30th CLEMSON UNIVERSITY
GLOBAL TIRE INDUSTRY CONFERENCE
APRIL 23 - 25, 2014
SSBR and NdBR Developments for Tire Tread

Judy Douglas, LANXESS Corporation
SSBR and NdBR Developments for Tire Tread – How LANXESS has responded to the demand for improved tire materials

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Performance Butadiene Rubbers (BU PBR)
Clemson University Global Tire Industry Conference
Hilton Head, SC April 23-25, 2014
Agenda

- Introduction and the global spread of tire labeling
- Retreading tires & testing capabilities
  - Benchmarking our new polymers in tire testing
- Nd-BR developments
  - High Molecular Nd-BR & Easy Processing grades
- S-SBR developments
  - Functionalization technologies (fct)
- Summary
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Tire labeling increases pressure to reduce CO$_2$ emissions and will create transparency for the customer.

- 20-30% of fuel consumption is attributable to tires.
- High-performance rubbers help to save a considerable part.
- Introduction of “Green Tires” in the early 90’s reduced rolling resistance by 20%.
- Further considerable savings are possible – with high-performance rubbers already on the market.

Cutting-edge tires help save energy.

* PBR: General Purpose Butadiene Rubber; ** fct.: Functionalized S-SBR for better integration of the filler into the polymer matrix.
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Tire building and testing to direct our product development

Virgin tires

Buffed tires

Retreading of the buffed tire with the new tread compound (mixed in K10)

Storage of the freshly retreaded tires before the vulcanization process

Mold for the vulcanization

1st Phase  2nd Phase  3rd Phase  4th Phase  5th Phase
Tire testing review

LXS internal tire tread test (PCR)

- Retreading PCR
- TNO trailer test for wet and dry traction
- TÜV RRc
- Treadwear can be tested as well as noise, handling and comfort
- Duration 3 to 4 months from mixing the new polymer to getting all tire data

Taken from www.tno.nl
“AA” tires

What does an “AA” PCR tire mean?

- Fuel saving potential from G to an A labelled PCR:
  
  50% on RRc = 10% on fuel
  
  ~ 0.65 l/100 Km
  
  (Truck even more)
  
- Wet traction performance from F to an A labelled PCR:

  ~ 20 m wet breaking distance

<table>
<thead>
<tr>
<th>Test results</th>
<th>Label limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>RRc</td>
<td>&lt; 6.5 = A</td>
</tr>
<tr>
<td>Wet Traction</td>
<td>&gt; 1.10 = A</td>
</tr>
</tbody>
</table>
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High molecular weights lead to improved tire compound properties like reduction of the rolling resistance* (1/2)

- Good correlation between energy dissipation / rebound and number average of molecular weight Mn
  - Number of free polymer chain ends depends on Mn with linear polymer = 2 x Mn, branched polymer = (2+x) x Mn

* Rebound at 60°C, tan d (max.)
High molecular weights lead to improved tire compound properties like reduction of the rolling resistance* (2/2)

### Physical Properties Disclaimer:
These items are provided as general information only. They are approximate values and are not considered part of the product specifications.

<table>
<thead>
<tr>
<th>High cis BR Grades</th>
<th>NiBR-1</th>
<th>NiBR - 2</th>
<th>NiBR - 3</th>
<th>Buna CB 1220</th>
<th>Buna CB 1203</th>
<th>BUNA CB Nd40</th>
<th>BUNA CB 24</th>
<th>BUNA CB Nd60</th>
<th>BUNA CB 22</th>
<th>BUNA CB 21</th>
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<tbody>
<tr>
<td><strong>Volcanizate properties</strong></td>
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<tr>
<td>Hardness @ 23°C</td>
<td>56.8</td>
<td>60.7</td>
<td>58.3</td>
<td>57.2</td>
<td>59.7</td>
<td>60.9</td>
<td>61.9</td>
<td>61.5</td>
<td>62.4</td>
<td>63.1</td>
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<tr>
<td>Hardness @ 60°C</td>
<td>53.3</td>
<td>58.2</td>
<td>56.3</td>
<td>55.4</td>
<td>57.2</td>
<td>58.8</td>
<td>58.5</td>
<td>60.6</td>
<td>61.2</td>
<td>60.8</td>
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<tr>
<td>Rebound @ 23°C</td>
<td>54.3</td>
<td>56.2</td>
<td>56.2</td>
<td>54.1</td>
<td>57.7</td>
<td>58.7</td>
<td>59.3</td>
<td>61.5</td>
<td>62.8</td>
<td>62.1</td>
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<td>Rebound @ 60°C</td>
<td>57.0</td>
<td>59.8</td>
<td>58.8</td>
<td>56.6</td>
<td>60.5</td>
<td>61.1</td>
<td>62.1</td>
<td>63.1</td>
<td>65.2</td>
<td>67.2</td>
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<td><strong>Tensile Strength @ 23°C</strong></td>
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<td></td>
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<td></td>
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<td></td>
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<tr>
<td>S10</td>
<td>0.4</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.6</td>
<td>0.6</td>
<td>0.5</td>
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<tr>
<td>S100</td>
<td>1.4</td>
<td>1.6</td>
<td>1.6</td>
<td>1.4</td>
<td>1.7</td>
<td>1.6</td>
<td>1.7</td>
<td>1.7</td>
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<td>1.8</td>
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<tr>
<td>S300</td>
<td>5.3</td>
<td>5.5</td>
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<td>4.9</td>
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<td>5.3</td>
<td>6.3</td>
<td>5.4</td>
<td>6.1</td>
</tr>
<tr>
<td>D Median</td>
<td>478</td>
<td>482</td>
<td>401</td>
<td>497</td>
<td>497</td>
<td>517</td>
<td>482</td>
<td>462</td>
<td>500</td>
<td>436</td>
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<tr>
<td>F Median</td>
<td>11.5</td>
<td>11.7</td>
<td>8.7</td>
<td>11.2</td>
<td>14</td>
<td>12.9</td>
<td>11.6</td>
<td>12.3</td>
<td>12.7</td>
<td>11.6</td>
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<tr>
<td>MTS Amplitude Sweep @ 60°C, 1Hz</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G* (0.5%)</td>
<td>1.72</td>
<td>2.04</td>
<td>1.72</td>
<td>1.85</td>
<td>1.93</td>
<td>2.08</td>
<td>2.16</td>
<td>1.9</td>
<td>1.97</td>
<td>1.73</td>
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<tr>
<td>G* (15%)</td>
<td>0.87</td>
<td>1.01</td>
<td>0.9</td>
<td>0.91</td>
<td>1.01</td>
<td>1.04</td>
<td>1.09</td>
<td>1.03</td>
<td>1.07</td>
<td>1.02</td>
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<tr>
<td>tan δ (max.)</td>
<td>0.182</td>
<td>0.179</td>
<td>0.181</td>
<td>0.19</td>
<td>0.164</td>
<td>0.161</td>
<td>0.163</td>
<td>0.145</td>
<td>0.145</td>
<td>0.138</td>
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</tbody>
</table>
Retreading tests with different polybutadienes* confirming superior behaviour of LANXESS Nd-BR grades (1/2)

RRc kg/ton

E

C

Rolling resistance classifications according to EU tire labeling

Significant improvement in the classification of the EU labeling for fuel economy possible

* Ni, Co & Nd-BR
Retreading tests with different polybutadienes* confirming superior behaviour of LANXESS Nd-BR grades (2/2)

<table>
<thead>
<tr>
<th>Abrasion index (14,000 km all wheels &gt; 100 is better)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buna CB 25</td>
</tr>
<tr>
<td>Buna 1203 CoBR</td>
</tr>
<tr>
<td>Buna CB24</td>
</tr>
<tr>
<td>NdComp</td>
</tr>
<tr>
<td>NiBR</td>
</tr>
<tr>
<td>Buna CB45 LiBR</td>
</tr>
</tbody>
</table>

Silica passenger car tread compound consisting of 55phr S-SBR and 45phr polybutadiene

In parallel improvements of the wear resistance are clearly observed with LANXESS Nd-BRs

* Ni, Co & Nd-BR
Several tire accounts experiencing issues to handle high molecular weighted Nd-BR during mixing and extrusion.

**Standard cis-BR’s: Influence of Mooney viscosity on extrusion behavior**

**Compound properties of high cis BR grades**

- NiBR 1
- NiBR 2
- NiBR 3
- Buna CB 1220
- Buna CB 1203
- BUNA CB Nd40
- BUNA CB 24
- BUNA CB 22
- BUNA CB 21
Newly commercialized products with modified Nd-BR

<table>
<thead>
<tr>
<th>PBR 4065</th>
<th>Commercialized as of 1st October 2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>▪ Next generation of easy processing Nd-BR (CB 24)</td>
<td></td>
</tr>
<tr>
<td>▪ More easy switch from basic technology Ni-BR or Co-BR to Nd-BR technology within existing tire plants</td>
<td></td>
</tr>
<tr>
<td>▪ Allow outstanding tire properties by less efficient mixing</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PBR 4076</th>
</tr>
</thead>
<tbody>
<tr>
<td>▪ Perfect combination of improved tire properties of high Mooney Nd-BR (CB 22) with improved processing behavior</td>
</tr>
<tr>
<td>▪ More easy step into high end Nd-BR technology for tire customers</td>
</tr>
</tbody>
</table>
Modified Nd-BR vs. standard BR for sidewall

- The same physical properties within the same ML range of LANXESS-Nd-BR
- Outstanding high properties Nd-BR vs. CoBR or NiBR

**Recipe: Sidewall compound**

<table>
<thead>
<tr>
<th>Component</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>High cis BR</td>
<td>70</td>
</tr>
<tr>
<td>TSR / RSS 3 DEFO 700</td>
<td>30</td>
</tr>
<tr>
<td>CORAX® N 326</td>
<td>50</td>
</tr>
<tr>
<td>VIVATEC 500</td>
<td>4</td>
</tr>
<tr>
<td>EDENOR® C 18 98-100</td>
<td>3</td>
</tr>
<tr>
<td>VULKANOX® 4020/LG</td>
<td>2</td>
</tr>
<tr>
<td>VULKANOX® HS/LG</td>
<td>3</td>
</tr>
<tr>
<td>ZINKWEISS ROTSIEGEL</td>
<td>2</td>
</tr>
<tr>
<td>VULKACIT® CZ/EGC</td>
<td>1,4</td>
</tr>
<tr>
<td>RHENOGRAN® IS 60-75</td>
<td>2,36</td>
</tr>
</tbody>
</table>

**Garvey profiles (ASTM) at 90°C & 50 upm**

- RRI: Rebound at 60°C / MTS tan max @ 60°C / tan Delta at 60°C Eplexor
- SI: Hardness at 23°C x Tensile Strength S300 x MTS G*(15%) x Mooney

CORAX® is a Registered Trademark of Orion Engineered Carbons GmbH
EDENOR® is a Registered Trademark of Emery Oligochemicals GmbH
VULKANOX®, VULKACIT® and RHENOGRAN® are Registered Trademarks of LANXESS Deutschland GmbH
**Modified Nd-BR vs. standard BR for sidewall**

- The same physical properties within the same ML range of LXS-Nd-BR
- Outstanding high properties Nd-BR vs. Co-BR or Ni-BR
- With easy processing properties like Co-BR group

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**Images of Garvey profiles at 120°** from 60 to 120 upm

Extrusion speed

- BUNA CB 24 (Standard Nd-BR)
- BUNA PBR 4065 (modified Nd-BR)
- BUNA CB 1203 (Standard Co-BR)
Modified Nd-BR vs. standard BR for PCR silica tread

**Extrusion**
- Strong interaction S-SBR-filler
  - Increase compound elasticity
  - Rough profiles by melt flow breaking

**Garvey profiles at 90°C, 50 upm**

<table>
<thead>
<tr>
<th>Nd-BR</th>
<th>S-SBR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buna CB24</td>
<td>VSL 5025-2</td>
</tr>
<tr>
<td>Buna PBR 4065</td>
<td>S-SBR: VSL 5025-2</td>
</tr>
<tr>
<td>Buna PBR 4070</td>
<td>S-SBR: PBR 4070</td>
</tr>
<tr>
<td>Buna CB 24</td>
<td>S-SBR: PBR 4070</td>
</tr>
</tbody>
</table>

- Smooth extrusion profiles also with polar modified S-SBR

**Compound stiffness indicator**

**Rolling resistance indicator**

RRI: Rebound at 60°C / MTS tan max @ 60°C / tan Delta at 60°C Eplexor

SI: Hardness at 23°C x Tensile Strength S300 x MTS

G*(15%) x Mooney
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Functionalized S-SBR (LANXESS 1st family) exhibit improved wet traction and rolling resistance over standard S-SBR.

**Results from S-SBR produced in batch process out of Cabo**

- **Improved wet grip**
  - tan δ (0 °C)

- **Improved rolling resistance**
  - tan δ (60 °C)
  - tan δ max (MTS)
  - rebound (60 °C)

<table>
<thead>
<tr>
<th>S-SBR</th>
<th>PBR 4031</th>
<th>PBR 4057</th>
<th>PBR 4060</th>
<th>PBR 4061</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functionalization</td>
<td>Non</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

* Results of a summer tire tread compound test
Tire rolling resistance can be significantly improved solely by using PBR functionalized S-SBR vs non-functionalized S-SBR.

Retreading tests:
- Brand new EU green tire buffed
- New tread compound applied based on LANXESS rubbers
- Vulcanized
- Tested on RRc, wet and dry grip
- 80/20phr: S-SBR / CB25
- 85phr silica; 35.8phr TDAE

A higher EU label classification can be attained just by using PBR 4057 (functionalized) over PBR 4031 (unfunctionalized) yet traction properties would be the same.

Note that the new EU green tire has 6.5 mm tread thickness; A commensurate 7.8mm tread would increase rolling resistance.
Continuous end-chain functionalized S-SBRs (LANXESS 1<sup>st</sup> family) provide significant improvements in tire properties.

- Composition of a silica tire tread compound:
  - 70 phr S-SBR
  - 30 phr Nd-BR
  - 90 phr Silica

- Also a high vinyl S-SBR version is already produced in Port-Jérôme and promoted in the tire industry as PBR 4078

- Status for PBR 4070:
  - Major approval gained so we intend to commercialize this grade during 2014

- Further distinct customer’s interest gained in the market at several accounts

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**Wet grip indicator**

**Rolling resistance indicators**
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LANXESS continues to develop functionalized S-SBRs and Nd-BR to support tire manufacturers in their quest to improve tire performance and achieve labeling requirements.

The use of LANXESS’s Nd-BRs in tires result in improved rolling resistance and treadwear resistance.

LANXESS has modified their higher performance Nd-BRs for easier processing while maintaining performance.

LANXESS has responded to the demands of our customers for improved tire materials and the development pipeline is flowing.
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Note: The information contained in this publication is current as of April, 2014. Please contact LANXESS Corporation to determine if this publication has been revised.