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**New functionalised S-SBRs  
to meet future  
tire performance demands**

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## Content

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- **S-SBR:  
chain-end versus backbone functionalisation**
- **Properties of tyre tread compounds containing  
backbone functionalised S-SBR lab samples**
- **Backbone functionalised high-vinyl S-SBR from  
production scale:  
polymer and tyre tread compound properties**

# Rolling resistance and fuel consumption

Major contributions of energy loss in a passenger car:



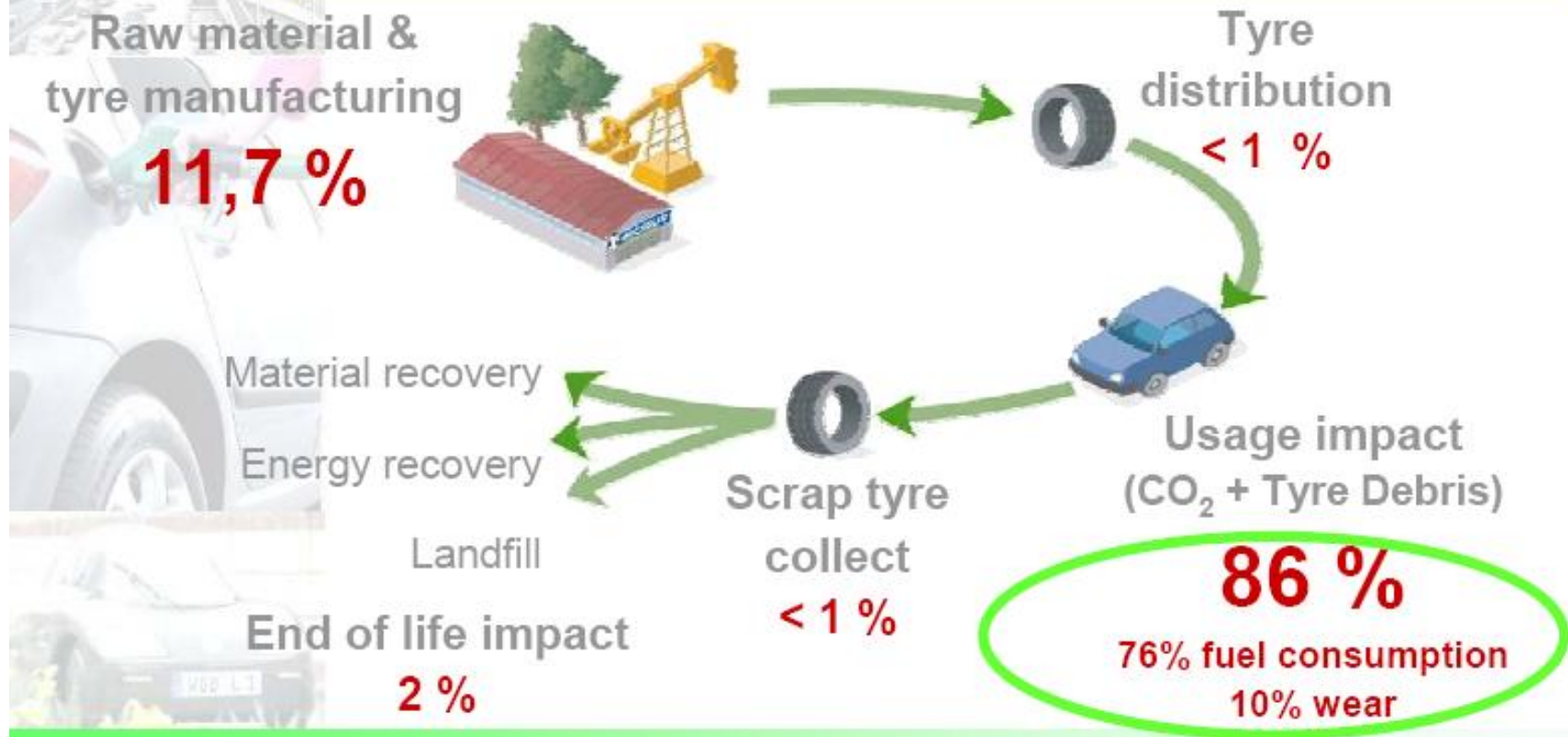
Source: Umweltbundesamt

## Tire's rolling resistance:

- Tyre rubber compounds are viscoelastic
- They dissipate energy on deformation
- Contribution to total fuel consumption varies from 15% to 30%

## IMPACT OF TIRE ON ENVIRONMENT

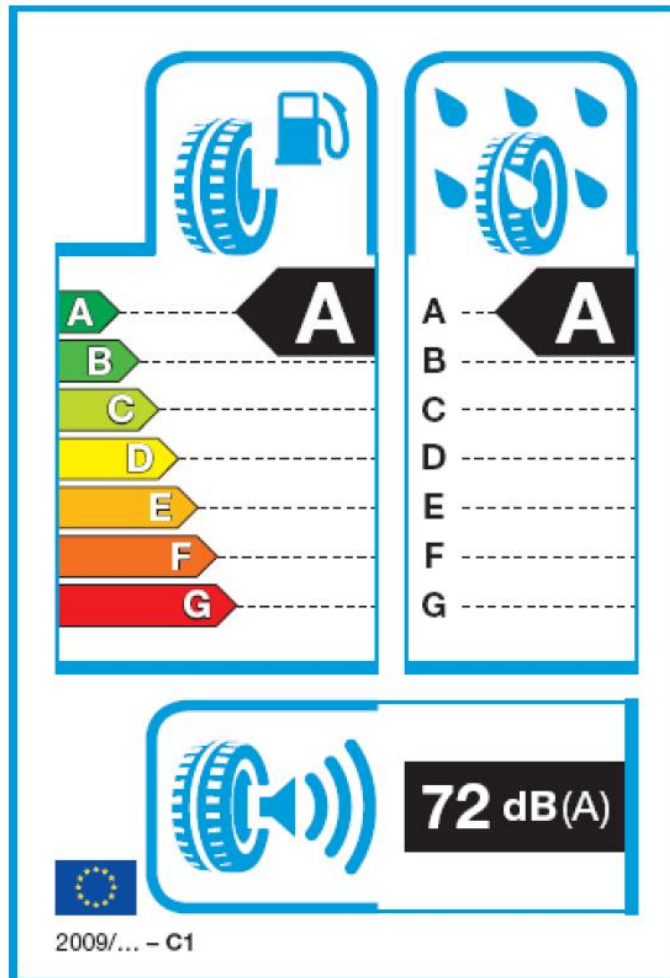
- Three-quarters of impact is due to fuel consumption
- One quarter to building, wearing and recycling the tyre



Method: Eco-indicator 99 (H) BLIC damage / Europe EI 99 (A) / weighting

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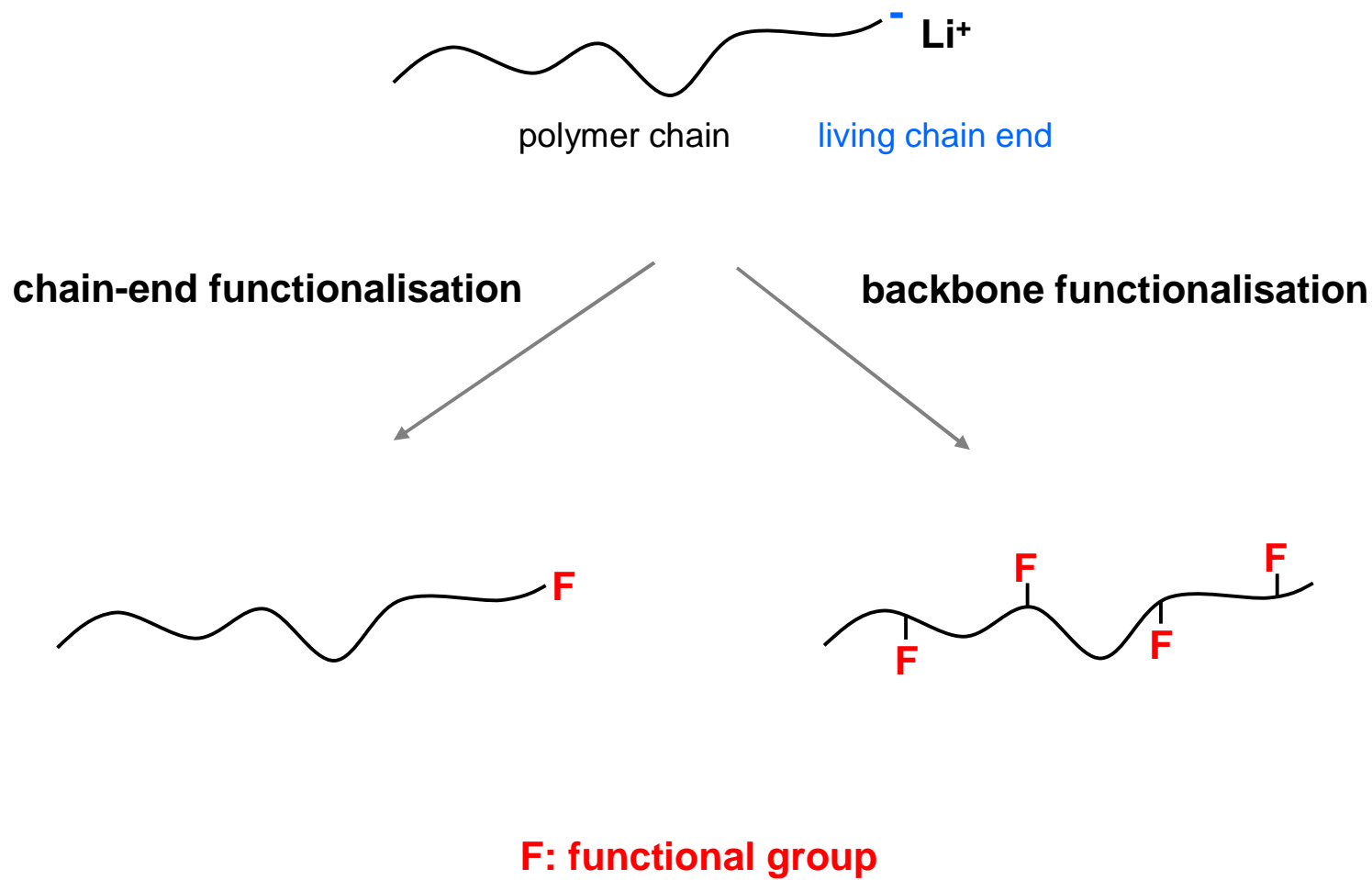
## So **NEW** European commission directive tire labelling



- Labelling of tyres regarding:
  - Rolling resistance
  - Wet grip
  - Rolling noise
- Applies for C1, C2 and C3 tires
- Scheduled start: November 2012

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# Chain-end functionalisation vs. backbone functionalisation



## Chain-end functionalisation vs. backbone functionalisation

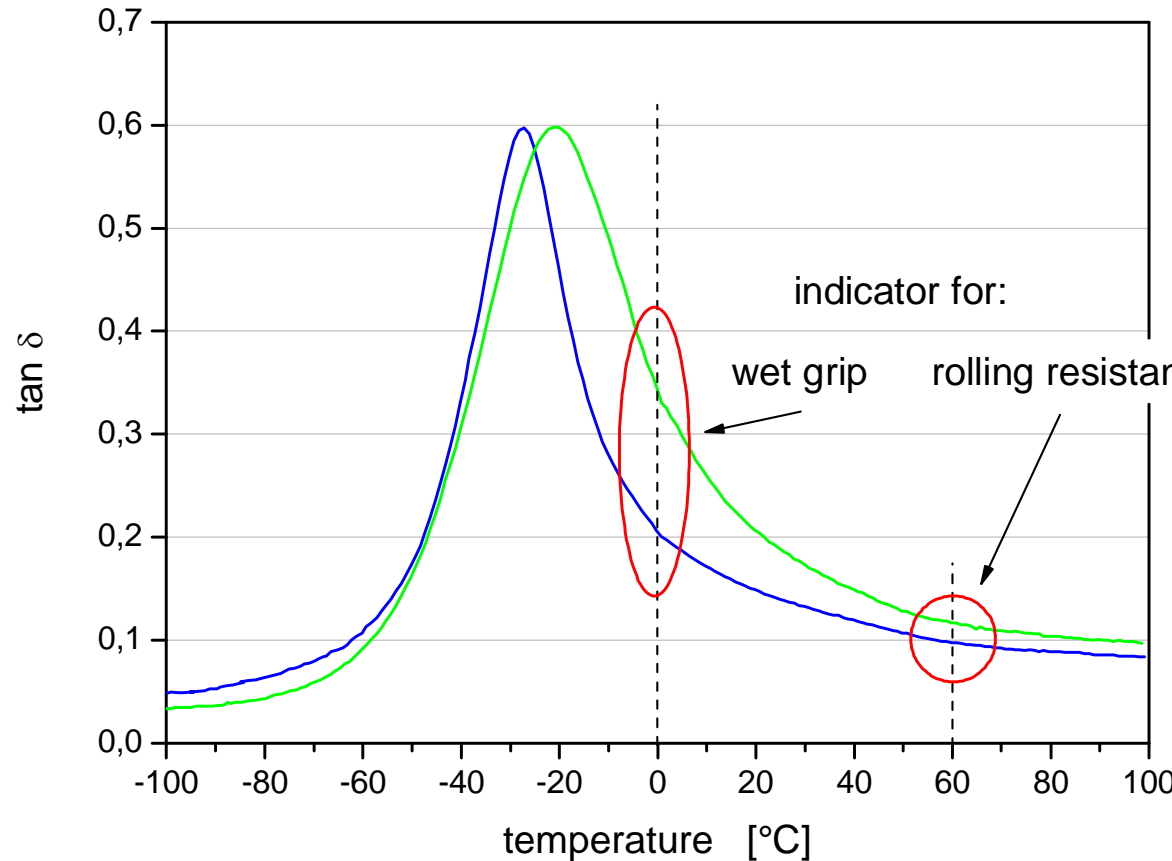
	<i>site of functionalisation:</i>	
	chain end	backbone
reduced mobility of chain end	+	-
improvement of filler dispersion	+	+
degree of fct. independent of number of chain ends	-	+
no reduction of degree of fct. with increasing chain length	-	+

+ : given, resp. advantage    - : not given, resp. disadvantage

# Influence of polymer composition on damping behaviour

State of the art: change of microstructure to improve wet grip leads to deterioration in rolling resistance and vice versa

Tan  $\delta$  temperature sweep (vulcanizate) for tyre tread formulation with silica filler  
(70 phr S-(S)BR / 30 phr high-cis BR / 90 phr silica)



High-vinyl BR  
resp. SBR in formulation:

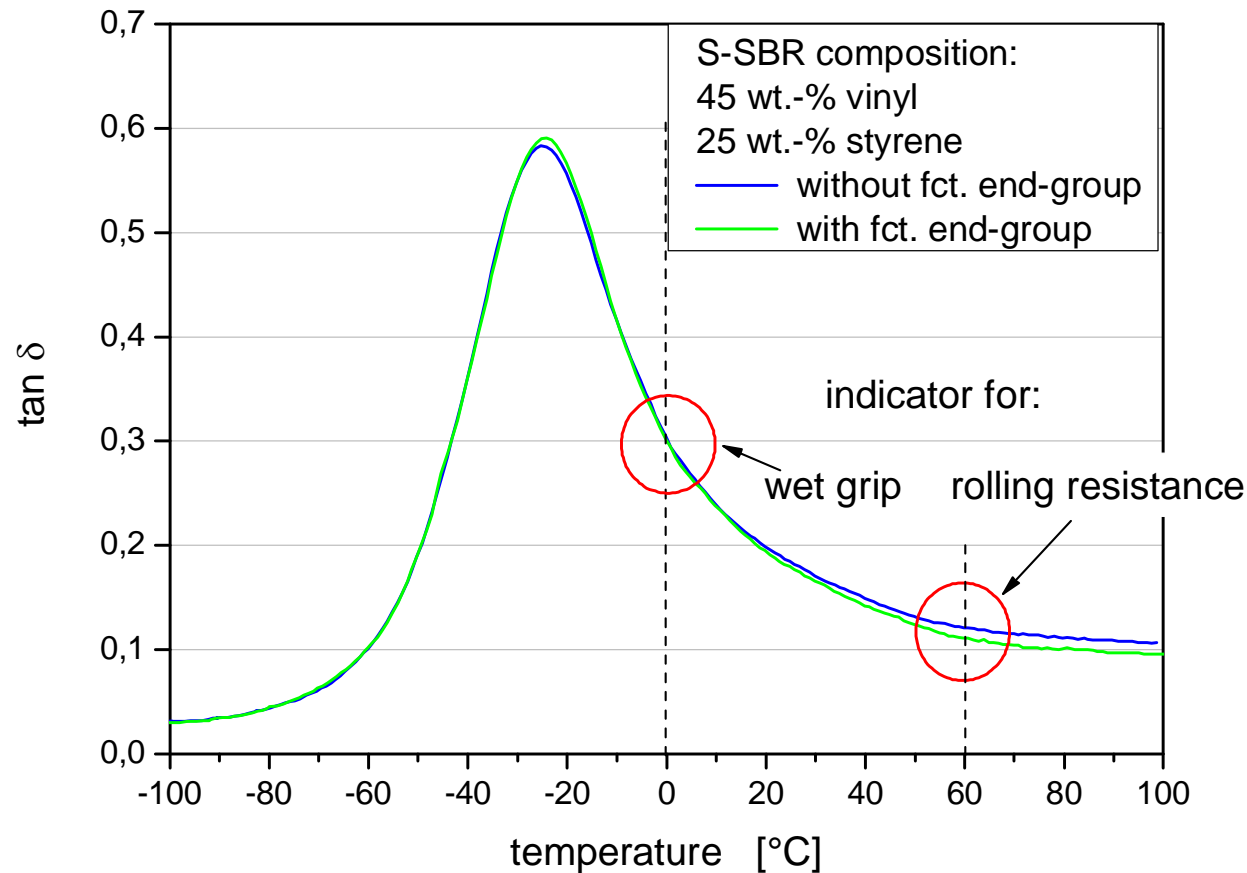
	BR	SBR
Vinyl [wt.-%]	75	50
Styrene [wt.-%]	0	24
Tg [°C]	-37	-15
Indicator for:		
Wet grip	-	+
Rolling resist.	+	-



# Influence of chain-end functionalisation on damping behaviour

State of the art: chain-end functionalisation can improve rolling resistance without deteriorating wet grip behaviour

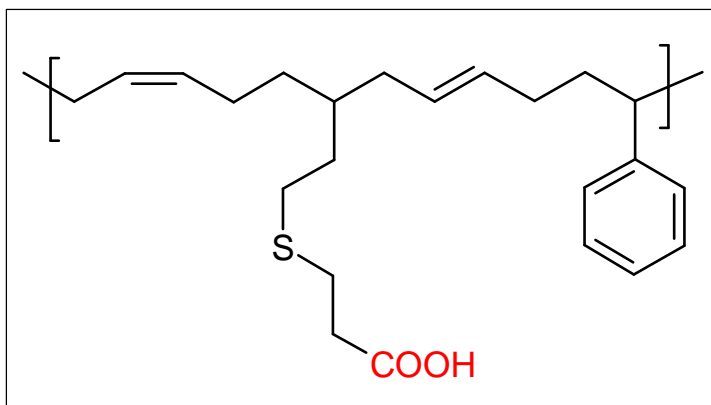
Tan  $\delta$  temperature sweep (vulcanizate) for tyre tread formulation with silica filler  
(70 phr S-SBR / 30 phr BR / 90 phr silica)



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## Backbone functionalised S-SBR from Lanxess

Introduction of functional groups of high polarity along the polymer chain



**Method of introduction: radical addition to C-C double bonds  
in a post-polymerisation reaction**

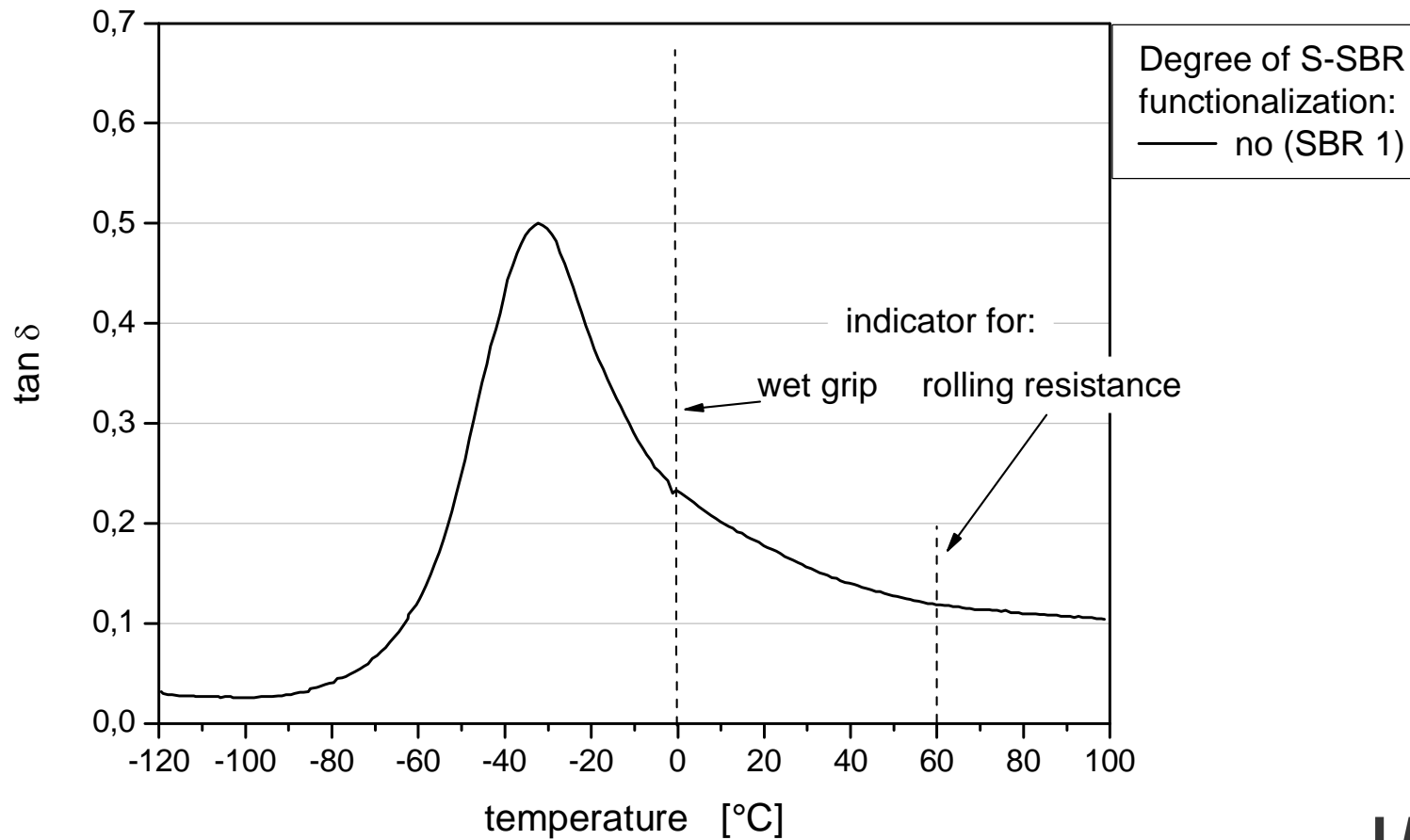
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# Formulation containing unfunctionalised S-SBR

## S-SBR of same microstructure and Tg

Vulcanizate properties of tyre tread formulation with silica filler

(70 phr S-SBR / 30 phr BR / 90 phr silica)



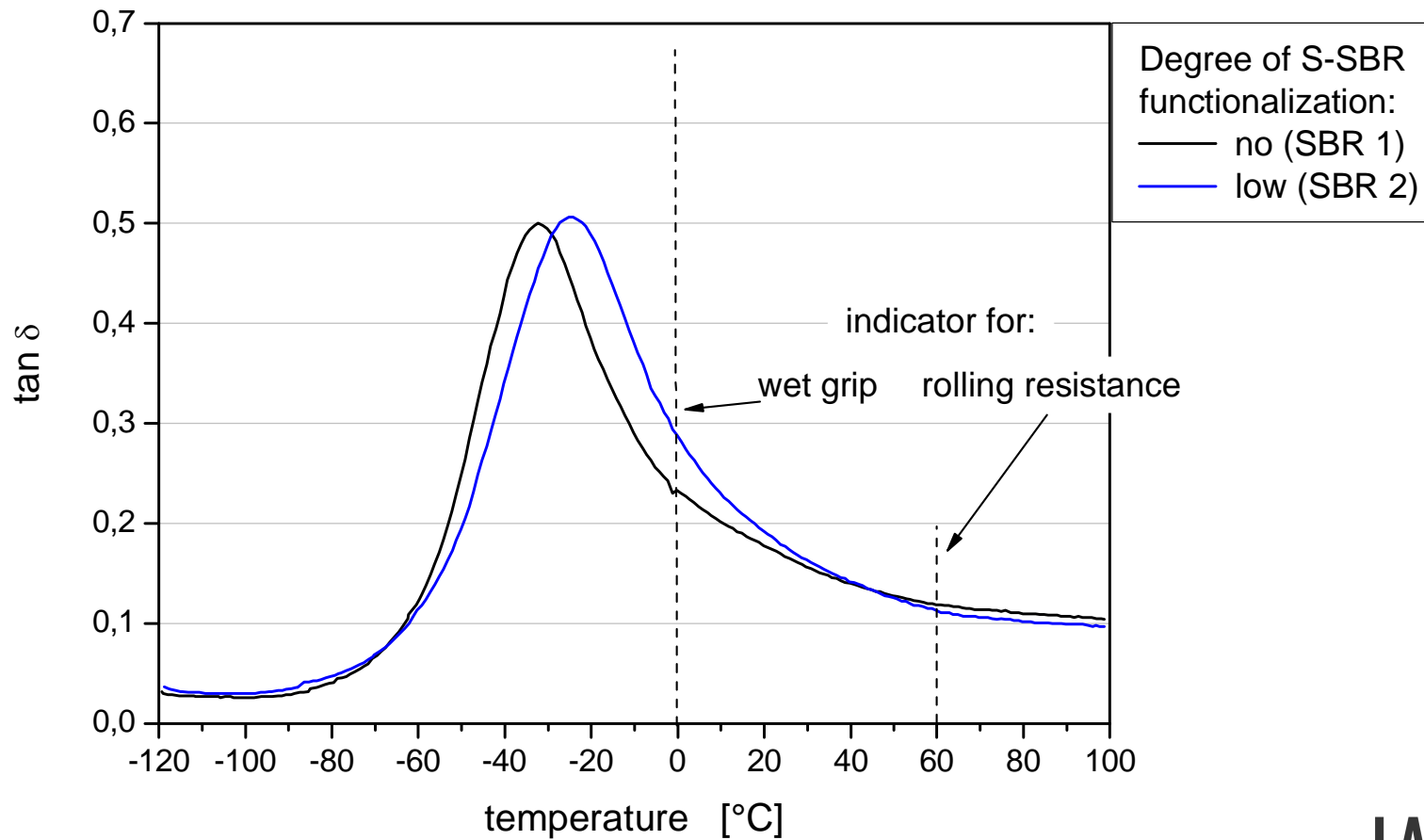
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# Formulation containing backbone functionalised S-SBR

## S-SBR of same microstructure and T<sub>g</sub>

Vulcanizate properties of tyre tread formulation with silica filler

(70 phr S-SBR / 30 phr BR / 90 phr silica)



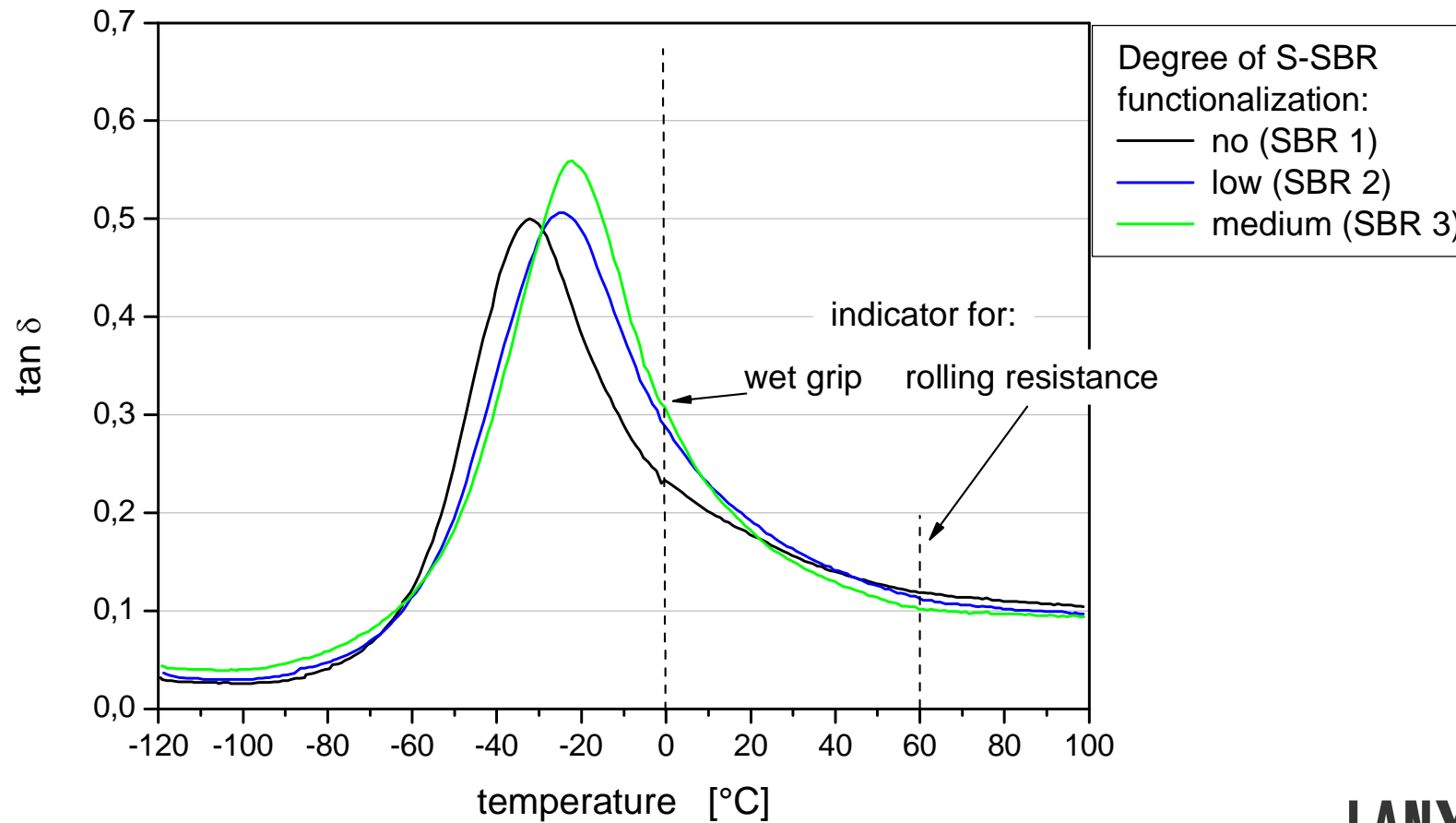
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# Formulations containing backbone functionalised S-SBR

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Vulcanizate properties of tyre tread formulation with silica filler

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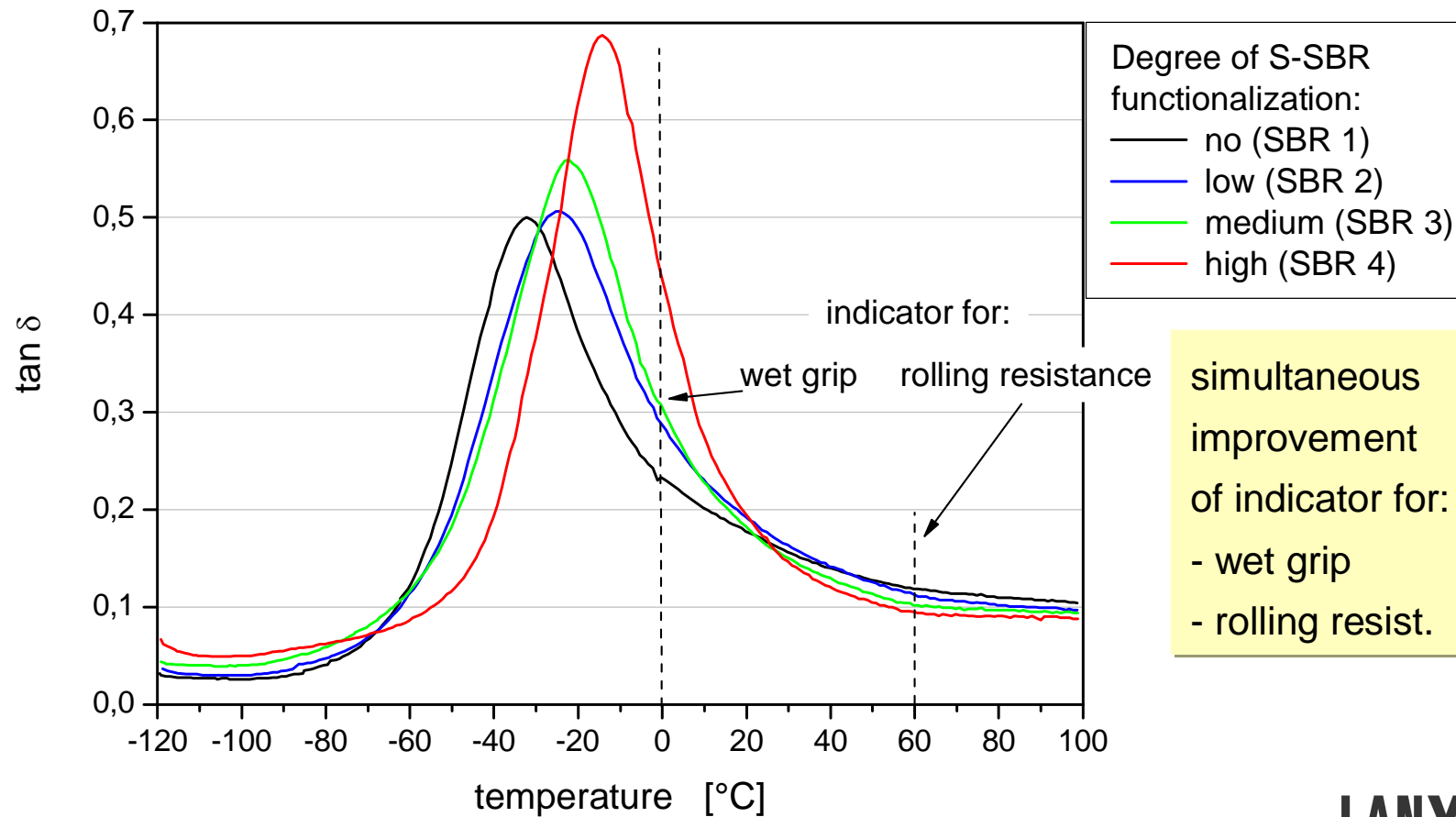
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# Formulations containing backbone functionalised S-SBR

## S-SBR of same microstructure and T<sub>g</sub>

Vulcanizate properties of tyre tread formulation with silica filler

(70 phr S-SBR / 30 phr BR / 90 phr silica)



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## Formulations containing backbone functionalised S-SBR

### S-SBR of same microstructure and T<sub>g</sub>

Vulcanizate properties of tyre tread formulation (70 phr S-SBR / 30 phr BR / 90 phr silica)

S-SBR		Tan $\delta$ temp. sweep (1K·min <sup>-1</sup> , 10 Hz)			Amplitude sweep: tan $\delta$ max.	Rebound at 60°C [%]	DIN Abrasion [mm <sup>3</sup> ]
No.	Degree of funct.	Temp. at tan $\delta$ max. [°C]	tan $\delta$ at 0°C	tan $\delta$ at 60°C			
1	no	-32	0.232	0.119	0.211	49.5	91
2	low	-25	0.287	0.112	0.191	54	89
3	medium	-22	0.305	0.102	0.161	58.5	81
4	high	-14	0.436	0.095	0.145	59	80

*indicator for:*

*wet grip*

*rolling resistance*

*abrasion*

S-SBR 1-4:  
40 % vinyl,  
24 % styrene  
T<sub>g</sub> (DSC): -33°C

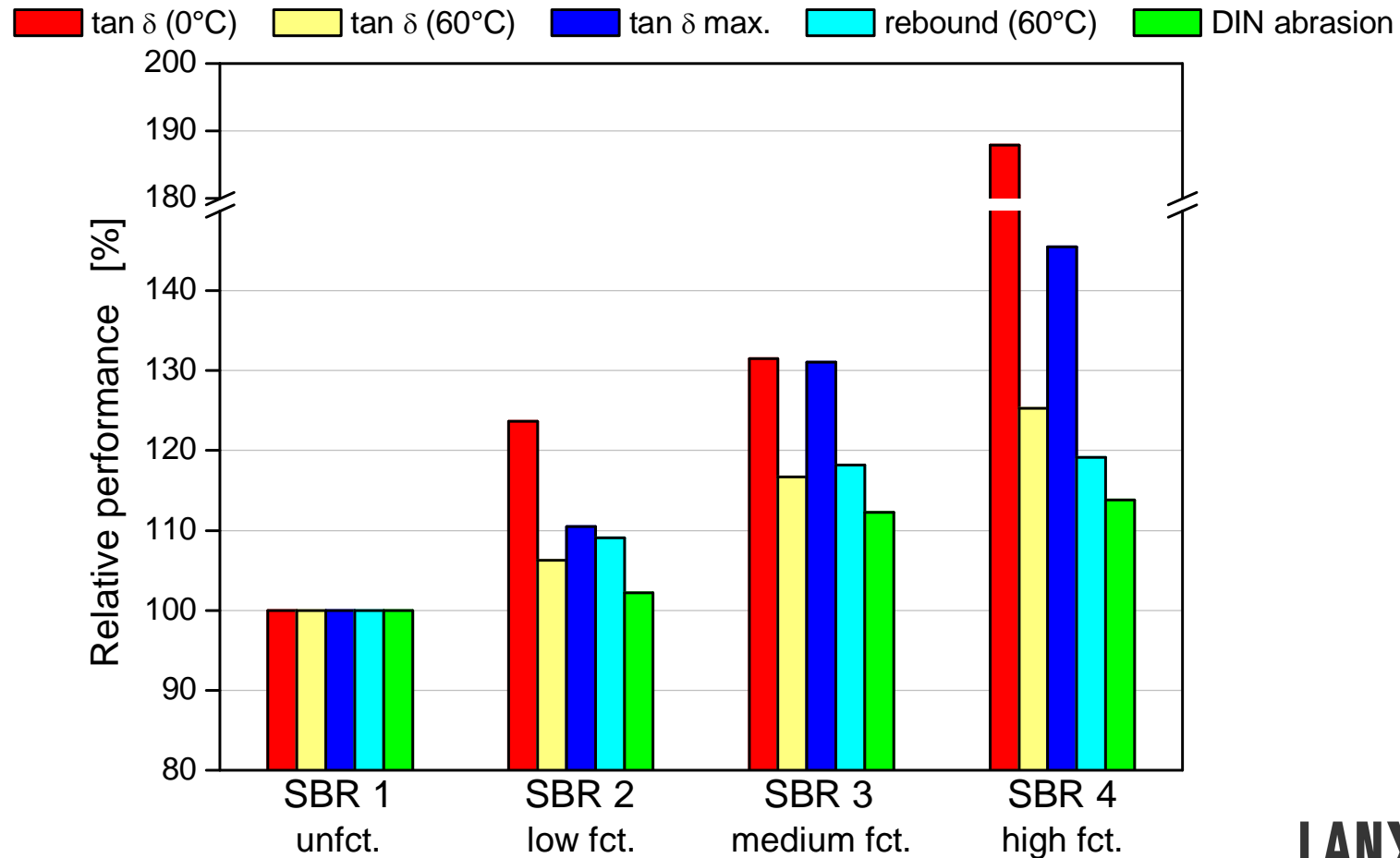
increasing degree of functionalisation leads to continuous improvement of properties indicative for:  
- wet grip   - rolling resistance   - abrasion

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# Formulations containing backbone functionalised S-SBR

## S-SBR of same microstructure and T<sub>g</sub>

Vulcanizate properties of tyre tread formulation (70 phr S-SBR / 30 phr BR / 90 phr silica)



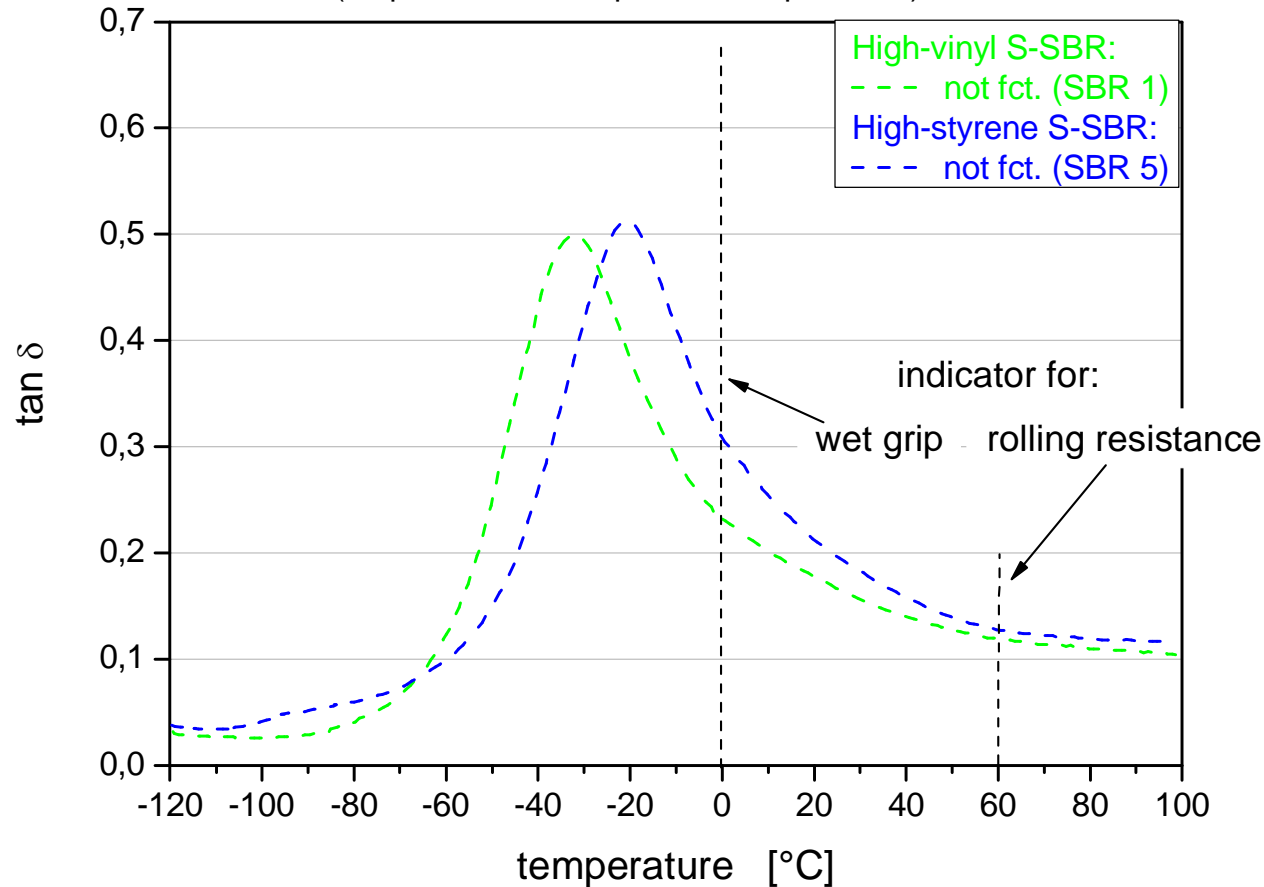
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# Formulations containing unfunctionalised S-SBR

## S-SBR of same T<sub>g</sub> and different microstructure

Vulcanizate properties of tyre tread formulation with silica filler

(70 phr S-SBR / 30 phr BR / 90 phr silica)



unfct. SBR:

improvement in

- wet grip

*leads to*

deterioration in

- rolling resistance

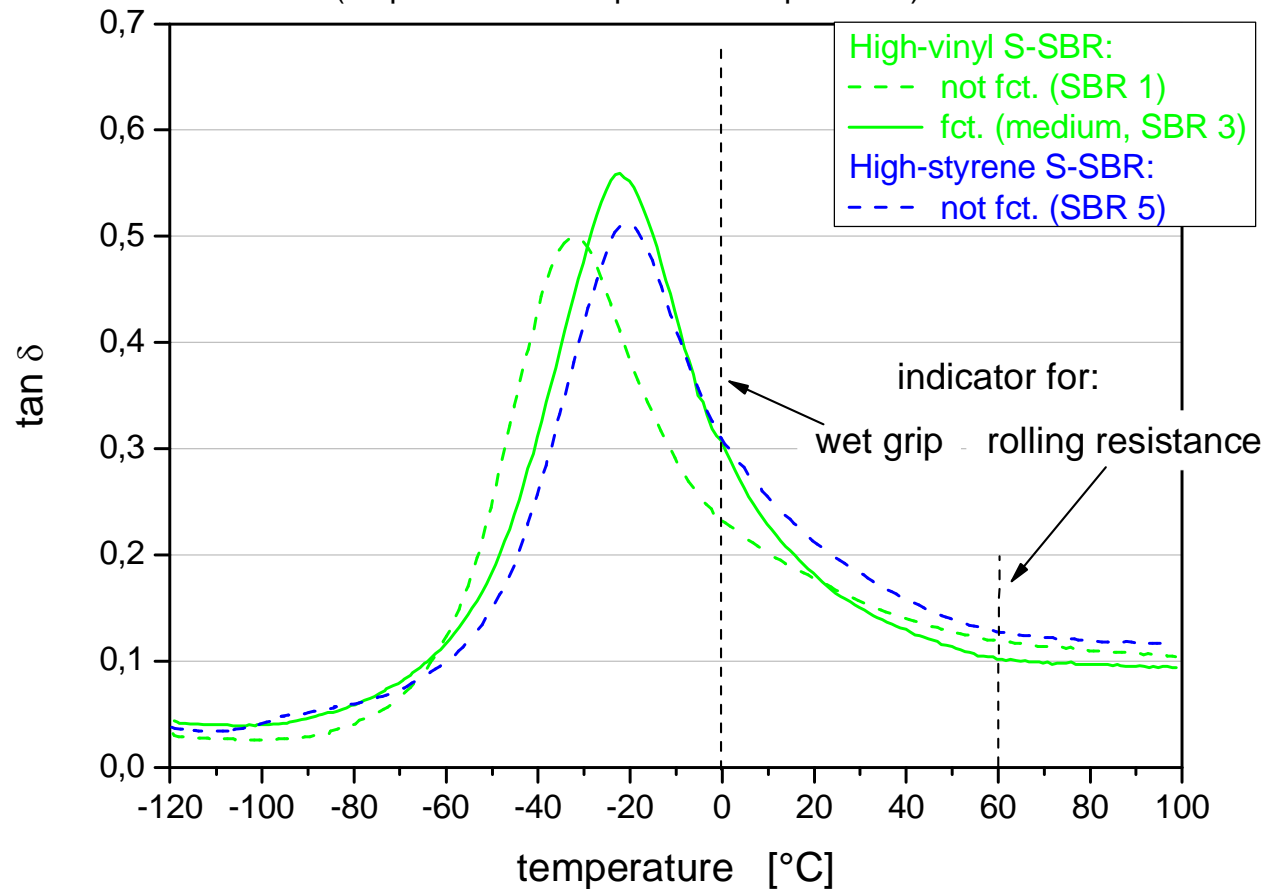
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# Formulation containing backbone functionalised S-SBR

## S-SBR of same T<sub>g</sub> and different microstructure

Vulcanizate properties of tyre tread formulation with silica filler

(70 phr S-SBR / 30 phr BR / 90 phr silica)



unfact. SBR:

improvement in

- wet grip

*leads to*

deterioration in

- rolling resistance

fact. SBR:

simultaneous

improvement of

- wet grip

*and*

- rolling resistance

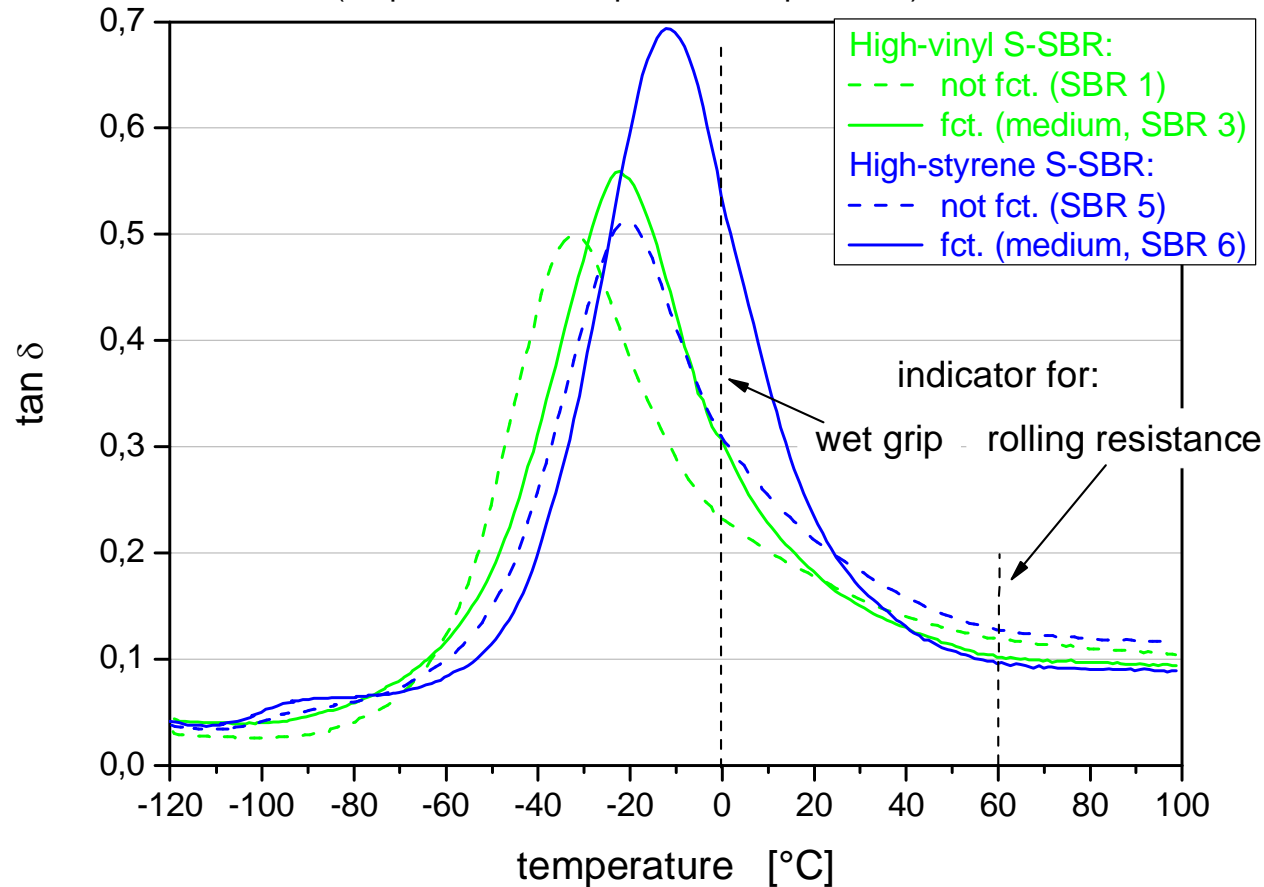
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# Formulations containing backbone functionalised S-SBR

## S-SBR of same T<sub>g</sub> and different microstructure

Vulcanizate properties of tyre tread formulation with silica filler

(70 phr S-SBR / 30 phr BR / 90 phr silica)



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## Formulations containing backbone functionalised S-SBR

### S-SBR of same T<sub>g</sub> and different microstructure

Vulcanizate properties of tyre tread formulation (70 phr S-SBR / 30 phr BR / 90 phr silica)

S-SBR		Tan $\delta$ temp. sweep (1K·min <sup>-1</sup> , 10 Hz)			Amplitude sweep: tan $\delta$ max.	Rebound at 60°C [%]	DIN Abrasion [mm <sup>3</sup> ]
No.	Degree of funct.	Temp. at tan $\delta$ max. [°C]	tan $\delta$ at 0°C	tan $\delta$ at 60°C			
<b><i>S-SBR in compound: high-vinyl S-SBR (40% vinyl, 24% styrene, T<sub>g</sub>: -33°C)</i></b>							
1	no	-32	0.232	0.119	0.211	49.5	91
3	medium	-22	0.305	0.102	0.161	58.5	81
<b><i>S-SBR in compound: high-styrene S-SBR (23% vinyl, 38% styrene, T<sub>g</sub>: -32°C)</i></b>							
5	no	-21	0.308	0.128	0.213	47	101
6	medium	-11	0.533	0.096	0.155	58	78

unfct. SBR: change in microstructure (SBR 1 → SBR 5) leads to improvement of indicator for wet grip, but deterioration of indicator for abrasion and rolling resist.

fct. SBR: change in microstructure (SBR 3 → SBR 6) leads to an overall improvement of indicators for wet grip, abrasion, and rolling resistance

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## Backbone functionalised high-vinyl S-SBR from production plant

### Polymer properties of S-SBR from production

	VSL 5025-2 unfct.	PBR 4003 fct.
<b>Vinyl</b> [wt.-%]	46	48
<b>Styrene</b> [wt.-%]	24	24
<b>Tg (DSC)</b> [°C]	-27.5	-26
<b>Mooney visc.</b> ML1+4 [MU]	50	53
<b>MSR</b> [MU/s]	0.482	0.338
<b>Oil content (TDAE)</b> [wt.-%]	27.5	28.3
<b>Mn (GPC)</b> [kg/mol]	373	313
<b>Mw / Mn</b>	1.79	2.54
<b>COOH functionality</b> [meq./kg]	-	35

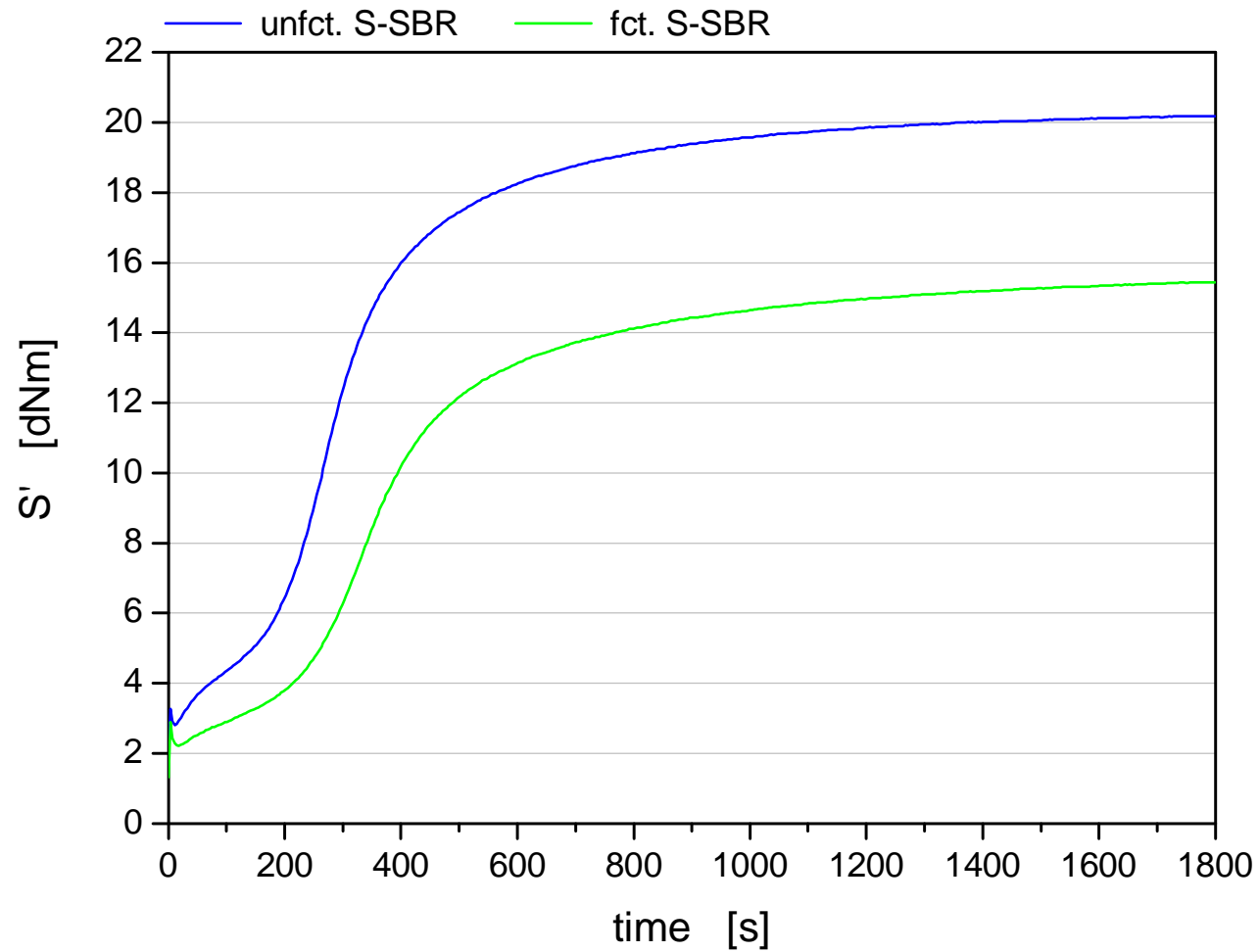
## Backbone functionalised high-vinyl S-SBR from production plant

### Silica compound composition (tyre tread formulation)

unfct. S-SBR (BUNA VSL 5025-2)	96.3	0
fct. S-SBR (PBR 4003)	0	97
High-cis BR (BUNA CB 24)	30	30
Silica (ULTRASIL 7000 GR)	90	90
Carbon black (VULCAN J/N 375)	7	7
TDAE oil (VIVATEC 500)	10	9.3
Zinc soap (AKTIPLAST GT)	3.5	3.5
Stearic acid (EDENOR C 18 98-100)	1	1
Antioxidant (VULKANOX 4020/LG)	2	2
Antioxidant (VULKANOX HS/LG)	2	2
Zinc oxide (ZINKWEISS ROTSIEGEL)	2	2
Wax (ANTILUX 654)	2	2
Silane (SI 69)	7.2	7.2
Diphenylguanidine (VULKACIT D/C)	2.2	2.2
Benzothiazolesulfenamide (VULKACIT NZ/EGC)	1.6	1.6
Sulphur	1.6	1.6
Sulfonamide (VULKALENT E/C)	0.2	0.2

# Backbone functionalised high-vinyl S-SBR from production plant

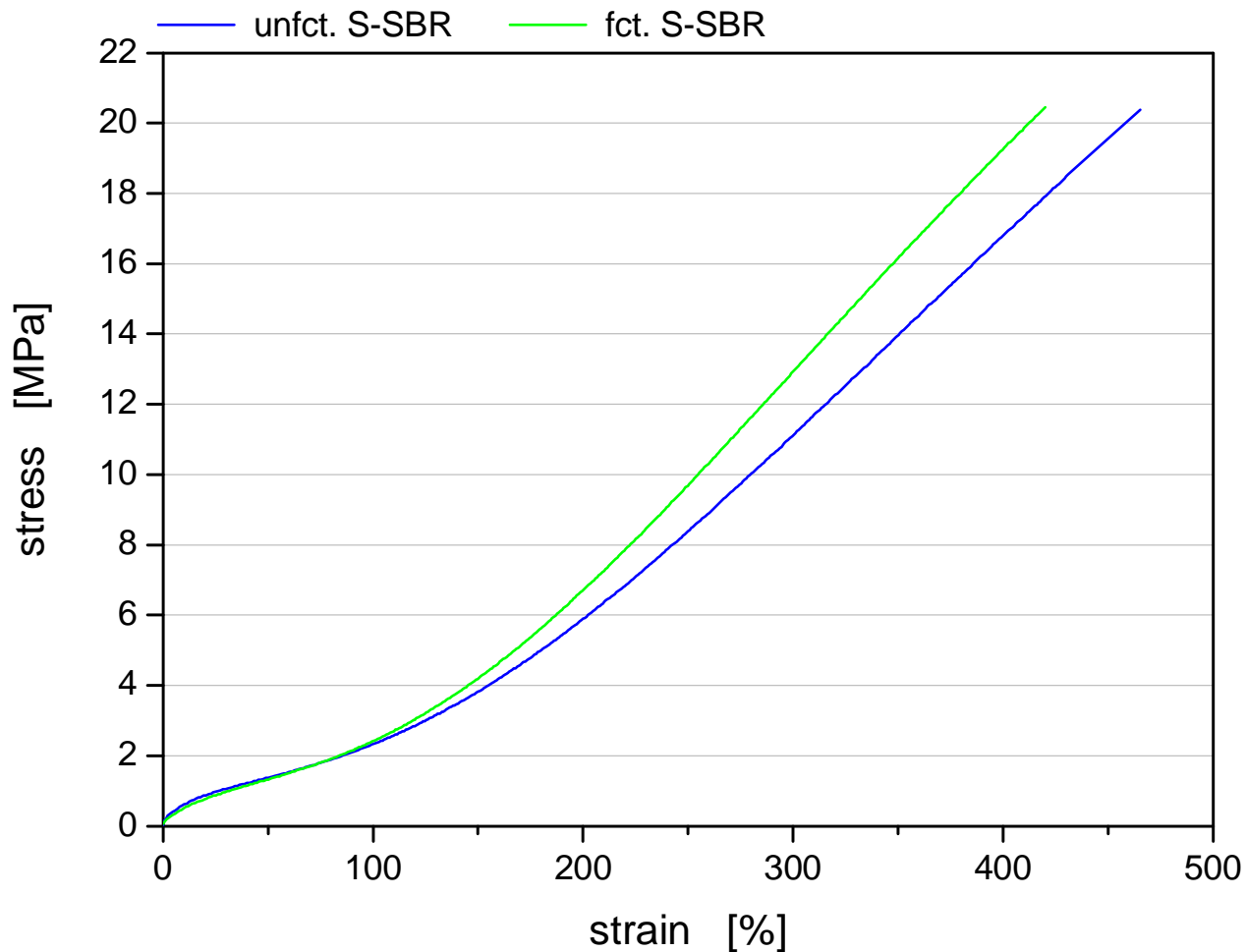
Vulcanization behaviour (MDR, 160°C)



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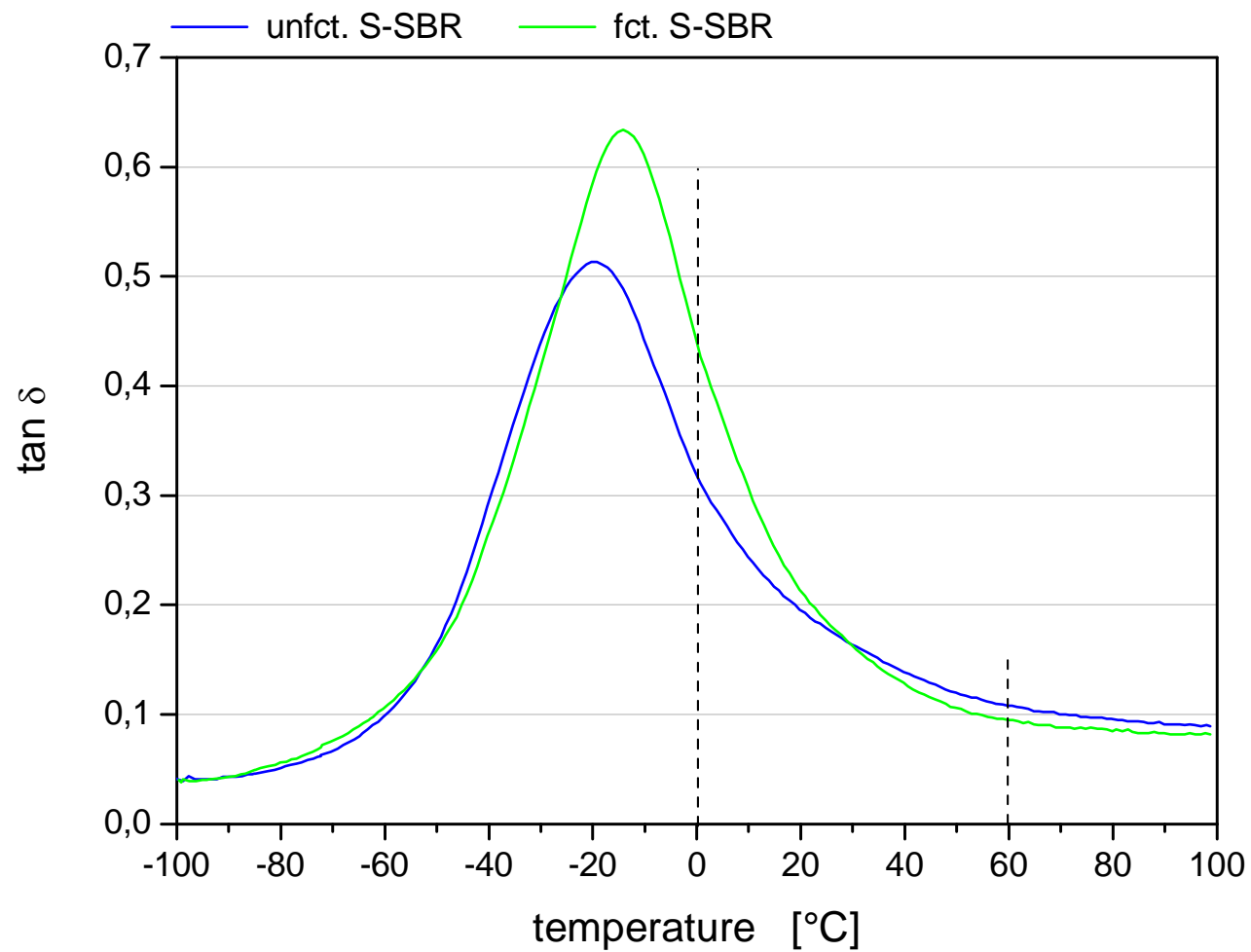
# Backbone functionalised high-vinyl S-SBR from production plant

## Stress-strain properties (S 2)



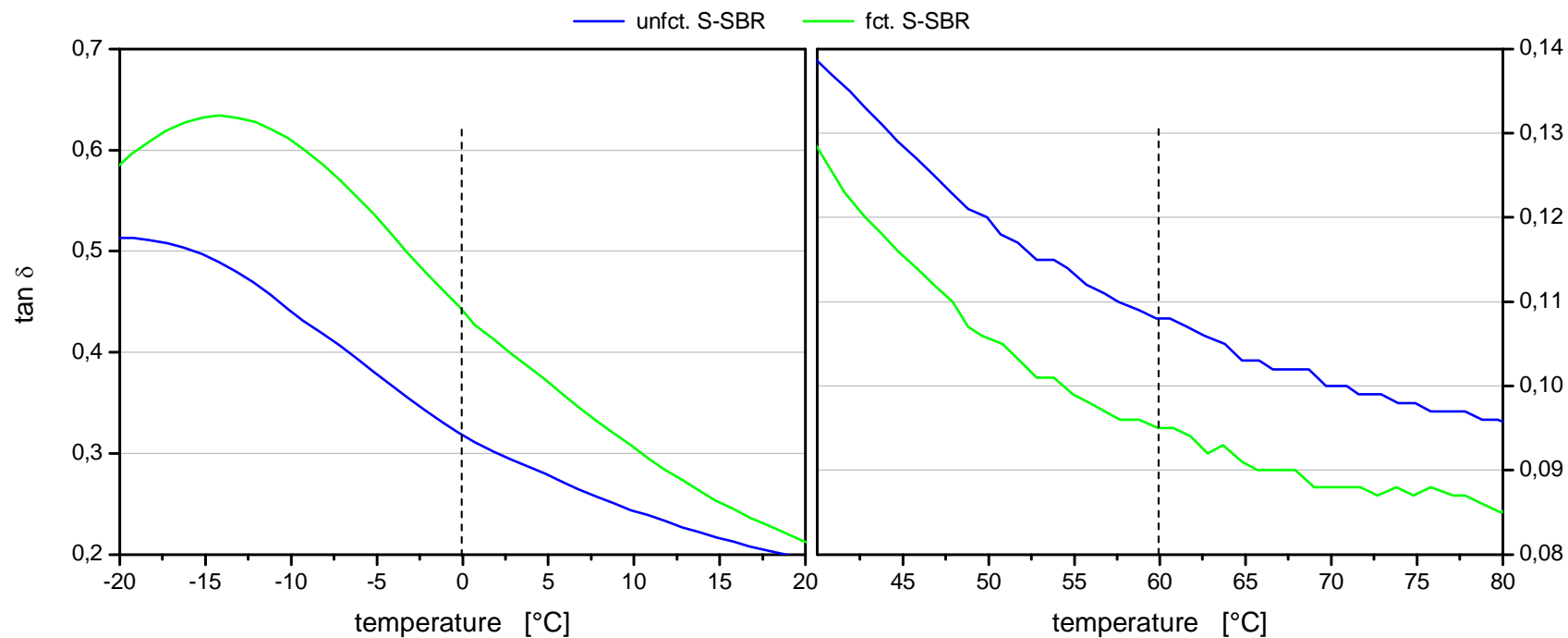
# Backbone functionalised high-vinyl S-SBR from production plant

Tan  $\delta$  temperature sweep (10 Hz, 1 K·min<sup>-1</sup>)



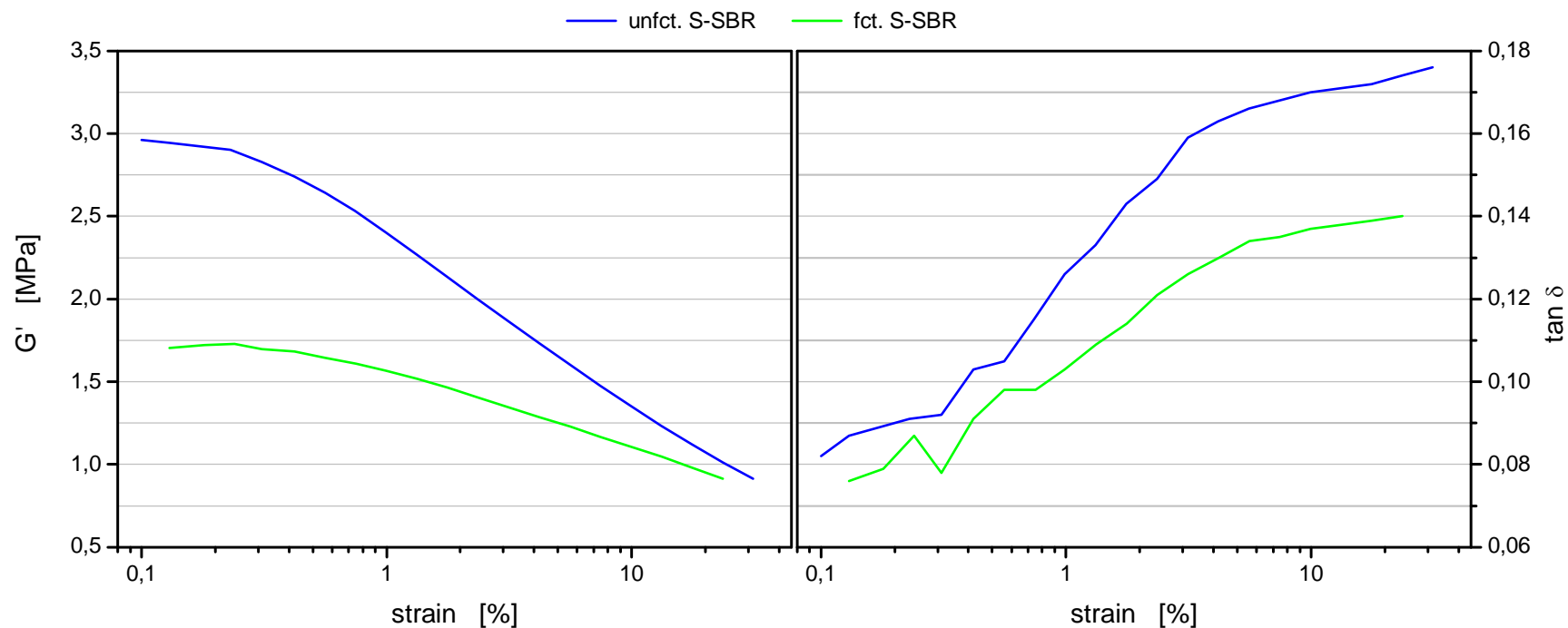
# Backbone functionalised high-vinyl S-SBR from production plant

Tan  $\delta$  temperature sweep (10 Hz, 1 K $\cdot$ min $^{-1}$ )



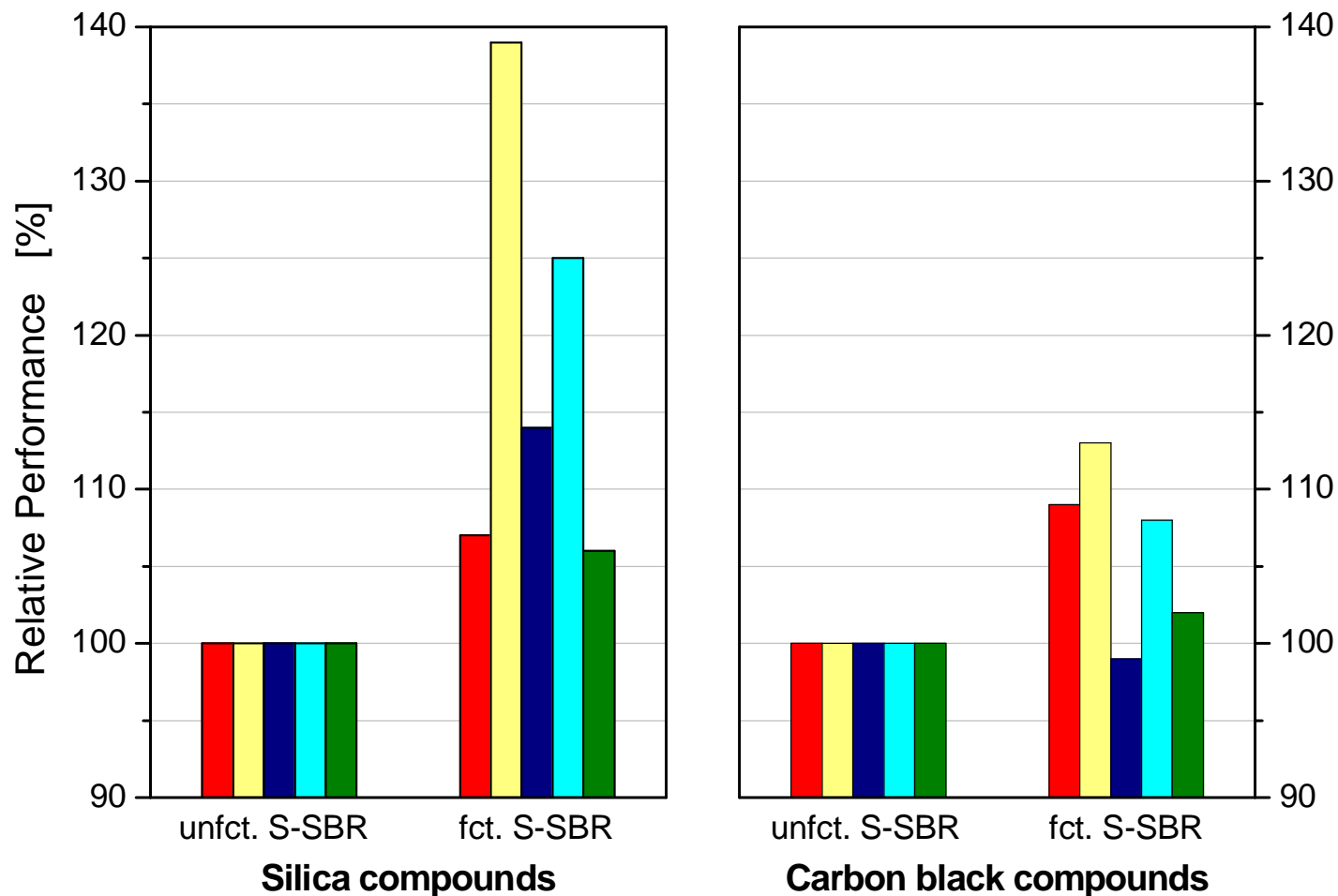
# Backbone functionalised high-vinyl S-SBR from production plant

G' and tan δ amplitude sweep (MTS, 60 °C, 1 Hz)



## Backbone functionalised high-vinyl S-SBR from production plant

■ DIN Abrasion   ■  $\tan \delta$  (0°C)   ■  $\tan \delta$  (60°C)   ■  $\tan \delta$  max. (MTS)   ■ Rebound (60°C)



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## Backbone functionalised S-SBR

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### Current state of development

- **lab studies concerning the influence of microstructure and degree of functionalization completed**
- **successful transfer to industrial scale (plant trials)**
- **tyre tests are running for the time being**

## Summary

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- Chain-end functionalisation on S-SBR can lead to improvement in rolling resistance without having a major impact on wet grip and abrasion in tire tread formulations
- Physical lab tests on tire tread formulations with backbone functionalised S-SBR indicate a simultaneous improvement of wet grip and rolling resistance and abrasion
- First results from tyre tests on backbone functionalised S-SBR confirm the lab test findings

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**Thank you for your attention!**

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