



# Silicone rubber

## for electrical insulators

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*Jim Goudie*  
Dow Corning Corporation  
USA

**M**ost electric power transmission is done via overhead lines, with insulators providing mechanical support and electrical protection. The two predominant designs are suspension- and post-type, both characterized by angled 'sheds' that direct water off the device and maximize the leakage distance between line and tower. (Leakage distance is the shortest path along the surface of the insulator from conductor to ground.)

Ceramic and glass have long been the materials of choice for high-voltage insulators and lightning arresters, offering good resistance to electrical stress and outdoor exposure without significant deterioration. The pros and cons of these materials are well known, and their use is addressed in acknowledged international standards.

*The market for composite insulators is growing steadily, both in long-rod line applications and hollow core station insulators. Composite designs typically use engineered polymers which offer higher mechanical strength, greater design flexibility, reduced weight, and lower breakage rates than ceramic components. The emerging shift to composites adds new importance to the debate over which polymeric material should be used for the housing. Insulator field experience and extensive, multi-stress lab testing of different elastomer formulations have shown silicone's unique surface behavior to be an advantage in these applications*

In the past decade, however, there has been a dramatic increase in the use of composites for a variety of applications, ranging from 500kV transmission line insulators and lightning arresters to cable accessories. Composite designs generally employ a fiberglass rod or hollow core for mechanical strength, with an outer housing made from either silicone rubber, EPDM or EPR.

Among their advantages, composite designs offer lighter weight, less breakage, improved seismic performance and more flexibility in design than ceramic insulators. These features can translate into lower installation cost, greater durability and more aesthetically pleasing line design.

### Insulator stress

Insulator service life can be affected by electrical, mechanical and environmental stresses. The greatest physical threats are generally mechanical loads, UV exposure and vandalism. Airborne contamination can also be a serious problem, as it leads to electrical discharge. Atmospheric contamination and moisture can form a conductive film, leading to leakage current, dry band arcing and eventually flashover, which is a fault to ground over the insulator.

Leakage currents increase as the material's surface loses its hydrophobicity and surface resistance over time, which happens in several ways. Ceramic glaze can be eroded by windblown sand and dirt, whereas resilient polymer surfaces are less susceptible to erosion from such abrasive particles.

### Surface contamination

One of the biggest problems in outdoor applications is airborne contamination that settles on the insulator surface. In some cases, these airborne particles are of natural origin, such as in a coastal region exposed to salt spray or ocean fog. Industrial sources, agricultural spraying and automotive exhaust can also contribute to reduced water

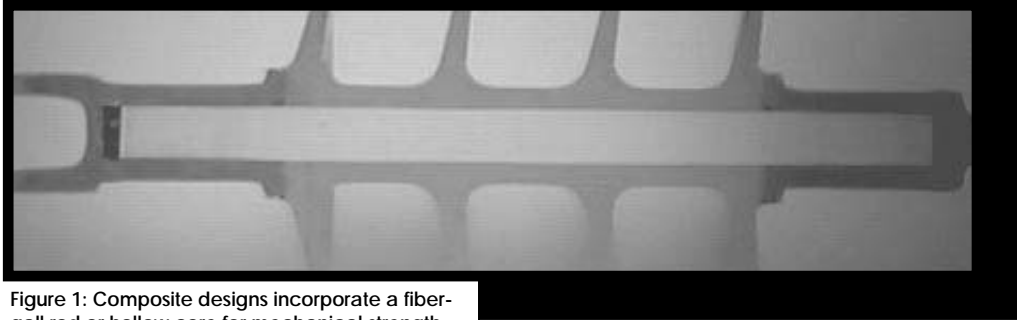


Figure 1: Composite designs incorporate a fiberglass rod or hollow core for mechanical strength

repellency and diminished electrical performance. Both ceramic and composite designs are subject to the build-up of contaminants.

When contamination build-up is exposed to moisture, an electrolytic film can develop, leading to excessive leakage current, dry band arcing and eventually to flashover. Coastal environments have a particular problem, as the weather creates cycles of contamination followed by high humidity or fog. Such were the conditions when Florida Power and Light experienced more than 170 outages over a single nine-day period in 1991 [1].

The basic mechanism for contamination-induced flashover on static surface materials like porcelain can be summarized as follows [2].

### Contamination/flashover mechanism

1. Contaminant deposition;
2. Conductive water film;
3. Leakage currents;
4. Local heating;
5. Dry-band formation;
6. Dry-band arcing;
7. Arc (and band) extension;
8. Air ionization;
9. Flashover.

In the event of a flashover, the intense localized energy causes an abrupt temperature elevation. If the arc is severe enough, a ceramic or glass insulator will fracture. During a less severe incident, the leakage currents frequently dry into

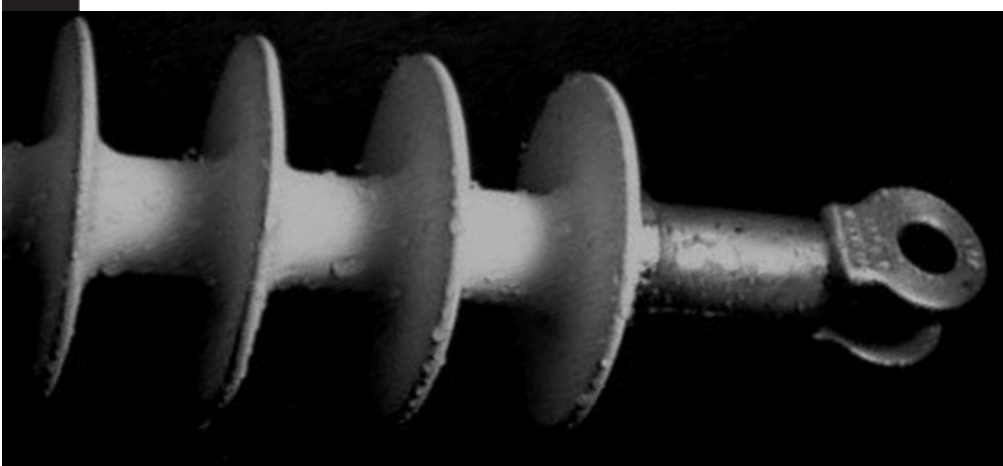
“When insulators are grouped together, such as in a substation, pressure washing or hand cleaning can be very difficult to accomplish”

pathways that later lead to dry-band arcing, which can be severe enough to damage the housing material.

Utilities have developed a number of other techniques for coping with contamination. High-pressure washing, silicone dielectric greases and RTV silicone coatings have all been applied to ceramic and glass insulators with some success. Each method has its drawbacks, however.

Washing of insulators is labor-intensive, and can be dangerous to workers, since it is generally impractical to shut down service. Results are sometimes inadequate – no amount of cleaning would have removed contamination fast enough to prevent the 1991 FP&L outages, for example. When insulators are grouped together, such as in a substation, pressure washing or hand cleaning can be very difficult to accomplish while the station is energized, due to the clearances that must be maintained. Washing can be economical on easily accessed lines, but can be very impractical in remote areas or difficult access locations. Silicone greases offer a longer-lasting solution, as silicone fluid within the grease formulation encapsulates contaminants, rendering them nonconductive and retaining a hydrophobic surface. However, the grease will eventually be overwhelmed by contamination, at which time it must be removed and replaced (generally from three months to five years, depending on the severity of the conditions).

Sprayable RTV silicone elastomers have proven more effective, offering much better long-term resistance to contamination and moisture. Developed from the same product family as construction sealants, the coatings are formulated with



arc resistant additives and dispersed in solvent. This solution offers longer remedial relief from contamination and associated problems, but utilities and OEMs continued to seek a more permanent solution, especially for new installations.

This need has led to the continued development of polymer housings for insulator and arrester designs. In particular, silicone rubber seems to be emerging as a material of choice among insulator specifiers. In fact, nearly every major insulator manufacturer now offers a design with a silicone housing. The increased demand for silicone rubber can be attributed to a general upsurge in composite design use, as well as a growing preference for silicone over other elastomers.

### Performance of silicone rubber

Composite insulators designed with silicone rubber have been found to reduce the need for maintenance in areas of moderate to high contamination. The surface of a silicone elastomer has a unique ability to interact with the contaminant and control leakage

'wettability' of silicone rubber, a phenomenon associated with the increase in surface oxygen content. After a rest period, the material's water-repellency returns. This hydrophobic recovery is thought to result at least in part from the diffusion of low molecular weight PDMS (polydimethylsiloxane) fluid to the surface, as well as a unique ability of the silicone surface to reorient after exposure [3, 4].

This free fluid in silicone rubber is also the key to another important surface characteristic of silicone rubber. The microscopic diffusion of fluid serves to encapsulate contaminant particles and prevent moisture absorption. Migration of the hydrophobic fluid helps maintain a high surface resistance and water-shedding ability.

### Compounding

Silicone compounds for high-voltage transmission line insulators are generally high-consistency rubber (HCR) formulations. Two types of filler are typically used – silica is the reinforcement that lends physical strength to the polymer, while alumina trihydrate (ATH) improves arc resistance.

possible to develop a product that will not only pass the required physical and electrical tests, but also help molders optimize processing techniques for their specific equipment.

### Testing

Test methods designed for ceramic insulators have not shown good correlation with actual service experience when applied to polymeric materials. Existing standards have been designed primarily for testing insulators made from porcelain, a static surface that has no interaction with contaminants; it will readily wet out. To improve the performance of insulators made from such materials, manufacturers simply increase creepage distances. For this reason, they can be tested by continuous arc exposure, which is designed to estimate long-term performance. Unfortunately, the procedure has little resemblance to actual service conditions with silicone rubber units. Silicone sheds control leakage currents to help prevent high-energy dry band arcing from occurring.

Similarly, some tests call for a massive build-up of contamination to be applied to simulate long service, followed by energized exposure to moisture and salt fog. Silicone rubber, however, has low surface energy and causes water to bead up. Its hydrophobic nature helps prevent contaminant build-up, and also allows a rain storm to help clean the surface. Applying a large dose of contamination is an unrealistic condition, one that silicone formulations are designed to avoid. Further, the natural encapsulation of particulates cannot occur if many years' worth of contaminants are applied all at once for a short-term test.

Developing new test methods and equipment specifically for polymeric materials is currently a priority for utilities, universities and research organizations. In one advancement, the Electric Power Research Institute (EPRI) High-Voltage Transmission Research Center in the USA has developed a fog chamber method that allows testing with variable contamination levels. A specific insulator design can be subjected to a number of stresses that closely resemble the actual service environment.

Despite the test refinements, much of the industry still relies on procedures developed decades ago for porcelain. While some manufacturers have adopted specific techniques to evaluate polymer compounds, they can vary widely from one company to another. Differences in process conditions among fabricators also complicate the development of standard compounds for molding HV insulators. As a result, some silicone suppliers have opted for a custom formulation approach.

The industry is rapidly accepting tests that appear to correlate better to field service



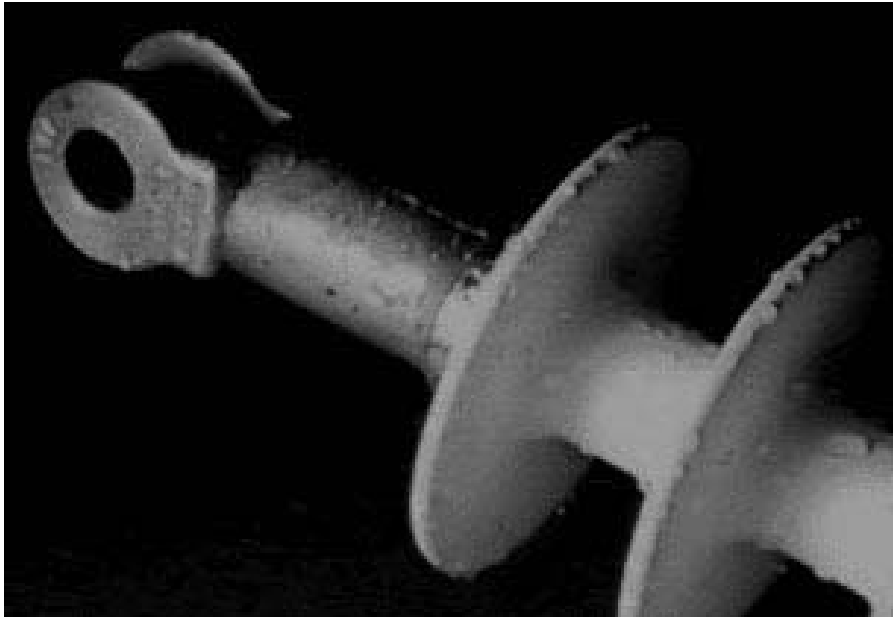
Figure 2: Airborne contamination is a major problem in high-voltage applications

currents, interrupting the normal process that leads to contamination-induced flashover. Improved control of leakage current helps prevent dry band arcing and subsequent flashover.

Silicone has demonstrated better hydrophobicity and lower surface energy than most organic polymers. The surface properties of silicone are such that the material recovers its hydrophobicity between contamination and/or corona episodes, while other materials progressively deteriorate. Corona exposure temporarily increases the

Filler treatments, pigments and/or cure agents may also be part of the formulation. The polymer-filler combination is important in formulating silicone compounds for molding insulators and other components.

Processing, physical properties and electrical performance are all affected by the molecular weight and structure of the polymer, as well as filler type, size, shape, surface treatment and residual catalyst or contaminants. The polymer-filler combination is critical. By custom compounding silicone materials for specific criteria, it is



experience. These tests put emphasis on the ability of an insulator or material to control leakage currents under reasonable simulated environmental conditions. Multiple stress tests with realistic cycles of energized exposure to ultraviolet radiation, moisture and contamination seem to be a much more accurate indicator of limitations and capabilities of a design or material [5].

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Numerous studies have been conducted on molded silicone rubber in the form of rods or finished insulators as well as silicone RTV-coated rods and ceramic insulators. They consistently show silicone's dramatic advantage in controlling leakage current versus porcelain and EPDM.

One recent study compared surge arrester housings made of silicone rubber, EVA, EPR, and an EPDM/silicone blend



Figure 3: Insulators and arresters molded from silicon rubber are gaining increasing recognition

elastomer. This 6,500-hour test alternated periods of salt fog, drying, fog and rain on actual energized components in a large environmental chamber. The leakage currents for the organic materials typically measured four to five times higher than the silicone sample, even in lower creepage distance designs. This lower leakage level results in less dry band arcing and less power

dissipation (watts loss). Therefore, the silicone rubber is exposed to less arcing and should be expected to provide a longer life [5].

In another test – a nine-year study at Chalmers University of Technology in Sweden – the effectiveness of various molded composite insulators was compared to porcelain and glass. The test concluded that “... the silicone rubber insulator had very low current pulses in the range of 6mA under severe weather conditions...” while EPDM and porcelain insulators showed very high discharge activity [6].

Current data indicates that highly-filled elastomers offer the best arc resistance in most tests, and silicone suppliers generally try to maintain as high a level of filler loading as possible and still achieve good processing characteristics. However, if a utility or insulator manufacturer insists on passing conventional tracking wheel tests or other standards that do not allow recovery time between stress incidents, it forces the compounder to reduce the level of alumina trihydrate filler.

## New material development

The newest generation of silicone insulators builds on the progress of the last 25 years. Much of the current study focuses on surface chemistry to better understand the effects of long-term aging and electrical discharge. The analytical tools have become more sophisticated, as researchers use Electron Microscopy (EM), Electron Spectroscopy for Chemical Analysis (ESCA), Scanning Auger Microprobe (SAM), and other techniques to make precise surface measurements at varying depths and angles.

The custom compounding approach to serving this material market is an advantage to molders, since by nature it allows material formulation changes to suit the specific component, service environment, and manufacturing process. There is little of the resistance to change which might be found in suppliers with a standard product line, and insulator manufacturers are able to reach a level of performance/processing efficiency that is difficult to duplicate with off-the-shelf materials. A custom compounded formulation requires fewer process adjustments during fabrication, as it has been formulated with that specific process in mind. Because of the wide differences between individual formulations, however, generalizing about the performance of silicone as a material class is not appropriate.

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