Basics of tire manufacturing

BME - Guest lecture, 2019

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Hankook Tire & Technology
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Content

1.) Hankook Tire & Technology – Company info
2.) Classification of tires; requirements
3.) Structure of radial tires
4.) Tire manufacturing process
5.) Raw materials of rubber compounds
6.) Compound analysis
7.) EU Labeling System
1.) Hankook Tire & Technology
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 supplier of DTM, Formula Renault Eurocup and other series
Product portfolio – Rácalmás

➢ OE (Original Equipment)

➢ RE (Replacement Equipment)
➢ Advanced technologies
2.) 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: All-season
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
3.) Structure of radial tires
Structure of radial tires

- Tread
- Sidewall
- Jointless belt (JLB)
- Steel belt
- Inner liner
- Carcass
- Bead
Cross-section of radial tires

Carcass:
- Rubber coated textile cords
- Backbone of tire
- Gives strength to tire

Inner liner:
- Maintains air pressure
- Special raw material: halobutyl rubber

JLB (jointless belt):
- Long, narrow band
- Prevents separation of steel belts

Steel belt:
- Rubber coated steel cords;
- 2 layers
- Enhance tire strength
- Endure exterior shock
- Orientation of cords (after cutting): ±20~30° to the center line

Sidewall:
- Protects the carcass from external shock
- Transmits torque to the tread

Bead:
- Contact between the tire and the rim
- Handling, comfort

Tread
- Contact with road
- Traction, rolling resistance, wear resistance

Contact:
- Wear resistance
4.) Tire manufacturing process
Tire manufacturing process

- Mixing
- Raw materials
- Rubber compounding
- Extrusion
- Extrusion of tread and sidewall
- Bead
- Topping of bead wire; extrusion of bead filler
- Calendering
- Topping of steel and textile cords
- Cutting
- Cutting of calendered semi-finished products
- Inspection
- Tire inspection:
  - Visual
  - Uniformity
  - Dynamic balance
- Curing
- Curing of green tire
- Building
- Assembling of semi-finished products → Green tire

Polimerek, Töltőanyagok, Adalékok, Textil, Acél ...

Raw materials

Ext

rusion

Calendering

Extrusion of tread and sidewall

Topping of bead wire; extrusion of bead filler

Topping of steel and textile cords

Cutting of calendered semi-finished products

Assembling of semi-finished products → Green tire
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 → continuous 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
Extrusion

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

![Diagram of extrusion process with labeled zones: Hopper, Feeding, Compression zone, Plasticization zone, Conveying solid state materials.](image)
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

**Belt cutting**

- Cutting line
- Joints

Set angle (~25-30°)

**Carcass cutting**

- Cutting line
- Joints

90°
Building

- Tread
- Steel belts
- JLB

- Bead
- Carcass
- Inner liner
- Sidewall

Belt drum

Carcass drum
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
5.) 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)

<table>
<thead>
<tr>
<th>Type</th>
<th>Raw material</th>
<th>PHR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polymer</td>
<td>Elastomers</td>
<td>100</td>
</tr>
<tr>
<td>Filler</td>
<td>Carbon black</td>
<td>55</td>
</tr>
<tr>
<td>Processing aid</td>
<td>Oil</td>
<td>35</td>
</tr>
<tr>
<td>Activators</td>
<td>Stearic acid</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Zinc oxide</td>
<td>4</td>
</tr>
<tr>
<td>Antidegradants</td>
<td>Antioxidant</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Wax</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Antiozonant</td>
<td>2</td>
</tr>
<tr>
<td>Curatives</td>
<td>Accelerator</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>Sulfur</td>
<td>1.5</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td>203</td>
</tr>
</tbody>
</table>
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

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

- Styrene content ↑: Elasticity ↓, T<sub>g</sub> ↑ (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
Butadiene rubber (BR)
- Cis, trans and vinyl content, branching, molecular weight, polydispersity
- Importance of catalyst

Production
- Solution polymerization, anoionic or Ziegler-Natta catalyst

Properties
- Low $T_g$
- Good wear resistance, fatigue resistance
- Poor processability, low green tackiness
- Low traction $\rightarrow$ usually it is used for NR or SBR blends
Raw materials – IIR

- Butyl rubber (IIR, Isobutylene-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

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

**Not reinforcing filler:**
- Calcium-carbonate (white sidewall)
Raw materials – Carbon black

- Carbon black (CB)
  - Organic filler. Physical-chemical interaction with polymer

Production
- Pyrolysis (Furnace method – Furnace Blacks)

Main properties
- Partical size
- Structure
- Specific surface area
- Surface activity / surface chemistry

Nomenclature
- N660
  - Normal vulcanization speed
  - Particle size
  - Structure

N990, N762, N121
(Particle sizes not to scale)
## Raw materials – Carbon black

<table>
<thead>
<tr>
<th>Property</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small partice size</td>
<td><strong>Better reinforcement</strong>, conductivity, low viscosity. Poor dispersibility</td>
</tr>
<tr>
<td>Higher structure</td>
<td><strong>Better reinforcement</strong>, higher viscosity. Smaller rheological swelling. Increases dispersibility</td>
</tr>
<tr>
<td>Higher porosity</td>
<td><strong>Higher conductivity</strong> and viscosity. Decreases specific gravity</td>
</tr>
<tr>
<td>Surface chemistry</td>
<td><strong>Higher oxygen content improves wetting</strong> (better dispersion). Decreases conductivity</td>
</tr>
</tbody>
</table>
Raw materials – Silica

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

- **Production**
  - Precipitation of silicium-dioxide with sulfuric acid

\[
\text{SiO}_2 + \text{Na}_2\text{CO}_3 \xrightarrow{\sim 1350^\circ C} \text{Na}_2\text{O} \cdot \text{SiO}_2 + \text{CO}_2
\]
(sand)

\[
\text{Na}_2\text{O} \cdot \text{SiO}_2 + \text{H}_2\text{SO}_4 \rightarrow \text{Silica} + \text{H}_2\text{O} + \text{Na}_2\text{SO}_4
\]

- **Main properties**
  - Specific surface
  - Moisture content
  - Structure
  - pH
Silica (hydrophilic) ↔ Polymer (hydrophobic)
Interaction: Low
Extra chemical need for proper dispersion
Chemical reaction of silanization:

Main parameters:
- Time (3~15 mins)
- Temperature (135~155°C)
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, O₂)
Raw materials – Curatives

- **Sulfur**
  - Grounded sulfur, $S_8$ (oil coated)
    - Cheap
    - Can bloom to surface!
  - Insoluble sulfur, $S_\infty$ polymer
    - Expensive
    - Insoluble in $CS_2$
    - Prevents migration
    - Reverts to $S_8 \rightarrow$ temperature control during storage and usage

- **Zinc oxide**
  - IIR (butyl-rubber): lack of double bonds $\rightarrow$ 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
The double bond activates the hydrogens on the $\alpha$ 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
6.) 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 strength
      - Hardness (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 economy = Low Rolling Resistance, LRR

Loss Modulus

⇒ Dissipated Energy: *The lower, the better rolling resistance!*
Viscoelasticity

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

Rolling resistance (RR)
- Lower, if we can win back more energy after deformation (low hysteresis)
- Lower $\tan\delta$ @ 60°C → lower rolling resistance

Wet traction
- Traction is better, if we lose more energy after deformation (high hysteresis)
  High $\tan\delta$ / Loss Modulus ($G''$) @ 0°C → Better wet traction

Magic triangle!
7.) EU labeling system
EU Labeling

A surface wet brake distance

Low fuel consumption

Higher fuel consumption

A

+/- 7.5% DIFFERENCE

G

+6 LITRES OF FUEL OVER 625mths

~0.1 dl / 100km / grade

~240g CO₂

Short wet brake distance

G

+18 METRES OR 4 AVERAGE CAR LENGTHS

~3 m / grade

Tanδ @ 60°C

Tanδ @ 0°C

A

B

C

D

E

F

G

1222/2009 – C1