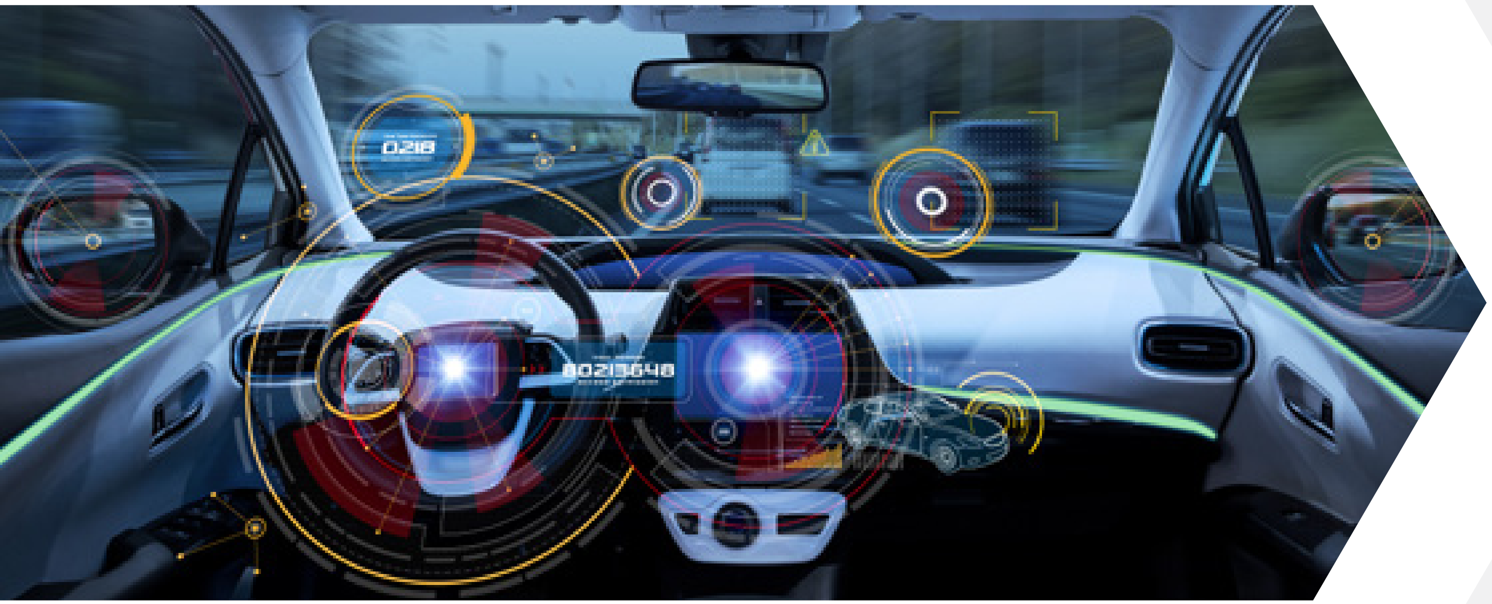
CABOT

PRODUCT AND APPLICATION GUIDE

ATHLOS™ SR1200 CNS



INCLUDED IN THIS GUIDE

Introduction

Cabot Corporation has a long history as a leader in conductive carbon additives; we have collaborated with our customers for over 135 years to drive innovation forward and solve performance challenges. The global trend of electrification across multiple industries and markets requires products to be lighter, smaller, thinner and more conductive without sacrificing strength. ATHLOS™ carbon nanostructures (CNS), Cabot's latest conductive carbon solution, delivers an exceptional combination of conductivity, shielding and mechanical strength for silicone applications.

Benefits of ATHLOS™ SR1200 CNS

The electrification of vehicles has created a demand for greater connectivity, reliability and compliance with tight safety regulations that require high-performance electromagnetic interference (EMI) shielding. Automotive applications such as electronic control units (ECU), cameras, radar, light detection and ranging (LiDAR) and other sensors and batteries all need dependable performance over time with zero defects. Design features for autonomous vehicles are also raising the bar for EMI shielding requirements because of their many sensor configurations.

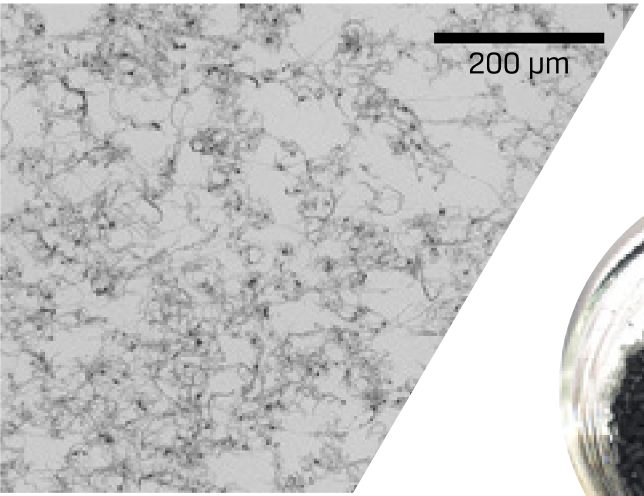
In the communications space, 5G base stations and wireless connections need greater data transfers at faster speeds that are challenged by electromagnetic compatibility (EMC). Consumer electronics with high-density packaging and smart architectures are also susceptible to electromagnetic pollution that can disrupt or disable circuits.

In all these applications and more the use of cost-effective high performance conductive and EMI shielding silicones is critical to the development of next generation products. ATHLOS™ SR1200 CNS enables several key performance features in these silicones including:

- High Electrical Conductivity
- Low Electrical Percolation Threshold
- High EMI Shieling Performance
- Synergy with conductive/nonconductive fillers
- Thixotropy
- Reinforcement
- Aging Stability
- Light-Weighting

ATHLOS™ CNS Electrical Conductivity Performance Data

ATHLOS™ SR1200 CNS can significantly enhance the electrical conductivity of silicone elastomers at low loading levels. The electrical percolation thresholds of ATHLOS SR1200 CNS are found to be between 0.1% and 0.25% by weight in cured High-Temperature Vulcanized (HTV) and Liquid-Silicone-Rubber (LSR) silicone elastomers. The percolation threshold of ATHLOS SR1200 CNS is significantly lower than typical conductive additives for silicone elastomers, e.g., nickel-coated graphite, carbon blacks and other metal or metal alloys/composites.



Dispersed CNS

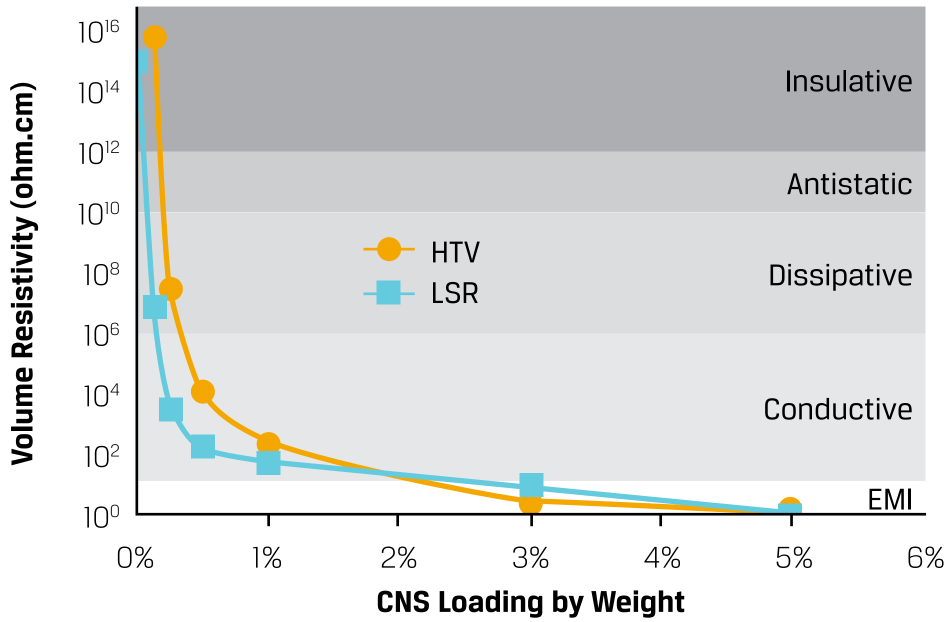


Fig 1: Electrical Percolation Curves of CNS in Silicone Elastomers

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ATHLOS™ CNS Electrical Conductivity Performance Data

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At approximately 3% loadings, the volume resistivity of the ATHLOS™ SR1200 CNS containing silicone elastomer composite can drop below 10 ohm.cm, which is a typical conductivity threshold required for high levels of electromagnetic interference shielding.

ATHLOS™ SR1200 CNS has synergies with other inorganic additives in silicones to meet conductivity, EMI shielding, light-weighting and mechanical property requirements. CNS can combine with or partially replace other conductive fillers, e.g., carbon black, Ni-coated graphite, or others to significantly improve electrical conductivity. In certain silicone compounds containing non-conductive fillers, e.g., fumed silicas, ATHLOS™ SR1200 CNS can still impart good electrical conductivity.

ATHLOS CNS aging stability performance data

The 3% ATHLOS™ SR1200 CNS-loaded HTV silicone was shown during testing to be stable for 90-day storage at room temperature and ambient humidity. The conductivity of the ATHLOS CNS-filled silicone elastomer can be expected to remain constant in other aging conditions (moisture and high-temperature).

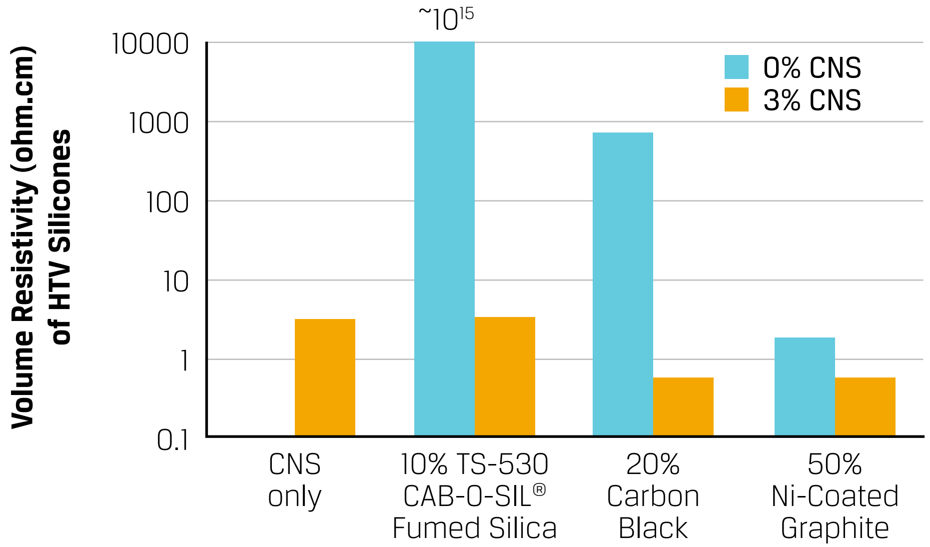

Fig 2: Increase in Conductivity of CNS-filler silicones

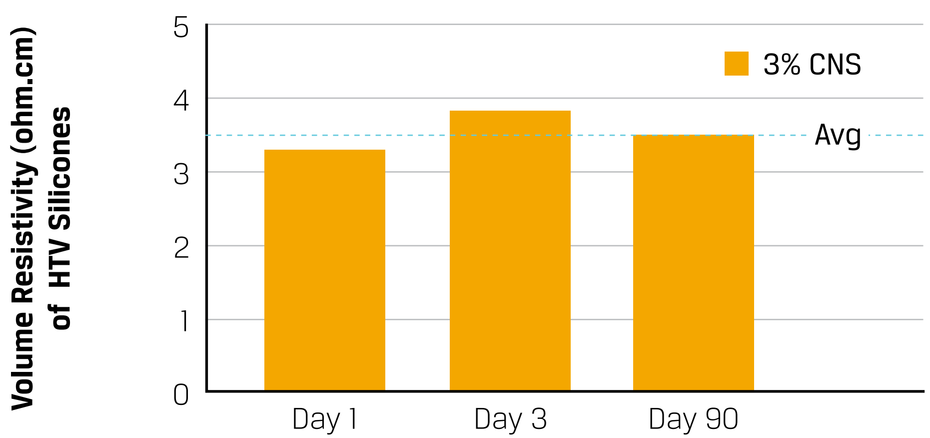

Fig 3: Aging stability of CNS in HTV Silicone

ATHLOS™ CNS EMI Shielding Performance Data

Electromagnetic interference (EMI) shielding effectiveness (SE) of a shielding material is a function of its conductivity, permeability and geometry (thickness). ATHLOS CNS products have excellent conductivity at low loadings, which enables superior EMI shielding properties over conventional conductive additives in silicones. ATHLOS SR1200 CNS's unique crosslinked nanotube morphology provides a very effective conductive network to shield electromagnetic waves. With an optimized additive package in the formulation as presented in Figure 4B, ATHLOS SR1200 CNS-filled silicone elastomers can match the performance of silver-filled compounds in ultra-high frequency range and above (2-18 GHz).

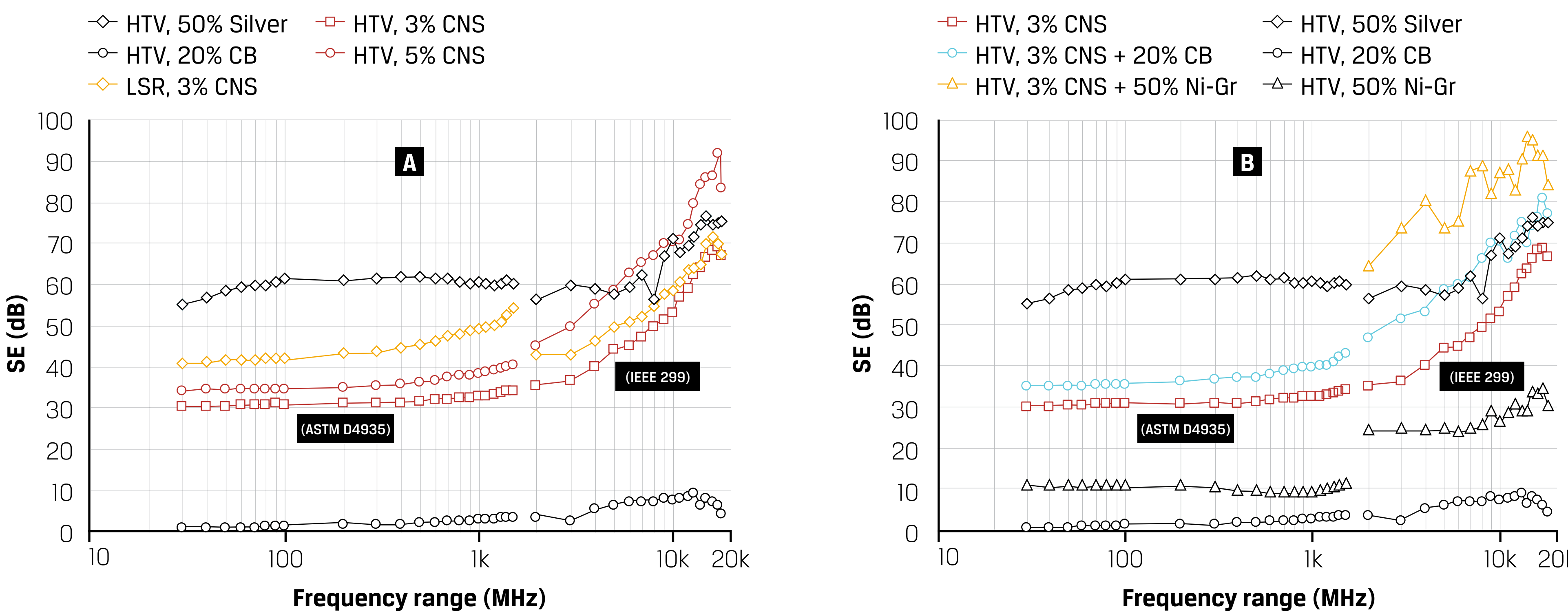

Fig 4: EMI shielding properties of CNS-filled silicone elastomers (Sample thickness: 2mm) (Ref. Test Standards)

ATHLOS™ CNS Reinforcement Performance Data

ATHLOS™ SR1200 CNS can improve the stiffness of silicone elastomers at very low loading levels. In the HTV tests, the tensile strength of the HTV elastomers increases with ATHLOS™ SR1200 CNS loading levels (Fig. 5). The elongation at break follows a reverse "S-shape" profile with respect to ATHLOS SR1200™ CNS loading levels.

In combination with other additives, in HTV formulations, ATHLOS™ SR1200 CNS in the test formulations at 3% loading increased tensile strength noticeably.

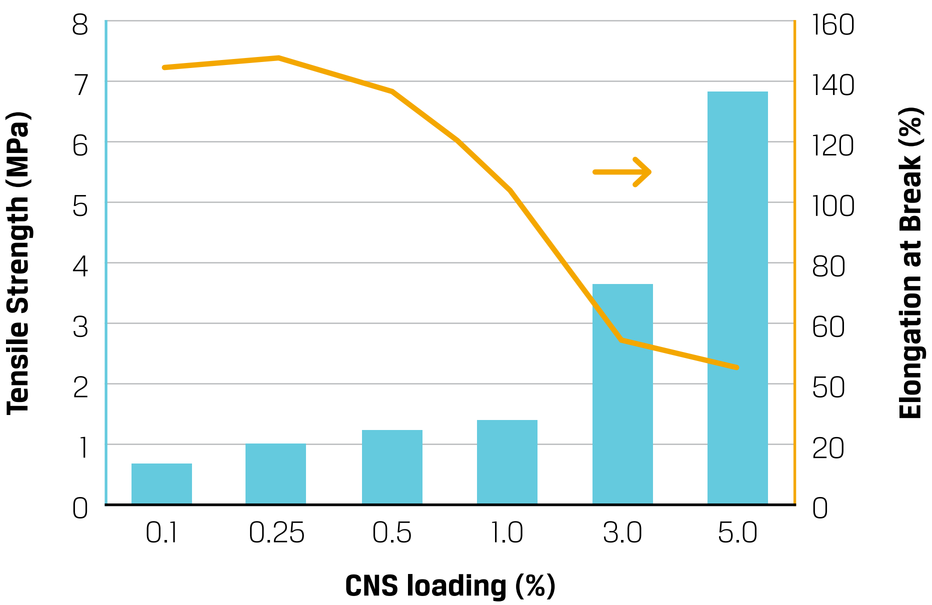

Fig 5: Mechanical properties of CNS-filled HTV

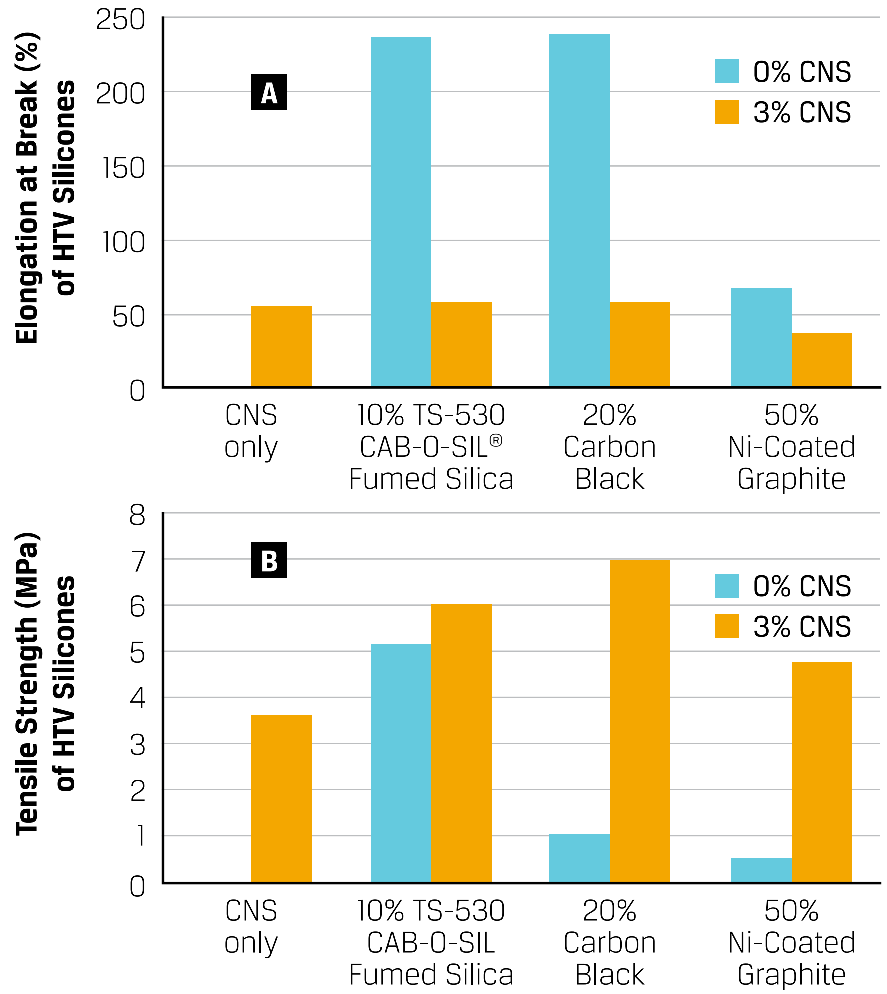

Fig 6: Mechanical properties of HTV silicones with a combination of fillers (A) Elongation at Break and (B) Tensile Strength

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Formulation and Process Guide for ATHLOS™ SR1200 CNS Used in Silicone Elastomers

ATHLOS™ SR1200 CNS can be formulated into silicone formulations through direct mixing and masterbatch (MB) processes using typical silicone elastomer mixing equipment. Direct mixing disperses CNS well in high viscosity silicone resin, e.g., vinyl gum, particularly in combination with other filler(s) or conductive additive(s). MB process generally is preferred for the silicone resins, e.g., LSR and RTV resins, that are incapable of providing sufficient shear to properly disperse CNS pellets. Examples of test silicone formulations and mixing procedures for ATHLOS™ SR1200 CNS are given below:

1.1 HTV Model Formulation and Mixing Procedure – Direct Mix

Ingredients	Grades	Percentage, %					
HTV resin	Vinyl gum, 0.2-0.3% Vinylmethylsiloxane	77.7	92.3	74.8	84.5	48.9	48.9
Additives	VULCAN® XC72R Carbon Black	20	-	20	-	-	-
	ATHLOS™ SR1200 CNS	-	5.0	3.0	3.0	-	-
	Ni-coated Graphite	-	-	-	-	50	-
	Silver flakes	-	-	-	-	-	50
	CAB-O-SIL® TS-530 Fumed Silica	-	-	-	10	-	-
Catalyst	Peroxide catalyst complex	2.3	2.7	2.2	2.5	1.1	1.1

- HTV resin and additives (fillers) were mixed in a 680 cc Brabender mixer (60°C, 60 rpm, fill factor 0.7) for 8 min;
- Added catalyst and mixed for another 2 min in the Brabender mixer at 60 °C, at 60 rpm, same fill factor.
- Milled on a Two-Roll mill for 2 min, at room temperature to create a curable silicone sheet.
- Cured HTV silicone sample in the molds at 170°C, for 10-20 min, under 20,000 lbs in a hot press, followed by cooling the sample/mold in a cold press for 5 min.

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Formulation and Process Guide for ATHLOS™ SR1200 CNS Used in Silicone Elastomers

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1.2 HTV Model Formulation and Mixing Procedure – CNS Masterbatch and Let-Down process

HTV MB Formulation

Ingredients	Grades	%
Silicone resin	Vinyl gum, 0.2-0.3% Vinylmethylsiloxane	95.0
Additive	ATHLOS SR1200 CNS	5.0
		100.0

HTV Let-Down Formulation (1% and 0.5% CNS)

Ingredients	Grades	%	%
CNS MB	5% ATHLOS™ SR1200 CNS	20.0	10.0
Silicone LD resin	Vinyl gum, 0.2-0.3% Vinylmethylsiloxane	77.2	87.2
Catalyst	Peroxide catalyst complex	2.8	2.8
		100.0	100.0

- Silicone resin and CNS in the amounts indicated in HTV MB table were mixed in a 680 cc Brabender mixer (60°C, 60 rpm, fill factor 0.7) for 8 min;
- Let-down (LD) was conducted in Brabender mixer to target CNS loading in Let-Down table;
- Milled on a Two-Roll mill for 2 min, at room temperature to create a curable silicone sheet.
- Cured HTV silicone sample in the molds at 170°C, for 10-20 min, under 20,000 lbs in a hot press, followed by cooling the sample/mold in a cold press for 5 min.

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Formulation and Process Guide for ATHLOS™ SR1200 CNS Used in Silicone Elastomers

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2.1 LSR Model Formulation and Mixing Procedure – CNS Masterbatch process

LSR MB Formulation

Ingredients	Grades	%
Silicone resin	Vinyl silicone, 0.08-0.12% Vinylmethylsiloxane, Viscosity: 10,000 cSt	95.0
Additive	ATHLOS™ SR1200 CNS	5.0
		100.0

- The liquid silicone resin and CNS were premixed in a planetary mixer for 30 sec to form a pasty blend at a moderate rpm, e.g., 1500 rpm.
- Silicone resin and CNS were mixed in a 680 cc Brabender mixer (60°C, 60 rpm, fill factor 0.7) for 8 min.

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Formulation and Process Guide for ATHLOS™ SR1200 CNS Used in Silicone Elastomers

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2.1 LSR Model Formulation and Mixing Procedure – CNS Masterbatch process

LSR Let-Down Formulation Cured by Platinum (3% CNS)

Ingredients	Grades	PHR	%
CNS Silicone MB	5% CNS in Vinyl Silicone Resin (MW 62,700g/mole, 0.03-0.04 Vinyl-eq/Kg)	100	59.95
Letdown resin	Vinyl silicone, 0.08-0.12% Vinylmethylsiloxane, Viscosity: 10,000 cSt	45.39	27.21
Additives	CAB-O-SIL® TS-530 fumed silica	16.67	10.0
Crosslinker	MethylHydrosiloxane-Dimethylsiloxane Copolymer, TMS Terminated, 25-35% MeHSiO	3.99	2.40
Inhibitor	1,3,5,7-Tetravinyl-1,3,5,7-tetramethylcyclotetrasiloxane	0.36	0.21
Pt catalyst	Platinum (0)-1,3-divinyl-1,1,3,3-tetramethyldisiloxane complex, soln. in vinyl PDMS	0.39	0.23
		166.79	100.00%

- Masterbatch, additional vinyl silicone Let-down resin, and CAB-O-SIL TS-530 silica in the amounts indicated in Table were combined and mixed in a 680 cc Brabender mixer (60°C, 60 rpm, fill factor 0.7) for 8 min;
- Added Crosslinker and inhibitor and mix for another 4 min, at the same mixing condition;
- Cool the mix to room temperature and the corresponding amount of catalyst was added to the compound and mixed in a 680 cc Brabender mixer (RT, 60 rpm, fill factor 0.7) for 2 min;
- Milled on a Two-Roll mill for 2 min, at room temperature to create a curable silicone sheet.
- Cured LSR silicone sample in the molds at 170°C, for 10-20 min, under 20,000 lbs in a hot press, followed by cooling the sample/mold in a cold press for 5 min.

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Formulation and Process Guide for ATHLOS™ SR1200 CNS Used in Silicone Elastomers

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2.2 Rheology Properties of CNS in LSR

ATHLOS™ SR1200 CNS can modify the rheological properties of the silicone resin even at a very low loading. In the test formulations, the CNS-free vinyl silicone resin exhibited a Newtonian fluid behavior, as shown in Figure 7. However, CNS-filled silicone compounds showed higher viscosity and shear-thinning behavior, which became more significant at high loadings. A good understanding of the rheological behavior of the compounds containing CNS can be important to determine the appropriate processing and application equipment.

- 5% ATHLOS™ SR1200 CNS-LSR MB prepared in section 2.1 was let down in a Planetary mixer (Flacktek DAC 600 Speedmixer) to the 0.1, 0.25, 0.5 and 1.0% loadings, at 1500rpm, 0.5-1.5 min per mixing run, total mixing time 18 min.
- Rheology test was conducted on Rheometer AR2000 (TA Instrument), stepped flow from 0.1 to 5000 Pa, at 25°C.
- 1 phr peroxide can be added to the above mixes and cured to obtain electrical percolation curve of CNS in LSR.

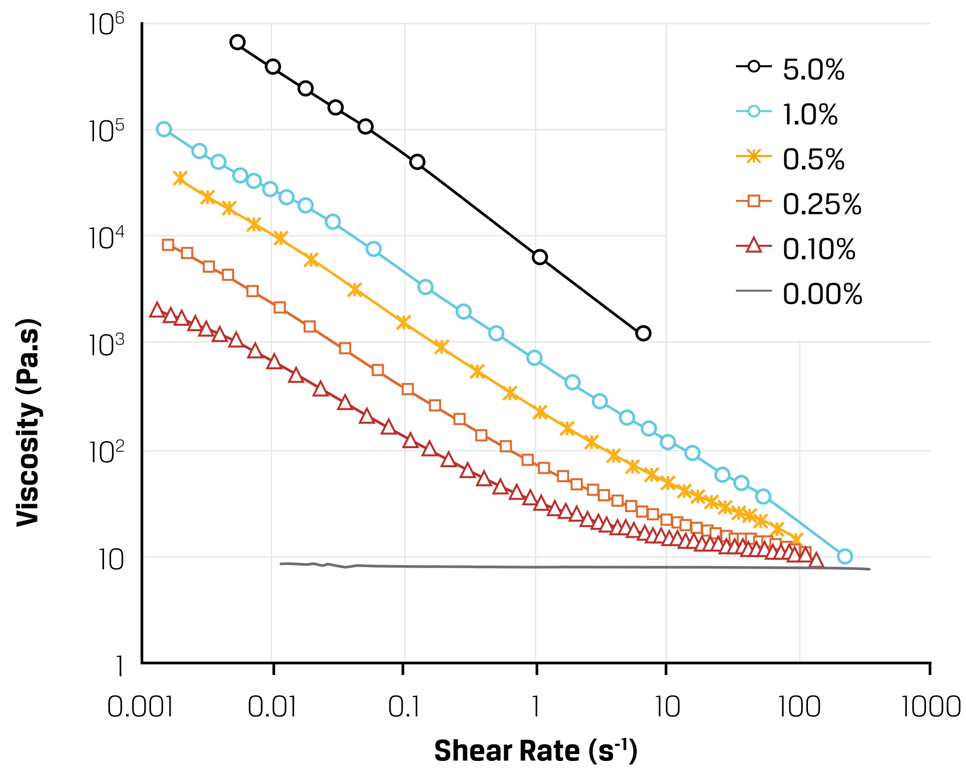

Figure 7: Viscosity of CNS in vinyl liquid silicone without curing agent

For more information about how ATHLOS™ SR1200 CNS can help improve the performance of silicones used in conductive applications, contact your Cabot representative or visit **cabotcorp.com/ATHLOS**

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