Insights into Material Composition of Tread, Sidewall and Innerliner through a Global Tire Survey
Tire & Specialty Rubber (TSR) Business Unit

S. Teertstra, Clemson University Global Tire Industry Conference Hilton Head, SC., April 14, 2016
ARLANXEO – a joint venture with two strong partners

Combination of two powerful partners

- World’s largest integrated energy enterprise
- Backward integration into feedstock for synthetic rubber
- Strategic commitment to further develop value chain downstream
- Leading market and technology positions in synthetic rubber
- Well invested asset base
- Broadest product portfolio in the rubber industry with leading brands and quality

#1 in feedstock

#1 in synthetic rubber
Tire & Specialty Rubber BU – World’s leading manufacturer of Performance Elastomers

**Facts**
- Part of: ARLANXEO
- Customers: > 250
- Market position: ARLANXEO No. 1-3 in synthetic rubber
- Production capacity: > 1,000,000 t/a (all rubber grades)

**Products & Brands**
- Product & brands:
  - BTR: Butyl rubber (X_Butyl™ IIR, CIIR, BIIR)
  - PBR: Polybutadiene rubber (Buna™ CB / Nd EZ)
  - S-SBR: Solution styrene butadiene rubber (Buna™ VSL, SL)
  - E-SBR: Emulsion styrene butadiene rubber (Buna™ SE)

**Applications**
- Tire
- Plastics
- Consumer & Pharma
- Golf & sport balls
ARLANXEO is the Global Leader in Synthetic Rubber Used in All Parts of the Tire
44 PCR Tires Included:

- Tire segment: replacement, 2013 production
- Tire type, size: summer, 205/55R16 91V
- Brands: 23 / 25 top producers (ERJ 2013 ranking), representing 80% of global tire sales
- Top 5 producers: 205/55R16 tires from 3 different regions and additional tire sizes included (175/65R14 and 245/40R18)
- Tires from all main manufacturing regions, procured in NA, EMEA, Japan and India (APO)
- Korean (APO) and Chinese (GCH) tires purchased in NA, therefore are ‘export quality’
- Tires from Japan selected from the Eco segment
Silica in tread technology widespread but not yet universal

- Low, medium and high silica loading groups
- EMEA region tires contain high silica levels due to tire labeling requirements for wet grip and fuel economy
- NA tires contain high or medium levels of silica – driven mainly by market requirements and to a lesser extent regulatory controls
- APAC, LATAM and GCH range from high to low levels of silica – due to high export rates to various regions

Analysis of Filler Composition in PCR Tread Segments
Predicted tire performance is improved with the use of silica technology in PCR tires

- Temperature sweep of test specimens cut from PCR tire treads
- One tire from each silica grouping selected (low, medium, high)
- Wet and dry grip predicted to improve with silica loading (tan delta @ 0 °C, 20 °C)
Predicted tire performance is improved with the use of silica technology in PCR tires

- PCR tread specimens tested in a strain sweep experiment (60 °C and 10 Hz)
- One tire from each silica grouping selected (low, medium, high)
- Improved fuel economy (lower RRc) with increased silica
- RRc improvements known when silica technology is combined with high performance synthetic elastomers (Buna® sSBR and Nd-BR)

Dynamic Mechanical Analysis of Tread Specimens Predicts Decreased Rolling Resistance

- Lower RRc with increased silica
- RRc improvements known when silica technology is combined with high performance synthetic elastomers (Buna® sSBR and Nd-BR)
Nd-BR is used in PCR tread and sidewall to improve fuel efficiency by decreasing rolling resistance of the tire

Elemental Analysis of PCR Tread and Sidewall Specimens for Trace Neodymium

- ICP analysis identifies trace Neodymium (Nd) from catalyst used to produce rubber
- Unique signature derived from Nd-BR
- Nd-BR found in a higher percentage of tires from the top 5 producers
- Fewer examples of tires containing Nd-BR from producers ranked 6 to 25
- Benefits of Nd-BR to improving RRc are more significant in sidewall due to higher BR content
Nd-BR molecular structure decreases rolling tire energy loss

- Nd-BR has lowest PDI among high cis-1,4-BR materials
- Nd-BR has lowest content of short chains and chain ends responsible for energy losses during deformation of tire
- Most homogeneous polymer network formation expected with Nd-BR
- Improved rolling resistance in tire sidewall and tread applications with Nd-BR
Nd-BR presence in the tire can be correlated with higher silica levels in the tread

- Nd-BR found predominantly in tires with high silica loadings in the tread
- In many cases Nd-BR present in both the tread and sidewall of tire
- Benefit of Nd-BR to improve RRc being used with silica technology for higher performance tires in NA and EMEA

Complementary Technologies Lower the Rolling Resistance of Tires

![Graph showing the correlation between Nd-BR presence and silica levels in tires](image-url)

- **63%** of tires contain Nd-BR in NAFTA
- **77%** of tires contain Nd-BR in EMEA
- **14%** of tires contain Nd-BR in GCH
- **13%** of tires contain Nd-BR in APO
- **0%** of tires contain Nd-BR in LATAM
PCR innerliner (IL) gauge was found to be dependent on the tire construction

- Average IL gauge for 44 PCR tires included in survey is 0.76 mm (min = 0.35 mm, max = 1.14 mm)
- 82% of PCR tires in survey contain a protection layer between cord and IL
- A thicker IL layer is needed without a protection layer due to IL flow into cord
- All GCH tires had full cushion
- EMEA and LATAM tires full or partial
- NA tires partial or no cushion
PCR tire construction differences

Examples of Different Tire Constructions Found in PCR Tires

No Cushion Layer

Cushion Layer

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Significant regional and segment differences observed for halobutyl type and content in the IL of PCR Tires

- 59% of PCR contain BIIR, 41% CIIR
- BIIR avg 88 phr (min = 48 phr, max = 100)
- CIIR avg 67 phr (min = 40 phr, max = 86)
- SBR found in some EMEA, GCH and APO tires at up to 30 phr
- Inclusion of significant NR and SBR will negatively affect air retention behavior
- GCH and LATAM lower avg IL gauge and mainly CIIR at lower levels (NR inclusion)
- NA and EMEA higher avg IL gauge, predominantly BIIR at higher levels
- Eco class tires mainly BIIR with lower avg IL gauge (effect of light-weight tires)
Mineral fillers are being used in half of the PCR tires included in the survey

- 57% of tires contain mineral filler at a level higher than 5 phr
- CaCO3 and clay used at the highest levels, on average at 23 and 17 phr
- Talc detected in high levels in 1 tire from APO (33 phr)
- Mineral fillers used with both CIIR and BIIR, complementary to the CB
- No regional preferences observed
- No correlation with IL gauge observed

Mineral Fillers Appear to be Present Mainly to Reduce IL Compound Cost

- None: 43%
- Clay: 23%
- Talc: 5%
- CaCO3: 30%
- Silica: 0%
Truck and Bus Tire Survey
TBR Tire Survey conducted from a global perspective representing a significant portion of the worldwide tire market

60 TBR Tires Included:

- Tire segment: OE and replacement, 2009 - 2014 production
- Tire size & type: 22.5” diameter medium truck and bus tires; steer, drive and trailer
- Brands: 27 of the top 40 global tire producers (ERJ 2013 ranking)
- 7 tube type tires from India included, 20” diameter
Carbon black is the main filler used in TBR treads with only small amounts of inorganic fillers observed in some cases

<table>
<thead>
<tr>
<th><strong>No Clear Regional or Manufacturer Trends Observed in Filler Data</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>▪ 40% of tires contain inorganic filler levels above 10 phr (assumes 5 phr ZnO max.)</td>
</tr>
<tr>
<td>▪ Inorganic filler ranges from 0 to ~ 20 phr,</td>
</tr>
<tr>
<td>▪ Lower CB at higher inorganic filler levels</td>
</tr>
<tr>
<td>▪ Presence of silica confirmed in most cases where inorganic filler levels &gt; 10 phr</td>
</tr>
<tr>
<td>▪ Wear resistance and heavy loads dictate NR usage and high CB levels in TBR tires</td>
</tr>
<tr>
<td>▪ Current RRc requirements/targets can be met without silica technology (eg. GHG Phase I, Smartway)</td>
</tr>
</tbody>
</table>

![Graph showing relationship between inorganic content and carbon black](image_url)
Predicted tire performance is improved with the use of silica technology in TBR tires

Dynamic Mechanical Analysis of Tread Specimens Predicts Decreased Rolling Resistance
Nd-BR is used in TBR sidewall to improve fuel efficiency by decreasing rolling resistance of the tire

- Nd-BR found in a higher percentage of tires from the top 5 producers
- 7 of 10 tires with Nd-BR are Smartway
- Various technologies are being used to improve RRc and meet regulations/targets

Elemental Analysis of TBR Sidewall Specimens for Trace Neodymium
Significantly thicker IL are used in TBR tires to retain air pressure

- IL gauge on average 2.5 X thicker than for PCR tires
- Full cushion construction
- GCH tires lower average IL thickness
- Tube tires contain a surprisingly thick IL
- All GCH tires had full cushion
- Performance requirements of TBR much higher due to high inflation pressure and high loads
- Maintaining air pressure is critical for fuel economy

A Thicker IL is Required in TBR Tires Due to the Service Conditions
A higher proportion of halobutyl is used in TBR tires to retain air pressure

- 57 of 60 tires contain BIIR at high levels
- Chlorine detected in 4 tires from GCH (CIIR or other chlorinated polymers)
- BIIR clearly is the standard in TBR
- Heat resistance of BIIR important for retreading operations in NA and EMEA (NR required with CIIR)
- Improved adhesion characteristics of BIIR at high levels versus CIIR

**BIIR is Used Almost Exclusively in TBR Tires Due to the Service Conditions**

<table>
<thead>
<tr>
<th>Tube Type</th>
<th># of Tires Included</th>
<th>HIIR in IL (phr)</th>
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<tr>
<td>Global Tubeless</td>
<td>53</td>
<td>88</td>
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<tr>
<td>GCH Tubeless</td>
<td>20</td>
<td>78</td>
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<tr>
<td>Global Excl. GCH</td>
<td>33</td>
<td>94</td>
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<tr>
<td>Tube Type</td>
<td>7</td>
<td>84</td>
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</table>

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Further improvement of tire technology through the use of advanced materials will be required to meet new regulations.

### Emissions & Fuel Economy Targets for Cars

<table>
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<tr>
<th>Country/Region</th>
<th>Target Year</th>
<th>Standard Type</th>
<th>Unadjusted Fleet Target</th>
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<tbody>
<tr>
<td>EU</td>
<td>2015 2021</td>
<td>CO\textsubscript{2} CO\textsubscript{2}</td>
<td>130 g/km 95 g/km</td>
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<tr>
<td>JP</td>
<td>2015 2020</td>
<td>Fuel economy</td>
<td>16.8 km/L 20.3 km/L</td>
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<tr>
<td>CA</td>
<td>2016</td>
<td>CO\textsubscript{2} + GHG</td>
<td>135 g/km</td>
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<tr>
<td></td>
<td>2025</td>
<td>CO\textsubscript{2} + GHG</td>
<td>98 g/km</td>
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<tr>
<td>US</td>
<td>2016</td>
<td>Fuel economy</td>
<td>36.2 mpg</td>
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<tr>
<td></td>
<td>2025</td>
<td>Fuel economy</td>
<td>56.2 mpg</td>
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<td>MX</td>
<td>2016</td>
<td>Fuel economy</td>
<td>39.3 mpg</td>
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<tr>
<td>CN</td>
<td>2015 2020*</td>
<td>Fuel economy</td>
<td>6.9 L / 100km 5.0 L / 100km</td>
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<td>KR</td>
<td>2015</td>
<td>Fuel economy</td>
<td>17 km / L</td>
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### GHG Phase II Standards

- Proposed reductions of CO\textsubscript{2} and fuel consumption for medium and heavy duty vehicles
- Phased in between 2021 and 2027
- 24% reduction compared to Phase I standard for combination tractors designed to pull trailers
- 8% reduction for trailers starting in 2018 compared to 2017 models
- 16% reduction for vocational vehicles, pick-up trucks and light vans compared to Phase I

Source: Arthur D. Little: The Automotive CO\textsubscript{2} Emissions Challenge, 2014
Testing Capabilities

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<tr>
<th>Analytical Testing</th>
<th>NMR</th>
<th>GPC</th>
<th>FTIR</th>
<th>TGA</th>
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<td>Xray</td>
<td>Volatiles</td>
<td>Elemental Analysis</td>
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<td>Mixing</td>
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<td>Tangential (1.5 L)</td>
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<td>Brabender (85 &amp; 375 mL)</td>
<td>DSM Microcompounder (15 mL)</td>
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<td>Compound Testing</td>
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<td>Tensile</td>
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<td>Permeability</td>
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<td>DeMattia Flex</td>
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<td>Rebound</td>
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<td>Capillary Rheometry</td>
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<td>Advanced Rubber Testing</td>
<td>Dynamic mechanical analysis</td>
<td>Payne Effect</td>
<td>Heat Build-Up</td>
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<td>Surface Characterization*</td>
<td>SEM/EDX</td>
<td>XPS</td>
<td>AFM</td>
<td>ToF-SIMS</td>
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<td>Optical Microscopy</td>
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* Via Surface Science Western located in same facility
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