

Lectoraat Kunststoftechnologie

Influence of resins in ground passenger car tire rubber on the devulcanization process

Professorship for Polymer Engineering



Colofon

Titel:	Influence of resins in ground passenger car tire rubber on the devulcanization process
Subtitel:	Proeftuin Recycling - Future Proof Polymers, project 395
Publicatie nummer:	LKT-CE-16407-1911
Publicatie datum:	november 2019
Auteurs:	Ir. J.W. van Hoek, Dr. Ir. G. Heideman, Dr. W.K. Dierkes, MSc. Y. Verdonk
Subsidieverstrekker:	EFRO
In samenwerking met:	Kraton Elastomer Technology and Engineering

Deze publicatie wordt uitgebracht door het Lectoraat Kunststoftechnologie, een praktijkgerichte onderzoeksgroep op Hogeschool Windesheim die zijn basis heeft in Engineering & Design. Zoals passend bij lectoraten in combinatie met de gebruikte subsidieregeling, is het onderzoek uitgewerkt tot een TRL niveau van maximaal 7: demonstratie systeemprototype in operationele omgeving. Het werk is zo opgeschreven dat het na-werkbaar is, maar bedrijfsspecifieke data is soms weggelaten

Dit is een uitgave van Christelijke Hogeschool Windesheim. Niets uit deze uitgave mag worden verveelvoudigd en/of openbaar gemaakt zonder voorafgaande schriftelijke toestemming van de uitgever.



Influence of resins in ground passenger car tire rubber on the devulcanization process

"Proeftuin Recycling - Future Proof Polymers, project 395"

Johannes W. van Hoek ^{1,2}, Geert Heideman ^{2,*}, Yvette Verdonk ³, Wilma K. Dierkes ¹

¹ Elastomer Technology and Engineering (ETE),
Department of Solids, Surfaces and Systems (MS3),
University of Twente, 7522 NB Enschede, The Netherlands;

² Professorship for Polymer Engineering,
University of Applied Sciences Windesheim,
8017 CA Zwolle, The Netherlands

³ Kraton Chemical B.V., Almere, the Netherlands,
a subsidiary of Kraton Corporation.

Correspondence: g.heideman@windesheim.nl; Tel.: + 31 (0)88 469 8919

Abstract

In the recent past, the use of resins in modern tread compounds has increased considerably, in order to further improve tire properties. Based on the experience with silica-silane filler system, which led to a different network structure and a significantly changed devulcanization behavior, the influence of resin addition need to be investigated as well. The influences on de- and revulcanization of a silica-silane based tread compound with 20 phr resin are investigated with respect to processing of the de- and revulcanizate, curing, mechanical and dynamic properties of the revulcanizate. The resin-containing for revulcanization prepared devulcanizates showed a difficulty in processing behaviour due to stickiness. $\tan \delta$ at 0 °C of the revulcanizates had increased considerably, as an indication of improved wet grip when used in a tire tread. A marginal increase of $\tan \delta$ at 60 °C was observed as well, which is an indication of a small increase in rolling resistance. All other investigated parameters concerning the de- and revulcanization process and the revulcanized material changed according to expectations.

Keywords

de-vulcanization, tire, recycling, car tire, sustainable, resin

1 INTRODUCTION

Considerable improvements in tire safety and driving economy were made possible by the use of silica in passenger car tire tread compounds. This technology was introduced in the market about 25 years ago. The end of life passenger car tires produced according to these new formulations are now a substantial part of rubber granulates (ground passenger

car tire rubber, GTR), as confirmed by the amount of silica in the granulates. The implications of the presence of silica in GTR for de- and revulcanization are also discussed. This is of increasing importance because of the growing interest for reusability of tire rubbers for new applications instead of incinerating the used tires. A new development in car tire manufacturing is the use of resins in silica containing tread compounds, to improve the durability of the tire, wet grip and improved rolling resistance over a broader temperature range¹⁻⁷: One of the aspects of using resins in tire compounds is an increased tan delta at 0 °C, which is an indicator for improved wet grip properties of tire compounds. tan delta at 60 °C is an indication of the rolling resistance of tire tread compounds. The increasing use of resins by tire manufacturers is confirmed by resin suppliers⁸, although not yet reflected in literature on this topic. The basic characteristics on which the application of resins in rubber compounds are based, are the relative high T_g and the influence hereof on the compounds. Also the relative high softening point and the influence on rolling properties of tires when replacing part of the plasticisers in the compounds by resins is a relevant parameter⁹. Commonly up to 1 wt% of resins is used as tackifier in green tread and undertread compounds for tires¹⁰.

The topic to be studied is the influence of de- and revulcanization on the properties of resin containing compounds. Taking into account the influences of silica in GTR and the implications for the reusability, the possible influences of resin containing compounds on the de- and revulcanization processes should be studied as well. Therefore resin containing silica based model tread compounds are studied in this chapter, with respect to processing during de- and revulcanization, mechanical and dynamic properties. For revulcanization, 100 % devulcanizate was used.

2 EXPERIMENTAL

In this study, four silica silane based model tread compounds were prepared: a reference compound (ref) and three resin containing compounds, each with a different kind of resin: Resin A, Resin B and Resin C, see Table 1 for the specifications. All materials are specified in Table 2. Formulations and compounding procedures were based on the patent by Pille-Wolf¹¹.

Table 1: Aromatic hydrocarbon resins properties

Resin	Type	Density [kg m ⁻³ @ 20 °C]	Softening point(*) [°C]	Flame point [°C]	Tg [°C]
A	polyterpene	980	115 RB	195	61
B	hydrocarbon	1060	85 RB	207	39
C	terpene-phenol	1010	150 MCB	246	97

(*) RB = Ring/ball; MCB = Mettler cup/ball
Resin B best miscible with SBR, BR

Table 2: Materials

Material		Supplier
<u>Polymers:</u>		
SBR	Styrene Butadiene Rubber, Grade: SPRINTAN SLR 4601 (50% vinyl, 25% styrene)	Trinseo Deutschland GmbH, Schkopau, Germany
BR	Butadiene Rubber grade BUNA CB24	Arlanxeo Deutschland GmbH, Leverkusen, Germany
<u>Fillers:</u>		
Silica	Silica grade Zeosil 1165MP	Rhodia Silices, France
<u>Processing oil:</u>		
TDAE	Treated Distillate Aromatic Extract, VIVATEC 500	Hansen & Rosenthal, Hamburg, Germany
<u>Coupling agents:</u>		
TESPD	bis[3-(TriEthoxySilyl)Propyl] Disulfide	Evonik Industries AG, Essen, Germany
<u>Vulcanization system:</u>		
ZnO	Zinc oxide	Merck KGaA, Darmstadt, Germany
St.A.	Stearic acid	
S	Sulfur	
TBBS	N-Tert-Butyl-2-BenzothiazoleSulfenamide	Lanxess Rhein Chemie GmbH, Cologne, Germany
DPG	1,3-DiPhenylGuanidine	
<u>Anti-oxidants, anti-ozonants:</u>		
6PPD	N-(1,3-dimethylbutyl)-N'-Phenyl-p-PhenyleneDiamine	Lanxess Rhein Chemie GmbH, Cologne, Germany
TMQ	2,2,4-Trimethyl-1,2-DihydroQuinoline	
<u>Devulcanization agents:</u>		
DBD	2-2'-DiBenzamidoDiphenylDisulfide	Schill and Seilacher GmbH, Hamburg, Germany
<u>Stabilizer:</u>		
TDTBP	Tris(2,4-Di-Tert-Butylphenyl)Phosphite	Sigma Aldrich Cooperation, Zwijndrecht, The Netherlands
<u>Resins:</u>		
A, B, C	See Table 1	Kraton Chemical B.V., Almere, the Netherlands

All compounds were mixed using a Brabender 350S internal mixer and subsequently milled on a two roll mill. The formulations for revulcanization are specified in Table 3, compounding was according to the procedures in Table 4. The compounds were vulcanized as 2 mm thick test pieces at 160 °C for $t_{c90}+2$ min using a Wickert laboratory press. For devulcanization the test pieces were ground using a Fritz pulverette with a screen of 2 mm, to a size between 0.85 mm and 2 mm, using laboratory sieves for screening. The granulates

Table 3: (Re)vulcanization formulations

Component	[phr]
SBR (SPRINTAN SLR4601)	70
BR	30
Resin (1)	- 20
Silica Zeosil	90
TESPD	7.2 [*]
TDAE	32.5 12.5
ZnO	2.5 [*]
Stearic acid	1 [*]
6PPD	2.0
TMQ	2.0
Sulfur	1.7 [*]
TBBS	1.7 [*]
DPG	2.0 [*]

(1) Resin A, B, C. Oil<>resin=1:1.
 [*] Components used for revulcanization.

Table 4: Compounding procedure, using the Brabender 390 mL mixer

Time [min.]	Processing Step	Time [min.]	Processing Step Cont.
	Set temperature at 65 °C.	0	Start silanization, keep temperature=155 °C by re-
	Set rotor to 100rpm.		ducing speed
	Fill factor: 0.7	4	Dump, cool, mill
	<u>Compounding</u>		Set temperature to 60 °C.
0	Polymers		Set rotor speed to 50rpm.
1	ZnO, stearic acid, silica, silane, TDAE, resin, anti-		Fill factor: 0.7
	oxidants		
	Mix until 155 °C		<u>Productive step</u>
	Dump and cool down, mill	0	Load compound
		1	S, TBBS, DPG
	Set temperature to 65 °C.		Keep temp. < 80 °C by reducing
	Set rotor to 100rpm.	2	speed
			Dump, mill
	<u>Silanization</u>		Relaxation for 12 h.
	Add polymers		
	Wait until temp.=155 °C		

Based on a Kraton patent¹¹.

are devulcanized and revulcanized using a Brabender Plasti-corder with a 50 mL chamber. For devulcanization, the formulation as mentioned in Table 5 was used, and the procedure as described in Table 6. The procedure for revulcanization was conform Table 7.

An RPA Elite from TA was used for measurement of the viscosity of the devulcanizate at processing temperatures and for the analysis of the cure behaviour and subsequently

Table 5: Devulcanization formulation

Component[wt%]	
DBD	3.9
TDAE	2
TDTBP	1

Table 6: Mixer based devulcanization procedure, using the Brabender 50 mL mixer

Set mixer temperature at 220 °C.
Set rotor speed to 5 rpm.
Fill factor: 0.6
<u>Devulcanization:</u>
Load mixture*.
0 Set rotor speed to 50 rpm.
6 Dump.
Quench in liquid N ₂ .
Mill with 0.1mm gap between rolls.

* Premix the granulated rubber with the devulcanization formulation prior to devulcanization

Table 7: Compounding procedure for revulcanizates, using the Brabender 50 mL mixer

Time [min.]	Processing Step	Time [min.]	Processing Step Cont.
	Set mixer at 155 °C.		Set mixer at 60 °C.
	Set rotor speed to 5 rpm.		Set rotor speed to 5 rpm.
	Fill factor: 0.6		
	<u>Silanization</u>		<u>Mixing</u>
	Add devulcanizate.		Add mixture.
0	Set rotor speed to 50 rpm.	0	Set rotor speed to 50 rpm.
1	Silane.	1	S, TBBS, DPG.
5	ZnO and stearic acid.	2	Dump, mill for 5 min.
6	Dump and cool down, mill.		Relaxation for 24 h.
	Relaxation for 72 h.		

measurement of tan delta at 60 °C as indication for the rolling resistance. A Zwick tensile tester was used for tensile properties, a Zwick shore A tester for the hardness, a Zwick-Roell 5109 for rebound and a DMA VA 200 from Metravib for determination of T_g and tan delta between −80 °C to 80 °C. The morphology of the fracture surfaces of the tensile test pieces was studied with a Keyence VHX 5000 microscope. A CAT60-FLIR infrared camera was used for thermal pictures.

3 RESULTS AND DISCUSSION

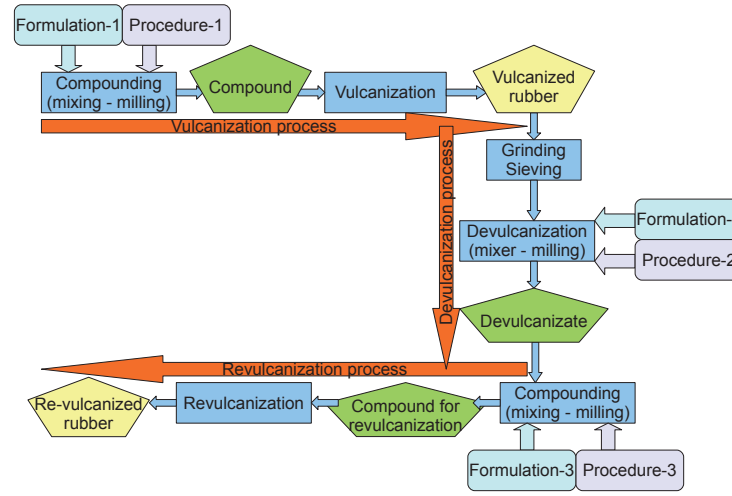
3.1 Processing

To clarify the different intermediate products from virgin rubber to revulcanized rubber, the following products are distinguished and marked in green in Figure 1:

Compound : The composition of polymers, fillers and all other ingredients after compounding, before the (first) vulcanization.

Devulcanizate : The material after devulcanization and post-processing of the rubber granulate.

Compound for revulcanization : The devulcanized material after compounding as preparation for revulcanization.



Definition of intermediate products in green pentagons

Figure 1: Devulcanization - revulcanization process

As indication of the processing properties of these intermediate products, the complex shear modulus against temperature is measured by the RPA, see Figure 2. The results of the three intermediate products are discussed hereafter:

Compounds: Figure 2a shows that the complex shear modulus decreases during the measurement almost linearly with temperature. At about 150 °C, the onset of curing can be observed by a steep rise in the shear modulus. The shear modulus of the resin containing compounds is slightly higher than of the reference, and from 100 °C on the shear modulus starts to deviate more, which is not to be expected based on the softening points of the resins. The viscosity of the compound with resin A, with a softening point of 115 °C, is the highest. The softening point for Resin B is 85 °C and for resin C 150 °C. This indicates that the softening point is a parameter with minor influence on the viscosity of the compounds. Considering the measurement time of 30 min, mass and dimensions of the samples, the melting behaviour of the resins is most unlikely to have a significant influence on the curves.

Devulcanizates: Figure 2b shows a similar pattern as the compounds, except:

- A steady decrease in shear modulus flattens at 100 °C, after which the viscosity does not decrease anymore. As the shear modulus of the polymers and resins is temperature dependent, this indicates a non-temperature dependent parameter, for which the visual grains of the devulcanizates are a probable explanation: at a certain

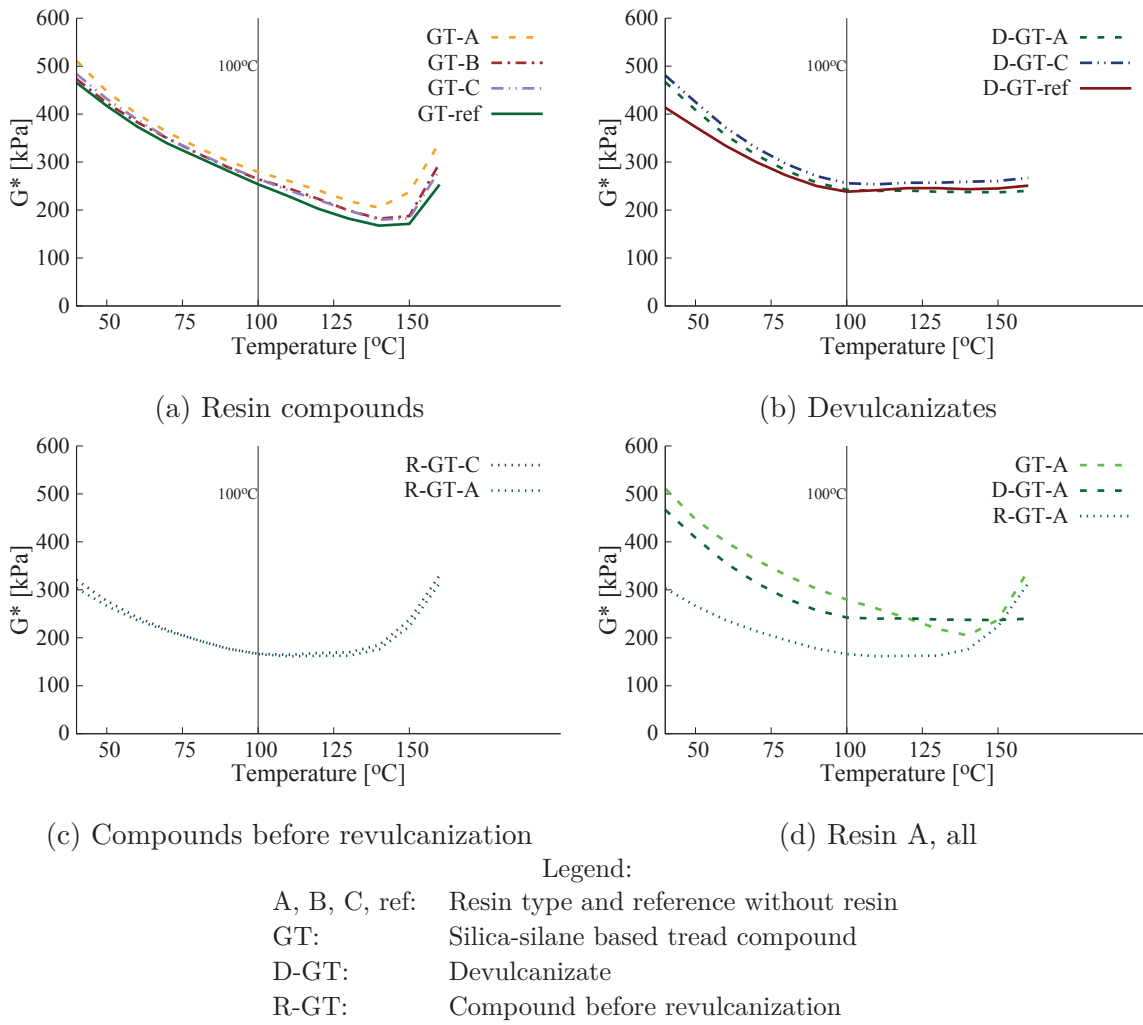


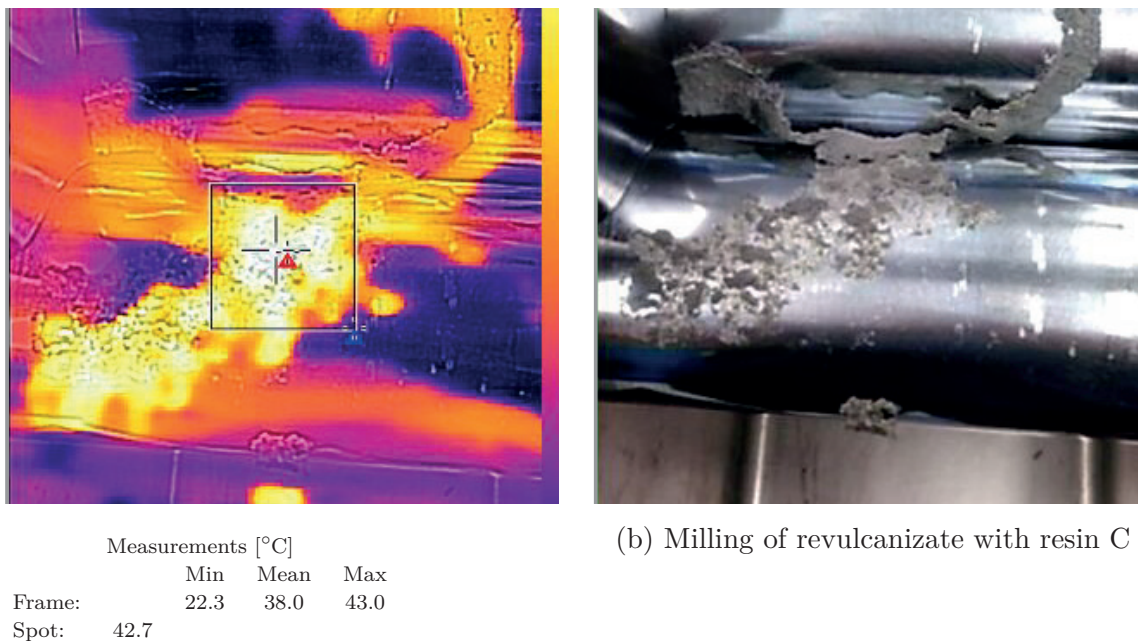
Figure 2: RPA complex shear modulus vs. temperature diagrams for the silica-silane resin based tread compounds before vulcanization, after devulcanization and before revulcanization, see Figure 1

temperature the influence of the friction between the hard particles might be of more influence than the influence of the decreasing viscosity.

- No increase of shear modulus at curing temperatures, which indicates that no remaining activity of the original curing system is left. This reconfirms the required curing formulation for revulcanization, i.e. similar to the vulcanization formulation.

Compound for revulcanization: Figure 2c shows hardly any difference between the curves of both resins. The onset of cure at about 140 °C is clearly visible and the modulus shows a similar flattening at 100 °C as was seen for the devulcanizates. The overall level of complex shear is lower than for the devulcanizates. This is consistent with the decrease in size of the visual grains due to the compounding, as is shown in Chapter ??, ?? too.

As is shown for the compounds with resin A in Figure 2d, the complex shear modulus of the devulcanizate is lower than the that of the compound but is not significant. However, a large change in modulus is measured between the devulcanizate and the compound for revulcanization, which is due to the influence of one of the processing steps, silanization and / or compounding, and the milling steps. This suggests a decrease in length of the main polymer chains compared to the compound, but also a decrease in size of the grain of the revulcanizate compared with the devulcanizate. The latter can indicate an increase in shear during the compounding procedure due to the higher viscosity of the resins compared to the plasticiser oil.



(a) Thermo image of milling of revulcanizate with resin C

(b) Milling of revulcanizate with resin C

Figure 3: Processing on a mill of silica-silane based tread compounds with resins before revulcanization

With respect to processing, the optimal milling temperature of the resin containing compound for revulcanization, approx. room temperature, is lower than the 60 °C for the reference compound. The tack of the resin A or C containing compounds is clearly noticeable as the material sticks to the mill, for compounds B this is noticed at elevated temperatures, 40 °C and more. This stickiness to the rolls of the mill, combined with a decreased cohesivity of the devulcanizates and hence a decreased cohesivity of the compound for revulcanization, lead to difficulties in milling of the resin containing compounds for revulcanization, see Figure 3b for resin C. An infra-red temperature image of the milling of the compound for revulcanization with resin C shows the actual milling temperature. The lowest reading of 22.3 °C is a measurement error because of the metal surface of the rolls of the mill, see Figure 3a.

3.2 Curing

The cure curves of the compounds show a marching modulus, as seen more often for silica-silane based compounds. The minimum torque of the compounds with resins is slightly higher than of the reference. This might be due to the higher viscosity of the resins as compared to the plasticizing oil, Figures 4a and 5a. The increasing torque differences at the end of the measurement indicate an effect of the resins on the crosslink density.

For the revulcanizates, the minimum torque is similar for all compounds. The scorch time has decreased for all revulcanizates compared to the compounds. This indicates that, although not active for curing as discussed before, some ingredients play an activating role in the revulcanization process. The curves of both revulcanizates with resins A and C show reversion while both other curves, the revulcanizates of the reference and with resin B, still show a marching modulus. This indicates that resins A and C have a negative effect on crosslinking after devulcanization, opposite to the influence on crosslinking in a virgin compound, Figure 4b. All revulcanizates show a decreased torque difference during curing compared with the compounds, Figure 5b. However, the decrease for the resin containing

revulcanizates is larger compared with the reference one. This indicates a negative effect of the resins on the crosslinking of revulcanizates, Figure 5b.

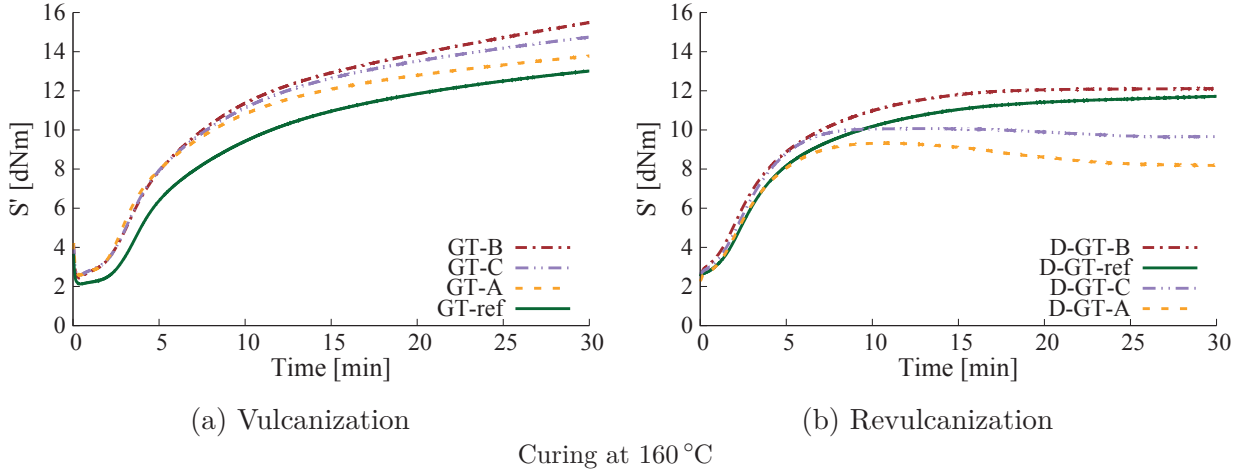


Figure 4: Cure curves of silica-silane based tread compounds with resins

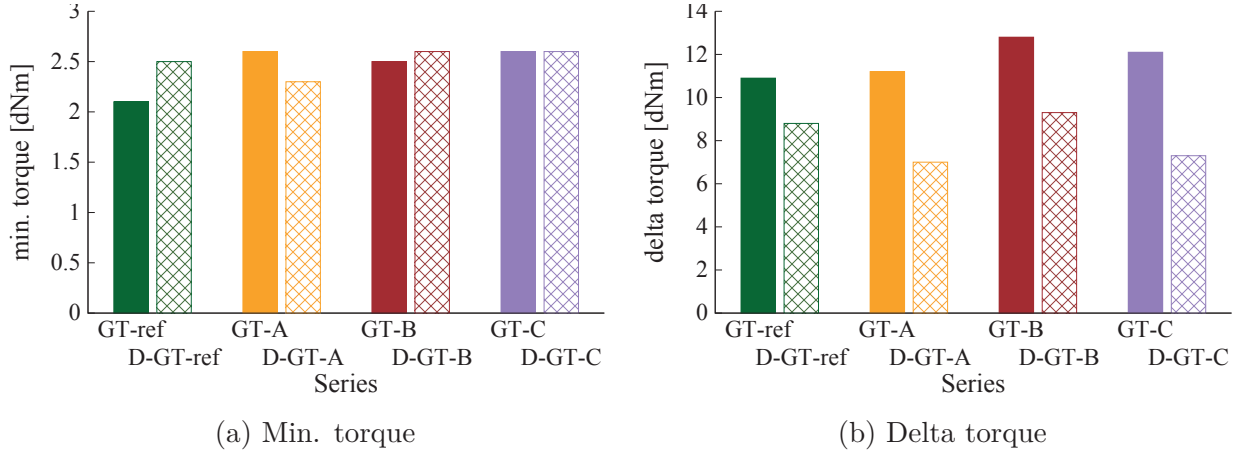


Figure 5: Torque of cure curves of silica-silane based tread compounds with resins

3.3 Morphology of the vulcanizate

It was shown in Chapter ??, ??, that silica as active filler causes a rather coarse morphology of the revulcanizates. As is shown in Figure 6 of the fraction surfaces of the tensile test pieces of both, the vulcanizates and revulcanizates, there is no substantial difference between the morphologies of the resin containing revulcanizates and the reference one: the morphology of the revulcanizates is mainly determined by the silica rather than by the resins in the revulcanizates.

3.4 Mechanical properties

The de- and revulcanization hardly seem to have an influence on the tensile strength and strain at break. For all compounds the differences are within the error margins, even for the two compounds with resin B, which show a larger difference in tensile strength. The differences between the compounds are within the error margins too, although the data suggests a slight positive influence of resins A and C on tensile strength and strain

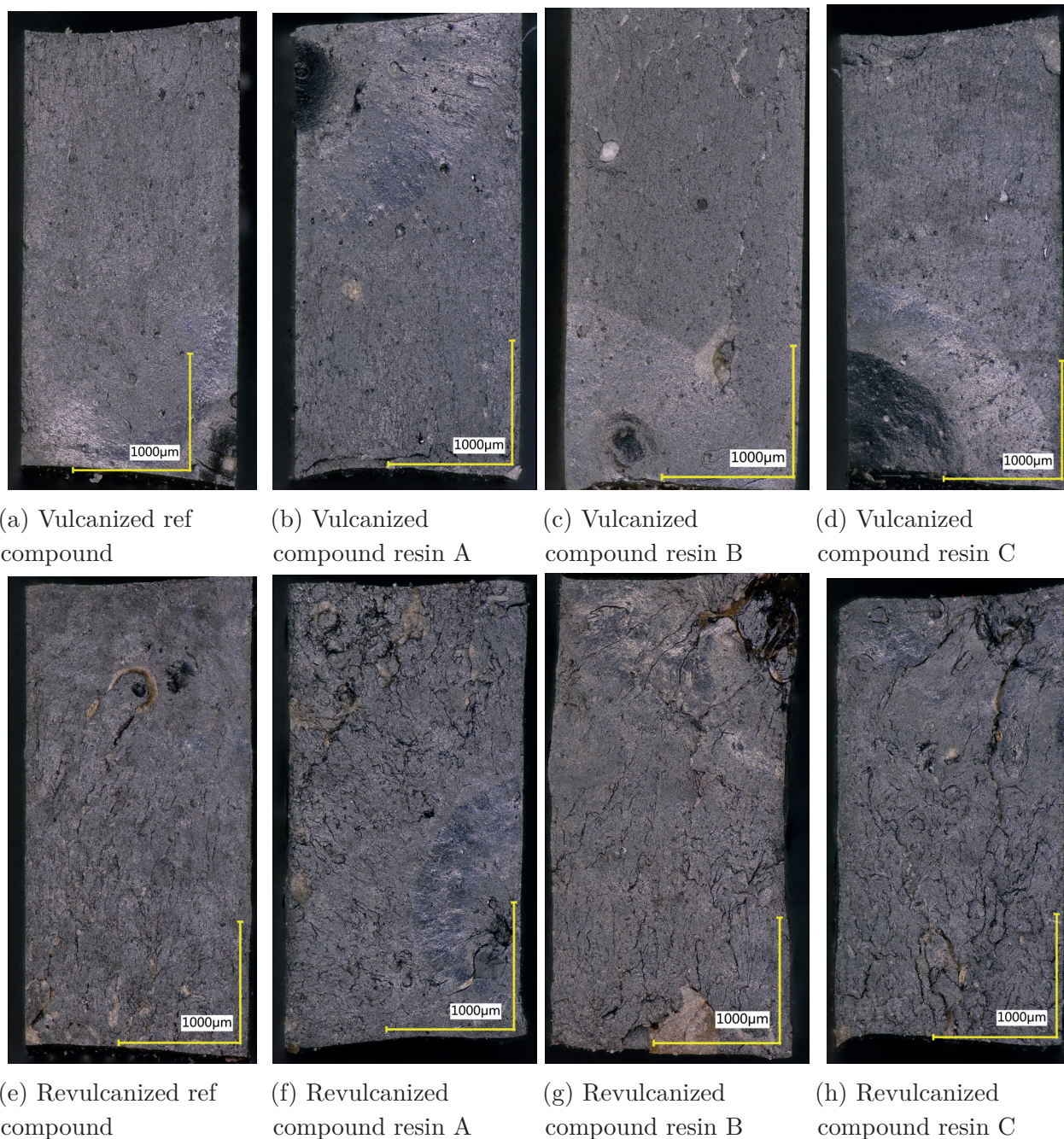
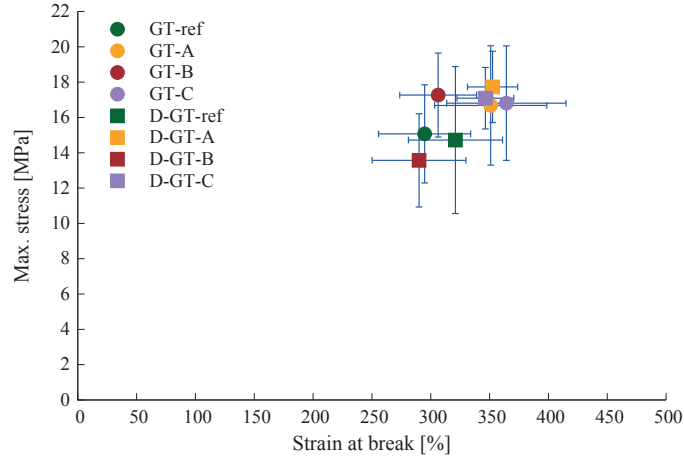


Figure 6: Morphology of resin containing compounds before and after devulcanization. Fracture surfaces of tensile test samples of vulcanized (a-d) and revulcanized (e-h) compounds.

at break of the revulcanizates compared with the compounds, see Figure 7. Despite the stickiness of the compounds for revulcanization, the homogeneity of these revulcanizates shows to be better than of the compounds, see Figure 8.

With respect to hardness, all revulcanizates show a slight decrease of approximate 5%, Figure 9. The initial hardness of both compounds with resins B and C is slightly higher than the hardness of the other compounds but the drop in hardness is similar to that of other revulcanizates. This is consistent with the reduction in delta torque for the revulcanizates, as indicated before, Figure 5b.



Mean values of 5 samples; Error bars are plus/minus 2σ

Figure 7: Tensile properties of silica based model compounds with resins after vulcanization and devulcanization-revulcanization

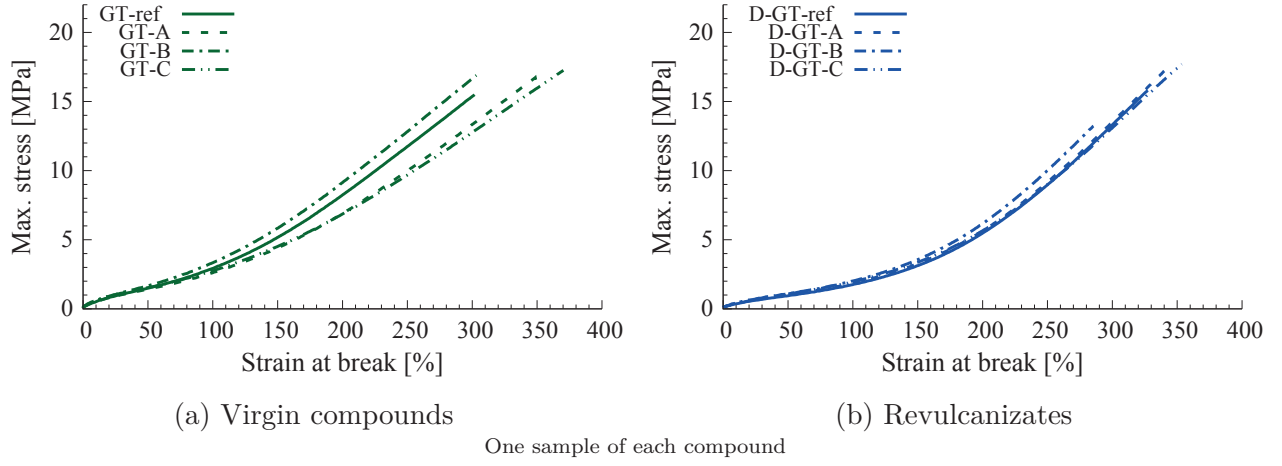


Figure 8: Tensile properties as graph of silica based model compounds with resins after vulcanization and devulcanization-revulcanization

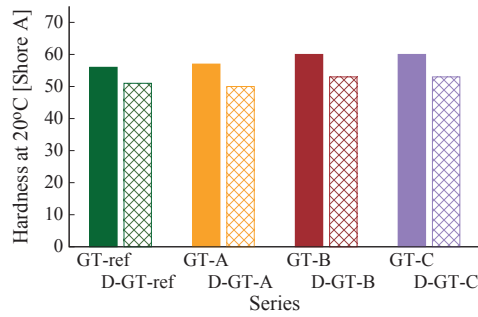


Figure 9: Hardness of silica-silane based tread compounds with resins before and after devulcanization

3.5 Dynamic properties

With respect to the DMA measurements, it can be noted that all revulcanizates show a clear increase of tan delta at T_g , Figure 10. This is as expected due to the devulcanization process, as, because of recrosslinking reactions during devulcanization, the structure of the revulcanizates are at a molecular level more complex than the virgin compounds. This implies more energy dissipation during deformation, indicated by an increased T_g . The

revulcanized samples, reference and with resin A, show an increase of T_g with about 10°C , with resin C about 15°C and the sample with resin B shows hardly any change. This suggests differences in homogeneity of the samples, most probably due to a difference in miscibility of the compounds and devulcanizates. As a consequence of both effects, tan delta at 0°C has increased for all revulcanized samples too, an indication of improved wet grip. The resin containing revulcanizates show a slightly increased tan delta at 60°C compared with both, the reference and the vulcanizates, see Figure 11 and Table 8, an indication of slightly increased rolling resistance.

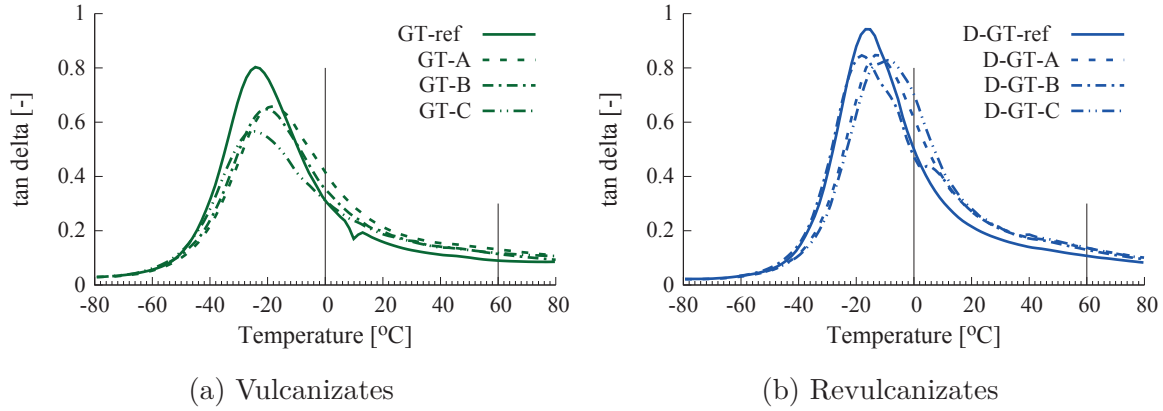


Figure 10: T_g and tan delta vs. temperature of silica-silane based tread compounds with resins, vulcanizates vs. revulcanizates for all compounds

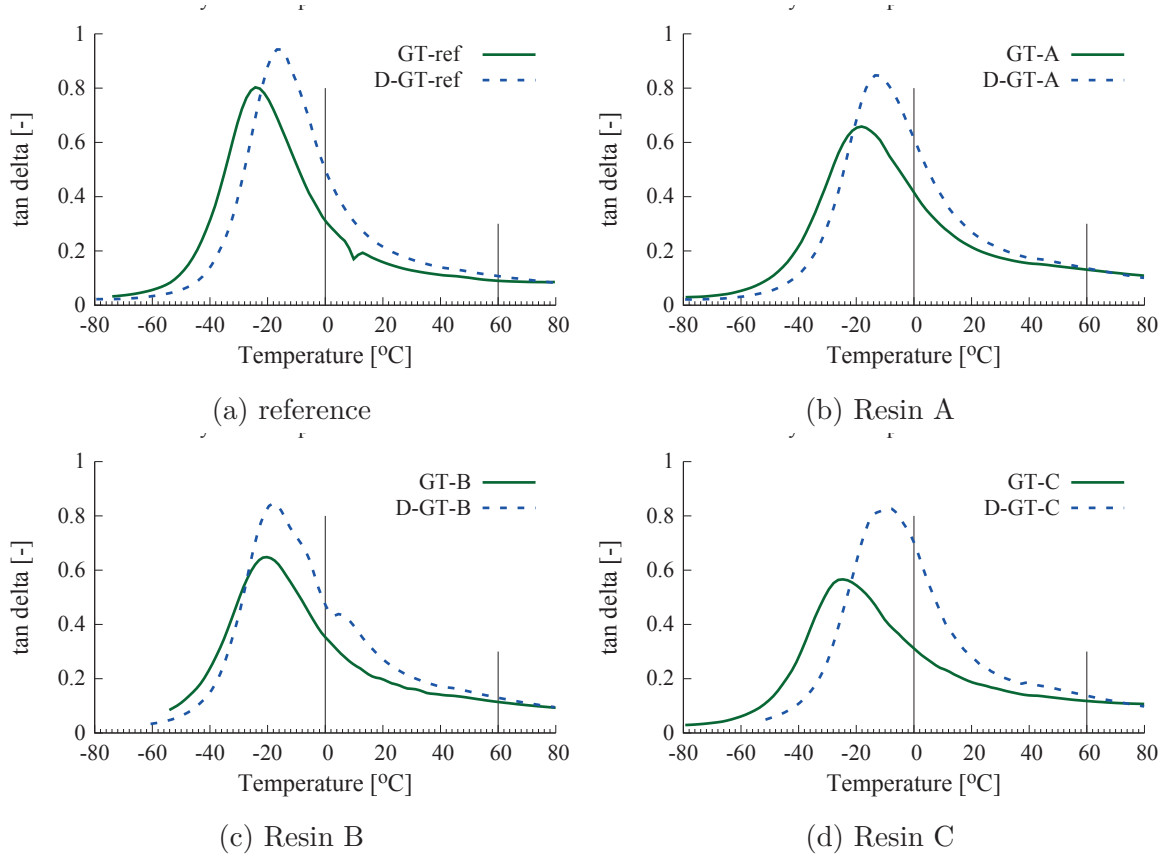


Figure 11: T_g and tan delta vs. temperature of silica-silane based tread compounds with resins, vulcanizates vs. revulcanizates, for each compound separated.

Table 8: tan delta at T_g of silica-silane based tread compounds with resins, vulcanizates vs. revulcanizates.

Resin	Vulcanizate				Revulcanizate			
	T_g [°C]	tan delta at:			T_g [°C]	tan delta at:		
		T_g	0 °C	60 °C		T_g	0 °C	60 °C
Ref.	−24	0.8	0.31	0.09	−16	0.94	0.50	0.11
A	−18	0.65	0.42	0.13	−12.5	0.85	0.62	0.135
B	−21	0.65	0.35	0.11	−18	0.84	0.48	0.13
C	−25	0.56	0.31	0.12	−8	0.83	0.7	0.135

The rebound test provides a fast indication of the energy losses during a dynamic load. As is shown in Figure 12, the rebound values of the resin containing vulcanizates are lower than of the reference. This is consistent with the higher tan delta values at 20 °C as shown in Figure 10a. For the revulcanizates, a similar pattern is shown, with a slight decrease in rebound values compared with those of the vulcanizates. This is again consistent with the tan delta values at 20 °C as shown in Figure 10b. This can be interpreted as a slight increase of the rolling resistance of the revulcanizates compared to the vulcanizates.

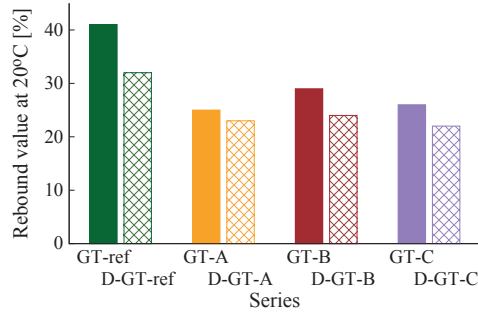


Figure 12: Rebound at 20 °C of silica-silane based tread compounds with resins before and after devulcanization.

Overall, the effect on the dynamic properties of de- and revulcanization is as expected. The increase in the wet grip parameter, however, is far better for the resin containing revulcanizates, compared with the reference.

4 CONCLUSIONS

De- and revulcanization of a compound influences the curing, mechanical and dynamic properties, especially for a silica containing rubber. Additional effects of the resin in the compounds with respect to the various parameters are listed below:

Processing: A significant reduction in viscosity of the compounds for revulcanization, compared to the devulcanizate, is observed, although it is not clear whether this can be attributed to the resins in the rubber.

Milling of the devulcanizates after silanization and of the revulcanizates containing resins A and C requires additional attention because of the tack of the revulcanizate.

Curing: The revulcanizates with resins A and C changed to a reversion curve instead of a marching one.

Tensile properties: Hardly any difference between the tensile properties of the compounds and the revulcanizates is measured.

Hardness: No additional increase in hardness compared to the reference revulcanizate is found.

T_g: A shift in T_g from 3 °C to 17 °C between the vulcanized and revulcanized compounds is measured, depending on the type of resin, with the shift for the reference compound being 8 °C.

A relative large increase of tan delta-peak at T_g of 0.2 to 0.27 (31 % to 48 %) for the revulcanizates containing resins is measured relative to the vulcanized compounds. For the reference compound this is 0.14 (17 %).

Wet grip: The wet grip indicator, tan delta at 0 °C, indicates a considerable increase of wet grip for the revulcanizates containing resins.

Rolling resistance: The rolling resistance indicator, tan delta at 60 °C, as well as the rebound values indicate a slight increase of the rolling resistance.

Acknowledgements

This study was financially sponsored by: the Netherlands Organization for Scientific Research (NWO) by means of a scholarship for teachers, project “Closing the Loop: re-use of devulcanized rubber in new tires”, Project Number 023.004.127; Tech for Future (TFF) “Centre of Expertise High Tech Systems and Materials (HTSM) East”, a cooperation of the Universities of Applied Sciences: Windesheim and Saxion; the European Regional Development Fund(EFRO) project 395 “Proeftuin Recycling - Future Proof Polymer”; Schill+Seilacher “Struktol” GmbH, Hamburg, Deutschland; Kraton Chemical B.V., Almere, the Netherlands; department Elastomer Technology and Engineering (ETE) of the University of Twente, Enschede, the Netherlands; Technical Department and the professorship for Polymer Engineering, the University of Applied Sciences Windesheim, Zwolle, the Netherlands.

Conflict of interests

The authors declare no conflict of interest. The sponsors had no role in the design of the study, in the collection, analyses, or interpretation of data or in the writing of the manuscript, and in the decision to publish the results.

References

- ¹R. Mildenberg, M. Zander, and G. Collin, *Hydrocarbon resins* (VCH-Wiley, Weinheim, 1997), p. 179.
- ²W. Pille-Wolf and A. Deshpande, “Tires and tread formed from Phenol-Aromatic-Terpene resin”, US 2010/0317800 A1 (2010).
- ³P. Sandstrom, E. Blok, and J. Verthe, “Pneumatic tire having a tread compound containing high levels of low to polymer and resin”, US 005901766A (1999).
- ⁴J. L. Ryba, P. H. Sandstrom, S. W. Cronin, and B. H. Marts, “Tire with rubber tread containing combinations of resin blend and functionalized elastomer”, US 8459319 B1 (2013).
- ⁵J. A. Schlademan, L. G. Wideman, E. J. Blok, H. Sandstrom, A. Bergomi, and M. Leslie jr. Kravovich, “Pneumatic tire having a tread containing resin”, US 6214919 B1 (2001).

- ⁶C. Ringot, “Tire with a tread compromising an emulsion SBR having a high trans content”, US 2014/0171557 (2014).
- ⁷N. Vleugels, W. Pille-Wolf, W. K. Dierkes, and J. W. M. Noordermeer, “Understanding the influence of oligomeric resins on traction and rolling resistance of silica-reinforced tire treads”, *Rubber Chem. Technol.* **88**, 65–79 (2015).
- ⁸Kraton, *Kraton prnewswire*, (2018) <https://www.prnewswire.com/news-releases/kraton-increases-capacity-for-sylvatrxxx-tread-enhancement-additives-300595154.html~8-02-2018> (visited on 05/01/2019).
- ⁹W. Pille-Wolf, N. Riddle, and H. Miller, “Tire rubber comprising modified tall oil pitch”, US 8637594 (2014).
- ¹⁰R. O. Babbitt, ed., *the Vanderbilt Rubber handbook* (R.T.vanderBilt Company inc, Norwalk, 1978).
- ¹¹W. Pille-Wolf, “Resin-extended rubber composition and tire rubber compositions prepared therewith”, WO 2017/117578 A1 (2017).

In samenwerking met



Europese Unie



Europees Fonds voor Regionale Ontwikkeling

KRATON™



**Elastomer Technology
and Engineering**



Lectoraat Kunststoftechnologie

Invloed van resins in autobandenrubber op het devulkanisatieproces

Over het lectoraat Kunststoftechnologie

Het lectoraat Kunststoftechnologie stimuleert innovatie op het gebied van kunststofverwerking en -producten in het midden- en kleinbedrijf. Vanuit de onderzoeksprojecten, uitgevoerd door docenten van de technische opleidingen bij de Hogeschool Windesheim in samenwerking met bedrijven, vloeien nieuwe kennis en inzichten naar het Hoger Onderwijs én het bedrijfsleven.

Samenvatting

Gebruikte autobanden vormen vanwege het grote volume en de duurzaamheid van het materiaal een belangrijke materiaalstroom voor hergebruik. Toepassing van dit materiaal in nieuwe autobanden heeft als grote voordeel dat het materiaal volledig hergebruikt kan worden voor kwalitatief hoogwaardige toepassingen. Daarvoor moet het rubber via een complex proces weer in een kneedbare toestand worden teruggebracht.