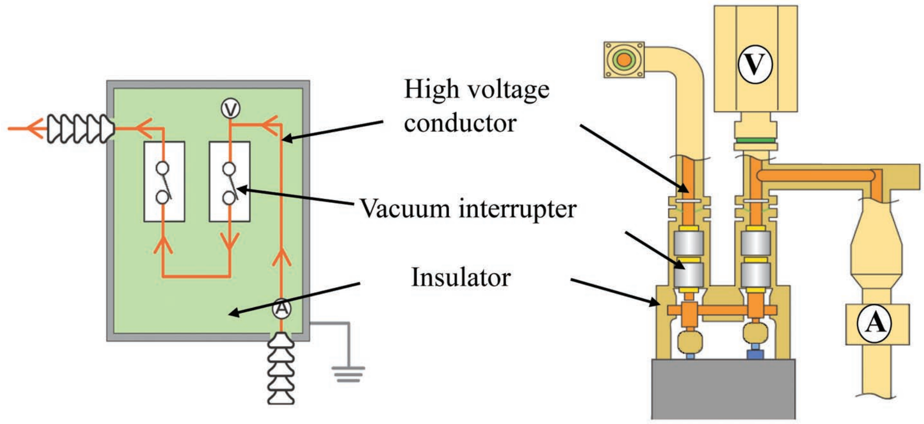
by Y. Ohki

Development of a High-Performance Casting Method for Solid-Insulated Switchgears



C-GIS		SIS
SF_6 gas	Insulator	Epoxy
VI , SF_6 gas, etc.	Switch	VI

Figure 1. Comparison between typical cubicle-type gas-insulated switchgear (C-GIS) and solid-insulated switchgear (SIS). VI: vacuum interrupter, V: 24 or 36 kV, A: 600–2,000 A.

Switchgear is an essential component of electric power networks for transmitting and distributing power and is installed in all related facilities. More than 100 years have passed since it was introduced. Air-insulated switchgear, which was vulnerable to dust and humidity, was used until the 1970s. Then a new gas-insulated switchgear (GIS) using sulfur hexafluoride (SF_6) gas, much superior in electrical insulating performance, was developed. However, in recent years SF_6 has been designated as a greenhouse gas, and the electric power industry has been working to reduce its use. One way is to use high-pressure air for insulation. However, such devices are inevitably bigger than the corresponding SF_6 devices, and they require pressure vessels. Another option is to use solid insulation. The electric strength of a typical epoxy compound is three times that of SF_6, and so smaller body size is practicable in an environmentally friendly solid-insulated switchgear (SIS). However, because of the difference in the coefficients of thermal expansion between ceramic and epoxy compounds, conventional epoxy compounds have insufficient mechanical strength to withstand internal stresses caused by differential expansion. Thus it is necessary to develop a high-performance epoxy compound that can be directly molded into a vacuum interrupter consisting of ceramic tubes.

Figure 1 shows a cubicle-type GIS using SF_6 gas in a pressure vessel, and an SIS using high-performance epoxy insulation. The molded vacuum interrupter in the SIS is easily broken if conventional epoxy insulation is used, as shown in Figure 2. Generally, if the filler content of an epoxy compound is high, its viscosity is high. Consequently product throughput, which depends on molding times, is reduced. In addition, as the thermal endurance improves, the mechanical toughness deteriorates. Thus a trade-off between these properties is necessary.

High-performance epoxy insulation should have (1) superior toughness, bending and tensile strength in the temperature range −5 to 40°C, with occasional short periods up to 115°C, and a service lifetime of at least 20 years, and (2) low viscosity and a long "pot life," i.e., a long period of time during which the resin is usable, so that product throughput is increased.

Kinoshita and coworkers at Toshiba synthesized epoxy insulation with these properties by using (a) regular-size and fine spherical silica particles, as shown in Figure 3, (b) two types of rubber with an acrylic acid core and a urethane shell, and (c) three types of filler, two consisting of silica particles and the third of a rubber core-shell, mixed at an optimum ratio into the base epoxy resin.

Figure 2. Test samples molded from conventional epoxy compounds.

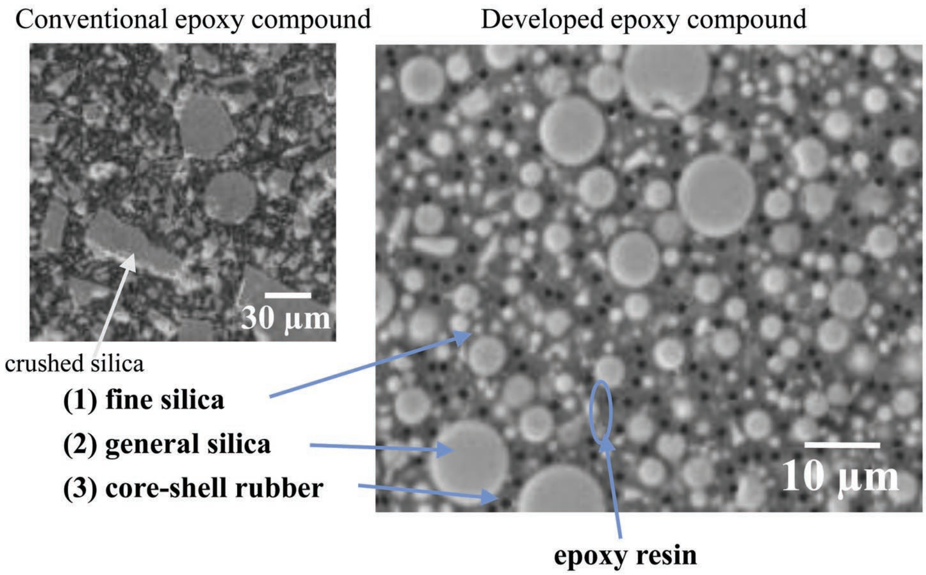


Figure 3. Comparison of conventional and developed epoxy compounds. (1) fine silica particles, (2) regular silica particles, (3) core-shell rubber.

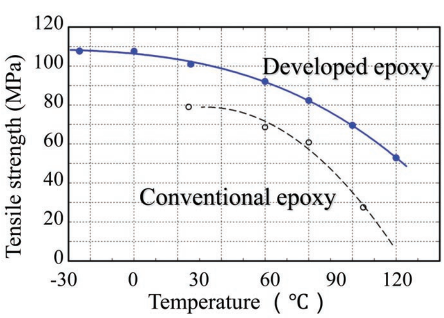


Figure 4. Tensile strength as a function of temperature.

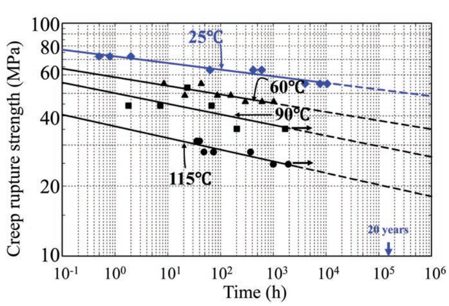


Figure 5. Creep rupture strength of the developed epoxy compound as a function of time at various temperatures. (Maximum design stress is 20 MPa for 20-year service life.)

Fine spherical silica has a larger adhesive-surface area than regular silica and, therefore, adheres better to the epoxy resin. At 115°C, the maximum temperature specified for switchgears, the tensile strength of the high-performance resin is higher than the design specification of 55 MPa, as shown in Figure 4, and the thermal expansion coefficient is smaller, approaching that of copper. Mixing fine-size and regular-size silica particles in the optimum ratio decreases the viscosity of the epoxy compound, ensuring good throughput for the insulated components, and the core-shell rubber increases the toughness of the epoxy compound. The creep rupture strength shown in Figure 5 implies a service lifetime of the resin longer than 20 years at 115°C. Thus the high-performance epoxy compound possesses high mechanical strength, high electrical insulation strength, good thermal endurance and low viscosity, and can be molded without cracking.

An SIS contains many epoxy-molded parts, e.g., connecting conductors, base conductors, and vacuum interrupters. In the conventional casting method, the epoxy compound must be allowed to cure slowly for about 12 hours after being poured into the mold, to ensure low residual mechanical stress, and the casting must be demolded manually after the curing, as shown in Figure 6. This procedure is time consuming and expensive. To produce thermoset epoxy compounds in about 1 h, an innovative technology using automatic pressure gelation is required. The most difficult problem in using automatic pressure gelation for SIS is achieving accurate resin curing control during the mold process at high temperature. Epoxy compounds usually change rapidly from liquid through gel to solid when cooling and shrink on the change from gel to solid. This shrinkage must be compensated for immediately or the parts will develop defects and exfoliation will occur between the epoxy compound and the conductors. Kinoshita and his collaborators used a customized automatic gelation machine in their factory, as shown in Figure 7, and developed rapid production technology incorporating accurate temperature control. They also simulated the flow and curing of the resin compound to optimize the manufacturing conditions.

Development of the high-performance epoxy compound and automatic gelation system realized the world's first 24-kV SIS in July 2002 and first 36-kV SIS in May 2004. As shown in Table 1, by reducing the number and weight of the parts, and avoiding the use of SF_6 gas, it was possible to produce a 24-kV

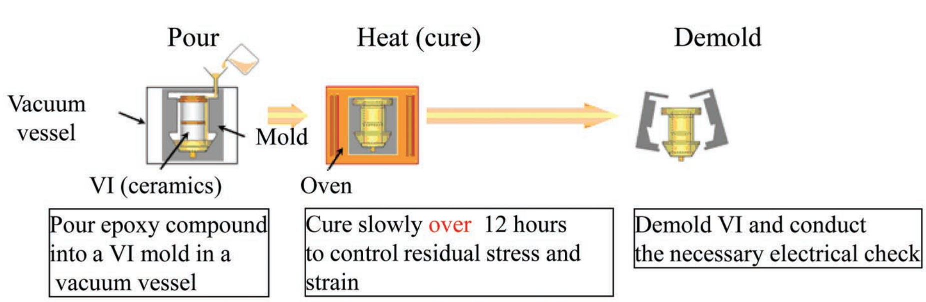


Figure 6. Conventional casting procedure. VI: vacuum interrupter.

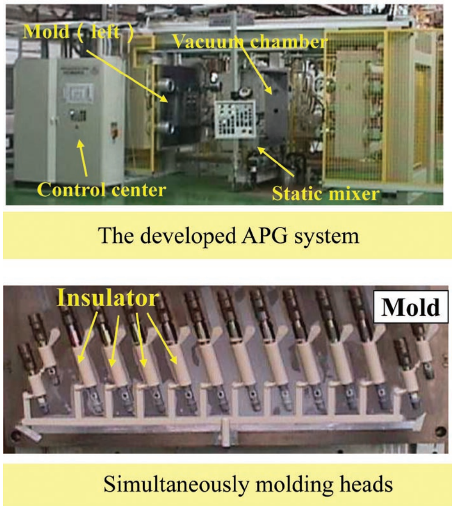


Figure 7. The developed automatic pressure gelation (APG) system with multiple molding heads.

SIS that is smaller and more reliable than a cubicle-type GIS. In addition, its CO_2 equivalent emission is 62% less than that of a cubicle-type GIS of the same class, as shown in Figure 8. Since 2002 Toshiba has installed many environmentally friendly SIS components throughout Japan. The new epoxy compound and the automatic gelation method have been applied to the production of other switchgear insulating parts, with increased product throughput, reduced cost, compactness, and high reliability.

Table 1. Comparison of C-GIS and SIS.[1]

Item	C-GIS	SIS
SF_6 gas	5 kg	0 kg
Weight	1,900 kg	850 kg
Number of parts	2,500	1,200
Loss of power	0.5 kW	0.16 kW
Volume	2.7 m^3	1.7 m^3

[1]C-GIS: cubicle-type gas-insulated switchgear; SIS: solid-insulated switchgear.

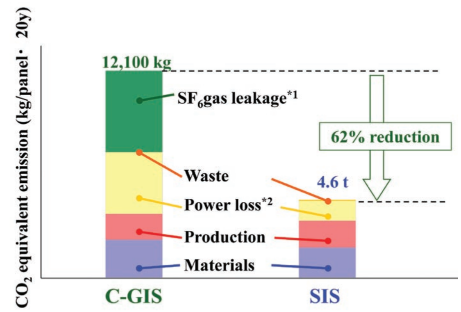


*Figure 8. Estimation of CO_2 equivalent emission by life cycle assessment. *1: Leakage rate: 0.2 wt%/year, global warming potential: 23900; *2: Operating rate: 30%.C-GIS: cubicle-type gas-insulated switchgear; SIS: solid-insulated switchgear.*

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