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The Characteristics of Arc Scattering and Fusing Current of Copper Wire in the Fault Process DB System of Cables in a PL Environment

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Abstract

The importance of identifying the causes of electrical faults cannot be overstated because of the accidents caused by over-current that take place at the home, the office and electrical facilities due to misuse, poor products and system faults. It is necessary to gather objective,scientific data pertaining to electrical fault investigation in a product liability (PL) environment. To date, no database (DB) has been built concerning the accurate cause analysis of faultyfacilities. In this paper, accident hazard and arc scattering when over-current flows in copper wire was investigated. It was found that when over-current flows in a copper wire, the copper wire became heated and bent and beads were scattered around the wire with a flash. It was determinedthat the fusing current and time was related to the current rise per second. For example, when the current rise per second was largethe fusing current was higher than when the current rise per second was small, and the beads dispersed along a wide area. Fusing time, however, was shorter. The possibility of electrical fault became highest when the fusing current was higher. As the current rise per second is short, the dendrite structure is distributed in the surface of the copper wire. These experimental results can be utilized for a fault process DB system in the investigation and the prevention of electrical faults.

Key Words : Over-current, Product liability, Electrical fault, Fusing current, Dendrite structure

1. Introduction

Electrical devices are designed to have their own protective functions concerning abnormal electrical signals. However, it is not unknown for fire to break out in aging structures or in areas where the risk of fire was thought to be unlikely. It is necessary to supervise the status of the safety of electrical devices and ensure the early detection of fire hazard. As consumption of electric power increases through the use and mass production of a variety of electrical appliances, a large scale of supply of electrically powered equipment is unavoidable and electrical accidents occur frequently[1-3]. Over-current accidents account for 8.8[%] in Korea accidentscaused by

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over-current account for the majority of accidents that occur in the home, office and factory due to negligent use of low voltage[4]. Fig. 1 shows faulty 6.6[kV] Class CV cable damaged by over-current. The investigation in the cause of accidents is performed by an objective judgment based on combustion direction, surrounding environment, and other factors[5-6].

Under the product liability (PL) law, which has been enforced in Korea since 2002, guarantee of product quality by expected life is required, and the manufacturer is held responsible for defective products. Nevertheless, the PL law has not been enforced to its potential in the area of heavy electrical machinery due to a lack of understanding. If an event happens, it is resolved by mutual agreement instead of by clear investigation of the cause. As a result, there is no database (DB) for an accurate cause analysis of faulty facilities.

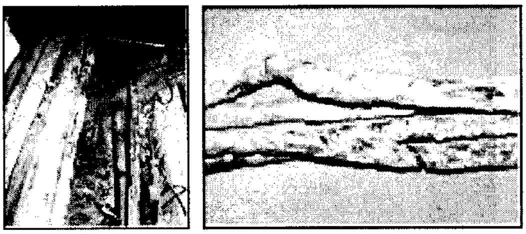


Fig. 1. Faulty 6.6[kV] Class CV cables damaged by over-current

Commonly, accidents caused by over-load are as follows, Over-current on the electrical machinery and the wire causes the occurrence of Joule's heat. The wire melts and becomes disconnected with arc scattering. According to whether there is a long-term over-current or a short-term over-current applied to the machinery, the damage caused by electrical accident varies. Therefore, it is necessary to understand the dependence of fusing current and arc scattering in the copper wire considering the current rise per second[7-8].

In this paper, fault occurrence due to over-current in copper wire was studied, and fusing characteristics of both AC and DC environments were compared. The arc phenomenon and the bead scattering progress were taken by a high-speed imaging system whilethe damaged copper wires were analyzed by stereo microscope and metallurgical microscope.

2. Experimental methods

Fig. 2 shows a schematic diagram of the experimental setup for the over-current properties of the electrical wire. Bare copper wire with a length of 150[mm] and diameters of 1.2[mm], 1.6[mm], 2[mm] was used. The copper wire was connected to a connectingterminal, and the current was applied to the copper wire using an AC/DC source (50[V]/3,000[A], IDX, Japan). The current was raised by 1, 2.5, 5, 7.5, 10, 20 and 150[A/sec] while current was made to flow by disconnection. The arc properties and fusing progress were observed by a high-speed imaging system (HSIS, HG-100[K], Redlake, USA), which can take photographs up to 100,000[fps]. The fusing current and fusing time were recorded by a data acquisition system (DAS, 1.2[M/s], NI, USA). The damaged specimens were analyzed by metallurgical microscope (Epiphot, Nikon, Japan) and stereo microscope (SV-11, CarlZeiss, Germany). The environmental conditions used were both atmosphere and liquid nitrogen.

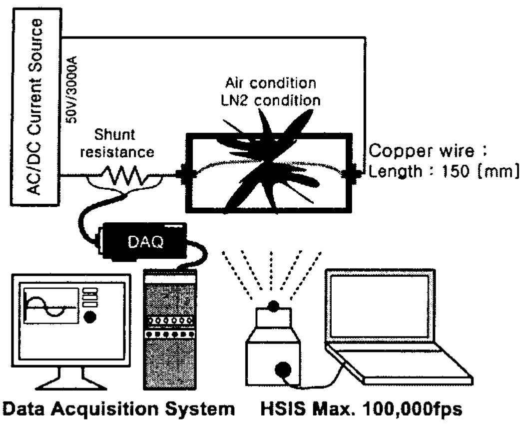


Fig. 2. Schematic diagram of experimental setup

3. Results and discussion

Fig. 3 shows the fusing current versus the fusing time of copper wire with AC. The measurement was taken 10 times in order to obtain reliable value. The values were then averaged. As shown in Fig. 3, when the diameter of copper wire became thicker, the fusing current value was higher and fusing time was longer. In addition, where the current rise per second was great, the fusing current was higher than where the current rise per second was small. Fusing time, however, was short. As shown in Fig. 4 (a) and (d), the fusing current and fusing time were 220[A], 220[sec], 708[A], and 4.71[sec], respectively.

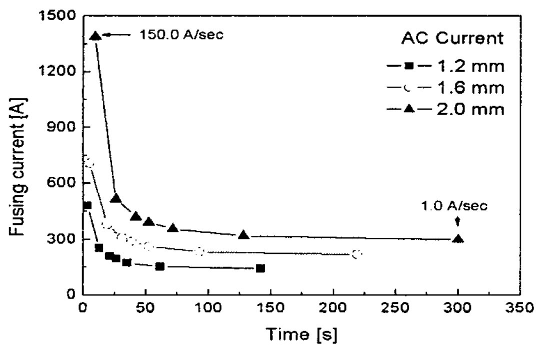
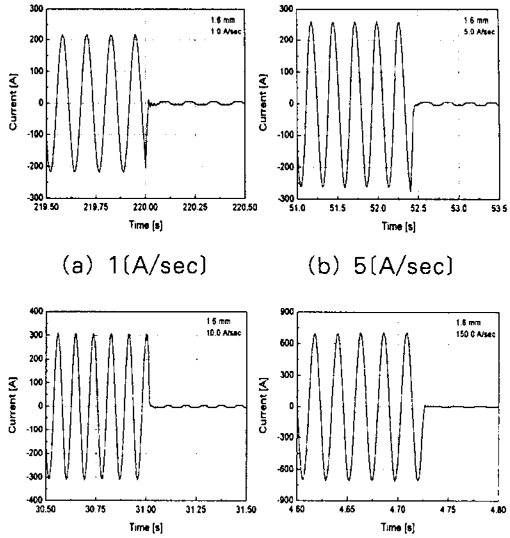


Fig. 3. Fusing current versus fusing time of copper wire with AC



(a) 1[A/sec] (b) 5[A/sec]

(c) 10[A/sec] (d) 150[A/sec]

Fig. 4. Fusing current waveform due to current rise with AC

Fig. 5 shows the fusing characteristic comparingAC and DC in the case of the 1.6[mm] diameter wire. As exemplified in Fig. 3, when the current rise per second was great, the fusing current was high fusing time was short with DC, as well. Where the current was raised at a rate of 150[A/sec] with AC, the fusing current and fusing time were 708[A] and 4.71[sec], respectively. In the case of AC, the fusing current and fusing time were 547[A] and 3.6[sec], respectively. The AC peak value of the fusing current and fusing time were greater than the DC value, but the AC_{rms} value was similar to the DC value. The fusing time of AC was greater than that of DC, because the ACvaried positively (+) and negatively (-).

Fig. 6 shows the arc scattering characteristics of copper wire according to a current rise with AC. Photographs were taken by using a high-speed imaging system at the rate of 500[fps]. As shown in Fig. 6 (a) and (b), the current increased at a rate of 1[A/sec] 5[A/sec], respectively. A lot of small beads were scattered from the center to the outside of the copper wire. In Fig. 6 (c), the current increased at a rate offlame was observed and many beads were scattered. In Fig. 6 (d), showing 150[A/sec], the flame was dispersed in all directions and the beads were scattered to the extent of their surrounding limits.

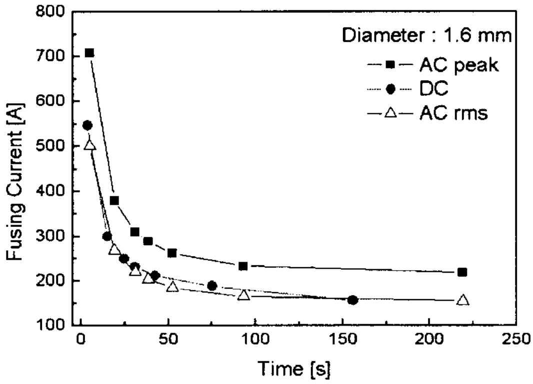
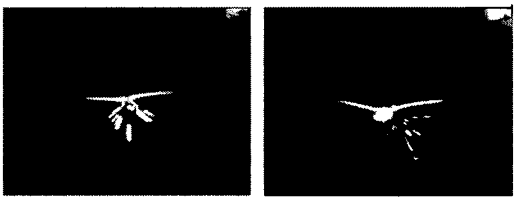
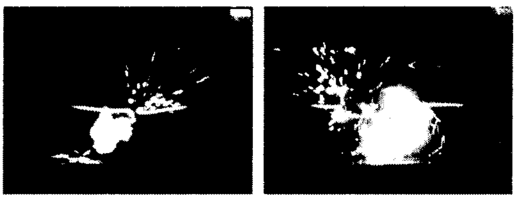


Fig. 5. Comparison of fusing characteristic between AC and DC



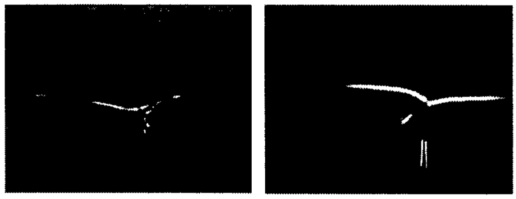
(a) 1[A/sec] (b) 5[A/sec]



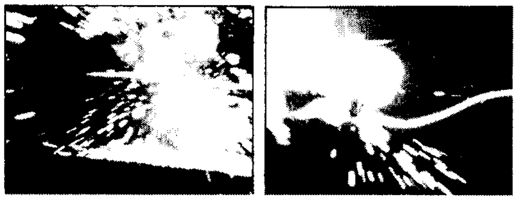
(c) 10[A/sec] (d) 150[A/sec]

Fig. 6. Characteristics of arc scattering for copper wire according to current rise with AC

Fig. 7 shows the arc scattering characteristics of copper wire according to current rise with DC. Like the AC photographs, as shown in Fig. 7 (a) and (b), as the current increased at a rate of 1[A/sec] and 5[A/sec], many small beads were scattered from the center to the outside of the copper wire. In Fig. 7 (c), showing 10[A/sec], flame was observed and many beads were scattered. In Fig. 7 (d), showing 150[A/sec], the flame was dispersed in all directions and the beads were scattered to the extent of their surrounding limits. In addition, the DC flame was observed to be greater than that of the AC. Thus, it was found that as the current rise increased, flame was dispersed slightly more and the beads were scattered. Therefore, the hazards of electrical accidents are greater at a higher level of current.



(a) 1[A/sec] (b) 5[A/sec]



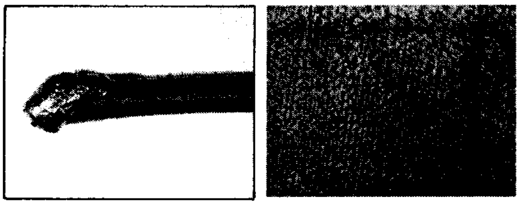
(c) 10[A/sec] (d) 150[A/sec]

Fig. 7. Arc scattering characteristics of copper wire according to current rising at DC

Fig. 8 and Fig. 9 show the stereoscope and metallurgical photographs of copper wire with AC and DC at a current rise of 1.0[A/sec]. As shown in Fig. 8 (a) and Fig. 9 (a), the surface of the copper wire was oxidized to a dark brown color and the tip of the wire took on a rounded shape. As shown in Fig. 8 (b) and Fig. 9 (b), dendrite in the cross-section structure was observed.

Fig. 10 and Fig. 11 show the stereoscopicand metallurgical photographs of the copper wire at a current rise of 150[A/sec]. In Fig. 10 (a) and Fig.

11 (a), the surface of the copper wire was oxidized to a dark brown color and an formed an irregular shape.



(a) Stereoscopic photograph (b) Metallurgical photograph

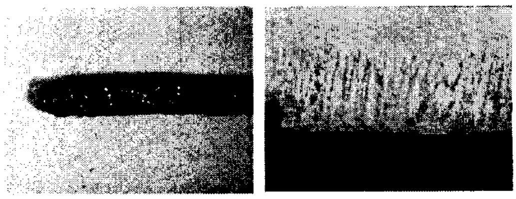
Fig. 8. Photographs of melted copper wire with an AC current rise of 1[A/sec]

(a) Stereoscopic photograph (b) Metallurgical photograph

Fig. 9. Photographs of melted copper wire with a DC current rise of 1[A/sec]

(a) Stereoscopic photograph (b) Metallurgical photograph

Fig. 10. Photographs of melted copper wire with an AC current rise of 150[A/sec]



(a) Stereoscopic photograph (b) Metallurgical photograph

Fig. 11. Photographs of melted copper wire with a DC current rise of 150[A/sec]

In Fig. 10 (b) and Fig. 11 (b), dendrite in the cross-section structure was concentrated on the surface of the wire because of a large amount of current flow over a short period of time. In a comparison of AC and DC, no differences were found between the external form and metallurgical photographs.

Fig. 12 shows the fusing current versus fusing time of copper wire with AC by frequency variation. As shown in Fig. 12, the fusing current and fusing time did not greatly depend on frequency variation. Because the length of the copper wire was 60[mm], inductance ingredients can be discounted. However, the coil that is used in electrical machine is judged to depend greatly on frequency because inductance ingredients dominate.

A cable is used at cryogenic temperatures to increase the current capacity in the same sectional area. Thus, investigation of the arc characteristics of copper wire according to temperature variation is needed because short circuiting and over-current. The copper wire was deposited in liquid nitrogen for stabilization owing to the difference of boiling temperature with room temperature. The currentwas raised by 10[A/sec] and photographs were taken with a high-speed imaging system at the rate of 500[fps].

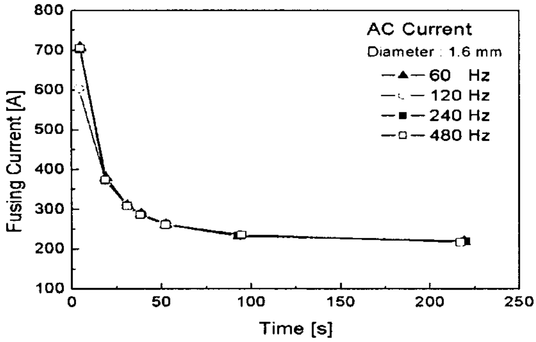
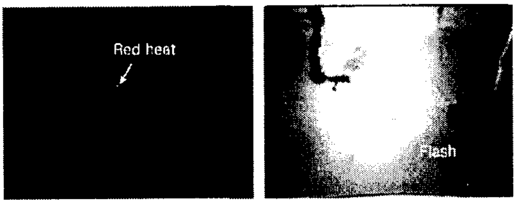


Fig. 12. Fusing current versus time of copper wire due to frequency

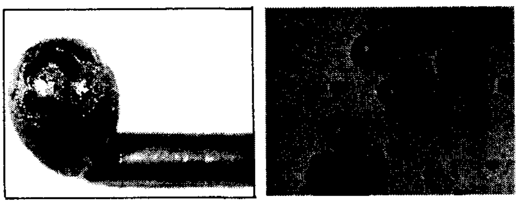
Fig. 13 shows the arc scattering of copper wire in liquid nitrogen. As shown in Fig. 13, the copper wire was became heated, a flash occurred, and beads scattered and disappeared. The fusing current and fusing time was 342[A], 34.2[sec], respectively these are higher than those at room temperature. However, the dispersion of the beads was not observed to as great an extent as in Fig. 7 (c), because the liquid nitrogen restrains the scattering of beads.



(a) Red heat (b) Flash

(c) Scattering (d) Extinction

Fig. 13. Characteristics of arc scattering for copper wire in liquid nitrogen



(a) Stereoscope photograph (b) Metallurgical photograph

Fig. 14. Photographs of melted copper wire at a current rise 10[A/sec]

Fig. 14 shows the stereoscopic and metallurgical photographs of copper wire with a DC current rise of10[A/sec] in liquid nitrogen. In Fig. 14 (a) and (b), the shape of the copper wire was rounded and the color was yellow. Dendrite structure was not observed. The surface of the wire was not oxidized and a dendritestructure was not formed because oxygen does not exist in liquid nitrogen.

5. Conclusions

In this paper, the dependence of fusing current and arc scattering in copper wire was studied in consideration of a current rise at a low voltage. As the diameter of copper wire thickened, the fusing current value was greater and time also was longer. Where the current rise per second was great, fusing current was high, but fusing time was very short. The AC peak value of fusing characteristics was greater than that of the DC value, but the AC_{rms} value was similar to DC value. The fusing time of AC was greater than that of DC because the AC varied both positively (+) and negatively (-).

As the current rise increased, flame was dispersed slightly more and beads were scattered. The surface of the copper wire was oxidized to a dark brown and the shape became irregular. The dendrite structure was concentrated on the surface of the wire because a large amount of current flowed during a short period of time. Thus, it was found that as the current rise increased, the hazard of electric accidents became higher.

For fusing current and fusing time in liquid nitrogen, these are higher than those of at room temperature. However, the dispersion of beads was not greatly observed compared with that at room temperature because the liquid nitrogen restrains the scattering of beads.

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References

[1] EUGENE LOH, "Physical Analysis of Data on Fused-Open Bond Wires", IEEE Trans. on CH & MT, Vol. CHMT-6, No.2, pp.209~217, 1983.
[2] Babrauskas, V., "Fires due to Electric Arcing: Can 'Cause' Beads Befrom 'Victim' Beads by Physical or Chemical Testing?", FireMaterials. pp. 189~201, 2003.
[3] John D. DeHaan, "Kirk's Fire Investigation", 5th edition, Prentice Hall, pp., 2002.
[4] Korea Electrical safety Corporation, "A Statistical Analysis on the Electrical Accident", 13th edition, pp. 7-24, 2004.
[5] Sheera. Knecht, "Fusing Current of Short Aluminum Bond Wire", IEEE ISC on TP, pp.329~332, 1996.
[6] Atila. Metrol, "Estimation of Aluminum and Gold Bond Wire Fusing Current and Fusing Time", IEEE Trans. on CP & MT, Vol.18, No.1, pp.210~214, 1995.
[7] Chung-Seog Choi et al, "The Analysis of Dendrite Structure of Electric Wire Melted by Fusing Current", 2003 Japan-Korea Joint Symposium on ED & HVE, pp.145-148, 2003.
[8] Kil-Mok Shong, Hyang-Kon Kim, Chung-Seog Choi and Hee-Ro Kwak, "A Study on the Electrical Fire Analysis of PVC Insulated Flexible Cord by Over-Current", KIEE 2003 spring conference, pp.131~133, 2003.

Biography

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Young-Seok Kim was born in Korea on April 27, 1974. He graduated from Gyeongsang National University, Korea, with B.S., M.S. and Ph.D. degrees in electrical engineering in 1996, 1999, and 2004, respectively. From 2001 to 2002, he was a visiting researcher at the Yamaguchi University. He is currently working as a researcher at the Electrical Safety Research Institute, a subsidiary of the Korea Electrical Safety Corporation. His interests include electrical facilities, electrical safety and electrical insulation.

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