Environmentally Responsive Technology for New Global MCCB and ELCB

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1. Introduction

The directive on the restriction of certain hazardous substances (RoHS) was put into effect on February 13, 2003 and was published in the Official Journal of the European Union (EU). The RoHS directive prohibited the usage of six types of substances (lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB) and polybrominated diphenyl ether (PBDE)) by July 1, 2006.

The impact of this RoHS directive extends beyond the EU, and countries such as China and South Korea are moving toward enacting similar restrictions. In Japan, a law concerning the “Marking of the Presence of Certain Chemical Substances in Electrical and Electronic Equipment” was enacted as JIS C 0950.

The new global MCCB and ELCB (earth leakage circuit breaker) were developed in consideration of the individual environmental regulations of each county.

In the development of new products, the materials used play an increasingly important role. This paper describes, from the perspective of materials used, several environmentally responsive technologies used in the development of the new global MCCB and ELCB.

2. Trends of Regulating Environmental Responsiveness

2.1 Main environmental regulations of the EU

The RoHS directive directly regulates electric and electronic devices, and therefore this regulation attracts most attention from manufacturers of electrical machinery. However, several other regulations concerning electric and electronic devices have been put into effect in the EU, or are slated to be put into effect. Table 1 lists the main environmental regulations. The packaging directive and the ELV directive have already been put into effect, and the EuP directive was

Table 1 Main environmental regulations of the EU

Environmental regulation	Through 2003	2004	2005	2006	2007 and beyond
(1) Packaging directive (package waste directive)	As of July 1, 2001, the total (1) lead, (2) mercury, (3) cadmium, and (4) hexavalent chrome shall not exceed 100 ppm.				
	Recovery rate of 60% and recycling rate of 55 to 80% to be achieved by December 31, 2008.				
(2) ELV directive (end-of-life-vehicles directive)	Use was decided on May 22, 2002 / As of July 1, 2003, usage of (1) lead, (2) mercury, (3) cadmium, and (4) hexavalent chrome shall be prohibited in cars for sale.				
	However, batteries are exempt. The start of the regulations may be delayed for some components.				
(3) WEEE directive (waste electrical and electronic equipment directive)	Construction of recovery and recycling system		Label shall be compliant by Aug. 13, 2005. Recycling costs to be borne.		
	Achieved regeneration rate and recycling rate			Dec. 31, 2006	
	Targets nearly all electrical and electronic equipment				
(4) RoHS directive (restriction of certain hazardous substances directive)	Content of 6 types of substances is prohibited. (1) lead, (2) mercury, (3) cadmium, (4) hexavalent chrome, (5) PBB, and (6) PBDE			Application to products for sale as of July 1, 2006	
	Medical equipment, monitoring and control equipment are not targeted ⇨				
(5) REACH proposal (proposed rule for chemical substances)	▼ July, Internet consultation deadline		Enforcement⇨registration deadline: 2008 to 2016		
	Make the registering, evaluation and authorization of chemical substances (including risk evaluation) mandatory.				
(6) EuP directive (eco-design directive)	▼ June, public announcement	Final adoption	July 22, 2005, published in EU Official Journal		
	Eco-design requested for devices that use energy. First directive having a new approach in the environment field.				

published in the Official Journal of the EU on July 22, 2005.

Representative environmental regulations of the EU are described below.

(1) Packaging directive (packaging and package waste directive)

This directive applies to all packaging placed on the market within the EU community. Member countries are requested to phase out usage of lead, mercury, cadmium, and hexavalent chromium in packaging materials, and after beginning on July 1, 2001, the total content of those substances is not to exceed 100 ppm.

(2) ELV directive (end-of-life-vehicles directive)

This directive obligates automobile manufacturers to dismantle end-of-life vehicles and to bear the cost of recycling. An important aspect for manufacturers of electrical machinery is that the use of lead, mercury, cadmium, and hexavalent chromium is prohibited in automobiles sold as of July 1, 2003. The threshold levels for these substances are 1,000 ppm for lead, mercury, and hexavalent chromium, and 100 ppm for cadmium.

(3) RoHS directive (restriction of certain hazardous substances directive)

This directive targets products in the categories of: ① large-size household appliances, ② small-size household appliances, ③ IT and communications devices, ④ AV related equipment, ⑤ lighting equipment, ⑥ electric tools, ⑦ toys, ⑧ medical equipment, ⑨ monitoring and control equipment, and ⑩ automated vending machines.

At present, the EU committee excludes ⑧ medical equipment and ⑨ monitoring and control equipment, however, is moving ahead with a reassessment of this directive.

In the RoHS directive, usage of the abovementioned six substances was prohibited, and the threshold levels of those substances were 1,000 ppm for lead, mercury, hexavalent chromium, PBB and PBDE, and 100 ppm for cadmium.

2.2 Main environmental regulations of Japan

In Japan, regulations concerning the emission of volatile organic compounds (VOC) have been strengthened with the "Act for Revising a Portion of the Building Standards Law and the like," in addition to the "Order for Enforcement of the Occupational Health and Safety Law" and the "Law Concerning Examination and Regulation of Manufacture and Handling of Chemical Substances."

Furthermore, with the enactment of the abovementioned law concerning the "Marking of the Presence of Certain Chemical Substances in Electrical and Electronic Equipment," the presence of certain chemical substances must be indicated with markings when that content exceeds a reference level in seven products, including PCs.

Meanwhile, leading global companies are exhibiting increased consideration of the environmental, and are acting independently to enact green procurement standards. These standards are enacted in consideration of the RoHS directive described in section 2.1, thus demonstrating that the EU directives are functioning as global standards.

3. Environmental Responsiveness in Low Voltage Equipment

3.1 Basic principals of responsiveness

Based on the global conditions as described above, Fuji Electric is developing low voltage equipment, such as the new global MCCB and ELCB, based on the following basic principles.

- ○ Compliance with each country's laws and regulations
- ○ Development based on product design assessment (reduction of volume, reuse of resources, environmental protection, safety, easier processing, more efficient packaging)
- ○ Construction of a system for managing environmental controlled substances

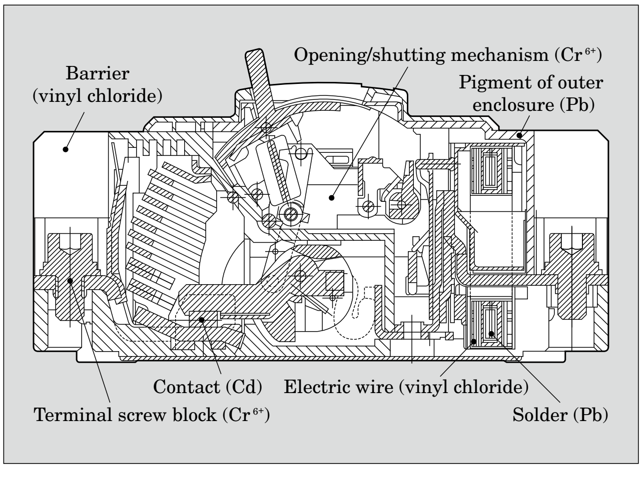
3.2 Targeted environmental controlled substances and its applied parts

Various types of environmental controlled substances have previously been used in MCCBs and ELCBs, as shown in Fig. 1.

- ○ Cadmium (Cd): Electrical contacts, pigment in various resin materials
- ○ Lead (Pb): Soldered joints, pigment, various additives
- ○ Hexavalent chromium (Cr^{6+}): Zinc-plated chromate processing
- ○ Vinyl chloride: Various electric wires, flexible resin

The environmental controlled substances listed above are extremely useful in industrial applications, and alternative substances require new types of ap-

Fig.1 Example of usage of environment control substances in conventional MCCB and ELCB



plied technologies. Several of the individual material technologies that support environmental responsiveness are introduced below.

3.3 Cadmium-free electrical contacts

A balance between temperature, wear and adhesion resistance is important for electrical contacts. Because of their excellent balance, cadmium silver oxide (AgCdO) contacts are used for a wide range of electrical currents. However, cadmium is a chronic poison that causes kidney and liver disorders and softening of bone, and is a prohibited substance according to the RoHS directive.

For this reason, several silver alloys such as AgWC, AgSn and AgC are being developed as alternative contact materials. Here, measures to prevent wear, mostly AgWC contacts, are described.

AgWC contacts exhibit somewhat more wear during current breaking than AgCdO contacts. As a countermeasure, the AgWC particle size was redesigned and distributed uniformly to increase the contact strength. Figure 2 is a photograph showing an AgWC contact that uses improved material. On the other hand, contact wear during current breaking is closely related to the structure of the arc-extinguishing chamber of the MCCB and ELCB. Thus, the arc-extinguishing chamber was devised so to reduce the length of time that the arc stagnates on the contact. Consequently, as shown in Fig. 3, the amount of wear is limited to approximately the same amount as for an AgCdO contact, thereby realizing an alternative to AgCdO contacts.

Fig.2 Photo showing texture of an AgWC contact

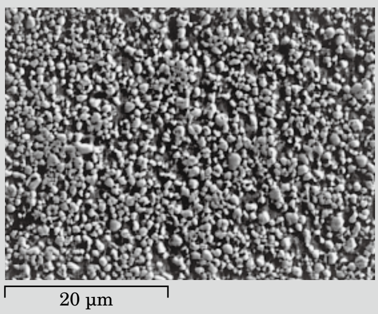
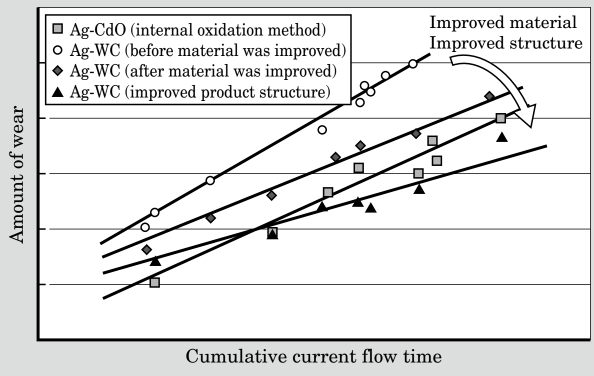


Fig.3 Improvement to lessen contact wear during short-circuit current breaking



3.4 Hexavalent chromium-free chromate process

Various surface treatments are being applied in order to improve the corrosion resistance of metal material. The occurrence of white rust is suppressed by depositing a passivation film above the zinc plating, and then treating the surface with a chromate containing self-repairing hexavalent chromium.

However, long-term exposure of the skin to hexavalent chromium causes irritation of the skin and ulcers, and therefore hexavalent chromium is a prohibited substance according to the RoHS directive.

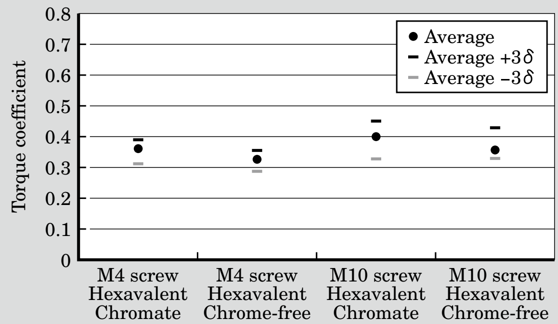
Fuji Electric is forging ahead with technological cooperation with manufacturers of plating solutions, and has used hexavalent chromium-free plating solution that exhibits an equivalent level of rust prevention strength. Figure 4 shows a sample having been subjected to a 72-hour salt spray test method. The sample exhibits the same level of resistance to corrosion.

With metal materials, a change in the plating solution affects not only the resistance to corrosion, but also screw torque characteristics, which have an important function. However, as shown in Fig. 5, no significant difference was observed at the component level. Moreover, various product evaluations that investigate the tightening strength of the terminals, wire pull-out strength, as well as vibration tests and mechanical

Fig.4 Comparison of corrosion resistance (after being sprayed with salt for 72 hours)

(a) Hexavalent chrome-free process (b) Hexavalent chrome process

Fig.5 Comparison of torque characteristics



impact test were implemented, and no problems were observed, thus realizing the hexavalent chromium-free plating solution as a viable alternative.

3.5 Development of vinyl chloride-free flexible material

Vinyl chloride is inexpensive and easily moldable, but its generation of dioxins is reported when combusted inappropriately. Moreover, lead compounds are sometimes mixed-in when used as a stabilizer. In electrical instruments, this material is being used in various types of electric wires and in barriers that require flexibility.

Vinyl chloride is not a prohibited substance, but in order to reduce its usage in the new global MCCB and ELCB, Fuji Electric is cooperating with materials manufacturers to begin developing alternative materials.

In the development of resin material, there is a tradeoff relationship between flexibility and flame resistance, but by incorporating innovative alloy components, a material that exhibits both properties has been developed and used as an alternative to vinyl chloride.

As can be seen in Table 2, which shows the physical properties of the newly developed material and the conventional product (vinyl chloride), the newly developed material is halogen-free, lead-free and realizes UL 94V-1.

Table 2 Comparison of physical properties of newly developed flexible material and vinyl chloride

Item	Newly developed material	Conventional material (vinyl chloride)
Flame class	V-1	HB
Flame retardant	Non-halogen	–
Flexibility	Passed	Passed
Moldability	Good	Good
Volatile organic compounds	No problems	No problems
Comparative tracking index	175 V or above	175 V or above

Table 3 Physical properties of newly developed polyester premixed molding compound

Item		Newly developed material	Conventional material
Flame class		V-1	HB
Relative temperature index (RTI)	Electrically	105°C	105°C
	Mechanically	130°C	130°C
Hot wire ignition		120 s or above	60 s or above
High current arc resistance to ignition		120 times or above	120 s or above
Comparative tracking index		600 V or above	600 V or above
Glow wire flammability index		960°C	960°C
Flexural strength (p.u.)		1.15	1.0
Charpy impact strength (p.u.)		1.35	1.0

3.6 Development of self-extinguishing and high-strength polyester premixed molding compound

The chassis of medium- and large-sized MCCBs and ELCBs often contains thermosetting material that stabilizes the shape during overheating or the like. With the trend toward increased globalization, self-extinguishing performance of the thermosetting material is an extremely important property and is being required for better safety. Moreover, for the integration of JIS and IEC standards, glow wire performance and the comparative tracking index have become especially important performance characteristics. On the other hand, since a large internal pressure is applied to the MCCB and ELCB chassis while breaking a short-circuit current, high mechanical strength is also required.

As the result of different types of packing material, redesigned particle size, more appropriate material mixing viscosity and the like for the new global MCCB and ELCB, a polyester premixed molding compound was developed having excellent thermal properties of a UL 94V-1 rating, a comparative tracking performance of 600 V or above, a glow wire flammability index of 960°C, and having 1.35 times the Charpy impact strength of the conventional product. Table 3 lists the physical properties of the new developed material. This material was used in the chassis, and short-circuit current breaking tests and the like were performed to evaluate various products. We confirmed that there

Fig.6 Component impact strength test conditions

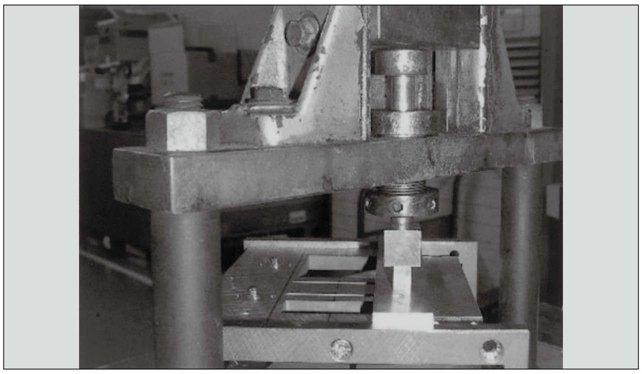
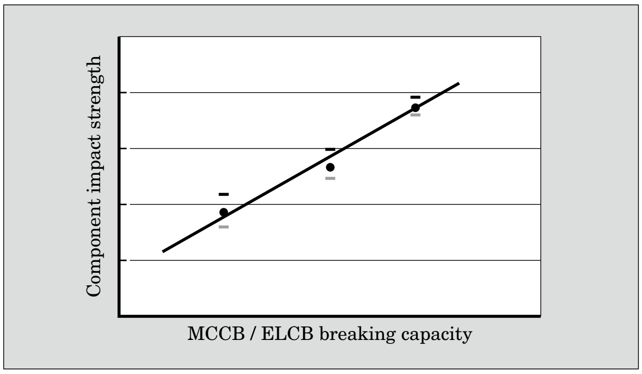


Fig.7 Relationship between MCCB / ELCB breaking capacity and component impact strength



were no problems with this newly developed material.

3.7 Application of copolymer-type polycarbonate material

Recent MCCBs and ELCBs are equipped with an attached top cover (cosmetic cover), and gray-color covers are commonly used in addition to the conventional black-color covers. The external appearance and dimensional stability are extremely important properties of the material used in the top cover. Moreover, since a portion of the internal pressure generated during breaking of a short-circuit current is applied to the top cover, the capability to withstand mechanical impact is also strongly required.

A copolymer-type polycarbonate material having excellent dimensional stability and chemical resistance has been used in the new global MCCBs and ELCBs.

As shown in Fig. 6 and in Fig. 7, we performed falling weight impact testing and assessed the relationship with breaking capacity, then we are using this data to speed up development and in daily components control.

4. Control System for Environmental Controlled Substances

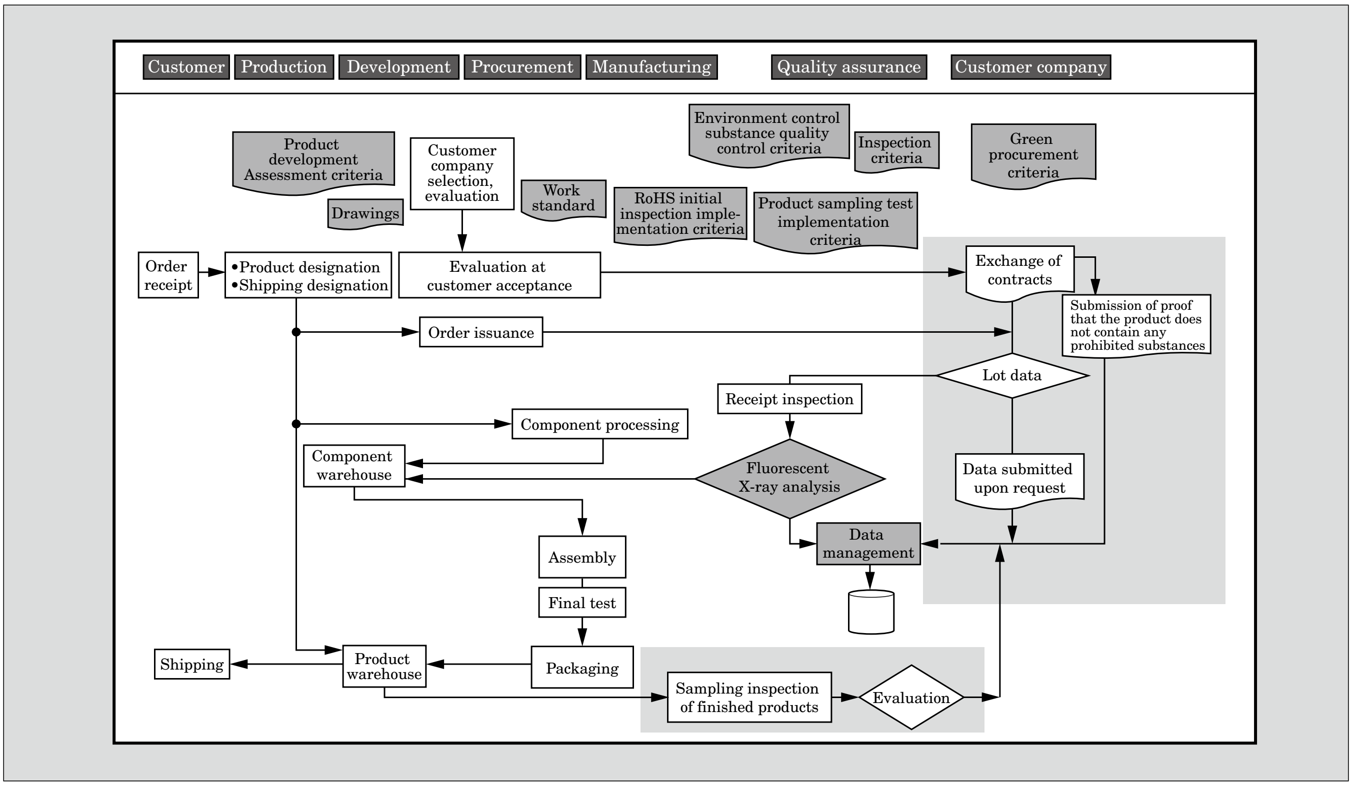
Environmentally responsive technologies in development process have been described in the above sections. This section describes a system for configuring and maintaining technology in development process.

The Fuji Electric Group established a second edition of the "Fuji Electric Group Green Procurement Guidelines" in October 2005. These guidelines designate RoHS prohibited substances, substances prohibited for manufacture according to domestic Japanese law, and persistent substances as prohibited substances, and were revised in conformance with JIG (joint industry guidelines). In accordance with the green procurement guidelines, customer companies require proof that the product does not contain any prohibited substances, and also require data of the content of controlled substances.

Moreover, we have strengthened the in-house inspection system — from order receipt to product shipment — and are using a fluorescent X-ray analyzer as

Fig.9 Example analyzer (ICP-AES) for environmental control substances

Fig.8 Control flowchart for environmental control substances



a screening device. Items treated as being in the "gray zone" with a fluorescent X-ray analyzer are judged by a highly sensitive analyzer such as an inductively coupled plasma atomic emission spectrometer (ICP-AES).

Furthermore, these data are managed in a database, and are also used to correct abnormal conditions and for corrective actions. Figure 8 shows a control flowchart for environmental control substances, and Fig. 9 shows an example of an in-house analyzer.

As described above, Fuji Electric implements a reliable system to ensure that products containing prohibited substances do not flow to sales routes.

5. Conclusion

Several materials technologies that support the environmental responsiveness of the new global MCCB and ELCB, and a control system have been introduced above. Fuji Electric is confident that these new products will help to expand further the global market. By cooperating with and receiving guidance from all concerned parties, Fuji Electric intends to improve environmentally compatible technology.