The Experimental Analysis on the Thermal and Electrical Characteristics of Impregnating Materials for Superconducting Magnets

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Abstract. In recent years, a development of Coated Conductor (CC) that is a called the second generation superconductor tape is opened out. Therefore a commercialization of superconducting power equipments will be realized presently. To realize a commercialization, it is necessary to develop a stable superconducting magnet. A superconducting magnet has to keep thermal stability as well as electrical stability. In this paper, thermal conductivity of impregnating materials, epoxy compounds, was measured at 65K, 77K, 100K and 200K. Dielectric Strength of superconducting magnet modeled electrode system with impregnating materials was also analyzed. Stycast® blue/catalyst 23LV is good materials to apply to the superconducting magnets.

1. Introduction

Recently, the status of R&D of Coated Conductor (CC) shows significant progress. According to development of coated conductor, coated conductor has many advantage that are high critical current, good switching characteristic, critical current characteristic under high magnetic field, etc[1], So superconducting magnets using coated conductor are researching with activity around the world. Yonsei University that takes part in 21th century Frontier R&D program started to develop the next generation winding type SFCL using superconducting magnet on the basis of inductive SFCL development technique.

In a process of a resistive SFCL, the quench is certainly occurred in limiting the fault current. For maintaining superconducting stability, a heat generated by the quench must be released quickly. Epoxy is used for supporting the magnet mechanically and increasing breakdown strength. Thus thermal conductivity of the epoxy is important.

In this paper, the thermal conductivity of Stycast® 2850ft blue/catalyst 23LV was measured. That was used generally for superconducting power equipment. And the breakdown strength was measured in 0.3 atmospheric pressure liquid nitrogen, because the operating temperature of SFCL is 64K. Generally critical current, breakdown strength and thermal stability are increased in sub-cooled nitrogen. Thus for evaluating the performance of the SFCL, SFCL is operated at 64K.
2. Experimental set up

2.1. Manufacture of the Specimen
If the void or cavity was generated inside of the specimen, the thermal conductivity was affected by the effects of void. Thus all of epoxy was hardened at a proper temperature in a vacuum oven after degassing. The Stycast® 2850ft blue/catalyst 23LV was cured at 50°C for 1.5 hours. The composition ratio of the Stycast® 2850ft blue/23LV is 100 : 7.5 on the basis of mass. The composition ratio of the specimen is based on the typical composition ratio of the manufacturer. Fig. 1 (a) is a procedure of epoxy manufacture. Because the composition ratio affects the thermal conductivity, mass of resin and hardener must exactly gauge.

2.2. Experiment Method
In this experiment, for effective measurement of the thermal conductivity, the specimen was manufactured to a cubic model. The edge length is 20 mm. Fig. 1 (b) shows a cross section of a block diagram for measurement thermal conductivity. This experiment uses a conduction cooling method. As cold head temperature of cryocooler was varied to 65K, 77K, 100K and 200K, we measured thermal conductivity. Silicon diode sensor was used for measuring the temperature of specimen. And temperature sensors were mounted on the specimen. When mounting the sensors, Con-grease was used for decreasing thermal resistance. If the thermal resistance decreases, the accuracy of thermal conductivity increases. The gap distance between sensors is 10 mm. Cold head, specimen and heater are in a vacuum box. After maintaining the proper temperature that is 65K, 77K, 100K and 200K, the voltage was applied to the heater using a DC power supply. Applying power is 0.2W.

2.3. Results of Thermal Conductivity
In steady state, the temperature wasn’t changed at certain point. In other words, the thermal conductivity is fixed through the cubical specimen.

The calculation equation of thermal conductivity is given by,

\[
\dot{Q} = -kA \frac{dT}{dx} \quad (W)
\]  

Where A is cross section area, k is a thermal conductivity.

The thermal conductivity k is
\[ k = -\frac{Q \cdot L}{A(T_1 - T_2)} \quad (W/m \cdot K) \]  

The temperature in Fig. 2 shows the measurement results at 200K when the applied voltage was 0.2W. The temperature is measured by the silicon diode sensors that were mounted on the specimen. The calculation of thermal conductivity is performed in steady state. In this experiment, the difference between the temperature decides the thermal conductivity.

Table 1 shows calculation values of thermal conductivity according to temperature. Each value is the average thermal conductivity when the energy of 0.2W is applied to the specimen.

| Temperature | Thermal conductivity (W/mK) |
|-------------|-----------------------------|
| 65K         | 1.532                       |
| 77K         | 1.661                       |
| 100K        | 1.834                       |
| 200K        | 3.396                       |

3. AC Breakdown in 64K Liquid Nitrogen

For investigating electrical characteristic of dielectric materials, as shown in Fig 3, the specimen and the frame were manufactured. The procedure of epoxy manufacture is the same to section 2.1. The diameter of stainless steel that was inserted in epoxy compounds 6 mm. When measuring the dielectric strength of Stycast® 2850ft/23LV, the test was carried out in 64K liquid nitrogen. For maintaining the temperature of cryostat 64K, rotary pump is used. Using the rotary pump, the inside pressure of cryostat is lower until the 0.3 atmospheric pressure. It takes approximately two hours to reach the 0.3 atmospheric pressure. The temperature of liquid nitrogen is measured by using silicon diode sensor. Fig. 4 shows the dielectric strength of Stycast® 2850ft at 64K. As shown Fig. 5, the average dielectric strength of Stycast® 2850ft is 118.8 kV/mm.

![Fig. 2. Temperature rising of the specimen](image)
4. Conclusion
At cryogenic temperature, the thermal conductivity of impregnating materials for the bifilar winding-type SFCL could affect to the protection of superconducting tape and the stability of cryogenic system. Thus it is necessary to secure the basic data of dielectric materials. In this experiment, the thermal conductivity and the dielectric strength of dielectric materials were measured. The thermal conductivity at 200K is twice than thermal conductivity at 77K. Dielectric strength and Thermal conductivity at 64K will be important data for superconducting magnet operated in sub-cooled nitrogen.

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