PE300 Cryogenic High Voltage Insulators

N. Bagrets, S. Fink, V. Zwecker

***Abstract*— In growing field of cryogenic applications the proper choice of material is an important issue. For example, in the Cryogenic High Voltage Lab at the KIT-ITEP a material is needed for investigations of flashover voltages at cryogenic temperatures. The following material properties are required for this application: high flashover resistance, smooth surface to enable easy detachment of SS components of HV facility, appropriate mechanical properties at RT and 77 K. Also, low costs and simple mechanical handling are desired. One possible candidate was found to be PE300. HV tests and mechanical investigations were performed on this material to check its applicability as an insulating material in the cryogenic environment. As it was expected, mechanical properties differ significantly when temperature changes from RT down to 77 K.**

In this report the flashover resistance and mechanical properties measurements results are presented, and usability concept of PE300 in cryogenic environment is discussed.

***Index Terms*— cryogenics, high voltage, insulators, polyethylene**

I. Introduction

FLASHOVERS in solid insulators embedded in liquid nitrogen can cause relevant mechanical or electrical degradation. Often the best solution is to prevent flashovers, but there are several reasons why this not always the case in real world application, e. g. a certain number of flashovers should be tolerated, the breakdown voltage is not correctly estimated or flashovers are even requested which was the motivation for the searching a flashover resistant insulator which is described in the following. In the present case a flashover resistant material was searched for the examination of flashover voltages in liquid nitrogen in the Cryogenic High Voltage Lab of the KIT-ITEP. The foreseen use of a high quality ceramic rod had been not successful and therefore other materials had been investigated for cryogenic high voltage usability.

I. Material Selection

Initially a ceramics tube made of Aluminium Oxide (Al2O3) FRIALIT F99.7 was used as a support insulator between a grounded stainless steel (SS) plate and a SS "bell" which was employed as a high voltage electrode. The bell can be moved along the insulator for changing the electrode distance. As a first disadvantage of this arrangement it was found that changing the electrode distance by moving the SS bell causes an abrasion of SS and SS covering of the ceramics surface which was difficult to remove. A second disadvantage was the damaging of the ceramics after some standard lightning impulses around 150 kV (Fig. 1).

Fig. 1. Degradation of the Aluminium Oxide ceramics tube after some flashovers around 150 kV.

Hence a high voltage test series with the following materials was performed: other ceramics, PLA, porcelain, PI, PE, PEEK, quartz glass, borosilicate glass.

The best compromise for the foreseen use between material resistance against destruction, cryogenic usability, costs, mechanical handling, sliding, availability, environmental aspects etc. was found with PE300. A possible disadvantage for the use of PE300 as insulator is its relatively low mechanical tensile and compressive strength. In respect of a general use of PE for post or suspension insulators this weak point of material properties was examined in detail in the Cryomak Lab of KIT-ITEP.

II. High Voltage Test Set-up

The described high voltage tests were planned as qualification tests for PE300 as flashover resistant high voltage insulator material as well as data basis for the determination of flashover length in liquid nitrogen under slightly boiling and under strong boiling conditions. The strong boiling case is examined with respect of a quench within a superconducting apparatus.

PE disks with a diameter of 40 mm and a thickness of 2 mm, 4 mm and 6 mm with a small center groove on the top side were used as insulators between a heatable ground plate of 300 mm diameter and a high voltage top plate with 100 mm diameter. A PA screw was fixed in the center of the top plate and retains the disk in its center groove. Multiple barriers avoid pollution of the liquid nitrogen around the insulator with ice because it turned out that especially DC breakdown values are decreasing in the presence of ice particles.

The arrangement was cooled down with liquid nitrogen in a EPP (extruded polypropylene) box which was surrounded with an frp (fiber reinforced plastic) box (Fig. 2).

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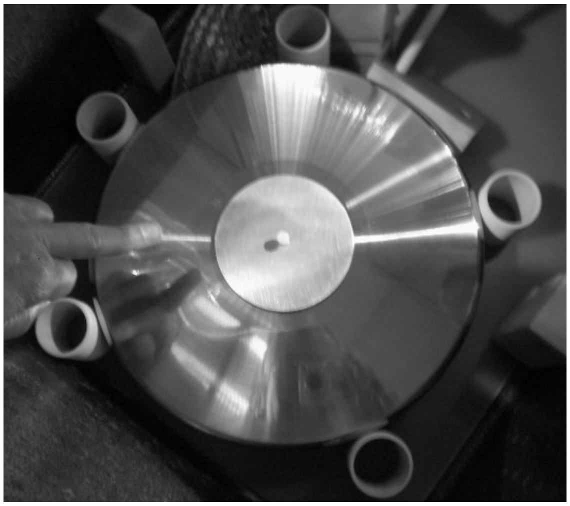

Fig. 2. Top view of a PE disk on the ground plane within cryostat box.

AC, DC and standard lightning impulses generated with a high voltage construction kit were applied on the high voltage electrode (Fig. 3). In case of DC and standard lighting tests both polarities were examined.

One type of high voltage tests is supposed to show that the insulators can tolerate a large number of flashovers (with preferably high energy). Besides these destruction tests another type of test was performed which shows that the flashover voltage is relatively high if PE as insulator is used. The later tests are labelled as withstand tests. This means that for the destruction tests a high breakdown probability is aimed in contradiction of the withstand tests where breakdowns have only the task to indicate the top limit of dielectric strength.

The destruction tests were performed with high field arrangements, i.e. relatively low distances or sharp edges.

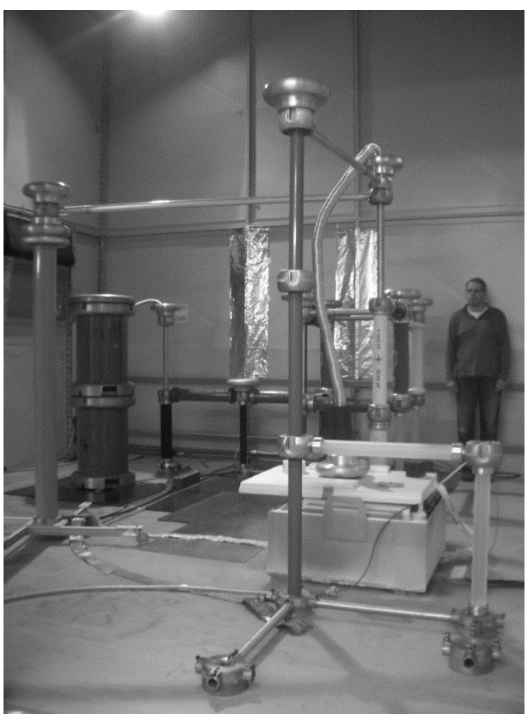

Fig. 3. Arrangement for standard lightning impulse testing up to 237 kV. The cryostat box is on the floor on the right sight.

A constant voltage value was applied for 15 min AC and DC withstand tests. Series of 20 impulses was applied for the standard lightning impulse withstand tests. In case of a breakdown during the withstand tests the voltage was decreased for about 10 % until no breakdown happens. This voltage was specified as withstand voltage value. The lowest voltage level with a breakdown was specified as breakdown voltage value. For bubble generation five 500 W heating impulses of 12 s each were generated within a 15 min test. For impulse voltages withstand testing the voltage was triggered after 10.0 s heating duration of the liquid nitrogen.

III. Results of High voltage tests

Destructive tests were performed with AC and standard lightning impulse. Few tests were also made with DC. Sometimes permanent grey color traces were produced on the surface of the PE300 sample (Fig. 4) but no cracks occurred. No decrease of flashover voltage was observed for test samples with traces and the traces did not accumulate on a certain location if no degradation of the electrode material occurred.

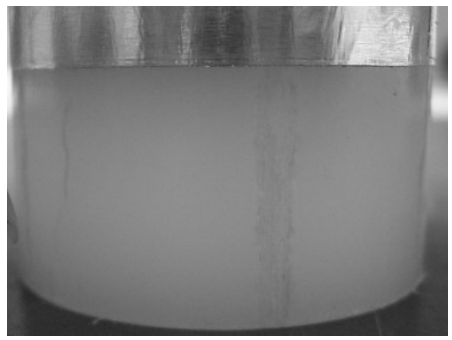

Fig. 4. PE300 sample with grey traces after multiple flashovers in liquid nitrogen. 10 of these flashovers had been at a standard lightning impulse voltage of about 200 kV.

A voltage range between 17.9 kV and 220 kV was covered with withstand and breakdown voltages during the withstand tests with PE300 insulator rod lengths of 2 mm up to 6 mm.

No large difference between ACpeak and DC flashover voltage can be found. Flashover voltages for standard lightning impulse are higher than DC or ACpeak if the heating conditions and insulator lengths are the same. The bubbles generated by heating reduce the dielectric strength. The amount of reduction is very different. Strong reduction by bubbles was always found for standard lightning impulse waveform. The relatively low DC and ACpeak values are presented in Fig. 5 in order to determine draft minimum flashover field strength. The minimum line flashover field strength 8.3 kV/mm is shown in Fig. 5, too. This value is in the range of the minimum AC flashover voltage reported in [1] for PMMA insulators in liquid nitrogen.

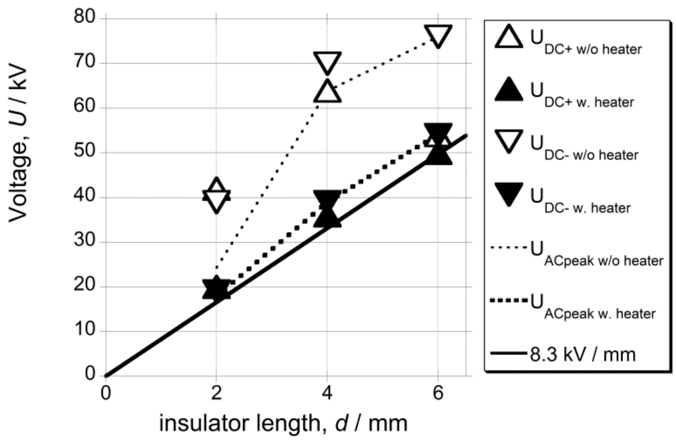

Fig. 5. Withstand values DC and AC versus insulator length for PE300 insulators with a diameter of 40 mm embedded in liquid nitrogen

Only one PE disk was destroyed during the test by a breakdown and not by flashover. The reason for the breakdown was a too large groove within a 4 mm disk. No conductive paths arose along the grey traces on the surface which is a large advantage compared to this potential problem on frp material.

IV. Results of Mechanical Tests

Tensile test specimen were cut out and tested on tensile specimen with 100 mm^2 of cross section and 240 mm long (see Fig. 6).

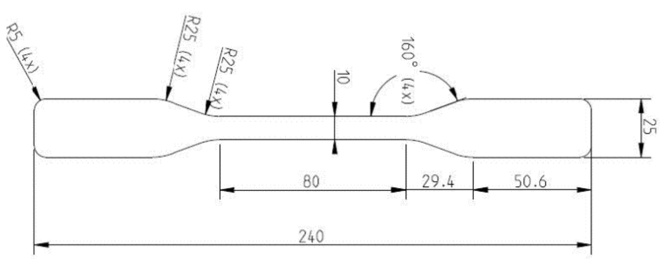

Fig 6. Tensile PE300 specimen.

Compressive tests were performed on cylindrical 15 mm diameter and 30 mm high specimen following ASTM D695. Tests were performed at 77 K and RT. For testing at 77 K samples with extensometers (displacement measurement sensors) were embedded in liquid nitrogen. Extensometers were calibrated for RT and 77 K.

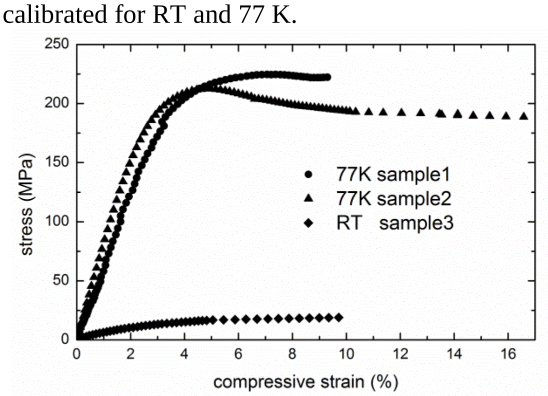

Fig. 7. Compressive strain-stress curves for 77 K and RT.

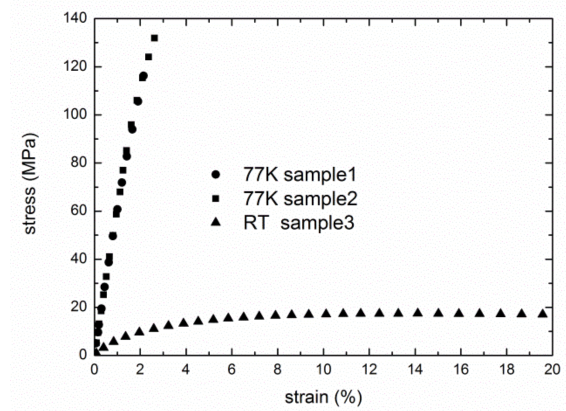

Fig. 8. Tensile strain-stress curves for 77 K and RT.

Strain-stress curves for tensile and compressive tests are shown in Fig. 7 and Fig. 8, respectively. Young´s modulus and ultimate strength are evaluated from these curves and are summarised in Table 1. Room temperature test was stopped after maximum stress was reached and curves reached plateau since breakage of material was not possible in used test configuration due to a limitation of the maximum length. At 77 K material shows significant change of its mechanical properties – Young´s modulus and ultimate strength is sufficiently higher. Tests at low temperatures were performed until breakage of samples. Some time ago low temperature tensile stress-strain diagrams for high-molecular PE was presented in [2]. The results are similar to that reported in this paper.

Table 1. Mechanical properties of PE300 at 77K and room temperature.

Sample	Temperature	Young´s modulus	Ultimate strength
	K	GPa	MPa
Tensile			
Sample1	77	6.3	116
Sample2	77	6.4	130
Sample3	RT	0.9	17.5
Compression			
Sample1	77	6.3	225
Sample2	77	7.9	214
Sample3	RT	0.7	20

At 77 K material shows much more enhanced mechanical properties comparing to RT properties. Therefore maximum possible load within cryogenic device should be defined for RT. In our application total mass load is 84 kg, which should be redistributed for four cylindrical insulating supports of 25 mm diameter (see Fig. 9). It corresponds to approx. 0.4 MPa of compressive stress. The strain at RT for this stress is less than 0.05 %, and even lower at 77 K. We have performed 200 cycles of compressive load up to 1 % of strain at RT. No significant change in geometry of sample was found after the test, and no damage of material was detected.

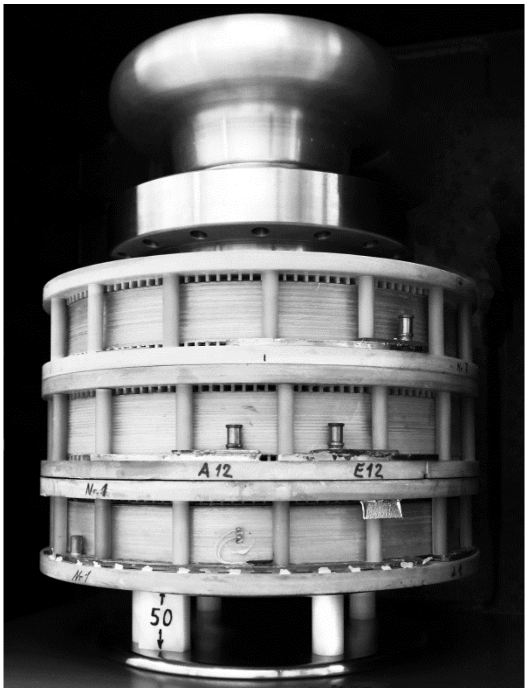

Fig. 9. Final test arrangement.

V. Final Test Arrangement

A setup with four PE300 insulators was subjected to a total mass load of 84 kg. Each insulator has a diameter of 25 mm and a length of 50 mm. This setup was stored for 1 day under room temperature conditions and then reassembled in a cryostat. After filling the cryostat with gaseous nitrogen the cool down was performed in a way that the PE insulators were covered with liquid nitrogen within less than half an hour. High voltage tests were started 45 min after stop filling. During the AC tests the liquid nitrogen level decreased to a lowest level of about 30 mm on the insulators, which means a maximum length of about 20 mm cold nitrogen gas surrounds the top part of the insulators during the high voltage test. The last and highest withstand test was successfully performed with an alternating voltage of 71 kVrms (corresponding to 100 kV peak) for 15 min without breakdown. Then the setup was warmed up and stored for a total time of 113 hours. An average compression of about 0.05 mm was found after disassembly.

VI. Summary

PE300 insulating material was investigated for usage in cryogenic high voltage facility. HV tests and mechanical investigations were performed on this material to check its applicability as an insulating material at liquid nitrogen temperature and at room temperature.

PE300 embedded in liquid nitrogen shows sufficient flashover voltage, high resistance against destruction during flashover, smooth surface to enable easy detachment of SS components, low material costs and simple machining.

Mechanical tensile and compressive stress-strain curves show different behavior at 77 K and RT. At RT mechanical properties are much weaker, so it should be taken into account in final design of cryogenic facility. Nevertheless, mechanical stability of PE300 was found to be sufficient for usage of KIT-ITEP High Voltage Lab.

References

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