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Creepage Discharge Characteristics of Solid Insulation Materials under Cryogenic Temperature for a Superconducting Apparatus

O. Lee [a], K. Jeong [a], S. Jeon [a], H. Choi [a], H. Lee [a], and Hyoungku Kang [a*]
[a] Dept. of Electrical Engineering, Korea National University of Transportation, Chungju, Korea

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Introduction

- ✓ Superconducting apparatuses operated in a high voltage condition could be damaged by unexpected dielectric accidents.
- ✓ Creepage discharge characteristics at the surface of solid insulation materials could be inferior to those of penetration electrical breakdown characteristics of gaseous and liquid insulation materials.
- ✓ Therefore, penetration and creepage discharge characteristics at the surface of solid insulation materials should be taken into consideration to conduct electrical insulation design.
- ✓ In this paper, studies on creepage discharge characteristics at the surface and interface of solid insulation materials and penetration characteristics are conducted.

Experimental Set-up

❖ Penetration experiments set-up

- ✓ Dielectric experiments on penetration electrical breakdown characteristics through a solid insulation material are conducted.
- ✓ The Stycast 2850FT and the Loctite CAT 9 are used as epoxy resin and hardener for creepage discharge experiment.
- ✓ They are mixed as the mass ratio of 100:3.5 and the mixed compound is heated for 48hrs at the temperature of 60℃ in a furnace.
- ✓ The curing conditions of epoxy resin for penetration electrical breakdown experiments are equally applied to epoxy resin for creepage discharge experiments.
- ✓ A brief schematic drawing of electrode systems for penetration electrical breakdown is shown in Fig. 1

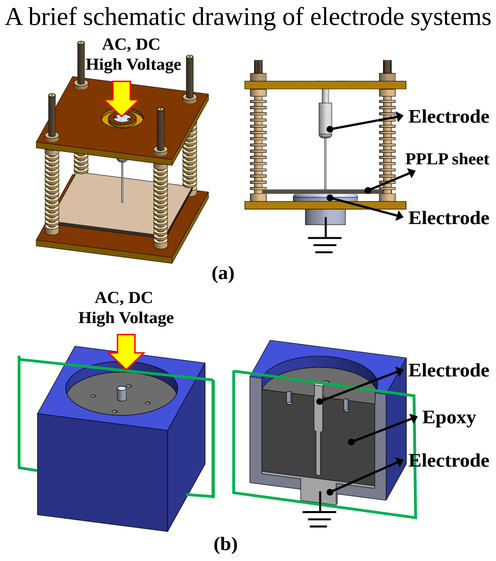

Fig. 1. Schematic drawings of a rod- plane electrode system for experiments on penetration electrical breakdown with specimens made of (a) PPLP (b) Epoxy

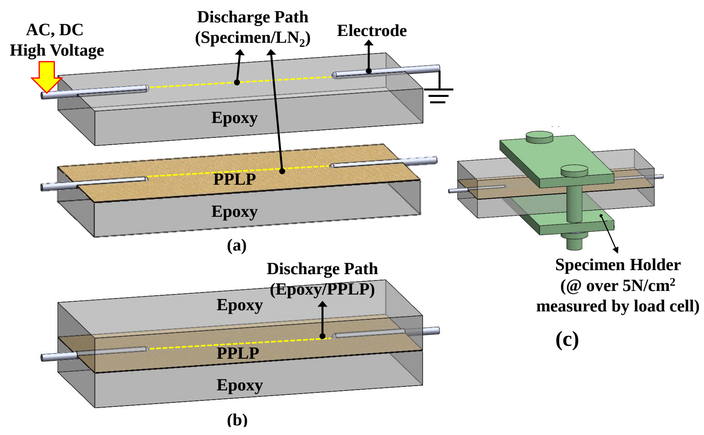

Fig. 2. Schematic drawings of rod-to-rod electrode systems for experiments on creepage discharge with insulating specimens made of (a) Epoxy resin or PPLP, (b) Epoxy/PPLP, (c) Specimen holder with interfacial pressure.

❖ Creepage discharge experiments set-up

- ✓ Schematic drawings of electrode systems for experiments on creepage discharge are shown in Fig. 2.
- ✓ Experiments on creepage discharge characteristics along the surface of a solid insulation material are conducted.
- ✓ A rod-rod electrode system is placed on the surface of solid insulation materials.
- ✓ Electrical breakdown voltage at creepage discharge is measured along the surfaces of epoxy resin and PPLP and along the interfaces between epoxy resin and PPLP in contact.
- ✓ Specimens for creepage discharge experiments are made of epoxy resin and PPLP as the shape of a plate.
- ✓ The surface of specimens made of epoxy resin is cleaned off with sand paper before every experiment for minimizing the influence of surface roughness.
- ✓ The interfacial pressure between two specimens is applied over 5N/cm² because it is known that creepage discharge characteristics are dependent on the interfacial pressure below 5N/cm².

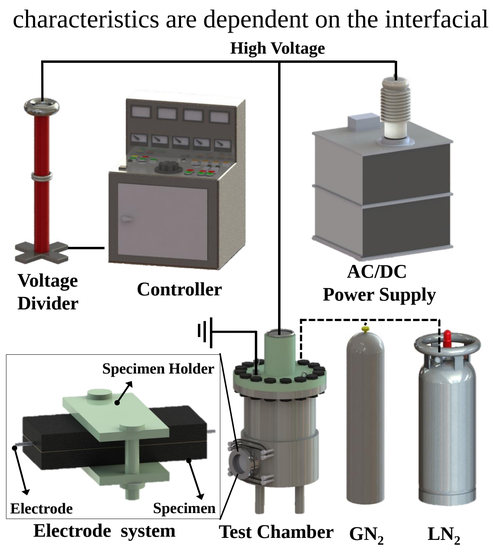

Fig. 3. Schematic drawing of dielectric experiments on creepage discharge

Table. I. Specifications of Experiments.

Diameter of a rod electrode (mm)	2
Diameter of a plane electrode (mm)	100
Radius of edge (mm)	1
Material of an electrode	stainless steel
Pressure (MPa)	0.1
Applied voltage	AC and lightning impulse
Environment	LN2 (77K)
Materials of specimen	epoxy resin, PPLP
Penetration thickness (mm)	0.5, 1, 1. 5, 2
Discharge path (mm)	5, 10, 35, 65, 80, 110
Frequency of AC	60Hz
Lightning impulse wave	1.2/50μs

Experimental Results and Analysis

❖ Penetration electrical breakdown

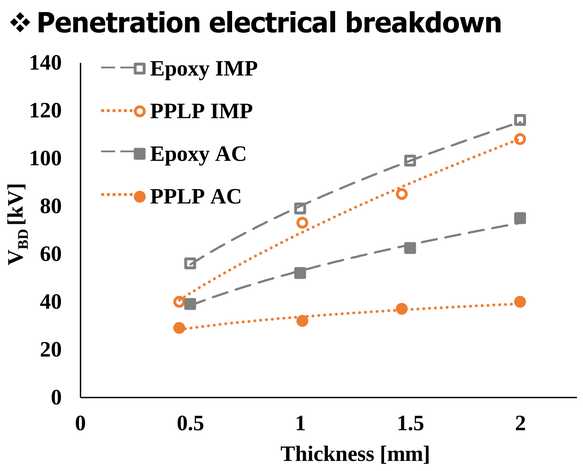

Fig. 4. V_{BD} according to thickness under AC and lightning impulse voltage.

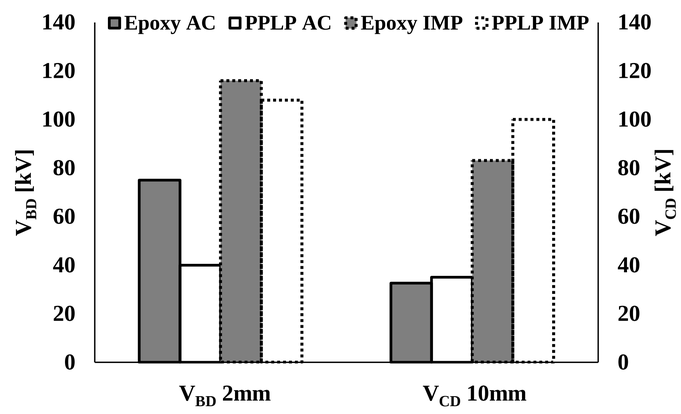

Fig. 5. Comparison of V_{BD} and V_{CD} for PPLP and epoxy resin under AC and lightning impulse voltages.

- ✓ The penetration breakdown voltage (V_{BD}) of solid insulation materials according to thickness (from 0.5mm to 2mm) is measured and experimental results are shown in Fig. 4.
- ✓ As the thickness of epoxy resin and PPLP increases, V_{BD} increases.
- ✓ It is observed that V_{BD} of epoxy resin specimen is higher than that of PPLP specimen regardless of applied power source.

❖ Creepage discharge

- ✓ As shown in Fig. 5, it is found that V_{BD} of a solid insulation material is higher than creepage discharge voltage (V_{CD}) of a solid insulation material although creepage discharge path is 5 times larger than penetration thickness of specimens.
- ✓ In addition, V_{CD} on a single solid insulation material and that on interface of different two solid insulation materials are compared.
- ✓ As shown in Fig. 6, V_{CD} of PPLP specimen is relatively higher than that of epoxy resin specimen regardless of applied voltage.
- ✓ It is observed that V_{CD} between two contacted solid insulation materials is lower than V_{CD} at the surface of a single sloid insulation material.
- ✓ V_{CD} at the interface between two different materials could be inferior to that at the surface of a single material because defects such as contaminants, dust, and voids.

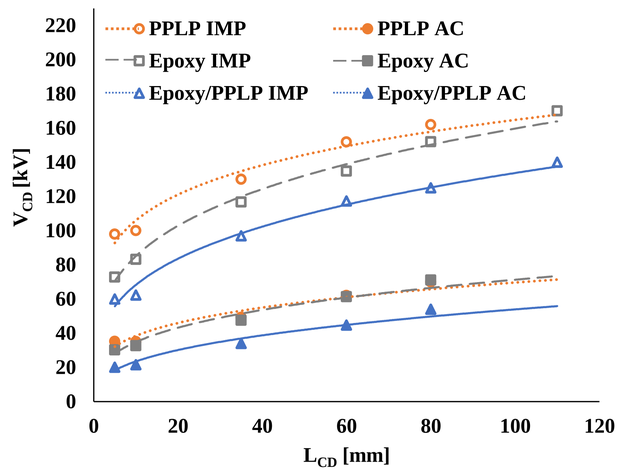

Fig. 6. V_{CD} according to L_{CD} under AC and lightning impulse voltages.

TABLE II. electric field criterion of creepage discharge.

Solid Insulation Material	AC	IMP
PPLP	0.8 kV/mm	1.6 kV/mm
Epoxy	0.7 kV/mm	1.5 kV/mm
Epoxy/PPLP	0.6 kV/mm	1.3 kV/mm

❖ Electrical field analysis

- ✓ Equation (2) represents the relationship between creepage discharge voltage and mean electric field intensity at creepage discharge voltage.
- ✓ E_{MEAN} indicates the mean electric field between two electrodes when 1kV is applied to an electrode system. $E_{CD,MEAN}$ can be calculated by using V_{CD} and E_{MEAN} as follws: $E_{CD,MEAN} = E_{MEAN} \times V_{CD}$ (1)
- ✓ As shown in Fig. 7, penetration electrical breakdown characteristics of solid insulation materials such as PPLP and epoxy resin can be explained by mean electric field intensity according to penetration thickness.
- ✓ Also, creepage discharge characteristics at surface and interface of solid insulation materials can be explained by mean electric field intensity according to L_{CD}.
- ✓ It is observed that $E_{CD,MEAN}$ is saturated as L_{CD} increases.
- ✓ As results, criterion of creepage discharge at surface and interface of solid insulation materials in saturated liquid nitrogen at 0.1MPa according to applied voltage are deduced as empirical formulae.
- ✓ The deduced empirical formulae are shown in Table 2.

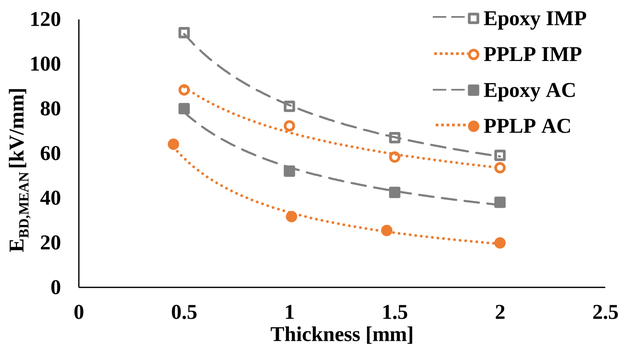

Fig. 7. $E_{BD,MEAN}$ characteristics of the insulator with respect to thickness in with AC and lightning impulse voltages.

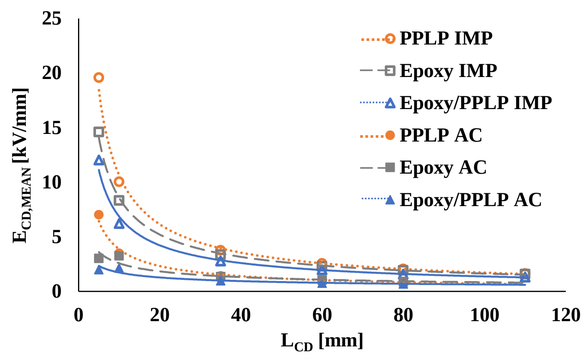

Fig. 8. $E_{BD,MEAN}$ characteristics of the insulator with respect to LCD in with AC and lightning impulse voltages.

Conclusions

- ✓ In this paper, penetration electrical breakdown and creepage discharge characteristics of solid insulation materials are experimented and analyzed for the insulation design of a high voltage superconducting apparatus. Dielectric characteristics of PPLP and epoxy resin in saturated liquid nitrogen are summarized as follows:

1) V_{BD} of epoxy resin is higher than V_{BD} of epoxy resin. Difference of penetration electrical breakdown voltage between under AC and lightning impulse voltage is getting large when the thickness of solid insulation materials increases. It is inferred that electrical breakdown characteristics under lightning impulse voltage is not affected by heat dissipation of solid insulation materials. However, electrical breakdown characteristics under AC voltage is dependent on accumulated heat by applied voltage in solid insulation materials.
2) Penetration electrical breakdown characteristics of solid insulation materials are expressed as a function of $E_{BD,MEAN}$ and penetration thickness. It is found that $E_{BD,MEAN}$ of PPLP and epoxy resin decreases as thickness increases.
3) V_{CD} at the surface of PPLP specimens is higher than that at the surface of epoxy resin specimen. V_{CD} at the interface between PPLP and epoxy resin is lower than that at the surface of single solid insulation materials. V_{CD} increases exponentially as L_{CD} increases.
4) Creepage discharge characteristics of solid insulation materials are expressed as a function of $E_{CD,MEAN}$ and L_{CD}. Criterion of creepage discharge at surface and interface of PPLP and epoxy resin in saturated liquid nitrogen at the pressure of 0.1MPa are deduced as empirical formulae.

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