubber is ground in a hammer mill producing rubber product ranging from 4 mesh down to very fine powder. For scrap tires the steel is separated out of the product by the use of magnets and conveyed to a collection hopper. It contains very little entrapped rubber and fiber making it suitable for sale as a by-product. The fiber is fluffed in the hammer mill and removed by aspiration and screening. The rubber crumb is then heated in a dryer and separated into the desired size ranges by screening. Because of moisture pickup in the cryo process, it should be noted that drying is required.

Additional very fine crumb is generally 30 mesh or smaller. If it is desired, a secondary high-intensity grinding stage is used. The feed material for this stage is usually clean, 4 mesh rubber crumb. The process is the same for clean industrial or post-consumer scrap except there are no steel and fiber removal steps and only one cryogenic grinding stage is needed. Liquid nitrogen requirements for this stage are 0.75 pounds on nitrogen per pound of rubber and up depending on the crumb size needed. New mills are being developed to economically produce 80 mesh and finer materials.

Besides the process described above there are processes that employ ambient and wet grinding technology after first cryogenic grinding to further size reduce the recycled rubber.

Implementation: The first step to implement cryogenic processing is to identify which material is to process and to understand what the application or market needs for its crumb characteristics. Because this process is sensitive to operating costs, it is best to engage a company that has the experience and expertise to design a turnkey system. A turnkey system optimizes the equipment and operating costs to produce an acceptable product from the available feed material.

Benefits: The benefits of cryogenic grinding include low power requirements, reduced power requirements, finer product, reduced maintenance, cleaner product, and product morphology. The disadvantages include the cost of liquid nitrogen and product morphology.

Application Sites: Application sites include Rouse Rubber, (601) 636-7141; Entire Recycling, (402) 873-3252; Rubber Recovery, Inc., (412) 351-5250; American Tire Recyclers, Inc., (800) 741-5201; Cryogenics Product Recovery, (616) 396-4942; and Midwest Elastomers, (800) 786-3539. Others are Central Michigan Recycling, BAS, Granular, Recover Technologies, Inc., Renewable Energy, and Cryopolymers.

Sources/Contacts: For more information about this Best Practice concerning turnkey cryogenic grinding systems, contact Mr. Jim Anderson, Recovery Technologies, Inc., (519) 740-6801 or Mr. George Cihlar, EnviroDynamics International, Inc., (519) 570-2025.

References: Experience

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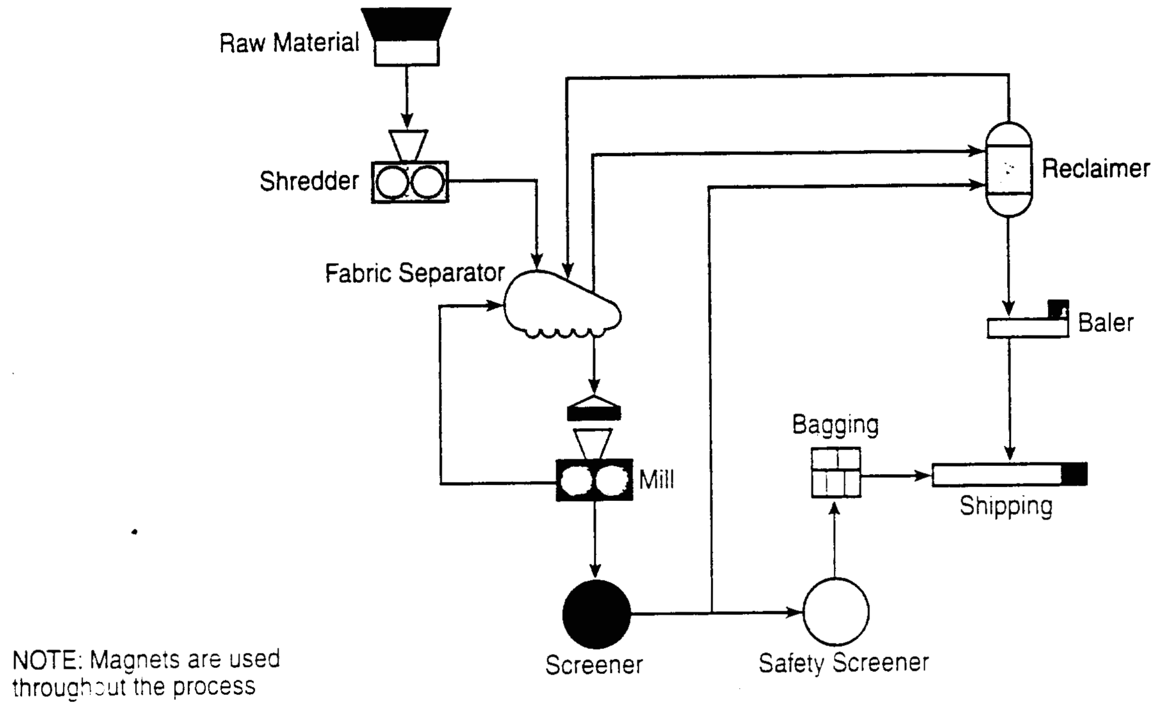
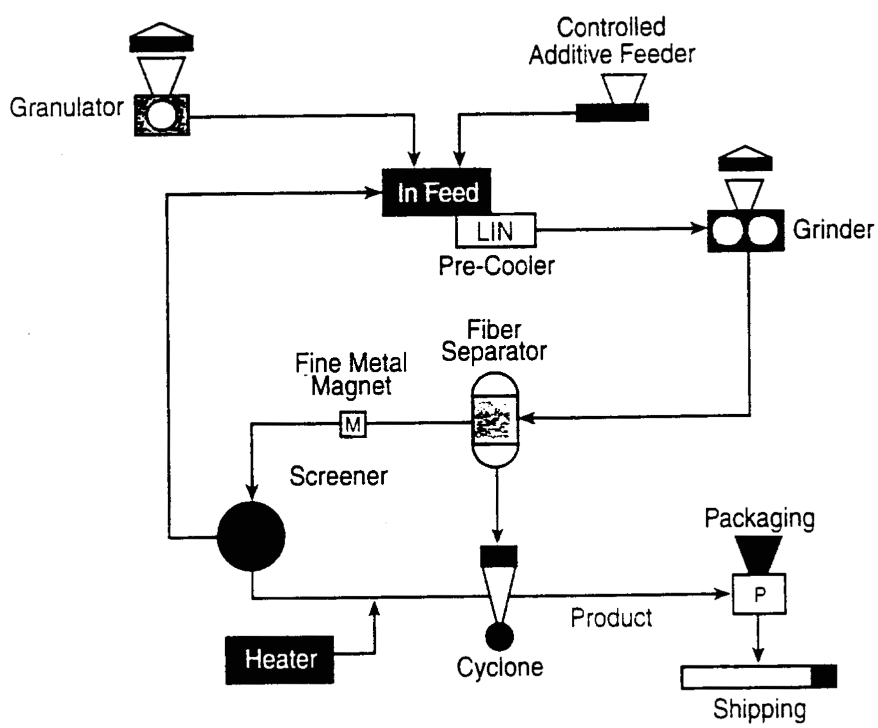
Grinding Systems

Typical Ambient Grinding System



Typical Cryogenic Grinding System



Ambient Versus Cryogenic Grinding

Material ***Recycled Rubber from Tires, Industrial Scrap Rubber, and Post-Consumer Scrap Rubber Products***

Issue: *There are several processes that can be used to produce ground rubber crumb. Two of the most common are ambient grinding using various types of grinding mills and cryogenicaly grinding of rubber by chilling with liquid nitrogen. This section will review the attributes and properties of crumb rubber produced by both methods.*

Best Practice: Vulcanized scrap rubber is first reduced to a 2" x 2" or 1" x1" chip. This can then be further reduced using ambient ground mills or frozen and "smashed" or ground into fine particles while frozen using cryogenic grinding. This best practice will compare the two methods.

The ambient process often uses a conventional high powdered rubber mill set a close nip and the vulcanized rubber is seared and ground into a small particle. It is common to produce 10 to 30 mesh material using this relatively inexpensive method to produce relatively large crumb. Typical yields are 2000 -2200 pounds per hour for 10-20 mesh and 1200 pounds per hour for 30-40 mesh.. The finer the desired particle the longer the rubber is let run on or in the mill. In addition multiple grinds can be used to reduce the particle size. The lower practical limit for the process is the production of 40 mesh material. Any fiber and extraneous material must be removed using an air separation or an air table. Metal is used using a magnetic separator. The resulting material is fairly clean.

The process produces a material with an irregular jagged particle shape. In addition the process generates a significant amount of heat in the rubber during processing. Excess heat can degrade the rubber and if not cooled properly combustion can occur upon storage.

Cryogenic grinding usually starts with chips or a fine crumb. This is cooled using a chiller. The rubber while frozen is put through a mill. This is often a paddle type mill. The Best Practice on Cryogenic Grinding covers this process in detail. The final product is a range of particle sizes which are sorted and either used as is or passed on and further size reduction performed e.g. using a wet grind method. A typical process generates 4000 to 6000 pounds per hour.

The cryogenic process produces fairly smooth fracture surfaces. Little or no heat is generated in the process. This results in less degradation of the rubber. In addition the most significant feature of the process is that almost all fiber or steel is liberated from the rubber resulting in a high yield of usable product and little loss of rubber. The price of liquid nitrogen has come down significantly recently and cryogenicaly ground rubber can compete on a large scale with ambient ground products.

Benefits: The following chart compares the properties and benefits of ambient and cryogenicaly ground rubbers.

Physical Property	Ambient Ground	Cryogenic Ground
Specific gravity	Same	Same
Particle shape	Irregular	Regular
Fiber content	0.5%	nil
Steel content	0.1%	nil
Cost	Comparable	Comparable

The following chart shows the particle size distribution for two typical 60 mesh ground rubbers. One was prepared ambiently and the other cryogenicaly.

Amount Retained	Ambient	Cryogenic
30 mesh	2%	2%
40 mesh	15%	10-12%
60 mesh	60-75%	35-40%
80 mesh	15%	35-40%
100 mesh	5%	20%
Pan	5-10%	2-10%

Application Sites: For cryogenic grinding see the Best Practice on Cryogenic Grinding. Ambient grinding is practiced at many locations. Some of the larger one are Rondy, Spartan, ACM, BAS, National, and many others.

Sources/Contacts: For more information about this Best Practice, contact Fernley Smith, ETA; John Trautwine, Midwest Elastomer; Dick Shope, Rubber Recovery: JD Jackson, Praxair; Rick Moore, ACM; Mike Rouse, Rouse Rubber.

References: "Comparison of Scrap Tire Processing Technologies; Ambient Processing vs. Cryogenic Processing", paper #35, by Charles Astafan and Rudi Kohler, ACS Rubber Division Meeting, Cleveland, Ohio, October 1995.

See Best Practice on Cryogenic Grinding

Issue Date / Update: February, 1997

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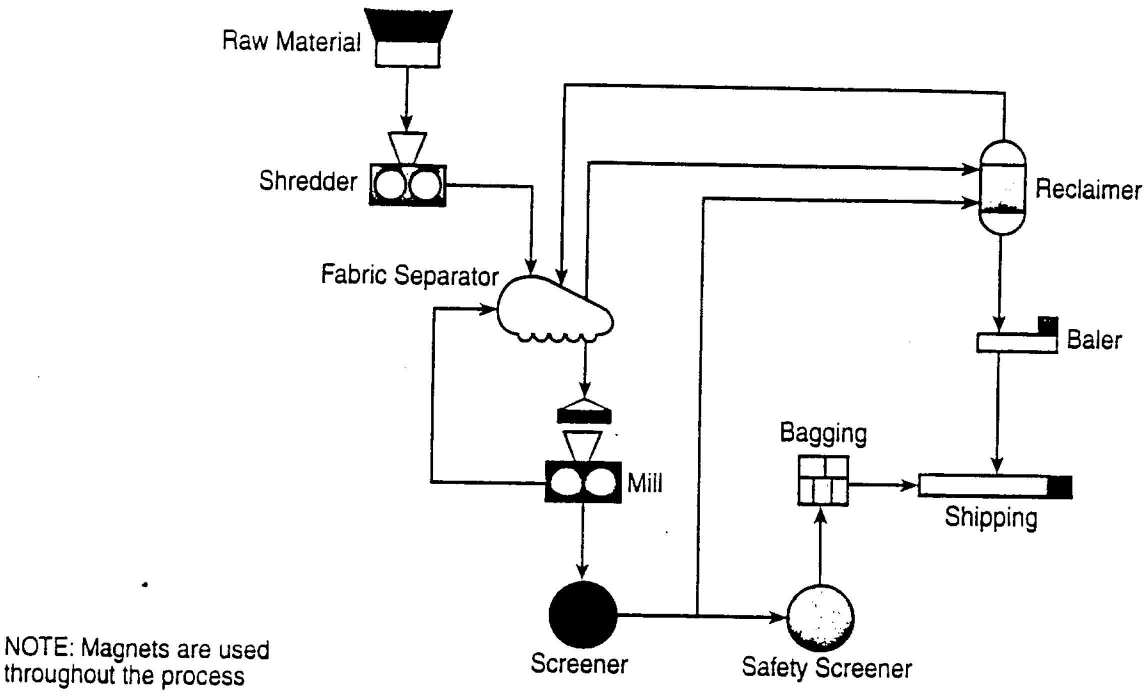
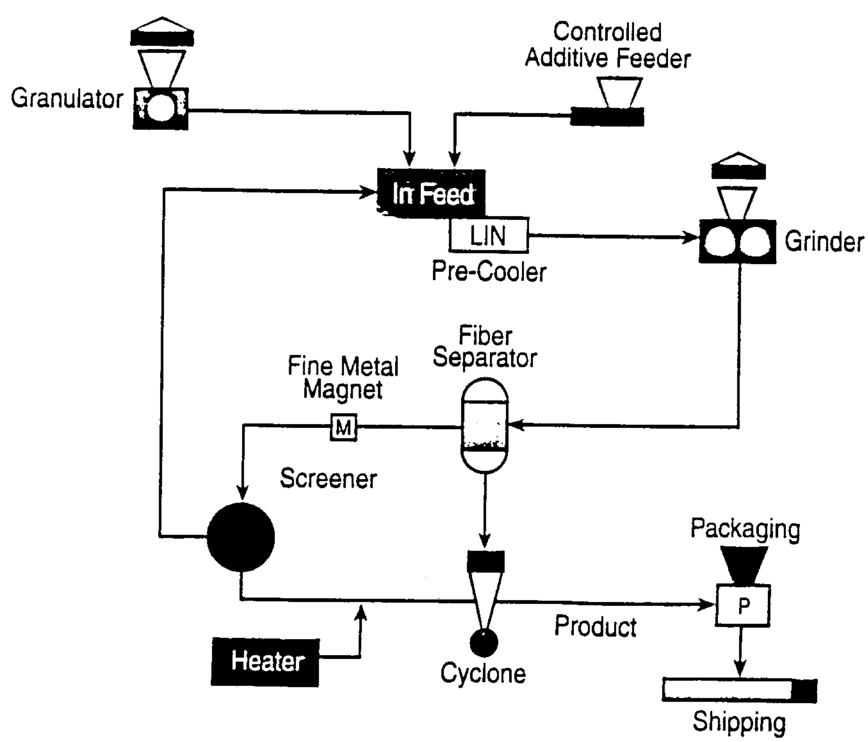
Attachment A

Grinding Systems

Typical Ambient Grinding System



Typical Cryogenic Grinding System



Feed Material Sizing

Material *Recycled Rubber from Tires, Industrial Scrap Rubber, and Post-Consumer Scrap Rubber Products*

Issue: *When rubber articles are removed from service or scrapped, they are usually to large to use in the recycling process as is. Therefore it is necessary to produce a raw material for further downstream processing whether that be ambient, cryogenic, or wet grinding technique. This best practice discusses some of the factors related to production of feed material.*

Best Practice: Tires are by far the largest rubber item recycled. The first step in the production of raw material from tires is shredding. The details on shredding are covered in another Best Practice. Basically the tire is cut into small pieces. These size of the pieces is controlled by a screen with openings on the bottom of the shredder. There are four types of screens commonly used. These are single deck disc, double deck disc, tommel screen and rotary screen. These are discussed in paper 82 given by Charles Astafan on Machines Used for Processing Whole Tires at the ACS Rubber Division Meeting in Cleveland, Ohio in October of 1995. As the tire as reduced in size and the pieces reach their desired size they are allowed to fall from the shredder The most common size produced from the shredder is 2 in. x 2 in. and 1 in. x 1 in.. These are then used for further size reduction in cryogenic and ambient grinding into moderately coarse rubber particles. Production of smaller chips is hard on the equipment and shortens tool life. Much of the chips produced from shredding are burned and used as TDF.

Another common source of feed material is buffings from the production of other rubber goods especially tires. These are a good material for use in cracker mill grinding. These commonly vary in size from small pieces 1/8 to 1/4 in. long down to 4 to 6 mesh if they are produced with a fine grinder rather than a rasp tool. The rasp tool produces the former sizes.

In addition some processors of fine material like to start with a 4 to 8 mesh cryogenically ground feed material and then produce 60 to 200 mesh material from this starting point.

Various types of screens and separators are used to size the feed material for most efficient production in downstream processing.

Implementation: The Scrap Tire Directory published by the Recycling Research Institute in Suffied, CT lists sources for buffings and equipment to perform sizing. In addition the Scrap Tire Management Council has performed a survey of the location of scrap tires and if one needs to obtain tires they have the various sources categorized by state.

Benefits: The major benefit in feed material size reduction and sizing is to use the most efficient size of raw material for further downstream processing. This optimizes the output and efficiency of the equipment.

Application Sites: Feed material sizing is performed at almost all locations where tires are shredded and in many locations where they produce their own raw material.

Sources/Contacts: For more information about this Best Practice, contact Fernley Smith, ETA; Mike Rouse, Rouse Rubber; Dick Shope, Rubber Recovery.

References:

Scrap Tire Directory, published by Recycling Research Institute of Suffield, CT (860) 668-5422.

in.Machines for Processing Whole Tires to Specifically Sized Pieces to be Used as Feed Material in Crumb Rubber Processing Systems in., Paper #82, by Charles G. Astafan, ACS Rubber Division Meeting, Cleveland, Ohio October 1995

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EPA

NIST MEP Environmental Program

Crumb Sizing

Material *Recycled Rubber from Tires, Industrial Scrap Rubber, and Post-Consumer Scrap Rubber Products*

Issue: *The production processes used to make ground or crumb rubber usually produce a range of particle sizes. It is necessary to sort and classify the ground rubber for use. This is accomplished using various screening techniques. This best practice will review some of the common methods that are used to sort and separate ground rubber.*

Best Practice: There are many manufactures of equipment for sorting and classifying ground rubber. They are all based on some type of rotating, vibrating or shaking screen.

The type found to be the most useful for dry screening uses and up and down shaking motion while a scrubbing motion is also going on. The most well known manufacture is Rotex, These machines are employed in many rubber recycle operations.

In addition there are vibrating screens, rotor sifter screens and variations of all these techniques. The rotor sifter screen is particularly effective for wet screening.

The output for the screen is based on the particle size of the rubbers being screened and the surface area of the screen. The larger the surface area of the screen the higher the yield and the larger the particle size the higher the output. Screens are most effective when sorting 10 to 40 mesh ground rubber. A typical yield is 1000 pounds per hour. At the smaller mesh sizes the yield falls off dramatically. On the very fine particles, smaller than 100 mesh screens are ineffective.

The general cost of a screening system is $15,000 to $20,000 US, except for the Rotex equipment. It costs $30,000 to $40,000US and for large systems $60,000 to $80,000US.

Implementation: To get equipped to do screening one must purchase a screen or contract the service. The Scrap Tire Directory list some suppliers of screens.

Benefits: The major benefit of crumb sizing and screening is the classification of the ground rubber into useful sizes. Some applications require small mesh sizes and some can use larger sizes. The screen allows the optimum product for each application.

Application Sites: All manufactures of ground, classified rubber perform crumb sizing using a screen.

Sources/Contacts: For more information about this Best Practice, contact Ed Fesus, G&E; Morgan White, Rouse Rubber; Fernley Smith, ETA.

References:

Scrap Tire Directory, published by Recycling Research Institute of Suffield, CT (860) 668-5422.

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Bulk Density

Material *Recycled Rubber from Tires, Industrial Scrap Rubber, and Post-Consumer Scrap Rubber Products*

Issue: *Control of particle size and density is important from storage, shipping and purchasing (in quantity) points of view. As particle size decreases, bulk density increases. ASTM D5603-94 cites method D297 section 16 for determining specific gravity. This method works well for single piece, and chunks of rubber but does not work well for crumbs with higher surface area.*

Best Practice: This best practice advocates use of bulk density rather than specific gravity for recycled rubber particulates. There is no such ASTM specification for crumbs. However, ASTM 1513 which is for carbon black pour density can be used for this purpose. The method calls for filling a cylindrical container, 624-cm^3 capacity, with carbon black up to the rim and weighing it. Knowing the mass and volume, bulk density can be calculated. Here, moisture content is very important; high moisture content may give erroneous bulk density values. Bulk density should be expressed as Kg/m^3 or $lbs./ft.^3$. Expected bulk density of current recycled rubber product is in the range of 28-34 $lbs./ft.^3$.

Implementation: Bulk density should be included in the material specification sheet of recycled rubber crumbs. Actual specification for a material should be determined at the vendor's plant site and agreed upon between vendor and the customer. Vendor should describe the technique used for determining the bulk density. Also, information on moisture content should be provided by the vendor.

Benefits: Good quality control, uniform, and standard material availability in the market.

Application Sites: All QC and other testing laboratories, processors, plant sites, end-users' plants.

Source(s)/Contact: Krishna C. Baranwal, Akron Rubber Development Laboratory, Akron, Ohio, Phone 330-794-6600; ASTM D1513; Fernley Smith, President, ETA, Port Clinton, Ohio.

References: ASTM D1513.

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Devulcanization - Chemical

Material *Recycled Rubber from Tires, Industrial Scrap Rubber, and Post-Consumer Scrap Rubber Products*

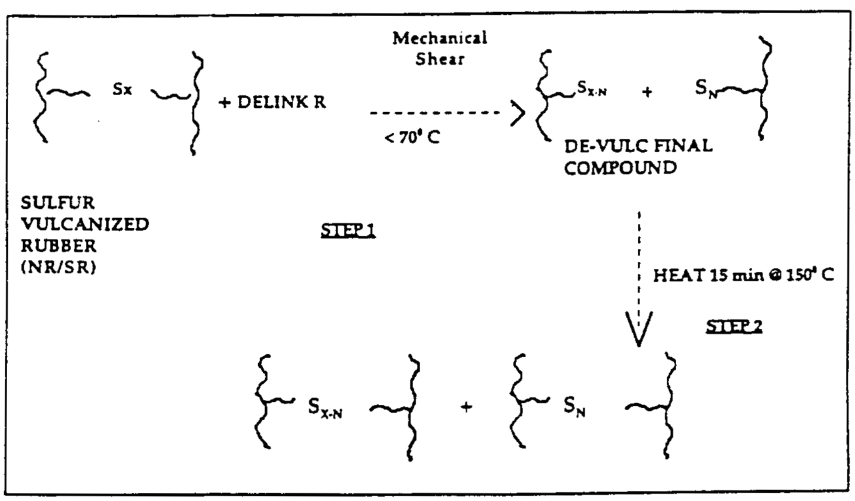
Issue: *The thermodynamically irreversible reaction of sulfur and rubber molecules creates a three dimensional network of sulfur polymer molecules. These crosslinks create the useful viscoelastic properties of rubber compounds. The crosslinked rubber possesses useful dynamic properties and good physical properties. The problem is that after the rubber article has used up its useful life, it is difficult to devulcanize the rubber compound and produce a useful material.*

Best Practice: A new system for reclaiming scrap tire rubber is being marketed by STI of America. This system incorporates a dry powdered or masterbatch mixture of reportedly common chemicals that are mixed into crumb rubber. The exact composition of the chemical mixture is not disclosed as yet, but it probably contains mercaptans, thiazoles, or dithiocarbamates and other simple petptizers used for rubber.

The STI process involves taking a small particle size rubber, typically 30 mesh, produced by cryogenic grinding. A mixture of the dry chemicals, known as DeLink®, is added to the rubber in a Banbury or on a mill. The rubber, after several minutes of smoking, becomes a dry, crumbly material. With additional time on the Banbury or in the mill, the rubber eventually becomes a formable mass of "devulcanized" rubber. The manufacturer reports that the resulting "devulcanized" material can be used for incorporated into virgin rubber products such as tires, mats, footwear, etc.. The final cost of the "devulcanized" rubber is reportedly in the $0.40 - 0.50 per pound range.

The STI theory is shown in Figure 1 and reprinted from an STI technical paper

DE-LINK PROCESS
AND
SEKHAR-KORMER-SOTNIKOVA REACTION



Source; STI Technical Bulletins

Implementation: Powdered DeLink® can be purchased from STI-K America. Devulcanized rubber can be purchased from Custom Cryogenic Grinding in Canada.

Benefits: The major advantages to the DeLink® process are that it is done by the customer in their own plant and it works on many polymers. The disadvantages are cost and the fact that it works best with polysulfidic compounds. DeLink® works best when the "devulcanized" rubber is incorporated back into a virgin compound of the same composition of the original scrap.

Application Sites: Custom Cryogenic Grinding in Canada.

Sources/Contacts: For more information about this Best Practice, contact Mr. Kok-Kee Hon, STI-K

References:

"Turning Waste Into Profit: Recycling Rubber with the De-Link Process", Technical Bulletin published by STI-K Polymers America, Inc., Custom Cryogenic Grinding Corp., and Praxair, Inc., October, 1995, 4 pp.

"De-Link Recycling System: A Revolutionary Process for Devulcanization of Post Consumer and Factory Waste", Kok-Kee Hon, B.C. Sekhar, S.W. Sin, ACS Rubber Division Meeting, Cleveland, OH, October 17-20, 1995.

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Devulcanization - Microwave

Material: Recycled Rubber from Tires, Industrial Scrap Rubber and Post Consumer Scrap Rubber Products

Issue: *The thermodynamically irreversible reaction of sulfur and rubber molecules creates a three dimensional network of sulfur polymer molecules. These crosslinks create the useful viscoelastic properties of rubber compounds. The crosslinked rubber possesses useful dynamic properties and good physical properties. The problem is that after the rubber article has used up its useful life, it is difficult to devulcanize the rubber compound and produce a useful material.*

Best Practice: Microwave energy is part of the electromagnetic spectra. The process utilizes frequencies of 915 and 2450 MHz. according to the Goodyear Tire microwave patent. The process produces rubber material that is reportedly devulcanized using impulses that can rupture atomic and molecular bonds. Microwave devulcanization involves exposing rubber materials to microwave energy under controlled conditions. These conditions theoretically sever sulfur bounds and produce a rubber material that can be compounded and used in virgin rubber compounds.

Implementation: Goodyear Tire and Rubber Co. obtained a patent for the use of microwave energy in "devulcanizing" rubber compounds in the late 1970's. They used the process to "devulcanize" sort ends of hose trim and out of specification EPDM hose. The resulting material, with the proper compound adjustments, such as oil/filler ratios, could be added back into non-OE and other industrial EPDM hose and industrial goods. The process was used for many years and then abandoned due to unfavorable economics.

Benefits: The major benefit of the process was to take scrap rubber ends and out of tolerance EPDM hose and produce a useful recycled product that was added to new rubber goods.

Application Sites: Formerly Goodyear Tire and Rubber Plant, Lincoln, NE. There are at least 2 other proprietary sites prototyping this process for commercial development.

Sources/Contacts: The source of this information was a former Goodyear employee involved in the development and use of the microwave process.

References:

U.S. Patent No. 4104205 issued August 1, 1978 to Goodyear Tire and Rubber Co., Akron, OH *(See Appendix)*

Westinghouse Electric, Nuclear Division, Personnel Communication

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ReTAP

Devulcanization - Ultrasound

Material **Recycled Rubber from Tires, Industrial Scrap Rubber, and Post-Consumer Scrap Rubber Products**

Issue: *Vulcanization introduces sulfur crosslinks between the elastomer chains. This introduction causes an irreversible reaction. The crosslinks are thermally stable and difficult to rupture. When a rubber product has had its useful life completed it would be desirable to "devulcanize" or remove the crosslinks.*

Best Practice: This process, which is in the commercial development phase, uses ultrasonic frequencies that run from 20,000 hertz up to 10 MHz. The lower frequency end is the upper limit to human hearing. The 10 MHz is used to inspect metals and the 0.5 to 2.5 MHz has been used to inspect rubber. Ultrasonic devulcanization reportedly uses frequencies from 20,000 to 50,000 hertz.

Ground scrap rubber of 10 to 30 mesh is extruded and exposed to ultrasonic energy. The process is shown in the schematic below. The ultrasonic energy is believed to create molecular cavatition of the chains. The result is cleaving of the sulfur bonds preferentially over the polymer chains. The sulfur bonds are known to be less stable than the carbon-to-carbon bonds and thereby break first. The Levin, Kim, and Isayev reference in RC&T discusses this reaction in detail.

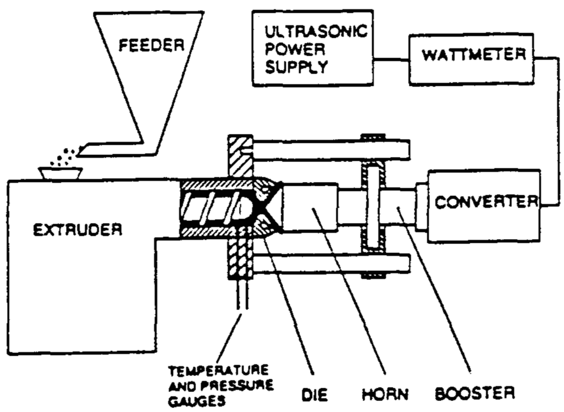

FIG. 1. — Schematic of the devulcanization reactor.

Implementation: A crumb "devulcanized" rubber is obtained from the end of the process. This crumb can be used as is and with sulfur and accelerators added, vulcanized into a rubber product or blended into other virgin rubber compounds.

Benefits: The ability to incorporate rubber that has been "devulcanized" rather than reclaimed into a virgin compound should improve the compatibility and homogeneity of the compound resulting in improve mixing, processing, and properties. The dynamic properties of the compound should especially be helped. If the rubber is truly "devulcanized", higher levels of cycled material should be able to be used. This process should generate recycled rubber that is compatible in a wide range of compounds and can be used in both molded and extruded goods. The following tables show the effect of adding 10% "devulcanized" rubber into a standard 1848 recipe.

Table : Formulations used for characterizing devulcanized rubber along with competing materials

Ingredient	A phr	B phr	C phr	D phr
SBR 1848	245	245	245	245
Devulcanized Rubber		25.2		
Whole Tire Reclaim			25.2	
0.59mm (30 mesh) Buffings				25.2
Zinc Oxide	3.0	3.0	3.0	3.0
BBTS (accelerator)	1.1	1.1	1.1	1.1
MBTS (accelerator)	-	-	-	-
Sulfur	2.0	2.0	2.0	2.0

Table : Test data for characterizing devulcanized rubber versus competing materials

Property	A	B	C	D
Ultimate Elongation, %	780	540	660	480
100% Modulus, MPa (lb/in^2)	1.2 (180)	1.3 (190)	1.2 (180)	1.2 (180)
300% Modulus, MPa (lb/in^2)	5.1 (740)	5.5 (790)	5.2 (760)	5.4 (780)
Tensile Strength, MPa (lb/in^2)	16.7 (2,415)	11.8 (1,705)	13.3 (1,940)	9.9 (1,440)
Hardness, Shore A	58	58	58	58

Application Sites: Research location: University of Akron, Polymer Science Bldg. Akron, Ohio. Prototype production: National Feedscrew and Machining, Massillon, Ohio.

Sources/Contacts: For more information about this Best Practice, Mr. Paul Roberson, National Feedscrew and Machining. 330-837-3868.

References:

"Ultrasonic Devulcanization of Tire Compounds", T. Boron, P. Roberson, and W. Klingensmith, Tire Technology International'96, Published by UK & International Press. 1996, pp. 82-84.

"Devulcanization of Waste Tire Rubber by Powerful Ultrasound", A. Turkachinsky, D. Schworm, and A. Isayev, Rubber Chemistry and Technology, Vol.96, No. 1, March-April 1996, pp. 92-103.

"Ultrasound Devulcanization of Sulfur Vulcanized SBR: Crosslink Density and Molecular Mobility", V. Levin. S. Kim and A. Isayev, RCT, Vol.96, No.1, pp. 104-114.

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EPA

NIST MEP Environmental Program

Surface Modified Recyclates

Material *Recycled Rubber from Tires, Industrial Scrap Rubber, and Post-Consumer Scrap Rubber Products*

Issue: *Most ground recyclate is incompatible with the major virgin rubber into which it is often added because ground is cured. Various polymer and chemical additives are available that try to overcome the incompatibility.*

Best Practice: The following is a list of some surface modified products offered to rubber companies:

PRODUCT	SUPPLIER	MODIFICATION
Vistamer™ (1)	Composite Particles	Halogenation
Tirecycle™	Goldsmith & Eggleton	Low MW polymer (System Specific)
• Rubber Bond	Rubber Technology	Styrene modification
(2)	Battelle	Sulfolobus bacteria (Breaks Xlinks)
Symar D™	National Rubber	N/A
Symar P™	National Rubber	N/A
Sucrum™	Vredestan	N/A
		N/A

(1) Very successful in coatings
(2) In development stage

Implementation: These products are added from 5 to 50 percent levels to rubber compounds. Some products like Sucrum, Symar P and D, Rubber Bond, and Tirecycle can be used at 100 percent levels and re-cured if the physical properties are sufficient for the application.

Benefits: A major benefit is the ability to use recycled rubber products incorporated into virgin compounds while at the same time enhancing the properties over untreated crumb. Cost reduction is also a major benefit.

Surface modified recycled rubber offers the manufacturer and the consumer an opportunity to enhance the value and performance of products containing recyclate. This area is in the early stages of technology development and the current applications are limited, but it is very likely to grow in the near future.

Application Sites: The following companies are involved in developing surface modified recyclates: Composite Particles, Allentown, PA; Goldsmith & Eggleton, Wadsworth, OH; Rubber Technology, Roberto, GA; Battelle, Richland, WA; National Rubber, Toronto, Ontario, Canada; and Vredestan, Netherlands.

Sources/Contacts: For more information about this Best Practice, contact one or more of the following people: Mr. Ed Fesus, Goldsmith & Eggleton, (330) 336-6616; Mr. Terence Cooke, Rubber Technology; Mr. Robert Romine, Battelle; Mr. Jim Jury, National Rubber; and Mr. Jim Huberman, Curtis Trade Group (Vredestan).

References:

Refer to technical literature from Composite Particles, Goldsmith & Eggleton, and Battelle.

National Rubber Patent

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Additives for Surface Modification

Material: Recycled Rubber from Tires, Industrial Scrap Rubber and Post Consumer Scrap Rubber Products

Issue: *Virgin rubbers are high viscosity liquids. Recycled rubbers are produced from used rubber items that are higher in viscosity and molecular weight. As a result, it is usually difficult to get good bonding and dispersion of recycled rubber in virgin rubber. Surface modifiers are added to improve the compatibility of recycled rubber with virgin rubber.*

Best Practice: A tremendous amount of research has been done in this area. The most practical applications of the surface modifiers are shown below:

Material	Supplier	Cost, $/lb.	Use
Urethanes	Bayer, Uniroyal	2.00	Moisture Seal for
SBR Latex	Many	0.50	Binder/Wetting Agent
NR Latex	Many	0.60	Binder/Wetting Agent
Ricon 100 (Sol SBR)	Ricon Resins	2.30	Binder/Adhesive
Vestamer	Huls	2.00	Thermoplastic Binder
Vestol 28	Struktol	1.00	Curable regrind wetting agent
Struktol 40 MS	Struktol	0.60	Curable regrind wetting agent
Flow PO	Flow Polymers	n/a	Binding Agent

Implementation: The materials listed above can be added to virgin compounds at application dependent levels during the mixing stage. The ultimate application of the compound will determine the type and amount of additive that needs to be used. Any manufacturing making rubber compounds is a candidate to use these materials.

Benefits: The reason for using surface modifiers is to improve compatibility, properties, and mix consistency when using recycled rubber. The urethanes make up 90-95% of surface modifiers used for modifying recycled rubber.

Application Sites: For detailed information about the suppliers and users of surface modifiers, see the Rubber Blue Book and the Scrap Tire Directory.

Sources/Contacts: For more information about this Best Practice, contact Mr. John Trautwine, Midwest Elastomers, Mr. Joe Wasko, Struktol Co., Mr. Ed Fesus, Goldsmith & Eggleton, and/or Mr. Fernly Smith, ETA.

References:

Struktol Téchnical Bulletin, "Struktol Vestol 28" (See Appendix)

US Patent to Fred Stark, Rubber Recovery Institute, on Surface Modification

(See Binders, Adhesives, and Bonding Agents Best Practice)

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struktol

Struktol Company of America
201 E. Steels Corners Road, P.O. Box 1649
Stow, OH 44224-0649 Phone 216•928-5188

TECHNICAL DATA

Quality Additives for Performance

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Customer Service: 1-800-327-2709
Fax. 330/928-8726

STRUKTOL® VESTOL 28

RUBBER RECYCLING

COMPOSITION

A curable rubber/oil matrix.

TYPICAL PROPERTIES	VESTOL 28
Appearance	semi solid amber mixture
Specific Gravity (g/cm³)	0.91
Storage Stability	one year under normal storage conditions
Packaging	375 lb. fiber drum

RECOMMENDATIONS FOR APPLICATIONS

STRUKTOL® VESTOL 28 is a low viscosity curable rubber matrix, used as an economical way to recycle ground or chopped rubber. The advantage of STRUKTOL® VESTOL 28 over conventional rubbers such as SBR or EPDM is its very low viscosity. The low viscosity enables the compounder to use either simple fluid mixers, open mills, or internal mixers to produce curable, low cost compounds.

The benefits of using STRUKTOL® VESTOL 28 are: makes ground rubber vulcanizable, and low cost-efficient mixing.

DOSAGE

COMPOUNDING TRIALS

COMPOUNDS	A	B	C	D	E
SBR/NR Waste, size <1mm	100	100	100	100	100
VESTOL 28	30	30	50	10	30
Zinc Oxide	3	3	3	3	3
Stearic Acid	1	1	1	1	1
N-539 Black	---	---	30	---	---
STRUKTOL® PEH-100	---	10	10	---	---
Sulfur	1.5	1.5	1.5	1.5	1.5
CBS	1.5	1.5	1.5	0.3	1.5
TOTAL	137	147	197	114.6	135.8

-over-

Physical Properties Cured 20 Minutes at 180°C	A	B	C	D	E
Hardness, Shore A	52	53	66	55	60
Tensile Strength, MPa	4.2	5.1	4.9	3.8	4
Elongation at Break, %	282	347	189	217	207
Modulus 100%, MPa	1.3	1.3	2.3	1.4	1.5
Resilience	50	44	35	49	---
C.S. 70 hrs at R.T.	17	26	28	17	---
C.S. 24 hrs at 70°C	16	18	17	---	---

Oven Aging 7 Days at 100°C	A	B	C	D	E
Hardness, Shore A	59	60	70	62	---
Tensile Strength, MPa	4	3.9	4	5.4	---
Elongation at Break, %	171	193	135	246	---

Preparations of Compounds:

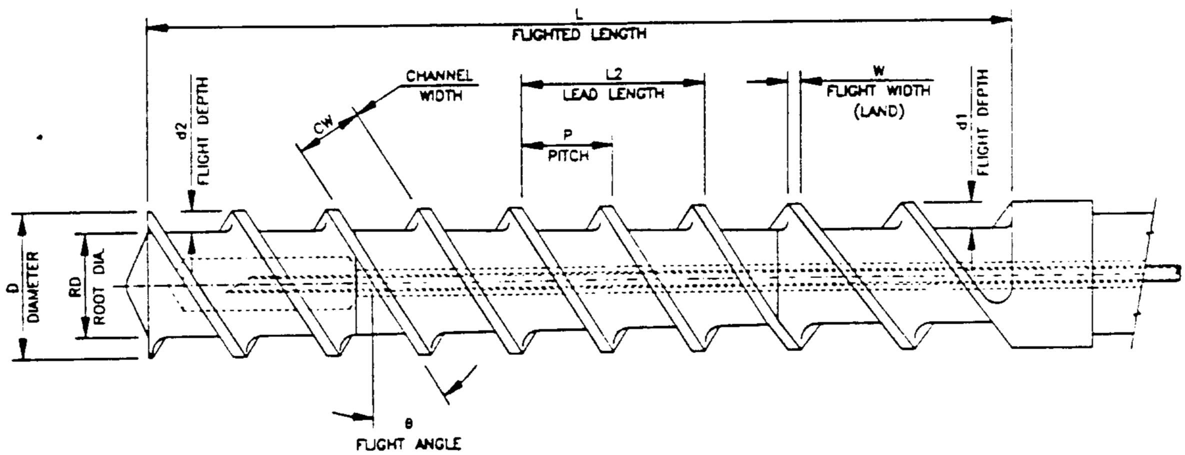
Compounds A, B, and C were mixed in 2 liter internal mixers, 60 rpm, for 4 minutes at 80°C. Compounds D and E were mixed in fluid mixers, 500 rpm, for 3 minutes at room temperature. Compound E was the only compound to be injection molded for 5 minutes at 180°C.

Extrusion

Material ***Recycled Rubber from Tires, Industrial Scrap Rubber, and Post-Consumer Scrap Rubber Products***

Issue: *One of the common methods used to form rubber products is extrusion. This Best Practice reviews the common factors of equipment for and products made from the extrusion method.*

Best Practice: Unvulcanized rubber is really a very high viscosity liquid. The unvulcanized rubber can be shaped and formed using a die. The rubber is forced through an opening of a designed shape. The rubber is forced using a metal screw contained in a metal barrel. The screw has flights or raised portions that transport the rubber down the barrel and through the die. A schematic of a screw is shown below.



There many different types of extruders. The major types are hot feed, cold feed and mixing extruders. A hot feed extruder requires the rubber compound be preheated prior to being introduced into the extruder. A cold feed extruder has a more aggressive screw design and accepts cold rubber compounds. A mixing extruder has different screw pitches and usually has pins inserted the shaft to introduce violent flow and mixing action.

Extruders are commonly used in tire manufacture to pre-form treads, sidewalls, bead apex compounds and various wedges and filler components. Hot feed extruders were commonly used for this purpose but are being replaced by the smaller more efficient, but more costly cold feed extruders.

As the name implies, mixing extruders are used to mix rubber compounds. These extruders find limited use in rubber, but are commonly used in the plastic industry.

Of particular note to recycled rubber interests is that when ground rubbers are added to virgin rubber compounds the die swell or expansion of the final product is increased. The smaller the particle size the lower the die swell. The higher the concentration the higher the die swell. In addition extruders can imparted a smooth surface to the final product. Recycled ground rubbers often create a rough appearing surface. This surface type is often objectionable such as with automotive weather-stripping. This condition has limited the acceptance of recycled rubber in such products.

Implementation: Extruders are used throughout the rubber industry to produce a wide range of final products.

Benefits: The major benefit of an extruder is the ability to easily form and shape rubber compounds for preparation for other steps in manufacturing or to actually form final products with a relatively simple piece of equipment that is easily maintained and lasts a long time.

Application Sites: All tire plants, hose, re-treaders, wire and cable, weather-stripping, and molding shops where pre-forming is done utilize extruders.

Sources/Contacts: For more information about this Best Practice, contact Mr. Paul Roberson, National Feedscrew and Machining, (330) 837-3868.

References:

"Extrusion and Extrusion Technology." Chapter 5, by Micheal I. Iddon, *Rubber Products Manufacturing Technology*, edited by A. Bhowmick, M. Hall, and H. Benarey, Marcel Dekker, 1994, pp. 267-314.

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Hot Molding

Material ***Recycled Rubber from Tires, Industrial Scrap Rubber, and Post-Consumer Scrap Rubber Products***

Issue: *Over 70 percent of all rubber products are produced by hot molding. Hot molding refers to compression, transfer, and injection molding. Recycled rubber is commonly used in all of these processes.*

Best Practice: There are three commonly used methods for hot molding. These are compression, transfer, and injection molding. All three involve placing an unvulcanized rubber compound into a mold and exerting pressure and applying heat. They differ on how the rubber is introduced into the mold, mold pressure, and curing time and temperature. Compression molding is the most common and is used to make pneumatic tires, solid tires, mats, and many small-to-medium-sized mechanical goods for automotive and industrial markets. When the number of parts to be made becomes large, then one often considers injection molding. Molded goods in many cases can use ground recycled rubber and reclaim and other forms of recycled rubbers.

Compression molding involves placing a performed slug of rubber into a preheated mold. The rubber weighs slightly more than the final part. The mold is held in a compression press. The press is closed and the part held under temperature and pressure from 10 to 40 minutes depending on the temperature and pressure. Typical pressures are 2,000-3,000 psi at 280-350°F. Compression molding can use 10-40 mesh ground recycled rubbers in parts experiencing low dynamic stress. The tensile strength of the rubber is lowered and the viscosity of the rubber is increased when they are incorporated. However there is usually sufficient force the rubber to flow even with the higher viscosity. Some of the new surface modified recycled rubbers do process better than their untreated counterparts. In ultra-high performance compression molding, 60-120 mesh is employed.

Transfer molding also uses a press with parallel platens. However the rubber is introduced as a slab into the upper transfer pot. It is cold or has been warmed slightly. The transfer piston is pushed against the rubber slab and this forces the rubber through a openings in the top of the mold and into the cavities (see Figure 2). The mold is then held under temperature and pressure. The times and temperatures are similar to those used in compression molding. Transfer molding requires the rubber to flow through an orifice in the upper mold plate. This means the viscosity control of the rubber is critical. It is usually necessary to use ground recycled rubber in the 40-80 mesh size to get sufficient flow and minimal effect on physical properties for transfer molding.

Injection molding uses an injection molding press. The rubber is feed as a strip into the machine, warmed and heated with a screw and injected hot into the mold cavities through a series of runners and sprues (see Figure 3). Curing is done at high temperature and pressure and is usually quick (e.g., from 30 to 120 seconds) at 350°F. The flow rates are high and the gates and sprues may be very small. As a result, in many cases ground recycled rubbers might inhibit the efficiency of the process. Also many high dynamic stress parts like bushings, gaskets, and seals are made by injection molding. These parts allow minimal use of ground recycled rubber. The amount used is also small. Finally, 60-120 mesh ground recycled rubber at low concentrations (from 2 to 5 percent) is generally used in injection molding.

Implementation: Any of these processes are implemented by buying the appropriate press and mold. A list of suppliers is shown in the *Rubber Red Book* or the *Rubbicana*. The ground recycled rubber is introduced in the mixing stage.

Benefits: First. compression presses and molds are the least expensive of the three and the least efficient. However, for small volume runs they are usually used. Secondly, the transfer mold process can often be done in compression presses. This process allows more parts to be made at one time and does not require performs. It also wastes a lot of rubber with the transfer pad. Thirdly, injection molding is usually used for high volume part runs. The presses and molds are the most expensive of the three processes. However, it is also the most efficient since the rubber is injected hot and cured at high temperature. Injection molding also generates a lot of scrap. Ground recycled rubbers are added to reduce cost and improve the removal of trapped air during vulcanization.

Application Sites: For detailed information about the many users and suppliers of hot processing equipment, see the *Rubber Red Book* and the *Rubbicana*.

Sources/Contacts: For more information about this Best Practice, contact Mr. Bill Klingensmith, Akron Consulting Company.

References:

Midwest Elastomers Technical Bulletins, "Processing and Properties," "Butyl," and "EPDM."
Polymeric Materials and Processing, J.M. Charrier, Hanser Publishing, NY, 1991, pp. 457-494

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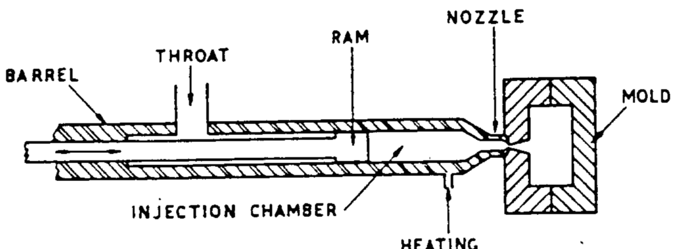
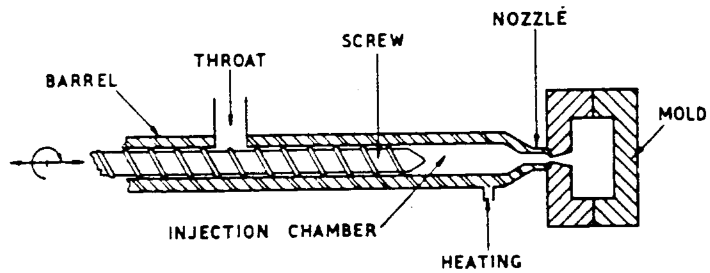
APPENDIX 1

Injection Molding



(a) - RAM



(b) SCREW

APPENDIX 2

Transfer Molding

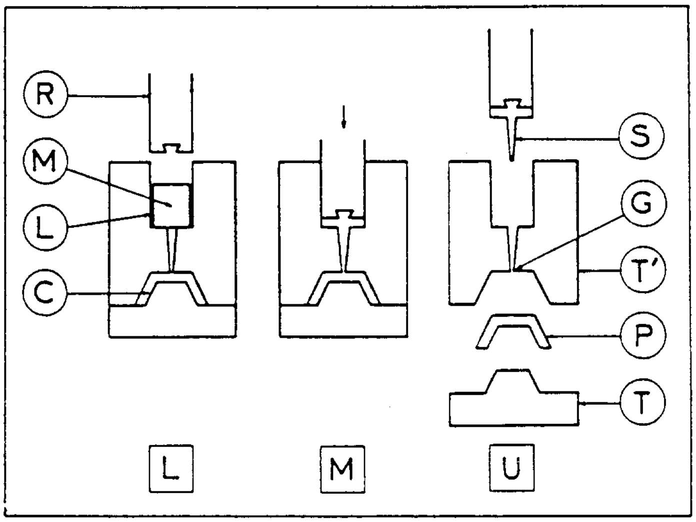


Figure 5. /. · Pot transfer molding · [L] Loading; [M] Molding; [U] Unloading; (C) Cavity; (L) Pot; (M) Material charge; (R) Transfer piston; (S) Sprue (scrap); (G) Gate; (T),(T') Mold halves; (P) Product

Cold Molding

Material: Recycled Rubber from Tires, Industrial Scrap Rubber and Post Consumer Scrap Rubber Products

Issue: *In Germany, during W.W.II, the Germans invented a process for recapping truck tires using the ambient desert heat (160-220°F). The process was brought to the United States and developed by the Bandag Company and later adapted by Goodyear, General Tire, Hercules, and others for retreading tires. This became known as cold molding or cold capping. This process has successfully incorporated scrap rubber into its process.*

Best Practice: Most rubber products are cured at temperatures of 280 - 400°F. The cure times vary from seconds to minutes. For passenger tires, typical curing conditions will be 350-400°F, while truck tires are cured at 285-320°F. In cold molding, the tread is cured in a compression mold using a platen press. The compound is typically an SBR-PBD blend reinforced with carbon black and extended with aromatic oil. This will be cured 20-30 minutes at 320-340°F. A squeegee or adhesion layer of uncured natural rubber is mixed and calendered separately. The rubber is designed to cure at a much lower temperature such as 210-230°F.

The tire to be retreaded has the old tread stripped from it. The surface is kept clean and a layer of cement adhesive is applied to the tire. The bonding layer, typically 0.040-0.060" thick is applied to the tire. The precured tread is applied to the tire and stitched to the tire with pressure. This is all done at ambient temperature.

The tire has a metal band wrapped around the outside of the tread and the entire assembly is placed in a rubber envelope that is heat resistant. A bladder is placed inside the tire and steam is applied to the inside and heat to the outside of the tire. The temperature is maintained at 210-230°F for 45-75 minutes depending on the tire thickness. The tire is removed from the envelope, bladder and metal band removed after curing and the result is a retreaded tire.

Implementation: The implementation of a cold molding process involves purchasing the precured treads and bonding layer form a supplier, buying the proper equipment to strip old treads from the tires, and purchasing numerous bands and bladders for different tire sizes. In addition, electrical and steam resources are required. The process is relatively inexpensive compared to hot molding.

With regard to recycled rubber, it is common practice in a cold molding manufacturing process to grind scrap of constant composition and mix it into virgin treads.

Benefits: The major advantage of the cold molding is less degradation to the tire cords and compounds due to heat and oxidation. In addition the bands and envelopes are generally less expensive than hot molding equipment.

Application Sites: Bandag Corporation, Muscatine, Iowa; Goodyear Tire and Rubber Company, Dallas, Texas.

Sources/Contacts: For more information about this Best Practice, please contact Mr. Frank Jenkins, retired, Continental-General Tire, phone 330-633-3263.

References:

Tire Technology article on advances in precured tread manufacture, 1995.

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ReTAP

Moisture Retention/Absorption

Material: Recycled Rubber from Tires, Industrial Scrap Rubber and Post Consumer Scrap Rubber Products

Issue: *Moisture is present during the entire process of grinding and processing recycled rubber. This Best Practice describes the accepted levels of moisture in the process.*

Best Practice: Water (moisture) is present during the entire grinding and processing of recycled rubber. This moisture is either inherent in the polymer itself from an outside source associated with the polymer. The accepted level of moisture in rubber materials is 1% CAP (Current Accepted Practice). The level of moisture typically runs at 1% or less in most rubber materials. The attached Rondy specification shows the typical description of moisture content.

Moisture can cause many problems in rubber materials including:

1. Materials Handling - Too much moisture in a compound can cause caking and inhibit flow during processing. Calcium carbonate or other anti-caking agents can be used to help this problem.

2. Acidity - Moisture build-up in an elastomer can lead to acidic conditions within the polymer which causes cure retardation, especially when clay fillers are involved in the compound.

3. Polarity - A high moisture content (2-3%) leads to increased polarity in the compound and can lead to poor bonding properties. This is especially harmful when working on retreading tires.

Moisture is especially problematic in the processing stage. Materials that are extruded or calendered are the most sensitive due to the lower processing pressure created by the moisture.

Implementation: To minimize the moisture level in reclaim rubber, store the material in a cool, dry place. When using dry materials, use a dessicant to control the moisture level in the compound, especially those intended for extrusion.

To test materials for moisture content, ASTM D 297 is the test method of choice. This method utilizes a 105°C weigh-dry technique. See the appendix for a copy of the method.

Benefits: Water is beneficial in the cooling of rubber during processing. However, excess water can effect the cure rate if it is at a high level. In regards to recycled rubber, it is important to keep the ground or crumb material dry so as to maximize the materials ability to be mixed into a virgin compound as an additive. Excess moisture will devalue a recycled rubber material and hinder its ability to be used effectively in many applications.

Application Sites: All sites making and processing virgin and recycled rubber are concerned about moisture. They monitor and test for moisture on a routine basis.

Sources/Contacts: For more information about this Best Practice, contact Mr. Fernly Smith, ETA, Mr. Mike Rouse, Rouse Rubber, Mr. Dick Shope, Rubber Recovery, or Mr. John Trautwine, Midwest Elastomers.

References:

Rondy Technical Bulletin, "Rondy 30 Mesh Rubber Buffings - Generic"

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RONDY & Co. Inc.
Rubber & Plastic Raw Materials

RONDY 30 MESH RUBBER BUFFINGS–GENERIC

SOURCE: TIRE TREAD PEEL

***TYPICAL COMPOSITION:**

RUBBER HYDROCARBON	45% OR GREATER
CARBON BLACK	35% MAX (TYPICAL 31.5 TO 33.0%)
ACETONE EXTRACT	19% MAX (TYPICAL 16.8 TO 18.0%)
ASH CONTENT	8% MAX (TYPICAL 3.5 TO 5%)
MOISTURE CONTENT	1% MAX (TYPICAL 0.5%)
SPECIFIC GRAVITY (ACTUAL SOURCE MATERIAL)	1.14 - 1.18
BULK DENSITY	UNKNOWN

SOURCE MATERIAL IS SIEVED THROUGH A COMBINATION OF 24 AND 30 MESH SCREENS.

24 MESH SCREEN	0.014 WIRE	SPACE 0.028 (INCHES)
30 MESH SCREEN	0.012 WIRE	SPACE 0.021 (INCHES)

***TYPICAL SCREEN ANALYSIS:**

RETAINED ON A 24 MESH	0% TO TRACE
RETAINED ON A 30 MESH	30-50%
PASSING THROUGH A 30 MESH	50% OR +

PACKAGING:

NORMALLY IN 50 POUND, MULTIPLY, PAPER BAGS OR IN LINERED GAYLORD BOXES. THE CUSTOMER CAN SPECIFY NET WEIGHT IN BAGS WHERE REQUIRED FOR INTERNAL MIXERS.

CONTAMINANTS:

THE MATERIAL IS DEMETALIZED. NO METAL, WOOD, PAPER!

APPLICATIONS:

BUFFINGS ARE GENERALLY USED AS A LOW VOLUME COST FILLER IN MANY BLACK COMPOUNDING APPLICATIONS.

EXAMPLES: INDUSTRIAL TIRE TREADS, SEMI-PNEUMATIC TREADS.
CASTORS BRAKE LINING COMPOUNDS
MATS, AUTOMOTIVE, AGRICULTURAL, SPORTING
RAILROAD CROSSING PADS
MISCELLANEOUS COMPRESSION MOLDED PRODUCTS

*TYPICAL "TYPICAL" IS NOT CONSTRUED TO BE AN ABSOLUTE SPECIFICATION; MERELY AN INDICATION OF RESULTS OBTAINED. THIS IS A SCRAP, REPROCESSED RAW MATERIAL. RONDY & CO., INC. MAKES NO WARRANTIES OF MERCHANTABILITY OR FITNESS TO ANY PROCESS OR END USE (ON ITS OWN, OR IN COMBINATION WITH OTHER CHEMICALS).

Revision D:Effective 4/1/94

Rondy & Co., Inc. 255 Wooster Road, N. • Barberton, Ohio 44203 • (216) 745-9016
FAX (216) 745-4886 • Telex 24[illegible]

Contaminants - Incompatible Rubber Polymers

Material: Recycled Rubber from Tires, Industrial Scrap Rubber and Post Consumer Scrap Rubber Products

Issue: *In producing recycled rubber, one has to be aware of the possibility of experiencing objects and materials that may cause contamination. This includes both objects that are foreign as well as materials that are included in the product being recycled that would be objectionable in the final product. In many instances, various types or grades of rubber may be incompatible when blended together. Incompatibility can lead to poor processing and performance characteristics.*

Best Practice: In the recycling of tires the obvious concern is over dirt, mud, and foreign matter that might be contained on or in the tire. It is obvious that these materials would lower the quality of a recyclate into which they are incorporated. Stones are an area of primary concern since they can do damage to processing equipment as well as contaminate the final product. Therefore, it is necessary to use general sanitary conditions that eliminate extraneous matter from the process. Within some OE and specialty tires there is a layer of tire sealant for puncture resistance. This layer (Gen-Seal, Royseal, etc.) is usually soft and composed of low molecular weight polymer, resin and filler, and is partially cured. This layer should be avoided if possible because they can cause downstream problems when working with small particle size materials.

Other contaminants of concern in tire, hose, and belt recycling and grinding are the textile and steel reinforcing members. These are removed in the case of the metal with a powerful magnetic separator. The fiber is removed using air cyclone separation during processing. Small amounts of fiber are often found in large particle size whole ground tire. On the other hand, cryogenic grinding is especially effective at removing fiber and steel from the recycled rubber.

One item that the recycler of rubber has to be aware of is to avoid incorporating specialty elastomers containing peroxides and halogens into general purpose polymers. Many hoses, belts, roofing materials, and o-rings contain specialty elastomers that will be less than compatible. These materials should only be co-mingled with themselves. The small amount of halogen in the innerliner of tubeless tires is not a problem and it is easily ground and incorporated into whole ground tire recyclate. EPDM, butyl, and nitrile rubber should also be avoided for blending into ground tire recyclates.

Implementation: The best way to avoid metal contamination is to use a magnetic separator in the process line. Fiber is best removed by air separation, and dirt and mud are best removed by thorough washing.

Benefits: The major benefit of keeping the recycled system clean is obvious, the recyclate has more useful properties and is more reproducible from lot to lot.

Application Sites: In general, all locations performing recycling of rubber possess some type of screening for their incoming source. They also in some cases wash the tires and other products.

Sources/Contacts: For more information about this Best Practice, contact Mr. Ed Fesus, Goldsmith & Eggleton, phone 330-336-6616, Mr. Dick Shope, Rubber Recovery, Mr. Mike Rouse, Rouse Rubber, or Mr. Fernly Smith, ETA.

References:

ASTM D Infrared Analysis of Rubber

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Contaminants - Fiber and Steel

Material: Recycled Rubber from Tires, Industrial Scrap Rubber and Post Consumer Scrap Rubber Products

Issue: *Tire recycling processes designed to reduce the rubber to small particle sizes result in the liberation of steel and fibre components of the tire. Generally, both the steel and the fibre are considered contaminants to the rubber particles and need to be removed to increase the value of the rubber. Scrap tires contain approximately 70% rubber, 15% steel, and 15% fibre by weight. These percentages vary depending on the type of scrap tire.*

Best Practice: In general the best practice for the removal of both fibre and rubber is to remove the material as early in the process as possible. Steel tends to have an adverse effect on equipment longevity and the fibre tends to limit throughput of rubber through the process. Fibre as it passes further through the system becomes shortened to the extent that it becomes more difficult to remove from the rubber using commercially available equipment.

Steel Removal -- It is best to remove truck tire beads before any size reduction is done. Truck tire beads are extremely difficult to shred and cause significant equipment wear. Some operations choose to shred truck tires without removing the bead. Passenger tire bead wire is much easier to process and cost/benefit analysis is required to determine if the benefits of removing the bead prior to size reduction outweigh the costs. There is an external scrap metal market for clean bead wire.

Bead wire can be cleanly removed by using commercially available bead pullers. These devices cleanly rip the bead wire from the tire.

Size reduction of the tire to 1" particle size liberates 50-70% of the steel in the tire. This steel can be removed with overband magnetic conveyors or drum magnetic configurations that are commercially available. The degree of steel removal at this stage is determined by the desired degree of rubber contamination in the steel. Rubber contamination reduces the value of the steel in the scrap metal market. The degree of steel removal is adjusted by varying the strength of the magnetic field used to pull the steel from the material stream. The magnets can be purchased with different magnetic field strengths or the magnets can be moved further from the material. All conveyors and guards around the magnetics must be fabricated from non-magnetic material to avoid build-up of steel on this equipment.

This principle steel separation should be performed after most size reduction stages. As the rubber/steel/fibre mixture is further size reduced the fibre also becomes liberated. There is a potential for contamination of the steel with the fibre, if the majority of the fibre is not removed prior to this stage. It is particularly important to use drum magnet steel separation on the final rubber product before packaging. Most ground rubber customers have stringent guidelines limiting steel content in the product they purchase.

Fibre Removal -- Various techniques exist for fibre removal. The most effective method depends on the size reduction achieved on the tire material.

Tire material that has been reduced to a nominal size of 3/8" has a large amount of fibre liberated. The fibre at this stage is approximately 1/2 to 3/4" long. At this stage the fibre can be separated using mechanical vibrating screen tables and pneumatic systems.

In a single pass system, the tire material, a mixture of rubber and fibre which has the majority of steel removal , is passed over an optimally laded vibrating screen table . The screen size is adjusted to maximize the fibre content in the oversize discharge. Note there will be a large concentration of large rubber pieces in the fibre. The undersize, which still contains fibre, continues on to the next stage of size reduction. The remaining fibre is removed at a later stage.

In a recirculating system, the tire material is also passed over a vibrating screen table. The screen size is adjusted to minimize the amount of fibre passing through the screen, yet maintain a steady flow of material for further size reduction. The oversize is discharged and passed through a two roll mill. The mill reduces the size of the rubber and shears it off of the fibre while maintaining fibre length. This material is then recirculated onto the screen table. The vibrating nature of the screen tends to stratify the material on the screen so that the fibre is on the top of the oversize and the rubber is on the bottom. The fibre can be removed pneumatically by "vacuuming" the long fibre off the top of the screen. It can also be separated using mass differential after it has been discharged from the screen oversize outlet.

The fibre in the tire material that passes on for further size reduction tends to fray or be reduced to very small particle sizes. This fibre can be removed using commercially available density separator tables. The density separator table is a vibrating, air fluidized bed which is angled upward from inlet to discharge. The bed is enclosed by a hood with a low pressure outlet at the top to draw off air from the bed and small fibre particles from the tire material. The material is dropped onto the bed and vibrates up the table. The more dense and massive the particle, the further up the table it travels. The remaining fibre in the material is collected in combination with the smallest particles at the least dense material discharge.

Implementation: Tire recyclers must consider the markets for the materials they will be generating. These markets will dictate the type of processes required to meet the market demands. An analysis of commercially available equipment capable of meeting processing needs is required. A design layout is also required before matching capacity and equipment size requirements.

The fibre is highly flammable and the steel has a tendency to accumulate and create friction generated hot spots. Proper engineering is required to prevent accumulations. Once in operation, the system must be carefully maintained from both a mechanical and housekeeping perspective to maintain productivity and prevent injury and loss.

Benefits: The benefits of following this best practice are cleaner, higher value materials that are very attractive to potential customers.

Application Sites: Any and all tire recycling facilities

Sources/Contacts: For more information about this Best Practice, contact Mr. Mike Schnekenburger, National Rubber Inc., (416) 652-4230.

References: National Rubber Inc.

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EPA

NIST MEP Environmental Program

Setting Crumb Material Specification

Material: Recycled Rubber Derived from Tires, Industrial Scrap and Post Consumer Scrap Rubber Products.

Issue: *ASTM D5603-94 (a copy is attached in Appendix I) describes classification of vulcanized particulate rubber based on parent materials. It also provides specification for properties of cured particulate recycled from whole tire and tire treads using ASTM standard test methods.*

However, this standard does not specifically state that it is for recycled rubber. Specification for NR is minimum 15%. This may force recyclers to add some high NR containing tires to a truck load of only passenger tires where NR content can be as low as 12%.

Best Practice: In spite of above issues, ASTM D5603 is used, in general, by the recycled rubber industry. In early 1995, an ASTM subcommittee, D11.26, was formed to address issues described above. This subcommittee has recommended lowering the minimum content to 10%, and eliminated specific gravity for lack of suitable method to determine specific gravity of crumbs. Weighing in water does not work because too much air is associated with crumb particles. Modified ASTM D5603 was sent to the main committee for approval. Minimum approval time is six months; it may, however, take a few years. Properties specified for tests are ash content, moisture content, carbon black and NR contents, hydrocarbon content and acetone extractables.

Implementation: Until the ASTM D11.26 subcommittee's recommendations are approved by ASTM, recyclers, recycle rubber users should continue using ASTM D5603-94. After approval, a new ASTM standard document number will be issued for recycled rubber and then the recycling industry should use that. The modified version still provides flexibility for other agreed upon specification between vendor and customer.

Benefits: Use of a common standard and specification will improve the quality of crumb. Vendors should comply to an ASTM standard for meeting quality standards and customer satisfaction.

Application Sites: Recycled rubber processors' plants, selling sites (such as Chicago Board of Trade) and end-users' sites.

Sources/Contacts: ASTM D5603-94; Krishna C. Baranwal, Chairman of ASTM Subcommittee D11.26, Akron Rubber Development Laboratory, Akron, Ohio, Phone 330-794-6600.

References: ASTM D5603-94; *Identifying Composition of Tire Rubber*, by G. W. Holland, B. Hu, and M. A. Smith, Rubber and Plastics News, Dec. 6, 1993.

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Setting Compound Specifications

Material: Recycled Rubber Derived from Tires, Industrial Scrap and Post Consumer Scrap Rubber Products.

Issue: *Compound specifications generally are set in terms of compound properties. Tensile, % elongation, modulus, tear strength, and compression set, etc., are the most common ones. The smaller the particle size of crumb, the smoother the extrudates and calendered sheets. It will be rather difficult to set compound specification for a given product since properties may depend on the polymer, filler, etc., in the original compound and crumb particle size and actual amount used.*

Best Practice: Two examples, (A) and (B), are included in Appendix I. Example A illustrates the effects of particle size of cryogenically ground EPDM on tensile strength and tear strength of compounds containing 10% and 20% of recycled rubber. The small particle size (60, 80, 100 mesh) impart same tensile strength as the control. The 40 mesh lowers the tensile by about 10% at both 10 and 20% concentrations. EPDM Control recipe is provided.

Example B shows effects of 5, 10, and 15% of 60 mesh cryogenically ground butyl rubber on Rheometer data, unaged physical properties and air permeability of an innerliner compound. At 10 and 15%, cure rate is slightly lower. Modulus at 300% elongation and tensile drop with increase in recycle rubber content. Air permeability also drops.

Implementation: In either case, it is not definite as to what should the compound specification be except stating that certain properties are lower or higher with the use of recycled rubber. It may be that 5 or 10% drop in properties may be acceptable for product performance.

It is, therefore, suggested that for high performance products, finer particles (80, 100 mesh) be evaluated in a given product compound and specifications be set between vendor and customer for that compound. For such products other critical tests such as flex properties, abrasion and cut growth, etc., be evaluated and not just depend on tensile strength alone.

For low end performance products, similar specifications may be set by using coarser crumbs.

Benefits: Compounds specification set between vendor and customer may be more realistic and achievable and will be more specific to a given product.

Application Sites: Vendors' and end-users' laboratories and plant sites.

Sources/Contacts: Krishna C. Baranwal, Akron Rubber Development Laboratory, Akron, Ohio, Phone 330-794-6600; Midwest Elastomers; William Klingensmith, Akron Consulting Company, Akron, Ohio.

References: Fine Particle Rubber Technology, a booklet from Midwest Elastomers, Inc.; Recycling, Production and Use of Reprocessed Rubbers, by William Klingensmith, Rubber World, pp. 16-19, March, 1991.

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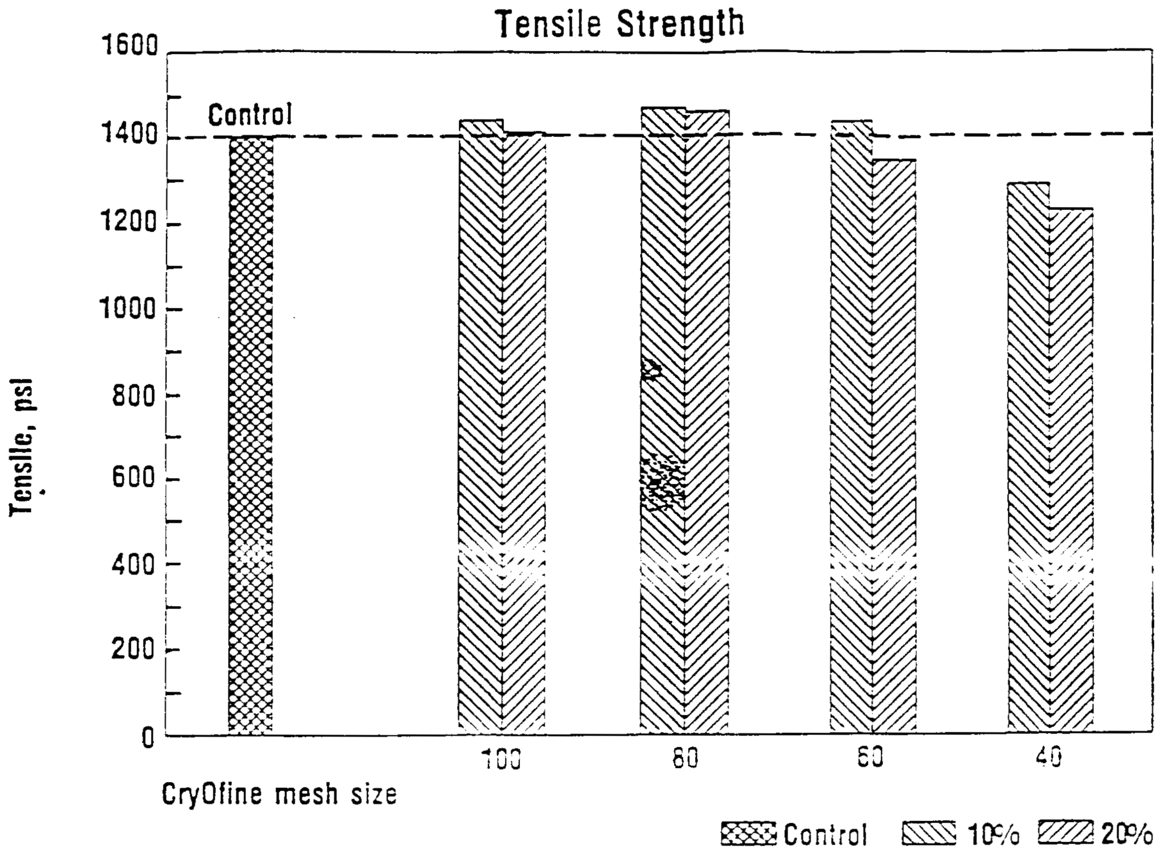
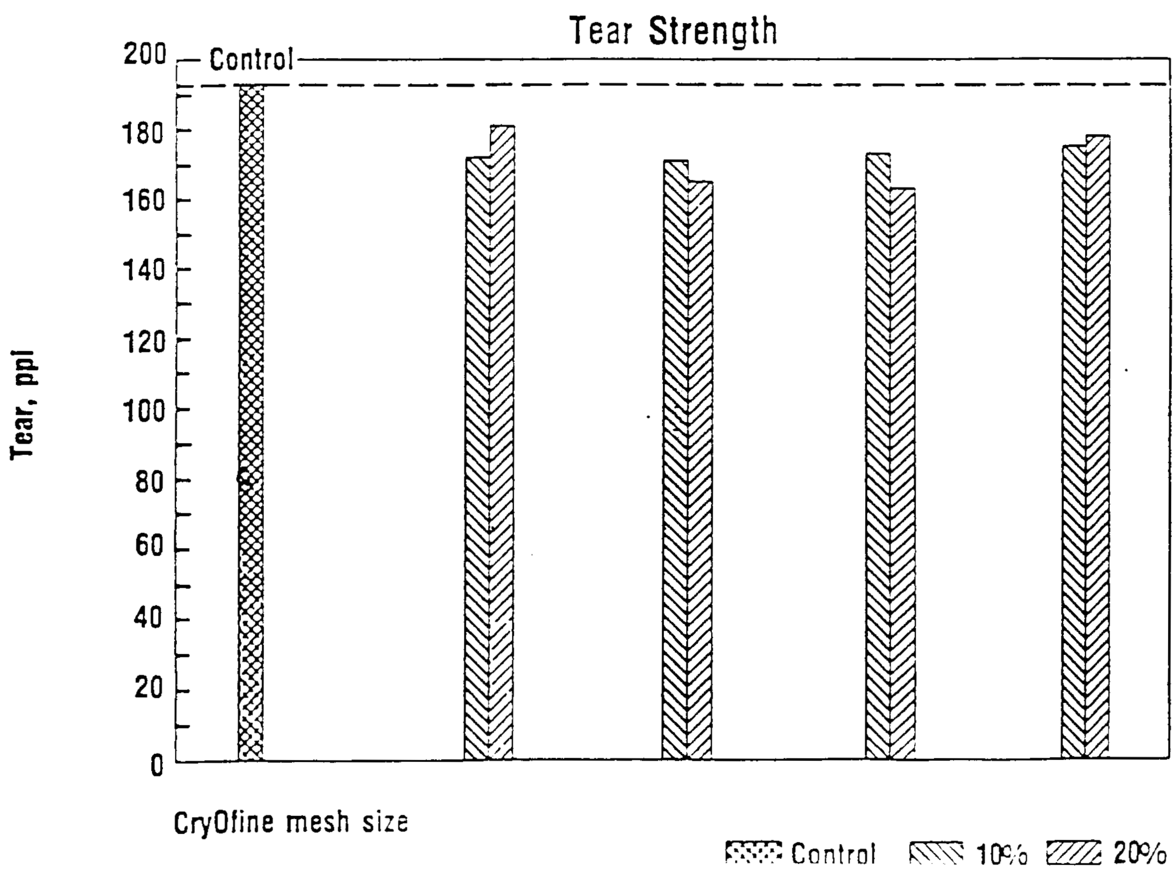
APPENDIX I

Example A





Control Recipe - EPDM Hose

	PHR
EPDM	100.0
N-650	70.0
N-774	130.0
Paraffinic Oil	130.0
Zinc Oxide	5.0
Low Mol Wt PE	5.0
Stearic Acid	1.0
Antioxidant	1.0
Sulfur	1.25
Sulfads	0.80
Methyltuads	0.80
Ethyl Tellurac	0.80
Altax	1.00
Total	446.65

APPENDIX I

Example B

Evaluation of Cryogenically Ground Butyl in the Innerliner

Master batch	
Butyl HT-1066	80.00
RSS #1	20.00
N650 carbon black	65.00
Mineral rubber	4.00
Durez 29095	4.00
Stearic acid	2.00
Sunthene 410	8.00
Zinc oxide	3.00
Devil A sulfur	0.50
MBTS	1.50
Total	188.00

Properties

Mill mixed final formulations

		Cryofine 60 mesh butyl		
	Control	(5%)	(10%)	(15%)
Master batch	188	178.60	169.20	159.80
Cryofine	--	9.40	18.80	26.20
Rheometer data - butyl				
Cure time, T_C90%, Minutes	47.50	46.25	47.00	46.50
Cure rate MC90- TS.1. Lbf. in/minute	0.59	0.58	0.55	0.56
Unaged physicals - butyl				
100% modulus, psi	415	410	365	365
300% modulus, psi	1120	1040	1000	950
Tensile strength, psi	1410	1350	1290	1280
Air permeability, Q(1)	4.71	4.70	4.47	4.16

(1) Q x 10^3 (ft. ^{3}/.001 inches/F° psi/day)

Fillers - Recycled Crumb Rubber

Material **Recycled Rubber from Tires, Industrial Scrap Rubber, and Post-Consumer Scrap Rubber Products**

Issue: *Ground rubber from tires, buffings, and other sources is commonly added into rubber compounds in order to lower costs and to use recyclate.*

Best Practice: The size of the ground rubber material varies from 6 to 100 mesh. Smaller particles are available but are not commonly used. When ground rubber is added as a filler, three things almost always occur:

1. The viscosity of the rubber compound increases
2. The tensile strength is lowered
3. The dynamic properties are reduced

One of the biggest reasons manufacturers used ground rubber as fillers in virgin compounds is to reduce costs. The ground rubber costs less than the virgin compound and the price reduction is generally in proportion to the level of ground rubber added. A lot of development work is taking place in this area with regards to surface modification, devulcanization, and treatments and binders to minimize the negative effects on properties and in fact enhance the properties of compounds containing ground rubber.

Implementation: Ground rubber is added into the rubber compound using an internal mixer. It is commonly used at levels from 5 to 75 percent, depending on the application. Tires and high performance compounds use from 3 to 10 percent, and mats, dock fenders, bedliners, and similar low dynamic stress products can use from 10 to 75 percent ground rubber. The smaller the particle size of the rubber, the less the negative effect on the compound properties.

Benefits: The following data shows the effects of a 20 mesh, ambient-ground rubber compounded into an SBR1502 compound. The ground rubber has been evaluated at 17-, 33-, and 50-percent levels. The compound recipe is as follows:

Ingredient	Level, phr
SBR 1502	100.0
Zinc Oxide	5.0
Stearic Acid	1.0
TMQ	2.0
N660 Carbon Black	90.0
Aromatic Oil	50.0
Sulfur	2.0
MBTS	1.0
TMTD	0.5

The 20 mesh crumb was added at 17, 33, and 50%

The properties of the materials are as follows:

	0% Ground	17% Ground	33% Ground	50% Ground
Mooney Viscosity	40	61	91	111
Rheometer Max Torque	59	47	33	34
tc90, min.	2.5	2.4	1.8	2.0
Tensile Strength, psi	1470	1150	870	560
Ultimate Elongation, %	330	330	300	270

The following data shows the effect of concentration and particle size of a cryogenically ground rubber on an EPDM compound:

CryOfine Ground Rubber Used at 10 percent levels (except control at 0 percent)

	Control	40 Mesh	60 Mesh	80 Mesh	100 Mesh
Tensile Strength, psi	1410	1290	1430	1470	1440
Ultimate Elongation, %	410	330	340	400	380
100% Modulus, psi	535	490	530	490	480
300% Modulus, psi	1180	1220	1230	1230	1220
Hardness, Shore A	73	70	70	70	71
Die C Tear, ppi	193	175	173	171	172

CryOfine Ground Rubber Used at 20 percent levels (except control at 0 percent)

	Control	40 Mesh	60 Mesh	80 Mesh	100 Mesh
Tensile Strength, psi	1410	1230	1360	1460	1410
Ultimate Elongation, %	410	320	390	390	390
100% Modulus, psi	535	450	500	460	460
300% Modulus, psi	1180	1220	1300	1200	1160
Hardness, Shore A	73	72	70	69	68
Die C Tear, ppi	193	178	163	165	181

Application Sites: Various sites around the world are either using or experimenting or both with the use of recycled rubber as a filler.

Sources/Contacts: For more information about this Best Practice, contact the references cited.

References:

See Appendix
(See Crumb Sizing and Size Distribution Best Practices)

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Recycled Rubber Content Effects on Properties of Virgin Compounds

Material: Recycled Rubber Derived from Tires, Industrial Scrap and Post Consumer Scrap Rubber Products.

Issue: *Recycled rubber content in a rubber compound may depend on two factors. One, required by the customer. The other is the limit in use of recycled rubber without any significant adverse effect on compound properties.*

Best Practice: Customer may require use of certain amount of recycled rubber in rubber products. For example, Ford has indicated use of 25% recycled rubber in automotive rubber parts except in tires where it might be up to 10%. In general, for high performance products (e.g., tire, belts) use of recycled rubber would be lower than for lower level performance products. Actual amount will depend on desired properties of the compound. However, some guidelines given here can be used for different processes, along with compound property requirements. For compression molding, particles as large as 6-8 mesh can be successfully used, e.g., in railroad crossing pads. In mechanical and compression molded goods such as mats, semi-pneumatic tires, bumpers, shocks, 10-30 mesh are commonly used at up to 30-40% levels.

For injection molding, 40-80 mesh recyclates are required to get good flow through the gates and sprues and to produce an acceptable surface finish. Levels up to 10% are commonly used.

For extrusion and calendered goods, 80-120 mesh recyclates are used. This is because the surface finish in these products requires the final product to be smooth. The larger particles do not give the desired smoothness. Three to ten percent levels of recyclates are used with 5% being typical.

Implementation: Customer may require vendor to use certain percentage of recycled rubber for environmental reasons and to be a good corporate citizen. Actual amount may depend on specification of product properties. Normally use of 5 to 10% recycled rubber with 60-100 mesh size particles does not significantly affect rubber properties.

Benefits: Use of recycled rubber will minimize environmental issues such as storage of old tires, fire hazard. Its use may lower the cost of rubber products.

Application Sites s: Plant sites of end-users and rubber product manufacturers.

Sources/Contacts: Krishna C. Baranwal, Akron Rubber Development Laboratory, Akron, Ohio, Phone 330-794-6600.

References: Midwest Elastomer Technical Bulletin on Fine Particle Rubber Technology.

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EPA

NIST MEP Environmental Program

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Fillers for Rubber Compounds - Carbon Black

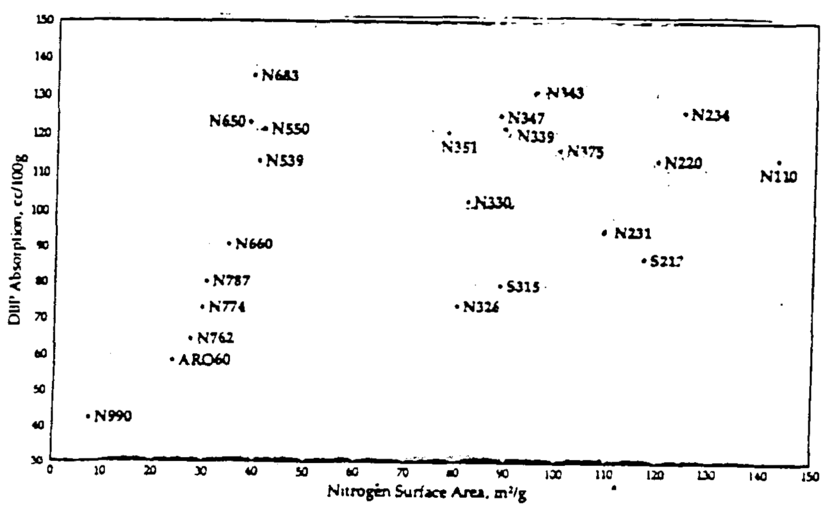
Material: Recycled Rubber from Tires, Industrial Scrap Rubber and Post Consumer Scrap Rubber Products

Issue: *Almost all virgin rubber compounds (99%) utilize either carbon black and inorganic fillers such as precipitated or fumed silica, clay, ground or precipitated calcium carbonate, titanium dioxide, zinc oxide, and several others. These materials are used as reinforcing agents and extender fillers for rubber compounds.*

Best Practice: This best practice reviews the black fillers used to reinforce rubber compounds such as those used for tires, hose, belts, mechanical goods, and other practical rubber goods. The major filler used in tire compounds is carbon black. Carbon black is made by the controlled cracking of low grade hydrocarbons into fine particle carbon particles. These are known as furnace blacks. Two other processes, thermal black and channel black are also used as small volume carbon black for specialty uses. Over 97% of all carbon black is produced by the furnace process.

Recycled rubber contains carbon black in the same proportions as the virgin rubber from which it is recovered. High reinforcing black in the virgin rubber will possess more reinforcing properties in the recycled form. However the properties of recycled rubber or more directly related to particle size. The smaller the size the more reinforcing the material.

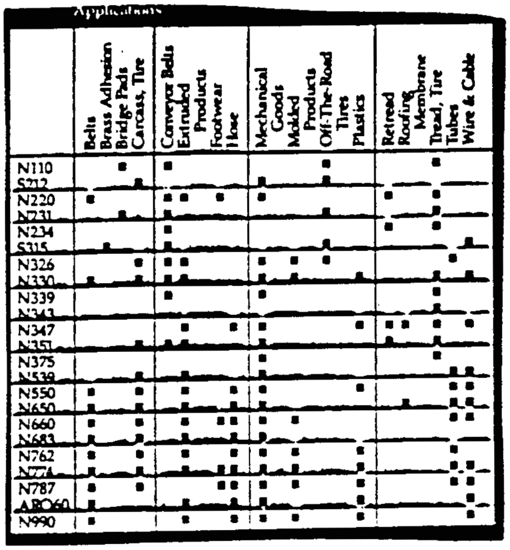
The following chart shows the range of particle sizes and structure of available commercial carbon blacks:



Implementation: Carbon black is mixed into compounds at controlled levels using a Banbury mixer. The type of carbon black used depends on the intended application of the compound.

Benefits: The higher the DPB Absorption, the higher the structure of a carbon black. As structure increases the abrasion resistance increases and the dynamic properties decrease. As particle size decreases, reinforcing properties increase.

Tires usually use four to six different types of carbon blacks in the various components. These are summarized in the following chart:



Application Sites: Carbon black is used at almost every location where rubber compounds are being mixed.

Sources/Contacts: For more information about this Best Practice, contact Engineered Carbons, Dallas , TX, phone 214-241-8822, Columbian Chemicals, Atlanta, GA , phone 404-951-7000, Cabot Corp., Norcross, GA, phone 800-472-4889, Cancarb Ltd., Medicine Hat, Alberta, Canada, phone 403-527-1121, Sid Richardson, Fort Worth, TX, or JM Huber, Macon, GA, phone 912-745-4751.

References:

Technical bulletin by Engineered Carbons, Inc. titled Carbon Black for Rubber, 1996.

Carbon Black, Jean-Baptiste Donnet, Roop Chand Bansal, Meng-Jiao Wang, Marcel Decker, Inc., New York, 1993.

(See Chemical Analysis Best Practice)

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Fillers for Rubber - Non Black

Material ***Recycled Rubber from Tires, Industrial Scrap Rubber, and Post-Consumer Scrap Rubber Products***

Issue: *Almost all virgin rubber compounds (99 percent) utilize either carbon black or inorganic fillers such as precipitated or fumed silica, clay, ground or precipitated calcium carbonate, titanium dioxide, zinc oxide and several others as either or both reinforcing agents or extenders for rubber compounds. Recycled rubber contains the same fillers as the virgin rubber from which the recyclate was produced.*

Best Practice: There are significant quantities of mineral fillers used in rubber compounds. These compounds include both natural and synthetic fillers. The major synthetic filler used is precipitated silica. This silica is 0.02 micron in average particle size. The silica is added to enhance the modulus and tear strength of tire compounds. It is also used as an ingredient in fabric and wire bonding systems. The silica, along with resorcinol and hexamethylene melamine, is used extensively in wire adhesion systems. Typically from 10 to 12 phr of silica is used. In addition, several tire compounds designed for very low rolling resistance have 60 phr of silica coupled with a silane coupling agent to achieve vary low tangent delta values in the tread. The silica has an average surface area from 150 to 175 square meters per gram. About 200 million pounds of silica are used per year in the U.S. and growing rapidly.

Clay is also used as a semi-reinforcing agent for rubber. About 900 million pounds per year are used in the U.S.. Most is hard clay mined in Georgia and South Carolina. It is used in tire carcasses, sidewalls and bead insulation. Clay offers some reinforcement to the rubber compound but less than reinforcing grades of carbon black. The cost of clay is typically $0.03 to $0.05 per pound. Silane modified white clays are used in white sidewalls.

Ground and precipitated calcium carbonate is used in rubber compounds. The ground products are added as extender fillers, while the precipitated types offer some reinforcement due to their small particle size. It is reported that over 1 billion pounds of calcium carbonate is used in rubber compounds in the U.S. per year.

In addition to the other fillers mentioned, zinc oxide is added for cure activation, titanium dioxide is added white sidewalls for whiteness, alumina trihydrate is used as a flame suppressant, talc is added as a filler and extrusion aid and several other mineral fillers are used for special purposes such as conductivity, color, etc.

Implementation: All of the above fillers are mixed into rubber compounds. In general, more mineral fillers are used in non-tire compounds than in tire compounds. Non-black fillers are used in mats, wire and cable, footwear, rolls, hoses, belts, weather-stripping and many other types of products.

The mineral fillers at added usually after the polymer in the internal mixer or on the mill. Levels commonly used are from 5 to 100 parts. Some EPODE compounds may have levels of several hundred phr for low cost materials.

Benefits: All mineral fillers are usually white or lightly colored so the obvious benefit is that non-black mineral fillers can be used to make lightly colored goods.

Silica is used from 10 to 15 phi in wire skim compound for steel belted tires. It increases Modulus and improves wire adhesion. In addition, it is used in many radial and passenger tire components to stiffen the compound. Silica is also used by Michelin and Goodyear in the treads of the fuel efficient low rolling resistance treads. It is used in conjunction with a polysulfidic silane coupling agent.

Clay is used in a few tire components. These include some carcasses and white sidewalls. It is used from 40 to 65 phr. Clay is extensively added to mechanical goods to lower cost and provide some reinforcement.

Calcium carbonate is added to lower cost, improving processing and impart light color. It generally provides very little reinforcement or strength enhancement to the rubber.

Application Sites: Non-black fillers are used at almost every location making rubber parts, including tires.

Sources/Contacts: For more information about this Best Practice with regard to the materials mentioned above, please contact:

For Silica:	PPG, Pittsburgh, PA, (412) 434-2413 Degussa, Ridgefield Park, NJ, (210) 641-6100 Flexsys, Akron, OH, (330) 668-8377
For Clays:	ECC International, (404) 303-4411 JM Huber, Macon, GA, (912) 454-4751 Polymer Valley Chemicals, Akron, OH, (330) 945-6499 Thiel Kaolin, (912) 553-951 Burgess, (912) 552-2544 Engelhardt, (908) 205-5000 RT Vanderbilt, (203) 853-1400
For Calcium Carbonate:	ECC International, (404) 303-4411 Genstar, Hunt Valley, MD, (410) 527-4225 Omya, Proctor, VT, (802) 459-3311

References:

Rubber Blue Book, 1995, Lippincott & Peto Inc. Akron, Ohio (330) 864-2212
"The Use of Nonblack Fillers in Tire Compounds." L. Evans and W. Waddell, 148th ACS Rubber Division Mtg., Cleveland, Ohio. October 1995

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Curing Agents and Accelerators

Material: Recycled Rubber from Tires, Industrial Scrap Rubber and Post Consumer Scrap Rubber Products

Issue: *Almost all practical rubber compounds need to be vulcanized in order to be useful. This section will discuss the common vulcanization or curing systems used for tires and some non-tire rubber products.*

Best Practice: Unvulcanized rubber can be considered a high viscosity liquid which will flow under pressure. To overcome most of the flow properties, rubber requires the addition of a curing agent and chemicals to accelerate the cure. The most common curing agent is sulfur. The sulfur is thought to introduce crosslinks between the polymer chains of the rubber molecules. It is these crosslinks that make it difficult to recover the virgin rubber properties in recycled rubber and limit the use of recycled rubber in some applications. When curing rubber, heat and pressure is required to produce the crosslinks sulfur alone requires many hours at high temperature (275-300°F) to react. Typical sulfur levels vary from 0.5 phr to 3.0 phr.

To reduce the curing time to more practical duration's, organic chemicals that accelerate the cure are added. These are added at 1-2 phr levels and it is common to add a combination of accelerators to achieve the desired cure rate and properties.

It has been found when using reclaim rubber that the levels of certain organic chemicals such as stearic acid in the original compound can be reduced. This indicates that some of the ingredients in the reclaim material can impart properties to the virgin compound.

The most common accelerator classes and their speed or response time are shown below:

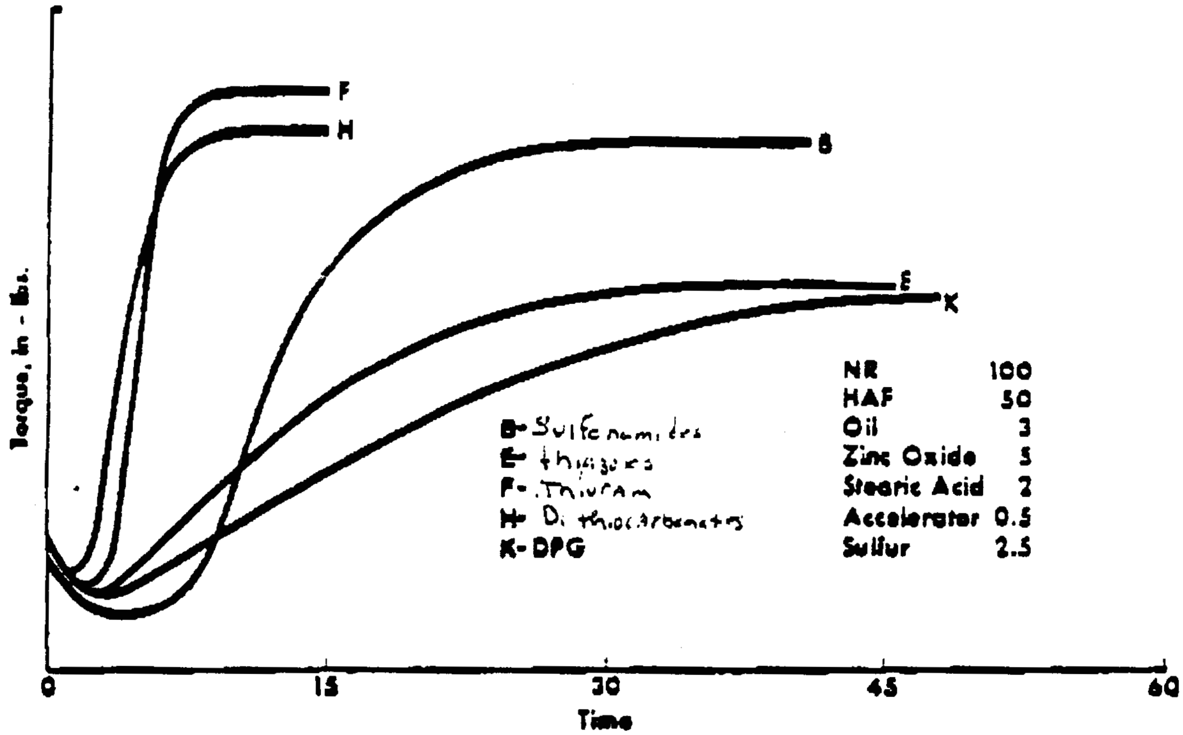
CLASS	RESPONSE TIME	ACRONYMS
Aldehyde-amine	Slow	
Guanidines	Medium	DPG, DOTG
Thiazoles	Semi-Fast	MBT, MBTS
Sulfenamides	Fast-Delayed Action	CBS, TBBS, MBS, DIBS
Dithiophosphates	Fast	ZBDP
Thiurams	Very Fast	TMTD, TMTM, TETD
Tithiocarbamates	Very Fast	ZMDC, ZBDC

In addition to sulfur curing systems, some elastomers are cured with peroxides to achieve good heat resistance.

Implementation: Accelerators and curing agents are weighed accurately based on the ratio desired in the compound. They are then added into the compound using an internal mixer or two-roll mill. They are usually added late in the mix cycle to reduce the tendency to scorch or to vulcanize too quickly.

Benefits: The major benefit of the curing agents and accelerators can best be seen in the following rheometer curve of a natural rubber compound containing the five major classes of accelerators. This was extracted from a Flexsys technical paper:

COMPARISON of ACCELERATOR CLASSES



Application Sites: Sulfur accelerated vulcanization is used at almost every location where rubber products are being made.

Sources/Contacts: For more information about this Best Practice, contact Flexsys L.P. (Formerly Monsanto) and request technical literature.

References:

"Vulcanization Systems", Byron To, Flexsys L.P., ACS Rubber Division, 148th Rubber Division Meeting, Cleveland, OH, October, 1995.

Vulcanization and Vulcanizing Agents, W. Hoffman, Palmerton Publishing Co., Inc., New York, 1967

(See Devulcanization - Reclaim, Devulcanization - Chemical, Devulcanization - Ultrasonic, and Devulcanization - Microwave Best Practices)

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Binders, Bonding Agents, and Adhesives

Material *Recycled Rubber from Tires, Industrial Scrap Rubber, and Post-Consumer Scrap Rubber Products*

Issue: In the production of virgin rubber compounds and new products it is often necessary to adhere or bond the rubber to another rubber piece, fabric, or metal. This best practice describes the materials used in these applications.

Description: Bonding Agents – This type is commonly used to adhere rubber to metal, plastic, and other rubber compounds. These agents are specialty prepared solvent and water based adhesives that are commonly applied to the bonding substrate. A primer is usually applied. Little is disclosed about the composition of the bonding agents.

Internal Adhesives, Bonding Agents, Binders – For metal and fiber reinforcement, such as steel belts and fabric in tires, hoses, and belts, a HRH (Hexa, Resourcinol, Hi-Sil) system is employed. This system involves adding Hexamethylene tetramine (HMT) or HMMM, resourcinol and precipitated silica into the rubber compound. This increases the stiffness of the unvulcanized rubber and the modulus of the cured rubber. The adhesion, or pull-out, force of steel or fabric from rubber is greatly enhanced with this method.

Recently, polymers with maleic anhydride modification have been introduced. EPDM, Hypalon, and PBD are currently available with this treatment. The compounds containing these modified polymers report improved adhesion.

Implementation: Bonding agents are commonly applied by spraying or painting. Internal adhesives are compounded into the virgin rubber.

Benefits: The major benefit is enhanced adhesion to metal, plastic, rubber, and other materials.

Application Sites: All sites where composite rubber products are made apply these materials.

Sources: Lord Corp. Literature, Morton Thixon Literature, Cytec Literature, Indspec Literature, Bayer Literature, Monsanto Literature, Interviews with Tire Company technical personnel.

References: See above

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Softeners, Oils, Plasticizers

Material: Recycled rubber from Tires, Industrial Scrap Rubber and Post Consumer Scrap Rubber Products

Issue: *Practical rubber compounds require the incorporation of petroleum oils and plasticizers to make them processable.*

Best Practice: Rubber polymers are high viscosity liquids. Inorganic fillers and carbon black are added to reinforce the rubber polymer. This increases the viscosity even further. To reduce the viscosity, improve processing and flow and reduce cost softeners (oils and plasticizers) are added to the rubber compound. Almost all rubber compounds are softened. Levels used vary from 5-10 phr for high performance treads like aircraft and off the road tires to several hundred phr in highly oil extended EPDM hose and extruded goods.

Plasticizing oils are arbitrarily divided into aliphatic, napththenic, and aromatic classes. The most widely used class is the aromatic oil. It is commonly added to passenger and truck tire treads, carcasses, and sidewalls as well as othe rcomponents. Napthtenic oils are added to white sidewalls and other components requiring non-staining properties. The recent trend in lowering the low rolling resistance of passenger tires has resulted in more naphhenic oil being used in treads and carcasses.

It should be noted that in the recycled rubber material, there is a residual oil from the orginal compounds in tires and non-tire products. A samll amount of oil may volatize in service. However most of it is still present. In the case of truck tires this will be mostly aromatic oil. In passenger tires this will be a blend of napthenic and aromatic oil. The aromatic oils are dark and in general staining. When added to a rubber compound the recyclate will impart staining characteristics in proportion to the amount of staining oil present.

Implementation: Plasticizers and oils are added into the rubber compound as liquids, dry liquid concentrates or oil extended masterbatch. The liquids are most commonly used and in large rubber plants are automatically injected into the internal mixer without opening the ram.

The amount of softener or oil present is measured using the acetone extract test. This is done by refluxing the rubber with acetone and weighing the amount removed. For tires this will typically be 10-25% by weight.

Benefits: Incorporation of oils and plasticizers lowers viscosity, improves processing and extrrusion properties, lowers hardness, improves low temperature flexibility and lowers cost. Proper selection of softener reduces and minimizes the loss in physical properties usually observed with thier addition.

Higher molecular weight oils have lower volatility and tend to be retained in the recyclate. At the present time compounding for softeners and oils does not take into account their use in recyclates.

Application Sites: Softeners are added to almost all rubber compounds. Therefore there are used at almost every rubber manufacturing site in the US and Canada. For a list of sites refer to the Rubbicana or Rubber Red Book directories of rubber companies.

Sources/Contacts: For more information about this Best Practice, contact Exxon, Sun, Ergon, and several others. The major plasticizer sources are CP Hall, Bayer, and Teknor Apex along with many others. Refer to the Rubber Blue Book for a more complete list of sources.

References:

Rubber Technology Handbook , Maurice Morton.
Sun Oil Trade Literature
CP Hall Trade Literature

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Rubber/Plastic Composites

Material ***Recycled Rubber from Tires, Industrial Scrap Rubber, and Post-Consumer Scrap Rubber Products***

Issue: *There is a need to find high volume applications for ground crumb or devulcanized rubber in order to increase the value of the recycling processes and to create stable, long-life markets for the materials.*

Best Practice: Ground scrap rubber and devulcanized rubber could be combined with various thermoplastic materials to provide reduced-cost "green" materials without sacrificing critical properties or processing characteristics. These materials are designed to be processed on conventional thermoplastic processing equipment such as singly injection molding, screw-extrusion, or blow molding, either as combined or separate processes.

Ground rubber particles of various mesh sizes are being used to modify materials such as Linear Low-Density Polyethylene (LLDPE), Polypropylene (PP), Polyurethane (PU), and Polyvinyl Chloride (PVC) among others. Typically the rubber particles are blended at levels from 5 to 70 percent into the thermoplastic material matrix using a batch mixer or melt extrusion system (twin-screw preferred) and chopped or cut into pellets suitable for further melt processing of the compounded material.

A variety of rubber scrap types are used in these blends, mostly as tire buffings, cryogenically ground tires, and shoe soles buffings and scrap. The properties of the resulting compounds depend on:

1. Mesh Size (Smaller = Stronger)
2. Elastomer Type
3. Recyclate Concentration

Recent advances in surface modification technologies of ground scrap rubber have greatly enhanced its value for use in thermoplastic compounds. Materials such as Vistamer and Ethylene-acrylic acid create more polar binding systems that allow the ground rubber blend better with the thermoplastic material, thus improving processing characteristics and material properties such and elongation and strength. These technologies open up opportunities for the compounds that until recently have been unreachable because of property deficiencies.

Devulcanized material is also finding use in thermoplastics, particularly as the soft phase when combined with PP in TPO materials. Typically, TPO materials are blends of varying ratios of PP and unvulcanized EPDM to provide toughened, higher impact resistant materials.

Implementation: Recycled rubber or plastic compounds can be used in a variety of end-use applications such as non-engineered automotive goods (e.g., brake pedal covers, acoustic barriers), and shoes as long as the cost-to-property ratio is competitive against similar virgin materials.

Benefits: Finding a large, continuing, value-added market for recycled rubber material is one of the biggest hurdles facing recyclers today. The successful use of scrap rubber in thermoplastic compounds produces this type of market and encourages further research into the development of more applications and technologies (i.e., surface modifiers) that eventually increase the size of the market already captured by these materials.

Application Sites: The automotive industry leads the push to find applications for "green" materials, or materials containing at least 25 percent recyclate, so major automotive material suppliers are extensively researching in this area. Current uses of this technology include G-Therm from Goldsmith & Eggleton and ECO-Flex from EcoTech (formerly Syntene).

Sources/Contacts: For more information about this Best Practice with regard to the materials mentioned above, please contact Mr. Edgar Gonzalez, EcoTech, (330) 769-4286, or Mr. Rob Eggleton, Goldsmith & Eggleton, (330) 336-6616.

References:

"Reactive Blending of Chemically and Physically Treated Waste Rubber with Polymethyl Methacrylate." A. Chidambaram, K . Min, SPE ANTEC '94 Conference Proceedings, May 1994, Vol. III, pp. 2927-34.

"High Value Engineering Materials from Scrap Rubber." B.D. Bauman, ACS Rubber Division 145th Meeting, Spring 1994 Conference Proceedings April 19-22, 1994, Paper No. 25.

"Development of Low Cost Toughened Plastics Using Recycled Rubber." P. Phinyocheep, F.H. Axtell, ACS Rubber Division 144th Meeting, Fall 1993 Conference Proceedings October 26-29, 1993, Paper No. 40.

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End Product Testing Requirements

Material: Recycled Rubber Derived from Tires, Industrial Scrap and Post Consumer Scrap Rubber Products.

Issue: *Recycled rubber finds applications in tires, hoses, belts and mats. Common tests for rubber products compounds are tensile, elongation, modulus and hardness. However, special tests are required for very specific applications. For instance, aging and heat build-up properties are a must for tire carcass compounds, and fuel resistance for automotive hose. With the use of recycled rubber, these properties remain equally important.*

Best Practice: In this best practice, examples of key test requirements for rubber products are listed below. Also, brief explanations of pertinent tests are given in Appendix I.

Products	Pertinent Tests
• All rubber compounds	• Mixing behavior, Mooney Viscosity
• All rubber products	• Tensile, modulus, elongation, hardness
• Tire carcass	• Heat build-up, adhesion to sidewall and belt coat compounds
• Automotive hose	• Fuel resistance, aging properties
• Conveyor belt	• Abrasion resistance, fatigue life, and aging properties
• Engine mounts	• Dynamic properties, fatigue life, aging properties at high temperatures, compression set
• Floor mats	• Abrasion, discoloration

Implementation: Testing of end-products need to be done both by recyclers and users. Processors need to know results for specific tests for pertinent applications for marketing recycled rubber. End-users need to have some ideas about what to expect in items of properties by using certain percentage of recycled rubber.

Benefits: Knowledge of required critical tests will generate more meaningful test results and will avoid unnecessary tests.

Application Sites: Procesors' and end-users' plant sites.

Sources/Contacts: Krishna C. Baranwal, Akron Rubber Development Laboratory, Akron, Ohio, Phone 330-794-6600.

References: ASTM D412, D573, D2240, D2228, D4482, D4483, D623, D624, D429, and D471. Titles of these are included in Appendix I.

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APPENDIX 1

Explanation of Various Tests for Rubber Products

1.	Mixing:	Mixing of rubber compounds using all necessary ingredients either in an internal mixer or on a mill, in a desired time with a good band on mill after mixing.
2.	Extrusion:	Extrudate to have surface and edges (not feathered). (ASTM D2230)
3.	Calendering:	Smooth surfaces of rubber sheets when calendered in a 3-roll machine.
4.	Molding:	Good mold flow to fill the mold and good knitting ability of compound.
5.	Mooney Viscosity:	To determine viscosity of a mixed, uncured compound. This gives some idea about processability of a compound (ASTM D4483).
6	Unaged Tensile Strength:	To determine tensile strength, elongation to break, and moduli at different elongations for cured, unaged samples (ASTM D412).
7.	Aged Tensile Strength:	Same as No. 6 above except for samples following accelerated aging in hot air or any other specified aging conditions (ASTM D573).
8.	Hardness:	Indicates reinforcing action of a black for cured, unaged specimen, and changes in hardness due to aging for aged specimen (ASTM D2240).
9.	Pico Abrasion Test:	To determine abrasion resistance of black-filled, cured compounds (ASTM D2228).
10.	Flex Fatigue Test:	Determines fatigue property of a compound, i.e., how long a compound lasts under certain fatigue conditions. Monsanto Flex Fatigue (ASTM D4482).
11.	Die B Tear Test:	Determines tear strength of a compound (ASTM D624).
12.	Heat Build-Up Test:	Determines heat generation due to compression flexing. BFGoodrich Flexometer is used for this test (ASTM D623).

APPENDIX 1 - cont.

13.	MTS Dynamic Properties:	Determines damping characteristics of a compound. provides data on elastic modulus (E′). loss modulus (E″) and tan δ.
14.	Rubber to Rubber Adhesion:	Example: How carcass compound will adhere to belt coat compound after curing. Normally. strip adhesion test is used for this (ASTM D429 - Rigid).
15.	Fuel Resistance:	How will a compound retains its properties aged in certain fuels (ASTM D471).

Non-Tire Uses of Recycled Rubber

Material **Recycled Rubber from Tires, Industrial Scrap Rubber, and Post-Consumer Scrap Rubber Products**

Issue: *Non-tire products make up from about 40 to 45 percent of all rubber goods manufactured. These goods include hoses, belts, o-rings, seals, footwear, weather-stripping, roofing, wire and cable, calendered sheeting and other mechanical rubber goods. This Best Practice lists some of the areas where recycled rubbers have been and are used.*

Best Practice: The following is a summary of areas that use recycled rubber:

Product Class	Product Type	Typical Reclaim %
Mechanical Rubber Goods	Extruded Tubing	5-10
Mechanical Rubber Goods	Weather-stripping	10-25
Mechanical Rubber Goods	Calandered Roofing Components	20-40
Mechanical Rubber Goods	Calandered Viton Sheet	10-30
Mechanical Rubber Goods	Viton Valve Stems	30-40
Mechanical Rubber Goods	Silicone Spark Plug Boots	10-30
Mechanical Rubber Goods	TPE in Brake, Clutch Pads	10-30
Mechanical Rubber Goods	Molded Roofing Components	10-30
Mechanical Rubber Goods	Automotive Shims and Spacers	60-60
Mechanical Rubber Goods	Railroad Crossings	0-80
Mechanical Rubber Goods	Mud Flaps	50-60
Mechanical Rubber Goods	Bed Liners	30-50
Mats	Floor Mats	10-100
Wire and Cable	None	0
Medical and Pharmaceutical	Crutch Tips, Wheelchair Tires	10-100
Hose	SBR Garden Hose, Soaker Hose	
Belts	Non-OE Belts	
Footwear	Shoe Soles	10-100

Implementation: Ground recycled rubbers and devulcanized and surface treated rubbers are incorporated in the mixing stage using a Banbury or two-roll mill. They are usually added near the end of the mixing cycle. Typical properties of these materials show that the viscosity of the unvulcanized rubber goes up and the tensile strength falls proportionate to the amount of recycled rubber added.

Benefits: The major benefit of using recycled rubber is usually cost reduction. In addition, ground rubber facilitates the removal of trapped air in molded goods, especially the low permeability rubbers like butyl, halobutyl, and fluoroelastomers.

Application Sites: For detailed information about the many users of recycled rubber materials, see the *Rubber Red Book* and the *Rubbicana*.

Sources/Contacts: For more information about this Best Practice, contact either Mr. Bill Klingensmith, Akron Consulting Company, or Mr. Fernly Smith, ETA, or both.

References:

(See Information Sources Best Practice)

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Applications in Tires for Recycled Rubber (Passenger and Light Truck)

Material *Recycled Rubber from Tires, Industrial Scrap Rubber, and Post-Consumer Scrap Rubber Products*

Issue: *Tires are the single largest user of rubber, fillers, oil and other compounding materials. The different compounds used to make tires can have recycled rubber added typically from 3 to 5 percent depending on the application area.*

Best Practice: The following table describes current or potential application sites for using recycled rubber in tire compounds. The table is limited to passenger car and light truck tires.

	Passenger Tires		Light Truck Tires	
	Bias	Radial	Bias	Radial
Treads	Yes	Unlikely (1)	Unlikely (1)	No
Subtreads	Unlikely (1)	No	Unlikely (1)	No
Carcasses	Yes	Yes	Yes	Yes
Bead Filler	Yes	Yes	Yes	Yes
Sidewalls	Yes	No	No	No
Wedges	Yes	Yes	Yes	Unlikely (1)
Squeeges	Yes	Unlikely (1)	Yes	Unlikely (1)
Apex	Yes	Yes	Yes	Unlikely (1)
Filler Strips	Yes	Yes	Yes	Yes
Wire Skim	DNA (2)	No	DNA (2)	No
Liner	Yes	Yes	Yes	Yes

(1) High dynamic performance requirements of this component make it unlikely, but recyclate might be used in some limited low demand tire applications.

(2) DNA = Does Not Apply

The tread, subtread, carcass, and sidewalls are the largest single components of the tire. The areas that represent the best prospect for the use of ground recycled rubber in the tire are the carcass, apex, wedges, filler strips, and squeeges.

Implementation: Recycled materials must be considered in the original development of the tires. Therefore, efforts to incorporate recycled rubber must begin with original compound testing and evaluation.

Benefits: The major benefits are cost reduction and less air entrapment during the molding operation.

Application Sites: Include all of the major tire manufacturers: Goodyear Tire & Rubber, Akron, OH; Bridgestone/Firestone Tire & Rubber, Akron, OH; Michelin Tire, Greenville, SC; Continental-General, Akron, OH; Dunlop Tire & Rubber, Buffalo, NY; Pirelli Armstrong, New Haven, CT; Cooper Tire, Findlay, OH; Denman Tire, Warren, OH; and Specialty Tire, Indiana, PA.

Sources/Contacts: For more information about this Best Practice, contact Mr. Frank Jenkins, Continental-General (Retired) or Mr. Walter Klamp, Goodyear (Retired). Other undisclosed sources at Goodyear, Michelin, and Bridgestone/Firestone were used for this Best Practice.

References:

"Tires as a Source of Raw Materials & Uses of Recycled Rubber." Smith, Klingensmith, ACS Rubber Division Conference, Spring 1990, Washington DC (Submitted Paper).

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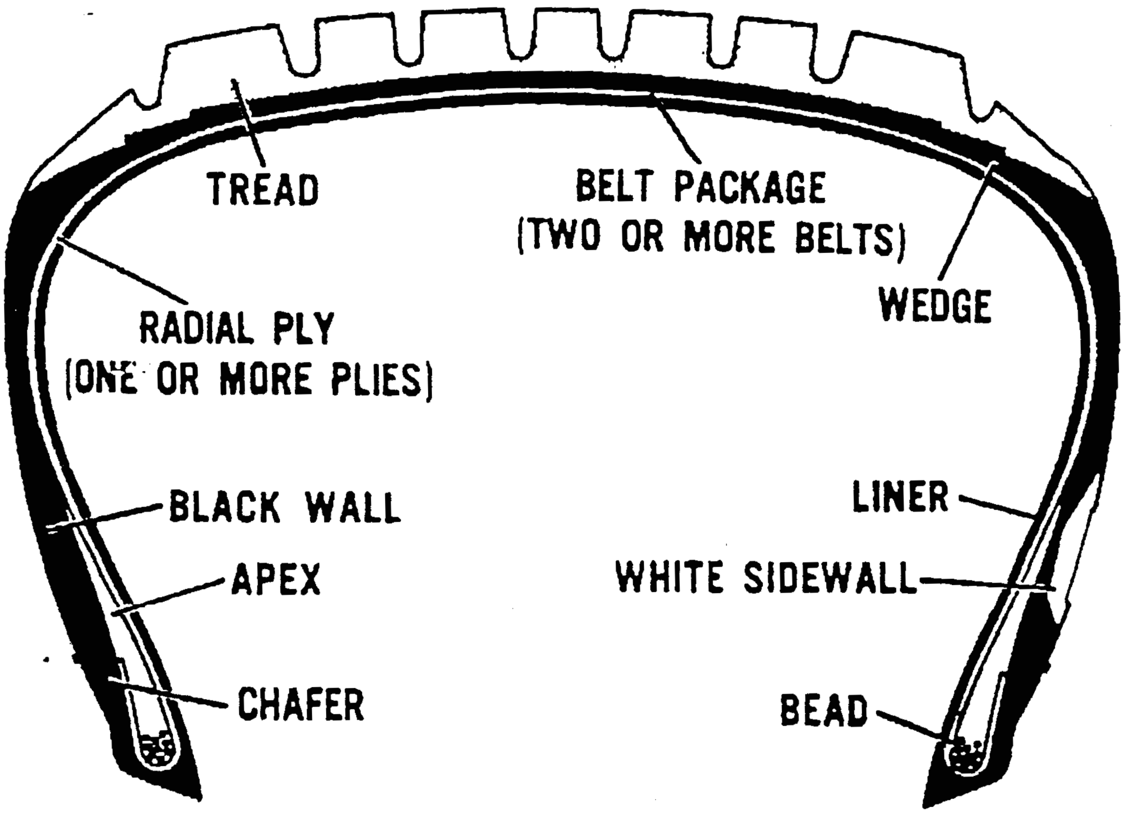


Figure 4: cross section of radial passenger tire

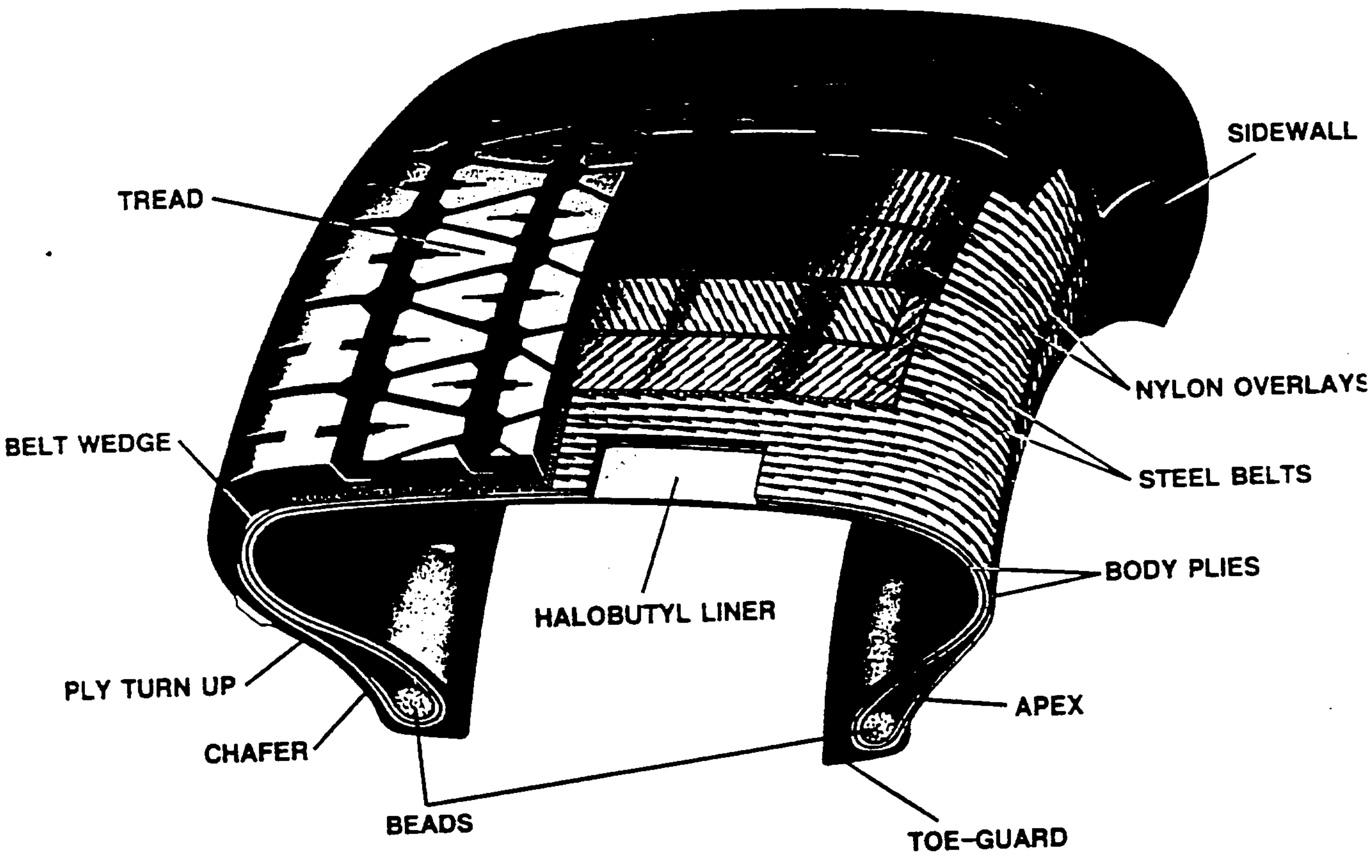
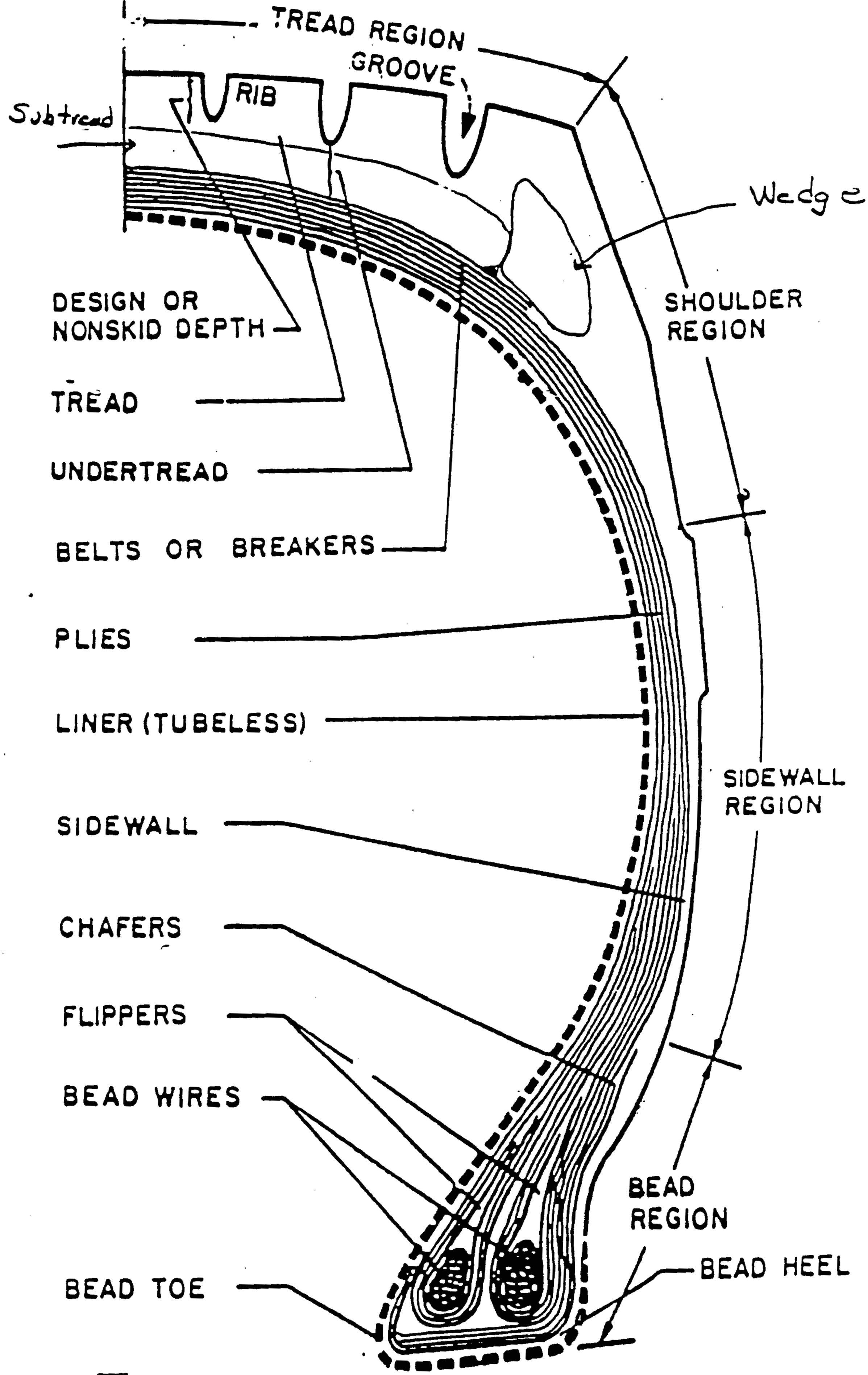


FIGURE Cross section of a high-performance passenger tire.



Truck Tire

Structural components.

Applications in Tires for Recycled Rubber (Heavy Truck and Other)

Material Recycled Rubber from Tires, Industrial Scrap Rubber, and Post-Consumer Scrap Rubber Products

Issue: *Tires are the single largest user of rubber, fillers, oil and other compounding materials. The different compounds used to make tires can have recycled rubber added typically from 3 to 5 percent depending on the application area.*

Best Practice: The following table describes current or potential application sites for using recycled rubber in tire compounds. The table is limited to heavy duty trucks and other tires including solid and semipneumatic bias tires.

	Heavy Duty Truck Tires		Other Tires	
	Bias	Radial	Solid	Semipneumatic
Treads	Unlikely (1)	No	Yes	Yes
Subtreads	Unlikely (1)	Unlikely (1)	Yes	Yes
Carcasses	Yes	No	Yes	Yes
Bead Filler	Yes	Unlikely (1)	Yes	Yes
Sidewalls	Yes	No	Unlikely (1)	Unlikely (1)
Wedges	Yes	No	DNA (2)	DNA (2)
Squeeges	Yes	Yes	DNA (2)	DNA (2)
Apex	Yes	Unlikely (1)	DNA (2)	DNA (2)
Filler Strips	Yes	No	DNA (2)	DNA (2)
Wire Skim	DNA (2)	No	DNA (2)	DNA (2)
Liner	Yes	No	Yes	Yes

(1) High dynamic performance requirements of this component make it unlikely, but recyclate might be used in some limited low demand tire applications.

(2) DNA = Does Not Apply

The tread, subtread, carcass, and sidewalls are the largest single components of the tire. The areas that represent the best prospect for the use of ground recycled rubber in the tire are the carcass, apex, wedges, filler strips, and squeeges.

Implementation: Recycled materials must be considered in the original development of the tires. Therefore, efforts to incorporate recycled rubber must begin with original compound testing and evaluation.

Benefits: The major benefits are cost reduction and less air entrapment during the molding operation.

Application Sites: Include all of the major tire manufacturers: Goodyear Tire & Rubber, Akron, OH; Bridgestone/Firestone Tire & Rubber, Akron, OH; Michelin Tire, Greenville, SC; Continental-General, Akron, OH; Dunlop Tire & Rubber, Buffalo, NY; Pirelli Armstrong, New Haven, CT; Cooper Tire, Findlay, OH; Denman Tire, Warren, OH; and Specialty Tire, Indiana, PA.

Sources/Contacts: For more information about this Best Practice, contact Mr. Frank Jenkins, Continental-General (Retired) or Mr. Walter Klamp, Goodyear (Retired). Other undisclosed sources at Goodyear, Michelin, and Bridgestone/Firestone were used for this Best Practice.

References:

"Tires as a Source of Raw Materials & Uses of Recycled Rubber." Smith, Klingensmith, ACS Rubber Division Conference, Spring 1990, Washington DC (Submitted Paper).

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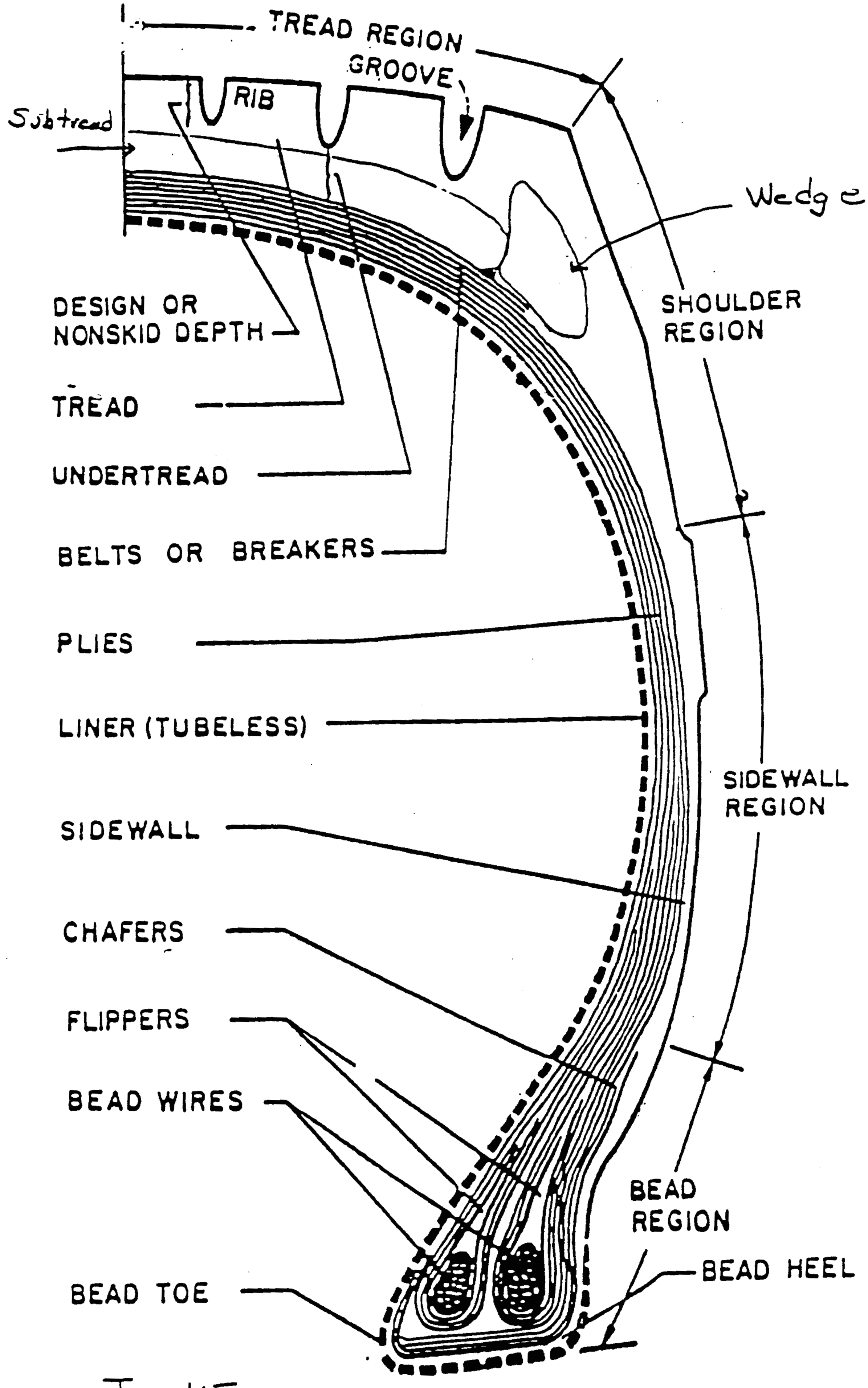

Truck Tire

Structural components.

Information Sources on Rubber Recycling

Material: Recycled rubber from Tires, Industrial Scrap Rubber and Post Consumer Scrap Rubber Products

Issue: *There are many sources of information on various topices related to rubber recycling. This best proctice lists the sources, locations, and a brief description of what is available from each.*

Best Practice: The following table outlines the information sources:.

Organization	Info Source	Publication	Information	Trade Show/ Convention
ACS - Rubber Recyclng Topical Group	Yes	None	Group of industry experts that share technology info.	Yes
Akron Consulting Co.	Yes	None	Offers expert consulting and industry information	No
Akron Rubber Development Laboratory	Yes	None	Consulting and testing laboratory	No
Clean Washington Center	Yes	Best Practices in Scrap Tire/Rubber Recycling	Reports on a variety of issues regarding rubber recycling	No
Crain Communication	Yes	Rubber & Plastics News	Weekly publication with regular articles on recycling plus annual recycling issue	No
Lippincott & Peto	Yes	Rubber World	Monthly rubber journal with articles on recycling	No
Palmerton Publishing	Yes	Rubber Red Book	Directory of rubber mfgs. and suppliers	No
Rubber & Plastics Research Association	Yes	RAPRA Database	CD-ROM database on all aspects of rubber	No
Rubber Research Institute	Yes	Scrap Tire Users Directory	Annual lists of equipment, suppliers, and products for recycling	No
Rubber Research Institute	Yes	Scrap Tire News	Monthly newsletter on tire recycling developments	No
Scrap Tire Management Council	Yes	Scrap Tire Update Reports	Periodic reports on all aspects of tire recycling	Yes
US Patent Office	Yes	US Patents	Historical and current data on recycling processes	No

Implementation: Puchase the appropriate publications or contact the organizations involved in rubber recycling.

Benefits: These information sources provide up to date information on technical, economic, environmental, and business aspects of rubber recycling.

Application Sites: Any and all companies involved in rubber recycling should be in contact with these information sources.

Sources/Contacts: For more information about this Best Practice, contact the following:

Source	Telephone	Fax	E-Mail
ACS - Rubber Recyclng Topical Group	(330) 972-7424	(330) 972-5269	
Akron Consulting Co.	(330) 644-0445	(330) 644-3516	
Akron Rubber Development Laboratory	(330) 794-6600	(330) 794-6610	
Clean Washington Center	(206) 587-4221	(330) 464-6908	
Crain Communication	(330) 867-9180		
Lippincott & Peto	(330) 864-2122	(330) 864-5298	
Palmerton Publishing	(404) 955-2500	(404) 955-0400	
Rubber & Plastics Research Association	(330) 972-7197		
Rubber Research Institute	(860) 668-5422	(860) 668-5655	
Scrap Tire Management Council	(202) 682-4882	(202) 682-4850	
US Patent Office			

References: None

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EPA

NIST MEP Environmental Program