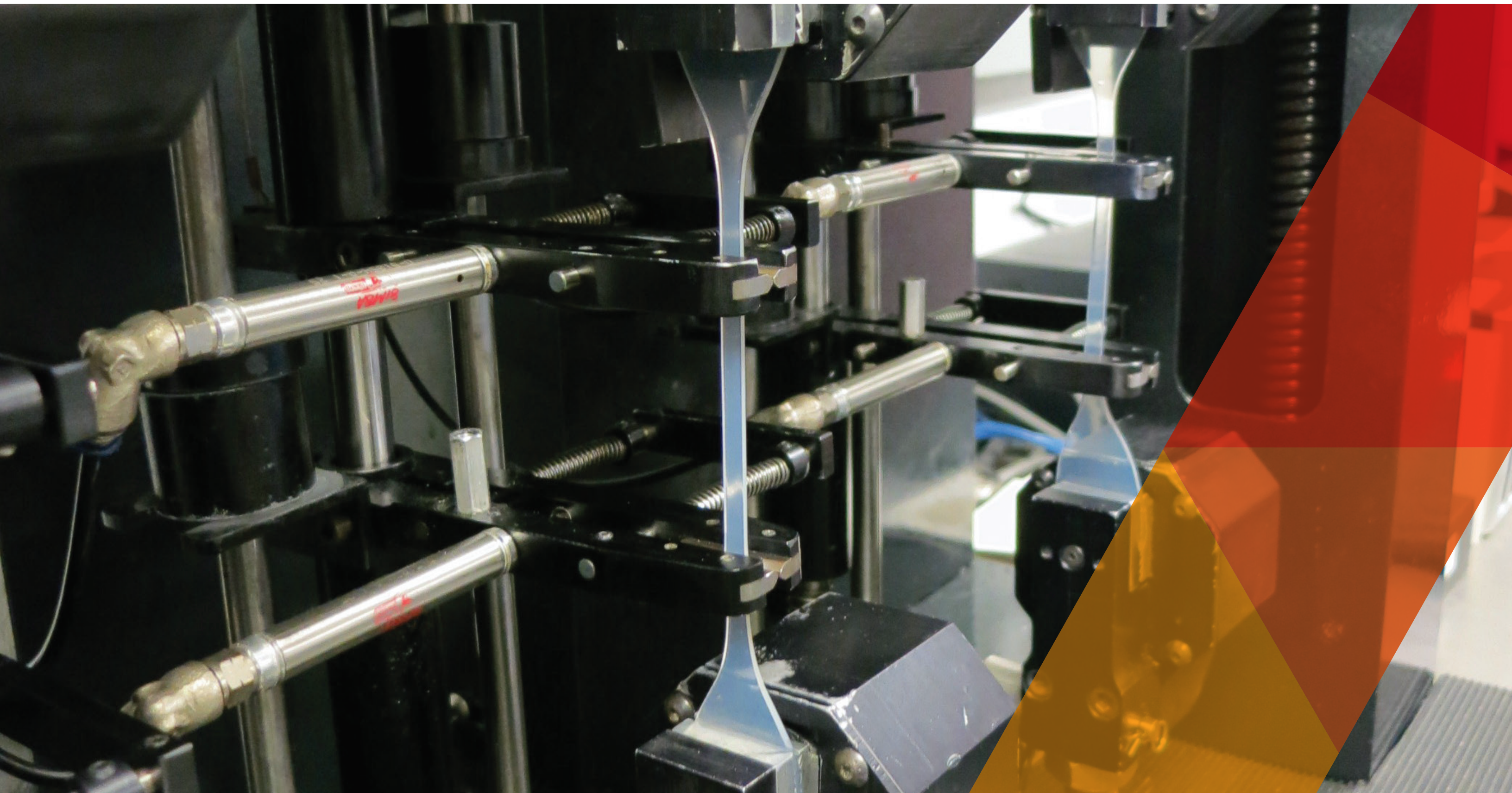
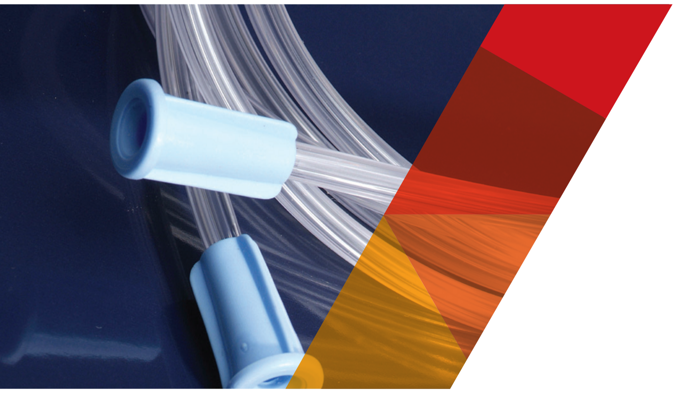
FUMED METAL OXIDES

APPLICATION GUIDE

CAB-O-SIL® Fumed Silica for Silicone Rubber





CAB-O-SIL® FUMED SILICA
FOR SILICONE RUBBER

For more than 50 years, Cabot Corporation has been delivering innovative material to silicone rubber customers. As one of the world's leading providers of performance additives, Cabot is committed to delivering products of the highest quality, consistency, and performance. Our goal is to expand what is possible in silicone rubbers.

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What is Silicone Rubber?

Silicone rubbers are high performance polymeric materials. The unique molecular structure of the silicone polymers, their interaction with reinforcing particles, and their crosslinking chemistry allows for formulations that can be tailored for a variety of applications. Silicone rubber's broad range of physical properties enable it to be used in virtually every industry, including aerospace, automotive, medical, biotechnology, renewable energy, electronics, building and construction, textiles, oil and gas, personal care, and coatings.

CAB-O-SIL Fumed Silica in Silicone Rubber Improves Mechanical Strength

High Temperature Vulcanized (HTV) silicone rubber and Liquid Silicone Rubber (LSR) possess strong mechanical properties in the elastomer product space for use in compression molding, extrusion and injection molding. However, even when cross-linked, the silicone polymer network is mechanically weak relative to many other elastomer systems. To remedy this, CAB-O-SIL fumed silica is incorporated into the polymer for mechanical reinforcement purposes.

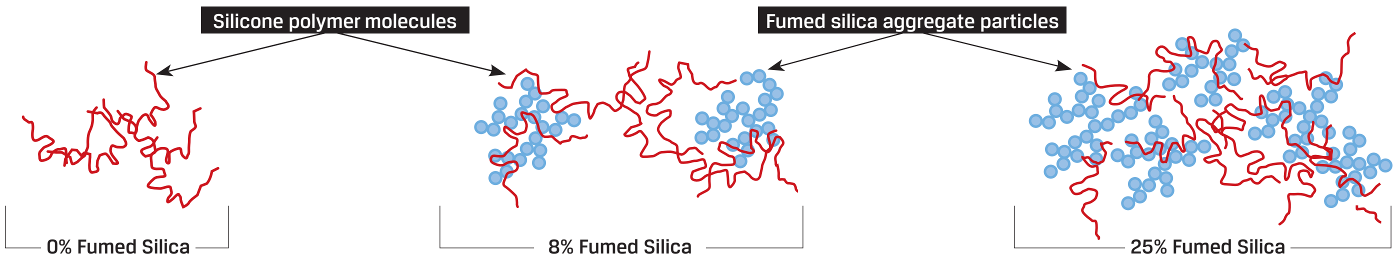
Final silicone rubber properties are influenced by:

- Base silicone resin choice
- Degree of crosslinking
- Type of fumed silica used
- Type and degree of fumed silica surface treatment
- State of silica dispersion

The Effect of CAB-O-SIL Fumed Silica Loading Level on Mechanical Reinforcement

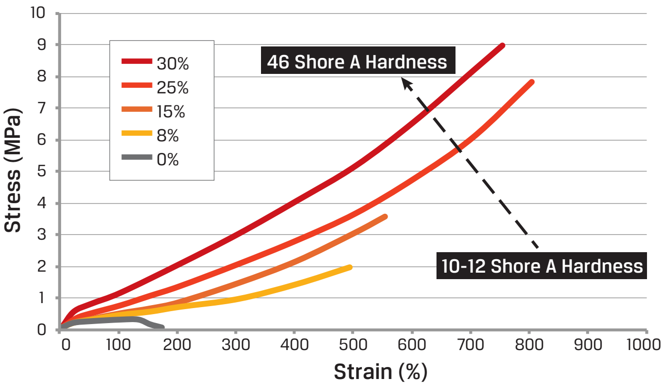
Polymer entanglement with the fumed silica particles enables greater composite material strength. Higher loadings of fumed silica in the elastomer provide greater tensile properties and hardness (see Figures 1 and 2).

Figure 1: Increasing fumed silica loading increases mechanical reinforcement by maximizing polymer-silica entanglement



Performance of Proxy LSR System with Pretreated CAB-O-SIL Fumed Silica at Various Loadings

Figure 2: Stress-strain behavior of proxy LSR system including CAB-O-SIL TS-530 fumed silica at various loadings in an addition-cured LSR



Properties Improved by Fumed Silica

- Toughness (area under the stress-strain curve)
- Elongation
- Tensile strength and modulus
- Hardness

LSR Proxy Formulation for Pre-treated Fumed Silica

MIXING

Formula	Weight (g)	Amount (%)
72,000 g/mol vinyl silicone fluid	73.4	73
CAB-O-SIL TS-530 fumed silica	25	25
3,000 g/mol hydrosiloxane crosslinker	1.4	1
Inhibitor	0.1	0
Total	**99.9 g**	**100%**

- All silica was pretreated with HMDZ
- Fumed silica was compounded into the silicone with a SpeedMixer™ DAC 150.1 FVZ-K
- Silane : vinyl molar ratio = 2.5
- Amounts are varied to change % silica content

CURE

Component	Weight (g)	Weight (%)
Compound	99.85	100
Platinum-vinyl catalyst complex	0.15	0
Total	**100.00 g**	**100%**

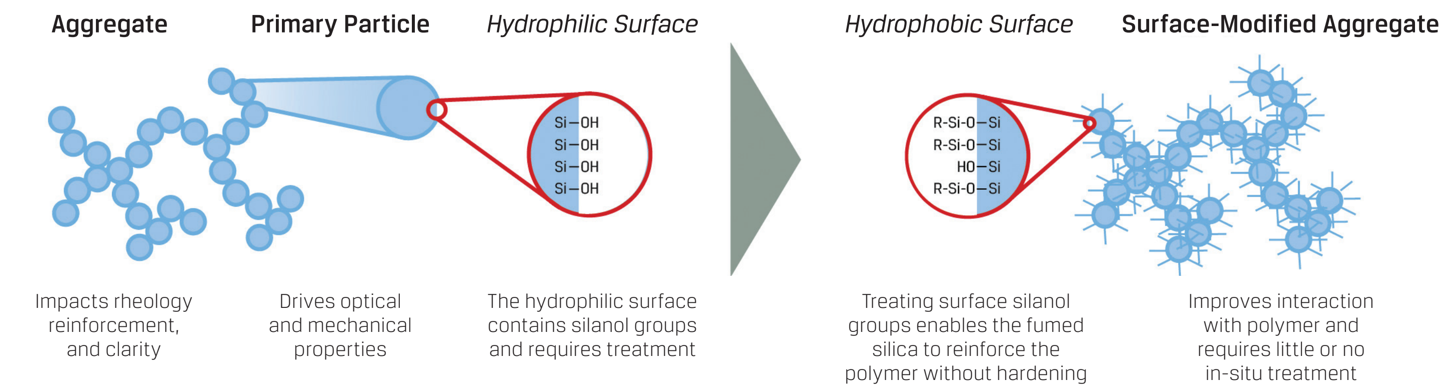
- Platinum catalyst concentration was mixed into the compound with a SpeedMixer™ DAC 150.1 FVZ-K
- Molded at room temperature
- Cured at 150 °C for 40 min. and 200 MPa
- Post cured at 200 °C for 4 hours

The Effect of CAB-O-SIL Fumed Silica Surface Treatment

As shown in Figure 3, treating the fumed silica surface with alkylsilanes maximizes performance by reducing polar interactions between the silicone polymer backbone and native fumed silica surface silanols, which can lead to hardening over time (commonly called crepe hardening). Alkylsilanes can be added during in-situ treatment or as pre-treatment to fumed silica prior to formulating. While in-situ treatment is the most common implementation, the benefits of pre-treatment include:

- Simplified processing and reduced batch time
- Safer operation (minimal hazardous off-gases generated)
- Improved mixing and more uniform silica surface treatment
- Improved product consistency and performance after aging

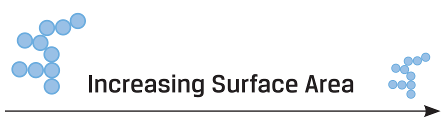
Figure 3: Features of the Fumed Silica Particle



Note: R denotes alkyl (hydrocarbon) groups. The most common material used for both in-situ treatment and pre-treatment is hexamethyldisilazane (HMDZ).

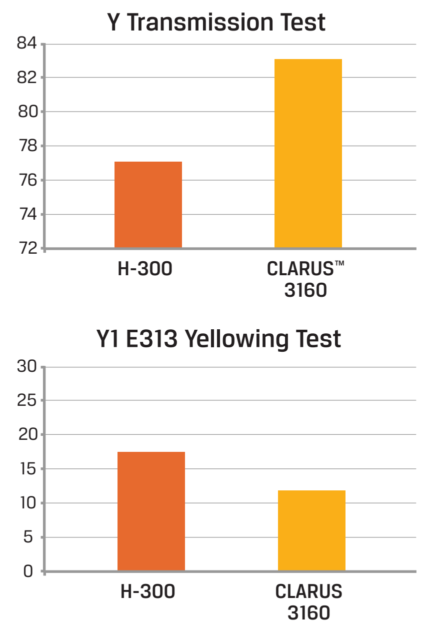
The Effect of CAB-O-SIL Fumed Silica Particle Size and Surface Area

Well-dispersed, smaller particles with higher specific surface areas typically offer better clarity and resistance to yellowing with similar mechanical properties.



Figures 4 & 5: LSR and HTV performance properties as a function of surface area

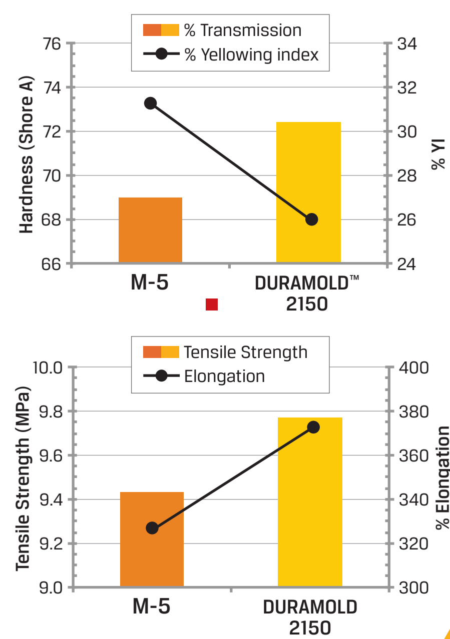
LSR Optical Properties with Sample CAB-O-SIL Fumed Silicas



For LSR
CAB-O-SIL fumed silica surface area:
H-300 < CLARUS 3160

For HTV
CAB-O-SIL fumed silica surface area:
M-5 < DURAMOLD 2150

HTV Mechanical and Optical Properties with Sample CAB-O-SIL Fumed Silicas



Data generated using the formulations on the following page.

Sample Formulations

In-Situ Treated LSR Proxy Formulation

FORMULA: BASE

Component	Weight (g)	Amount (%)
10,000 cP vinyl PDMS	1000	55.94
Fumed silica (BET 400 m^2/g)	600	33.57
HMDZ	150	8.39
Water	37.5	2.10
Total	**1787.5 g**	**100%**

- A Kneader® NHZ-5 internal mixer was used
- Ratio of HMDZ to fumed silica surface area was held constant

LETDOWN

Component	Weight (g)	Amount (%)
10,000 cP vinyl PDMS	111.48	18.58
Fumed silica (BET 400 m^2/g)	31.44	5.24
Base compound	457.08	76.18
Total	**600 g**	**100%**

- Fumed silica loading = 28.6%
- Letdown was mixed in a Ross PDM-0.5 planetary mixer

CURE

Component	Weight (g)	Amount (%)
Compound	150	99.0
H-oil (1.5%) hydrosiloxane crosslinker	1.1	0.73
Platinum catalyst	0.4	0.28
Inhibitor	A/R	A/R
Total	**151.5 g**	**100%**

- Crosslinker, inhibitor and catalyst added to Ross PDM-0.5 planetary mixer
- Molded at room temperature
- Cured at 150 °C for 500 seconds at 20 MPa
- Post cured at 200 ºC for 4 hours

In-Situ Treated HTV Proxy Formulation

STAGE 1: COMPOUNDING

Component	Weight (g)	Amount (%)
600 kg/mol methylvinyl silicone gum (0.1% vinyl)	500	31.6
600 kg/mol methylvinyl silicone gum (0.2% vinyl)	500	31.6
MethylHydrosiloxane-Dimethylsiloxane (1.6% hydride)	4.3	0
Fumed Silica (e.g. M-5)	500	31.6
Treating agent: OH terminated PDMS (8.5% OH groups)	75	4.7
Zn-stearate (release aid)	1.4	0
Total	**1580.7 g**	**100%**

- A Kneader NHZ-5 internal mixer was used
- Adjustments were made for different surface areas: DURAMOLD™ 2150 fumed silica requires 75 g hydroxyl silicone oil

STAGE 2: MILLING

Component	Weight (g)	Amount (%)
Compound (masterbatch)	200	99
Peroxide catalyst complex	2	1
Total	**202 g**	**100%**

- A Wujing Xiechang X(S)K-160 two roll mill was used to disperse the peroxide initiator

STAGE 3: CURING

- Molded at room temperature
- Cured at 170 °C for 10 minutes at 20 MPa
- Post cured at 200 ºC for 4 hours

The Effect of Mixing Rate and CAB-O-SIL Fumed Silica Treatment Level on Mechanical and Optical Properties in LSR

Results Summary

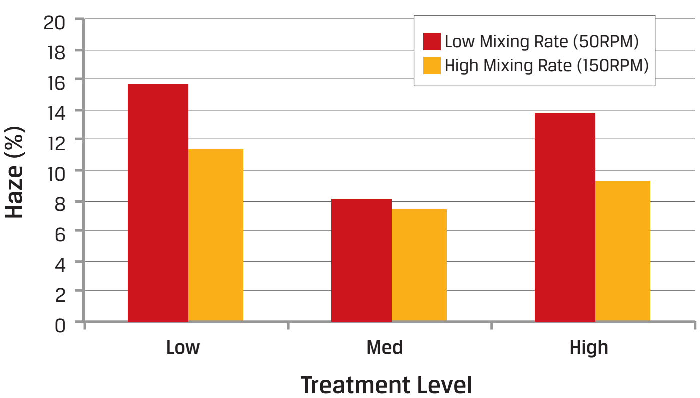
In general, medium treatment levels and higher mixing rates lead to a better balance of optical and mechanical properties

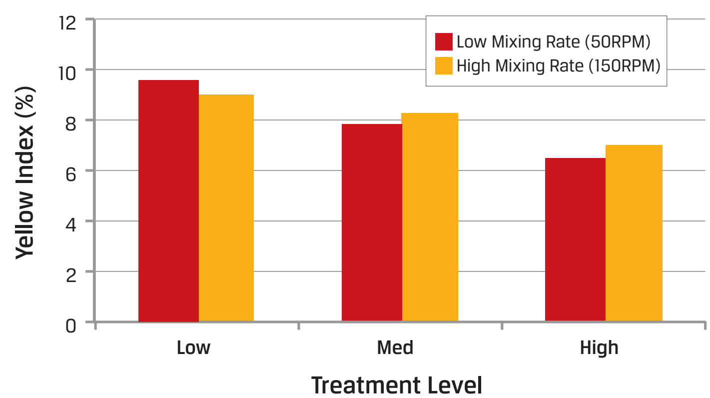
- **Mixing rate:** Higher mixing rate typically yields better dispersion, and therefore higher clarity (lower haze) and greater elongation, but potentially lower hardness
- **Treatment level:** Generally, lower HMDZ treatment levels lead to higher hardness, increased haze (reduced clarity) and lower elongation

	Fumed Silica Treatment Level			Mixing Rate	
LSR Properties	**Low**	**Med**	**High**	**Low**	**High**
Haze	○	●	○	○	●
Yellowing	○	◐	●	◐	◐
Hardness	○	●	◐	●	◐
Tensile strength	◐	◐	◐	●	○
Elongation	○	●	◐	○	●
Net Summary	○	●	◐	◐	●

● Improvement ◐ No Change ○ Worsened

Optical Properties





Haze

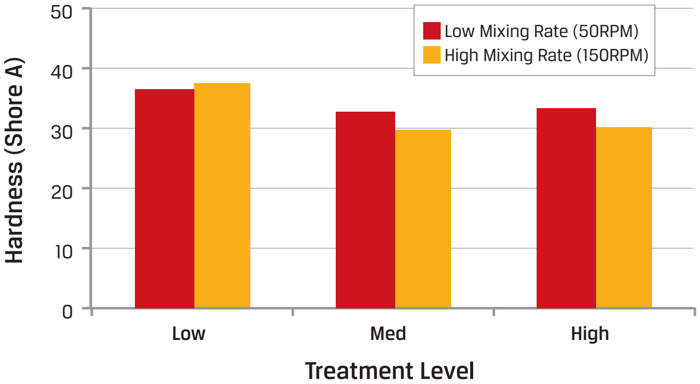
- **Mixing rate:** Higher mixing rates show improved dispersion in this study, reducing haze
- **Treatment level:** Medium treatment levels are best relative to low treatment level and provided the lowest haze in this study

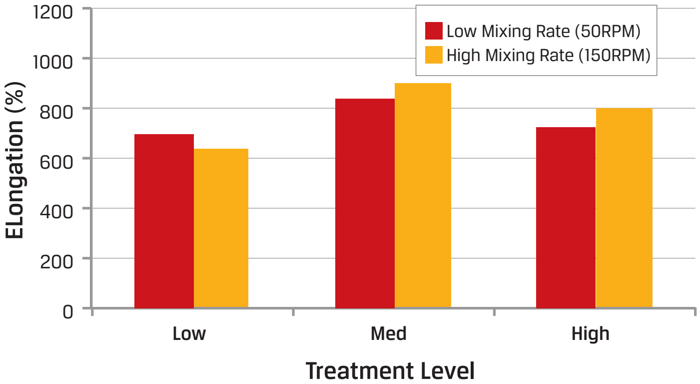
Yellowing

- **Mixing rate:** Greater mixing rates show improved dispersion in this study, exposing more surface area, which may lead to more yellowing. In general, lower mixing rate exposes less surface area, which may lead to less yellowing
- **Treatment level:** Increasing treatment level can improve polymer/particle interaction and may improve stability over time, reducing yellowing

Note: Formulation and mixing details for this study is on the following page.

Mechanical Properties



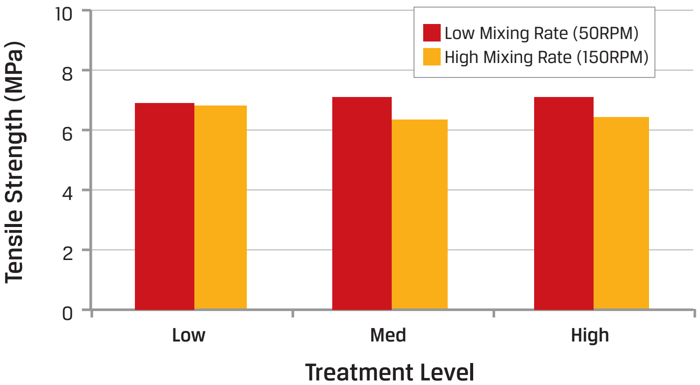


Hardness

- Mixing rate: Higher mixing rates can improve dispersion, reducing hardness, which can be detrimental to performance (e.g. crepe hardening)
- Treatment level: Lower treatment levels can lead to higher hardness

Elongation

- Mixing rate: Higher mixing rates can yield better dispersion, which increases elongation
- Treatment level: Higher treatment levels can improve dispersion by reducing silicone-particle interactions to yield greater elongation



Tensile strength

- Mixing rate: Low mixing rates resulted in higher tensile strength likely due to more extensive silica networks that can more effectively reinforce the silicone.
- Treatment level: Tensile strength was relatively insensitive to treatment level

LSR Proxy Formulation

The formulation used for the study on the effect of mixing rate and treatment level was the same as the LSR proxy formulation used on page 3, with a few key changes:

- A different mixer was used to enable greater control over mixing rate. The mixer was a Haake™ Rheocord PolyLab 300p System with a rheomix 3000P head, which was run at either:
  – Low mixing rate: 50 RPM
  – High mixing rate: 150 RPM
- The fumed silica used had a 400 m^2/g nominal surface area, and was pretreated at different levels:
  – Low: 8.5 g HMDZ / 50 g fumed silica
  – Medium: 12 g HMDZ / 50 g fumed silica
  – High: 20 g HMDZ / 50g fumed silica

Global Capability, Local Relationships

With five fumed silica manufacturing sites around the world, Cabot is a leading global producer of fumed silica. In addition, Cabot has invested in R&D and applications development facilities in the Americas, Europe, and Asia to better tailor products to meet specific regional requirements. At Cabot, we provide support during all phases of the product lifecycle, wherever our customers may be.

Whether your silicone elastomers application requires transparency, controlled extrusion rate, extreme mechanical properties, or specific viscosity attributes, Cabot technical specialists will help you select the appropriate product for your application.

For more information, please go to cabotcorp.com or contact your local Cabot representative.

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