Technical Insight of KURARAY LIQUID RUBBER

# GS-LR test result in f-SSBR formulation

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# Agenda

Our silane-modified LBR; GS-L-BR is the latest development of KURARAY LIQUID RUBBER grades.

1) Silane modified LBR (GS-L-BR)

2) Mechanism analysis

# Silane modified LBR

| Grade Name [Development Code] | Structure | Functional Group | Mw | Tg (°C) | Number of functional group / chain | Viscosity at 38°C (Pa • s) |
|---|---|---|---|---|---|---|
| GS-L-BR-114 [SB-005] | Polybutadiene /Graft silane | Triethoxysilane | 6,000 | -50 | 2 | 6 |
| GS-L-BR-188 [SB-006] | Polybutadiene /Graft silane | Triethoxysilane | 38,000 | -88 | 4 | 124 |

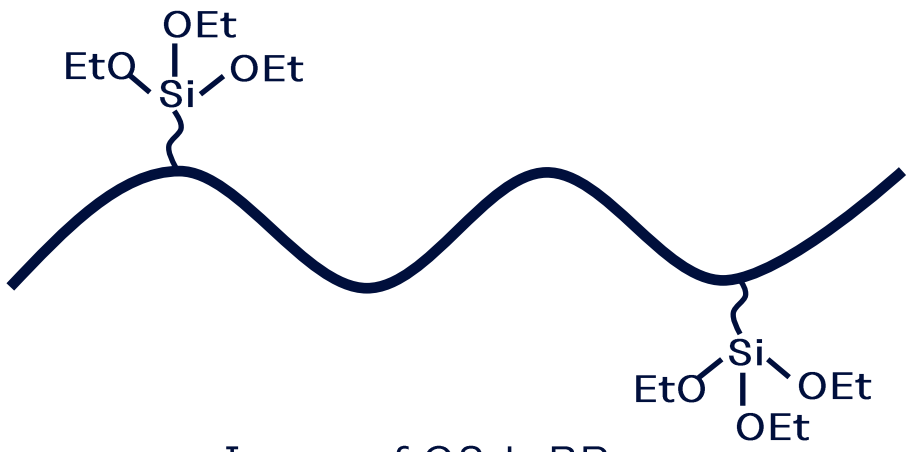



Image of GS-L-BR

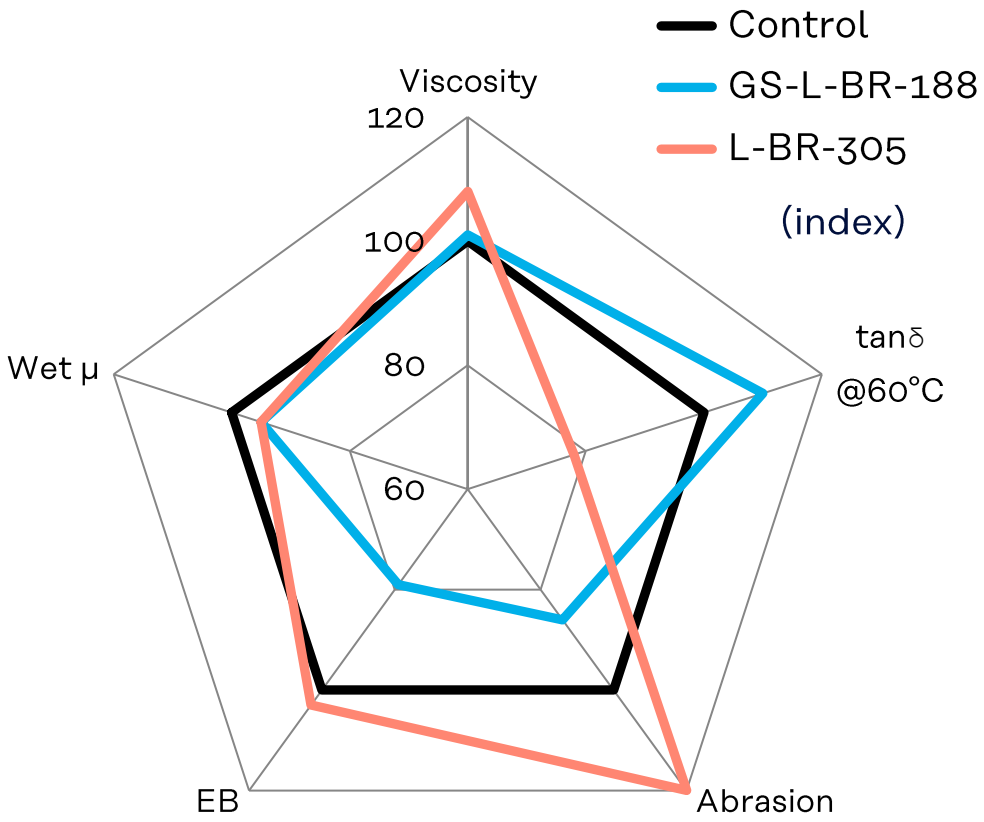
- High reactivity with silica
- Improve dispersibility of silica
- Crosslinkable with base rubber

# Formulation

| | Control | Sample |
|---|---|---|
| f-SSBR | 80 | 80 |
| BR | 20 | 20 |
| Silica | 100 | 100 |
| SCA | 8 | 8 |
| TDAE | 40 | 28 |
| Liquid rubber | | 12 |
| Chemicals | ZnO 3.0, Stearic acid 2.5, 6PPD 2.5, Wax 2.0 | |
| Sulfur Accelerator | OT-20 1.9<br>DPG 0.5, CBS 0.35, TBTD 1.5 | |

TDAE was partially replaced with liquid rubber

# Trial results: GS-L-BR-188

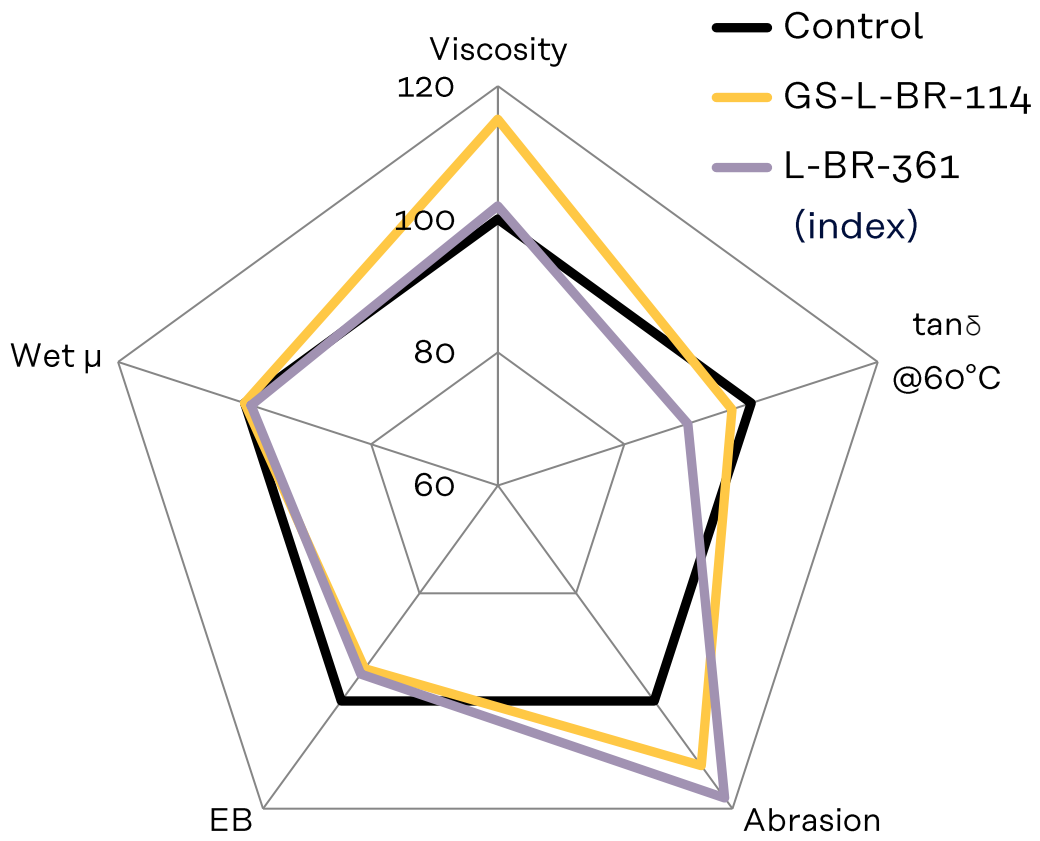



(normalized value to control)

| Sample | Control | GS-L-BR-188 | L-BR-305 |
|---|---|---|---|
| Mooney vis. | 100 | 101 | 108 |
| tanδ @60°C | 100 | 110 | 78 |
| FPS abrasion | 100 | 86 | 120 |
| EB | 100 | 79 | 103 |
| Wet μ | 100 | 95 | 95 |

GS-L-BR-188 improves RR but deteriorates EB and abrasion.

# Trial results: GS-L-BR-114




(normalized value to control)

| Sample | Control | GS-L-BR-114 | L-BR-361 |
|---|---|---|---|
| Mooney vis. | 100 | 115 | 102 |
| tanδ @60°C | 100 | 97 | 90 |
| FPS abrasion | 100 | 112 | 118 |
| EB | 100 | 94 | 95 |
| Wet μ | 100 | 100 | 99 |

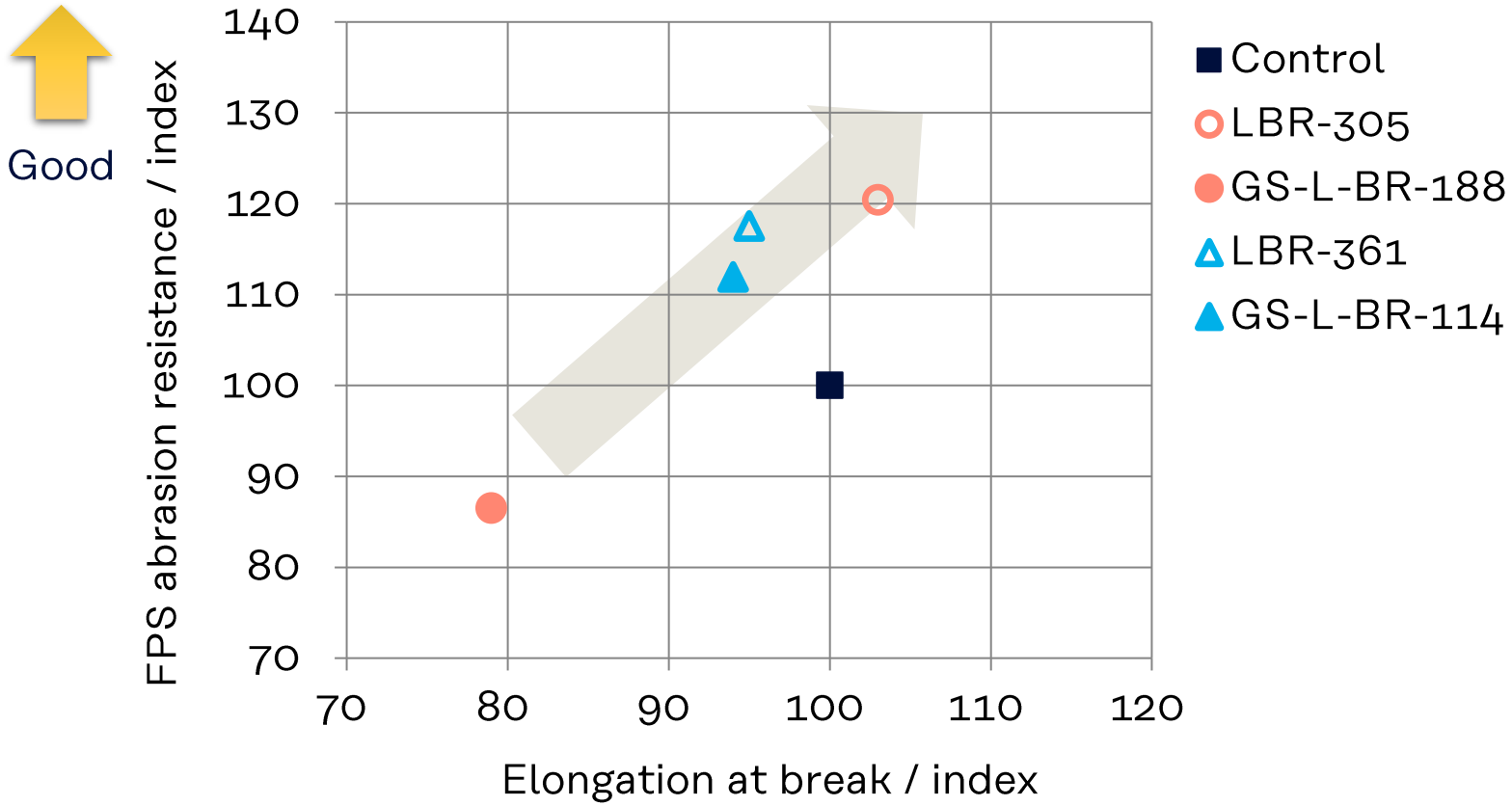
GS-L-BR-114 improves Mooney viscosity and abrasion.

# Agenda

1) Silane modified LBR (GS-L-BR)

2) Mechanism analysis

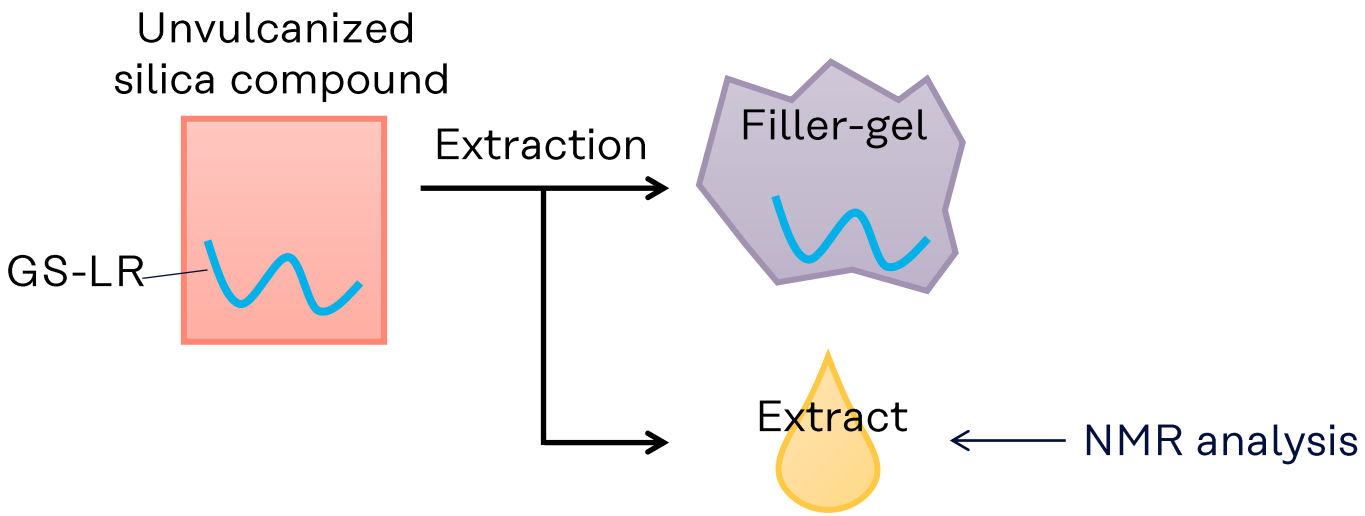
# Mechanism analysis ~abrasion improvement~




- Abrasion resistance has a high correlation with elongation.
- Higher elongation contributes to less cracking. => good abrasion

# Mechanism analysis ~Location of GS-LR in rubber compound~

## Where is GS-LR located in rubber compound?

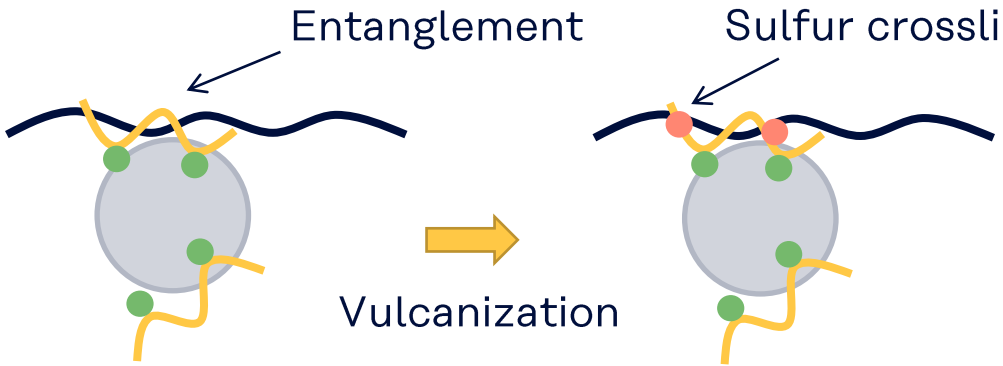



We confirmed that GS-LR localized in filler(silica)-gel.

# Mechanism analysis ~Function of GS-LR~

## What is the function of GS-LR in rubber compound?


- GS-L-BR-188 (High Mw)



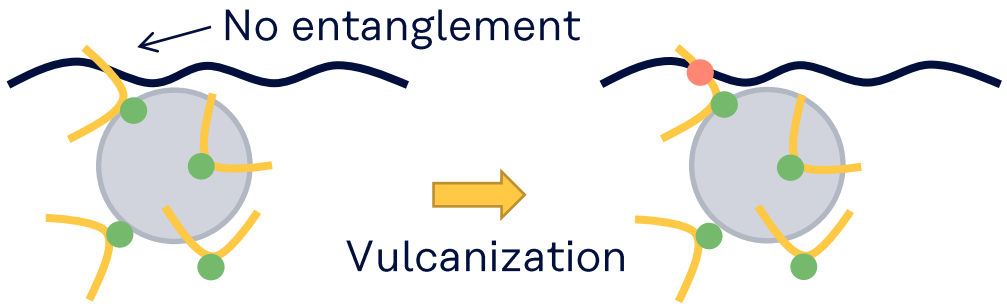

- Absorbed on silica

=> Lower tanδ

- High entanglement with solid rubber

=> Lower elongation

- GS-L-BR-114 (Low Mw)




- Absorbed on silica

=> Lower tanδ

- Low entanglement with solid rubber

=> Equivalent plasticizing effect and elongation to non-functionalized liquid rubber

# Summary

## Silane modified LBR in f-SSBR formulation

- GS-L-BR-188 (High Mw)
  - High interaction with silica and solid rubber
  - Excellent fuel efficiency but low mechanical properties

- GS-L-BR-114 (Low Mw)
  - High interaction with silica as well as plasticizing effect due to low Mw
  - Well-balanced properties with good processability and abrasion resistance

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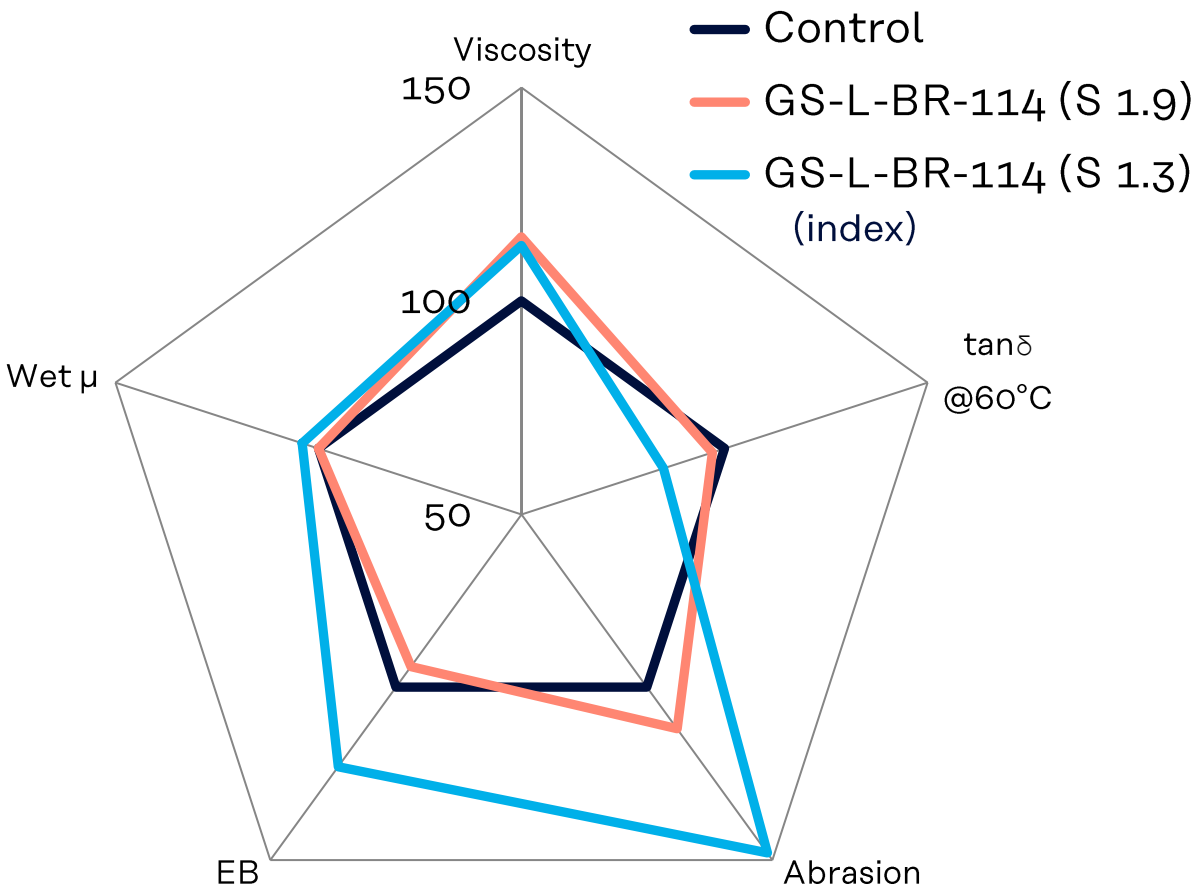
# Raw material

| Material | Product Name | Manufacturer | Note |
|---|---|---|---|
| Styrene-butadiene rubber | JSR HPR850 | JSR Corporation | Styrene content: 27.5%<br>Mooney Vis. @100°C: 65<br>Tg: -24°C |
| Butadiene Rubber | JSR BR01 | JSR Corporation | Cis content: 95%<br>Mooney Vis. @100°C: 45 |
| Silica | ULTRASIL® 7000 GR | Evonik Industries AG | Specific surface area (N2)<br>175 $m^2/g$ |
| Silane Coupling Agent | Si 75® | Evonik Industries AG | |
| TDAE | VIVATEC 500 | H&R GmbH Co. KGaA | |
| Insoluble sulfur | MUCRON OT-20 | SHIKOKU CHEMICALS CORPORATION | Sulfur/Oil = 80/20 |

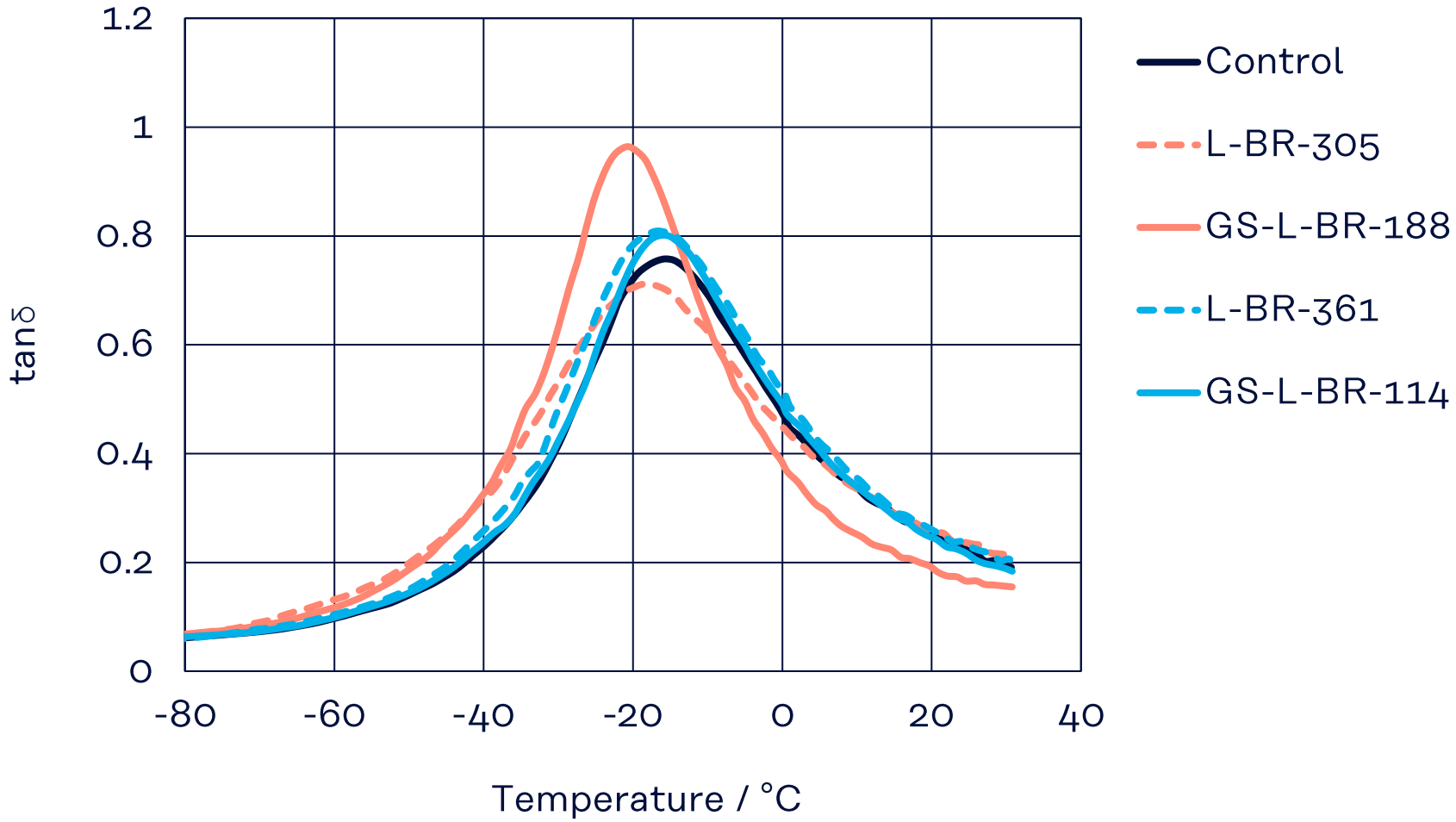
# Trial results -sulfur adjustment-




| Sample | Control | GS-L-BR-114 | |
|---|---|---|---|
| | | S 1.9 | S 1.3 |
| Mooney vis. | 100 | 115 | 113 |
| tanδ @60°C | 100 | 97 | 85 |
| FPS abrasion | 100 | 112 | 148 |
| EB | 100 | 94 | 123 |
| Wet μ | 100 | 100 | 104 |

Abrasion and EB were improved when amount of sulfur reduced to 1.3.

# Trial results: tanδ curve



# Summary of properties

| Item | | unit | Control | L-BR-305 | L-BR-361 | GS-L-BR-188 | GS-L-BR-114 | |
|---|---|---|---|---|---|---|---|---|
| Sulfur | | | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.3 |
| Mooney Vis. (ML1+4, 130°C) | | | 58.0 | 53.5 | 56.8 | 57.7 | 50.3 | 51.5 |
| Mechanical properties | | | | | | | | |
| Hs | | (Type A) | 59 | 56 | 58 | 61 | 63 | 60 |
| EB | | [%] | 433 | 445 | 412 | 341 | 408 | 531 |
| TB | | [MPa] | 23.3 | 20.2 | 20.2 | 20.3 | 20.3 | 21.7 |
| M100 | | [MPa] | 2.44 | 2.08 | 2.24 | 3.11 | 2.49 | 2.16 |
| M300 | | [MPa] | 14.2 | 11.5 | 12.5 | 16.9 | 13.6 | 10.1 |
| Tear strength | | [kN/m] | 55.7 | 48.1 | 57.6 | 48.4 | 57.1 | 54.7 |
| Payne effect (E'0.5%-5%) | | | 2.01 | 1.65 | 1.76 | 1.21 | 2.03 | 2.48 |
| Viscoelasticity | | | | | | | | |
| E' | 0°C | [MPa] | 10.52 | 9.58 | 10.26 | 9.14 | 12.6 | 12.6 |
| | 25°C | [MPa] | 5.65 | 5.38 | 5.44 | 6.05 | 6.88 | 6.98 |
| | 60°C | [MPa] | 4.33 | 3.99 | 4.03 | 4.85 | 5.09 | 4.98 |
| tanδ | 0°C | [-] | 0.643 | 0.576 | 0.640 | 0.440 | 0.618 | 0.596 |
| | 25°C | [-] | 0.279 | 0.297 | 0.298 | 0.203 | 0.278 | 0.292 |
| | 60°C | [-] | 0.136 | 0.175 | 0.152 | 0.123 | 0.141 | 0.161 |
| Abrasion resistance | | | | | | | | |
| 5% / Slip ratio | | (index) | 100 | 120 | 118 | 86 | 112 | 148 |