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Carbo NXT* Silane

Coupling Agent for Silica-Reinforced Tire Tread Compounds

MARKETING BULLETIN SILANES - TIRE & RUBBER

Carbo NXT silane is NXT silane in powder form, for use when a liquid is inconvenient. Carbo NXT silane generally provides the same potential for enhanced tire performance and overall systems cost-efficiencies for tire manufacturers as NXT liquid silane.

It has been demonstrated that Carbo NXT silane, containing thiocarboxylate functional silane and N 330 type carbon black, typically enables reduced rolling resistance without loss of wet traction, while increasing overall production efficiency for tire manufacturers as compared to standard sulfur silanes. Silica compounds coupled with Carbo NXT silane have exhibited improved silica dispersion, easier mixing and faster, pliable processing. Compounds containing Carbo NXT silane have shown lower Payne Effect, improved tan delta values, and better resilience properties. In addition, Carbo NXT silane typically can be used with high surface area silica and functionalized polymers for easy processing of high performance compounds. Green compounds made with Carbo NXT silane have demonstrated stability for a significantly longer time without reflocculation.

Key Features and Typical Benefits

- Fewer non-productive mixing steps
- Reduced compound viscosity
- Faster extrusion
- Improved Payne Effect
- Increased resilience
- Reduced tan δ max
- Excellent dynamic properties at low temperature (-20 °C to +10 °C)

Typical Physical Properties	
Physical Form	Powder
Color	Black
Flash Point, °C	176
Density, g/cm^3	1.800

Typical properties are average data and are not to be used as or to develop specifications.

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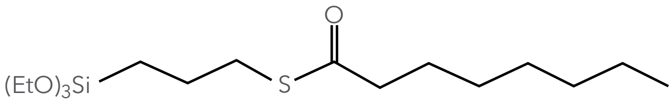
Chemical Structure



3-Octanoylthio-1-propyltriethoxysilane (Mol. Wt. 364)

Table 1: Sample Silica-Reinforced Tire Tread Formulations Used to Evaluate Carbo NXT Silane

Ingredients	S2	S4	NXT Silane	Carbo NXT Silane
Buna VSL† 5525-1, OE	103.2	103.2	103.2	103.2
Budene† 1207	25	25	25	25
Zeosil† 1165MP	80	80	80	80
N-330 CB	10	10	10	3.6
DAE Oil	5	5	5	5
6PPD	2	2	2	2
MC Wax	1.5	1.5	1.5	1.5
TESPD, S2 Silane	**5.65**			
TESPT, S4 Silane		**6.41**		
NXT Silane			**6.40**	
Carbo NXT Silane				**12.80**
ZnO	2.5	2.5	2.5	2.5
Stearic Acid	2	2	2	2
REMILL				
Sulfur	1.865	1.100	2.060	2.060
CBS	2	2	2	2
DPG	2	2	2	2
Total sulfur xlinks, 10^{22}	4.93	4.93	4.93	4.93

† Buna VSL is a trademark of Lanxess Deutschland GmbH.
† Budene is a trademark of The Goodyear Tire & Rubber Company.
† Zeosil is a trademark of Rhoda, Inc.

Product formulations are included as illustrative examples only. Momentive makes no representation or warranty of any kind with respect to any such formulations, including, without limitation, concerning the efficacy or safety of any product manufactured using such formulations.

Potential Applications

For improved rolling resistance without loss of wet traction in tires, Carbo NXT silane can be considered for use in tire tread compounds to enable high silica loading while typically managing compound viscosity, improving processibility and increasing mixing temperatures, even in functionalized polymer and high surface area silica compounds. Carbo NXT silane can be mixed at temperatures as high as 170 °C without scorch and the number and duration of non-productive mixing steps can be minimized to achieve maximum silica dispersion.

Potential Applications (continued)

Compounding procedures for traditional polysulfide S2 (TESPD) and S4 (TESPT) silanes require two or more non-productive mixes. Differences in mixing procedures between Carbo NXT silane and these traditional polysulfide silanes are shown in Table 2.

Table 2: Mixing Procedures for Polysulfide and Carbo NXT Silanes

Two Step Mix Procedure for S4 (TESPT) Silane		Two Step Mix Procedure for S2 (TESPD) and Carbo NXT Silanes	
Size "OOC" mixer – 4.2 L capacity, 70% FF		Size "OOC" mixer – 4.2 L capacity, 70% FF	
First Non-Productive Pass at 55 rpm, 70 °C		**First Non-Productive Pass at 55 rpm, 70 °C**	
$t_{0\ min}$	Add polymers, ram down mix (RDM) 30 seconds	$t_{0\ min}$	Add polymers, ram down mix (RDM) 30 seconds
$t_{0.5\ min}$	Add 50% silica, all silane, RDM 60 seconds	$t_{0.5\ min}$	Add 50% silica, all silane, RDM 60 seconds
$t_{1.5\ min}$	Add 50% silica, chemicals, RDM 60 seconds	$t_{1.5\ min}$	Add 50% silica, chemicals, RDM 60 seconds
$t_{2.5\ min}$	Add CB, oil at 125 °C	$t_{2.5\ min}$	Add CB, oil at 125 °C
$t_{2.5\ min}$	Reduce rotor speed to 35 rpm, RDM 90 seconds	$t_{2.5\ min}$	Reduce rotor speed to 35 rpm, RDM 90 seconds
$t_{4\ min}$	Sweep, RDM 120 seconds	$t_{4\ min}$	Sweep, RDM 120 seconds
$t_{4\ min}$	Hold temperature at 135-140 °C for 2 minutes	$t_{4\ min}$	Hold temperature at 145-150 °C for 2 minutes
$t_{6\ min}$	Discharge at 145 °C	$t_{6\ min}$	Discharge at 155 °C
Mill Blend, sheet off 80-90 °C roll mill, cool to near room temperature		Mill Blend, sheet off 80-90 °C roll mill, cool to near room temperature	
Second Non-Productive Pass at 50 rpm, 70 °C		**Second Non-Productive Pass at 50 rpm, 70 °C**	
$t_{0\ min}$	Add compound from first pass, RDM 60 seconds	$t_{0\ min}$	Add compound from first pass, RDM 60 seconds
$t_{1\ min}$	Add remainder of ingredients, RDM 60 seconds	$t_{1\ min}$	Add remainder of ingredients, RDM 60 seconds
$t_{2\ min}$	Sweep, RDM 120 seconds	$t_{2\ min}$	Sweep, RDM 120 seconds
$t_{2\ min}$	Hold temperature at 135-140 °C for 2 minutes	$t_{2\ min}$	Hold temperature at 145-150 °C for 2 minutes
$t_{4\ min}$	Discharge at 145 °C	$t_{4\ min}$	Discharge at 155 °C
Mill Blend, sheet off 80-90 °C roll mill, cool to near room temperature		Mill Blend, sheet off 80-90 °C roll mill, cool to near room temperature	
Final Productive Pass at 45 rpm, 50 °C		**Final Productive Pass at 45 rpm, 50 °C**	
$t_{0\ min}$	Add compound from second pass, cure package RDM 60 seconds	$t_{0\ min}$	Add compound from second pass, cure package RDM 60 seconds
$t_{1\ min}$	Sweep, RDM 90 seconds	$t_{1\ min}$	Sweep, RDM 90 seconds
$t_{1\ min}$	Hold temperature at 90-95 °C for 1.5 minutes	$t_{1\ min}$	Hold temperature at 90-95 °C for 1.5 minutes
$t_{2.5\ min}$	Discharge at 100-105 °C	$t_{2.5\ min}$	Discharge at 100-105 °C
Mill Blend, sheet off 80-90 °C roll mill, cool to near room temperature		Mill Blend, sheet off 80-90 °C roll mill, cool to near room temperature	

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Potential Applications (continued)

Table 3: Comparison of Rubber Compounds Containing Carbo NXT Silane, NXT Silane, Standard S2 (TESPD) Silane or Standard S4 (TESPT) Silane

Silane	**S2**	**S4**	**NXT Silane**	**Carbo NXT Silane**
Silane phr	**5.65**	**6.41**	**6.4**	**12.8**
Number of Mixing Steps	2	2	2	2
Reaction Temperature	155	145	160	160
Mooney Viscosity at 100 °C				
ML (1+4)	85	86	75	75
Mooney Scorch at 135 °C				
MS1+, t3, Minutes	17	12	14	14
Rheometer (160 °C, 30 Mins.)				
ML, dN-m	3.20	3.38	2.46	2.55
MH, dN-m	21.78	21.74	20.04	20.64
Δ Torque, dN-m	18.58	18.36	17.58	18.09
T90, minutes	17.71	17.90	15.48	15.69
Dynamic Properties				
Strain Sweep at 55 °C				
E′ max	13.05	13.07	12.09	13.12
E′ min	5.35	5.15	5.55	5.77
E′ mean	8.86	8.77	8.62	9.16
ΔE′ (MPa)	7.70	7.92	6.63	7.35
E″ max (MPa)	2.12	2.08	1.65	1.80
Tan δ max	0.224	0.225	0.186	0.191
Physical Properties at 25 °C				
Shore A at RT	70	70	68	69
Shore A at 70 °C	66	66	64	65
Elongation (%)	365	396	370	367
Tensile Strength (MPa)	14.8	14.9	15.4	14.9
50% Modulus (MPa)	1.5	1.5	1.6	1.6
100% Modulus (MPa)	2.7	2.5	2.9	2.9
300% Modulus (MPa)	12.8	11.7	13.2	13.0
RI (M_{300}/M_{100})	4.8	4.8	4.6	4.5
Break Energy (J/cm^3)	21	23	23	22
Rebound				
0°C (%)	10	9	9	9
RT (%)	18	19	19	18
70°C (%)	40	40	43	43
70°C - RT (%)	22	21	25	25
Temp Sweep at 0.5% Strain				
Tan δ at Tg	0.586	0.574	0.607	0.606
Tan δ at 0 °C	0.723	0.796	0.775	0.826
Tan δ at 60 °C	0.195	0.180	0.154	0.160
E* at 25 °C	19	19	16	16

Note: Test data. Actual results may vary.

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Potential Applications (continued)

All figures shown below compare rubber compounds containing Carbo NXT silane, NXT silane, standard S4 (TESPT) silane or standard S2 (TESPD) silane.

Figure 1: Comparison of Batch Viscosities

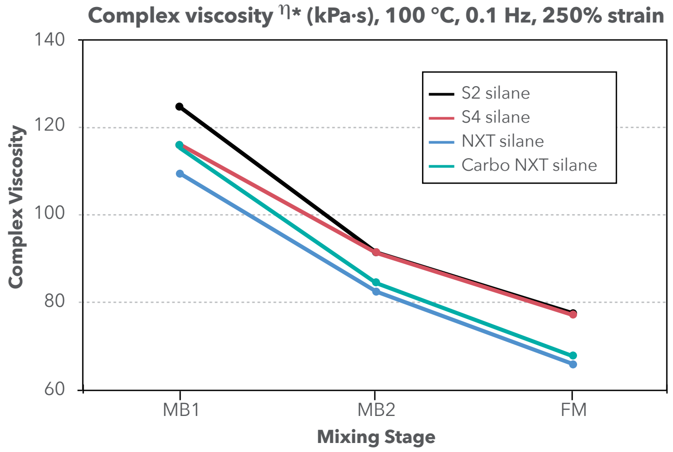


Figure 2: Cure Curve Comparison MDR at 160 °C

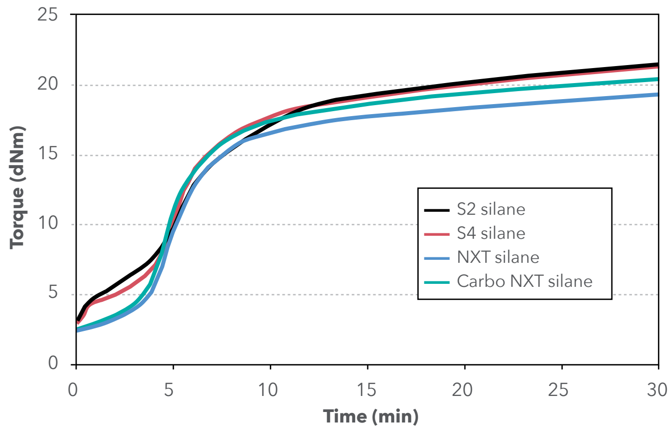
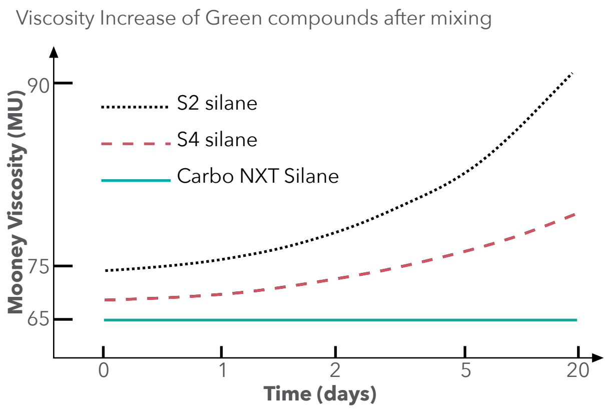


Figure 3: Low Viscosity and Improved Storage Stability with Carbo NXT Silane



Note: Test data. Actual results may vary.

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Potential Applications (continued)

Figure 4: Temperature Sweep, 10.0 Hz, at 0.5% Strain

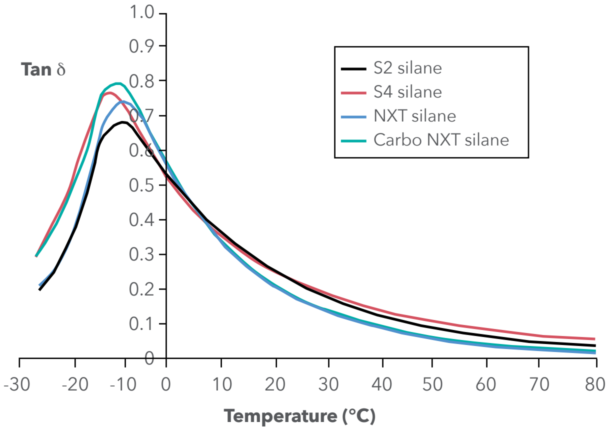


Figure 5: Strain Sweep, 10.0 Hz, at 55 °C

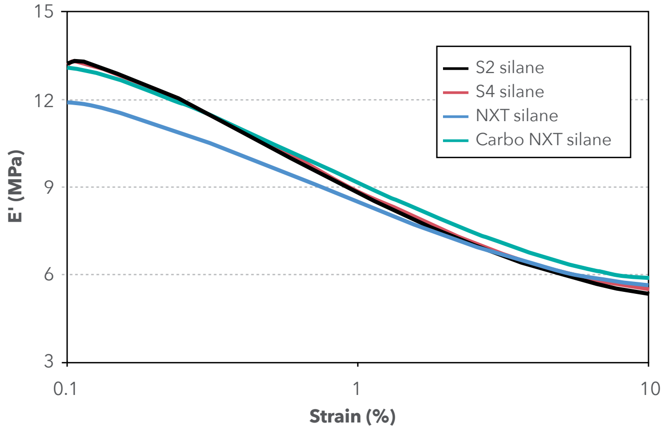


Figure 6: Tan δ Max Values, 10.0 Hz, at 55 °C

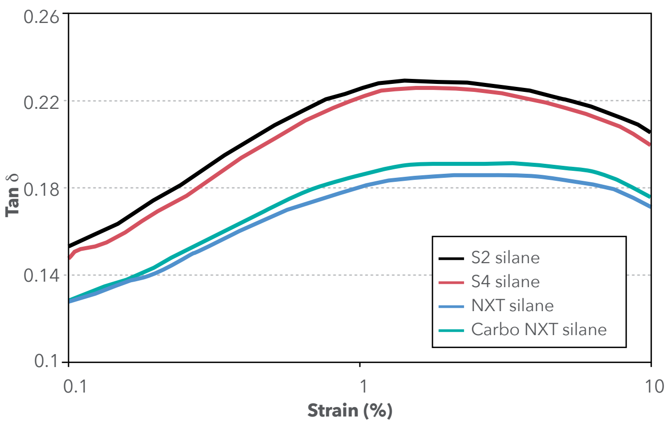
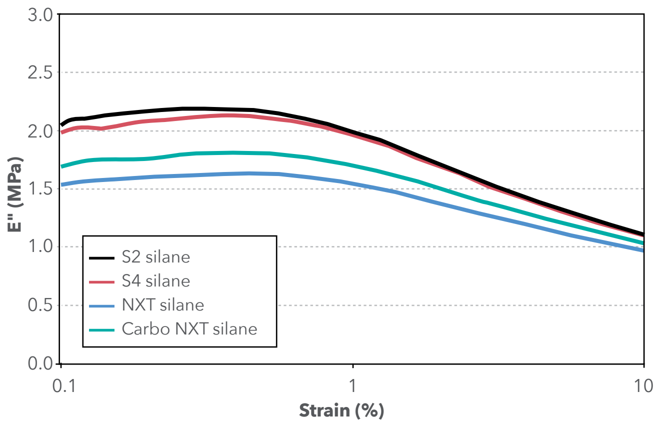


Figure 7: E" Values, 10.0 Hz, at 55 °C



Note: Test data. Actual results may vary.

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General Instructions for Use

Please refer to Tables 1 and 2 for details regarding example formulation and mixing procedures using Carbo NXT silane.

Dynamic properties with Carbo NXT silane compounds have been shown to be equivalent to NXT liquid silane and superior to standard S2 (TESPD) and S4 (TESPT) silane compounds in the 60-110 phr equivalent silica loading range. At 80 phr silica loading, 6.41 phr of standard S4 (TESPT) silane contains 35% more VOCs than 12.8 phr of Carbo NXT silane.

Maximum coupling strength can be achieved when there is a 16% loading of Carbo NXT silane based on the phr loading of silica. That is equivalent to 12.8-13.6 phr of Carbo NXT silane in an 80-85 phr silica formulation, respectively. Carbo NXT silane coupling strength was improved with higher mixing temperatures and higher vinyl content of the SBR polymer. In formulations in which the Shore A Hardness is slightly less than the control compound, 1-5 phr of silica can be added to increase hardness without reducing physical or dynamic properties.

Carbo NXT silane's reaction mechanism allowed non-conventional solutions for common compound challenges. Modulus 300% may be increased by adding silane, silica, and stearic acid in the first non-productive mix, while adding zinc oxide in the second non-productive mix. The accelerator, DPG (0.5-1.0 phr), can be added late in the second non-productive mix to increase bound rubber content. Compound viscosity can be reduced substantially by adding 0.5-1.0 phr of CBS in the second non-productive mix.

Patent Status

Nothing contained herein shall be construed to imply the nonexistence of any relevant patents or to constitute the permission, inducement or recommendation to practice any invention covered by any patent, without authority from the owner of the patent.

Limitations

Customers must evaluate Momentive Performance Materials products and make their own determination as to fitness of use in their particular applications.

Product Safety, Handling and Storage

Customers should review the latest Safety Data Sheet (SDS) and label for product safety information, safe handling instructions, personal protective equipment if necessary, emergency service contact information, and any special storage conditions required for safety. Momentive Performance Materials (MPM) maintains an around-the-clock emergency service for its products. SDS are available at www.momentive.com or, upon request, from any MPM representative.

For product storage and handling procedures to maintain the product quality within our stated specifications, please review Certificates of Analysis, which are available in the Order Center. Use of other materials in conjunction with MPM products (for example, primers) may require additional precautions. Please review and follow the safety information provided by the manufacturer of such other materials.

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