Environmentally Friendly Material Technology for Power Distribution, Switching and Control Equipment Components

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ABSTRACT

With distribution, switching and control equipment components, requirements for employed materials are becoming stricter year by year due to the tightening of environmental regulations such as the RoHS Directive and to address environmental issues including global warming.

Concerning metal materials, Fuji Electric has worked on eliminating Cd from contacts and realized it by achieving the wear resistance and temperature rise targets. For polymeric materials, we have successfully replaced thermosetting resin in insulating parts with thermoplastic resin and reduced waste in thermosetting resin.

1. Introduction

For power distribution, switching and control equipment components, it has become essential to develop products satisfying global requirements. Beginning with the RoHS Directive*1 which came into effect in 2003, regulations restricting hazardous substances are spreading in terms of environmental protection and healthcare.

This paper describes the trend in environmental efforts and the environmentally friendly material technologies for metal and polymeric materials currently developed by Fuji Electric.

2. Trend of Environmental Efforts

2.1 Major EU environmental regulations

From July 2006, the RoHS Directive has made it obligatory to keep the content percentage of six restricted substances of lead (Pb), mercury (Hg), cadmium (Cd), hexavalent chromium (Cr^{6+}), polybrominated biphenyls (PBB) and polybrominated diphenyl ethers (PBDE) to specified extremely low levels or less in the products in Categories 1 to 7 and 10 (such as household appliances and toys) ahead of other categories. Power distribution, switching and control equipment components are classified as monitoring and control instruments and became subject to the directive officially

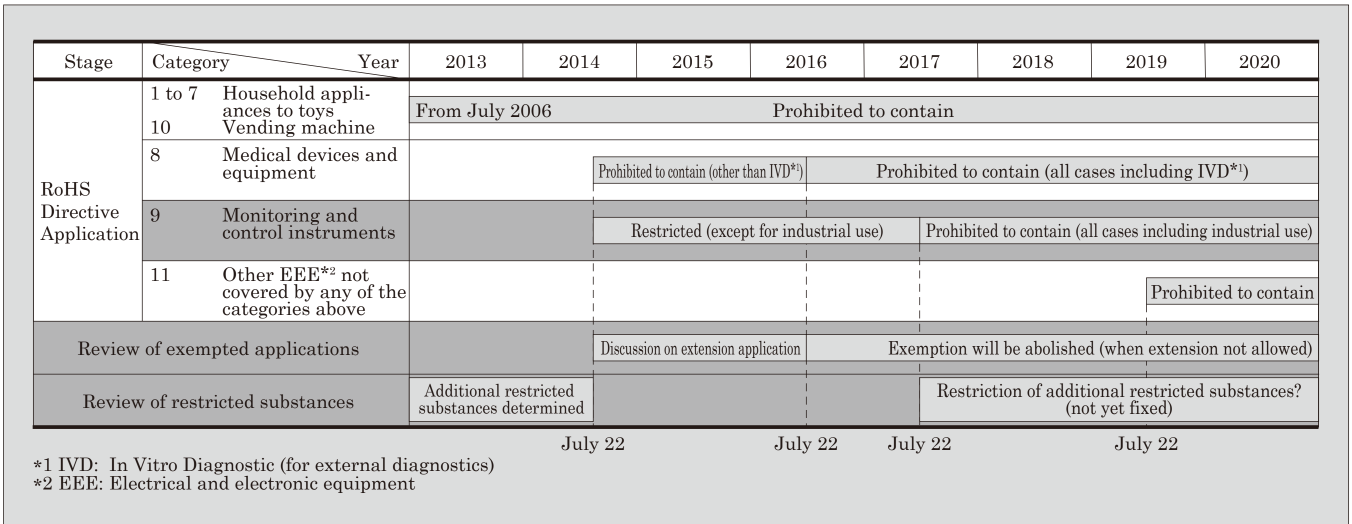

Fig.1 Time schedule for revising RoHS Directive

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*1: RoHS Directive: European Union (EU) Directive regarding restrictions of the use of certain hazardous substances contained in electrical and electronic equipment from July 2014 (see Fig. 1).

2.2 Trend of environmental efforts in Japan

In Japan, companies are required to reduce power consumption and CO_2 emissions through their products, aiming to construct an environmentally friendly economic society to solve global warming and other environmental problems. Moreover, the "Basic Act on Establishing a Sound Material-Cycle Society" stipulates that companies should promote 3R (Reducing waste generation, Reusing products and parts and Recycling wastes as raw material) in order to construct a sound material-cycle society while encouraging the recycling of non-ferrous metal resources and developing alternative materials in order to secure a stable supply of mineral resources.

This trend of promoting 3R is sharply accelerating also for polymeric materials. As for thermosetting resin parts which were discarded as industrial wastes, efforts have been made including reducing wastes amount, changing over to thermoplastic resin, recycling in production sites and reusing or recycling recovered parts.

3. Environmental Efforts for Metal Materials

3.1 Fuji Electric's previous efforts

As for the substances restricted by the RoHS Directive, such as chromate containing Cr^{6+} and Pb containing solder, Fuji Electric and its affiliated manufacturers developed alternative technologies and switched to using them in 2005 through 2006(1). However, we continued using Cd contained components in some products of power distribution, switching and control equipment components that required high electric performance and long operating life. This was because Cd was exempted from the restriction by the RoHS Directive [Annex III-8(b)], and that AgCdO contacts had an excellent balance of the characteristics required of electrical contacts such as wear resistance and welding resistance.

The use of AgCdO contacts, however, is anticipated to be prohibited after the RoHS Directive exemption provisions are reviewed. Consequently, we are moving forward with changing all contacts in power distribution, switching and control equipment components to Cd-free materials ahead of the regulation.

3.2 Changeover to Cd-free contacts in low-voltage circuit breakers

Contacts are the heart of power distribution, switching and control equipment components and they are required to have a "stable open/release mechanism" and "stable low contact resistance" as shown in Fig. 2. In order to provide these characteristics, we need to optimize the product structure, its electrical and mechanical characteristics and mass productivity (ease of assembly, cost). For contacts, however, one characteristic is often improved at the sacrifice of the others. It is important to attain a proper balance of characteristics.

Some of the Cd-free contacts applicable to low-voltage circuit breakers are silver tin oxide ($AgSnO_2$) contacts and silver tungsten carbide/silver tungsten carbide carbon (AgWC/AgWCC) contacts (see Table 1).

We conducted a product evaluation for these two types of Cd-free contacts. As a result, we confirmed that $AgSnO_2$ contacts showed no problem in wear resistance and welding resistance and that they were applicable to products with a low-to-middle breaking

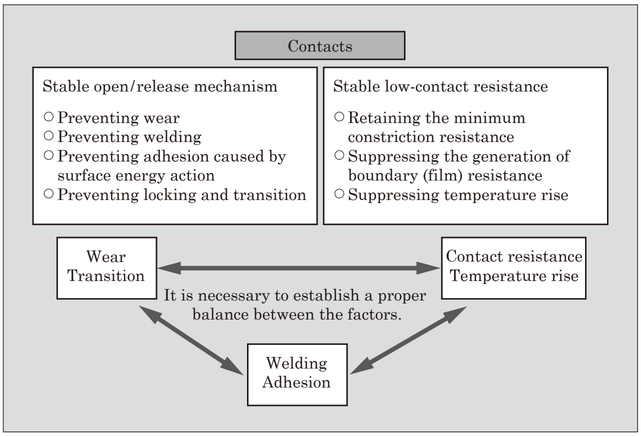


Fig.2 Basic characteristics of contacts

Table 1 Cd contact and Cd-free contact for low-voltage circuit breakers

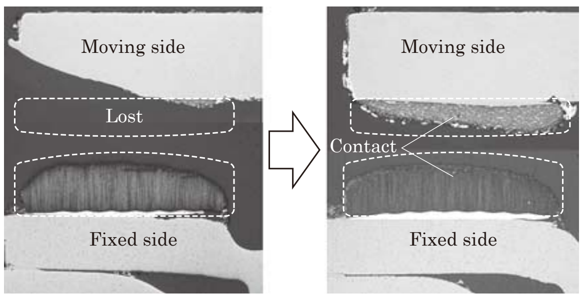
Contact material	Characteristic	Performance*			Applicable current range
		Wear resistance	Welding resistance	Contact resistance	
AgCdO	Cd contacts have been used for over 40 years. Their performance has been greatly improved by internal oxidation and other methods. The sublimation of CdO provides advantageous temperature characteristics.	○	○	○	Small to medium current
$AgSnO_2$ +α	This is the prime candidate for replacing Cd contacts. Their performance has been greatly improved with In and other additives.	◎	○	△	
AgWC/AgWCC	A large amount of W, which has a high melting point, has been added to improve the arc resistance. Moreover, the transformation into WC suppresses the oxidation of W. The combination with Ag-WC-C used for a fixed contact improves contact resistance. The problem is that Ag-WC-C contacts wear quickly.	△	◎	○	Medium to large current

*Performance ◎: excellent, ○: favorable, △: somewhat inferior capacity. As for AgWC contacts, those having the same composition as the contacts already used in the products with a large current rating could not satisfy the wear resistance and other specifications.

Hence we tried to improve the wear resistance and temperature characteristic by making the constituent particles finer and ensuring a more uniform distribution at a higher density while reducing the thermal load placed on the contact by redesigning the open/release mechanism, for both moving and fixed contacts.

Figure 3 shows photographs of the cross-section surfaces of the contacts before and after the composition improvement taken after a interruption test finished. Before the improvement, the fixed contact was lost, whereas after the improvement, the contact remained. Moreover, we parameterized the thicknesses of the moving and fixed contacts respectively and investigated their relationship with the wear after an interruption test to optimize their volume.

Figure 4 shows the resultant relationship between the arc energy at breaking and the volume wear ratio of the moving contact for samples of AgCdO and AgWC/AgWCC contacts.



(a) Before improvement (b) After improvement

Fig.3 Photographs of the cross-sectional surfaces of contacts after an interruption test

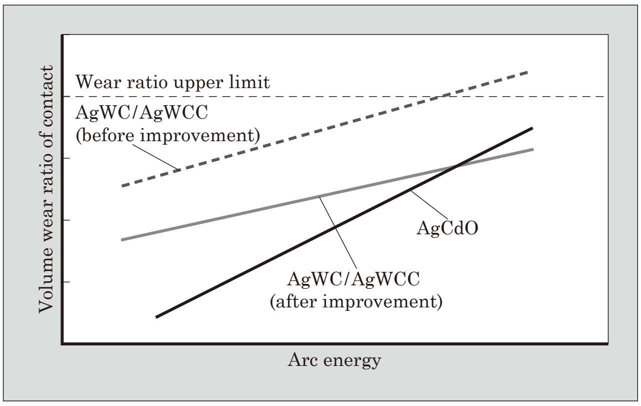


Fig.4 Arc energy vs. volume wear ratio of moving contacts at breaking

The AgCdO contact showed the least wear and the AgWC/AgWCC contact before improvement was very much inferior to AgCdO contact. The improved AgWC/AgWCC contact, however, showed no difference from the AgCdO contact in the region of high arc energy, proving that there is no problem with its wear resistance.

As for the problems of welding and temperature rise, we could satisfy the product specifications by optimizing the WC and C concentration.

4. Environment Effort for Polymeric Materials

4.1 Changeover to thermoplastic resin for the parts of the "SK Series"

The changes in the plastic materials used for small magnetic contactors are shown in Fig. 5. For the "S Series" released in 1965, thermosetting resin (phenol

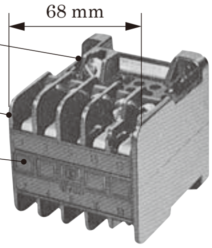
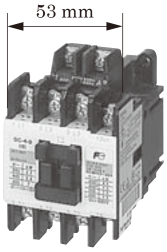
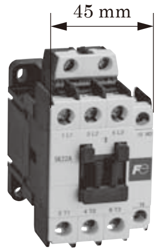
Series	S Series	SC Series	SK Series
Appearance			
Volume	338 cm^3	343 cm^3	292 cm^3
Lower frame	Thermosetting resin	Thermoplastic resin	Thermoplastic resin (Engineering plastic)
Upper frame	Thermosetting resin	Thermosetting resin	Thermoplastic resin (Engineering plastic)
Contact support	Thermosetting resin	Thermosetting resin	Thermoplastic resin (Super-engineering plastic)
Sales period	1965 to 1988	1988 to present	2011 to present

Fig.5 Changes in the plastic materials used for small magnetic contactors

Table 2 Characteristic comparison among plastic materials

Plastic material	Strength	Thermal resistance (melting point)	Recycling
Thermosetting resin	Medium	No effect	Not possible
Thermoplastic resin (Engineering plastic)	High	200°C to 270°C	Possible
Thermoplastic resin (Super-engineering plastic)	High	290°C to 350°C	Possible

resin) was used for the lower frame, upper frame and contact support parts. For the “SC Series” released in 1988, we promoted the use of thermoplastic resin, which allowed thin-wall molding, for the lower frame, in order to achieve the productivity improvement (recycling) and downsizing of the parts.

For the “SK Series,” it was essential to use thermoplastic resin also for the upper frame having current-holding function and the contact support in order to meet the market demand of further downsizing. To use thermoplastic resin for the parts, we needed to improve its heat-resistant characteristics (ability to retain shape, wear resistance) against the heat and arc generated when an overload current flows.

We reduced the heat generated by a current flow in the “SK Series” by increasing the conductivity and cross-sectional area of the contact base that is a current-carrying part. Furthermore, we satisfied the heat-resistant characteristic of the contact support, which is a current-holding part, by applying thermoplastic resin with a high melting point that does not cause melting or deformation but provides good wear resistance. We also achieved downsizing, 15% reduction in volume compared to the “SC Series.” The thermoplastic resins we used are engineering plastics and super-engineering plastics (aromatic nylon, cross-linked nylon). Their characteristics are shown in Table 2.

4.2 Suppressing the waste of insulation shaft “MULTI. VCB”

The “MULTI.VCB” is a middle-voltage circuit breaker designed to improve stability and reliability in a power supply. Its parts are required to have stable strength and voltage resistant capability.

The insulation shaft of the MULTI.VCB (see Fig. 6), in particular, is required to function as mechanical parts that open/close the contact inside a three-phase vacuum valve and ensure insulation among the phases. To satisfy these requirements, the parts are manufactured in a production process where a metal shaft is inserted into thermosetting resin BMC (bulk molding compound material using polyester premix) before compression molding. Although BMC is a material with excellent electrical characteristics, heat resistance, dimensional stability and mechanical characteristics, this material is difficult to recycle, so defective parts are discarded as industrial waste. To solve the problem, we studied a way to reduce the number of defective parts and thus suppress wastes generation.

In the stage of prototyping the insulation shaft in the development of the MULTI.VCB, defects (voids, cracks) were found inside the molded parts, resulting in a pressure resistance failure rate of 40%. We conducted factor analysis on the parts shape, mold structure and molding conditions and implemented improvements shown in Table 3.

As for the fluidity of the material, we optimized the parts shape in ways such as changing the thickness and corner roundness to prevent the formation of a weld line (a line which is formed when resin flows meet) that often causes internal defects in the section where withstand voltage is required.

The insulation shaft mold has three separate phases of insulating parts as shown in Fig. 6. Consequently, appropriate amount of BMC is measured for each phase, placed in the respective mold and molded with compressed pressure and heat. The pres-

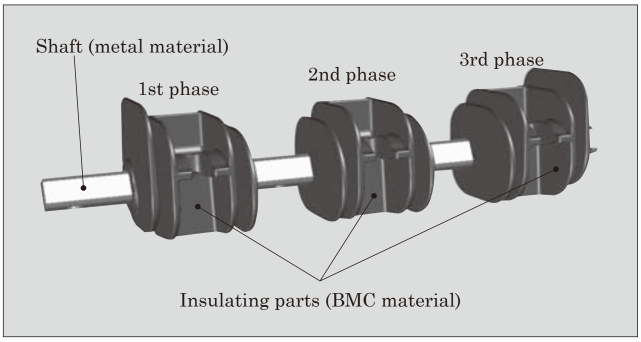


Fig.6 Molded parts on the insulation shaft of "MULTI.VCB"

Table 3 Cause of pressure-resistance failure (internal defects) and countermeasure

Cause	Countermeasure (improving factor)
Fluidity of the material	Shape optimization in the fluidity study (components shape)
Change in the internal pressure due to separate structure	Change of the mold pressurizing method (mold structure)
	Monitoring the mold internal pressure (molding condition)

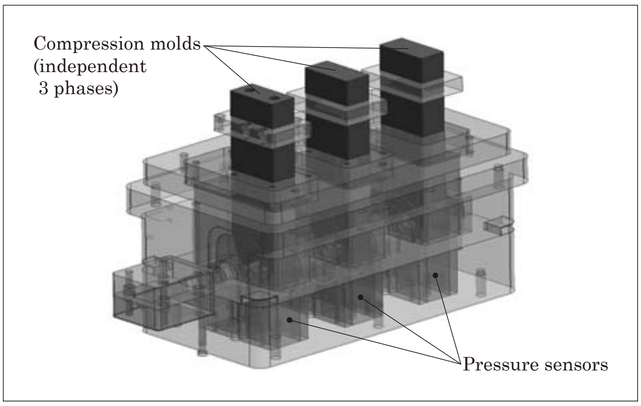


Fig.7 Insulation shaft mold structure

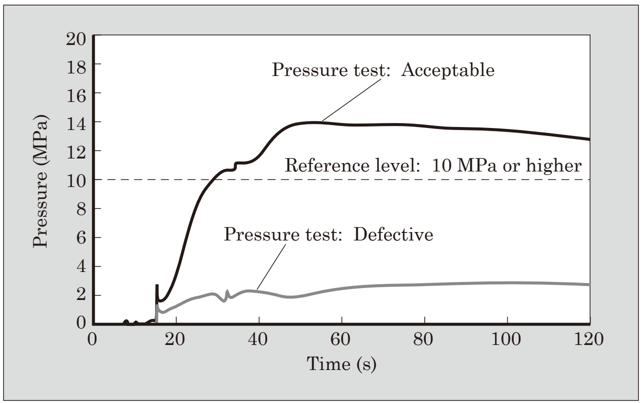


Fig.8 Mold internal pressure

sure applied to each phase varies greatly due to the difference in the amount of material, resulting in defects. Therefore, we adopted a mold structure that enabled independent pressurization of the three phases (see Fig. 7) to stabilize the pressure.

In addition, we embedded pressure sensors in the mold to visualize the internal pressure as shown in Fig. 8 to optimize the molding conditions and set production control values at the production site. In this way, we could reduce the number of defects inside the molded parts.

With these measures, we could completely eliminate the pressure resistance failure rate, which had been 40% in the prototyping stage, by the time of mass production and release and thus have reduced waste and environmental impact.

5. Postscript

The polymeric materials and metal materials used for power distribution, switching and control equipment components are constantly required to provide both environmental resistance and functionality. Consequently, the requirements for material development are anticipated to become more difficult and strict. Fuji Electric will continuously contribute to the realization of a society in which people can live without worry by actively promoting the development of environment-friendly materials and applying them to our products ahead of global laws and regulations.

References

(1) Shiozaki, K. Environmentally Responsive Technology for New Global MCCB and ELCB. FUJI ELECTRIC REVIEW. 2006, vol.52, no.4, p.124-129.

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