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A Study on the Carbonization Characteristics of Insulating Materials between RCD Terminals Deteriorated by NaCl Solutions

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Abstract: To protect equipments from electric leakage current, we generally use Residual Current Device(RCD). In this paper, we studied on the carbonization characteristics of insulating materials between the source terminals of RCD deteriorated by NaCl solutions. The process of ignition was taken by high speed camera. And the carbonization materials were analyzed by Fourier Transform Infrared spectrometer(FT-IR) and Differential Thermal Analyzer(DTA). In comparison with the virgin sample, the spectra of carbonized materials did not have absorption peak near $1509.5cm^{-1}$. In the results of thermal analysis, the exothermic peaks of carbonized materials showed differences according to the number of droplets and carbonization time.

1. INTRODUCTION

Electricity, one of the most versatile and widely used power sources, can cause serious harm if handled improperly. Electrical accidents result from disordered electrical equipment and unsafe usage. Specially, electrical accidents can result in electric fire. Among all fires in Korea, electric fire possesses the greatest part. So, we need to analyze electric fire to protect electrical accidents.

Generally, electrical accidents are influenced by environments such as contamination, dust, humidity, flammables, mileage and rapid temperature change. In case of fire, it is hard to find out the causes because of the loss of evidence materials in the fire. On the occasion of overload or electric leakage in house or plant, RCD cut off the their circuit immediately. But if discharge current flows through the source terminals of RCD, the RCD does not operate. This can cause electrical accidents or fire[1-3].

In this study, on purpose to find out the causes of electric fires and prevent these fires, we experimented and analyzed on the source terminals of RCD deteriorated by contamination[4-6]. Surface, chemical and thermal analysis were carried out by optical microscope(Ephiphot-200, Nikon, Japan), FT-IR(Spectrum GX, PerkinElmer, USA) and DTA(SDT-2960 TA Ins., USA).

2. EXPERIMENT

Phenolic resins are widely used in industry because of superior electrical properties, mechanical properties, heat resistance, dimensional stability and cheapness. So, they are used for electrical appliances such as RCD. These are produced by combining phenol and formaldehyde in presence of a catalyst. There are two types of phenolic resins(resol and novolak). Resol is synthesized from phenol and formaldehyde using an alkaline catalyst, whereas Novolac is produced from the condensation reaction of phenol and formaldehyde using an acid catalyst. The ignition temperature of phenolic resins is 450℃. When insulating materials are carbonized by external fire, the structures of them are amorphous(electrical insulator). In case insulating materials are carbonized by surface discharge, the structures of them are crystalline because of the oxygen-free condition under the influence of rapid temperature change. These carbonized materials are good electrical conductors. Therefore, the discrimination between amorphous and crystal is the important data for the judgement of electric fire. To analyze the carbonized characteristics of phenolic resin (especially, between source terminals of RCD), we experimented on the RCD as shown Fig.1.

RCD(other name: Earth Leakage Circuit Breaker) is an electrical safety device specially designed to immediately switch the electricity off when electric leakage is detected at a level harmful to a person using electrical equipment.

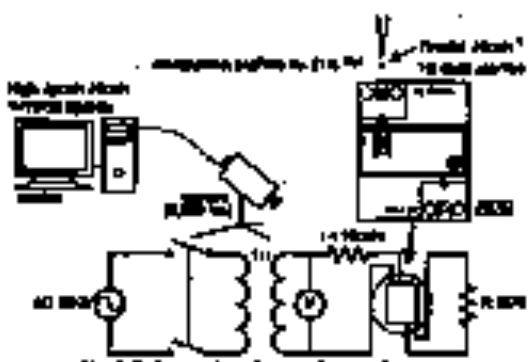

Fig.1 Schematic of experimental system

We used the following RCD for experiment; rated voltage single-phase 220V, sensitivity 30mA, active time within 0.03sec. we dropped NaCl solution(1%) of 20mm³ size between source terminals of RCD and the time interval between each other 10~20 drops is 30seconds. The distance between source terminals was 17mm and the height of drops was 15mm. Lamp load(30W) is connected to the load terminals of RCD. We took pictures of ignition process with High Speed Camera(MotionXtra, HG-100K, REDLAKE, USA).

Fig.2 Experiment and analysis process

After the carbonization experiment shown in Fig.1, we got carbonized materials between source terminals and analyzed these materials according to the process shown in Fig.2. With these results, we are going to present the cause of electric fire and the safety countermeasure.

3. RESULTS AND DISCUSSION

3.1 Ignition process and surface change

Fig.3 shows the ignition process on the source terminals of RCD deteriorated by NaCl solution. We dropped 20 droplets(drops interval; 30sec) at a time between source terminals until main circuit breaker cut off the circuit. The number of explosions was about 80 times for about 550msec.

In Fig.3 (a) partially conducting paths are formed from discharge centers. It is glowing red through these paths. In Fig.3 (b), the fire flame is spreading after carbonized conductive paths are formed between source terminals of RCD. It takes 5.2msec to start the first flame and 16msec to start the second flame. In Fig.3 (c), the carbonized conductive paths are glowing white and explosion is seen above the paths. It takes 433.4msec after Fig.3 (a).

Fig.3 The images of ignition process

Fig.3 (d) shows the last flame(explosion). It takes 490msec after the first flame. In Fig.3 (e) and (f), carbonized particles are spreading right after the last explosion.

It takes about 15min to form carbonized conductive paths, but it only takes 550msec from the formation of conductive paths to the last explosion.

(a) 20drops (b) 15drops (c) 10drops

Fig.4 Surface of RCD case According to carbonization time

Fig.4 shows the carbonized surface between source terminals of RCD according to carbonization time and the number of droplets. In Fig.4 (a), 20 droplets fell continually between source terminals and the time interval each added 20 drops was 30secs. The resistance between terminals was 10.5Ω, and it took 11mins to start the explosion. In Fig.4 (b), 15 droplets fell and the time interval was 30secs.

The resistance was 115Ω and it took 28mins to start the explosion. In Fig.4 (c), 18 droplets fell and the time interval was 31mins. The resistance was 1056Ω and it took 35mins to start the explosion.

The number of droplets was related to the deterioration time and the resistance between terminals. The longer deterioration time was, the wider the carbonized paths were.

3.2 Chemical characteristics

By using the method of a Br(potassium bromide) pellet FT-IR spectroscopy, we compared virgin sample with the sample shown in Fig.4 (c). Sample was ground thoroughly with KBr in approximately 5% by weight and pressed into a pellet with a thickness of 1mm. The diameter of the KBr pellet was 13mm.

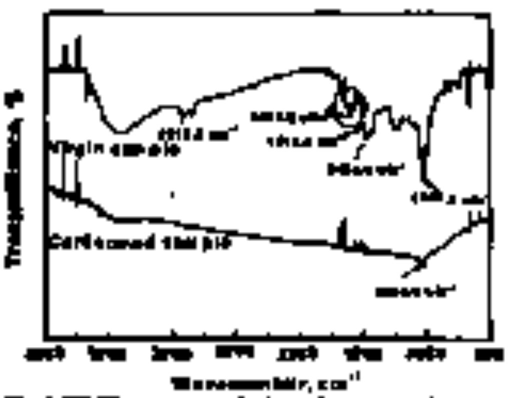

Fig.3 FT-IR spectra of virgin and carbonized sample

In Fig.3, the absorption peak of the virgin sample at $1476.4cm^{-1}$, $1511.0cm^{-1}$ and $1609.5cm^{-1}$ results from benzene ring. On the other hand, the absorption peak of carbonized sample did not appear at $1476.4cm^{-1}$, $1511.0cm^{-1}$ and $1609.5cm^{-1}$. So, we can distinguish virgin sample from carbonized sample by absorption peaks.

3.3 Thermal characteristics

When organic insulating materials are carbonized by different reasons, the thermal characteristics of each material are also different. If the materials were changed into graphite under electrical current, they would be gasified into CO, CO_2, etc. at 600 to 900℃. In case of the materials are carbonized under heat or fire, the exothermic peak is about 500℃. This is one of the important factors of judging the cause of fire.

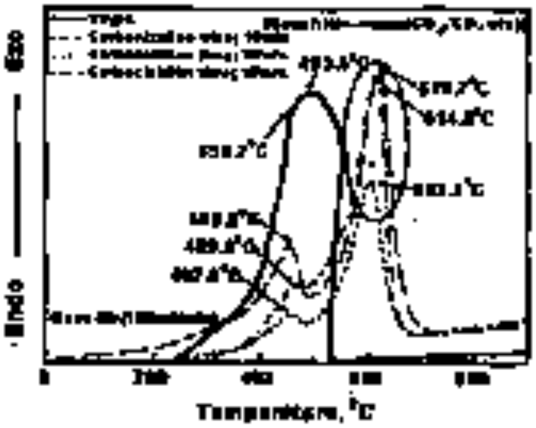

Fig.4 FT-IR spectra of virgin and carbonized sample

DTA was used to analyze the thermal characteristics of the virgin sample and carbonized materials according to deterioration time. The flow rate of air was of 100ml/min. Temperature was increased to 900℃ (ramp 10℃/min). Fig.4 shows the exothermic peaks of virgin sample at 459.1℃ and 625.4℃ results from resin materials and filler. With the deteriorated samples shown in Fig.4, we analyzed the exothermic peaks of the samples and the curves were shown in Fig.4. The exothermic peaks of deteriorated samples are shown at 459.2℃, 469.4℃ and 467.8℃ (carbonization time: 15mins, 25mins and 35mins respectively) results from resin materials. And the exothermic peaks of deteriorated samples are shown at 603.1℃, 614.3℃ and 619.7℃ (carbonization time: 20mins, 25mins and 15mins respectively) results from graphite.

4. CONCLUSIONS

On the occasion of standard or electric leakage current, RCD cut off the fault circuit immediately. But if there are problems between source terminals of RCD, it can't prevent the circuit. So, we should be careful about this. If the source terminals of RCD are deteriorated by accumulation, discharge current flows through the source terminals of RCD. It can cause electrical accidents of fire. We experimented on the RCD deteriorated by NaCl solutions and analyzed the carbonized materials. And the following conclusions were drawn the experiments and analysis.

(1) In the ignition process, the number of droplets was related to the carbonization time and the resistance between source terminals. And the number of explosions was about 50 times for about 530mins. It was shown some regardless of carbonization time.

(2) It takes 5.2minutes to start the first explosion and 16minutes to start the second explosion. As time goes by, the explosion interval was shorter and larger explosion happened.

(3) The longer carbonization time was, the wider the carbonized paths and stains were. The carbonized area was wider because discharge time was longer.

(4) In the result of FT-IR, the absorption peak of the virgin sample at 1476.45cm^{-1}, 1511.85cm^{-1} and 1609.5cm^{-1} results from benzene ring. On the other hand, the absorption peak of carbonized sample did not appeared at 1476.45cm^{-1}, 1511.05cm^{-1} and 1609.5cm^{-1}. We could distinguish virgin sample from carbonized samples(graphite) by absorption peaks.

(5) In the result of DTA, the exothermic peaks of virgin sample showed at 430.7℃ and 491.4℃ and those of deteriorated samples showed at 436.7℃, 439.6℃, 487.6℃, 483.1℃, 614.3℃ and 619.7℃. We could distinguish virgin sample from carbonized samples(graphite) by the exothermic peak at about 600℃.

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REFERENCES

[1] Chung-Seog Choi, Kil-Mok Shong, Hyung-Rae Kim, Hyung-Kon Kim, Dong-Ook Kim, Dong-Woo Kim, "A Study on the Flame Pattern and Electrical Properties of Electric Cables Fired in Standby Mode", KIFSE Trans. vol. 16, No. 1, pp.39–44, 2002.

[2] Chung-Seog Choi, Kil-Mok Shong, Hyung-Kon Kim, Dong-Woo Kim, "A Study on the characteristics of tracking deterioration between electrodes on phenolic resin used for low voltage", KIEE 2002 conference, pp.1183-1190, July, 2002.

[3] J. Mackevicius, R. S. Gorur, B. McAlister, D. Kingsbury, "Brittle Fracture in Nonceramic Insulators: Electrical Aspects of Microcracks, Fibers in Glass Reinforced Plastic(GRP) Rod", IEEE Trans. DEI Vol. 9, No. 2, pp.244 - 252.

[4] IEC Publ. 112, "Method for determining the comparative and the proof tracking indices of solid insulating materials under moist conditions", 2nd Ed., 1979.

[5] ASTM D 3638, "Standard Test Method for Comparative Tracking Index of Electrical Insulating Materials", 1993.