Effect of Laminated Polypropylene Paper on the Breakdown Strength of Multi-layer Insulation for HTS Cable

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Abstract

Laminated Polypropylene Paper (LPP) and Kraft paper were used as ac power insulation for conventional cable as well as high temperature superconducting (HTS) cable because of its prominent insulating characteristics. However, researches on the use of LPP/Kraft paper in HTS cables are thinly scattered. In this paper, the effect of laminate polypropylene paper on the breakdown strength of LPP/Kraft multi-layer sample impregnated with liquid nitrogen (LN2)under ac and impulse applied voltage was studied. In addition, the breakdown strength characteristics of LPP and Kraft multi-layer sample were also investigated. It was found from the experimental data that the LPP has higher breakdown strength value than Kraft paper in ac and impulse. Especially in the ac case, the breakdown strength increases as the component ratio of LPP in the LPP/Kraftsample increases and slightly affected by the inserting position of LPP but in impulse case, the breakdown strength strongly depends on the number of LPP and the relative position of LPP.

Key Words : Polypropylene, HTS cable, multi-layer, breakdown strength, liquid nitroge

1. INTRODUCTION

The high temperature superconducting (HTS) cable is predicted to transmit high power densities with strongly reduced conductor loss at lower voltage because of high critical current density property of HTS conductor compared to that of conventional copper ones [1,2]. Laminated polypropylene paper (LPP) has been used as oil-filled power cable insulation to replace Kraft paper because of its lower dielectric loss and higher dielectric strength [3,4]. Recently, LPP is being used as tape insulation in HTS power cable because it can be easily impregnated with liquid nitrogen (LN2) and its dielectric loss is smaller than that of Kraft paper but nearly the same with OPPL. Moreover, the breakdown strength of LPP is little higher than that of Kraft paper [5,6]. In Korea, in support to the 21st century project, the research on the use of LPP as tape insulation for HTS cable has been carried out [7,8]. Nevertheless, the dielectric breakdown mechanism of LPP/Kraft has not been investigated sufficiently.

In this paper, the effect of LPP on the breakdown strength of LPP/Kraft was studied. The object of the study is to investigate the dielectric breakdown mechanism of LPP/Kraft and compare to LPP and Kraft paper under ac and impulse.

2.EXPERIMENTALPROCEDURES

Two kinds of material insulation were used in this experiment; these are 0.1 mm thickness

Kraft paper and 0.119 mm thickness LPP. LPP consists of two sheets of Kraft paper laminated by extruded PP. Because of the highly hygroscopic nature of Kraft paper, vacuum drying of sample was done at a temperature of 100oC for 24 h prior to testing [9]. In determining the breakdown characteristics of LPP and Kraft multi-layer, two kinds of samples were used. These are, the sample with buttgap and without buttgap and the number of sheets wera varied from two to seven. In the case of studying the effect of PP on the breakdown strength of LPP/Kraft multi-layer, nine kinds of seven-sheet specimens were used as shown in figure 1. All specimens, the bottom layer is the LPP having a buttgap of 6 mm in diameter at the center.

Figure 2 shows the electrode configuration for experiment. Multi-layer insulation samples were laminated between sphere and plane electrodes. The diameter of sphere and plane were 8 mm and 60 mm, respectively. The electrodes were made of stainless steel, and the sphere electrode was molded with epoxy resin to avoid partial discharge on the surface of sphere electrode.

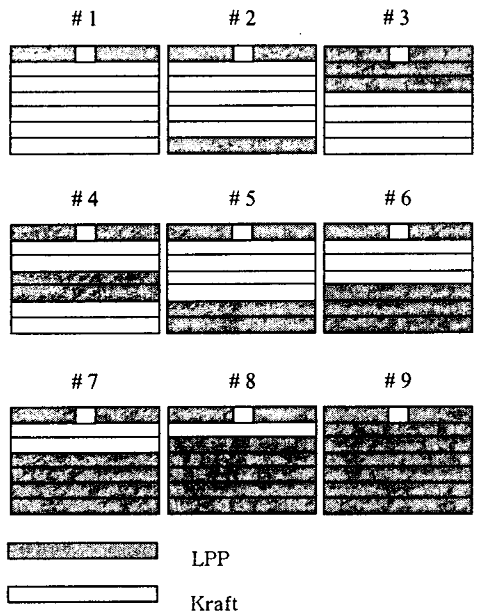


Fig.1. Specimens for experiment.

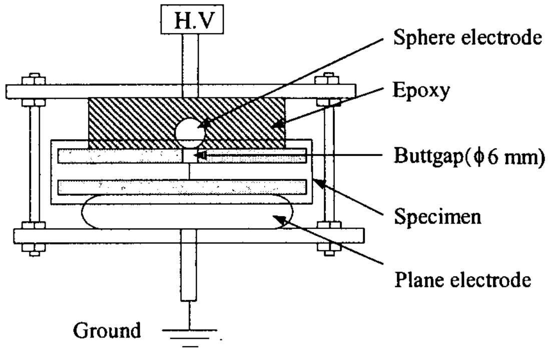


Fig.2. Electrode configuration.

Figure 3 shows a diagram of experimental apparatus (a cryostat) used for measurement of electrical characteristics of the samples. The electrode system was set in a dewar flask of LN2 in the innermost layer of the cryostat with a high voltage bushing. The outer layer is filled with atmospheric liquid nitrogen (1 atm, 77 K) to prevent the temperature rise of the liquid nitrogen in the innermost layer. The electrical test apparatus are ac dielectric strength test set, which is made of Kyonan Electric CO., LTD (50/60 Hz, 100 kV, 1 kVA) and impulse voltage tester system, which made of Dae Yang Electric CO., LTD (1.2 50 s, 400 kV, 15 kJ).

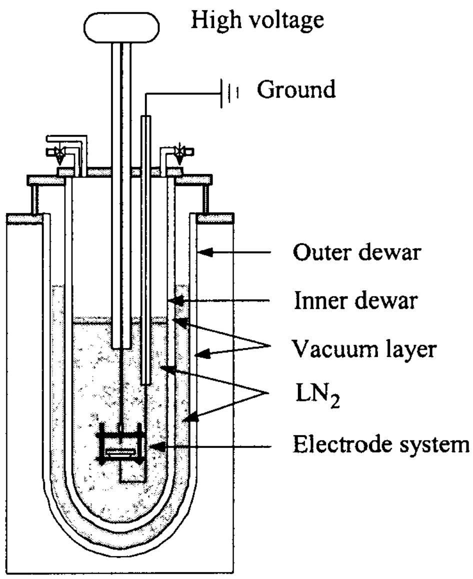


Fig.3. Cryostat and experimental setup.

Ac breakdown test was carried out according to standard method. The test samples were subjected to a slow ac ramp (1 kV/s) one by one until breakdown occurred [10]. In case of impulse test, firstly, a voltage estimated to be 70 % of breakdown value, was applied to a test object. The voltage was then increased in steps of 4 kV until a breakdown occurred [11]. The polarity of applied impulse voltage was also changed. For both of ac and impulse test, the breakdown test was repeated 10 times for each sample to obtain an average value of breakdown voltage.

3. RESULTS AND DISCUSSION

3.1. LPP Breakdown Characteristics

The breakdown voltage of LPP multi-layer as a function of number of sheets is shown in figure 4. The breakdown voltage increases nonlinearly with increasing number of sheets and standard deviation also increases. However, the breakdown voltage of LPP multi layer without buttgap is higher than the sample with buttgap due to the effect of buttgap [7]. Moreover, in both cases, the value of impulse breakdown voltage is much higher than that of ac voltage and the standard deviation of impulse breakdown voltage is larger than that of ac breakdown voltage. However, the value of negative impulse breakdown voltage is higher than that of positive impulse breakdown voltage due to the formation of positive streamer and the positive charge trapping on the surface of PP film [11].

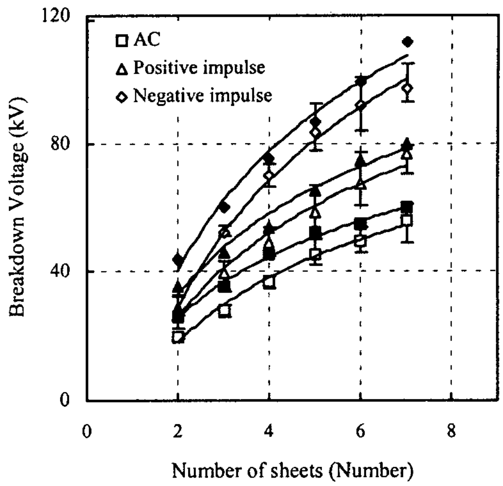


Fig. 4. Breakdown voltage versus number of sheets. Full symbols for without buttgap; empty symbols for with buttgap.

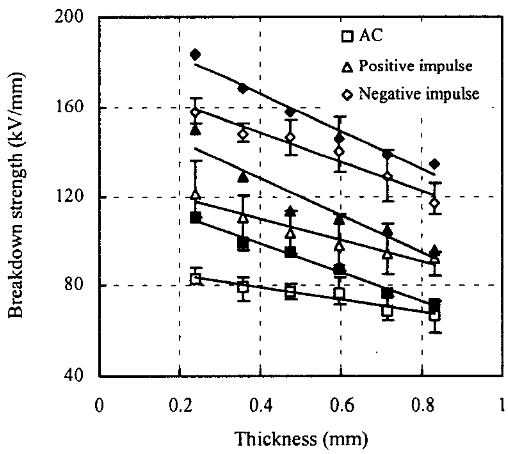


Fig.5. Breakdown strength versus thickness. Full symbols for without buttgap; empty symbols for with buttgap.

The breakdown strength of LPP multi-layer is presented in figure 5. It shows that breakdown strength decreases linearly with increasing thickness and impulse breakdown strength is much higher than ac breakdown strength. Moreover, negative impulse breakdown strength is much higher than that of positive impulse strength, so the polarity of applied voltage has a strong effect to the breakdown strength voltage of LPP. In addition, the decline of impulse breakdown strength is larger than that of ac breakdown strength and the slope of breakdown strength line in the LPP multi layer without buttgap is much larger than in with buttgap. From these results, it is clearly seen that the impulse breakdown strength is more thickness dependent than the ac breakdown voltage and the LPP sample without buttgap has more thickness effect than with buttgap sample.

3.2.KraftCharacteristics

Figure 6 shows the breakdown voltage of Karft as a function of the number of sheets. The breakdown voltage increases nonlinearly as the number of sheets increases and the value of breakdown voltage in the sample without buttgap is higher than that of with buttgap. Moreover, the value of impulse breakdown voltage is always higher than that of ac breakdown voltage. However, the value of negative and positive impulse breakdown voltage are nearly the same because the positive and negative charges spread easily into Kraft paper.

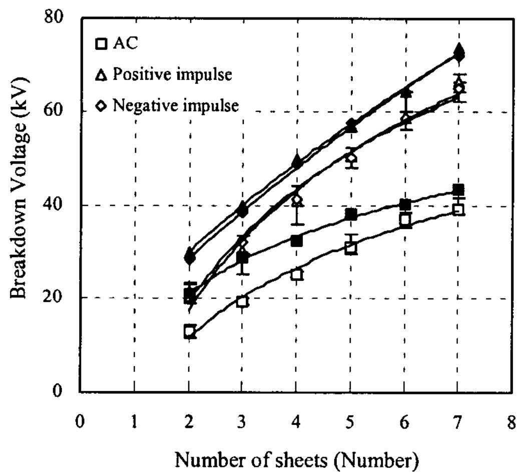


Fig. 6. Breakdown voltage versus number of sheets. Full symbols for without buttgap; empty symbols for with buttgap.

The relation between breakdown strength and thickness is expressed in figure 7. It shows that the breakdown strength decreases linearly as thickness increase and the value of breakdown strength in the sample without buttgap is always higher than that of with buttgap. Moreover, the impulse breakdown strength is higher than that of the ac and standard deviation in impulse case is also larger than in ac. However, the positive and negative breakdown strength is nearly the same so the polarity of applied voltage has no effect on breakdown strength of Kraft paper. The impulse breakdown strength line seems to be parallel to ac breakdown strength line in both with buttgap and without buttgap. However, the breakdown strength line in the sample without buttgap is much steeper than with buttgap. It is clearly observed that the effect of thickness on breakdown strength of Kraft is slightly dependent on the kind of applied voltage but strongly dependent on the state of sample, which has a buttgap or not.

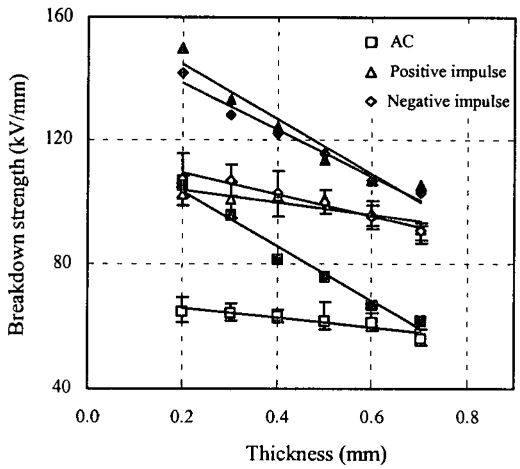


Fig.7. Breakdown strength versus thickness. Full symbols for without buttgap; empty symbols for with buttgap.

3.3.LPP/Kraftcharacterictics

The comparison on breakdown strength between LPP and Kraf paper as a function of thickness is shown in figure 8.

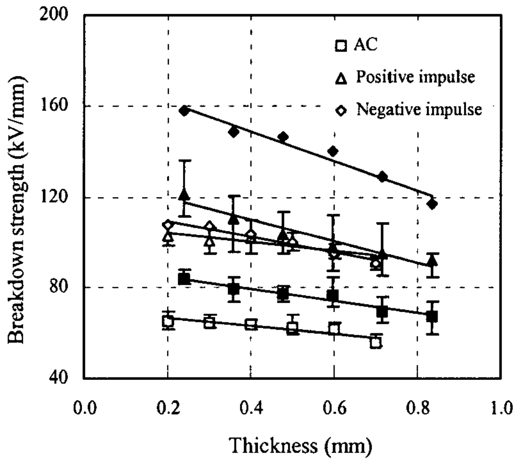


Fig. 8. Breakdown strength comparison. Full symbols for LPP; empty symbols for Kraft.

The breakdown strength and standard deviation of LPP is higher than Kraft but standard deviation is also higher for LPP case. In addition, the breakdown strength line of LPP is steeper than Kraft. The thickness of LPP has a significant effect on the breakdown strength characteristics as compared to Kraft paper.

The ac breakdown strength of LPP/Kraft is shown in figure 9. It shows that ac breakdown strength of specimen 9 (LPP only) got the highest value while specimen 1 (Kraft only) had the lowest value. However,the breakdown strength fluctuated as the specimen with inserting place of LPP (see 3, 4, 5) changes. The results showed that ac breakdown strength of LPP/Kraft specimen is slightly affected by the relative position of LPP in the specimen but rather strongly affected by the component of LPP and Kraft paper in LPP/Kraft

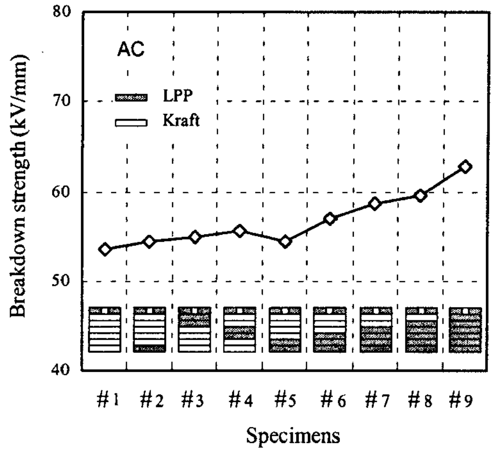


Fig.9. Ac breakdown strength.

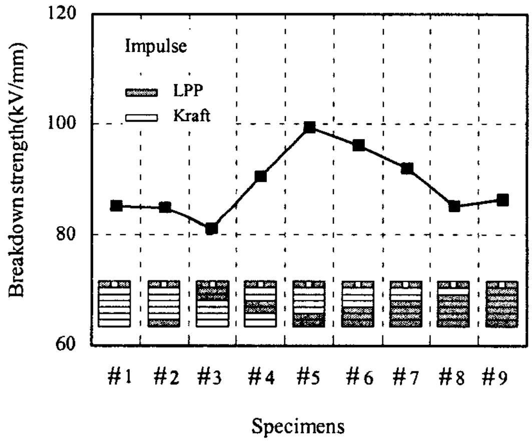
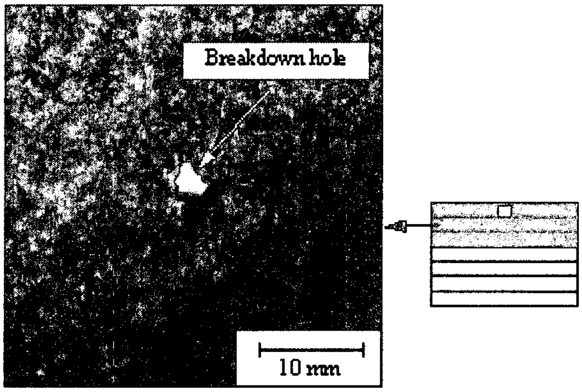


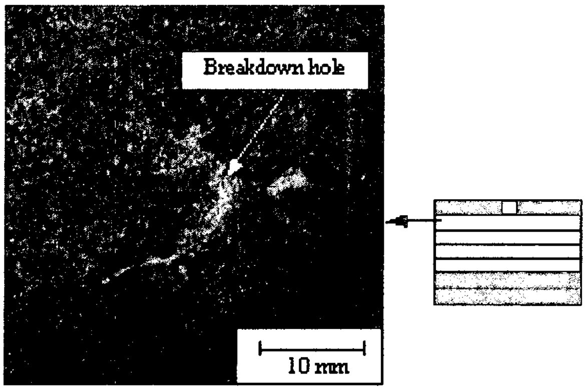
Fig.10. Impuse breakdown strength.

The positive impulse breakdown strength of LPP/Kraft is shown in figure 10. It shows that the breakdown strength of LPP (9) is a little higher than that of Kraft paper (1) due to the effect of thickness. The impulse breakdown strength of specimen 5 got the highest value in comparison with specimen 3 and 4, which indicates that thethe breakdown strength becomes larger as position of LPP from positive electrode become larger. This is due to the effect of positive charges, which are trapped on the PP film [11]. The breakdown strength varied depending on the number and the position of LPP in LPP/Kraft as observed in specimen 5. This explained why the impulse breakdown strength of LPP/Kraft is also higher than Kraft or LPP alone.

Figure 11 shows the breakdown-spot pictures of LPP layer in specimen 3 and Kraft layer in specimen 5 after positive impulse breakdown. The breakdown spot of LPP layer is obvious and breakdown hole is big. On the other hand, the breakdown spot of Kraft layer looks complicated and breakdown hole is small. This result is due to the fact that positive charges are trapped on the surface of LPP while it can spread easily into Kraft paper



(a) LPP positive impulse breakdown spot



(b) Kraft positive impulse breakdown spot

Fig.11. Positive impulse breakdown spot pictures.

4. CONCLUSIONS

Based on the results, the following conclusions can be drawn:

1.LPP has higher breakdown strength value than Kraft in ac and in impulse but the thickness dependence of LPP is higher than that of Kraft.
2.LPP is strongly affected by the polarity of applied-voltage but not for Kraft.
3.In ac case, the breakdown strength is strongly dependent on the component of LPP in the LPP/Kraft sample but slightly dependent on the relative position of LPP.
4.In impulse case, the breakdown strength of LPP/Kraft has the highest value in comparison with LPP or Kraft.
5.The impulse breakdown strength of LPP/Kraft is strongly dependent on the component of LPP and the position of LPP.

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