A Study on the Electrical Strength of Insulating Materials for High-Tc Superconducting Devices

Duck Kweon Bae[a]
Mechanical Systems Reliability Research Center, Korea Institute of Machinery and Materials, 171 Jang-dong, Yuseong-gu, Daejeon 305-343, Korea

Chung-Hyeok Kim and Min Sun Pak
Division of General Education, Kwangwoon University, 447-1 Wolgye-dong, Nowon-gu, Seoul 139-701, Korea

Yong Cheul Oh, Jin Sa Kim, Cheol Gee Shin, and Joon Ung Lee
Department of Electrical Engineering, Kwangwoon University, 447-1 Wolgye-dong, Nowon-gu, Seoul 139-701, Korea

Min Jong Song
Department of Medical Information Engineering, Kwangju Health College, Sinchang-dong, Gwangsan-gu, Kwangju 506-701, Korea

Woon Shik Choi
Department of Electrical Engineering, Daebul University, Samho-eup, Yeongam-gun, Jeonnam-do 526-702, Korea

[a]E-mail : porthos@kimm.re.kr

(Received November 1 2005, Accepted December 6 2005)

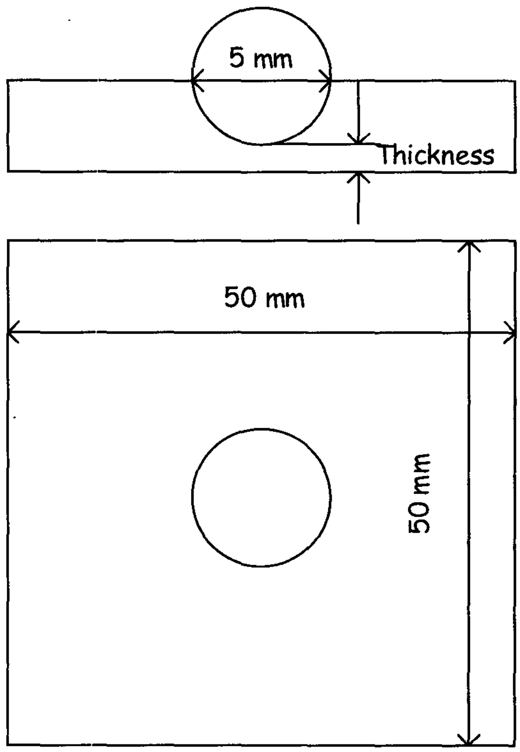
According to the trend for electric power equipment of high capacity and reduction of its size, the needs for the new high performance electric equipments become more and more important. On of the possible solution is high temperature superconducting (HTS) power application. Following the successful development of practical HTS wires, there have been renewed activities in developing superconducting power equipment. HTS equipments have to be operated in a coolant such as liquid nitrogen (LN_2) or cooled by conduction-cooling method such as using Gifford-McMahon (G-M) cryocooler to maintain the temperature below critical level. In this paper, the dielectric strength of some insulating materials, such as unfilled epoxy, filled epoxy, and polyimide in LN_2 was analyzed. Epoxy is a good insulating material but fragile at cryogenic temperature. The filled epoxy composite not only compensates for this fragile property but enhances its dielectric strength.

Keywords : Superconducting magnet, Cryogenic insulation, Surface flashover, Dielectric strength

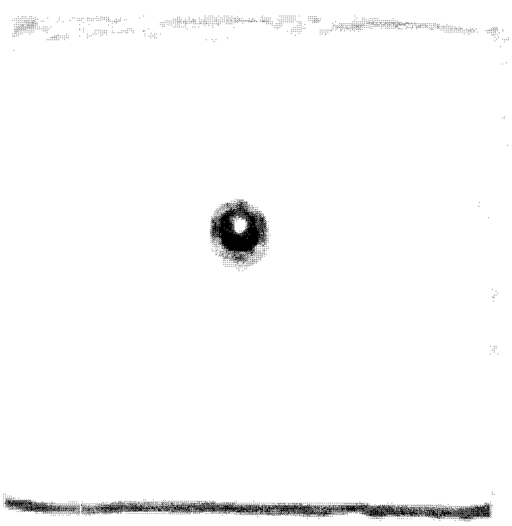
1. INTRODUCTION

The existing commercialized superconducting magnetic resonance imaging (MRI) and nuclear magnetic resonance (NMR) actualize the high and uniformity magnetic field by using Low-Tc superconducting (LTS) magnet. The development of HTS power equipments have been actively progressing since Bi-2223 wire, the successfully commercialized HTS wire, appeared and was used [1]. For the purpose of their successful development, the development of the cryogenic temperature insulation system has to be carried out side by side[2-5]. The skills of companies with the insulation system under room temperature have been developed well but the study on cryogenic temperature insulation material is still under-developed. The study on the materials should be actively implemented to promote successful development for HTS power equipments.

This paper is about the study of the insulation system



(a) Structure of specimen



(b) Manufactured UFE specimen

Fig. 1. Preparation of specimen.

for HTS power equipments, such as HTS magnets, HTS current leads, HTS power cables, and so on. The dielectric strength of unfilled and filled epoxy, and polyimide was investigated.

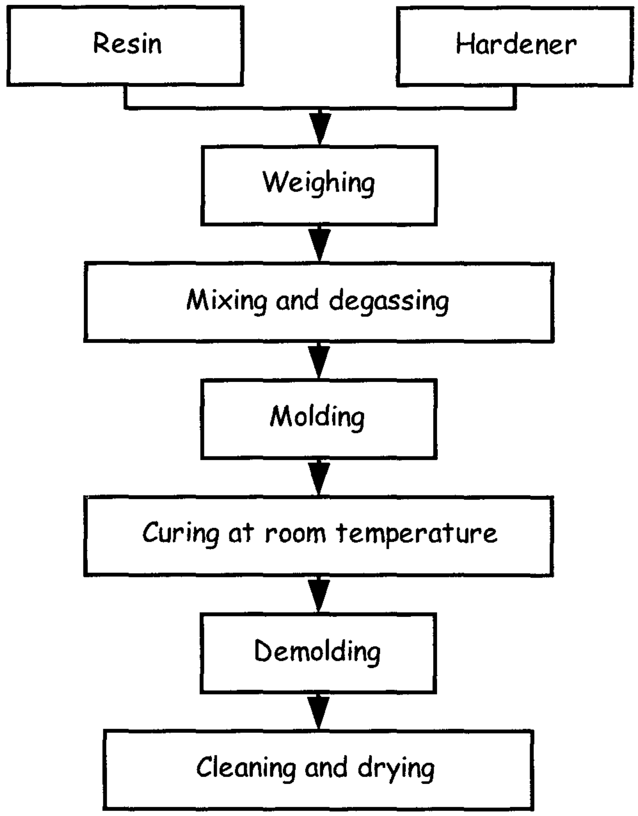


Fig. 2. Manufacturing process of specimen.

2. PREPARATION OF SPECIMENS AND EXPERIMENTAL SETUP

2.1 Preparation of specimens

The specimens were made of two kinds of epoxy composites, which are UFE (unfilled epoxy) made of Stycast 1266 part A and part B and FE (filled epoxy) made of Stycast 2850FT and Catalyst 23LV, and polyimide. The thicknesses of UFE and FE, as shown in Fig. 1, were 100, 150 and 200 μm and it of polyimide was 50, 75, 125 μm, respectively. Figure 1 shows the structure of specimen and manufactured UFE specimen. Figure 2 shows the making procedure of specimen. As room temperature curing hardener was used in the manufacturing, all specimens were cured at room temperature in a drying oven. The cured each specimen was separated from molder, cleaned and dried in the drying oven.

For practical design applications in HTS power equipment, the uniform electric field breakdown strength of a particular composite is important factor to know. Sphere-to-plane electrode system was used to make uniform electric field in this paper. Figure 3 shows the equi-potential lines between sphere electrode (+) and plane electrode (-). As shown in the Fig. 3, center point

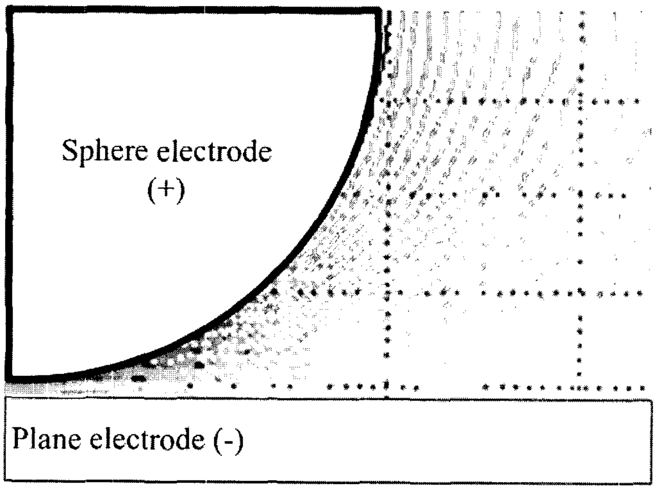


Fig. 3. Equi-potential lines between sphere electrode (+) and plane electrode (-).

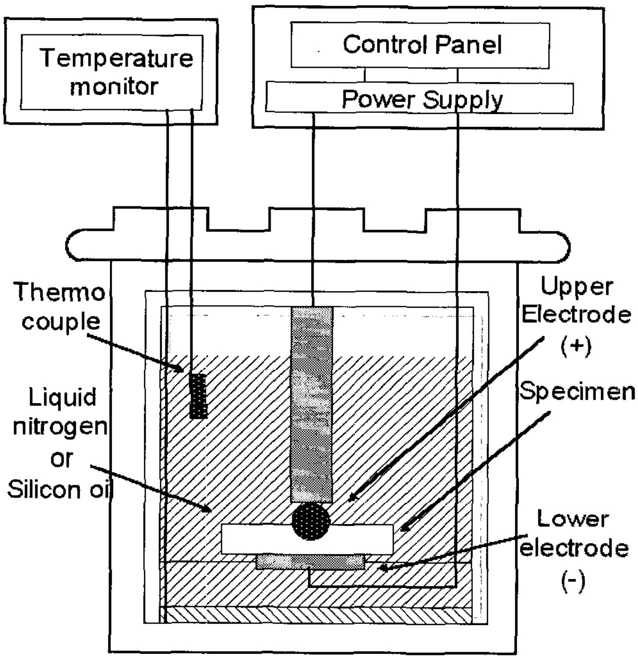


Fig. 4. Experimental setup.

between two electrodes, where the electric field is uniform, have the highest electric field, then it was expected that the breakdown of specimen would occurred at this point.

2.2 Experimental setup

Test method was selected according to the short-time test (current setting: 10 mA, rate-of-rise: 500 V/s) of ASTM D 149-97a (Dielectric breakdown voltage and dielectric strength of solid electrical insulating materials at commercial power frequencies). Figure 4 shows the

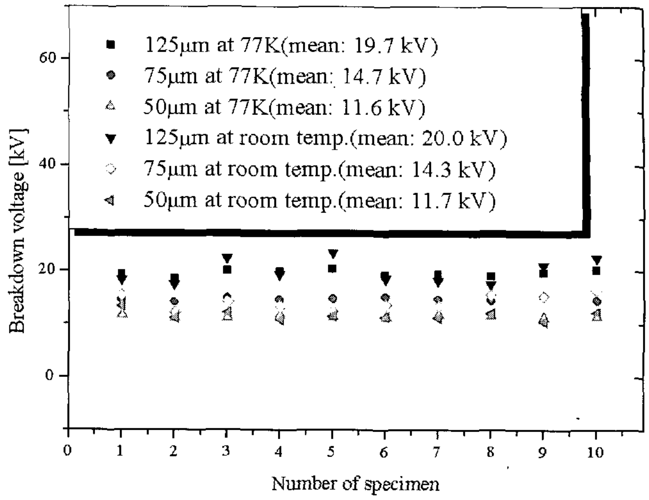


Fig. 5. Breakdown voltage of polyimide specimen.

structure of experimental system. The dielectric strength of the each type of specimen was measured both at room temperature and 77 K. Before the measurement at 77 K, because of the weakness to thermal shock, the each specimen was immersed in the liquid nitrogen vessel very carefully and slowly. It took about 5 minutes in immersing the specimen into LN_2. The sudden change of the temperature may make the mechanical crack in the specimen. All specimens were immersed in LN_2 vessel for 30 minutes before breakdown test.

3. RESULTS AND DISCUSSION

3.1 Breakdown voltage of polyimide

Figure 5 shows the breakdown voltage of polyimide specimen. The mean breakdown voltages of 3 types of specimens (thickness of 50, 75, 125 μm) at 77 K were 11.6, 14.7, 19.7 kV, respectively and those at room temperature were respectively 11.7, 14.3, 20.2 kV. The breakdown strength of polyimide at room temperature was similar to that at room temperature and 77 K. The dependence of the breakdown voltage measured at 77 K in kV was proportional to $d^{0.58}$, which shows that the breakdown voltage is also proportional to the root of the variation of material thickness ($d^{0.5}$) at cryogenic temperature[6].

3.2 Breakdown voltage of unfilled epoxy

A stycast 1266A/B was selected as an unfilled epoxy. It is a clear, low viscosity, room temperature curable and also has good moisture resistance, good electrical properties, and good impact strength. Figure 6 show the breakdown voltage of unfilled epoxy specimen. The measured breakdown voltage at room temperature was

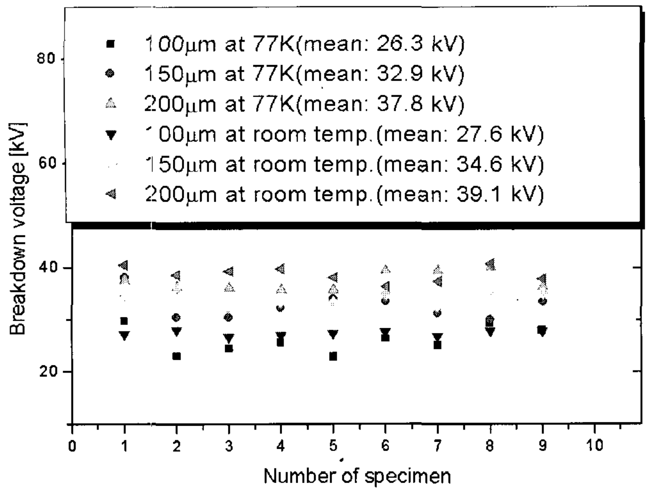


Fig. 6. Breakdown voltage of UFE specimen.

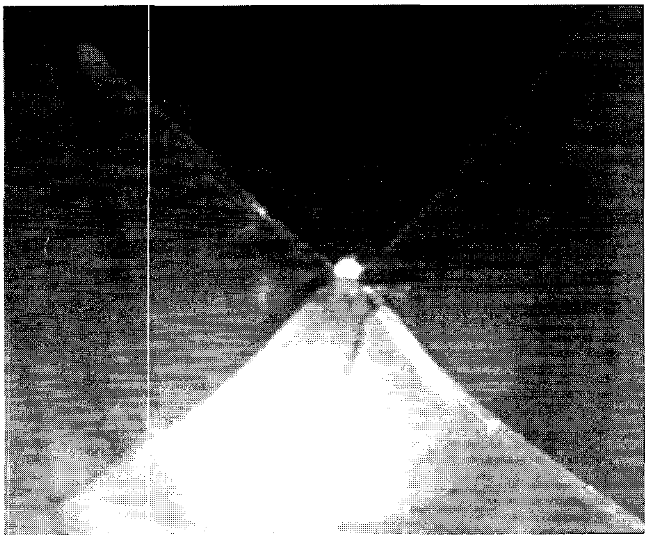


Fig. 7. Cracks in unfilled specimen.

slightly higher than that at 77 K. The dependence of the breakdown voltage measured at 77 K in kV was proportional to $d^{0.54}$, and it at room temperature was proportional to $d^{0.53}$. Although each specimen was immersed into LN_2 very carefully and slowly in this measurement, some specimen had very low dielectric strength due to the crack formation caused by the thermal shock. Figure 7 shows the crack. One possible reason is the different thermal expansion between stainless sphere electrode and unfilled epoxy.

3.3 Breakdown voltage of filled epoxy

A stycast 2850FT/23LV, which has a low coefficient of thermal expansion and good electrical insulation

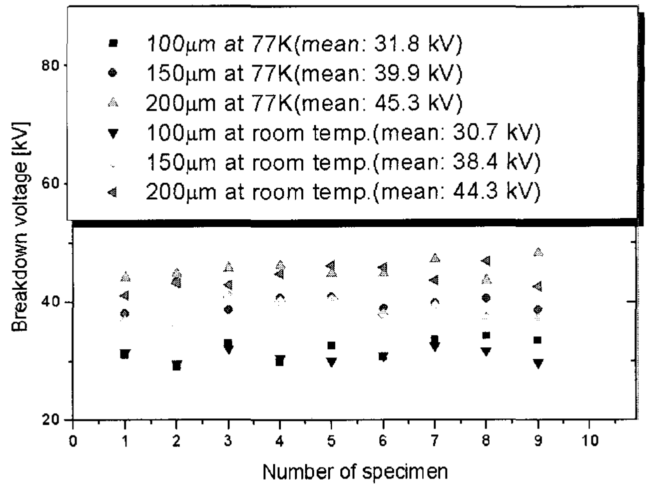


Fig. 8. Breakdown voltage of FE specimen.

properties, was selected as a unfilled epoxy. Figure 8 shows the breakdown voltage at 77 K and room temperature of filled epoxy specimen. The dependence of the breakdown voltage measured at 77 K in kV was proportional to $d^{0.52}$, and it at room temperature was proportional to $d^{0.53}$. The dielectric strength of FE was higher than that of UFE. Moreover, there was no evidence of crack formation during all the experiments.

Because of the heat generated by the displacement of dipoles, the AC breakdown voltage is generally lower than DC one. First, it is expected that the breakdown voltage at cryogenic temperature is higher than that at room temperature. But the measured results was some different to the expectation. Although there are some results concerning this phenomenon, they are different to each other[7-9].

There are some results concerning to the thermal property of filled epoxy. It reported that filling powder in epoxy enhances the thermal conductivity of epoxy[10].

4. SUMMERY

The insulation characteristics of some insulating materials for the insulation of superconducting power devices was investigated in this paper. The dielectric strength of polyimide, selected unfilled epoxy and filled epoxy at cryogenic temperature (77 K) was similar to that at room temperature. The breakdown voltage is also proportional to the root of the variation of material thickness ($d^{0.5}$) at cryogenic temperature. The filled epoxy has both good electrical insulation property and good thermal properties. The measured data can use in the practical design in superconducting power devices.

ACKNOWLEDGMENTS

The present Research has been conducted by the Research Grant of Kwangwoon University in 2005.

REFERENCES

[1] S. S. Kalsi, "Development status of superconducting rotating machines",` IEEE Power Engineering Society Winter Meeting, p. 401, 2002.

[2] E. R. Lee, S. J. Lee, C. J. Lee, H.-J. Suh, D. K. Bae, H. M. Kim, Y.-S. Yoon, and T. K. Ko, "Test of DC reactor type fault current limiter using SMES magnet for optimal design", IEEE Trans. on Applied Superconductivity, Vol. 12, No. 1, p. 850, 2002.

[3] D. K. Bae, Y. S. Yoon, M. C. Ahn, H. S. Ha, T. K. Ko, and S. S. Oh, "Characteristic analysis of a heater-triggered switching system for the charging of Bi-2223 double-pancake load", IEEE Trans. on Applied Superconductivity, Vol. 13, No. 2, p. 2227, 2003.

[4] J. A. Waynert, H. J. Boenig, C. H. Mielke, J. O. willis, and B. L. Burley, "Restoration and testing of an HTS fault current controller", IEEE Trans. on Applied Superconductivity, Vol. 13, No. 2, p. 1984, 2003.

[5] T. Kiyoshi, S. Matsumoto, M. Kosuge, M. Yuyama, H. Nagai, F. Matsumoto, and H. Wada, "Superconducting inserts in high-field solenoids", IEEE Trans. on Applied Superconductivity, Vol. 12, No. 1, p. 470, 2002.

[6] Standard Test Method for Dielectric Breakdown Voltage Test and Dielectric Strength of Solid Electrical Insulating Materials at Commercial Power.Frequencies, ASTM D 149-97a.

[7] I. Sauers, D. R. James, A. R. Ellis, and M. O. Pace, "High voltage studies of dielectric materials for HTS power equipment", IEEE Trans. on DEI, Vol. 9, No. 6, p. 922, 2003.

[8] S. H. Kim, T. Y. Ma, H. H. Kim, S. Y. Jung, and Y. S. Kim, "Mechanical and electrical properties of insulating materials at cryogenic temperature", J. of KIEEME(in Korean), Vol. 9, No. 10, p. 1033, 1996.

[9] D. K. Bae, J.-M. Juog, S.-M. Baek, C.-J. Lee, S.-J. Lee, T.-K. Ko, and S.-H. Kim, "Characteristic analysis of solid materials for electrical insulation of HTS magnets", IEEE Trans. on Applied Superconductivity, Vol. 14, No. 2, p. 1189, 2004.

[10] S. E. Yang, D. K. Bae, K. Y. Yoon, Y. S. Yoon, T. K. Ko, and S.-H. Kim, "Analysis on the thermal and electrical characteristics of impregnating materials for the bifilar winding-type superconducting fault current limiter", ACASC 2004, p. 12, 2004.