WACKER

CREATING TOMORROW'S SOLUTIONS

ELASTOSIL®

POWERSIL®

HIGH-PERFORMANCE SILICONES FOR TRANSMISSION AND DISTRIBUTION

WACKER SILICONES
STAND FOR OPERATIONAL SAFETY AND DURABILITY

Thanks to their molecular structure, silicones are the perfect solution for insulating applications in the transmission and distribution sector. For example, silicone composite insulators covered with pollution layers have much lower leakage currents than insulators made of porcelain, glass or EPDM. This prevents pollution flashovers, even if the surface is extremely dirty.

However, not only insulators profit from silicones. Nowadays, silicone insulating materials are used in medium- and high-voltage applications wherever high operational safety and long service lives are required, for example, silicone fluid in transformers or silicone elastomer terminations of high-voltage cables.

60 Years of Research to Ensure Reliable Transmission Networks

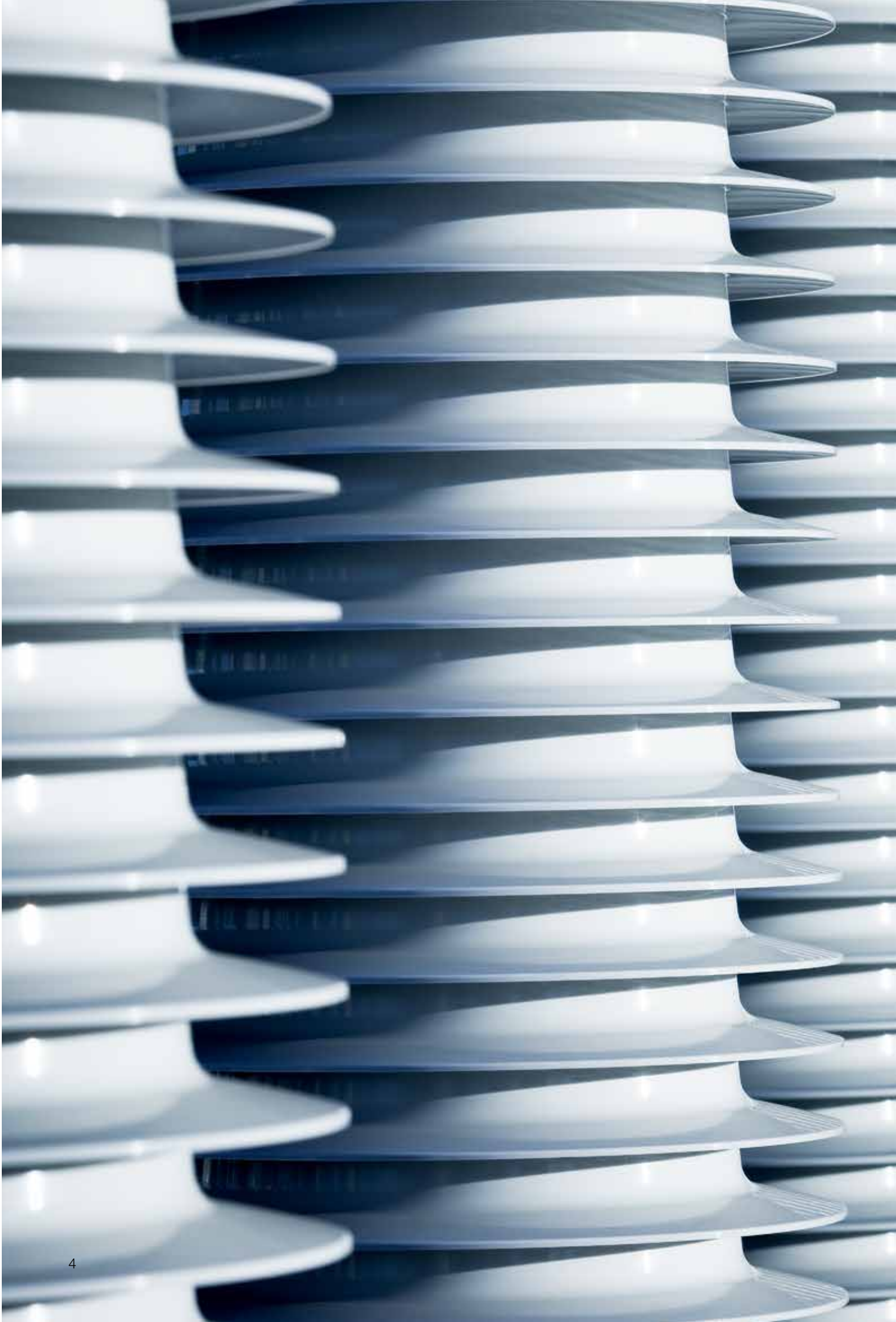
WACKER has been continuously researching new silicone products for more than six decades. The key focus used to be on the formulation itself, but now additional issues relating to production economics and environmental protection have moved to the forefront. WACKER meets these stricter requirements with continuous developments and innovations.

Leading Manufacturer of Silicones for Transmission and Distribution Applications

With the POWERSIL® products, WACKER was the first silicone manufacturer to offer its customers a complete range of insulating and electrically conductive silicone rubber grades for medium- and high-voltage applications. Silicone products from WACKER have been used to make generations of insulators and other insulating components.

Global Production – Local Customer Support

The silicones that WACKER manufactures at its various production sites worldwide meet identical quality standards.
What's more, we have set up technical centers across the globe to offer wide ranging support for product selection, manufacturing, and end-product specification. For more information, visit: www.wacker.com



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CHAPTER 1:
WACKER SILICONES

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1.1 PROPERTIES OF SILICONES

Thanks to their chemical structure, silicones are extremely suitable for applications in the transmission and distribution sector. They have an impressive spectrum of electrical, physical, mechanical and chemical properties.

Hydrophobicity

Compared to other materials, silicones exhibit very good, long-lasting water-repellency, also known as hydrophobicity. Insulating components made of silicone rubber compounds still repel water after many years. The leakage current is minimized and thus pollution flashover is prevented. This also applies to very dirty surfaces, because the water-repelling effect is transferred to the pollution layer. This is known as hydrophobicity transfer. Such an effect can also be achieved by treating glass and porcelain insulators with a silicone coating, making repeated cleaning processes unnecessary.

Resistance to UV Radiation and Weathering

Compared to other materials, silicone elastomers are particularly resistant to UV radiation. Even harsh weather conditions, as found in coastal regions or deserts, have little effect on their properties. Typically silicones show only slight changes of mechanical and hydrophobic properties, even after extended accelerated weathering tests of more than 3,000 hours.

Low Flammability

Silicones only ignite at very high temperatures. This makes them particularly safe in operation. Even if they did ever catch fire, they would not produce any toxic gases. This is why they are the ideal choice for applications subject to strict fire safety requirements, for example in subways and high-rise buildings.

Elasticity

Silicone insulating materials are extremely elastic. This facilitates installation and makes for novel installation techniques, e.g. cold shrinking on cables.

Dielectric Properties

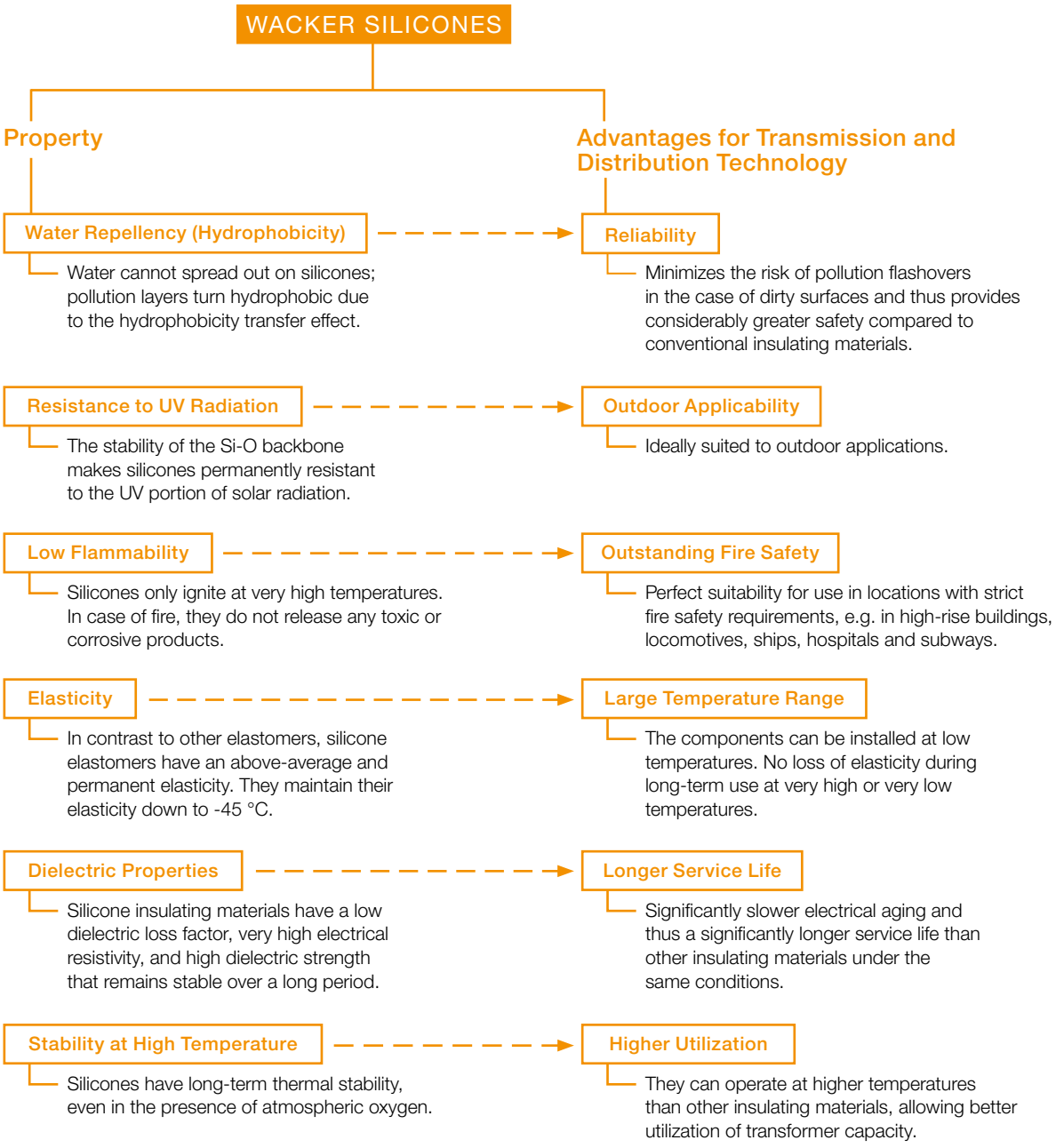
Silicones have high electrical resistivity and a low dielectric loss factor. They exhibit extremely low electrical aging compared to other insulating materials.

Temperature Stability

Owing to their chemical structure, silicones have particularly high thermal stability. Another benefit of silicones is their high temperature resistance. For example, silicones maintain their elasticity down to -45 °C, which makes them particularly suitable for use at high altitudes and in polar regions.

1.1 PROPERTIES OF SILICONES

PROPERTIES AT A GLANCE



1.1 PROPERTIES OF SILICONES
KEY PROPERTIES

Silicone insulating components have been used in transmission networks for more than 60 years. For each new application, silicones were chosen as the insulating material for a variety of reasons.

Key Properties for Electrical Applications

Over the last 60 years, silicones have gained acceptance in many fields of the transmission and distribution industry. Although silicones already offered attractive properties, each new application also required a specific key property. In the case of insulator coatings, the original focus was solely on the water-repelling effect of the silicones. In subsequently developed insulators, the high UV resistance of silicone elastomers was an additional advantage. The key properties for individual applications have remained largely the same. One exception is transformer fluids. Originally, the main focus was on their low flammability, but now the emphasis is on their temperature resistance.

Property Relevance with Regard to the Applications

	Hydrophobicity	Resistance to UV Radiation	Processing Properties of Low-Viscosity Silicone Elastomers	Low Flammability	Permanent Elasticity	Dielectric Properties	Temperature Resistance
Silicone fluids for modern transformers				●		●	○
Cable joints					●	○	
Cable terminations	●	●	●	●	○		
Arresters	●	●		○			
Composite hollow-core insulators	●	●	○	●			
Composite long-rod insulators	●	○		●			
Insulator coatings	○						

○ = Key property ● = Further important property

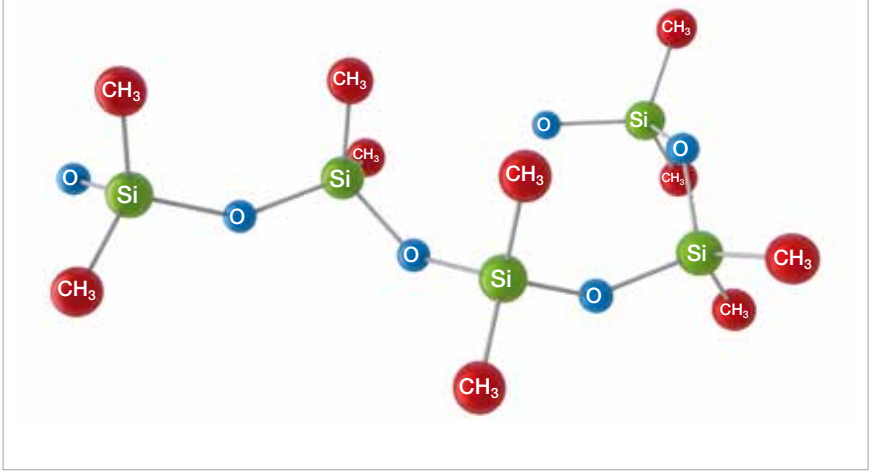
1.1 PROPERTIES OF SILICONES
MOLECULAR STRUCTURE OF SILICONES

The excellent stability and high formulation flexibility of silicones arise from the basic chemical structure. This is the major advantage of silicones, and the reason why they are superior to other materials.

Exceptional Stability

Silicones, called polyorganosilioxanes by chemists, have a similar structure to organically modified quartz. They consist of a backbone comprising alternating silicon and oxygen atoms. The high bonding energy of the siliconoxygen backbone (Si-O) gives silicones a high stability. Thus silicones are more stable than polymers with a carbon (C-C) backbone, such as EPDM. The energy of C-C bonds is 348 kJ/mol, as opposed to 444 kJ/mol for Si-O bonds. Shortwave sunlight (300 nm) has an energy content of about 6.2×10^{-22} kJ (= 398 kJ/mol) and can therefore cleave C-C bonds, whereas the Si-O bond remains stable.

Chemical Structure of a Linear Silicone Polymer



The silicon-oxygen backbone makes silicones very stable.

Tailored to Your Electrical Application

WACKER specialists have more than 60 years of experience with silicone insulating materials for transmission networks. They develop silicones tailored to meet your application and processing technology requirements as well as local guidelines. Please contact your WACKER specialist.

1.2 SILICONE PRODUCT GROUPS

Elastomers

Silicone elastomers and silicone coatings are the most important group of silicone products in the transmission and distribution sector. Owing to the wide range of potential applications, they are continually undergoing development.

Silicone polymers are the raw materials for manufacturing silicone elastomers. Elastomers differ with respect to their viscosity and curing system. Whereas insulating components used to be made of RTV-2 silicone rubbers by casting, nowadays, there is a trend toward new technologies.

Silicone Gels

Silicone gels are a special group of insulating materials. They can replace liquids or elastomers, depending on the application. Silicone gels pose less risk of leakages than fluids.

Silicone gels can fill hollow spaces perfectly, even those with a complicated shape. They adhere excellently to the interior walls of components. Silicone gels are usually low-viscosity, 2-component products. By using special fillers, it is possible to produce compressible and modified gels.

Silicone Fluids

Silicone fluids have proven to be excellent coolants and insulating materials in modern transformers. Owing to their outstanding temperature resistance, it can be expected that new applications to meet similarly strict demands will emerge. A further important application field for silicone fluids is high-voltage cable accessories.

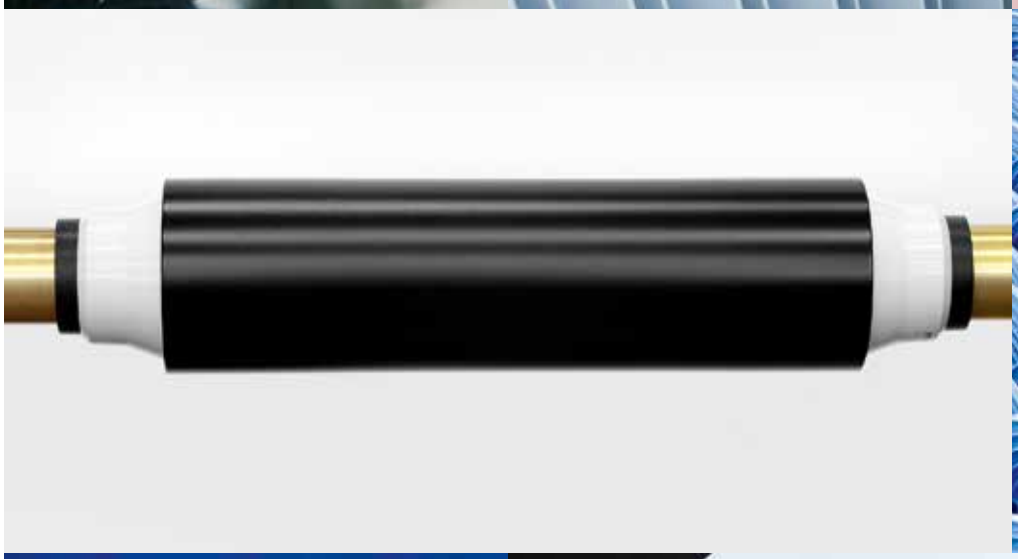
Silicone fluids are linear polymers with a chain length ranging from two to well over 1,000 Si atoms. The silicon atoms alternate with bridging oxygen atoms.

Overview of Silicone Rubbers				
Silicone Rubber	**Typical Mixing Ratio**	**Silicone Product Family**	**Processing**	**Properties**
Low-viscosity, 2-component rubber	9:1	RTV-2	Low-pressure mold filling (casting)	• Good electrical properties • Good mechanical properties • Simple production technologies
Low-viscosity, 2-component liquid rubber	1:1	POWERSIL® XLR®	Low-pressure mold filling with mixing and dosing equipment	• Ideal combination of electrical and mechanical properties • Potential for further developments in processing machinery
2-component liquid rubber	1:1	LSR	Injection molding	• Excellent mechanical properties • Extensive product range available, including, for example, grades modified to be electrically conductive and grades for outdoor applications • Potential for new developments and modifications
Solid rubber, 1-component	–	HCR	Injection molding	• Wide product range for various processing technologies, such as injection molding and extrusion • Grades modified to be electrically conductive and grades for outdoor applications • Wide variety of modification options with respect to the curing process, color, and other properties
1-component solution or emulsion coating	–	RTV-1	Spraying, painting, dipping	• Provides hydrophobicity and UV-resistance of the coated layer • Adhesion to many substrates

RTV = Room-Temperature-Curing (Vulcanizing)
POWERSIL® XLR® = Extra Liquid Rubber
LSR = Liquid Silicone Rubber
HCR = High Consistency Rubber






1.3 TYPICAL APPLICATIONS FOR SILICONES

Application	Silicone Product Family	Key Property	Benefits Compared to Conventional Insulating Materials
Coating of insulators (and other insulating components) >> Page 24 – 25	• RTV-1	Hydrophobicity	• Low leakage current • Higher pollution-flashover voltage • Lower maintenance costs • Longer service life
Long-rod composite insulators with a silicone elastomer sheath >> Page 20 – 21	• HCR • RTV-2 • LSR	Resistance to UV radiation	• Low leakage current • Higher pollution-flashover voltage • Lower maintenance costs • Longer service life
Composite hollow-core insulators with a silicone elastomer sheath >> Page 22 – 23	• HCR • RTV-2 • LSR	Resistance to UV radiation + processing properties	• Low leakage current • Higher pollution-flashover voltage • Lower maintenance costs • Longer service life
Surge arresters >> Page 20 – 21	• HCR • RTV-2 • LSR	Reliability with respect to overloading and low flammability	• Greater safety
Cable terminations >> Page 28 – 35	• HCR • RTV-2 • LSR	Permanent elasticity	• Longer service life • Lower or no maintenance costs
Cable joints >> Page 28 – 35	• HCR • RTV-2 • LSR	Stability of the important electrical and mechanical properties in the temperature range of the applications	• Longer service life, • Lower or no maintenance costs
Applications for silicone gels >> Page 39	• Silicone gels	Leakage protection and interface behavior	• Greater environmental safety
Transformer fluid >> Page 38	• Silicone fluids	Thermal resistance and low flammability	• Highest flame resistance

1.4 OUR PHILOSOPHY: MORE LOCAL PRESENCE, HIGHER QUALITY

Benefit from WACKER's Silicone Experts and Their Know-How

We'll gladly share our research results with you. Whether providing advice on process engineering or helping you to create new applications – your WACKER customer advisor looks forward to working with you.

WACKER Technical Centers

Across the globe, our state-of-the-art technical centers are focused on finding the best solution for each customer – whether they need product modifications or optimized formulations, have questions about processing, or need help with tests to comply with particular standards.

Local presence is already reality at WACKER. Over the decades, we have developed many silicone products in close cooperation with our customers.

Tailored Silicone Products

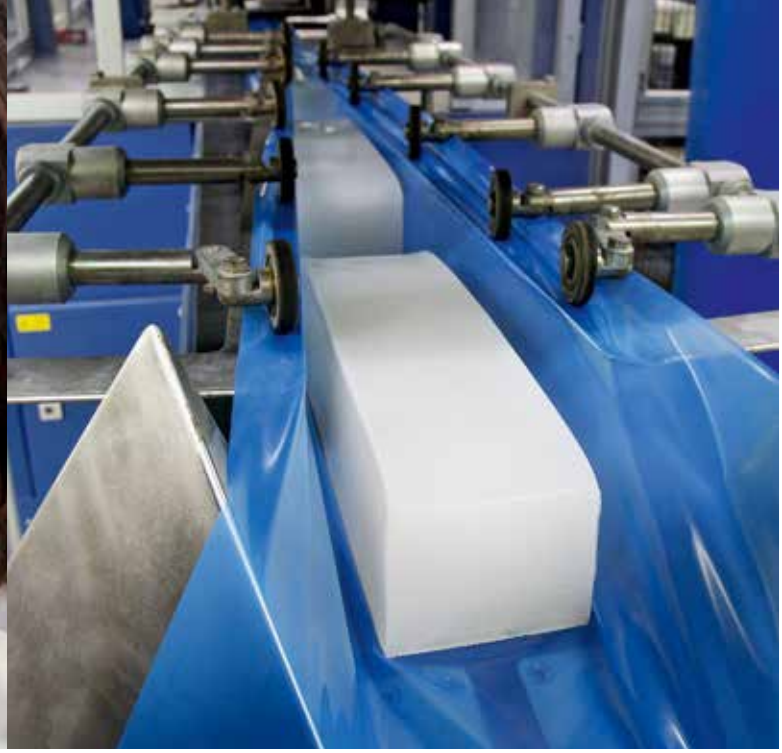
Specialists at WACKER develop solutions tailored to market requirements. We focus on

- Optimizing mechanical and electrical properties, such as tracking and erosion resistance
- Optimizing products for customers' manufacturing processes
- Compliance with international standards

Diverse Test Procedures

WACKER has laboratories around the globe that can test silicone elastomers according to current standard test procedures. WACKER provides comprehensive application engineering and research resources for the development of new test procedures.

Recently, WACKER silicone specialists participated in the development of several new test procedures, including methods of assessing hydrophobicity and of investigating and evaluating the stability of the electrical conductivity of carbon-black-filled silicone elastomers. Another new field of research relates to methods of evaluating the electrical strength of silicone elastomers.



Participation in International Committees

Specialists from WACKER participate in many international committees and working groups. These include the Deutsche Elektrotechnische Kommission (DKE), the Conseil International des Grands Réseaux Électriques (CIGRE), and the International Electrotechnical Commission (IEC). Wherever possible, WACKER is active in standardization committees in the interests of its customers.

Utilization of the Latest Research Findings

Our own silicone research department at WACKER provides customers with access to the latest scientific findings and technologies.

Globally Certified Manufacturing Processes

The manufacture of WACKER silicone products is regulated by globally certified processes. This guarantees the processing company a continuously consistent quality.

WACKER Technical Center

Our Technical Center (Technikum) offers modern production facilities suitable for both extrusion and injection molding, where we can test prototypes and new products. Plus, we will advise you at your premises.

WACKER ACADEMY

At the WACKER ACADEMY, we share our more than 80 years of market experience with you, from basic chemistry to regionally tailored training courses on applications, and innovation workshops – we provide a platform that promotes networking and allows people to showcase their skills.

CHAPTER 2:
INSULATORS / INSULATOR COATINGS

Contents

2.1 LONG-ROD INSULATORS / SURGE ARRESTERS

Silicone long-rod insulators are used from 10 kV to 1,000 kV, for example as suspension and tension insulators or post and railway insulators.

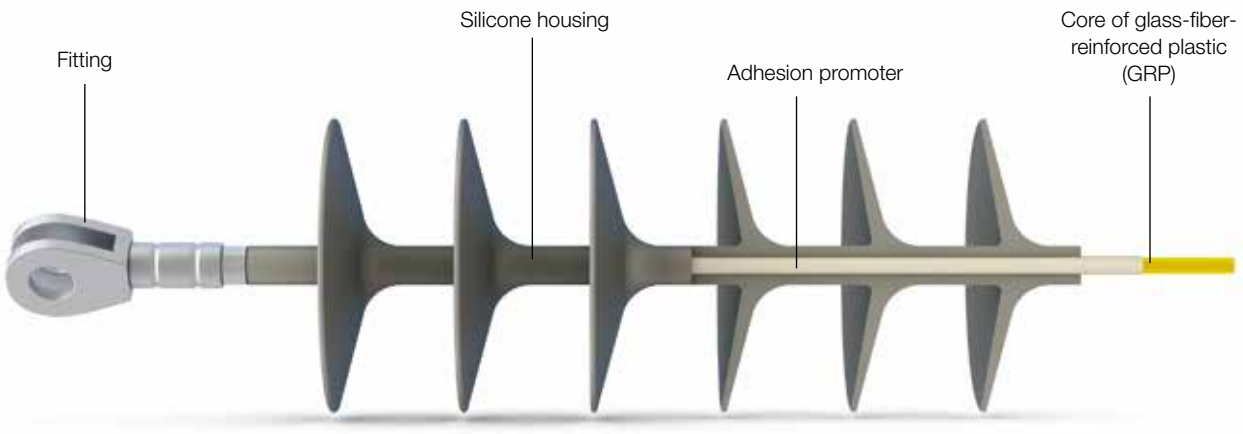
Advantages of Using Silicones in Long-Rod Insulators

Silicones have been used in long-rod insulators for more than 60 years on account of their high weathering resistance and good tracking and erosion resistance. Further advantages include:

- **Long service life**
  POWERSIL® silicone rubbers have excellent hydrophobic properties and outstanding resistance to temperature, UV radiation and ozone.
- **Low weight**
  Long-rod insulators weigh up to 80 percent less than conventional porcelain and glass insulators. This facilitates installation in challenging locations, for example in mountainous regions.
- **Good impact and shock resistance**
  The flexibility of silicone insulating materials reduces the risk of breakage during transport and installation. Failure as the result of vandalism is rare.
- **High flashover resistance at high pollution**
  The surface hydrophobicity of silicones provides long-lasting protection against leakage currents and flashovers, even if the surface is very dirty. In such situations, this increases the reliability of the power supply, for example in industrial, coastal and desert regions and for railways.
- **Low maintenance costs**
  Due to the transfer of hydrophobic properties, the water-repelling effect is maintained even if the surface is dirty, which means that the insulators do not need regular cleaning.

Composite GRP silicone elastomer long-rod insulator: the insulating materials' beneficial properties complement each other perfectly in a lightweight, durable and thus environmentally sound product.

Design Principle of a Long-Rod Insulator



Manufacture and Processing of Long-Rod Insulators

These insulating parts are produced by applying a silicone housing onto the glass-fiber-reinforced epoxy resin or the active part of the surge arrester.

- **Manufacturing process**
  Injection molding, low-pressure mold filling (casting), modular "shed by shed" process
- **Grades**
  The choice of product – POWERSIL® solid silicone rubber (HCR), extra-liquid systems (POWERSIL® XLR®) or LSR – depends on the manufacturing process.

2.2 HOLLOW-CORE INSULATORS

Hollow-core insulators are used for arresters, bushings, and instrument transformers at high voltages of up to 1,000 kV. State-of-the-art production processes permit diameters up to one meter in size, and lengths of several meters.

Advantages of Using Silicones in Hollow-Core Insulators

- **Reliable production process**
  The low-pressure molding process produces silicone hollow-core insulators with considerable reliability and flexibility, making products available on demand.
- **Good handling due to low weight**
  Hollow-core insulators are up to 80 percent lighter than conventional porcelain insulators. This facilitates transport and installation in challenging locations.
- **Good impact and shock resistance**
  The flexibility of silicone insulating materials reduces the risk of breakage during transport, installation and earthquakes.
- **High flashover resistance of polluted surfaces**
  The surface hydrophobicity of silicones provides long-lasting protection against tracking currents, and thus against flashovers, even if the surface is highly polluted and wet.

Silicone Rubber for Insulators

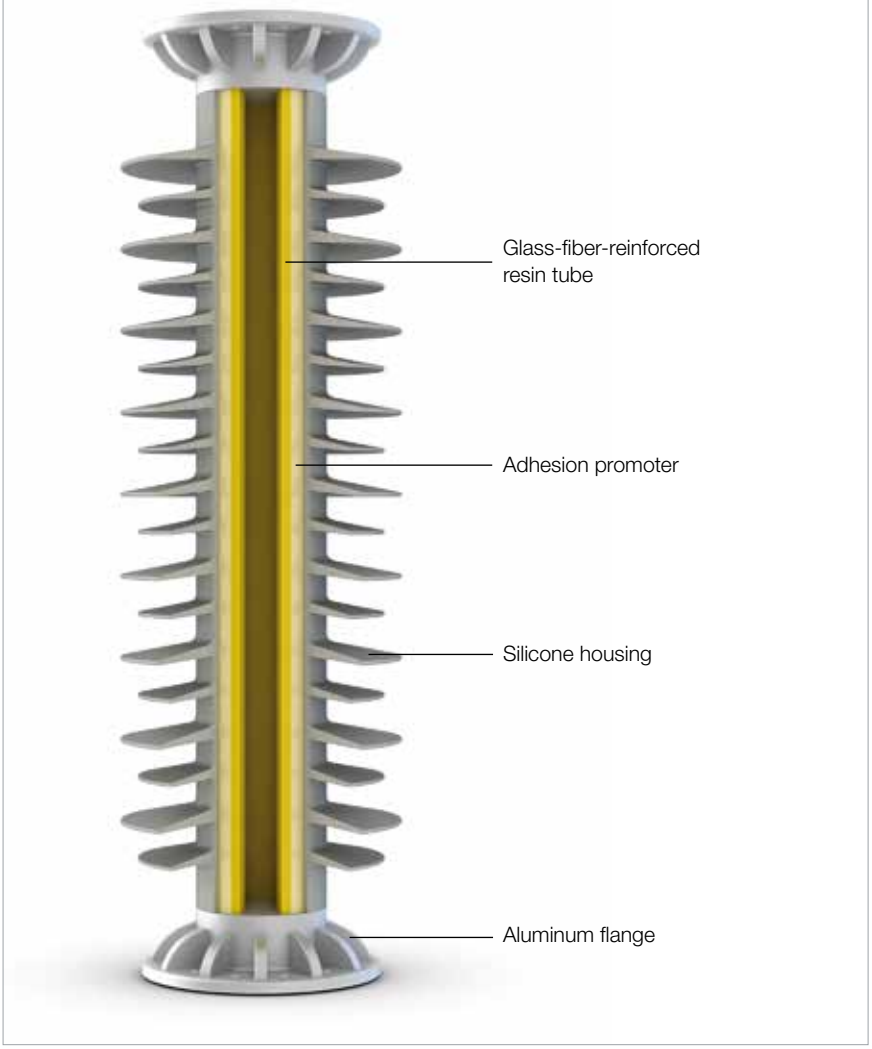
Silicone	Processing
Insulating HCR	Injection molding
Insulating HCR	Extrusion
Insulating LSR	Injection molding
Insulating LSR	Low-pressure mold filling
Insulating RTV-2	Low-pressure mold filling
Silicone Gel	Casting

Manufacture and Processing of Hollow-Core Insulators

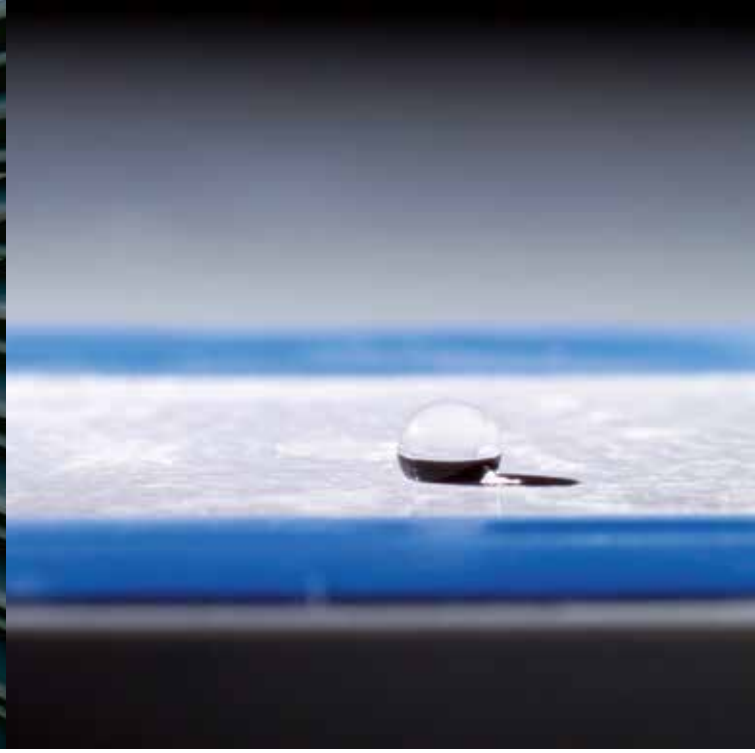
Hollow-core insulators are made of glass-fiber-reinforced resin tubes that are housed using silicone rubber:

- **Manufacturing process**
  Low-pressure filling of the mold (casting), extrusion
- **Grades**
  The choice of product – POWERSIL® room-temperature-vulcanizing systems (RTV-2), low-viscosity LSR and POWERSIL® XLR® systems or a special solid silicone rubber (HCR) – depends on the manufacturing process.

Design Principle of a Hollow-Core Insulator



Material	Hardness Shore A ISO 868	Elongation at Break [%] ISO 37	Tear Strength [N/mm] ASTMD 624B	Tracking Resistance IEC 60587	Viscosity [mPa·s] Shear Rate 10 s^{-1} ISO 3219	Volume Resistivity [Ωcm] IEC60093	Density [g/cm^3] ISO 1183-1A
POWERSIL® 310	70	250	16	1 A 4.5	–	$>10^{14}$	1.55
POWERSIL® 3100	70	350	18	1 A 4.5	–	$>10^{14}$	1.55
POWERSIL® 3500	45	850	40	1 A 3.5	–	$>10^{15}$	1.11
POWERSIL® 190	75	300	20	1 A 4.5	–	$>10^{14}$	1.57
POWERSIL® 730	35	600	26	1 A 4.5	150,000	$>10^{15}$	1.09
POWERSIL® 735	39	500	30	1 A 4.5	150,000	$>10^{15}$	1.08
POWERSIL® XLR® 630	35	450	25	1 A 4.5	13,000	$>10^{15}$	1.14
POWERSIL® XLR® 640	40	400	20	1 A 4.5	35,000	$>10^{15}$	1.15
POWERSIL® 600	30	500	20	1 A 3.5	10,000	$>10^{15}$	1.10
POWERSIL® Gel	Gel	–	–	–	1,000	$>10^{15}$	0.97
POWERSIL® Gel FC (fast cure)	Gel	–	–	–	1,000	$>10^{15}$	0.97
POWERSIL® Gel C 670 (compressible)	Gel	–	–	–	4,000	$>10^{15}$	0.70



2.3 SILICONE COATINGS FOR INSULATORS

Silicone Coating as Turnkey Solution through WACKER Partners

Silicone coatings are usually sold as a complete turnkey solution package covering supply and application. WACKER works with experienced specialists who will provide both the materials and the coating services. Your WACKER consultant can give you further guidance in this respect.

The risk of conventional insulators failing increases with the rate of pollution. Insulators can be made operationally reliable again by applying a subsequent silicone coating.

Improved Electrical Properties

A pollution layer on insulators made of porcelain, glass, or epoxy resin can cause pollution flashovers. This hazard can be prevented by regular cleaning. However, a more cost-effective and long-term alternative is a hydrophobic silicone coating on the insulator.

A silicone coating improves the electrical properties, even on aged epoxy resin insulators, outdoor testing equipment and antenna systems. Some manufacturers of porcelain and glass insulators have recently started to promote the application of silicone coatings (also in the factory) to make their products water repellent.

Silicone Insulator Coatings from WACKER

Silicone	Material	Color	Density (Cured) [g/cm³]	1,000 h Salt-Fog-Test acc. to IEC 62217
RTV-1*	POWERSIL® 552	Dark gray	1.44	Successfully passed
RTV-1*	POWERSIL® 567	Light gray	1.10	Successfully passed
RTV-1**	POWERSIL® 577 PLUS	Light gray	1.10	Successfully passed

* Solvent-based solution
** Water-based emulsion, solvent-free

Advantages of Silicone Coatings on Insulators

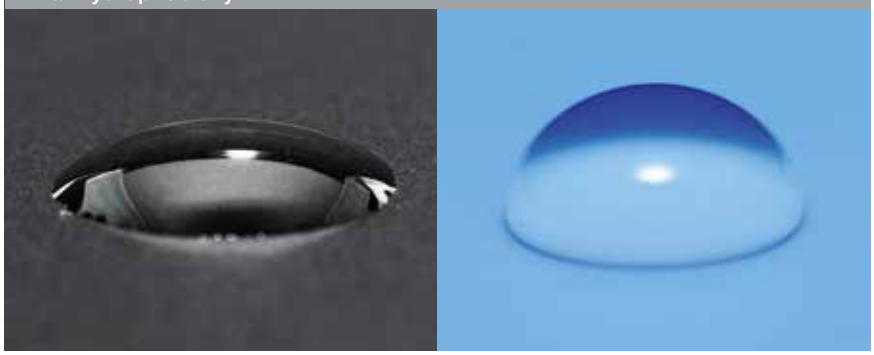
- **Higher operational reliability**
  Low leakage current measured in microamps is the norm due to the outstanding hydrophobic properties. Pollution flashovers can thus be avoided, even if the surface is very dirty or even wet.
- **Retrofitting of existing installations**
  Silicone coatings offer a cost-effective option for hydrophobic coating of insulators made of porcelain, glass, or epoxy resin. This saves the costs for periodic cleaning or for a replacement with composite insulators.
- **Longer service life**
  Silicone coatings lengthen the service life of existing installations, thus contributing to effective resource management. Experience has shown that the service life of silicone coatings is 15 years or more.

Processing of Silicone Coatings

POWERSIL® silicone coatings are delivered ready-to-use; however, before they are filled into the processing machine, they should be thoroughly stirred whilst still in their packaging. POWERSIL® insulator coatings are usually processed using so-called airless membrane equipment, as is used for high-quality paintwork. The surfaces being coated should be thoroughly cleaned beforehand to ensure good adhesion to the substrate.

The application of silicone coatings is as important as the coating itself and requires sophisticated, highly controlled procedures and expertise.

Initial Hydrophobicity



Water droplet on a porcelain surface.

Water droplet on a silicone-coated surface.

Transfer of Hydrophobic Properties

Water droplet on a clean silicone surface.

Water droplet on a dirty silicone surface.

Stable Hydrophobic Properties

Water droplet on a dirty silicone coating.

Water droplet on a clean silicone coating.

CHAPTER 3:
CABLE ACCESSORIES

Contents

3.1 CABLE ACCESSORIES

Cable accessories are used outdoors and in the ground. This requires outstanding insulating properties. In addition, slip-on and cold-shrink accessories must be highly elastic if connections are to be permanently secure. WACKER silicone rubbers have been meeting these requirements perfectly for many years.

Application Fields for Cable Accessories

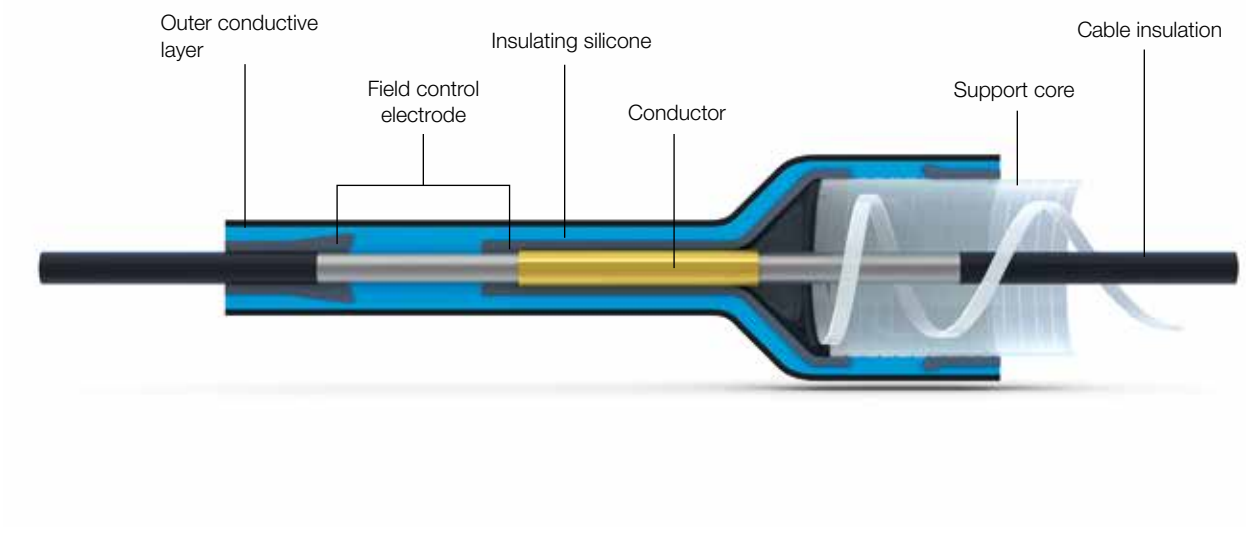
Cable joints, terminations and connectors made of WACKER silicone elastomers are used worldwide for voltages ranging from 10 kV to above 500 kV. Low-voltage joints can be economically filled with silicone gel, which does not require classification as a hazardous substance.

Advantages of WACKER Silicone Elastomers for Cable Accessories

- **Long service life**
  WACKER silicone rubbers have excellent hydrophobic properties and outstanding resistance to temperature, UV radiation and ozone. Thanks to their excellent long-term electrical behavior, they are perfect insulating materials for cable accessories. There is hardly any aging due to the effects of an electric field alone.
- **High operational reliability**
  WACKER silicone rubbers show very good tracking and arc resistance. They also have a high flashover resistance, even if the surface is very dirty.
- **Permanent elasticity**
  Cable accessories made of silicone elastomers are highly and permanently elastic over a wide temperature range.

Thanks to the favorable stress /elongation ratio and the outstanding resilience, the insulating element fits perfect on the cable wires without any gaps. The electrical insulation is permanently maintained.

Design Principle of a Cold-Shrinkable Cable Joint



Manufacture of Cable Accessories

WACKER silicone rubbers are suitable for both slip-on and cold-shrink technology. The choice of product – solid silicone rubbers (HCR), liquid silicone rubbers (LSR), extra-liquid systems (POWERSIL® XLR®), or room-temperature-vulcanizing systems (RTV-2) – depends on the manufacturing process.

Manufacturing of cable accessories from silicone rubber can be performed by

- Injection molding (HCR, LSR)
- Low pressure mold filling (XLR®, RTV-2)
- Extrusion (HCR)

3.2 FIELD GRADING WITH CABLE ACCESSORIES

Using special silicone elastomers from WACKER, the electrical field strength within the cable joints, terminations and connectors can be efficiently graded to reduce localized high field strengths.

Field Grading with WACKER Silicone Rubbers

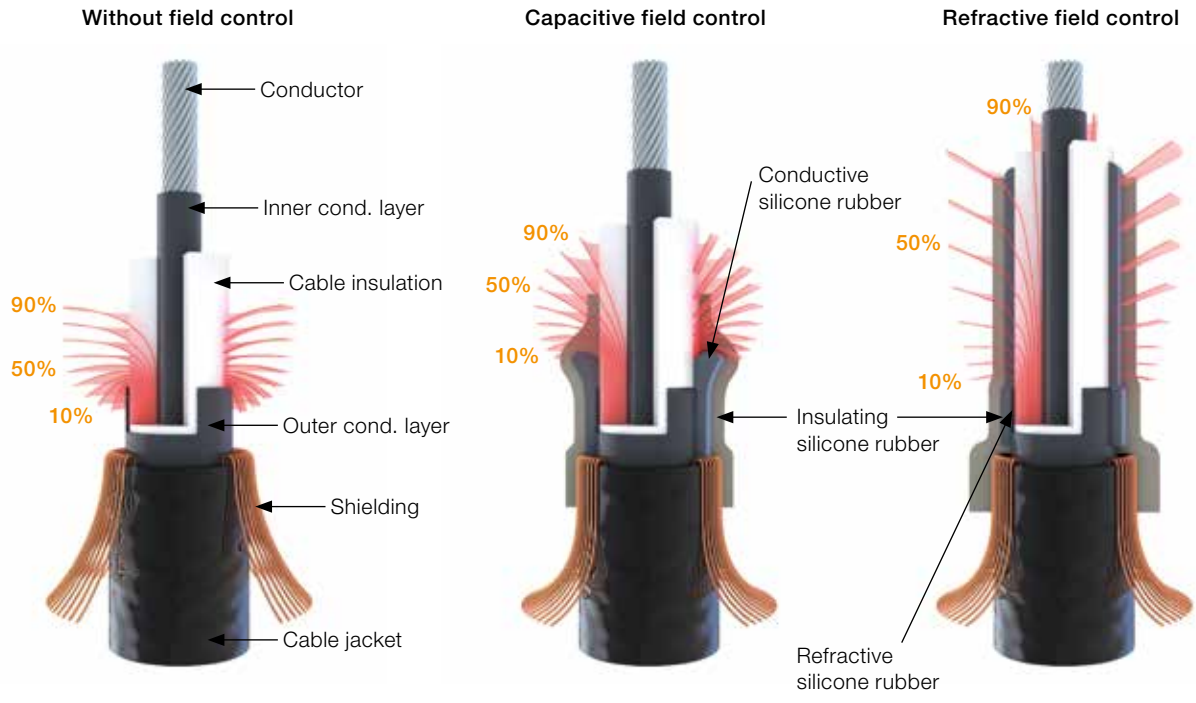
For field grading applications, WACKER offers a wide range of high permittivity grades and grades that have been modified to be electrically conductive. The electric field can be graded geometrically or refractively:

- Geometric field grading is carried out with specially shaped conductive electrodes (deflectors) that usually have a volume resistivity of less than 100 Ωcm. The outer conducting layer of the cable is continued inside the accessory.
- Refractive field grading is based on the deflection of field lines at the interface between materials with a different permittivity. Silicone elastomers with a high relative permittivity are used in such cases. Particularly suitable grades have a high permittivity ranging from 10 to 30, depending on the grade.

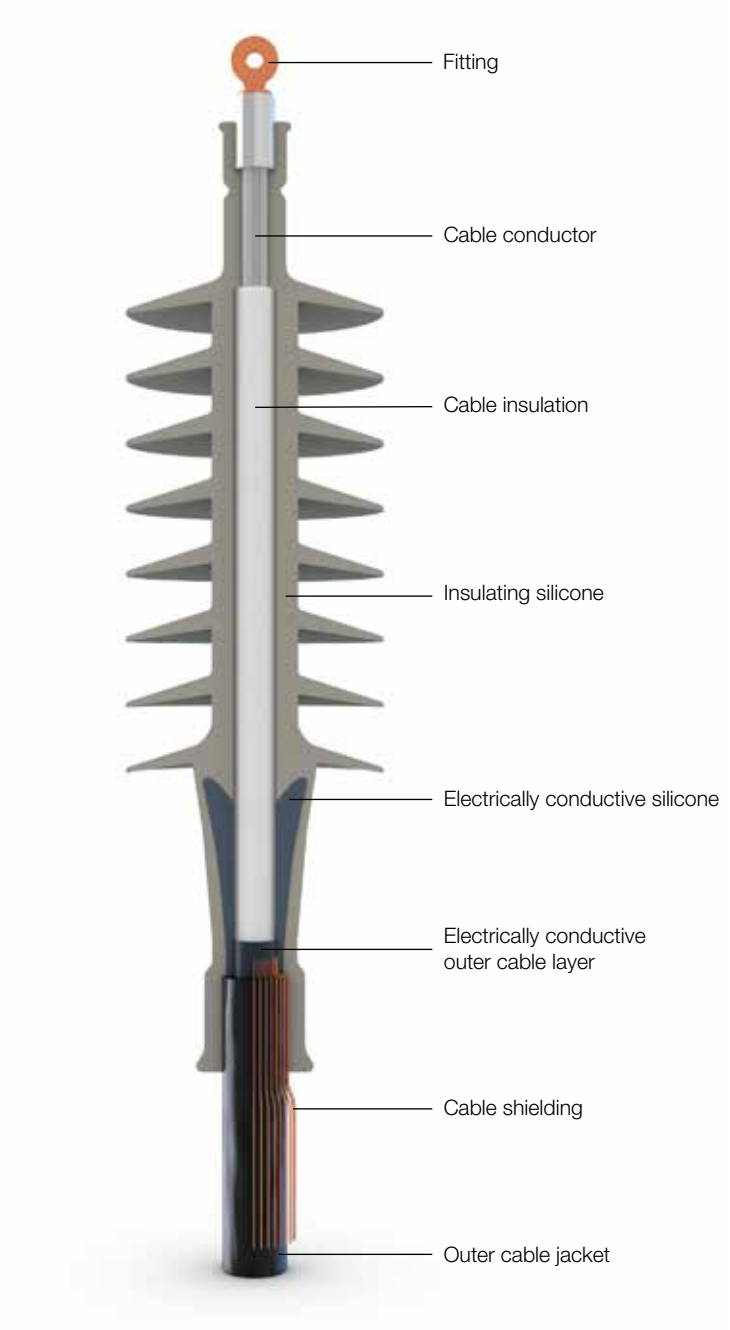
Electrically Conductive Silicone Dispersions

An electrically conductive coating on cable joints and connectors ensures high operational reliability and a long service life for the products. For coating applications, WACKER has a series of electrically conductive silicone dispersions, including POWERSIL® 402, which can also be used as an adhesion-promoting primer, e.g. for deflectors.

Equipotential Lines Capacitive and Refractive Field Control



Design Principle of a Cable Termination



Perfect field grading is required in order to reduce the electric field strength at the end of the outer conductive layer of the cable. Special silicone rubbers have properties that can be used to grade electric fields.

3.3 CABLE ACCESSORIES: SILICONE PRODUCTS AND PROPERTIES (HCR)

Silicone	Processing	Material	Hardness Shore A ISO 868	Elongation at Break [%] ISO 37	Tear Strength [N/mm] ASTMD 624B
Insulating HCR	Injection molding	POWERSIL® 351	38	800	30
		POWERSIL® 352	45	700	25
		POWERSIL® 3525	23	1,200	45
		POWERSIL® 3500	45	850	40
		POWERSIL® 3540	38	900	28
		ELASTOSIL® R 401	10 – 90	300 – 1,200	17 – 26
		ELASTOSIL® R 420	30 – 70	550 – 1,000	25 – 40
Electrically Conductive HCR	Injection molding	ELASTOSIL® R 570/50	50	310	10
		ELASTOSIL® R 570/70	71	180	13
		POWERSIL® 440	43	500	15
HCR with a High Dielectric Constant	Injection molding	POWERSIL® 415	41	450	25
Insulating HCR	Extrusion	ELASTOSIL® R *plus* 4305/40	40	900	35
Electrically Conductive HCR	Extrusion	ELASTOSIL® R *plus* 573/50	50	350	12
HCR with a High Dielectric Constant	Extrusion	POWERSIL® 412	54	300	11

Tracking Resistance IEC 60587	Volume Resistivity [Ωcm] IEC60093	Density [g/cm³] ISO 1183-1A	Main Properties
1 A 3.5	$>10^{15}$	1.10	High tracking resistance, excellent mechanical properties
1 A 3.5	$>10^{15}$	1.13	High tracking resistance, low tension set
1 A 3.5	$>10^{15}$	1.09	High tracking resistance, excellent mechanical properties, fast-curing 1-component system
1 A 3.5	$>10^{15}$	1.11	High tracking resistance, excellent mechanical properties, fast-curing 1-component system
1 A 3.5	$>10^{15}$	1.11	High tracking resistance, excellent mechanical properties, fast-curing 1-component system
1 A 2.5	$>10^{15}$	1.12 – 1.19	Standard grade
1 A 2.5	$>10^{15}$	1.09 – 1.19	Standard grade with excellent mechanical properties
–	5	1.11	Standard grade with excellent electrical conductivity
–	4	1.19	Standard grade with excellent electrical conductivity
–	50	1.11	Good mechanical properties, low tension set
–	10^{12} $\varepsilon_r = 15$	1.32	High permittivity; $\varepsilon_r \approx 15$
1 A 2.5	$>10^{15}$	1.09	Outstanding mechanical properties, fast-curing, 2-component system
–	5	1.13	Very good electrical conductivity, fast-curing system for extrusion
–	10^{12} $\varepsilon_r = 28$	1.34	High permittivity; $\varepsilon_r \approx 28$

3.3 CABLE ACCESSORIES: SILICONE PRODUCTS AND PROPERTIES (LSR AND AUXILIARIES)

Silicone	Processing	Material	Hardness Shore A ISO 868	Elongation at Break [%] ISO 37	Tear Strength [N/mm] ASTMD 624B
Insulating LSR	Injection molding	POWERSIL® 730	35	600	26
		POWERSIL® 732 CS	33	720	37
		POWERSIL® 735	39	500	30
		POWERSIL® 740	40	670	38
		ELASTOSIL® LR 3003	5 – 80	300 – 700	7 – 35
		ELASTOSIL® LR 3003/30 CS	30	700	33
		ELASTOSIL® LR 3043	30 – 70	450 – 690	30 – 45
Electrically Conductive LSR	Injection molding	POWERSIL® 464	50	350	25
		POWERSIL® 466	38	650	28
		POWERSIL® 466 LV	32	690	22
Insulating LSR	Low-pressure mold filling	POWERSIL® 735	39	500	30
		POWERSIL® XLR® 620	33	400	15
		ELASTOSIL® LR 3002/35	33	450	25
Electrically Conductive LSR	Low-pressure mold filling	POWERSIL® 464	50	350	25
Insulating RTV-2	Casting	POWERSIL® 600	30	500	20
Electrically Conductive Silicone Dispersion	Spraying	POWERSIL® 402	–	–	–
		POWERSIL® 403	–	–	–
		POWERSIL® 420	–	–	–
		POWERSIL® 79032	–	–	–
Silicone Lubricants		POWERSIL® PASTE AP	–	–	–
		PASTE P	–	–	–
		PASTE P 250	–	–	–
		PASTE P 300	–	–	–
Silicone Gel	Casting	POWERSIL® Gel	Gel	–	–
		POWERSIL® Gel FC	Gel	–	–
		POWERSIL® Gel C 670	Gel	–	–

Tracking Resistance IEC 60587	Viscosity [mPa·s] Shear Rate 10 s^{-1} ISO 3219	Volume Resistivity [Ωcm] IEC60093	Density [g/cm^3] ISO 1183-1A	Main Properties
1 A 4.5	150,000	$>10^{15}$	1.09	High tracking resistance, very good mechanical properties
1 A 4.5	375,000	$>10^{15}$	1.11	High tracking resistance, excellent mechanical properties, optimized for cold-shrink accessories
1 A 4.5	150,000	$>10^{15}$	1.08	High tracking resistance, very good mechanical properties
1 A 4.5	425,000	$>10^{15}$	1.14	High tracking resistance, excellent mechanical properties
1 A 2.5	25,000 – 540,000	$>10^{15}$	1.05 – 1.19	Standard grade with very good mechanical properties
1 A 2.5	300,000	$>10^{15}$	1.11	Highly elastic grade for cold-shrink technology
1 A 2.5	320,000 – 630,000	$>10^{15}$	1.10 – 1.14	Standard grade with excellent mechanical properties
–	425,000	75	1.10	RTV-2 adheres well to overmolded POWERSIL® 464
–	600,000	30	1.08	Excellent mechanical properties
–	400,000	40	1.08	Excellent mechanical properties, low viscosity
1 A 4.5	150,000	$>10^{15}$	1.08	High tracking resistance, very good mechanical properties
1 A 4.5	15,000	$>10^{15}$	1.10	High tracking resistance, very low viscosity
1 A 2.5	70,000	$>10^{15}$	1.09	Very good mechanical properties
–	425,000	75	1.10	RTV-2 adheres well to overmolded POWERSIL® 464
1 A 3.5	10,000	$>10^{15}$	1.10	High tracking resistance, very low viscosity
–	–	5	1.22	Volume resistivity 5 Ωcm
–	–	25	1.1	Cold shrink applications
–	–	0.5	1.24	Volume resistivity 0.5 Ωcm
–	–	5	1.22	Volume resistivity 5 Ωcm, 1-component material
–	250,000	–	1.02	Very good lubricating properties, no swelling of silicone elastomers in contact with the paste
–	170,000	–	1.0	General purpose grade BfR, FDA approval
–	210,000	–	0.98	Good insulating electrical properties, good adhesion to metals and ceramic materials, excellent water repellency
–	50,000	–	0.94	Good insulating electrical properties, good adhesion to metals and ceramic materials, excellent water repellency
–	1,000	$>10^{15}$	0.97	Very low viscosity, excellent adhesion
–	1,000	$>10^{15}$	0.97	Very low viscosity, excellent adhesion, fast curing
–	4,000	$>10^{15}$	0.70	Compressible

CHAPTER 4:
INSULATING MATERIALS

Contents

4.1 SILICONE FLUID

Modern transformers generate a lot of heat during operation. Silicone fluids have proven to be excellent coolants and dielectrics. High-voltage cable terminations are a further important application field for silicone fluids.

Composition and Properties

Silicone fluids used for electrical insulation are typically polydimethylsiloxanes. They are transparent, colorless and odorless liquids. Their molar mass ranges from 1,000 to 150,000 g/mol. They have viscosities ranging from 0.65 to one million mm^2/s, and continuous operating temperatures ranging from the pour point (-60 °C to -40 °C, depending on the viscosity) to about 180 °C.

Temperature changes have little effect on the key properties of silicone fluids, for example the dielectric loss factor and the viscosity. This distinguishes them from other electrical insulating fluids such as mineral oils and ester fluids. Special grades have an extended application range that includes lower and higher temperatures (-100 °C to +250 °C).

The Classic Solution for Transformers

Marketed under the name POWERSIL® Fluid, WACKER offers silicone fluids that have been specially optimized for insulation systems in modern high-performance transformers. Although they were originally developed to replace PCB, POWERSIL® Fluid TR 50 and POWERSIL® Fluid TR 20 are now used mainly on account of their excellent resistance to oxidation and their high flash point. A special feature of the silicone fluids is that they exhibit only a moderate increase in viscosity at low temperatures.

Advantages of Silicone Fluid

- High temperature resistance
- Extremely low dielectric loss factor
- Only minor changes in the electrical properties over a wide temperature range
- High flash point

Product Properties of POWERSIL® Fluid TR 50

Typical General Characteristics	Inspection Method	Properties
Density at 20 °C	ISO 3675	0.96 g/cm^3
Viscosity, kinematic at 40 °C	ISO 3104	40 mm^2/s
Flash point	ISO 2719	> 240 °C
Fire point	ISO 2592	> 340 °C [1]
Pour point	ISO 3016	< -50 °C
Neutralizing value	IEC 60836	< 0.01 mg KOH/g
Breakdown voltage	IEC 60156	> 40 kV
Dissipation factor tan δ at 90 °C and 50 Hz	IEC 60247	< 0.001
Permittivity at 90 °C and 50 Hz	IEC 60247	2.55 (+/- 0.05)
Volume resistivity 90 °C	IEC 60247	> 10^{13} Ω cm (>100 GΩm)

4.2 SILICONE GELS

Silicone gels are used as insulating potting compounds, e.g. for cable accessories.

Properties

Silicone gels are pourable, addition-curing, two-component silicones. Silicone gels do not cure to a silicone elastomer in the conventional sense, but to soft, gel-like products. The components of POWERSIL® Gels have a very low viscosity with excellent pouring properties. The cured silicone pretty much adheres to all substrates in contact with the gel. It also has excellent dielectric properties. Special fillers allow the modification of gels. WACKER offers a compressible gel that can be used to fill gaps in electrical equipment.

Advantages of Silicone Gels

- High dielectric strength
- Low modulus
- Low viscosity

Product Properties of POWERSIL® Gels

Processing	Material	Viscosity [mPa·s] Shear Rate 10 s^{-1} ISO 3219	Volume Resistivity IEC60093 [Ωcm]	Density ISO 2781 [g/cm^3]	Main Properties
Casting	POWERSIL® Gel	1,000	$>10^{15}$	0.97	Very low viscosity, excellent adhesion
Casting	POWERSIL® Gel FC	1,000	$>10^{15}$	0.97	Very low viscosity, excellent adhesion, fast curing
Casting	POWERSIL® Gel C 670	4,000	$>10^{15}$	0.70	Compressible


WACKER
SILICONES
SILICONE

CHAPTER 5:
AUXILIARY MATERIALS

Contents

5.1 ADHESION PROMOTERS / INSULATOR FINISH / ADHESIVES / MOLD RELEASE AGENTS

Adhesion Promoters

Insulating elements are made of different materials. Adhesion promoters are used to ensure a tightly sealed interface.

Grades

- WACKER® Primer G 790 and WACKER® Primer G 790 Toluene Free are recommended to promote adhesion between liquid rubbers (LSR, XLR® grades) or RTV-2 silicone rubbers and other materials, such as glass-fiber-reinforced plastics and metal fittings
- WACKER® Primer G 791 promotes adhesion between vulcanized silicone rubber and another layer of RTV-2 or liquid silicone rubber (LSR, XLR® grades)
- WACKER® Primer G 3243 is used to promote adhesion between peroxide-cured solid rubbers and other materials, such as glass-fiber-reinforced plastics (GRP) or metal fittings
- WACKER® Primer G 800 promotes adhesion between addition-curing solid rubbers and other materials
- Electrically conductive POWERSIL® 402 primer may be used to promote adhesion of insulating RTV-2 and liquid rubbers to silicone rubbers that have been modified to be electrically conductive.

Advantages

- Tested auxiliary products from a single source, in conjunction with the silicone rubbers, ensure reliable and safe use for the customer.
- WACKER has its own range of adhesion promoters for all applications.

Insulator Finish

Insulator finish is used to repair small damaged areas and for subsequent filling of cavities. A self-curing silicone rubber is used for this.

Grades

- POWERSIL® INSULATOR FINISH

Advantages

- The product has a high tracking resistance
- WACKER manufactures and supplies finishing rubber
- Same color as POWERSIL® 310, POWERSIL® 3100, POWERSIL® XLR® 630 etc.

Adhesives

Cured silicone rubber parts can be joined by RTV-1 silicone rubber.

Grades

- ELASTOSIL® R 3113 A/B
- ELASTOSIL® E 4
- ELASTOSIL® E 43

Mold Release Agents

Mold release agents ensure an efficient production of molded parts. This is particularly important when using certain solid rubbers. External release agents also facilitate demolding when a new mold is being run in.

Chemical Structure and Properties

The surfactant structure of mold release agents for silicone rubber grades gives them their excellent release effect. A 1% aqueous solution is sprayed into the hot mold.

Grades

- ELASTOSIL® AUX MOLD RELEASE AGENT 32

Insulator Cleaner

Composite, ceramic and glass insulators can all benefit of the professional care provided by a tailor-made silicone solution.

Grades

- POWERSIL® SHINE

5.2 SLIDING AND FILLING SILICONE PASTES

Sliding and Filling Silicone Pastes

WACKER silicone pastes are designed as slip-on aids and lubricants for application in the field of medium- and high-voltage cable accessories. In addition to their excellent lubricating properties, WACKER silicone pastes exhibit good electrical properties and an excellent release effect with respect to elastomers and plastics. Furthermore, WACKER is the first manufacturer to present a completely boron-free paste portfolio.

Chemical Structure and Properties

Silicone pastes are composed of thermostable siloxanes and inorganic fillers. The exceptional properties of WACKER silicone pastes give them a very wide performance spectrum. Silicone pastes provide excellent electrical insulation, i.e. high dielectric strength and a low dielectric loss factor.

Because of their excellent oxidation resistance, silicone pastes have long-term resistance to weathering. They can be used as lubricants, installation aids, sealants, release agents, heat sink pastes, moisture protection and much more. Due to their high water repellency, silicone pastes are used to embed electrical equipment and protect it from moisture and corrosion.

In the field of transmission and distribution, the main application of WACKER silicone pastes is for the installation of cable accessories such as cable joints and terminations.

Grades

- POWERSIL® PASTE AP is an opaque to whitish paste of medium consistency that combines the outstanding dielectric properties of a silicone paste with good lubricating and release properties. Due to its special formulation with phenyl-modified silicone oil, this paste causes no substantial swelling of silicone elastomers that come into contact with it. POWERSIL® PASTE AP is seen as the standard product for the assembly of cable accessories and other parts in the transmission and distribution industries.
- WACKER® SILICONE PASTE P is a translucent, vaseline-like, relatively stiff, water-repellent paste. WACKER® SILICONE PASTE P becomes softer when subjected to shear stress or other mechanical stress such as kneading, which in many instances makes processing easier. The pasty consistency is little affected by changes in temperature. The components of Paste P are on the positive lists of the following regulations for food contact: Regulation (EU) No. 10/2011, Recommendation XV. Silicones of the BfR (Federal Institute for Risk Assessment) and the FDA Code of Federal Regulations Title 21 §175.3570 Lubricants with Incidental Food Contact.
- WACKER® SILICONE PASTE P 250 is opaque, of medium consistency and slightly thixotropic. It displays good electrical insulation, as well as good adhesion to metals and ceramic materials. Parts coated with WACKER® SILICONE PASTE P 250 exhibit excellent water repellency, resulting in a certain degree of protection against corrosion. The properties of the paste facilitate its use as an embedding compound, release agent for compression molding and extruder die rings, lubricant for shut-off valves and control devices as well as cable terminations and joints.
- WACKER® SILICONE PASTE P 300 is opaque, of medium to soft consistency and slightly pseudoplastic. In general, it shows very similar properties to WACKER® SILICONE PASTE P 250 but is softer in consistency with an unworked penetration of 290 – 300 $^{1}/_{10}$ mm.

Product Properties of POWERSIL® and WACKER® Silicone Pastes

	Density (25 °C)	Unworked Penetration ISO 2137	Operating Temperature Range	Dielectric Strength DIN 53481	Dielectric Constant ε_r IEC 60250	Dissipation Factor IEC 60250
POWERSIL® PASTE AP	1.1 g/cm³	250 – 280 $^{1}/_{10}$ mm	-40 – +200 °C	20 kV/mm	3.7 ε_r	0.0003
PASTE P	1.00 g/cm³	180 – 220 $^{1}/_{10}$ mm	-40 – +200 °C	20 kV/mm	2.8 ε_r	0.0005
PASTE P 250	0.98 g/cm³	220 – 270 $^{1}/_{10}$ mm	-40 – +200 °C	19 kV/mm	3.8 ε_r	0.0003
PASTE P 300	1.00 g/cm³	290 – 330 $^{1}/_{10}$ mm	-40 – +150 °C	20 kV/mm	3.1 ε_r	0.007


proSafe
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CHAPTER 6:
PROCESSING TECHNOLOGIES

Contents

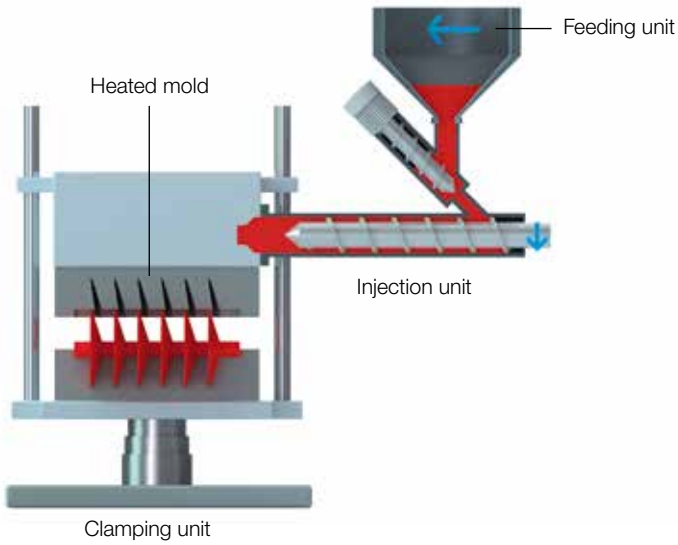
6.1 INJECTION MOLDING

Injection molding is currently the most popular and efficient method of processing large quantities of silicones and obtaining consistently high product quality.

When modern silicone elastomers are injection-molded, very fast cycle times and, thus, high production output can be achieved. Suitably configured machinery and tools permit flexible production and extremely low material losses. This process is used for both solid rubbers (HCR) and liquid rubbers (LSR).

The modern processing technology for solid silicone rubbers is injection molding. With the available equipment, it is possible to manufacture insulating components up to about 140 cm in length in one step. For longer components, e.g. high-voltage insulators, multiple processes in which different sections are produced sequentially or in parallel are used.

HCR Injection Molding



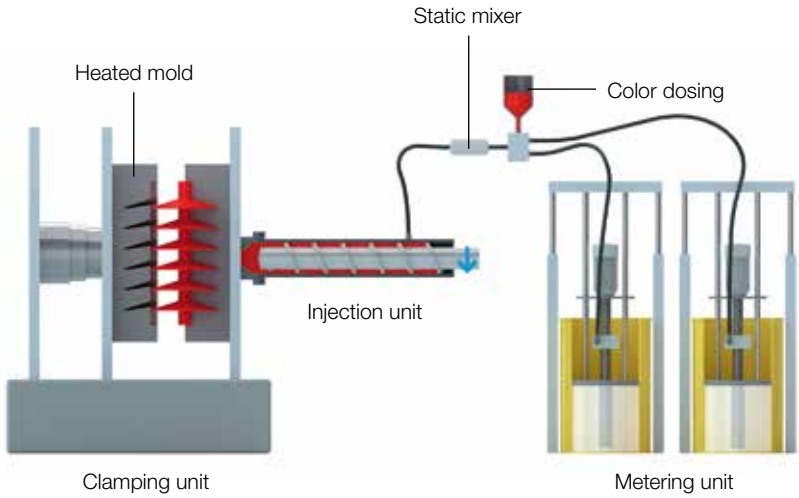
Grades

The latest solid and liquid silicone rubbers (HCR and LSR, respectively) from WACKER are ideal for injection molding.

Characteristics of the Injection Molding Process

- Suitable for large numbers of small to medium-sized parts
- High dimensional accuracy
- High productivity
- High curing temperatures of 120 °C to 180 °C
- High mold clamping force required

LSR Injection Molding



Injection molding is used to process liquid silicone rubber grades. This method is used to manufacture comparatively thin-walled components. Liquid rubber injection molding is ideal for terminations, cable joints, connectors and other mass-produced components. Often, several layers are produced in sequence.

Liquid rubber is always processed and fed by means of mixing and metering equipment.

WACKER Technical Center

Our Technical Center (Technikum) offers modern production facilities suitable for both extrusion and injection molding, where customers can test prototypes and new products. Plus, we will advise you at your premises.

6.2 LOW-PRESSURE MOLD FILLING

Grades

Room-temperature vulcanizing, two-component silicone rubbers (RTV-2) and certain low-viscosity liquid silicone rubbers (LSR and POWERSIL® XLR®) were specially developed by WACKER for this technology.

Characteristics of the Low-Pressure Mold Filling Process

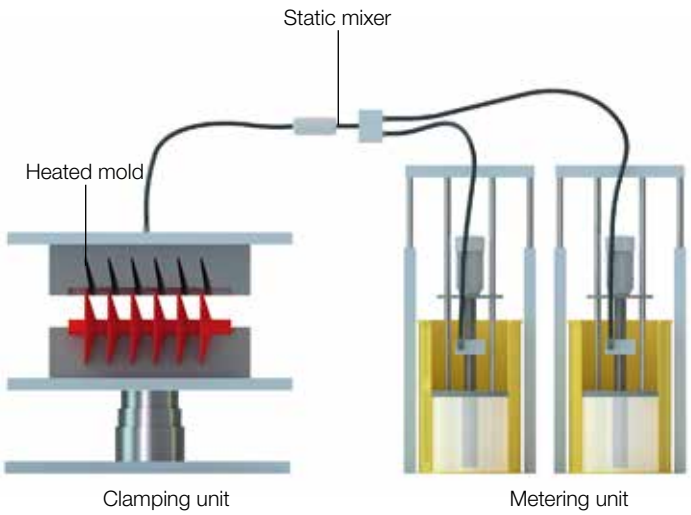
- Cost-efficient process for prototypes, large-volume parts, and small series
- Low curing temperatures from room temperature to 120 °C
- Requires a relatively low mold clamping force
- Medium capital outlay

Low-pressure mold filling (or casting) is especially suitable for large-volume silicone moldings, such as high-voltage cable joints or hollow-core insulators. A low-viscosity silicone rubber with good flow properties is generally used in such cases. This guarantees a high volumetric flow rate and reliable, bubble-free production.

RTV-2 silicone rubbers, low-viscosity liquid rubbers and so-called extra liquid rubbers (POWERSIL® XLR®) can be processed using simple casting techniques together with mixing and metering equipment.

Low-pressure mold filling involves filling the mold with low-viscosity liquid rubber directly from the mixing and metering equipment.

Low-Pressure Mold Filling



Process Consultation with WACKER Process Engineers

The correct choice of silicone rubber depends on many factors, including the manufacturing process, volume, mold and quantities. Our specialists will gladly help you find the most cost-effective solution. Your WACKER consultant will be happy to advise you.

6.3 EXTRUSION

Extrusion is the most efficient method of producing profiles that are subsequently cured without pressure. This process is the most typical for the production of cables, but is also suitable for slip-on or cold-shrink cable joints, for encapsulating GRP rods and tubes, and for hollow-core insulators produced by spiral extrusion.

Solid silicone rubbers can also be processed by extrusion. Special peroxide or addition-curing grades must be used to permit subsequent pressureless curing.

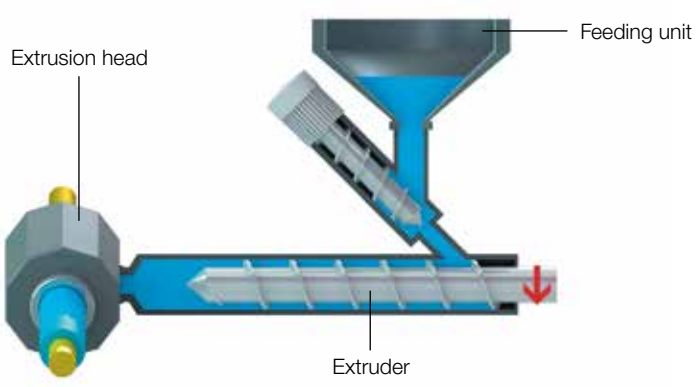
Grades

WACKER has developed special high-temperature-vulcanizing (HCR) silicone rubbers for extrusion. There is a choice of insulating, electrically conductive, or HCR grades with a high dielectric constant, depending on the application.

Characteristics of the Extrusion Process

- This process is suitable for simple geometries and for co-extrusion
- Efficient method of manufacturing profiles
- Suitable peroxides are Crosslinkers E and C6. However, modern extrusion silicones are cured with a platinum catalyst.

Extrusion



**Extrusion (shown here schematically) is used to manufacture state-of-the-art insulating components in modified molds.
For example, repeated extrusion is suitable for the production of tubular components used in cable accessories.**

6.4 CROSSLINKING OF EXTRUDATES

Extrudates are usually crosslinked via vertical or horizontal heating zones, with or without pressure. Silicone rubber can also be crosslinked in a salt bath, though this option is rarely used.

Crosslinking in Heating Zones without Pressure

Tubing, cables and profiles are usually crosslinked in a heating zone (at 200 – 500 °C) without the application of external pressure. Horizontal or vertical heating tunnels are heated by means of resistance heaters, infrared heating bars with reflectors, hot-air systems or ceramic dark radiators. The extrudates are conveyed on sheet-steel or mesh conveyor belts. The conveyor belts run on movable deflector rolls to compensate for the thermal expansion of the belt. Their velocity can be regulated. The conveyor belt return should be located in the heating tunnel to prevent excessive cooling. If this is not possible, use covers to prevent rapid heat loss. To avoid pressure marks resulting from the conveyor belt, a shock tunnel can be fitted upstream in horizontal heating zones to pre-vulcanize the parts at about 600 °C. In many instances, it is preferable to extrude vertically using an extruder head deflected through 90°. This prevents belt pressure marks, so that even very soft materials can be easily processed.

INNOVATIONS:
MAKING GOOD INSULATING MATERIALS EVEN BETTER

WACKER silicone specialists continuously research new methods and possible applications, to meet the continuing inexorable growth in global power consumption. This requires silicone insulating materials that can be manufactured even more efficiently and are also durable and environmentally friendly.

New Methods of Field Grading

WACKER is developing innovative materials that can be used for new field-grading techniques. Possible applications include cable accessories and insulators.

Future-Oriented Curing Technologies

The numbers of silicone composite insulators and silicone cable accessories have been rapidly increasing. Commonly used methods of curing silicone rubbers for electrical engineering components are approaching their limits. There is already a demand for even higher processing speeds. WACKER is always looking for new solutions. One future-oriented curing technology for the transmission and distribution industry is UV curing of a new, highly tracking-resistant silicone elastomer.

Researching New Applications

Future applications are understood to be long-distance DC lines for the transmission of electrical power. WACKER's contribution is to optimize insulation materials to achieve an even better performance under DC voltage compared to already existing systems.

Acknowledgement:
We are extremely grateful to our customers for having kindly provided the images in this brochure:

Beijing Jiumen Power Co.,Ltd.
Brugg Kabel AG
Cellpack GmbH
Elektrokeramik Sonneberg GmbH (SEVES)
Lapp Insulators GmbH
PFISTERER SEFAG AG
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EXPERTISE AND SERVICE NETWORK ON FIVE CONTINENTS

• Sales offices and production sites, plus 22 technical centers, ensure you a local presence worldwide.

WACKER is one of the world's leading and most research-intensive chemical companies, with total sales of €5.3 billion. Products range from silicones, binders and polymer additives for diverse industrial sectors to bioengineered pharmaceutical actives and hyperpure silicon for semiconductor and solar applications. As a technology leader focusing on sustainability, WACKER promotes products and ideas that offer a high value-added potential to ensure that current and future generations enjoy a better quality of life based on energy efficiency and protection of the climate and environment.

Spanning the globe with 5 business divisions, we offer our customers highly-specialized products and comprehensive service via 25 production sites, 22 technical competence centers, 12 WACKER ACADEMY training centers and 50 sales offices in Europe, North and South America, and Asia – including a presence in China. With a workforce of some 17,000, we see ourselves as a reliable innovation partner that develops trailblazing solutions for,

and in collaboration with, our customers. We also help them boost their own success. Our technical centers employ local specialists who assist customers worldwide in the development of products tailored to regional demands, supporting them during every stage of their complex production processes, if required.
WACKER e-solutions are online services provided via our customer portal and as integrated process solutions. Our customers and business partners thus benefit from comprehensive information and reliable service to enable projects and orders to be handled fast, reliably and highly efficiently.
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All figures are based on fiscal 2015.

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