PARTIAL DISCHARGES OF THERMALLY AGED INSULATION

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Abstract: This paper is focused on thermal aging and accompanied partial discharge diagnostics of two mainly used resin rich mica tapes, which are utilized as a part of insulation system of large rotating machines like turbo or hydro generators. The first tested specimen was mica composite material based on glass fibre and epoxy resin and the second one was composite based on PET and epoxy resin as well.
The specimens were tested under laboratory conditions. The materials were thermally aged and the changes of its physical and chemical properties were measured and evaluated. For accelerating the aging process different temperature values (170 - 186°C) were chosen. The aging time was determined for each temperature value. Specimens of tested material were performed and cured as flat plate 100×100 mm. The measuring of these specimens was carrying out by test voltage at special electrode test setup. For comparing the aging process of the investigated material the trends of measured partial discharge (pd) parameters (inception voltage, extinguish voltage, peak charge level) were studied and described in dependence on exposure time, temperature and applied voltage during measurement. It was found, that the results differ when the same material is tested on air or in insulating oil. In the case of testing under air conditions the measured data of PD have a significant more variance of values, than under oil. Inception voltage shows an decreasing trend during aging at particular temperatures, but the value is higher if the aging temperature increases. The differences of this magnitude are obvious for particular aging temperatures (170°C – 186°C). Inception voltage value is the lowest for aging temperature at 170°C. The measured peak charge Qiec has a trend of increasing the magnitude during aging time.

1 INTRODUCTION

The operational lifetime of electrical machines is primary influenced by the insulation system quality. The operational lifetime of electrical insulating system is commonly determined, estimated and predicted in terms of accelerated laboratory aging of tested insulating materials. Accelerated aging could be applied as single factor aging like thermal or electrical aging or multiple factor aging as well. During the multiple factor aging all factors take effect together in the same time. Degradation of an insulation system occurs during the accelerated aging. The degradation is related to the physical and chemical changes within material structure. These changes are consequently detectable with physical or chemical test methods.

Partial discharge testing belongs to one of the high applicable test method of insulating materials within electrical machines. This non-destructive test method allows to determine the degradation ratio or homogeneity of insulation.

The investigated mica resin rich composite based on glass fibre and epoxy resin was thermally aged and the changes of its physical- and chemical properties were measured during accelerated aging. Partial discharges were measured as well. The characteristic parameters according to IEC 20 670 as inception voltage (Ui), extinguish voltage (Ue) and apparent charge level (Qiec) were measured and analyzed.

At first the preliminary thermally aging lifetime curves of tested materials were performed. As a result of these tests the values of aging temperature and aging time for each temperature level could be determined [1]. Two values characterize the preliminary lifetime curve. First value is the maximal temperature; second one is the minimal endurance temperature. Maximal endurance temperature is given by eight hours endurance test. Minimal endurance temperature is given by temperature class and by the material manufacturer who declared lifetime of material for 30 years at this temperature. The eight hours maximal temperature was determined by the fact that the loss factor value was increased rapidly in comparison to the virgin state or according to the visual changes of specimen (deformations, delaminating, bending, deflection etc). The aging time was determined according to the preliminary lifetime curves ([1], fig.1). The aging temperature values are chosen according to the experimentally total duration and cost as well.

Four aging temperature values for glass fibre material (170, 175, 180, 186°C) and for PET material (170, 178, 186, 194°C) were chosen for material accelerated aging (table 1). The aging time was determined for each temperature value ([1], fig.1, table 1).

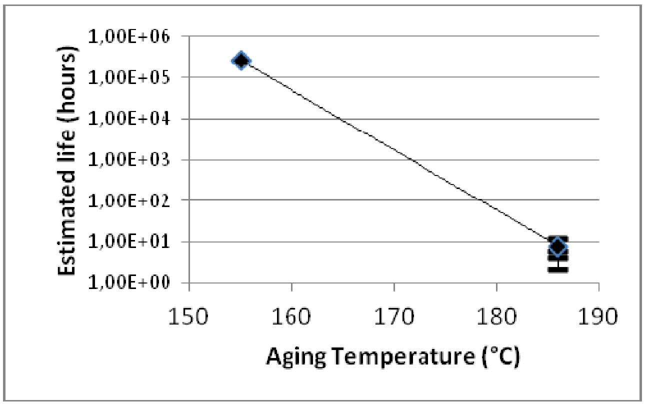

Figure 1: Preliminary lifetime curve

Table 1: Aging temperature values and aging times

Temperature (°C)	Aging time at given temperature (hour)				
Glass fibre					
186°C	2	4	6	8	10
180°C	8	16	24	32	48
175°C	48	96	144	192	240
170°C	192	288	384	480	600
PET					
194°C	1	1,5	2	2,5	3
186°C	2	10	15	20	25
178°C	24	48	72	96	120
170°C	192	288	384	480	600

2 TEST PROCEDURE

Partial discharge measurement

The pd testing was performed using a commonly available test system[1], which allowed the measurement of the recommended IEC- magnitudes included the describing of the pd behaviour in a well known PRPD-pattern. The specimens of tested material were performed and cured as flat plate 100×100 mm, located in a special test setup and measured in a standardized pd test circuit[2] (fig.2, fig.3). The impact force F to the upper electrode was realized by a spring and had a constant value at each test.

[1] LEMKE PD SMART
[2] the noise level was under 3 pC threshold

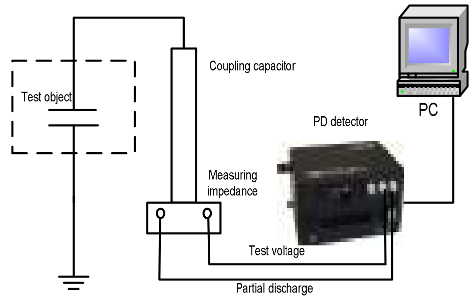

Figure 2: PD circuit

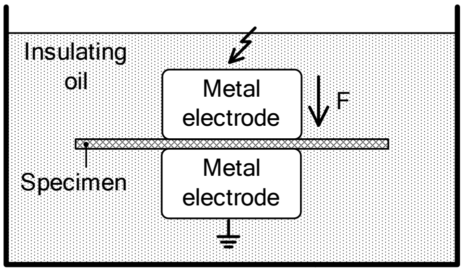

Figure 3: Test Setup

The measuring of partial discharges was performed according to the IEC 60270 [3] requirements with five specimens aged at one particular temperature and time. The following measuring procedure was carried out: The test voltage was increased up to the inception voltage U_i .When the inception voltage was reached this value was stored and the voltage was again increased up to 1.2 U_i (~14kV). After 10 minutes at that value the test voltage was decreased stepwise (ΔU ~ 1 kV) down to the extinguish voltage U_e at each step the value Q_{iec} was measured Then the test voltage was decreased on 20% (~ 9 kV) and the same procedure as described was repeated. Because of the statistic evaluation the procedure was repeated 7 times. It was assumed, that the electrical aging during these procedure can be neglected

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Breakdown voltage measurement

Breakdown voltage was measured according to the IEC 60243-1 [2]. The breakdown occurs between 10 and 20 second after the moment the voltage was applied and linearly increased. The breakdown was detected by a breakdown detector and the value of voltage was stored. For each value of selected aging temperature and time 7 specimens were tested.

3 RESULTS

Partial discharge behaviour

The pd behaviour of PET and glass fibre based material shows independent of the aging process (temperature, time) some significant difference. At low values of electrical intensity[3] the measured charge Q_{iec} of glass fibre are significant smaller than those of

[3] For a better generalizing of obtained results the electrical intensity (U/d) was calculated (d => sample thickness)

PET based material (fig.4). If the electrical intensity reaches a value of ~25 kV/mm, the measured charge is rapidly increased and exceeds even the value of the PET material. In the same case the PET specimen “started” at higher electrical intensity but with higher values of the measured charge.

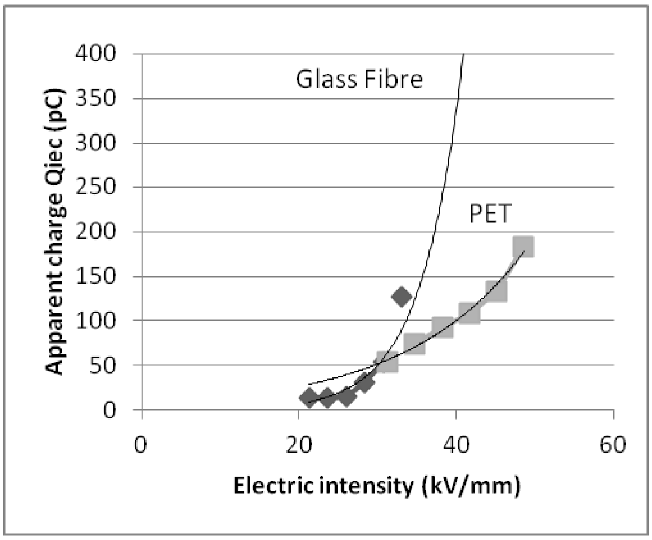

Figure 4: Value Q_{iec} versus electric intensity - results over the whole aging process (temperature, time)

This behaviour is expressed also in the dependencies of the pd inception intensity at different aging temperature (fig.5, 6).

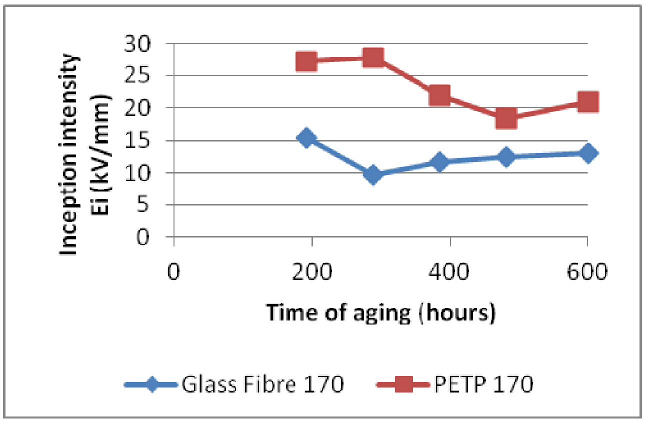

Figure 5: Inception intensity of Glass and PET at aging temperature 170°C

The inception intensity over the aging time at lower aging temperature (170 °C) shows a typical behaviour over the time- after some higher values the inception intensity decreases to a local minimum, but after that increases again (fig.5). It seems to be some structural changes in the material could be occur. At higher aging temperature (186 °C) the inception intensity is more and less constant over the time (fig.6). In both cases the inception intensity is significantly lower for glass fibre materials. It shall be noticed, that the range of the measured values related to the average value in case of PET is much higher (~30 – 50 %) than for glass fibre materials (15 – 25 %).

That means, that the manufacturing process for the PET materials should have a larger complexity than the glass fibre insulation. Another question is the possible influence of cumulated internal charges on the aging process. If can be assumed, that the difference between the inception and extinguish intensity is a certain measure for internal cumulated charge, so can be seen, that only in case of PET materials a small change of charge intensity could be measured over the aging time at different aging temperature (fig.7, 8). At glass fibre materials this difference does not occur (fig. 9, 10).

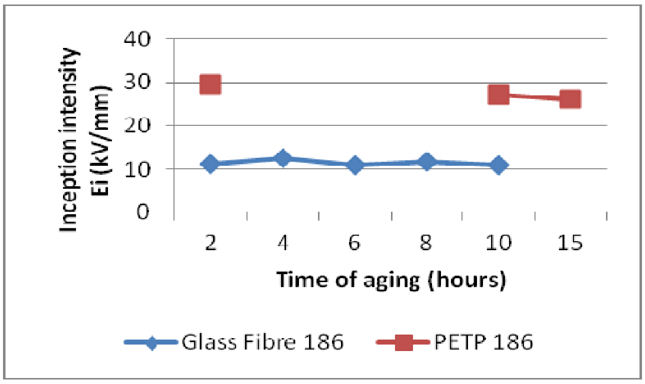

Figure 6: Inception intensity of Glass and PET at aging temperature 186°C

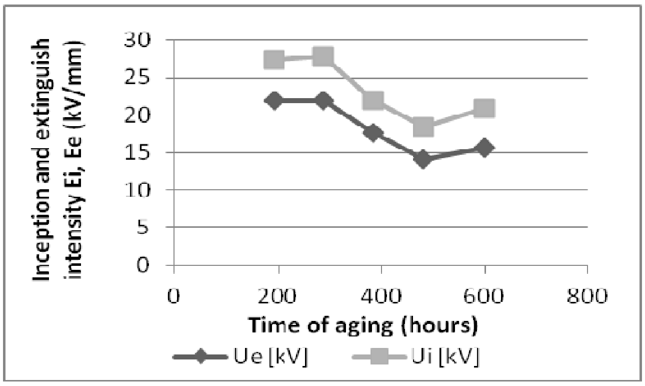

Figure 7: Inception and extinguish intensity of PET aged at 170°C

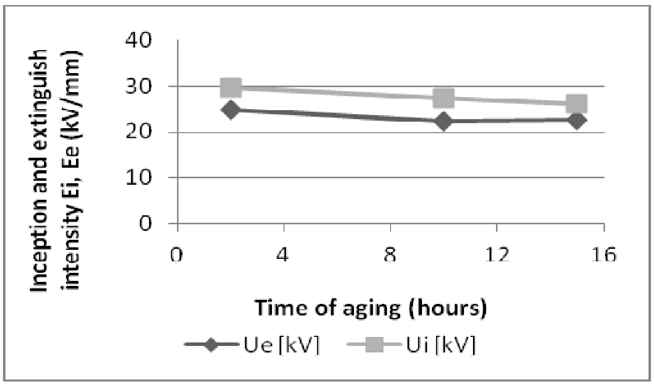

Figure 8: Inception and extinguish intensity of PET aged at 186°C

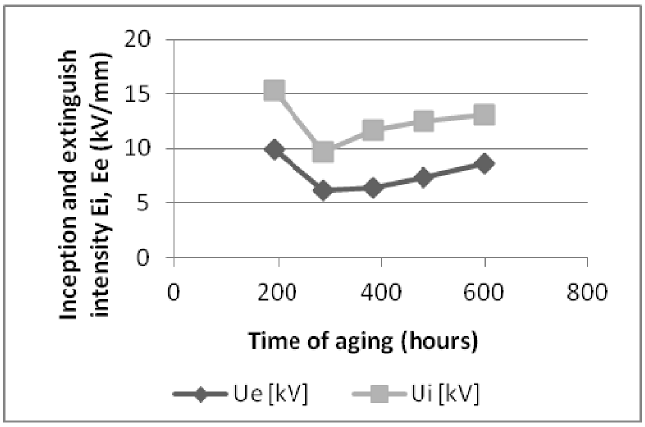

Figure 9: Inception and extinguish intensity of Glass aged at 170°C

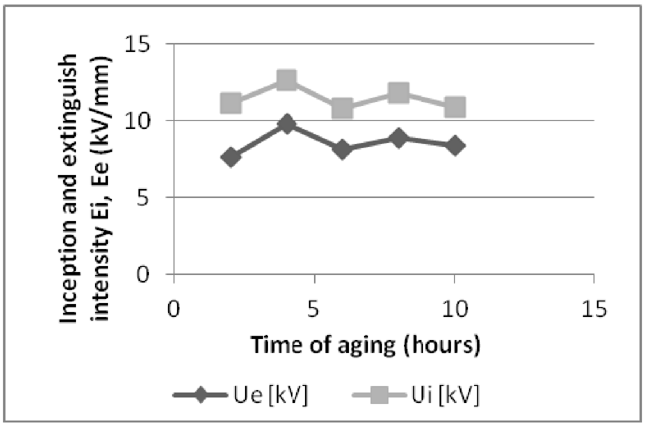

Figure 10: Inception and extinguish intensity of Glass aged at 186°C

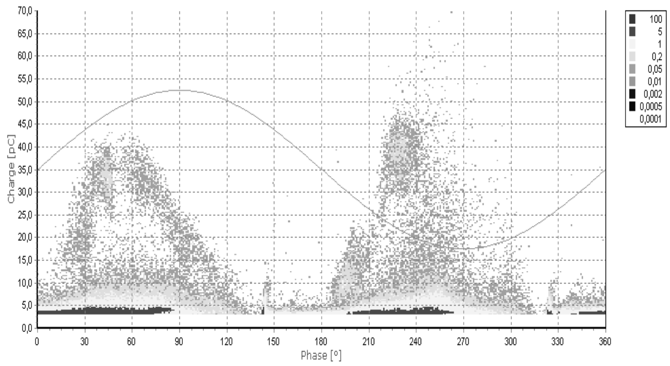

Figure 11: PRPD- pattern for PET at 14 kV

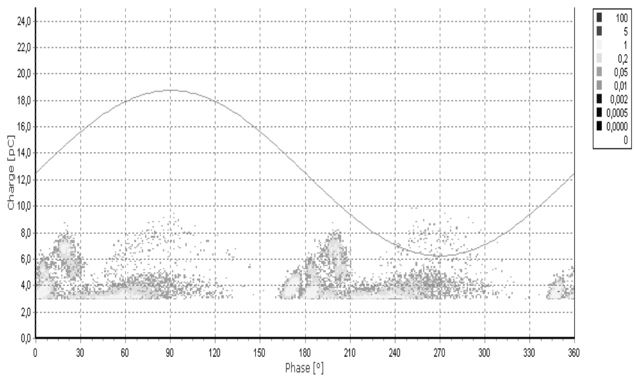

Figure 12: PRPD- pattern for Glass Fiber at 14 kV

The typical PRPD- pattern are shown in fig. 11, 12 at 14 kV and 170 °C and the values of apparent charge during aging is shown in figure 13. At higher aging temperature this pd- behaviour does not change its principal PRPD- characteristic, but their charge values are as shown in figures 14 and 15.

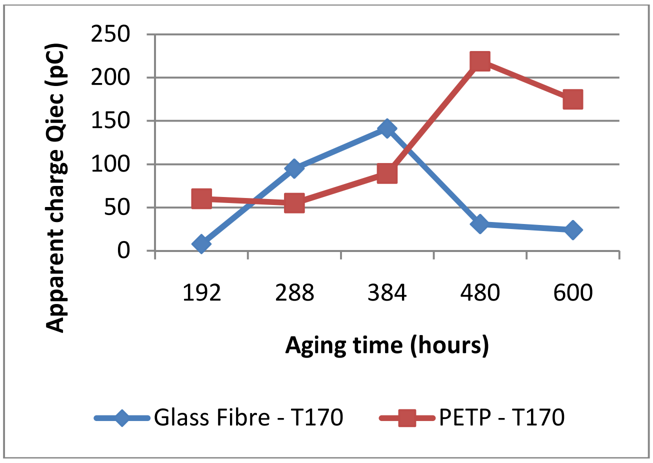

Figure 13: Apparent charge values at 170°C during aging time

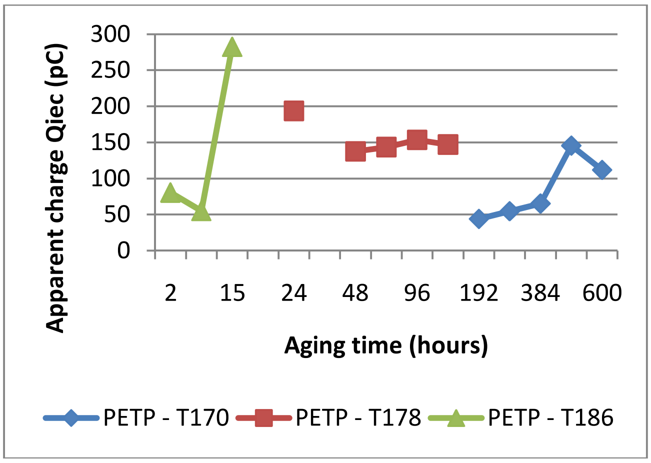

Figure 14: Apparent charge values of PET during aging time

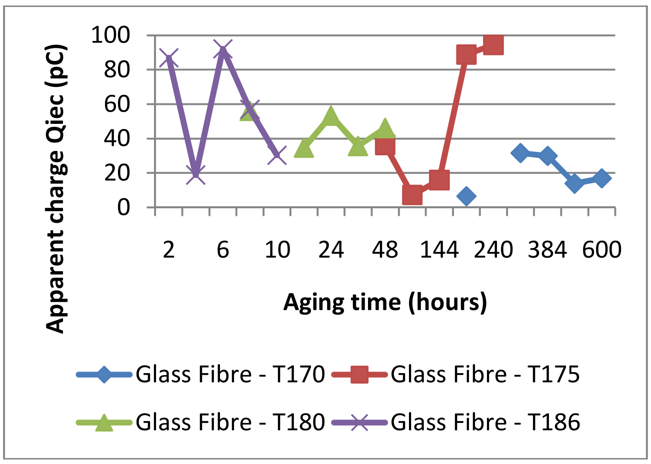

Figure 15: Apparent charge values of PET during aging time

Breakdown Voltage Measurement

Despite of the described pd measurements the breakdown voltage respectively the breakdown strength were measured, too. Assuming in every case a weibull- distribution of the measured values the median (63 %- quantil) of PET based material is significantly higher than those of glass fibre material (fig. 14, 15). That confirmed the results obtained from the pd measurement described above.

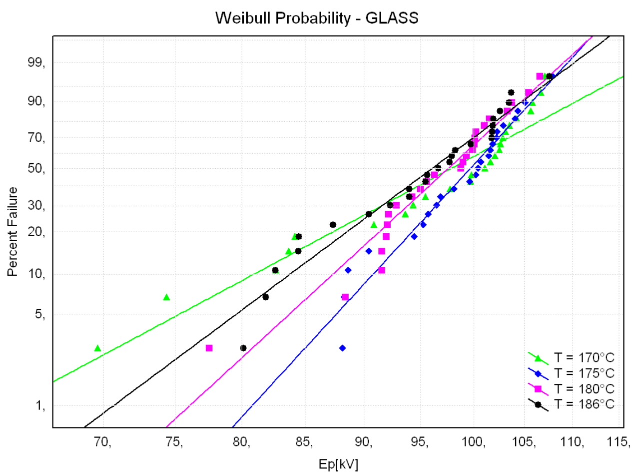

Figure 16: Electrical breakdown strength at different aging temperature - Glass fibre material

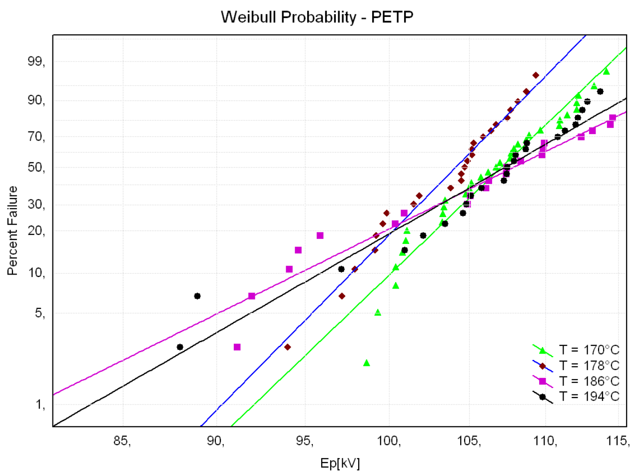

Figure 17: Electrical breakdown strength at different aging temperature - PET material

Besides the significant difference of median values the breakdown behaviour at the given aging temperature values is different for investigated materials. In case of PET the dispersion of measured values is smaller at the lowest temperature (170 °C) and increases with higher temperature values (fig.14). In opposition to that for glass fibre material the dispersion of the measured values is the highest at the lowest temperature (fig.11). That behaviour shows that during the thermal aging process some different structural changes occur. For a more detailed explanation of the described process a further investigation seems to be necessary.

4 SUMMARY

In the paper some experimental results of two different materials typically used for insulating of large rotating machines are given. The results of measured pd behaviour and breakdown voltage were described. It was shown that the pd measurement could be more sensitive to detect the changes within material structure during thermal aging than the breakdown voltage test.
The obtained results show that the PET based material is more robust against thermal aging than the glass fibre materials and, therefore, more appropriate for using in the insulation of large rotating machines. For better understanding of aging process further investigation seems to be necessary.

5 ACKNOWLEDGEMENTS

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