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AUTOMOBILES RUNNING ON ROAD FOLLOWS ON VULCANIZED RUBBER TYRES

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ABSTRACT
Rubber Tires are specialized components made from natural and synthetic rubber, mixed with materials like carbon black, sulphur, and steel to provide durability, traction, and elasticity. They are used across vehicles—cars, motorcycles, industrial equipment—in both pneumatic (air-filled) and solid forms. Key applications include automotive, trolleys, and robotics.

KEYWORDS: Tyre, vulcanized rubber, buna-S rubber, sulphur cross linking, pneumatic, vee rubber, galvanization, halobutyl rubber.

Key Aspects of Rubber Tires

Composition: Modern Tires use a blend of natural rubber (for flexibility) and synthetic rubber (styrene-butadiene, polybutadiene) to maximize performance.

Production: Tires are constructed on drums, reinforced with steel belts, and then vulcanized (cured) at high temperatures (~180°C) to create a strong, elastic material.[1]

Types

Pneumatic Tires: Common for vehicles, offering cushioning via compressed air.

Solid Rubber Tires: Used for industrial applications, trolleys, and heavy machinery, providing high load capacity and puncture resistance.

Properties: Tires are designed to handle, grip, and provide a long service life under high pressure.

Common Tire Suppliers and Products

Vee Rubber: Manufactures various two-wheeler tire patterns.

Figure 1: Tyres.

Industrial/Solid Tires: Available for trolleys and equipment (e.g., 14"×3" or 12"×3.5" sizes).
Small/Robot Wheels: Rubber wheels for hobbyist robots (65mm, etc.).
Manufacturing Processes: Natural rubber is derived from latex, which is collected, processed, and smoked before being sent to factories. The rubber is then combined with additives to achieve the required hardness.

"Tire" and "tyre" refer to the same rubber vehicle component but differ by region. "Tire" is the standard spelling in American and Canadian English, while "tyre" is used in British English, Australia, New Zealand, and many other Commonwealth countries. Both are correct within their respective regional conventions.

Key Regional Differences
Tire (US/Canada): Used in the United States and Canada (99% and 100% preference respectively). It is also the verb used to describe becoming weary.
Tyre (UK/Other): Used in the United Kingdom, Australia, India, and New Zealand.

Origin: Both refer to the pneumatic rubber covering on a wheel that provides traction and supports the vehicle's load.

Why the Difference?
The distinction helps differentiate the noun (the item on the wheel) from the verb (to become tired) in British English, where "tyre" is exclusively the object.[2]

Vulcanizing a tire is a permanent repair process that uses raw, uncured rubber, vulcanizing cement, and a heated press to create a chemical bond as strong as the original rubber. It fixes major damage, such as sidewall gashes or large punctures, by melting new rubber into the damaged area. This creates an air-tight seal superior to simple adhesive patches. Vulcanization of tyres is a thermosetting chemical process that transforms soft, sticky raw rubber into elastic, durable, and wear-resistant rubber by heating it with sulphur (or other curing agents) at 150°C-180°C. This mechanism creates three-dimensional sulphur cross-links between rubber polymer chains, preventing them from slipping and increasing the rubber's tensile strength, elasticity, and temperature resistance.[3]

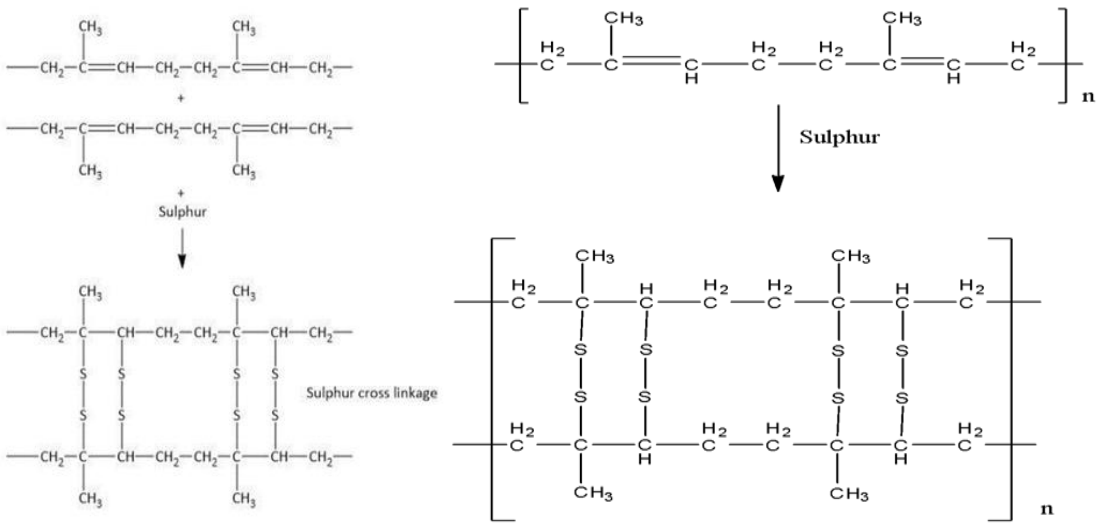

Figure 2: Vulcanization cross linking by sulphur.

Key Mechanisms and Elements
Cross-linking: Sulphur forms sulphur bridges (cross-links) between the long polyisoprene polymer chains. This changes the structure from linear to a cross-linked network.
Additives (Accelerators/Activators): To make the process efficient, chemicals like sulphur, accelerators (e.g., sulfonamides), and activators (e.g., zinc oxide) are added to the raw rubber. These allow vulcanization to occur faster and at lower temperatures, reducing the need for high sulphur amounts.

Heat and Pressure: The process requires high-pressure steam, which provides the necessary heat to activate the reaction and forces the rubber against the mold to ensure proper shaping and density.

"Green" Tyre Stage: The "green" (unvulcanized) tyre is placed in a mold, where a bladder holds the tyre internally, enabling the heat and pressure to be applied uniformly. "Green" or sustainable tires are designed to minimize environmental impact through eco-friendly materials (silica, bio-based oils, recycled nylon) and reduced rolling resistance. They offer lower fuel consumption and CO_2 emissions, with manufacturers like Michelin, Goodyear, and Apollo introducing sustainable models to reduce reliance on petroleum-based products.

Environmental and Economic Impact
- Emission Reduction: By reducing fuel consumption, they directly decrease emissions.

- Reduced Waste: Improved durability and recyclability minimize landfilled tires.
- Cost Savings: Lower fuel consumption and reduced maintenance needs provide economic advantages for operators.
- Industry Trends
- Major Players: Companies like Michelin, Goodyear, and others are actively developing these technologies.
- Market Growth: The sustainable tire market is experiencing significant growth, with a high compound annual growth rate.
- Future Focus: The focus is shifting toward fully renewable components and enhanced recycling technologies, as discussed.

Key Features and Benefits

- Lower Rolling Resistance: Green tires require less energy to move, reducing vehicle fuel consumption.
- Sustainable Materials: These tires use materials like rice husk ash-derived silica, dandelion rubber, and recycled PET [Polyethylene terephthalate] bottles.
- Enhanced Durability & Safety: Designed to last longer, reducing waste, and often enhancing wet grip.
- EV Optimization: Specialized tires are tailored for electric vehicles to improve battery efficiency and range

Physical Changes

Elasticity & Strength: The cross-linked rubber network improves elasticity, hardness, and tensile strength.

Stability: The material becomes more resistant to heat, abrasion, and temperature fluctuations.

Durability: The finished tire is cured into its final, rigid, and durable shape.

Buna-S, also known as Styrene-Butadiene Rubber (SBR), is a synthetic rubber primarily used in tyre manufacturing due to its high abrasion resistance, toughness, and durability. It is produced through the emulsion polymerization (or sometimes solution polymerization) of 1,3-butadiene and styrene.

Sulphur's most common structure is octasulphur (S_8), which exists as a puckered, crown-shaped eight-membered ring. These rings are arranged in different crystal forms, primarily rhombic (at room temperature) or monoclinic (above 95.2ºC). Sulphur has a molecular formula of S_8 and is a bright yellow, non-metallic solid.[4]

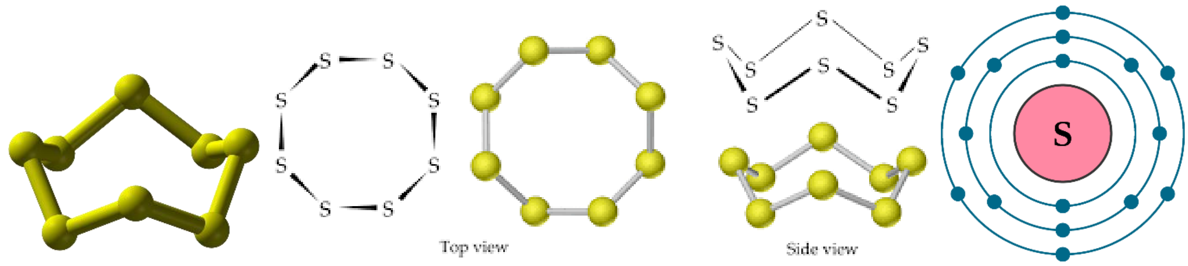

Figure 3: Sulphur structure.

Atomic Structure (Bohr Model)

- **Nucleus:** 16 protons and 16 neutrons. $_{16}S^{32}$: Electronic configuration: $1s^2s^22p^63s^23p^4$
- **Electrons:** 16 total electrons, with an electron configuration of $Ne3s^23p^4$ (2 in the first shell, 8 in the second, and 6 in the third).
- **Key Allotropes and Molecular Structure S_8 (Cyclooctasulphur):** The most stable allotrope, existing as a "crown" shaped ring.
- **Rhombic Sulphur (σ-sulphur):** Stable below 95.2ºC (203.4ºF). It is a bright yellow crystalline solid with S_8 rings organized in an orthorhombic lattice.
- **Monoclinic Sulphur (β-sulphur):** Stable above 95.2ºC (203.4°F) up to the melting point (119.6°C). It forms needle-shaped crystals.
- Liquid Sulphur: Changes viscosity significantly, becoming more viscous as S_8 rings break and polymerize, then less viscous at higher temperatures (above 200°C) as they depolymerize.
- **Other Forms:** Sulphur can form smaller ring structures (like S_6) or larger polymer chains.

Physical Properties

- **Color:** Bright yellow.
- **State:** Solid at room temperature, melts at 115.21°C (239.38°F).
- **Electrical Conductivity:** Excellent electrical insulator.
- **Solubility:** Insoluble in water, but soluble in organic solvents like carbon disulfide (CS_2).

Mechanism of Buna-S Synthesis: Buna-S is formed through a free radical addition copolymerization process.

Monomer Setup: A 3:1 mixture of 1,3-butadiene and styrene is typically used.

Initiation: A peroxide catalyst (such as potassium persulfate) is used, often at low temperatures (5ºC for "cold rubber") to initiate the reaction.

Propagation: The radicals add to the monomer double bonds, creating a random copolymer chain. The butadiene units provide elasticity, while the styrene units contribute to rigidity and wear resistance.

Emulsifiers: The reaction takes place in an water-based emulsion with soap, allowing for temperature control.

Chain Termination: Modifiers such as mercaptans are used to control molecular weight and prevent the polymer from becoming too branched or rigid.
Vulcanization Mechanism (Tyre Durability): Raw Buna-S is soft and sticky. To make it suitable for tyres, it undergoes vulcanization.
Process: The raw polymer is heated with sulphur at 150-160°C.
Action: The sulphur creates cross-links between the polymer chains, linking butadiene segments.
Result: This transforms the material into a robust, tough, and elastic rubber with high abrasion resistance.

Key Properties of Buna-S in Tyres
Abrasion Resistance: Superior to natural rubber, making it ideal for road wear.
Aging Stability: Good resistance to aging and thermal degradation when properly treated.
Composition: Contains roughly 75% butadiene and 25% styrene.
Appearance: Often filled with carbon black, resulting in a black, matte appearance.

Buna-S (Styrene-Butadiene Rubber or SBR) is a synthetic rubber primarily used for manufacturing automobile tires, while vulcanizing is the heat-and-sulphur treatment process that makes this rubber durable and usable. Buna-S is highly elastic, resistant to abrasion, and acts as a cost-effective, durable alternative to natural rubber, making it ideal for tires and shoe soles. Vulcanization is the process that bridges the raw Buna-S polymer chains to increase strength, elasticity, and heat resistance.[5]

Key Differences: Buna-S Rubber vs. Vulcanizing Process
Definition & Role
Buna-S (SBR): The raw synthetic polymer material (monomer of 1,3-butadiene and styrene) used as a base for tires.
Vulcanizing: The process/treatment applied to the raw Buna-S (usually by adding sulphur and heat at 150-160°C) to make it hard and durable.

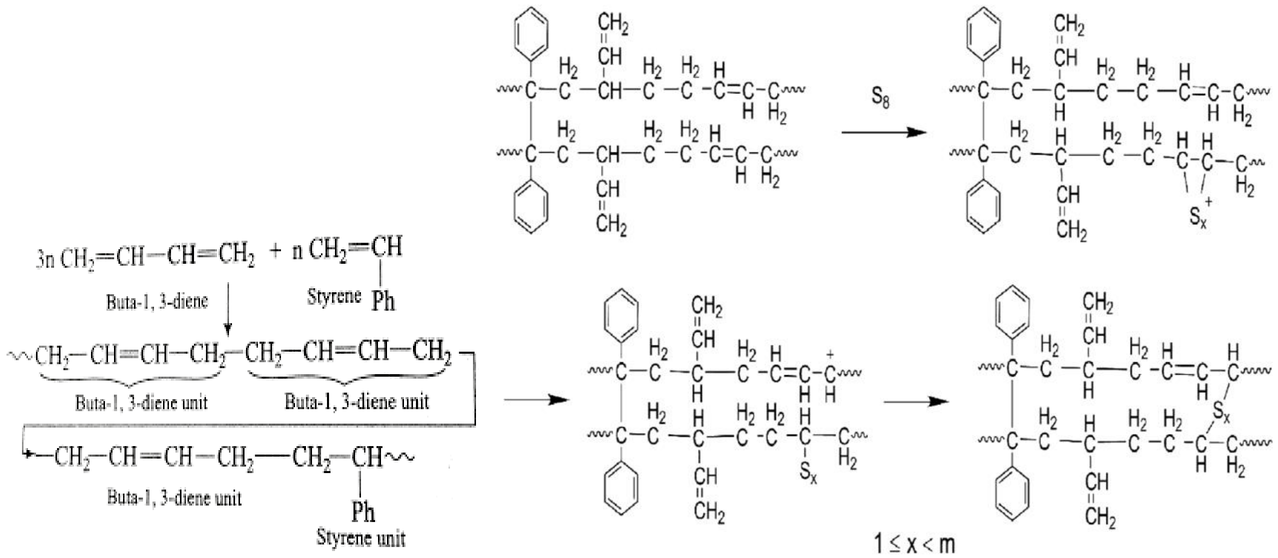

Figure 4: Buna-S crosslinking.

Physical State
Buna-S: In its raw state, it is soft and sticky. Vulcanized Buna-S: Non-sticky, hard, elastic, and abrasion-resistant.

Function in Tires
Buna-S: Provides the material composition for the tire treads.
Vulcanization: Transforms the material from a weak compound to a high-tensile strength rubber that can withstand road stress.[6]

Summary of Properties (Vulcanized Buna-S)
Tires: Good abrasion resistance and aging stability.
Heat & Wear: Excellent durability against friction.
Weakness: Less resistant to oils/fuels compared to Buna-N (Nitrile).

Key Differences from Buna-N
Buna-S (SBR): Used for tyres, inner tubes, and rubber soles.
Buna-N (NBR): Used for oil seals, conveyor belts, and gaskets due to high oil resistance.
Tyre developers: John Boyd Dunlop [5 February 1840 – 23 October 1921] is credited with inventing the first practical pneumatic (air-filled) tyre in 1887-1888 to improve his son's tricycle ride. While Robert William Thomson patented the first pneumatic tyre in 1845, it was Dunlop who successfully commercialized it.

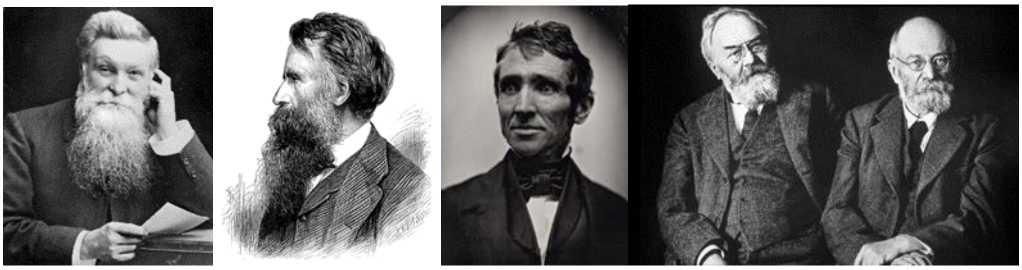

Figure-5: Inventors of rubber tyres

Key Historical Figures

John Boyd Dunlop (1887/1888): A Scottish veterinarian based in Belfast, he developed the first functional air-filled rubber tire to provide a smoother ride, leading to the Dunlop Pneumatic Tyre Co. Ltd.

Robert William Thomson (29 June 1822 – 8 March 1873; 1845): Patented the very first pneumatic tire, but it was not widely adopted at the time.

Charles Goodyear (December 29, 1800 – July 1, 1860; 1839): Patented vulcanized rubber, which made durable rubber tires possible.

The Michelin Brothers (1891): André and Édouard Michelin developed the first detachable pneumatic tire for bicycles and cars. André (1853–1931) and Édouard Michelin (1859–1940) were French industrialists who founded the modern tire company in 1889 in Clermont-Ferrand. They revolutionized transportation by patenting the first removable pneumatic bicycle tire (1891) and applying it to cars. They created the Michelin Guide (1900) and the mascot Bibendum (Michelin Man) to boost tourism and tire sales.

Dunlop's invention came about to solve the problem of harsh rides from solid iron or wood wheels, revolutionizing transport.

Vulcanization is a chemical process that strengthens rubber by creating cross-links between polymer chains, typically by heating rubber with sulphur (often 5-30%) and accelerating agents (like zinc oxide) . This mechanism forms covalent sulphur bonds (sulphide bridges) that prevent polymer chains from sliding, transforming soft, sticky rubber into a durable, elastic, and heat-resistant material.[7]

Figure 6: Different types of tyres.

Key Aspects of the Vulcanization Mechanism

The Cross-linking Process: Sulphur atoms bond to the double bonds in rubber molecules (like polyisoprene), forming sulphur bridges (C-S_x-C) as S_8 is sulphur between adjacent polymer chains.

Role of Sulphur: Sulphur atoms connect the rubber chains together, forming monosulfide, disulfide, or polysulfide bridges that lock the structure.

Accelerators and Activators: Accelerators (e.g., thiazoles, sulfenamides) reduce the required reaction temperature and time, while activators (e.g., zinc oxide, stearic acid) increase efficiency.

Stages of Vulcanization

Induction/Scorch: Initial heating where cross-linking starts slowly, allowing for shaping.

Curing/Cross-linking: High-temperature phase (200-400^{O}C) where rapid cross-linking occurs.

Overcure: Continued heating beyond optimal strength, which can degrade properties.

Common Vulcanization Methods

Sulphur Vulcanization: The standard method using sulphur and heat.

Peroxide Vulcanization: Uses organic peroxides to create stronger carbon-carbon cross-links.

Cold Vulcanization: Uses sulphur dichloride for thin rubber items.

Effects on Rubber Properties: Vulcanization converts rubber from a thermoplastic state (soft when heated, brittle when cold) to an elastomeric state that maintains its shape and functionality. It improves tensile strength, elasticity, and resistance to abrasion, chemicals, and temperature fluctuations.

Buna-S (Styrene-Butadiene Rubber) and vulcanized rubber are not competing products, but rather two different stages in the creation of a tire. Buna-S is the raw material (synthetic rubber), while vulcanization is the process that makes that raw material hard, durable, and functional.

Here is the difference between them

1. Buna-S (Raw Synthetic Rubber)

What it is: A synthetic copolymer of styrene and butadiene, often called SBR (Styrene-Butadiene Rubber).

State: Raw Buna-S is soft, sticky, and thermoplastic (melts when heated). It has very low tensile strength and cannot be used for tires in this state.

Properties: Highly elastic, abrasion-resistant, and flexible at low temperatures.

Usage: It is used as a superior alternative to natural rubber for tire treads because of its excellent wear resistance.[8]

2. Vulcanized Rubber (Finished Product)

What it is: The end product formed by heating Buna-S (or natural rubber) with sulphur and other chemicals (like carbon black) to create cross-links between polymer chains.

- State: Hard, non-sticky, tough, and thermoset (does not melt).
- Properties: High tensile strength, high elasticity, and high resistance to abrasion, heat, and aging.
- Usage: Used for the final, finished tire that can withstand high pressure and stress.

Key Differences Summary

Table 1: Difference between Buna-S and Vulcanized rubber.

Feature	Buna-S (Raw)	Vulcanized Rubber
Material Type	Polymer (Raw Synthetic Rubber)	Cross-linked Polymer (Finished)
State	Soft, Sticky, Thermoplastic	Hard, Tough, Thermoset
Tensile Strength	Low	High
Elasticity	High, but easily deformed	High, returns to shape
Abrasion Resistance	Moderate	Very High (due to additives)
Role in Tire	The raw ingredient	The finished tire structure

How They Work Together: Tires are generally made of a mixture of raw Buna-S and natural rubber. This mix is moulded and then vulcanized at 150-160°C to turn the soft mixture into a durable, heat-resistant tire tread. The vulcanization process gives the rubber its necessary toughness, prevents it from becoming sticky in summer, and stops it from becoming brittle in winter. Tyres are constructed from a complex mix of materials, roughly 41% natural and synthetic rubber, 30% reinforcing fillers (carbon black, silica), 15% metallic/textile reinforcements, and various chemical agents. Key ingredients include rubber (for elasticity), carbon black (for strength/wear), steel (for structure), textiles like rayon or nylon (for plies), and sulphur for vulcanization.

Core Tyre Ingredients

- **Rubber (Natural & Synthetic):** Provides elasticity, heat resistance, and durability. Natural rubber is prized for heavy-duty applications, while synthetic rubber (styrene-butadiene, polybutadiene) excels in passenger tyres.
- **Carbon Black:** Acting as a reinforcing filler, this fine powder strengthens the rubber, boosts wear resistance, and protects against UV damage.
- **Silica:** Commonly used to enhance wet grip and reduce rolling resistance.
- **Steel (Wires & Belts):** High-tensile steel is used to construct bead cores (to seat the tyre on the rim) and steel belts for, enabling structural strength, puncture resistance, and stability.
- **Textile Fabric Cords:** Rayon, nylon, or polyester cords are used in the plies to provide flexible yet strong structural support.
- **Sulphur & Chemical Additives:** Sulphur vulcanizes the rubber, linking molecules for elasticity. Additives include antiozonants/antioxidants (to prevent cracking), oils and resins (for flexibility).

- **Common Tire Components & Materials**

Inner Liner: Airtight synthetic butyl rubber that eliminates the need for an inner tube.

Tread: A specific blend of natural/synthetic rubber optimized for wear resistance and grip.

Sidewall: Flexible, durable rubber designed to protect the carcass from environmental damage. The tyre sidewall is the flexible, vertical rubber component between the tread and the bead, crucial for protecting the internal casing from damage, supporting vehicle load, and providing riding comfort. It consists of specialized, flexible rubber compounds reinforced with body plies (cord layers) that run from bead to bead.[9]

Key Sidewall Construction Features

- **Structure:** Comprised of flexible rubber to withstand constant flexing.
- Light truck tyres often feature stronger, more robust sidewalls to handle higher loads compared to passenger tyres.
- **Reinforcement (Plies):** In radial tyres, fabric cords (such as rayon, nylon, or polyester) run radially from bead to bead, providing strength and flexibility, while supporting the sidewall's shape.
- **Protection:** It protects the inner casing layers from ozone, weather, and road hazards like curbs.
- **Markings:** The sidewall displays crucial information including manufacturer, tyre size (e.g., 265/70 R16, where 70 indicates the ratio of height to width), load index, and speed rating.

Common Components

Rubber Compound: Specifically designed for flexibility and fatigue resistance.

Inner Liner: A thin layer of halobutyl rubber inside the tyre, often covering the sidewall area in tubeless tyres to prevent air leakage. Halobutyl rubber (chlorobutyl or bromobutyl) is a synthetic elastomer derived from butyl rubber (isobutylene-isoprene) that offers superior curing speeds, improved adhesion, and enhanced heat/chemical resistance. It is primarily used for tire inner liners due to exceptional air impermeability, alongside pharmaceutical stoppers and industrial sealant applications.

Key Properties and Benefits

Low Permeability: Exceptional gas and moisture barrier properties.

Improved Curing: Faster, more efficient curing than standard butyl rubber, enabling better covulcanization with natural or styrene-butadiene rubbers (SBR).

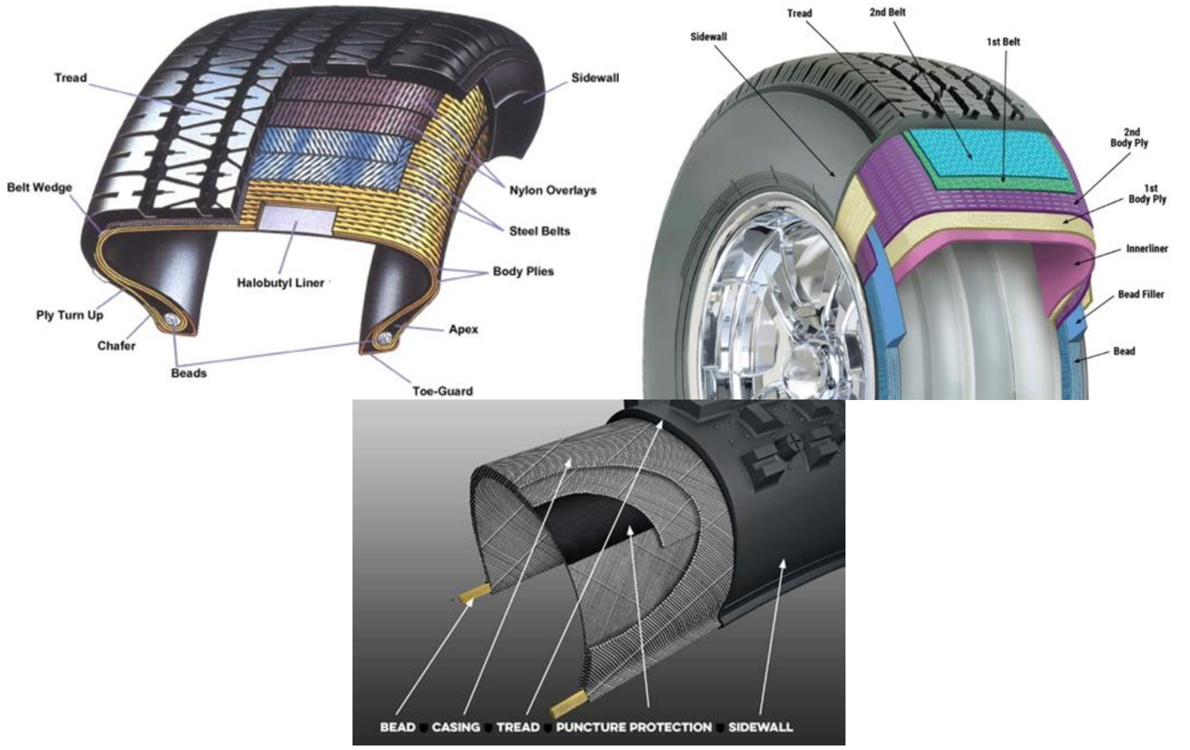

Figure 7: Tyre Bead.

Environmental Resistance: High resistance to oxygen, ozone, and chemical aging.
Versatility: Available as bromobutyl (BIIR) and chlorobutyl (CIIR)

Body Ply/Casing: Textile cords, such as rayon or nylon, that make up the structural skeleton of the sidewall.
Sidewall stiffness varies based on the aspect ratio (the ratio of sidewall height to tread width).
Lower aspect ratios generally mean stiffer, shorter sidewalls for better handling

Bead: A steel wire bundle coated in rubber that keeps the tyre secured to the rim. The tyre bead is a high-strength, steel-reinforced rubber hoop that anchors the tyre securely to the wheel rim, ensuring an airtight seal for tubeless tyres. Located at the inner edge of the sidewall, this component maintains the tyre's position against cornering forces, braking, and accelerating stresses.

Key Aspects of the Tyre Bead
Structure: Composed of a bundle of high-tensile steel wires (the bead core) encased in specialized rubber, designed to be both rigid for strength and flexible for mounting. Steel wire in tyres (bead wire and belts) provides structural integrity, strength, and durability, often comprising 20-25% of a tire's weight. These high-carbon, brass-plated steel cords are crucial for maintaining tire shape, enhancing puncture resistance, and bearing heavy loads. The wire is highly recyclable and is recovered during recycling through shredding and magnetic separation.

Key Functions and Components
Bead Wire: A high-tensile strength, high-carbon steel wire that holds the tire onto the wheel rim, preventing it from popping off.

Steel Belts: Layers under the tread that enhance stiffness, durability, and prevent punctures.

Composition: High-carbon steel (0.70-.95% carbon) is used for its strength, while the surface is brass or bronze-plated to ensure strong bonding with the rubber.

Recycling and Scrap Wire
Removal Process: Tires are shredded in a primary shredder and processed in a "rasper," which tears the rubber away to expose the steel. Large magnets then lift the steel wire away from the rubber crumbs.

Sustainability: This recovered wire, often called "tyre wire scrap," is repurposed for manufacturing steel products or used as a high-strength material in other industries.

Value: It is prized for its high-tensile nature, and because it is durable and often high-grade, it is often recycled into new metal goods.

Function: It locks the tyre to the wheel flange using pressure, which keeps the tyre from slipping or popping off during use.

Airtight Seal: In tubeless tyres, the bead ensures an airtight connection with the rim's flange, eliminating the need for an inner tube.[10]

The fundamental difference between vulcanized and galvanized materials lies in the material being treated and the purpose of the process. Galvanizing is a metallurgical process for protecting metal (iron/steel) from rust using zinc. Vulcanization is a chemical process that enhances the durability and elasticity of rubber or polymers using heat and sulphur.

Components: The assembly includes the bead core (steel wires) and bead filler (or apex), which is a hard rubber compound providing structural support and helping with lateral stability. Damaged or ill-fitting beads can lead to rapid deflation or improper tire seating, making this component essential for safety and performance. Modern tyres can contain over 200 different raw materials to achieve specific performance goals, such as fuel efficiency or high speed.

Table 2: Difference between galvanized and vulcanised matter.

Feature	Galvanized	Vulcanized
Material Treated	Steel or Iron	Rubber (natural or synthetic)
Primary Agent	Zinc (Molten or Electroplating)	Sulfur (or similar curatives)
Purpose	Prevent corrosion (rust)	Improve durability, elasticity, & heat resistance
Process	Hot-dip or Electrogalvanizing	Chemical cross-linking
Common Uses	Outdoor structures, pipes, fencing	Tires, rubber hoses, seals

Galvanized (Protection for Metal)

Galvanization involves coating iron or steel with a protective layer of zinc to prevent rust and corrosion.

How it Works: The zinc acts as a barrier and provides "sacrificial" protection, meaning the zinc corrodes before the underlying steel does.

Methods

Hot-Dip Galvanizing: Steel is dipped in molten zinc (approx. 450°C), creating a thick, durable bond.

Electrogalvanizing: Zinc is deposited on the metal using an electric current, providing a thinner, smoother finish.

Benefits: High corrosion resistance, long lifespan (20-50+ years), low maintenance.

Vulcanized (Durability for Rubber): Vulcanization is a chemical process that transforms natural or synthetic rubber into a more durable, stable material.

How it Works: Raw rubber is heated with sulphur or other curatives, creating chemical cross-links between polymer chains.

Benefits: Increased elasticity, higher tensile strength, reduced stickiness, and improved resistance to temperature changes.

Common Applications: Vehicle tires, rubber belts, shoe soles, hoses, and seals.

SUMMARY OF DIFFERENCES

Purpose: Galvanizing keeps metal from rusting; Vulcanizing keeps rubber from degrading/melting.

Materials: Galvanizing is metal-related; Vulcanizing is polymer-related.

Bonding: Galvanizing creates a metallurgical bond with zinc; Vulcanizing creates a chemical cross-link with sulphur.

CONCLUSION

Tyres are essential for vehicle operation, providing necessary traction for acceleration, braking, and steering while supporting the vehicle's weight. They improve fuel efficiency through reduced rolling resistance, offer cushioning against road vibrations, and ensure stability across different terrains and weather conditions.

Key Functions and Utility of Tyres

Traction and Grip: Tyres provide the necessary friction between the vehicle and the road, crucial for braking, steering, and manoeuvring in both dry and wet conditions.

Load Support: They support the entire weight of the vehicle, passengers, and cargo, with reinforced sidewalls providing structural integrity.

Shock Absorption: Tyres act as the first line of suspension, damping road irregularities and vibrations to provide a smoother ride.

Fuel Efficiency: Proper tyre selection and maintenance (including regular rotation) reduce rolling resistance, which improves fuel economy.

Versatility: Different types of tyres are optimized for various surfaces, such as asphalt, mud, or snow, ensuring safety and performance.

Repurposing: Old tyres are often repurposed for gardening containers, playground equipment, furniture, and as protective barriers to prevent soil erosion.

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