TIRE APPLICATIONS OF ELASTOMERS

presented to

National Highway Traffic Safety Administration

Washington, DC

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August 22, 2006
2006PYBA 20; 2004 PYBP XT1045

Outline

- **Pneumatic Tires**
  - **Function**
  - **Consumer Tires**
- **Tire Components**
- **Casing Compounds**
- **Summary**

Pneumatic Tire

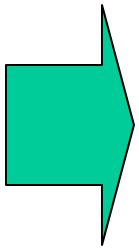
Ref: Bhakuni, Mowdood, Waddell, Rai and Knight, "Tires"
in "Encyclopedia of Polymer Science and Engineering", Second Edition (1989)

- **Tire is a toroidal, high-performance polymeric composite providing load carrying capability, cushioning and road-handling abilities**
- **It transmits driving and braking forces, and performs all functions essential to locomotion**
- **It is a complex system of interacting components, each with specific properties for maximum effectiveness**
- **Tire performance depends on properties and interactions of components, and service conditions**

Functions of a Pneumatic Tire

Ref: Kovac and Rodgers,"Tire Engineering" in Science & Technology of Rubber (1994)

- **Load-carrying capacity**
- **Cushioning ability**
- **Transmit driving / braking torque**
  - **Produce cornering force**
  - **Provide steering response**
- **Provide dimensional stability**
- **Provide adequate treadlife**
- **Consume minimum power**
- **Have minimum noise and vibration**
- **Be durable and safe**



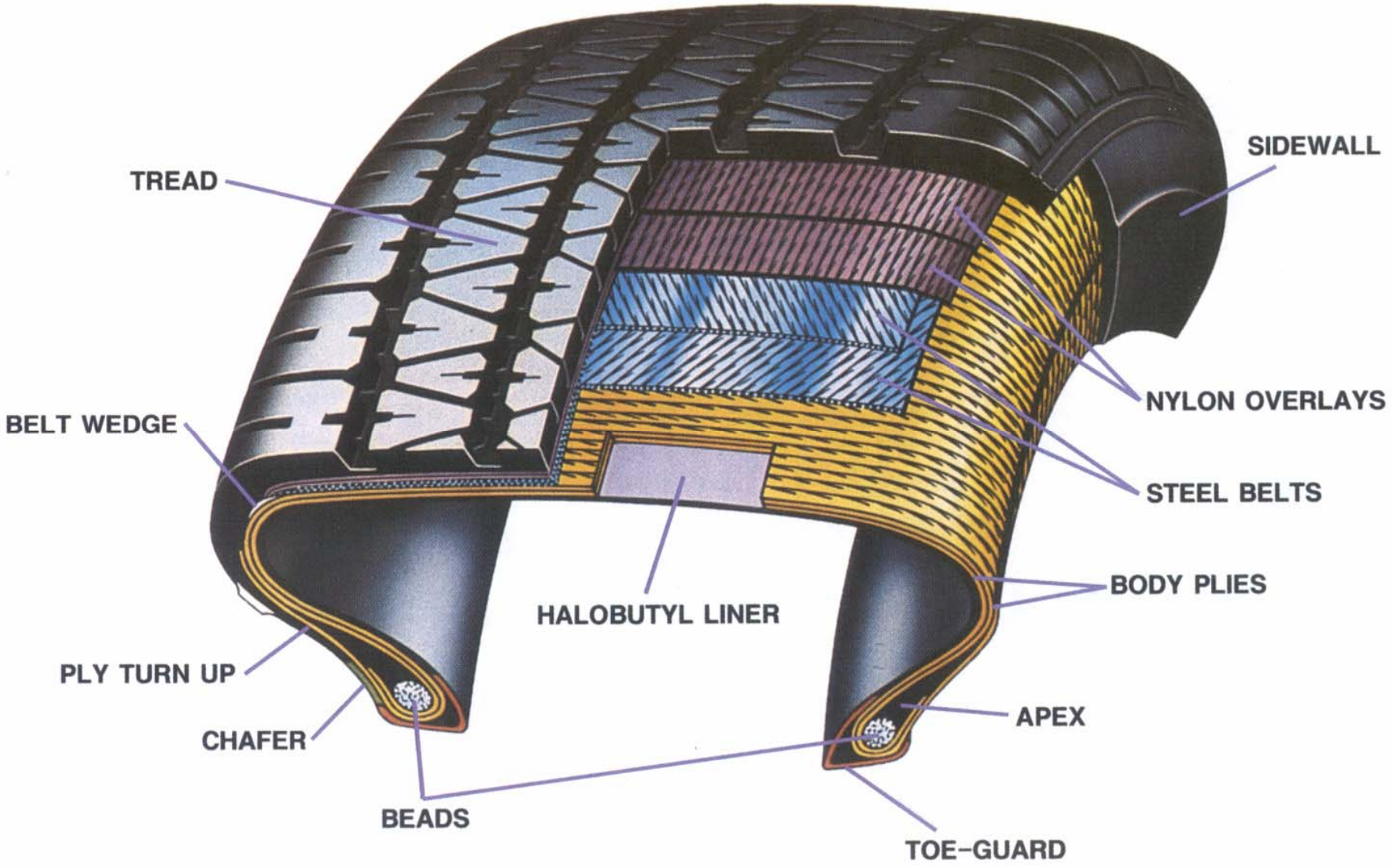
- **Traction**
- **Damage resistance**
- **Chip / Chunk / Cut**
- **Fuel economy**
- **Retreadability**
- **Tread wear**
- **Handling and Comfort**

Consumer Tire Applications

Automobile, Light Truck, Sport Utility Vehicle Tires

Schematic: Radial Passenger Tire

Ref: Kovac and Rodgers, in Science & Technology of Rubber, Mark and Eirich, Eds. (1994)



Outline

- **Pneumatic Tires**
- **Tire Components**
  - **Tread Area**
  - **Tire Casing**
    - **Belt Area**
    - **Ply Cord Area**
    - **Bead Area**
    - **Sidewall Area**
    - **Innerliner**
- **Casing Compounds**
- **Summary**

Tire Components

- **Pneumatic tire consists of two basic areas**
  - **Tread area**
  - **Casing components**
- **Tread area is responsible for ground contact**
- **Casing is responsible for supporting load, transmitting power to the tread area, and cushioning**
- **Each of these areas has several components with different properties each of which serves specific and unique functions, and all of which must interact for maximum tire performance**

Tread Components

- **Tread (also called the tread cap)**
  - **Wear-resistant component that contacts the road surface. It is designed for abrasion resistance, traction, speed, stability, and casing protection. It provides frictional contact for transmission of driving, braking and cornering forces.**
- **Base (also called the tread base compound)**
  - **Rubber compound placed in between the bottom of the non-skid grooves of the tread and the carcass. It is formulated for low hysteresis, fatigue, tear, durability, and compatibility with the tread compound.**
- **Cushion**
  - **Rubber compound placed in between the tread and the belt, or in between the base and the belt. It is formulated to give good adhesion, low heat build-up, fatigue and age resistance, and compatibility with the base compound.**

Casing Components: Belt Area

- **Belt**
  - Layers of rubber-coated, brass-plated, cabled steel wire forming a hoop under the tread. They restrict deformation of the casing and provide rigidity to the tread thereby allowing improved wear and handling performance, better damage resistance and protection of the body ply cords.
- **Wire Coat** (also called the belt coat or wire skim compound)
  - Must possess adhesion to brass-coated steel which provides stress transfer from the very rigid steel cord to the considerably more flexible tread, sidewall, and textile carcass components. Normally formulated to provide resistance to tearing, fatigue and aging.
- **Gum Strips**
  - Small strips of rubber placed at various parts of the tire to provide local reinforcement and corrosion resistance at the belt endings.
- **Overlay** (also called a cap ply)
  - Rubber-coated fabric reinforcement laid over the top belt. Acts to counter and restrain centrifugal forces when tire is operating at high speed.

Casing Components: Ply Cord Area

- **Wedge (also called shoulder wedge compound)**
  - **Formulated for high dynamic stiffness, resilience, fatigue adhesion, and tear resistance to reduce belt-edge sheer stresses while tying the belt to the carcass, and reducing hysteresis.**
- **Ply Cords (or plies)**
  - **Rubber-coated steel or fabric extending from bead to bead. Serves as the primary reinforcing member of the tire casing by providing strength and structural rigidity thus contributing to high-pressure air retention.**
  - **Passenger, aircraft, farm, bias earthmover and motorcycle tires plies normally are soft and flexible textile cord, i.e. polyester or rayon fabrics.**
  - **Radial medium truck tires normally a use steel cord ply, and radial earthmover tires are also constructed using steel cord plies.**
- **Carcass Coat (also called ply coat or casing coat compound)**
  - **Functions are similar to the wire coat compound. It is normally formulated for good adhesion to polyester or rayon fabrics, and for resistance to tearing, flex fatigue, and aging.**

Casing Components: Bead Area

- **Bead**
  - Rigid steel wire loop which anchors plies and locks tire onto wheel or rim so that the tire will not slip or rock on rim. Usually consists of multiple strands of high-tensile, bronze-plated steel coated with rubber.
- **Bead Insulation**
  - Compound that must possess good adhesion to the bronze-coated steel bead wire loop for enclosing the ply cords of the tire and holding the tire to the rim. It provides a seal to prevent air leakage.
- **Apex** (often referred to as bead filler compound)
  - Formulated for dynamic stiffness to facilitate stress distribution and provide good vehicle handling properties.
- **Chafer** (also called rim strip compound)
  - Narrow strip of reinforcing cord-rubber composite around bead, it protects plies from rim abrasion and seals the tire to the rim.

Casing Components: Sidewall Area

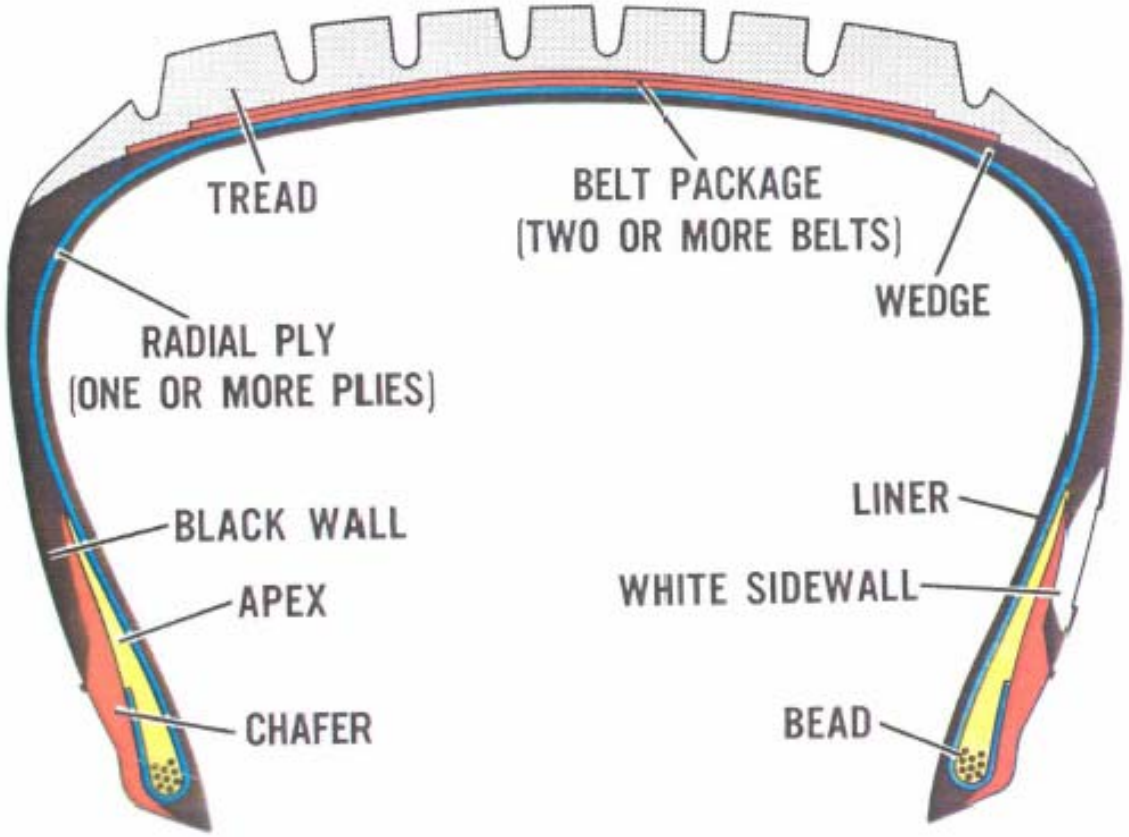
- **Sidewall**
  - Outer rubber layer that protects the tire from impact and curb scuffing, and to provide long-term weathering protection of the casing. It is formulated to protect the ply cord, and must possess resistance to weathering from heat, oxygen, and ozone, and provide abrasion, tear and flex fatigue resistance.
- **White Sidewall**
  - Non-reinforcing, decorative sidewall component usually displayed on the exterior sidewall as a continuous white or colored strip or as raised lettering.
- **White Sidewall Coverstrip**
  - Non-reinforcing, black outer rubber layer over the white sidewall component. It is formulated to protect the white sidewall compound, and must possess resistance to weathering from heat, oxygen, and ozone.

Casing Components: Liner

- **Innerliner**
  - **Thin layer of rubber laminated to the inside of a tubeless tire to ensure good air and moisture permeation resistance, and to resist moist, hot air aging.**

- **Barrier (also called squeegee or liner-backing compound)**
  - **Layer of rubber positioned between the liner and ply. It is intended to prevent the ply cords pulling through (strike through) into the innerliner during assembly and vulcanization.**

Tire Components: Polymer Applications



Component Elastomers

- **Tread: NR, SBR, and blends with BR**
- **Sidewall: NR / BR blends; HIIR, EPDM in WSW**
- **Ply coats: NR, SBR, BR blends**
- **Innerliner: BIIR, CIIR/NR blend**
- **Natural rubber is predominant polymer used in**
  - **Wire coat**
  - **Gum strips**
  - **Cushion**
  - **Base**
  - **Barrier**
  - **Apex**
  - **Chafer**

Outline

- **Pneumatic Tires**
- **Tire Components**
- **Casing Compounds**
  - **Model Wire Coat**
  - **Model Carcass Coat**
  - **Model Innerliner**
- **Summary**

Wire Coat

Wire coat compound is formulated for:

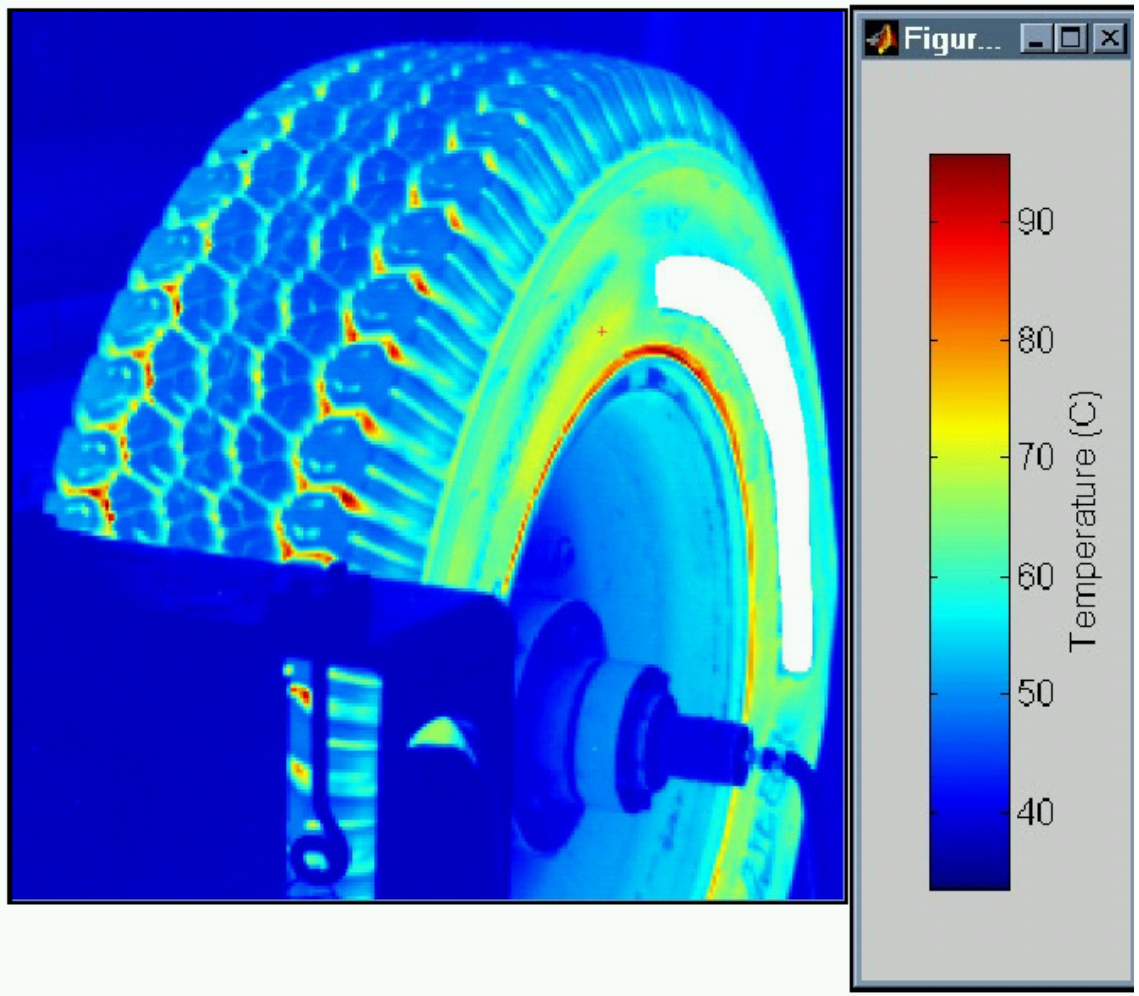
- **adhesion to brass-coated steel wire**
- **adhesion to adjoining tire components**
- **cure rate compatible with processing and curing of the green tire composite**
- **resistance to degradation by heat and oxygen**
- **resistance to tearing**
- **resistance to flex fatigue**

Natural rubber is usually the polymer of choice

- **controlled viscosity, i.e.. CV60, or technically specified grades**
- **synthetic cis-1,4-polyisoprene is also used**
- **peptizer also generally used**

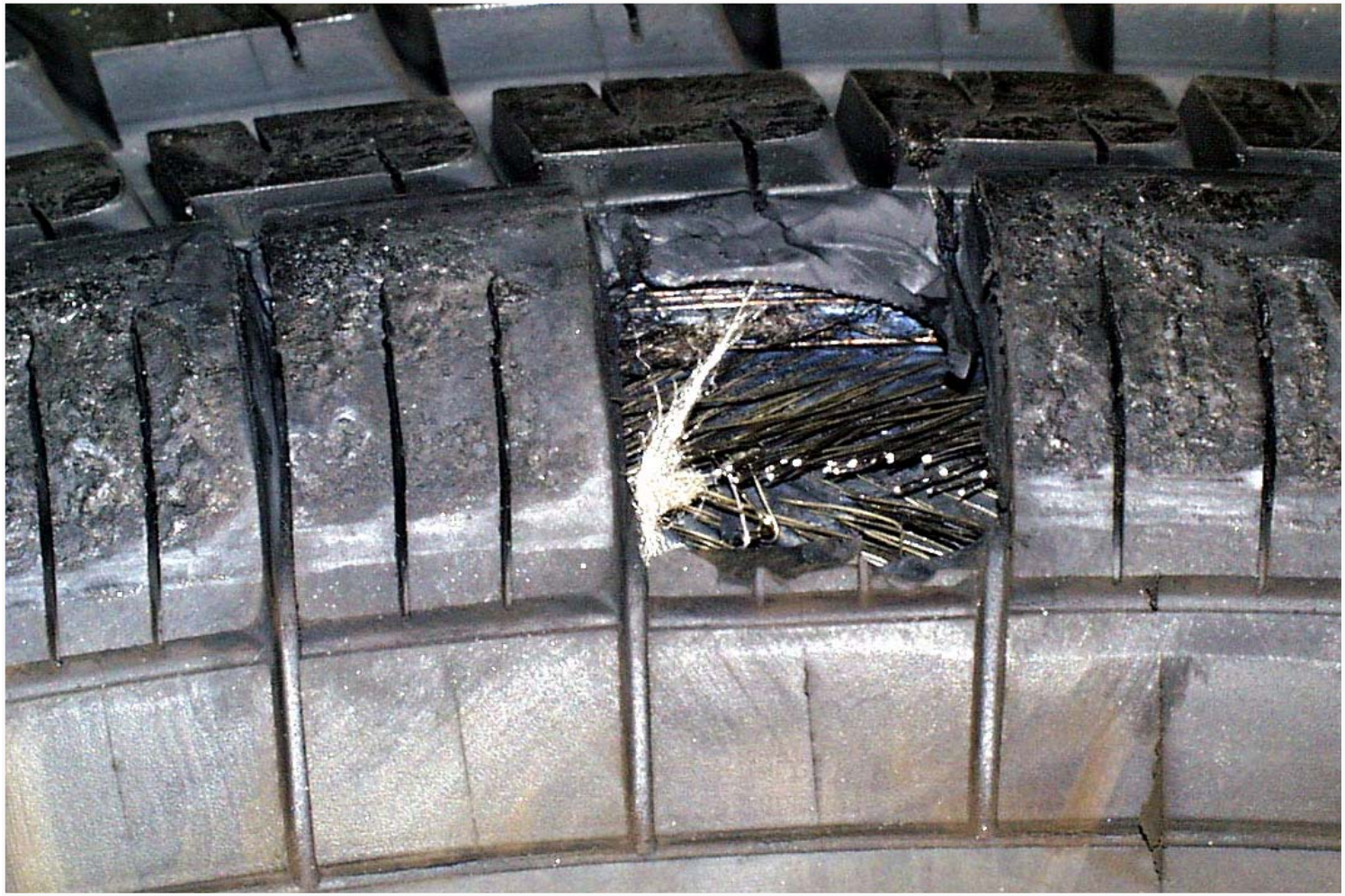
Heat Aging of Tire

Ref: Candido (Bridgestone/Firestone), “Tread Act New Regulations: A Tire Industry Perspective” , International Tire Conference and Exposition, paper 33E (2002)



Tires Heat-up at Steel Belts

Typical Durability Test Failures



Belt Edge Separation

Typical Durability Test Failures

Tread Wing Separation probably due to Belt Edge Separation

Model Tire Wire Coat: Cobalt

Ref: Evans, Hope, Okel and Waddell, Rubber World, 214, 21-26 (June, 1996)

	PHR
Natural Rubber	75
cis-Polyisoprene, Natsyn 2200	25
Carbon Black, N326	55
Silica	10
Aromatic Oil	3
Cobalt Neodecanoate	1.5
Antidegradant, aryl para-phenylenediamine	1
Stearic Acid	2
Zinc Oxide	8
Accelerator, Santocure MOR	0.8
Sulfur	4.5

Model Tire Wire Coat: Cobalt / Resin

Ref: Peterson, (Indspec) “Compounding for Brass Wire Adhesion” in Rubber Technology, Dick, Ed. (2001)

	PHR
Natural Rubber, CV60	100
Carbon Black, N326	50
Cobalt Naphthenate	0.83
Aromatic Oil	3
Antidegradant, 6PPD	2
Stearic Acid	0.5
RF Resin	3
Zinc Oxide	9.5
Insoluble Sulfur	5.6
HMMM	2
DCBS Accelerator	1.4
Inhibitor, N-Cyclohexylthiophthalimide	0.2

Carcass Coats

Variety of compounds are used to rubberize the carcass ply cords, the overlay and the flipper. All are normally formulated for:

- **good adhesion to fabric materials**
  - **polyester, rayon, nylon**
- **adhesion to adjoining tire components**
- **cure rate compatible with processing and cure of the green tire composite**
- **resistance to degradation by heat and oxygen**
- **resistance to tearing**
- **resistance to flex fatigue**
- **low heat build-up**

Blends of natural rubber, styrene-butadiene rubber and/or polybutadiene are often used

Model Tire Ply Coat

Ref: Waddell, Bhakuni, Barbin and Sandstrom, “Pneumatic Tire Compounding”, in The Vanderbilt Rubber Handbook, 13th edition (1990)

	PHR
Natural Rubber	70
BR 1220	30
Carbon Black, N660	50
Aromatic Oil	8
Antioxidant, Polybutylated Bisphenol A	1
Antiozonant	3
Stearic Acid	1
Zinc Oxide	3
Sulfur	2
Sulfenamide Accelerator, OBTS	0.8

Black Sidewall

Tire black sidewall is the outer surface of the tire that protects casing against weathering. Formulated for:

- **resistance to weathering from heat, oxygen, or ozone attack**
- **adhesion to adjoining tire components**
- **resistance to tear and cut / crack propagation**
- **resistance to abrasion (curb scuffing)**
- **cure rate compatible with processing and cure of the green tire composite resistance to radial and circumferential cracking**
- **good fatigue life**
- **low heat build-up**

Blends of natural rubber and cis-polybutadiene generally used

- **highly unsaturated elastomers such as isobutylene-based or EPDM polymers are used for non-staining applications**

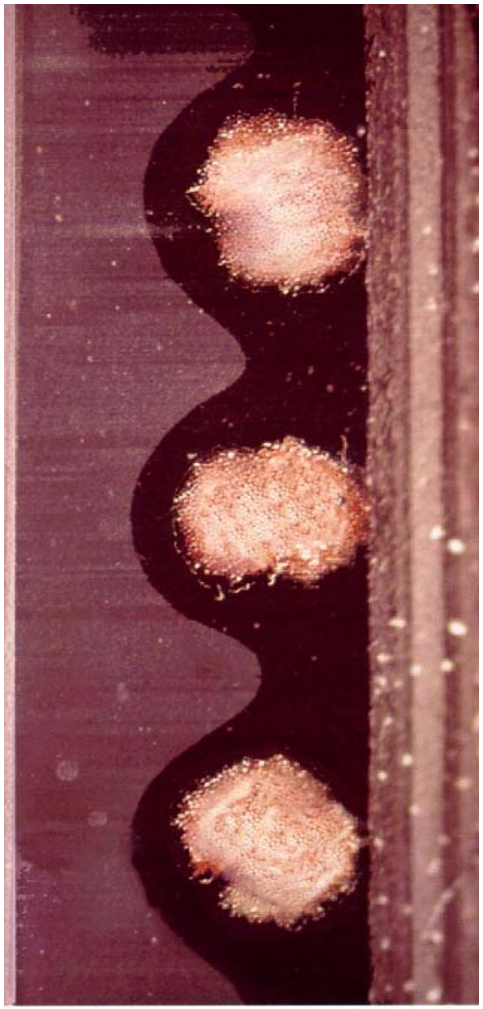
Model Tire Black Sidewall

Ref:.Barbin and Rodgers, “Science of Rubber Compounding”
in Science & Technology of Rubber, Chapter 9, Mark and Eirich, Eds. (1994)

	PHR
Natural Rubber	40
Polybutadiene	60
Carbon Black, N330	40
Peptizer	0.25
Paraffin Wax	1
Microcrystalline Wax	2
Naphthenic Oil	5
Antioxidant, TMQ (2,2,4-trimethyl-1,2-dihydroquinoline polymer)	1.5
Antiozonant, 6PPD (N-1,3-Dimethyl-N'-phenyl-p-phenylene diamine)	3
Stearic Acid	1.5
Zinc Oxide	3
Sulfur	1.25
Sulfenamide Accelerator, TBBS	0.8

Innerliner

Thin layer of rubber laminated to the inside of a tubeless tire to ensure good tire performance and durability



Formulated with halobutyl rubber to impart:

- **air impermeability**
- **moisture vapor barrier**
- **flex-fatigue resistance**
- **heat resistance**
- **resistance to oxygen aging**
- **adhesion to carcass ply coat**
- **cure rate compatible with processing and cure of the green tire composite**

Model Passenger Tire Innerliner

	PHR
Bromobutyl 2222	100
Carbon Black, N660	60
Naphthenic Oil	8
Struktol 40 MS	7
Phenolic Resin	4
Stearic Acid	1
Zinc Oxide	1
Accelerator, MBTS	1.25
Sulfur	0.5

Natural Rubber Use Increases Air / Moisture Permeability, and Decreases Age Resistance of Innerliner Compound

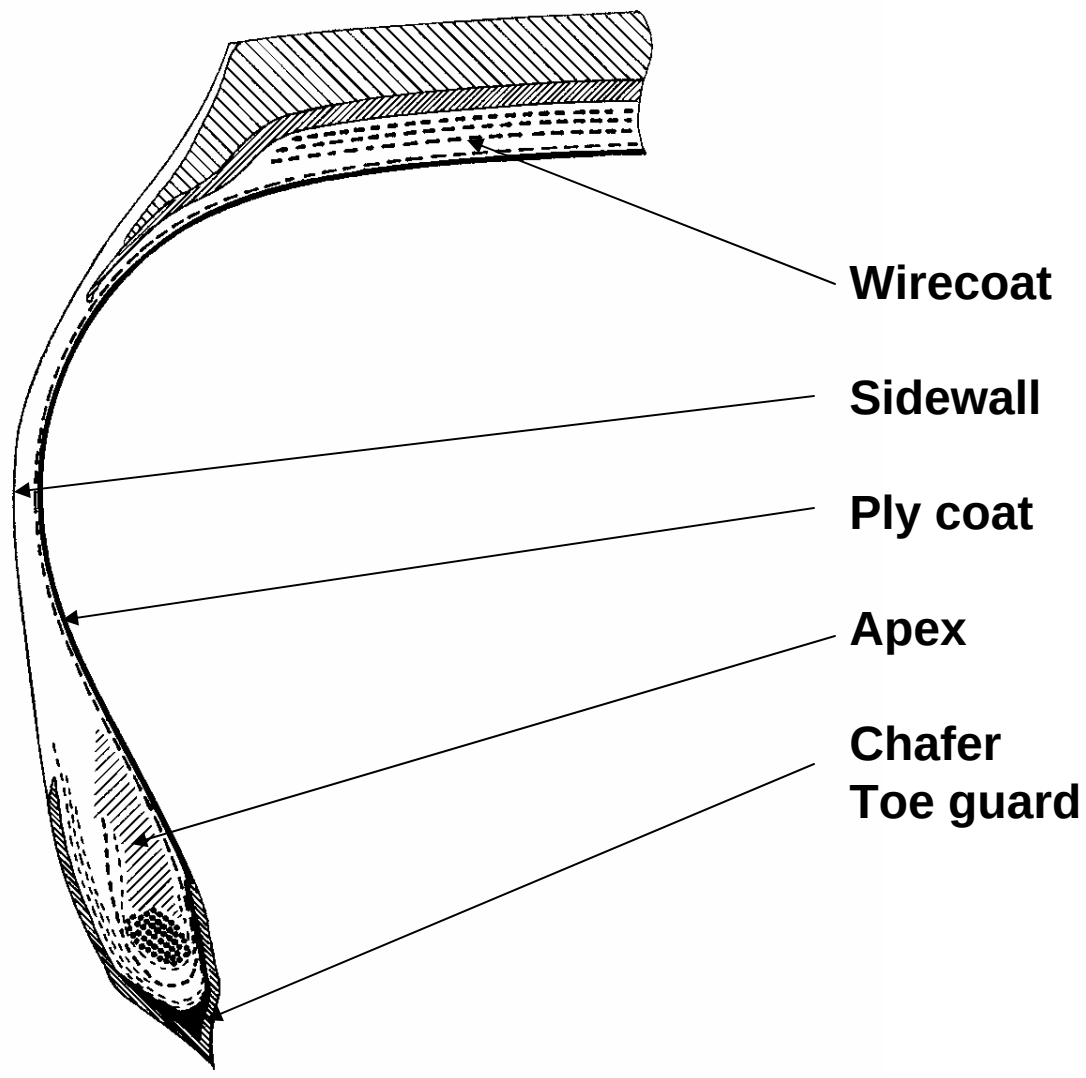
Summary

- **Key parameters governing tire tread physical and material design**
  - **Performance: Must meet end user requirements**
    - **Wide variety of consumer (car, light truck, sport utility) and commercial (medium truck, bus, farm, aircraft, off-the-road) applications with very different performance requirements**
  - **Quality: Must be durable, uniform, and have good appearance**
  - **Environmental: Product, manufacturing processes, and materials composition must be in compliance with existing regulatory requirements, and potential future obligations**
  - **Cost: Materials scientist must consider all factors including compound uniformity, consistency, manufacturing throughput, raw materials cost and conversion costs**
    - **Wide variety of elastomers available commercially**

Summary

- **Capability of a casing construction to perform it's specific mission is a function of the design and composition of individual rubbery and reinforcing components**
- **Reinforcing components include the bead wire hoop, ply cords, belts, overlay and flipper**
  - **Up to six types of steel wire (beads, ply cord, belts) or fabrics used**
- **Rubbery components include reinforcement coat stocks (wire, ply, overlay, flipper, bead insulation), associated wedges and gum strips, apex and chafer, barrier, innerliner, black sidewall and white sidewall**
- **Natural rubber polymer of choice in many carcass applications**
  - **Polybutadiene and styrene-butadiene rubbers used to enhance performance of specific components**
- **Halogenated butyl rubber is the polymer of choice in tire innerliners**

Summary: NR in Casing Components



Properties afforded

- Tear strength
- Component-to-component adhesion
- Cool running
- Good hysteretic properties
- Tensile strength
- Green strength

Tire Applications of Elastomers

Disclaimer

Bead Insulation

Bead insulation compound is formulated for:

- **adhesion to bronze-coated steel wire**
- **providing a seal to prevent air leakage around the rim**
- **adhesion to adjoining tire components**
- **cure rate compatible with processing and curing of the green tire composite**
- **resistance to degradation by heat and oxygen**
- **resistance to tearing**

Model Tire Bead Insulation

Ref: Benko, Mowdood, Sandstrom, Waddell, Wideman (Goodyear), U.S. 4,605,696 (1986)

	PHR
SBR	100
Peptizer	0.25
Filler	140
Processing Oils	25
Stearic Acid	0.5
Zinc Oxide	5
Sulfenamide Accelerators	1.22
Sulfur	4

Model Tire Bead Insulation

Ref: Waddell, Bhakuni, Barbin, Sandstrom, "Pneumatic Tire Compounding" in "Vanderbilt Rubber Handbook", 13th Ed. (1990)

	PHR
SBR 1500	100
N660 Black	100
Aromatic Oil	10
Rosin Oil	10
Sulfonated Paraffinic Oil Plastizer	2
Antioxidant, TMQ	2
Stearic Acid	2
Zinc Oxide	4
Sulfenamide Accelerator	1
Sulfur	3.6

White Sidewall and Cover Strip

Tire white sidewall compound is formulated to deliver a variety of properties including

- **resistance to degradation by oxygen and ozone**
- **whiteness, both original and after UV aging**
- **adhesion to adjoining tire components**
- **cure rate compatible with processing and cure of the green tire composite**
- **hardness and stress-strain properties**
- **resistance to tear and cut/crack propagation**
- **resistance to abrasion**
- **buffability**
- **lowest possible cost**

Highly unsaturated elastomers such as chlorobutyl rubber and EPDM polymers are used for this non-staining application

Model Tire White Sidewall

Ref: Exxon Chlorobutyl Rubber, Compounding and Applications

	PHR
Chlorobutyl Rubber, CIIR 1066	60
EPDM, Vistalon 6505	20
Natural Rubber, SMR 5	20
Titanium Dioxide	25
Clay, Nucap 290	32.5
Talc, Mistron Vapor	34
Stearic Acid	1
Petroleum Wax, Sunolite 240	3
Ultramarine Blue	0.2
Resin, SP 1077	4
Zinc Oxide	5
Sulfur	0.5
Accelerator, Alkyl Phenol Disulfide	1.3
Accelerator, Benzothiazyl Disulfide, MBTS	1

Model Tire Non-Staining WSW Cover Strip

Ref: Exxon Chlorobutyl Rubber, Compounding and Applications

	PHR
Natural Rubber, SMR 5	35
Chlorobutyl Rubber, CIIR 1068	60
EPDM, Vistalon 6505	5
Carbon Black, N550	50
Wax, Sunolite 240	4
Naphthenic Oil	12
Zinc Oxide	5
Accelerator, Alkyl Phenol Disulfide	0.8
Accelerator, Benzothiazyl Disulfide	1