Basics of tire manufacturing

BME - Guest lecture, 2021

Szabolcs OLÁH

Hankook Tire & Technology

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driving emotion

Tartalom

Hankook Tire & Technology

- 8 plants worldwide
  - Korea (2), China (3), Indonesia, USA, ***Hungary (Rácalmás)***
- Total annual capacity: 102 million tires
- Almost 21,000 employees
- 5 R&D centers
- Official suplier of DTM and Formula Renault Eurocup, Formula E

Hankook Tire & Technology - Hungary

Product portfolio – Rácalmás

- **OE (Original Equipment)**

- **RE (Replacement Equipment)**
- Advanced technologies

1.) Classification of tires; requirements

Classification of tires

1. Groups by vehicle type

Passenger car (PC)

Light truck (LT)

Truck and bus (TB)

Aircraft (AC)

Agriculture (AG)

Off-the-Road (OTR)

Industrial (ID)

Motorcycle (MC)

2. Groups by season

Ventus V12 Evo2

Summer

iCept Evo2

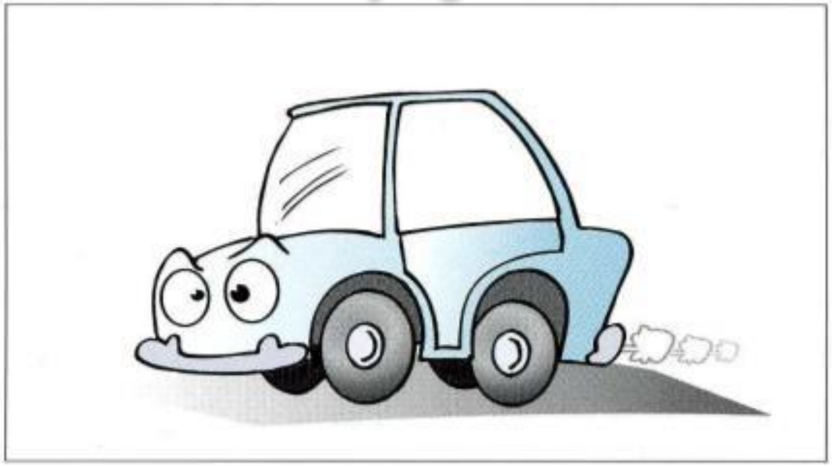
Winter

Optimo 4S

Négyévszakos

Requirements – Functions of tire

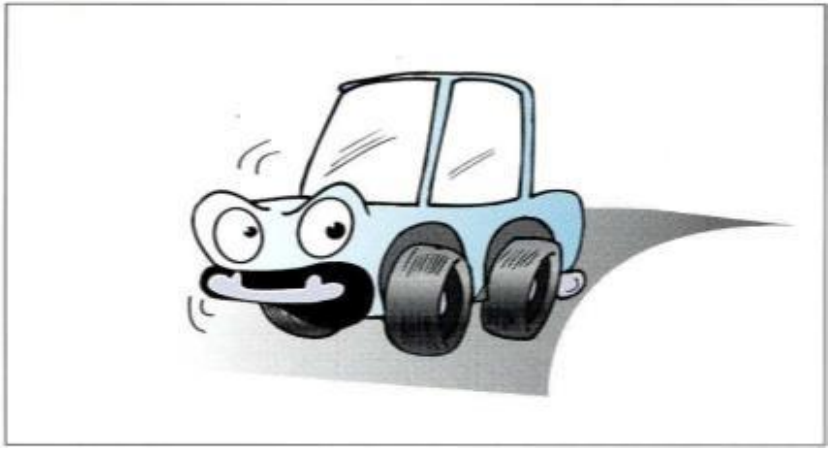
Carrying loads



Transmission of forces to the road surface

Decreasing vibration from road surface

Handling, cornering



Requirements

Stability

- Durability
- Resistance of external forces
- Low air-permeability
- Handling stability

Economy

- Resistance of damages
- Wear resistance
- Fuel economy

Comfort

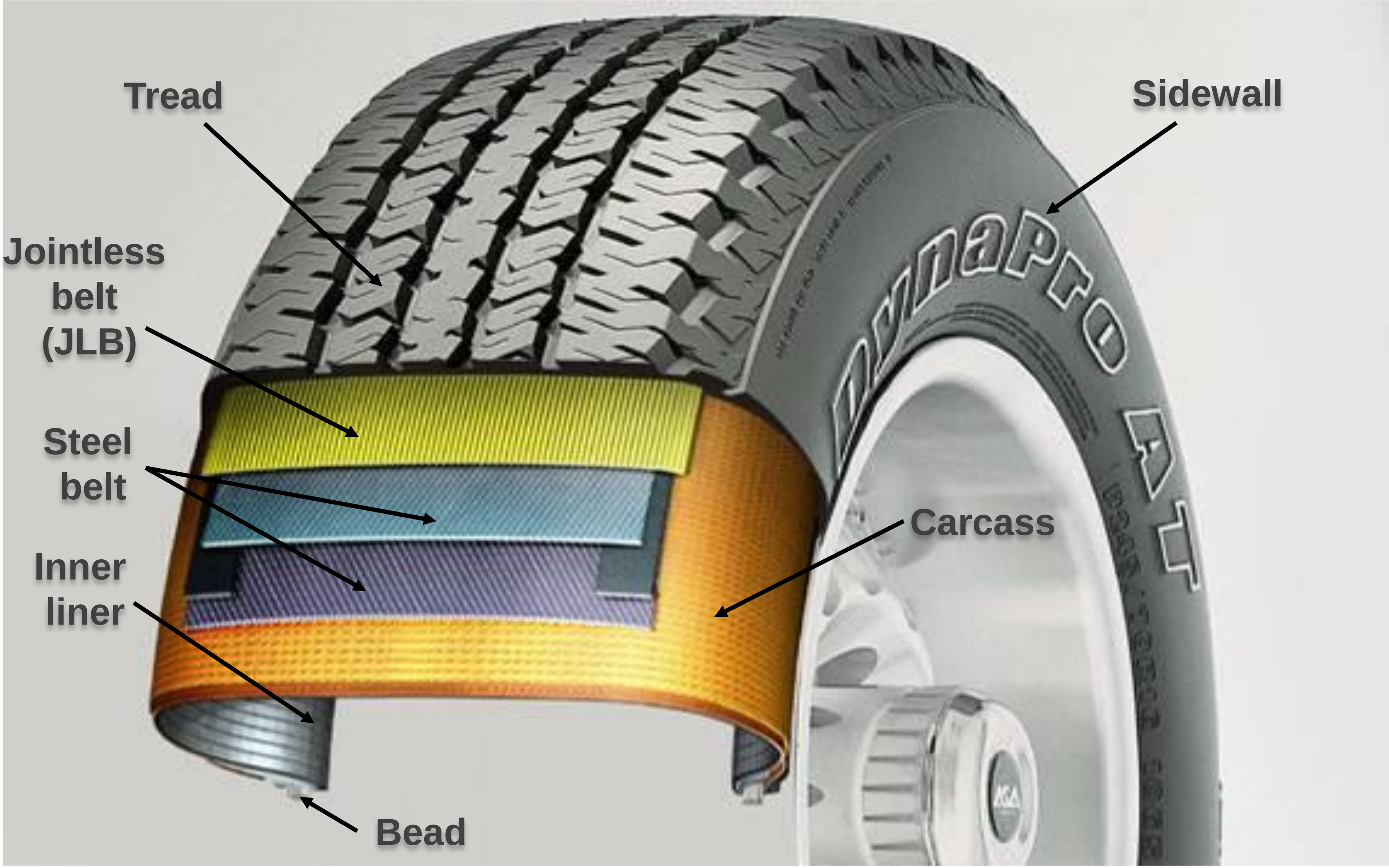
- Low noise
- Absorption of vibration
- Handling

Environment

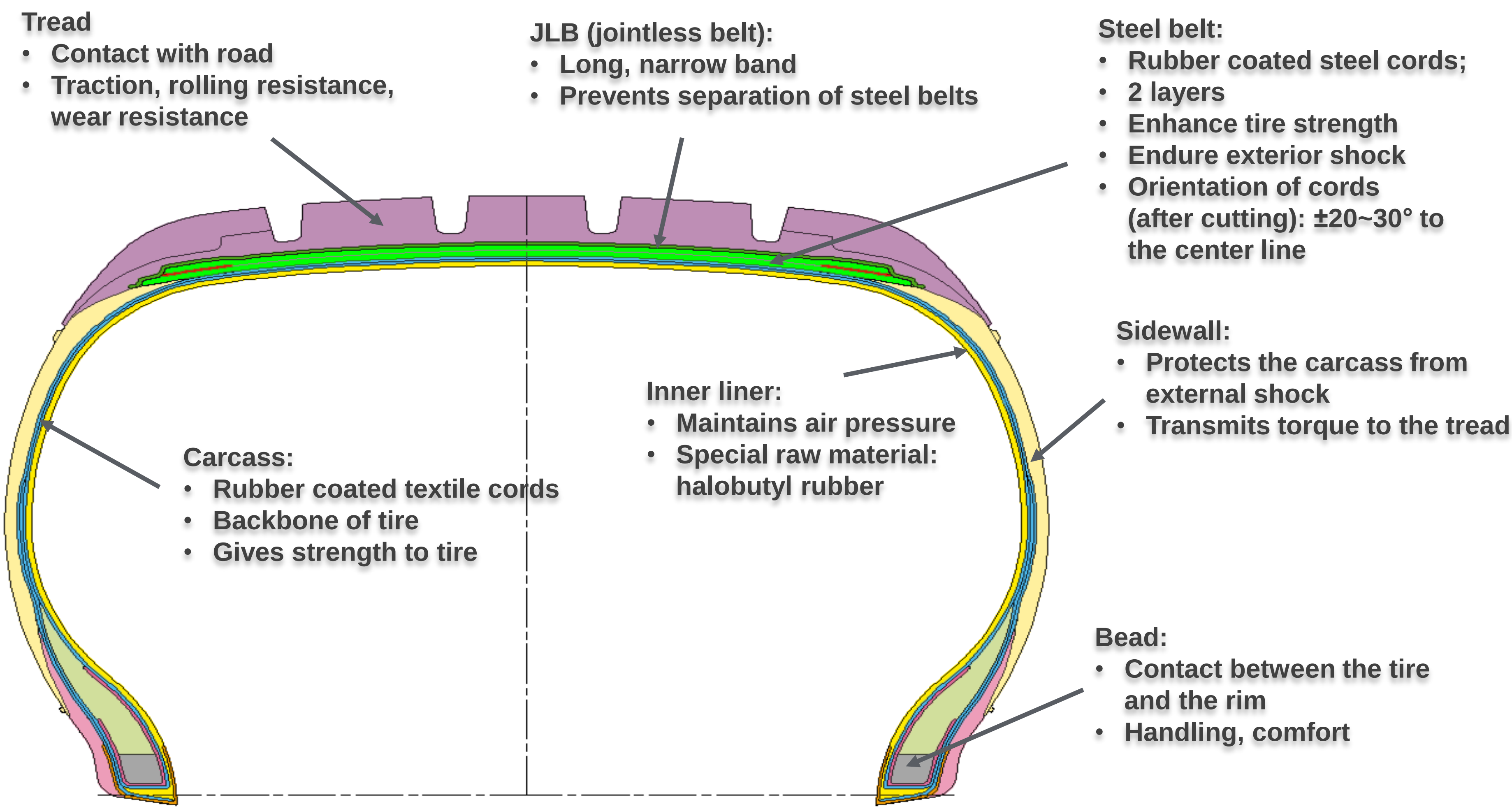
- Low noise
- Environmentally friendly raw materials

2.) Structure of radial tires

Structure of radial tires



Cross-section of radial tires



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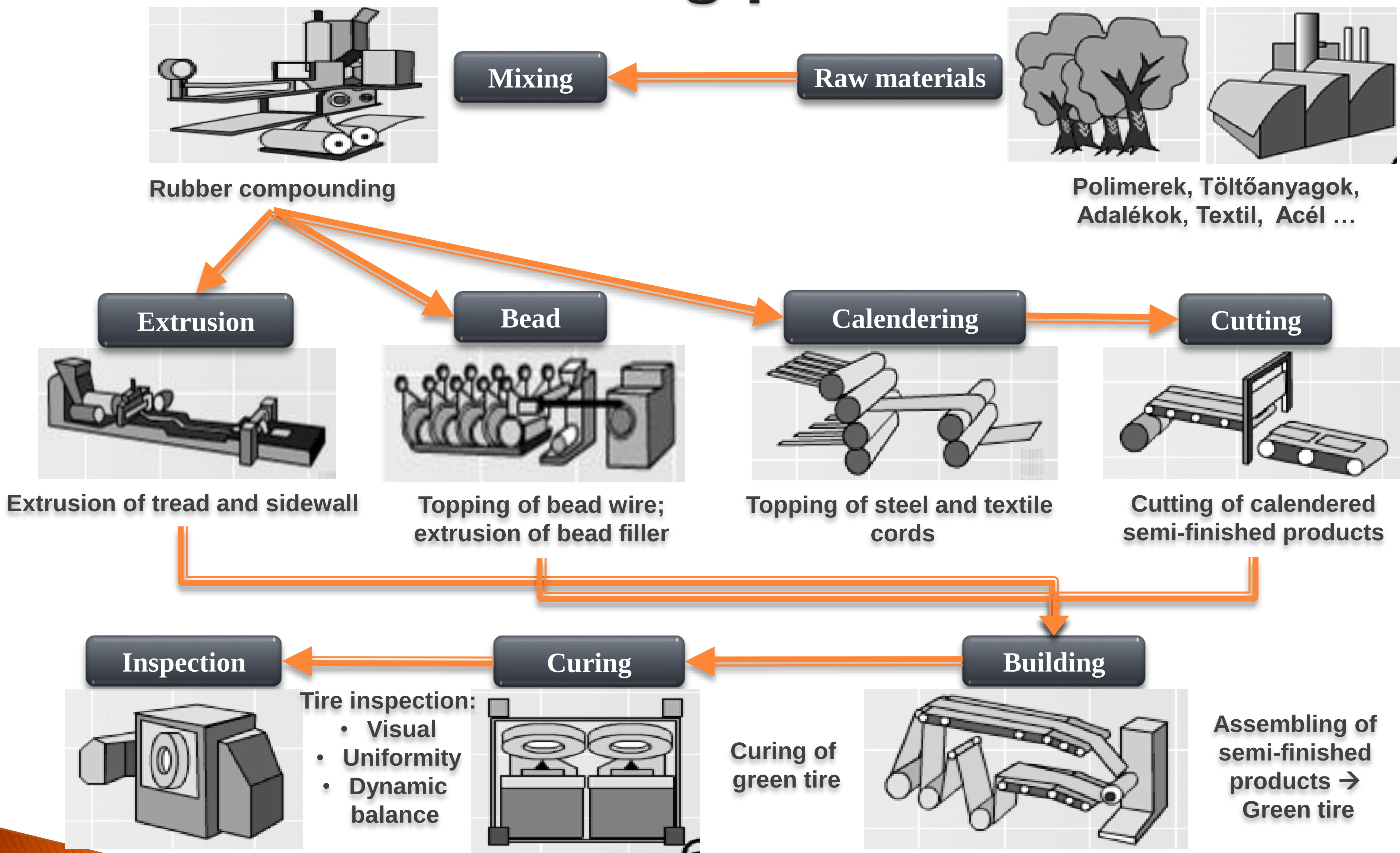
3.) Tire manufacturing process

Tire manufacturing process



Raw materials

- Rubber compound

  - Rubber (natural, synthetic)
  - Filler (carbon black, silica, other inorganic fillers)
  - Oil (natural, synthetic)
  - Curatives (sulfur, accelerators, retarders)

  - Processing aids

  - Antidegradants
- Textile cord

- Steel cords and wires

Mixing

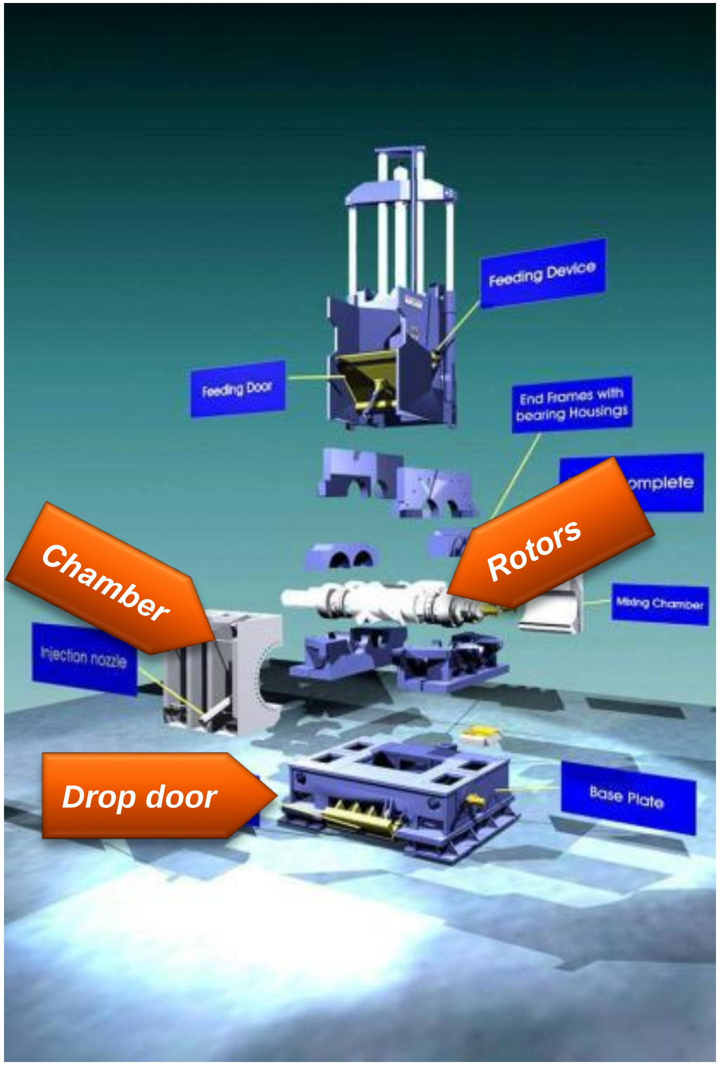
- **Disperse the ingredients of the rubber compound in the polymer matrix**
- **Equipments:**
  - Internal mixers
  - Open mills
  - (Mixing extruders → continous production)

  (Internal mixers and open mills: batch production)

- **Mixing stages:**
  - Non-pro: all of the ingredients, except curatives
  - Final: dispersion of vulcanizing agents

Mixing - Internal mixers

- **Main parts:**
  - **Chamber**
    - A space closed by the ram on top and the drop door on the bottom where the mixing happens
  - **Rotors**
    - Rotating parts of the mixer that crush and disperse the raw materials
  - **Drop door**
    - Openable part at the bottom of the chamber to discharge the compound



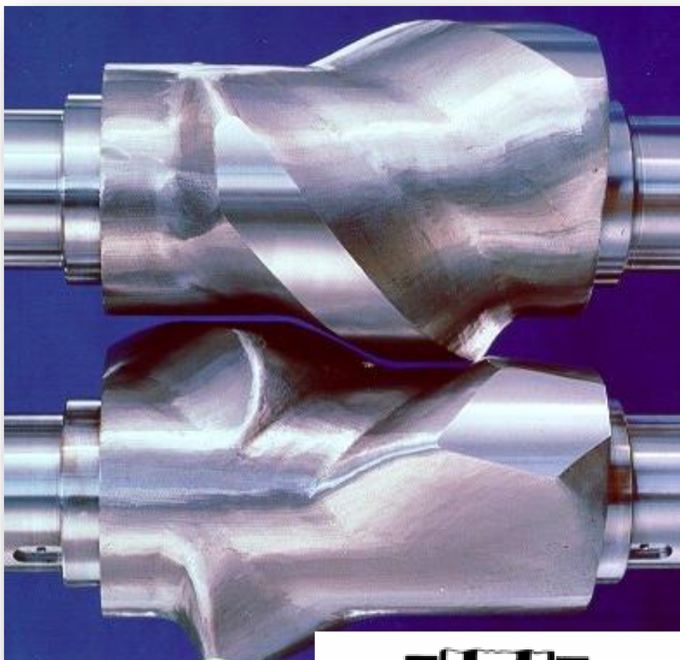
Mixing - Rotor types

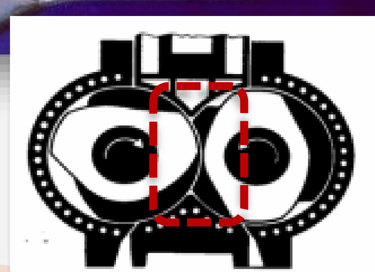
Intermeshing

- Constant gap
- More cooled surface
- Better filler dispersion
- Silica compounds!

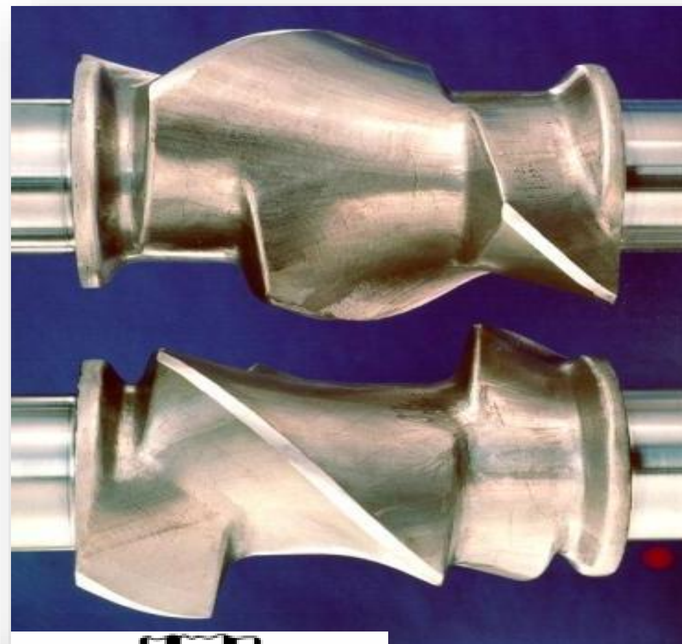
Tangential

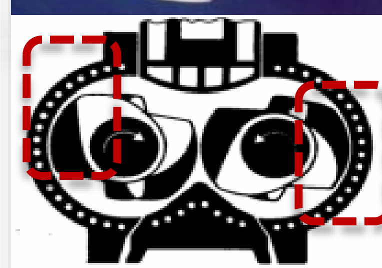
- Different gap along the axis
- Higher mixer capacity
- Worse filler dispersion
- Carbon compounds





High-shear zone:
between rotor tips





High-shear zone:
between the rotor tip and the chamber wall

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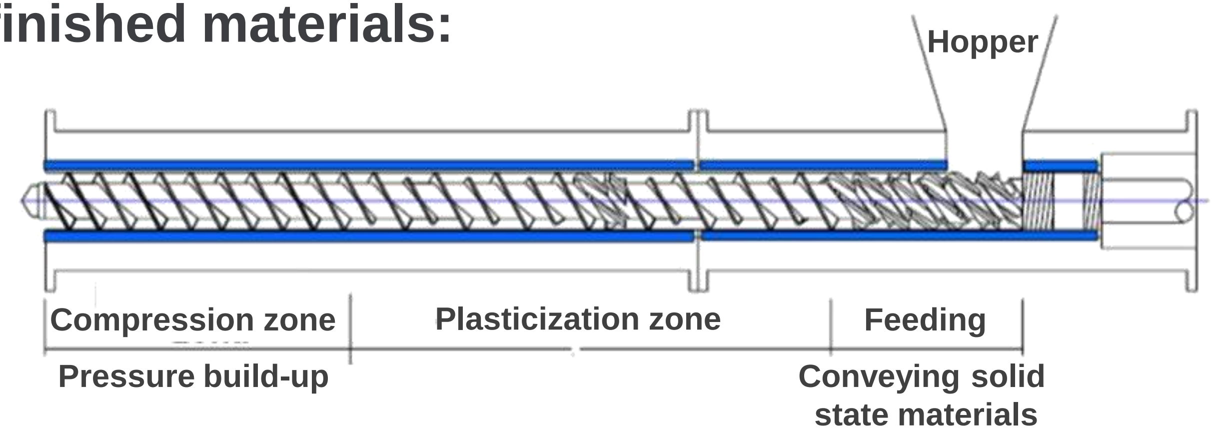
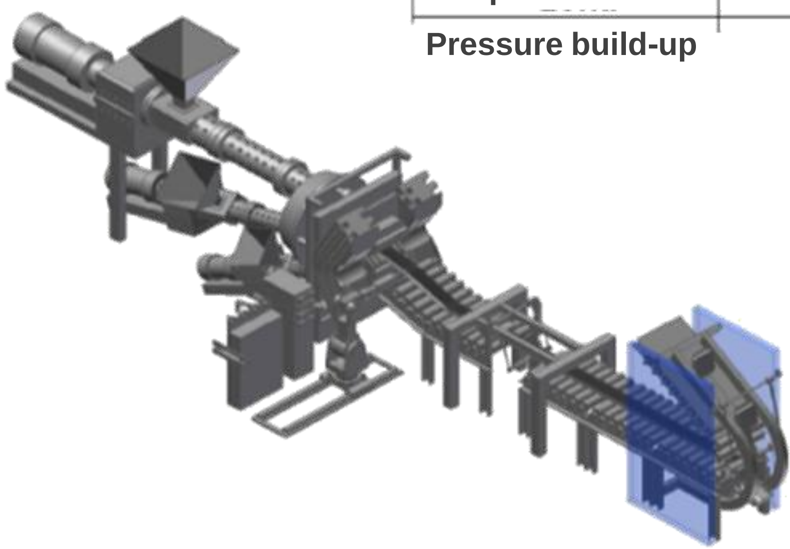
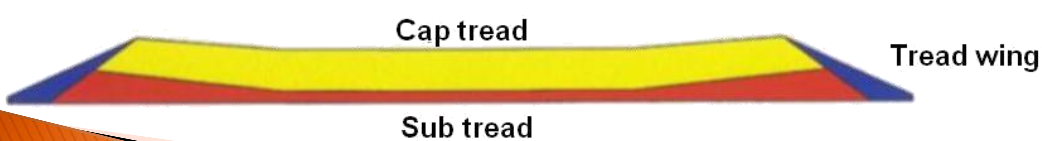
Extrusion

- **Pressing the plasticized comp'd through a die to give it a profile**
- **Extruded semi-finished materials:**
  - Tread
  - Sidewall
  - Bead filler







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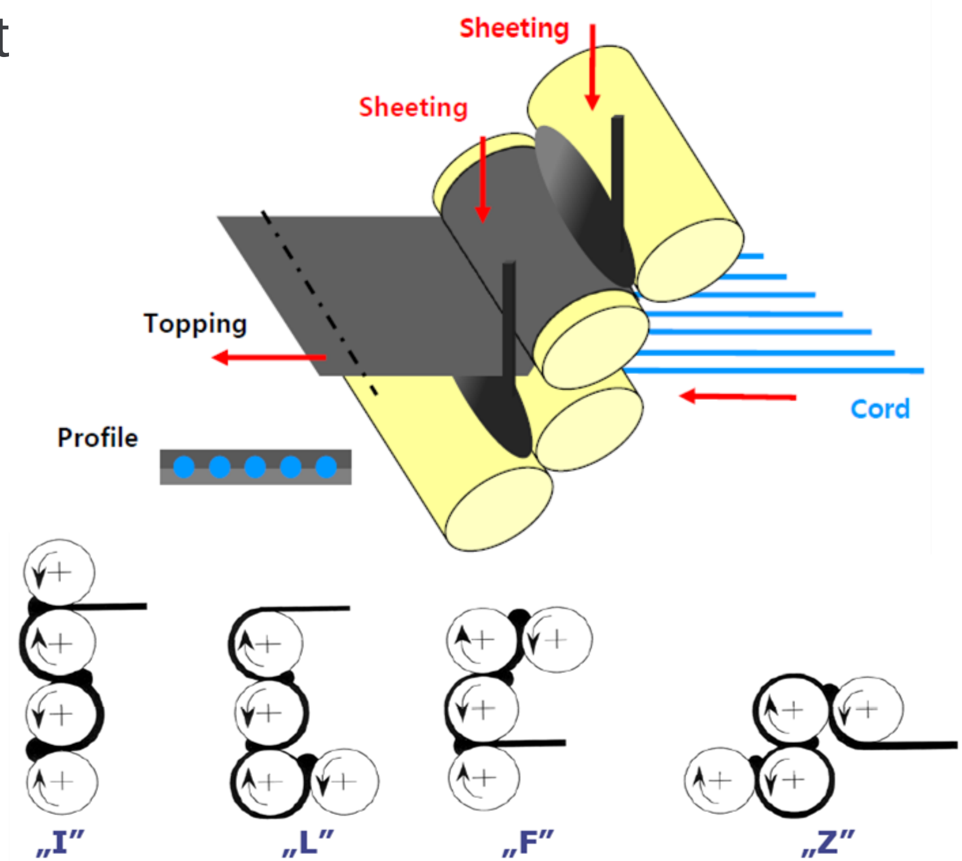
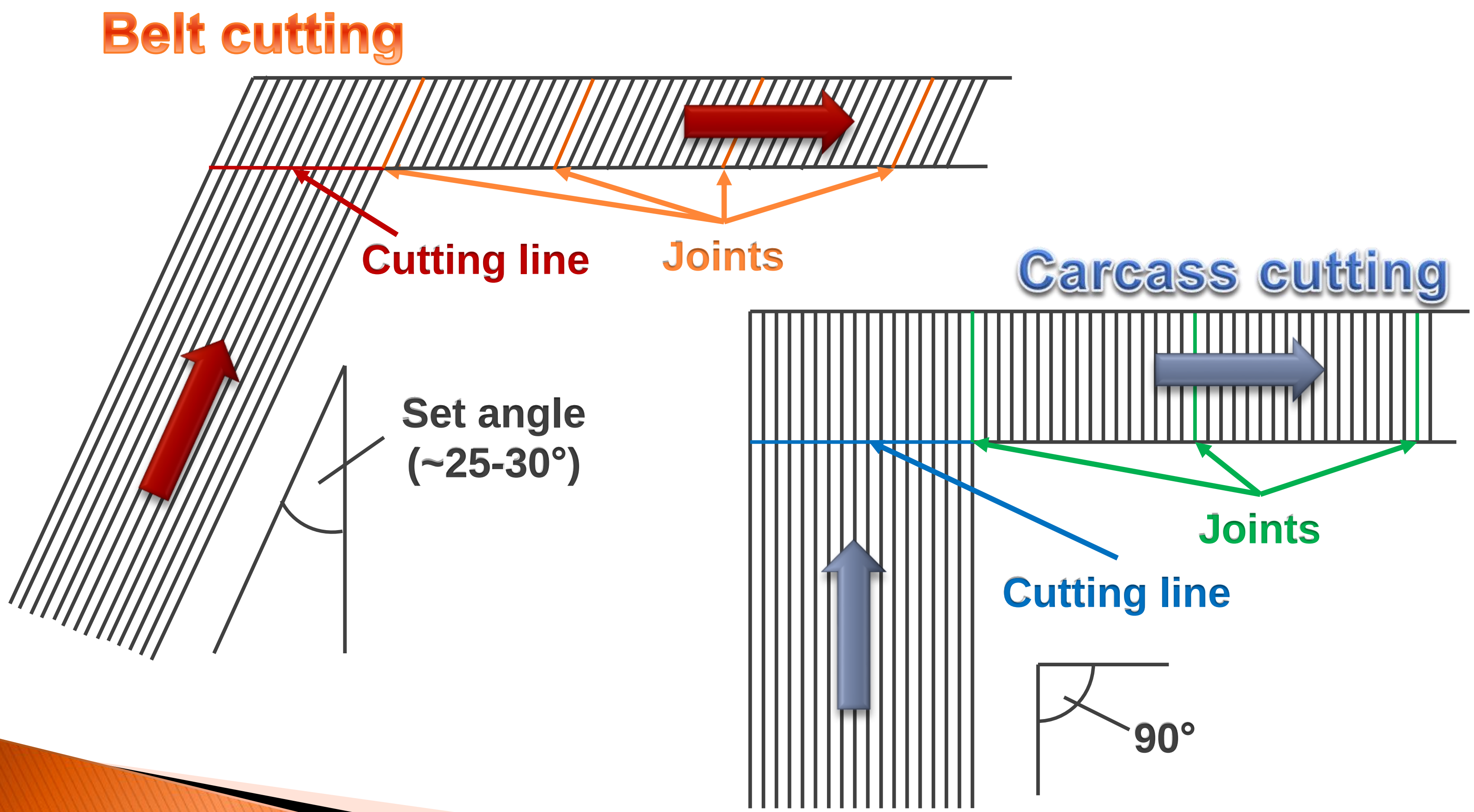
Calendering

- Topping the textile or steel cords with a thin layer of rubber.
- For better adhesion cords are treated and/or coated with special materials.
- **Textile** → **Carcass** – the base of the tire
- **Steel** → **Belt** - reinforcement

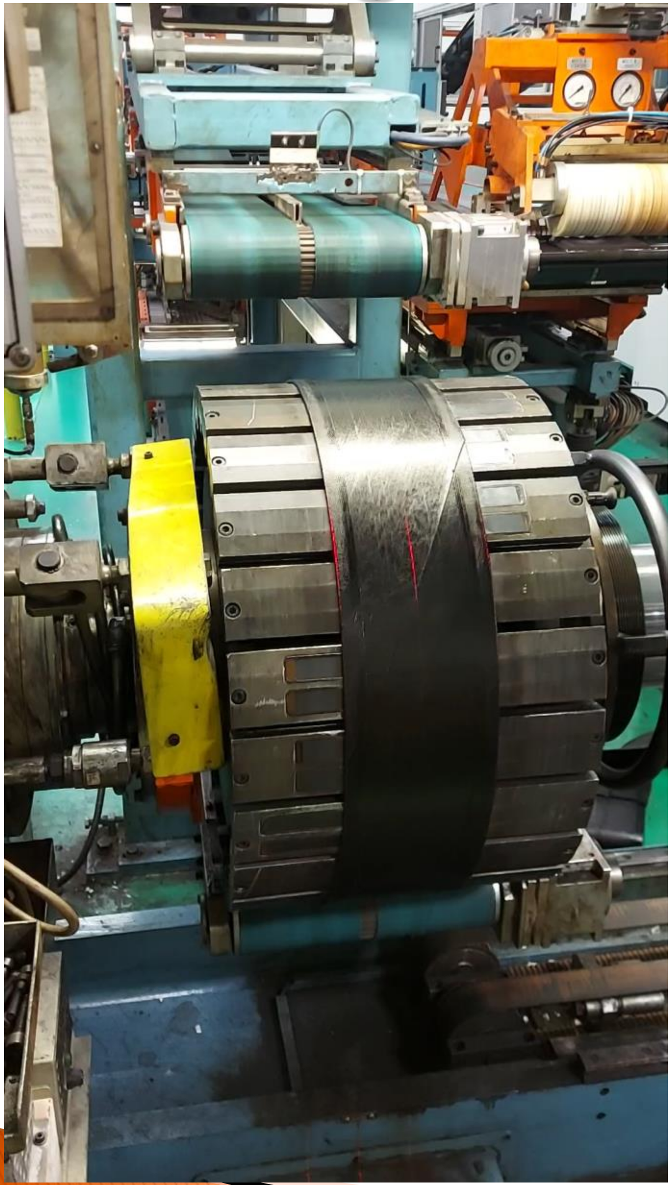


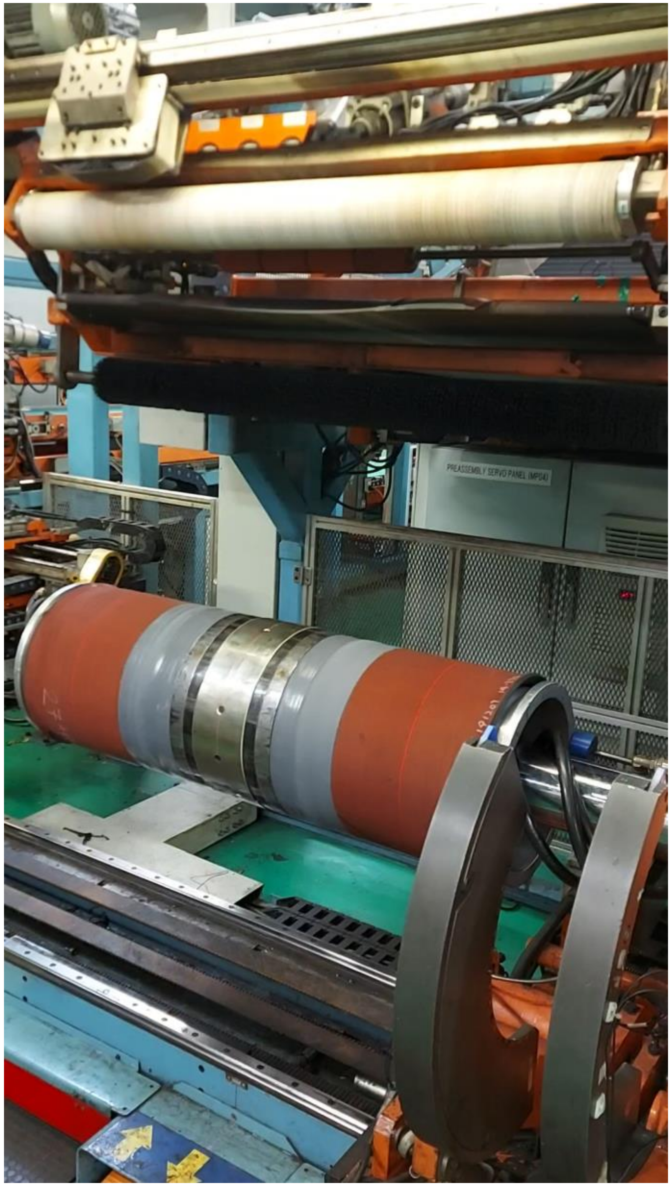
Cutting

- Cutting the calendered material to the right size (defined by the specification)
- Changing the orientation of cords in the semi-finished product



Building





Curing

- Main parameters: time, temperature, pressure
- 150-178°C, 10-25 mins, 8-17 bar
- Application of mold release agents
- Silica compounds: formation of bonds between silica – coupling agent - polymer

2-piece mold

Sectional mold

4.) Raw materials of rubber compounds

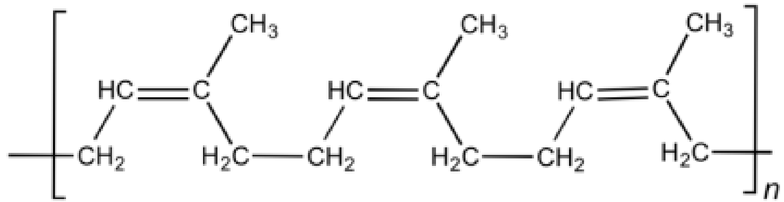
Formulation

- **PHR: Parts per Hundred Rubber**
- **Non-pro compound**
  - Rubber (Natural, Synthetic)
  - Filler (Carbon black, Silica)
  - Processing aids (Oil, Additives)
  - Tackifiers
  - Antidegradants (Waxes)
  - Activator (ZnO, Fatty acid)
- **Final compound**
  - Vulcanizing agents
    - Sulfur
    - Accelerator
    - (Retarder)

Type	Raw material	PHR
Polymer	Elastomers	100
Filler	Carbon black	55
Processing aid	Oil	35
Activators	Stearic acid	2
	Zinc oxide	4
Antidegradants	Antioxidant	1
	Wax	1
	Antiozonant	2
Curatives	Accelerator	1.5
	Sulfur	1.5
TOTAL		203

Raw materials - NR

- **Natural rubber (NR)**
  - Cis-1,4-polyisoprene
  - ~5% other components (proteins, fatty acids, resins etc)



- **Production**
  - Collecting latex → coagulation with formic acid → washing → smoking → baling

- **Production**
  - Good processability
  - Good green tackiness
  - Medium wear resistance
  - Easily oxidizes (aging resistance ↓)
  - Crystallization (stretching, 15°C)

Raw materials - SBR

- **Styrene-butadiene rubber (SBR)**
  - Cis-, trans- and vinyl content, branching, molecular weight, polydispersity
  - Styrene content; importance of production method
- **Production**
  - Emulsion or solution polymerization

	E-SBR	S-SBR	Effect
Styrene content *[wt.-%]*	0 - 60	0 - 45	Traction, wear resistance, rolling resistance
Vinyl content *[wt.-%]*	~ 18	10 - 90	Traction, wear resistance, rolling resistance
Molecular weight dispersion	Wide	Narrow	Narrow: better RR and wear resistance
Monomer dispersion	random	random or block	Random: lower rolling resistance
Branching	random	Controlled (linear or brached)	Decrease in dynamic performance
Functionalization	None	Can be functionalized easily	Low rolling resistance

  - Styrene content ↑: Elasticity ↓, T_g ↑ (Wet traction ↑)
- **Properties**
  - Can be easily modified based on requirements (S-SBR)
  - Good processability
  - Good wear resistance and wet traction
  - High heat generation, low green tackiness

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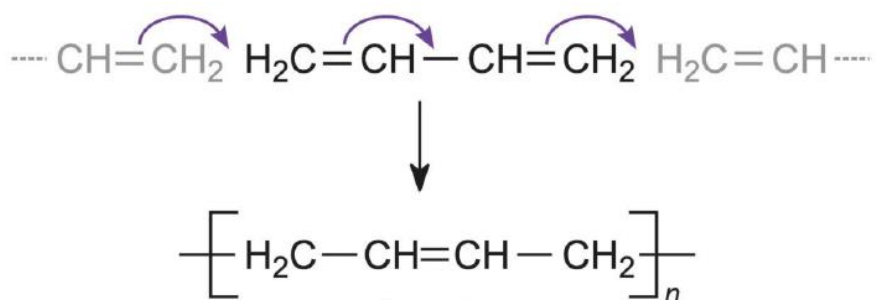
Raw materials - BR

- **Butadiene rubber (BR)**
  - Cis, trans and vinyl content, branching, molecular weight, polydispersity
  - Importance of catalyst

Catalyst	Nd	Co	Ni	Ti	Li
Microstructure					
1.4-cis content (%)	98	97	97	93	38
1.2-vinyl content (%)	0,5	1,7	1,8	5	11
Glas Transition Temperature Tg (°C)	-109	-107	-107	-104	-93
Branching (%)	< 5	20	20	15	< 5
Polydispersity PDI (Mw / Mn)	2,1	3,1	4,2	3,4	2,0

- **Production**
  - Solution polymerization, anoionic or Ziegler-Natta catalyst

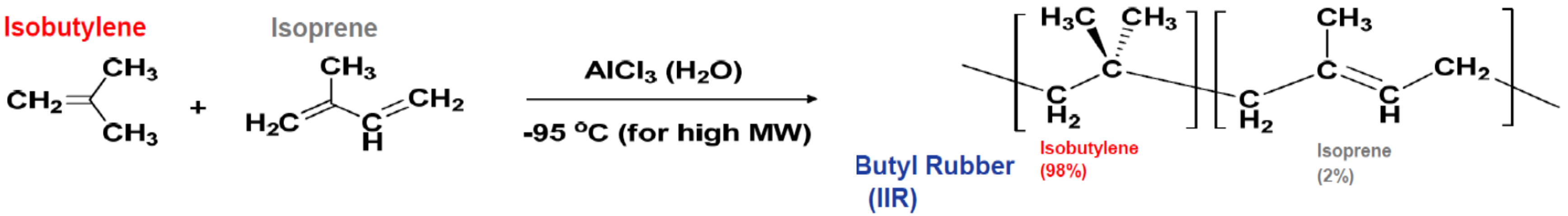


poly(butadiene)

- **Properties**
  - Low T_g
  - Good wear resistance, fatigue resistance
  - Poor processability, low green tackiness
  - Low traction → usually it is used for NR or SBR blends

Raw materials – IIR

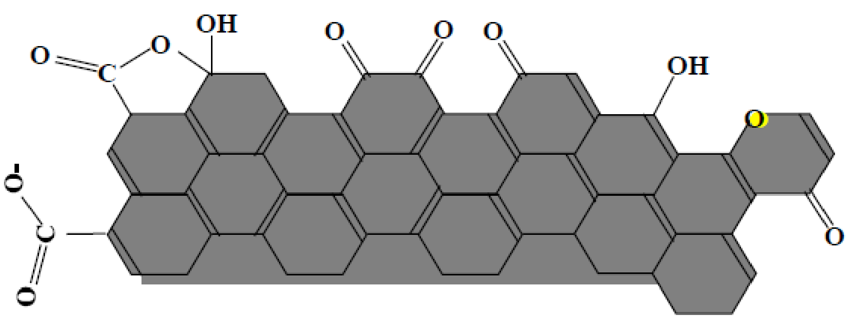
- **Butyl rubber (IIR, Isobutilene-Isoprene rubber)**
  - Isobutylene (98%) and isoprene (2%) copolimer
  - Preferably used type: halo-butyl (Cl, Br)
- **Production**
  - Batch cationic solution polymerization (Friedel-Crafts)

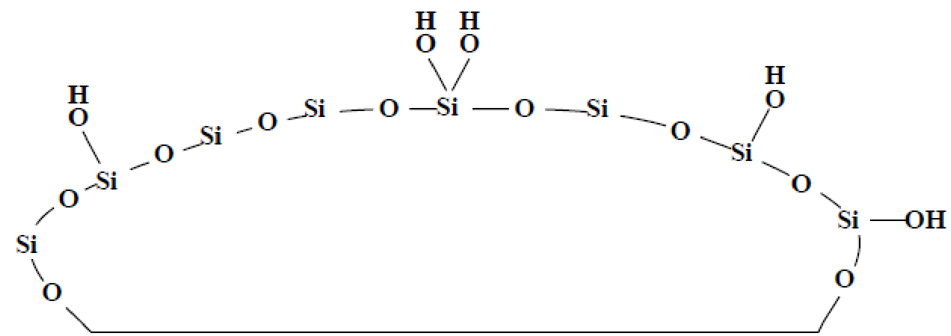


- **Properties**
  - Good chemical resistance
  - Very low air-permeability
  - Good fatigue resistance
  - Very low tensile strength
  - Incompatible with other polymers
  - Few unsaturation → Application of special curing system

Raw materials - Fillers

- **Properties**
  - Insoluble in rubber, make solid phase
- **Functions**
  - Better processability
  - Favorable mechanical properties
  - Cost reduction





Carbon black:

- Cheap
- Physical interaction with polymers
- Used for all of semi-finished products

Not reinforcing filler:

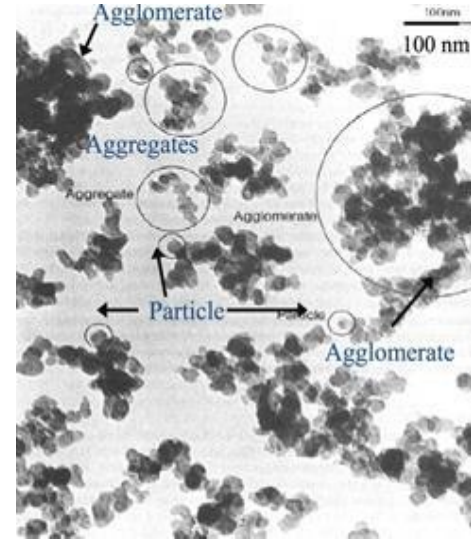
- Calcium-carbonate (white sidewall)

Silica:

- Expensive
- Chemical bond with polymers → needs a coupling agent
- Usage: cap tread
  - Improved wet traction
  - Lower rolling resistance

Raw materials – Carbon black

- **Carbon black (CB)**
  - Organic filler. Physical-chemical interaction with polymer
- **Production**
  - Pirolysis (Furnace method – Furnace Blacks)
- **Main properties**
  - Partical size
  - Structure
  - Specific surface area
  - Surface activity / surface chemistry



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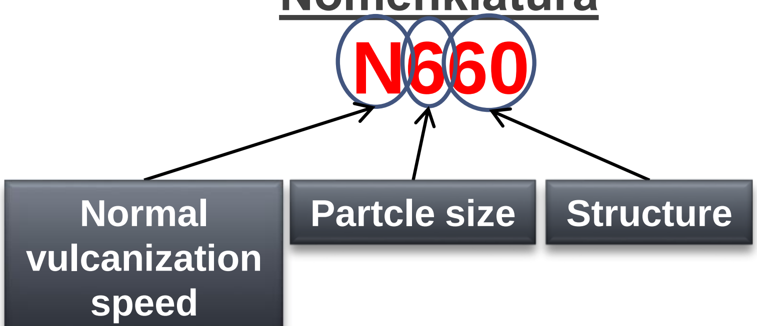
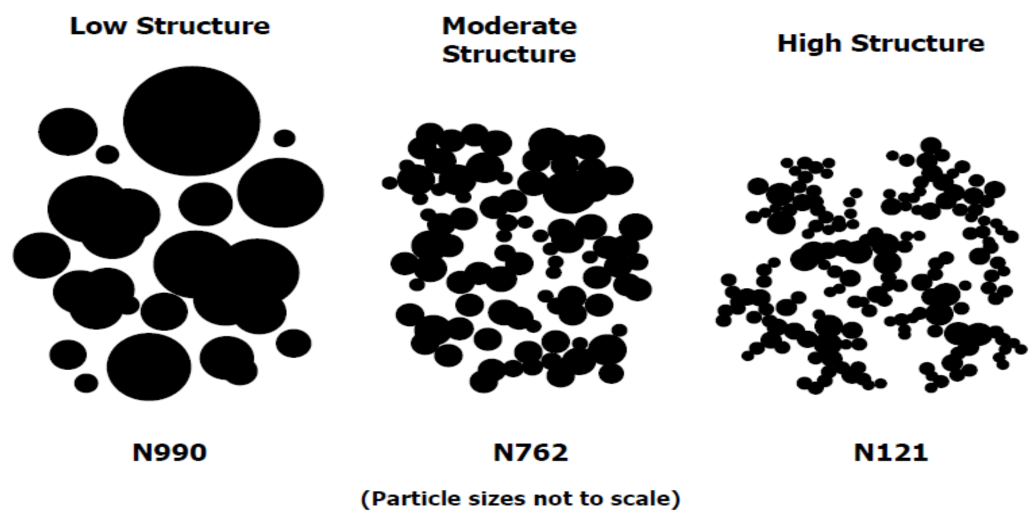


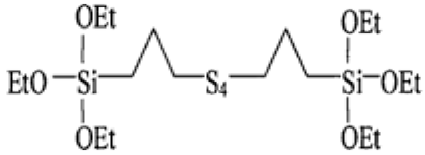


Raw materials – Carbon black

Property	Effect
	Small partice size: **Better reinforcement,** conductivity, low viscosity. **Poor dispersibility**
	Higher structure: **Better reinforcement, higher viscosity**. Smaller rheological swelling. **Increases dispersibility**
	Higher porosity: **Higher conductivity** and viscosity. Decreases specific gravity
	Surface chemistry: **Higher oxygen content improves wetting (better dispersion).** Decreases conductivity

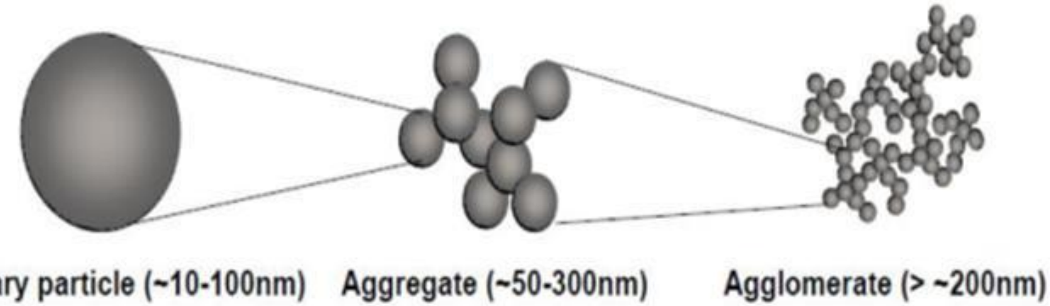
Raw materials – Silica

- **Silica**
  - Precipitated silicium-dioxide. Chemical bond with the polymer.
  - Coupling agent is required.

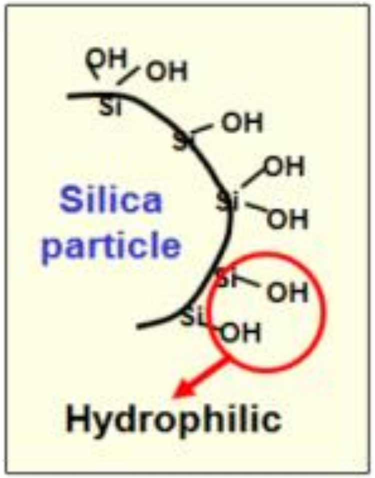


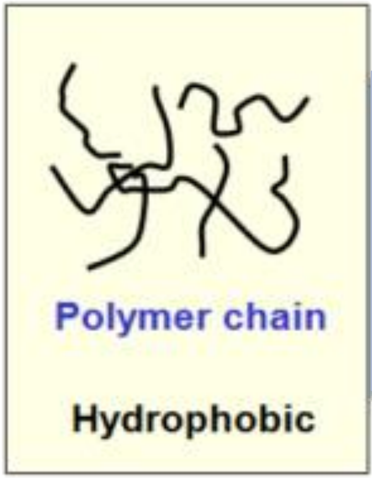
- **Production**
  - Precipitation of sodium-silicate with sulfuric acid
  - $SiO_2 + Na_2CO_3 \xrightarrow{\sim 1350°C} Na_2O \cdot SiO_2 + CO_2$
    (sand)
  - $Na_2O \cdot SiO_2 + H_2SO_4 \rightarrow Silica + H_2O + Na_2SO_4$

- **Main properties**
  - Specific surface area
  - Moisture content
  - Structure
  - pH

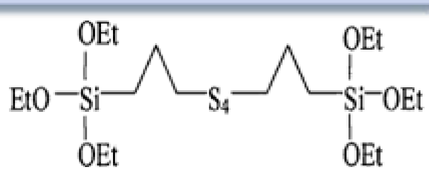


Raw materials – Silica



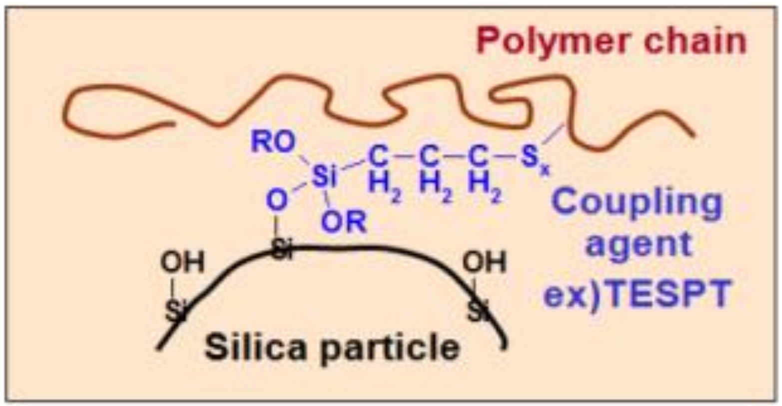


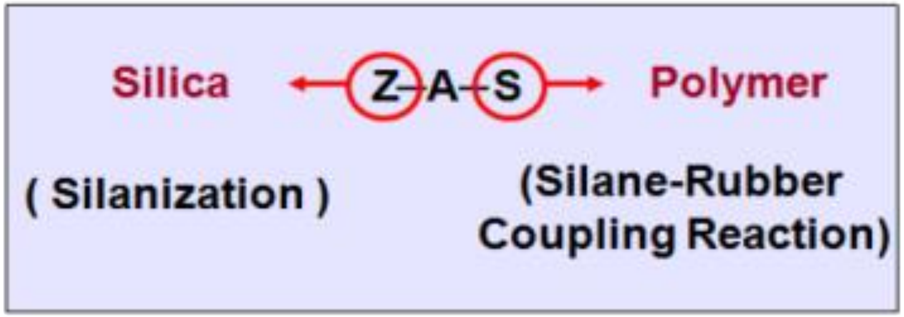
- Silica (hydrophilic) ↔ Polymer (hydrophobic)
  Interaction: Low
- Extra chemical need for proper dispersion



Coupling agent

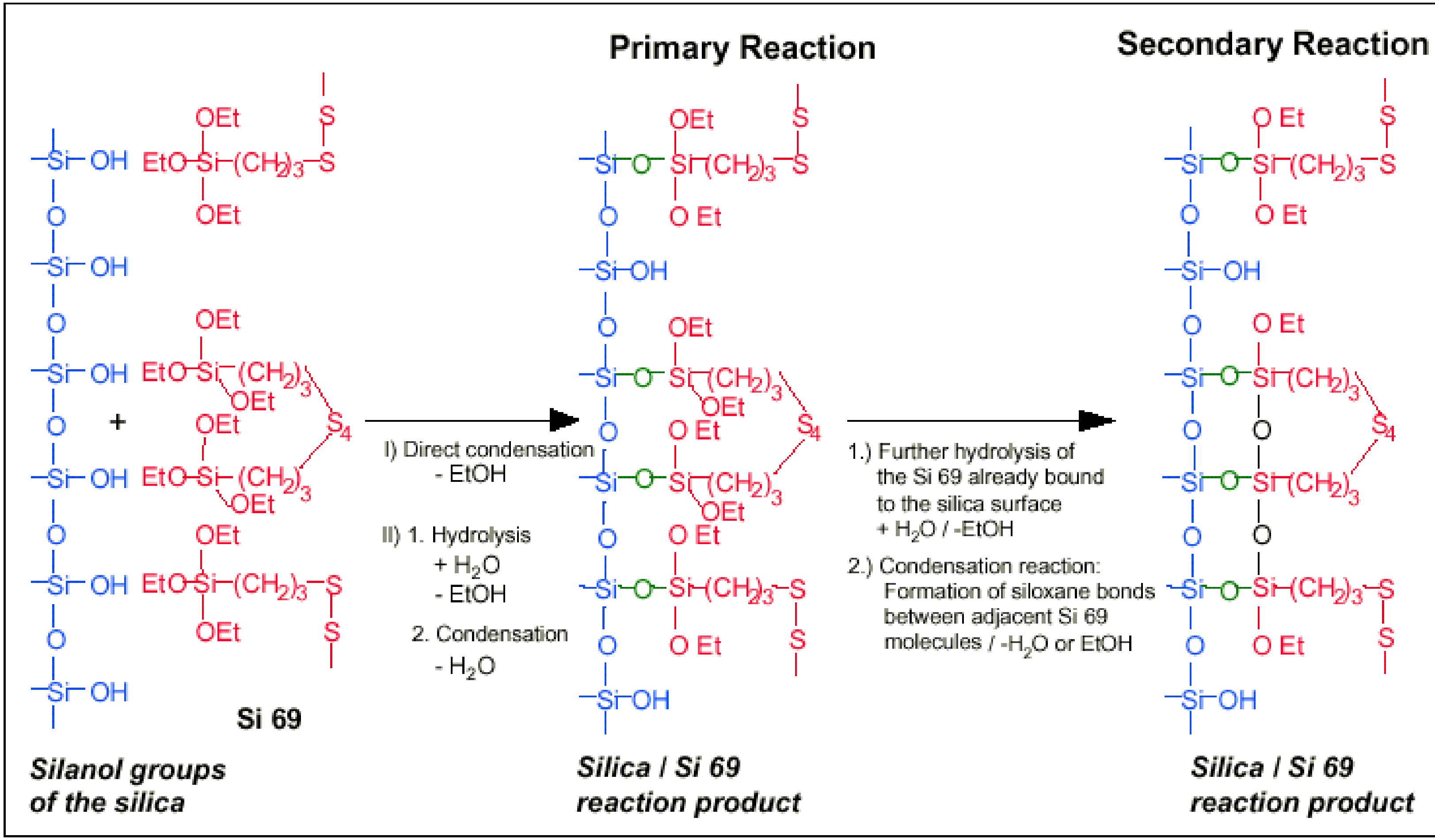
Silica - polymer coupling mechnism





Raw materials – Fillers

Chemical reaction of silanization:



Main parameters:

- Time (3~15 mins)
- Temperature (135~155°C)

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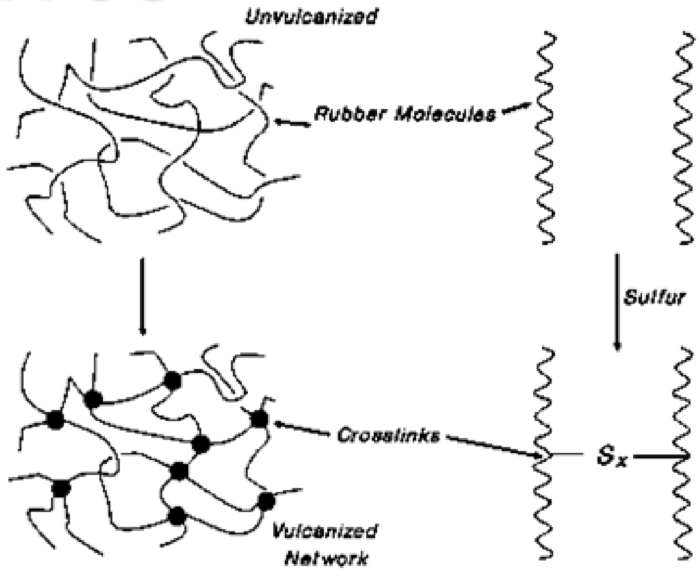
Alapanyagok - Adalékok

- **Processing aids / Oils**
  - Softening
  - Wetting (fillers)
  - Homogenization
- **Tackifiers**
  - Natural / synthetic
  - Resins:
    - Increase hardness and stickiness
    - Support vulcanization

- **Adhesion promoters**
  - Improved adhesion between rubber and steel (cords, wires)
- **Antidegradants**
  - Antioxidants, antiozonants
  - Waxes: prevent degradation of polymer chains (heat, UV, O_2)

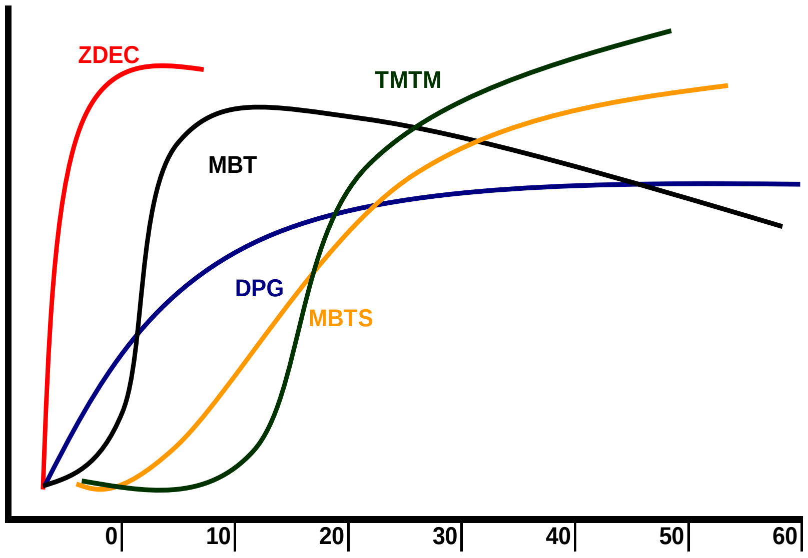
Raw materials – Curatives



- **Sulfur**
  - **Grounded sulfur, S_8 (oil coated)**
    - Cheap
    - Can migrate to surface!
  - **Insoluble sulfur, S_∞ polymer**
    - Expensive
    - Insoluble in CS_2
    - Prevents migration
    - Reverts to S_8 → temperature control during storage and usage
- **Zinc oxide**
  - **IIR (butyl-rubber): lack of double bonds → sulfur curing doesn't work**
  - Accelerated ZnO crosslinking:
    - Using ZnO to remove halogen atoms from the chain and create active spots to crosslink (in the presence of sulfur)

Raw materials – Curatives

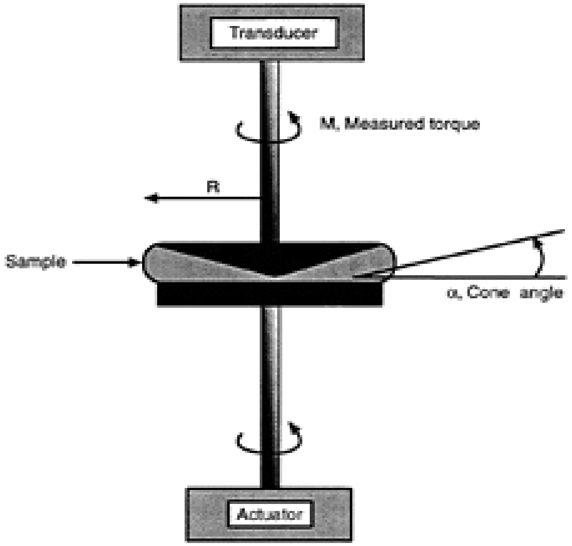
- **Accelerators:**
  - **Increase the speed of vulcanization**
  - **Sulfur compounds**
    - Dithiocarbamates
    - Thiazoles
    - Benzothiazole sulfenamides
    - Guanidines

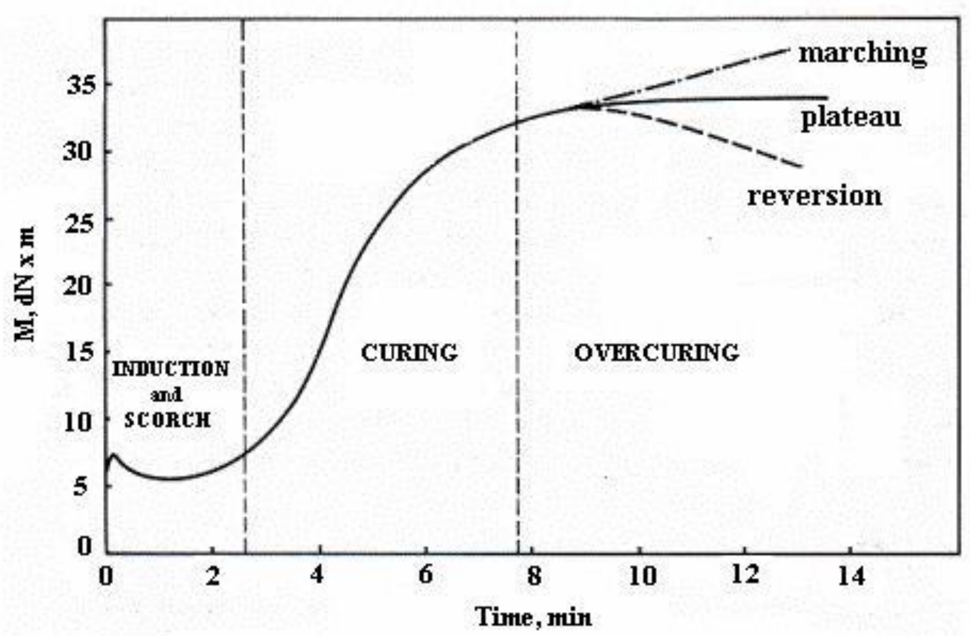


- **Activators:**
  - Activation of accelerators
  - ZnO + Stearic acid (forming Zn-stearate)
- **Retarders:**
  - Prevent premature vulcanization (scorching)

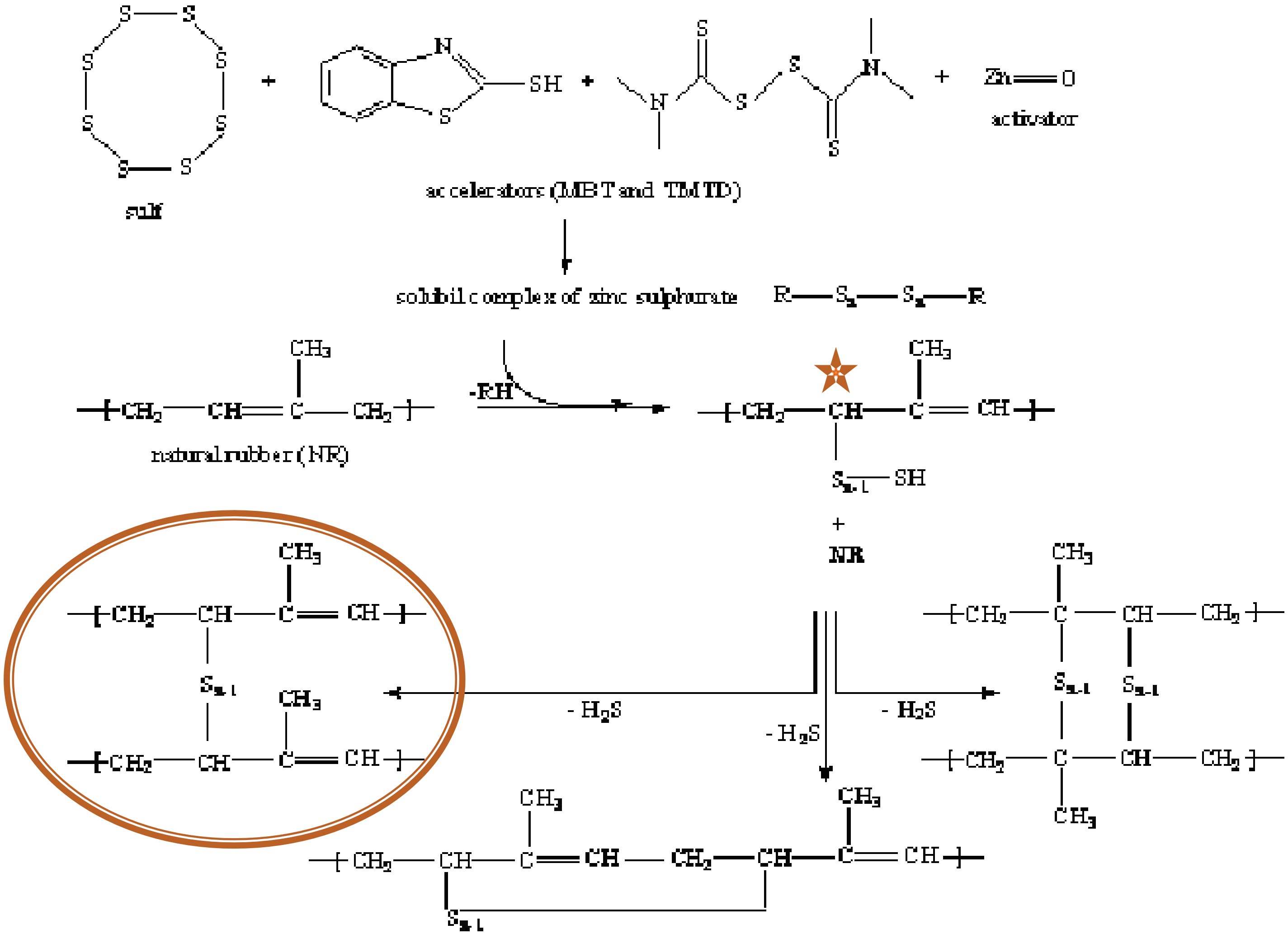
Vulcanization

- **Forming of chemical crosslinks between polymer chains**
- **Vulcanization curve: MDR (Moving Die Rheometer)**
- Vulcanization (curing) of a sample between a still & an oscillating plate
- Registration of torque needed to keep fix deformation





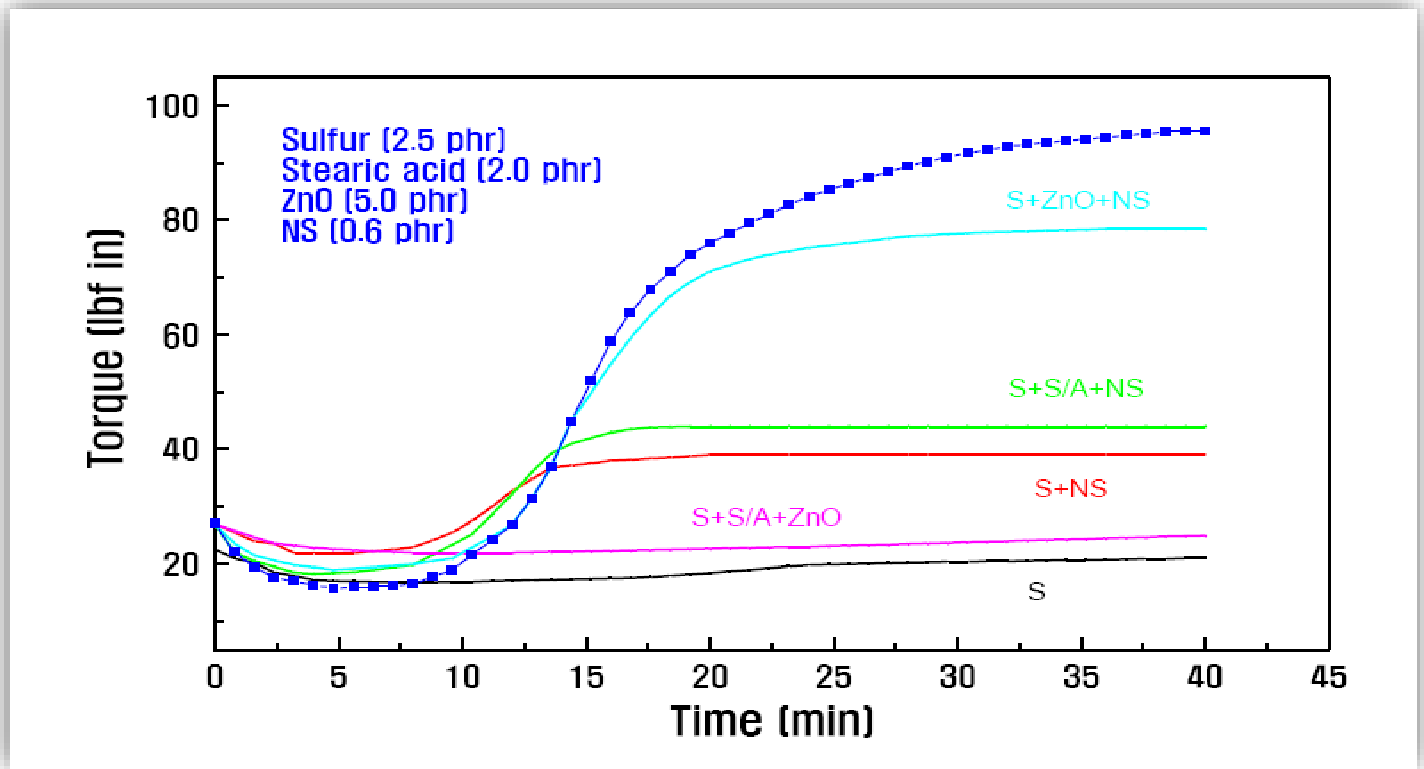
Vulcanization



The double bond activates the hidrigens on the α carbon → The vulcanizing complex attacks here. The double bond remains!

Vulcanization - Curing

- **The Rheo curve & the properties of cured rubber are determined by the curing system**
  - Sulphur / Accelerator ratio
  - Accelerator(s) type



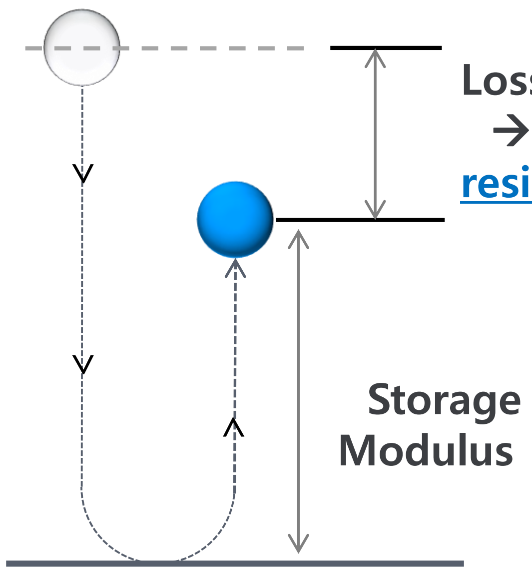
5.) Compound Analysis

Compound Analysis

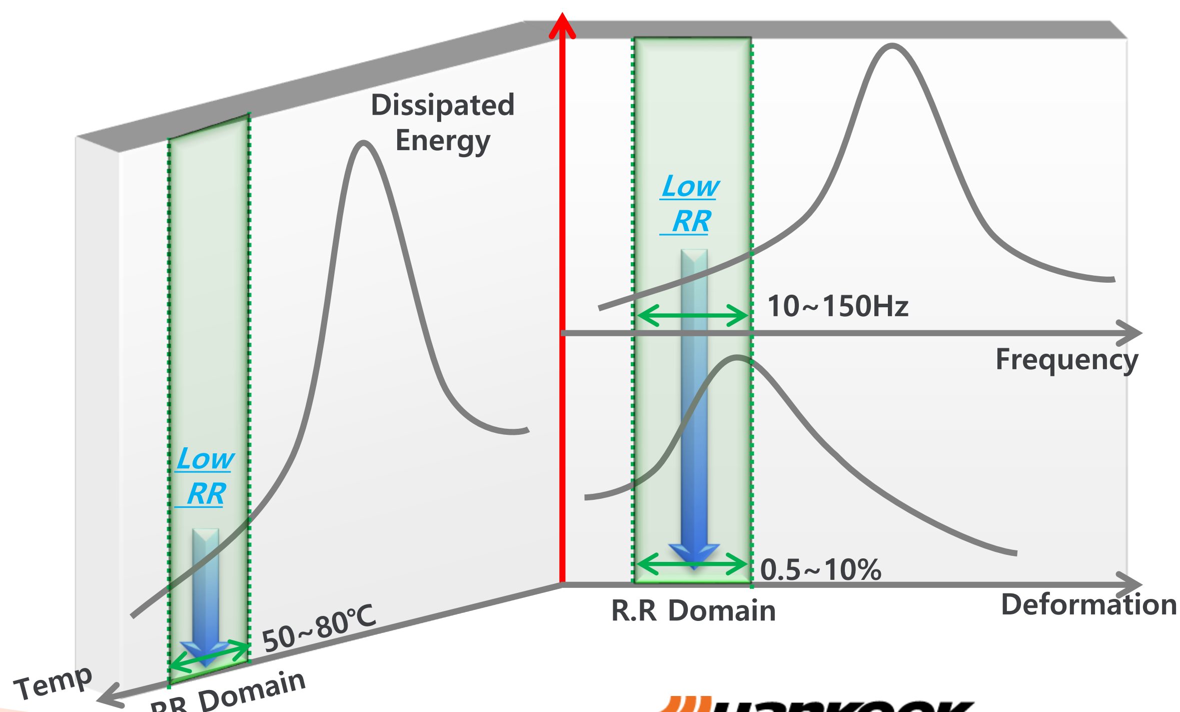
- **Cured & Uncured Rubber Compound**
- **Uncured (not vulcanized):**
  - In correlation with processability of compound
    - Viscosity, Scorch time
    - Rheology (MDR, vulcanization times)
- **Cured (vulcanized):**
  - In correlation with properties of finished tire
    - Modulus, Elongation at break, tensile shrenght
    - Hardnes (Shore A)
    - Viscoelastic properties
- **Specific Gravity:**
  - In correlation with raw materials (quality & quantity)

Viscoelasticity

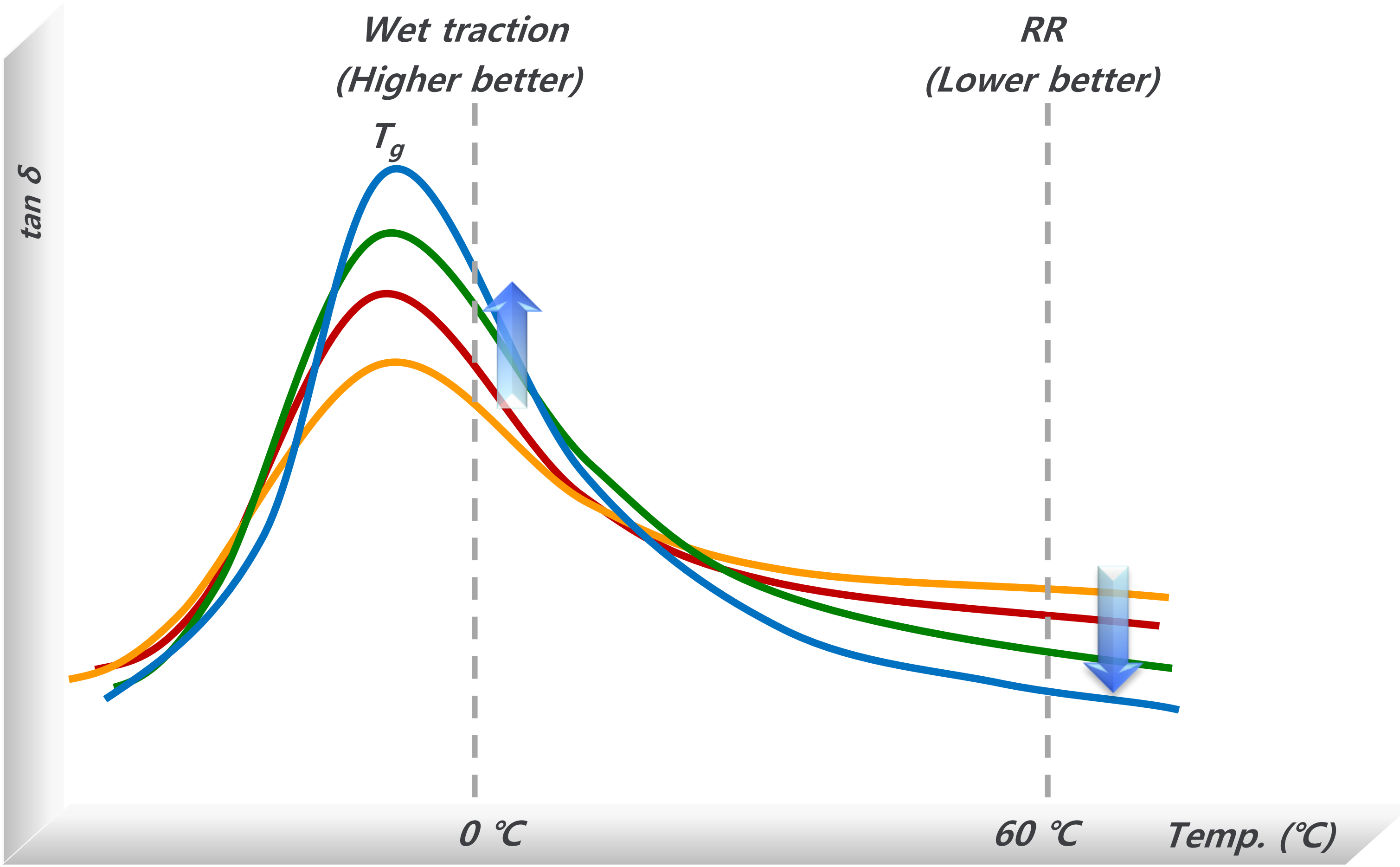
- **Rubber Compound is a Viscoelastic material**
  - Deformation – Reversion: Energy dissipates (Hysteresis)
  - Fuel economic = Low Rolling Resistance, LRR



Loss Modulus
→ Dissipated Energy: The lower, the better roling resistance!



Viscoelasticity



- T_g: Glass transition temperature
  - Below T_g polymers become rigid

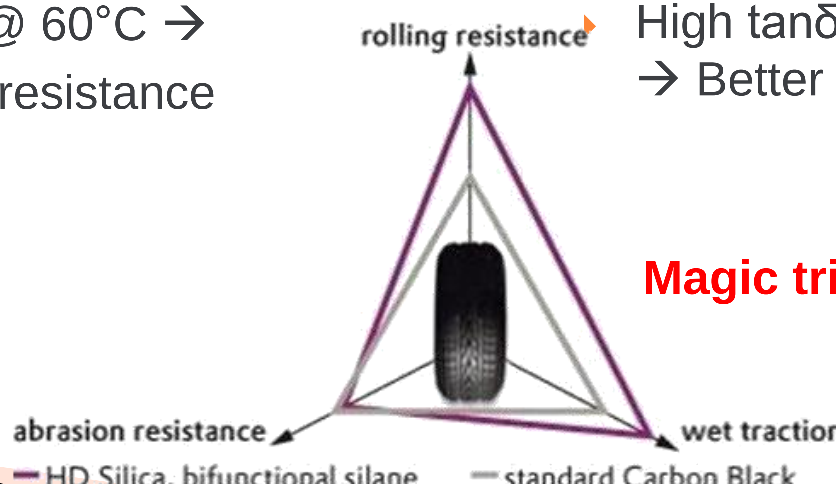
Viscoelasticity

Rolling resistance(RR)

- Lower, if we can win back back more energy after deformation (low hysteresis)
- Lower tanδ @ 60°C → lower rolling resistance

Wet traction

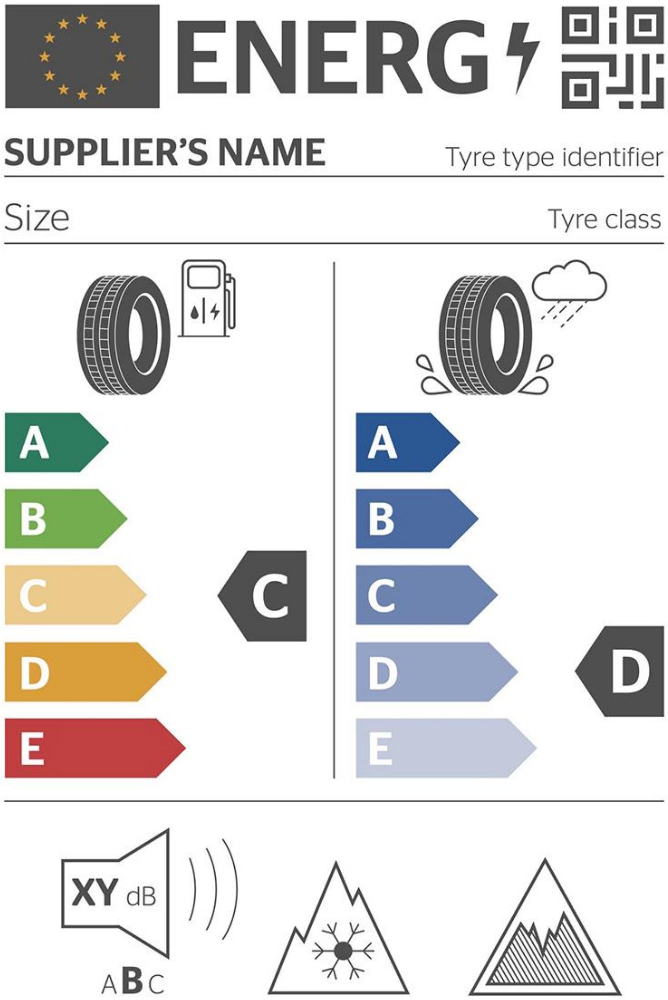
- Traction is better, if we loose more energy after deformation (high hysteresis)
- High tanδ / Loss Modulus (G") @ 0°C → Better wet traction

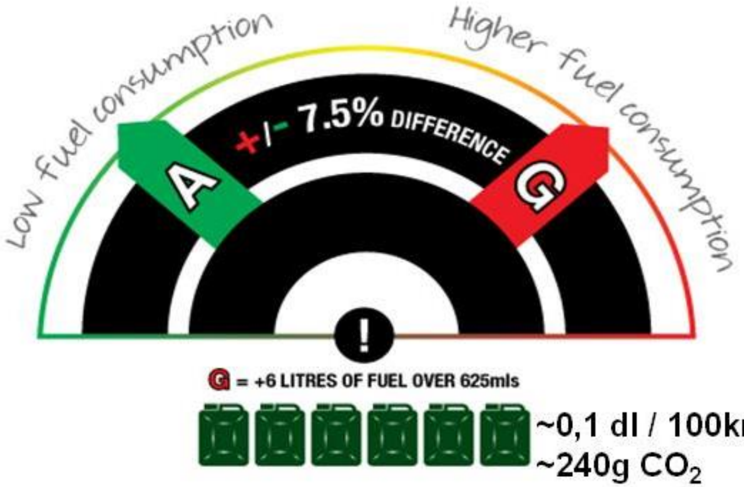


Magic triangle!

6. EU labeling system

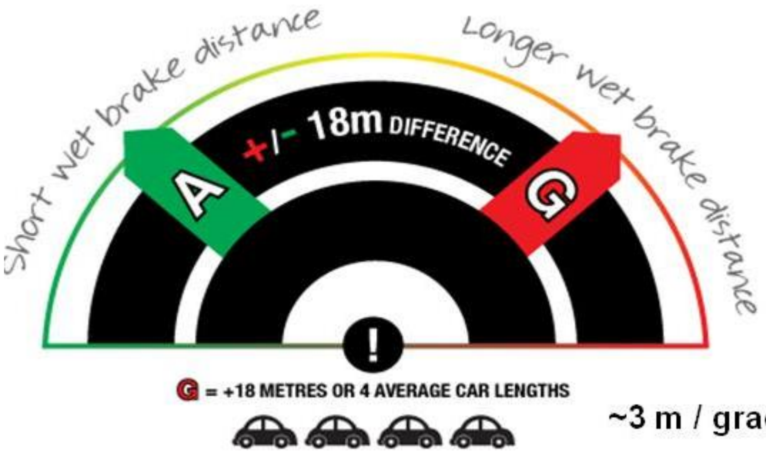
EU Labeling





~0,1 dl / 100km / grade

~240g CO_2



~3 m / grade

Hankook driving emotion