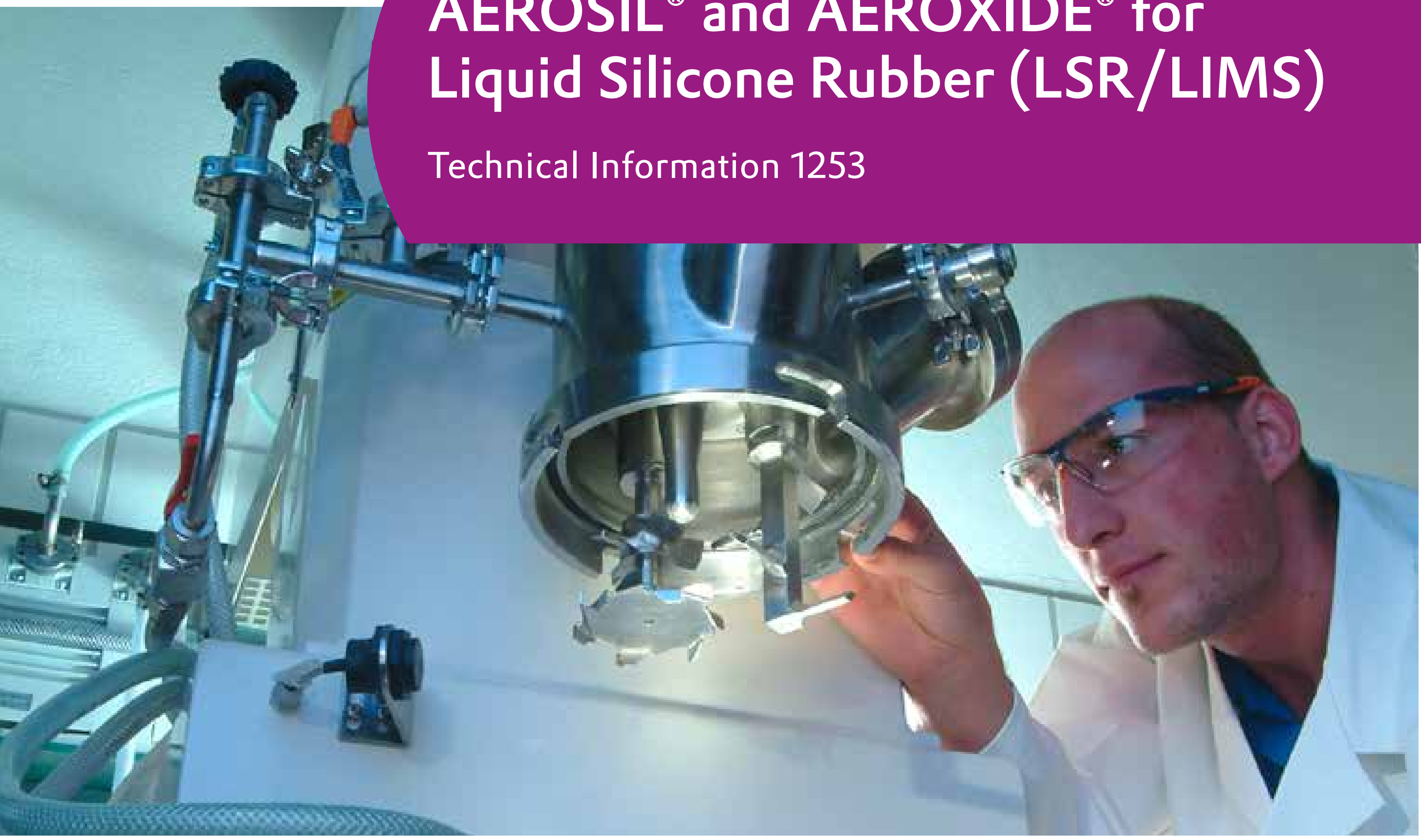
AEROSIL® and AEROXIDE® for Liquid Silicone Rubber (LSR/LIMS)

Technical Information 1253



Evonik. Power to create.

We would like to express our gratitude to the following firms for providing us with photographic material:

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NETZSCH Feinmahltechnik GmbH
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1 Introduction

Synthetic silicas from Evonik Industries AG have been known for many years in the silicone industry. Both fumed and precipitated silicas are used to control the properties of silicone rubber.

The fumed silicas, in the form of different hydrophilic and hydrophobic AEROSIL® products, are applied in numerous silicone systems (see **Figure 1**).

For example, as effective thixotropic additives, they control the viscosity and stability of uncured silicone sealing compounds. Their efficiency as reinforcing component also positively affects the mechanical properties of the different silicone products. The use of special AEROSIL® grades even makes it possible to manufacture products with excellent optical properties (transparency).

Manufactured by flame hydrolysis of chlorosilanes, and with a silicon dioxide content of more than 99.8 %, AEROSIL® is one of the purest silicas commercially available. These inorganic substances, which are completely amorphous, fulfill all consumer requirements regarding reliable, physically safe raw materials.

Metallic oxide AEROXIDE® TiO_2 P 25 from Evonik is also manufactured using the well-known AEROSIL® process. AEROXIDE® can be used in silicone rubber to improve the heat stability.

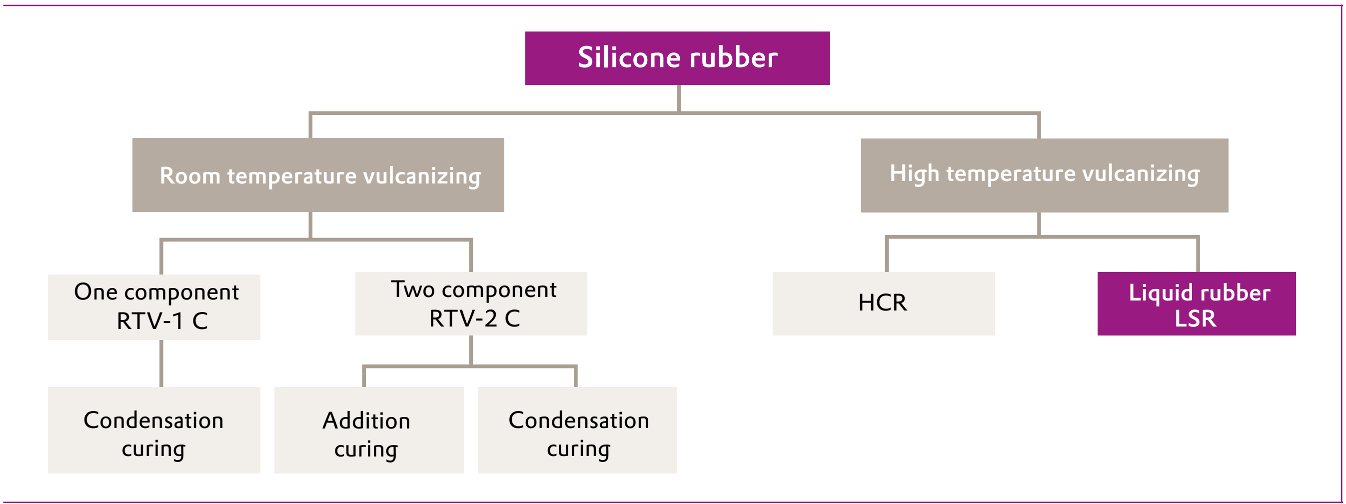
In this Technical Information brochure, we would like to present the properties of hydrophilic and hydrophobic grades of AEROSIL®, and of AEROXIDE® TiO_2 in liquid silicone rubber applications. A series of new and innovative experimental products for this growing silicone application are currently undergoing trials, making it necessary to revise this present Technical Information fairly soon. In the event of further questions, please feel free to contact our team of specialists at any time.

1.1 Liquid Silicone Rubber (LSR/LIMS) – A material of growing significance

Addition cross-linking liquid silicone rubber (**LSR**) was developed at the end of the 1970's by Dow Corning. Liquid silicone rubbers have become increasingly important over the past few years, as a result of their good material and processing properties. Due to their fluid consistency and short cross-linking times, a high rate of productivity can be achieved with high-speed, automatic, environmentally-friendly processing methods using liquid injection molding systems (**LIMS**). The changeover in production from compression molding to automatic processing is an economic factor requiring serious consideration. The result would be a tangible reduction in the piece price. Here are some of the most significant fields of application:

- Construction of automobiles and other vehicles
- Electronics and electrical engineering
- Human and food sector
- Medical technology
- Sanitary and household goods

Figure 1 Overview of the different silicone cross-linking systems



Consequently, fields of application for LSR products are to be found in almost all branches of industry. Some important products, for example, are keypads, seals and gaskets, insulators in high voltage technology, and baby bottle nipples.
Due to the fact that the material can be sterilized and displays good biocompatibility properties, it is also used in numerous medical applications. The spectrum of building components ranges at present from small and precision parts weighing less than 0.05 g per piece, and produced in large quantities, to high-volume components of up to 80 kg in weight, manufactured in small or medium-sized series.

The diversity of suitable applications is currently undergoing a new revolution. Thanks to the two-component or dual color injection molding technology now available for use with liquid silicone rubber, it is also possible to bond plastics with silicone rubber in one working step.

1.2 Components of the LSR system

LSR is made up of a two-component system, whose components A and B generally require mixing in a ratio of 1:1. They consist of polysiloxane polymers or copolymers, containing active or inactive fillers and additives. Prior to vulcanization, LSR is a mixture of silicone polymers containing vinyl groups and a cross-linking component with Si-H groups.

Their consistency and cross-linking behavior allow excellent processibility. Their viscosity is very low compared to that of solid silicone rubber (HCR). In a resting state, they have paste-like characteristics. Vulcanization works on the mechanism of hydrosilation. The result of this chemical reaction is a highly elastic, three-dimensional network with excellent mechanical, electrical, and optical properties. Unlike with peroxide curing, no by-products are released during the vulcanization of LSR compounds. Good storage stability is achieved by the use of inhibitors and the right choice of silica.

1.3 Processing of LSR

The much faster vulcanization process, compared to peroxide curing, is a deciding factor for the processing. Short cycles mean lower piece prices. Generally, the injection molding of LSR is fully automatic. As **Figure 2** shows, components A and B are metered during production at room temperature, together with a pigment paste or other additives, if required, from a dosing apparatus into a static mixer, and subsequently injected into a hot mold. During the dwell time in the hot mold, the mixture cures to a solid, elastic component, which may be extracted by means of an automatic handling system, or manually, after the mold is opened.

The cycle times obtainable with liquid silicone rubber vary between a few seconds and several minutes. In order to release volatiles, and to bring about a more complete vulcanization, the molded parts can be then postcured at about 200 °C. In many cases, a curing time of four hours is sufficient for this.

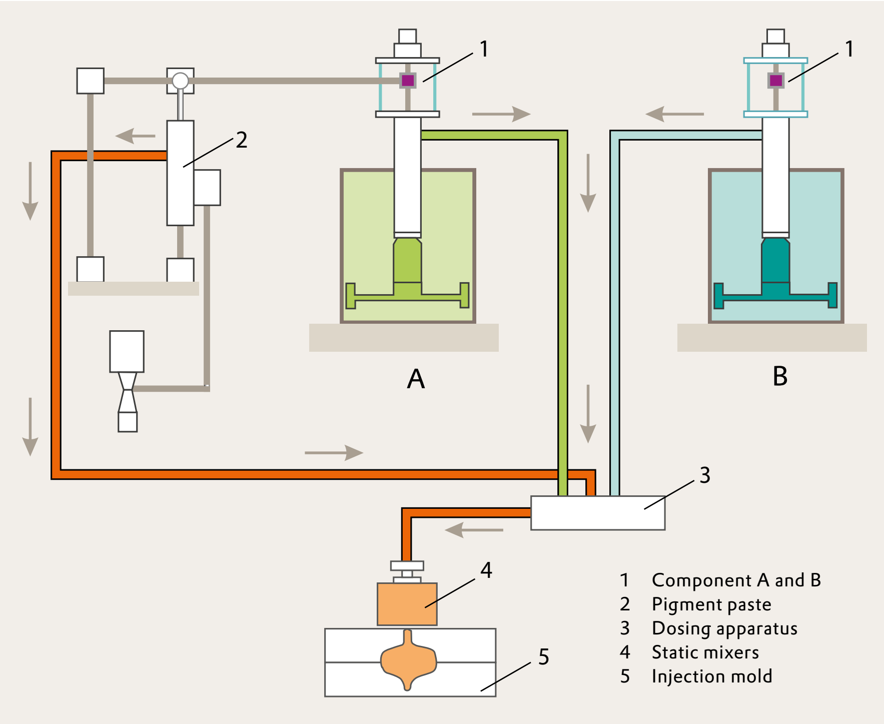


Figure 2 Operating diagram of an injection molding machine for processing LSR

2 The high requirements made on silicas from Evonik during the production of LSR compounds, and during the processing and application of LSR products

The high standards are not just expected of the silicas during the production of the LSR compounds, but also during the processing of the finished compounds using injection molding technology (see **Figure 3**). The challenge issued to the silica is to provide very high mechanical properties in the finished product and the lowest rheological properties in the compound – a somewhat contradictory demand in itself! Top quality LSR products requiring a high level of mechanical and optical properties (transparency), are produced exclusively with fumed silicas. Precipitated silicas may also be used in certain applications requiring dynamic properties, for example in keypads made of silicone rubber.

Demands on the silica in different LSR products

- Very good mechanical properties (e. g. hardness, tensile strength, resistance to tear)
- Excellent optical properties (e. g. highly transparent baby bottle nipple)
- Very good dynamic properties (low compression set, e. g. for key pads)
- Good electrical and dielectric properties (e. g. for insulators)
- Excellent physiological compatibility (e. g. in medical applications)
- Good temperature resistance (e. g. molds for baking or ice cubes)

Figure 3 LSR injection molding machine; Manufacturer: ARBURG GmbH + Co., Lossburg, Germany

Demands on the silica during the production of LSR

- A high degree of purity (no metallic contamination)
- Good storage stability (low moisture adsorption)
- Rapid incorporation behavior
- Good and rapid dispersibility
- Minimal thickening, i. e. very low level of rheology at high levels of loading

Demands on the silica in the LSR compound and during the processing of LSR

- Good level of rheology (low viscosity)
- Good flow properties (low yield point)
- Good storage stability (no subsequent thickening)

Figure 4 Highly transparent bottle nipple made of LSR for baby food

3 The production and properties of fumed grades of AEROSIL®

3.1 Production

AEROSIL® is a synthetic, amorphous silicon dioxide manufactured by hydrolysis of chlorosilanes in an oxyhydrogen flame, in accordance with the reaction formula **$SiCl_4 + 2H_2 + O_2 \rightarrow SiO_2 + 4\,HCl$**. The production process was patented by DEGUSSA back in 1942, used for largescale manufacturing in the 1950's, and has been continuously developed ever since. AEROSIL® is classified as a fumed silicon dioxide or fumed silica, due to the process of flame hydrolysis used in its production, and is also described as a finely-divided silicon dioxide, due to the small size of its particles.

High degree of purity

The raw materials used are entirely of chemical origin and are very pure. With its SiO_2 content of more than 99.8 % by weight (related to the ignited substance), AEROSIL® is one of the purest silicas commercially available. The heavy metal content lies below the detection limit of standard methods of analysis. Neither animal- nor plant-based raw materials are used in the manufacture of AEROSIL®, and neither are solvents. The AEROSIL® process is used by Evonik to manufacture fumed titanium and aluminum oxides, together with a variety of mixed oxides.

Diversity of product modifications

The properties of AEROSIL® may be greatly varied. For example, the specific surface of AEROSIL® OX 50 is only 50 m^2/g, whereas that of AEROSIL® 380 is almost eight times as much. The surface and structure of AEROSIL® may be modified in many different ways, to suit the requirements for modern silicone rubber products. For instance, dimethyl silyl, trimethyl silyl, or siloxane groups may be chemically anchored on the AEROSIL® surface by means of chemical reaction with organic silicon compounds. Examples of surface-modified products are AEROSIL® R 972, AEROSIL® R 812 S and AEROSIL® R 202. AEROSIL® R 8200 is a structurally-modified product that was developed specially for the applications LSR and RTV-2 component. Special fumed silicas in beaded form are available from Evonik under the trade name AEROPERL®.

3.2 Properties

Finely-divided Structure

AEROSIL® is a fine, white, amorphous powder, made up of primary particles ranging from approx. 7 to 40 nm in size – depending on the specific surface of the product. The primary particles are not present in an isolated state, but are clumped together as stable aggregates, which may be several hundred nanometers in size. These aggregates group together to form agglomerates in the micrometer range that readily disintegrate during application.

Hydrophilic and hydrophobic grades of fumed silica

Silanol and siloxane groups are situated on the surface of untreated AEROSIL®. As a result of these, AEROSIL® has a strong affinity with water – it is hydrophilic – and may be totally wetted. AEROSIL® 200, for instance, is able to adsorb considerable quantities of water. This does not change its aggregate state: it remains a free-flowing powder. By converting the silanol groups with silanes or siloxanes, as described above, alkylsilyl-groups become chemically anchored on the surface. The resulting products now repel water – they are hydrophobic – and adsorb only very small quantities of water. These products are labeled with the suffix "R" (R = repellent), e.g. AEROSIL® R 812 S.

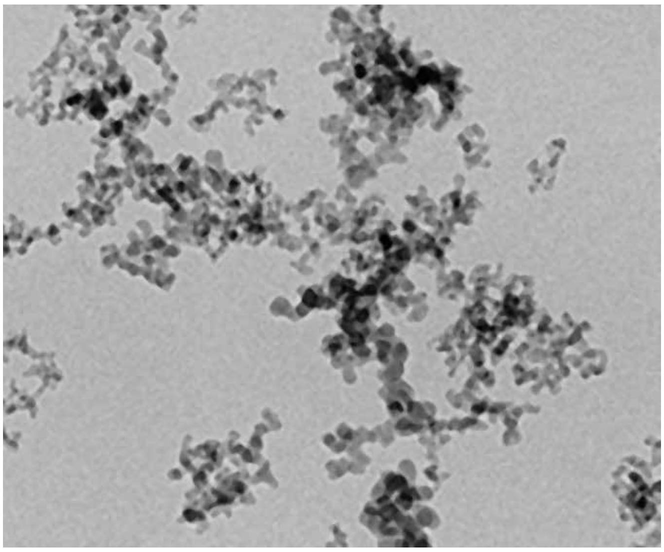


Figure 5 TEM of AEROSIL® 200

Figure 6 Behavior of AEROSIL® 200 (left) and AEROSIL® R 812 S (right) in the presence of water. AEROSIL® 200 may be readily dispersed in water, whereas AEROSIL® R 812 S is not wettable and floats on the surface of the water.

Table 1 Physico-chemical properties

		AEROSIL®			
Test method	200	300	380	R 812 S	R 8200
Behavior in the presence of water	hydrophilic			hydrophobic	
Appearance	loose white powder				
Surface[1] acc. to BET m²/g	200 ± 25	300 ± 30	380 ± 30	220 ± 25	160 ± 25
Tamped density[2] approx. value g/l	50	50	50	60	140
Loss on drying[3] (2 hours at 105 °C) on leaving the production plant %	≤ 1.5	≤ 1.5	≤ 2.0	≤ 0.5	≤ 0.5
pH value	3.7–4.5	3.7–4.5	3.7–4.5	5.5–9.0[6]	≥ 5.0[6]
C content %	–	–	–	3.0–4.0	2.0–4.0
SiO_2 content[5] %	≥ 99.8	≥ 99.8	≥ 99.8	≥ 99.8	≥ 99.8

[1] in acc. to DIN ISO 9277
[2] in acc. to DIN EN ISO 787-11
[3] in acc. to DIN EN ISO 787-2
[4] Water: methanol = 1:1
[5] related to the substance ignited for 2 hours at 1000 °C

The data have no binding force.

4 The production of LSR systems

A variety of kneaders and other mixers with high shearing action are used to produce LSR compounds. **Figure 7** shows a planetary dissolver, Type PMH 1400 from the company Netzsch Feinmahltechnik GmbH, Germany, with a usable volume of 1400 liters, as used on a production scale. Basically, LSR compounds can be manufactured using hydrophilic and/or hydrophobic silicas. Mixers and silicas should be chosen according to the method of production used. In principle, there are two different manufacturing options: these are briefly described in the following section.

Figure 7 LSR planetary dissolver, production scale, 1400 l; Manufacturer: Netzsch Feinmahltechnik GmbH, Selb, Germany

4.1 Compounding by means of the "in situ" hydrophobizing of hydrophilic silicas

The so-called "in situ" hydrophobizing of hydrophilic silicas, combines several processing steps. This involves the loading of batches containing different LSR polymers and/or silicone oils with hydrophilic silicas. These highly viscous raw compounds are then blended using mixers with strong shearing action. The mixing process is carried out at a high temperature. At the same time, the hydrophilic silica, is rendered hydrophobic "in situ" by the addition of silanes (e.g. Dynasylan® HMDS), i.e. the silanol groups on the surface of the silica react with the silane used. This causes the silica to become extremely hydrophobic and, due to the strong shearing action, it also undergoes structural modification at the same time. Outstanding flow characteristics, combined with excellent mechanical and optical properties, can be obtained in this way, after the LSR batch has been cut back to the desired level of silica loading using a pure polymer.

In addition to the know-how required to carry out this complex process, large investments in special equipment and mixing aggregates are necessary. High energy costs are also incurred, due to the necessary processing temperatures of up to 200 °C, and the relatively long batch times (approx. 4 hours). A further major disadvantage of this compounding method is the release of reactive by-products that require proper disposal.

4.2 Compounding with hydrophobic silicas

In order to offer an alternative to the compounding method described above, with its "in situ" hydrophobizing, we would like to give you a closer look in this Technical Information brochure at two special products made by Evonik. These hydrophobic grades of AEROSIL® make it possible to simplify the compounding process based on the LSR formulation.
By using the hydrophobic grades AEROSIL® R 812 S and AEROSIL® R 8200, it is possible to dispense with the "in situ" technology described in **Chapter 4.1**. The effects obtainable with these hydrophobic products are summarized below. Detailed results are described in **Chapter 5**.

AEROSIL® R 812 S

By means of a special modification, trimethylsilyl groups are chemically anchored on the surface of this fumed silica. AEROSIL® R 812 S can be used in LSR without the use of processing additives, such as hexamethyldisilazane (Dynasylan HMDS). The very hydrophobic nature of AEROSIL® R 812 S enables rapid incorporation and dispersion of the silica in the LSR polymer. Vulcanisates of unusually high transparency can be produced with this silica.

AEROSIL® R 8200

AEROSIL® R 8200 was specially developed for the application LSR and can also be incorporated without the use of processing additives. Special modification has also left this fumed silica with trimethylsilyl groups chemically anchored on the surface. AEROSIL® R 8200 is not merely very hydrophobic, but has been structurally modified by means of an additional processing step.

This silica is characterized by its very low thickening effect even when high levels of loading are used. Hence, it is possible to produce easily dispersible compounds with very good flow properties by using AEROSIL® R 8200. Based on its special structural modification, high levels of loading produce excellent mechanical properties, together with very low levels of viscosity, and good storage stability. The relatively high tapped density of approx. 140 g/l, and comparatively low BET surface of 160 m^2/g, enable a very rapid incorporation of AEROSIL® R 8200 in polymer systems.

Advantages of compounding with hydrophobic silicas:

- No "in situ" hydrophobizing necessary
- Low investment costs (mixers and safety equipment)
- Savings in the cost of raw materials, as no silanes are needed
- Savings in energy costs, as no high temperatures are needed
- Environmentally-friendly processing, as no by-products (ammonia) are released
- Rapid incorporation of the silica is possible, resulting in short batch times and capacity expansion
- Continuous production of LSR possible
- Production site can be independent of location

5 The effects of different grades of hydrophobic AEROSIL® in an LSR formulation

In order to test the technical application properties of various hydrophobic grades of AEROSIL®, planetary dissolvers (see **Figure 11**) were used to produce a variety of LSR mixtures on a laboratory scale, that were subsequently cured. Detailed information on the formulation used, together with the test procedure, is given in the experimental section (**chapter 6.1**).

The following technical application properties were determined: the time required to incorporate the silica, the rheological properties (viscosity and yield point), the mechanical properties of the vulcanisates (hardness, resilience, tensile strength, resistance to tear propagation and elongation at break), and the optical properties (transparency). The individual results will be presented and discussed in the following chapter. Two ready-to-use two-component LSR products were used as reference materials.

5.1 Rheological properties of the uncured LSR compounds

As the name of this application **LSR** (**L**iquid **S**ilicone **R**ubber) implies, the rheological properties of these systems are of elementary primary significance. A low level of rheology is required during the processing of the LSR compounds, i. e. low levels of viscosity combined with good flow properties (low yield points).

The length of time needed for incorporation is additionally important for the processing of the silica. **Table 2** shows the required incorporation times, the viscosities, and the yield points of various compounds based on differing levels of loading of AEROSIL® R 812 S and AEROSIL® R 8200.

Table 2 Rheological properties of the uncured LSR compounds

Silica / Product	Level of Loading [%]	IT/Sil* [min]	Yield Point [Pa]	Viscosity [Pas] D = 10 s^{-1}
AEROSIL® R 812 S	20	12	0	183
AEROSIL® R 812 S	25	20	171	432
AEROSIL® R 812 S	30	28	370	1,050
AEROSIL® R 812 S	35	40	1,800	6,000
AEROSIL® R 8200	20	3	0	34
AEROSIL® R 8200	25	4	0	62
AEROSIL® R 8200	30	5	50	128
AEROSIL® R 8200	35	6	312	340
AEROSIL® R 8200	40	8	1,680	1,530
AEROSIL® R 8200	45	10	5,500	6,000
L 2–4, **Component A**	–	–	52	344
L 2–4, **Component B**	–	–	180	244
L 2–7, **Component A**	–	–	228	372
L 2–7, **Component B**	–	–	380	340

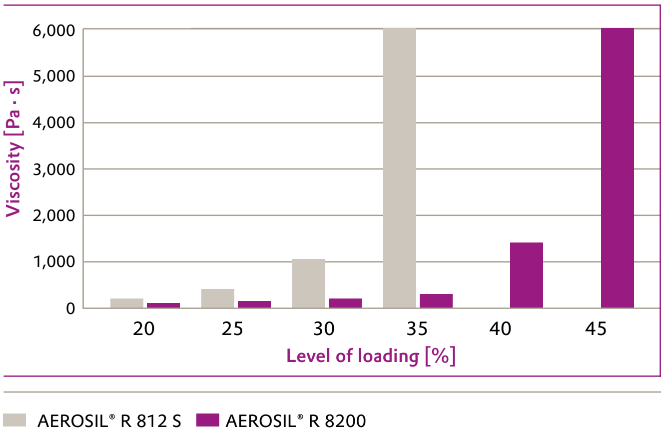
* incorporation time required for silica

The measurement of the rheological properties shows a clear result. When a 20–25 % loading level of AEROSIL® R 812 S is used, the viscosity level and yield point of the compounds are approximately the same as those of the reference material L 2–4.

As illustrated in **Figure 8**, the viscosity and the yield point increase as the level of loading is raised. In order to use a higher level of loading than 35 %, the structure of the silica must be modified.

The results based on AEROSIL® R 8200 demonstrate that higher levels of loading are possible when using a structurally modified product, without negatively influencing the level of rheology. The rheological properties, especially the flow properties, are comparable to those of the reference material L 2–7 when a 35 % loading level of AEROSIL® R 8200 is used.

Figure 8 Viscosity as a function of the loading level



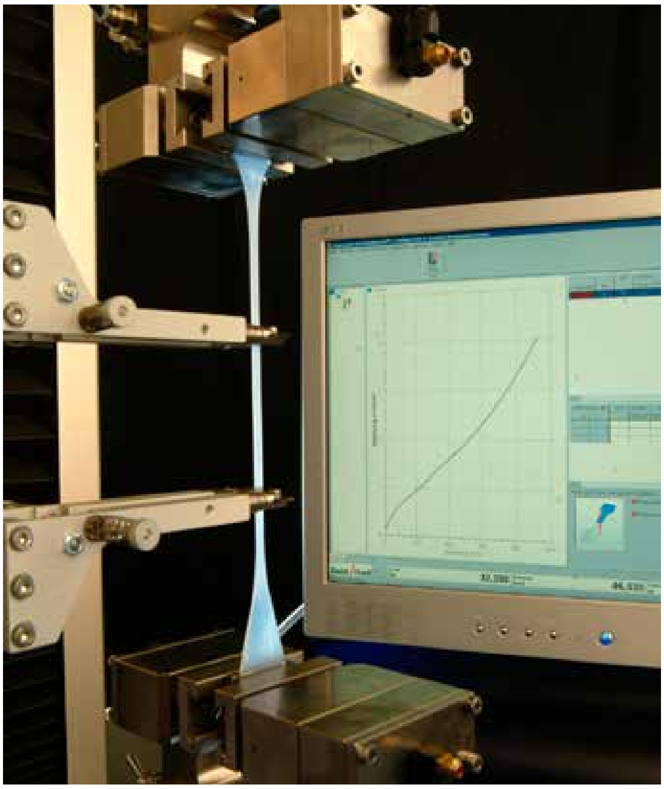


Figure 9 Machine for testing tensile strength; Manufacturer: Zwick GmbH & Co. KG, Ulm, Germany

5.2 Mechanical properties of the cured LSR samples,

The mechanical properties of the cured LSR samples, based on differing loading levels of AEROSIL® R 812 S and AEROSIL® R 8200, are compiled in **Table 3**.

As can be expected, the mechanical properties of the LSR vulcanisates improve as the loading level of silica is increased. Depending on the level of loading, vulcanisate durometer hardness levels (Shore A) of around 40, 50, 60 or 70 were achieved. **Figure 10** clearly demonstrates how the tensile strength improves as the concentrations of AEROSIL® R 812 S and AEROSIL® R 8200 increase.

However of particular interest is the considerable improvement of the resistance to tear propagation with increasing loading level of silica.

Figure 10 Tensile strength in relation to the loading level of silica

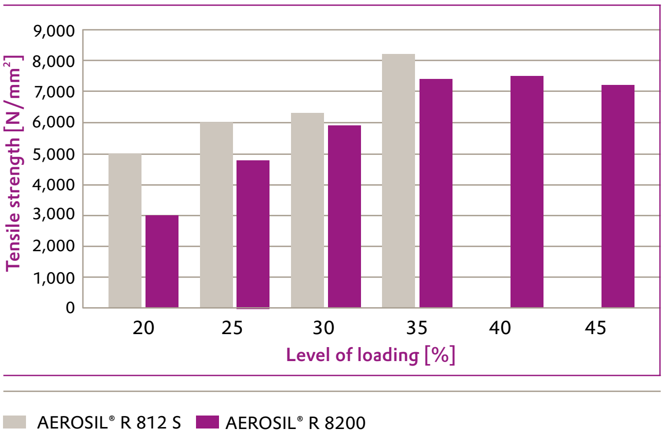


Table 3 Mechanical properties of the cured LSR samples

Silica / Product	Level of Loading [%]	Tensile Strength [N/mm²]	Elongation at Break [%]	Resistance to Tear Propagation [N/mm]	Hardness [Shore A]	Impact Resilience [%]
AEROSIL® R 812 S	20	5.0	350	19	43	59
AEROSIL® R 812 S	25	6.1	350	27	51	53
AEROSIL® R 812 S	30	6.3	300	34	62	50
AEROSIL® R 812 S	35	8.2	280	34	69	46
AEROSIL® R 8200	20	3.1	310	12	36	61
AEROSIL® R 8200	25	4.8	360	20	41	59
AEROSIL® R 8200	30	5.9	380	27	47	54
AEROSIL® R 8200	35	7.4	410	36	53	50
AEROSIL® R 8200	40	7.5	380	37	61	44
AEROSIL® R 8200	45	7.3	240	34	71	37
L 2–4	–	8.1	600	37	45	48
L 2–4	–	8.9	320	44	71	61

5.3 Optical properties of the cured LSR samples

The optical properties of the cured LSR samples based on differing loading levels of AEROSIL® R 812 S and AEROSIL® R 8200, are presented in **Table 4**.

The optical properties of the silicas examined are of a high level throughout. The use of higher loading levels can initially cause a reduction in the transparency of the vulcanisates. A possible explanation for this can be the less effective dispersion, which depends on the small sized lab equipment.

Table 4 Optical properties of the LSR vulcanisates

Silica / Product	Level of Loading [%]	Transparency directly after curing [DE*/D 65]
AEROSIL® R 812 S	20	42
AEROSIL® R 812 S	25	36
AEROSIL® R 812 S	30	39
AEROSIL® R 812 S	35	38
AEROSIL® R 8200	20	37
AEROSIL® R 8200	25	41
AEROSIL® R 8200	30	40
AEROSIL® R 8200	35	41
AEROSIL® R 8200	40	34
AEROSIL® R 8200	45	35
L 2–4	–	54
L 2–4	–	54

6 Experimental section

6.1 LSR formulation and LSR compounding

Liquid silicone rubber is generally a ready-to-use mixture of paste-like or liquid consistency. In practice, the addition curing rubber system consists of two components. In order to test all the relevant technical application properties, it is necessary to produce vulcanisates.

The necessary components A and B were combined into a one-component system in the following formulation to allow better handling on a laboratory scale.

Table 5 LSR base-formulation

Formulation (1000 g batch)	Name (Manufacturer of the component)
60–80 % Silicone polymer	Polymer VS 10.000 (Evonik Hanse GmbH)
20–40 % Silica	AEROSIL® (Evonik Industries AG)

Figure 11 Planetary dissolver;
Manufacturer: Hermann Linden, Marienheide, Germany

First of all, the polysiloxane is placed into a planetary dissolver (see **Figure 11**). The silica is then incorporated at a low rotational speed. Subsequently, this basic mixture is dispersed under vacuum and with water cooling for 30 minutes at a higher velocity speed. The rheological properties can now be determined from this basic mixture (see **Chapter 5**).

Table 6 LSR standard formulation

LSR formulation [350 g batch, Example for 20 % silica]	Proportion [%]	Name (Manufacturer of the component)
Polysiloxane	**77.5**	Polymer VS 10.000 (Evonik Hanse GmbH)
Synthetic silica	**19.4**	AEROSIL® R 812 S (Evonik Industries AG)
Platinum catalyst (10 ppm pure Pt/ECH)	**0.2**	PT-VTS-C 0.522 % in Toluol (Umicore AG & Co. KG)
Inhibitor (340 ppm pure Pt/CH)	**1.7**	1-Ethinyl-1-cyclo-hexanol (Fa. Aldrich) 2 % in Polymer VS 1.000 (Evonik Hanse GmbH)
SiH cross-linking agent	**1.2**	Crosslinker 100 (Evonik Hanse GmbH)

The remaining formulation components were added step by step to the basic mixture in the order given in **Table 5**, and were well homogenized. The compounds were then de-aerated in a vacuum drying cabinet oven.

6.2 Cross-linking and postvulcanization

Cross-linking

In order to produce a variety of LSR vulcanisates for different test purposes, specially prepared plates containing defined amounts of LSR compound were cured in a vulcanization press (see **Figure 12**) for between 10 and 12 minutes, according to the thickness of the vulcanisates, at a pressure of 100 bar, and a temperature of 120 °C

Figure 12 Vulcanization press; Manufacturer: Wickert Maschinenbau GmbH, Landau, Germany

Postvulcanization

The cured compounds released from the mold were then post-cured for 4 h at 200 °C in a convection oven to achieve a total vulcanization, and to remove any volatiles.The mechanical and optical properties were determined (see **Chapter 5**) after the vulcanisates had been stored for 72 h in a standardized climate at 23 °C and 50 % humidity.

7 Heat stabilizer for LSR formulations

As mentioned in **Chapter 1**, the finely divided metallic oxide available from Evonik, AEROXIDE® TiO_2 is also manufactured using the well-known AEROSIL® process.

AEROXIDE® TiO_2 P 25 and AEROXIDE® TiO_2 PF 2 can be used in silicone rubber to improve the heat stability.

7.1 Production and properties of AEROXIDE® TiO_2 P 25

7.1.1 Production

AEROXIDE® TiO_2 P 25 is manufactured by flame hydrolysis of titanium tetrachloride (see **Figure 13**).

The more effective product AEROXIDE® TiO_2 PF 2 is also produced by this method. The addition of FeCl gives a AEROXIDE® TiO_2 mixed with 2 % Fe_2O_3.

AEROXIDE® TiO_2 P 25

$$TiCl_4 + 2\,H_2 + O_2 \rightarrow TiO_2 + 4\,HCl$$

AEROXIDE® TiO_2 PF 2

$$TiCl_4 + 2\,H_2 + O_2 \rightarrow TiO_2 + 4\,HCl$$

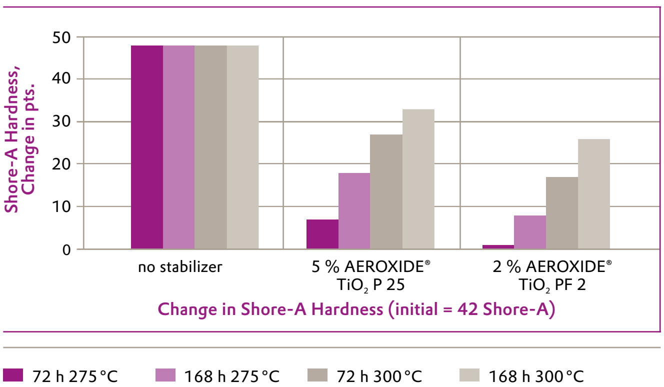
and

$$2\,FeCl_3 + 3\,H_2 + 1.5\,O_2 \rightarrow Fe_2O_3 + 6\,HCl$$

Figure 13 Chemical reaction

7.2 LSR Shore-A Hardness Change during storage at high temperatures

Figure 14 Liquid silicone rubber high temperature resistance



Further information on heat stability properties of our AEROXIDE® products can be found in Technical Information No. 1218.

8 Summary and product recommendations

8.1 Summary

In principle, both hydrophilic and hydrophobic fumed silica are suitable for use in the manufacture of LSR products. The choice of silicas should be made according to the most significant properties for the processing of the LSR compound, such as

- low level of rheology
- good flow properties
- rapid vulcanization behavior
- good storage stability

and the properties that are to be achieved in the corresponding final product, e.g.

- good mechanical properties
- high transparency
- good electrical properties

8.2 Product recommendations

We would like to recommend the following Evonik products for LSR applications:

AEROSIL® 200, AEROSIL® 300, AEROSIL® 380 These fumed silicas are hydrophilic. The BET surface of AEROSIL® 200 is approximately 200 m^2/g, whereas the higher surface areas are displayed by AEROSIL® 300 with approx.
300 m^2/g, and 380m^2/g in the case of AEROSIL® 380. Each of these products is readily dispersible and very well suited for "in situ" hydrophobizing. The favorable reaction behavior of these products with processing additives, such as silanes (Dynasylan® HMDS), results in compounds with very good flow properties, and good storage stability. In addition to the excellent mechanical properties (high tensile strength and high tear resistance), it is possible to achieve cured LSR compounds with a very high degree of transparency. The choice of product depends on the desired rheological level of the LSR compound. Since the viscosity of the compound increases as the BET surface gets bigger, and the transparency of the vulcanisates is also dependent on the size of the active surface, the commitment to a certain product can only be made after a series of tests have been carried out.

AEROSIL® R 812 S

This fumed specialty product has undergone special modification to chemically anchor trimethylsilyl groups on its surface. AEROSIL® R 812 S can be used in LSR without additional processing auxiliaries. This product stands out especially due to its extremely hydrophobic nature, which permits rapid processing (incorporation) and very good dispersibility. Vulcanisates of high transparency can be achieved, due to its relatively high BET surface of approx. 220 m^2/g.

AEROSIL® R 8200

This fumed specialty product also underwent special modification to chemically anchor trimethylsilyl groups on its surface. AEROSIL® R 8200 is not just extremely hydrophobic, it has also been structurally modified by an additional processing step. AEROSIL® R 8200 was developed for use in LSR applications, and is characterized by its very low thickening effect even at high levels of loading. For this reason, it is possible to manufacture compounds with very good flow properties by using AEROSIL® R 8200. Due to its special structural modification, high levels of loading result in very low viscosity, combined with excellent mechanical properties. AEROSIL® R 8200 can be very rapidly incorporated into polymer systems as a result of its relatively high tapped density of approx. 140 g/L and its comparatively low BET surface of about 160 m^2/g.

AEROXIDE® TiO_2 P 25

AEROXIDE® TiO_2 P 25 is a effective heat stabilizer in silicone rubber and is produced by flame hydrolysis of titanium tetrachloride. A financially favorable and effective stabilization up to 250 °C is possible, thanks to the very good results obtainable with a relatively small addition of 0.5 to 3.0 %, related to the total formulation amount.

AEROXIDE® TiO_2 PF 2

The product AEROXIDER TiO_2 PF 2 is also produced by flame hydrolysis of titanium tetrachloride. The addition of $FeCl_3$ gives a AEROXIDE® TiO_2 mixed with 2 % of Fe_2O_3. It is a yellowish white powder and gives excellent heat stability at temperatures > 250 °C. The recommended usage level is 0.5 – 1.5 %, related to the total formulation amount.

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