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The Effect of High Concentrations of MgO on Space Charge Accumulation and Electric Field Distribution in Epoxy Resin

Jiří Kopřiva, Jaroslav Hornak, Pavel Trnka, Ondřej Michal
Department of Materials and Technology, FEE
University of West Bohemia
Pilsen, Czech Republic
jkopriva@fel.zcu.cz

Štefan Hardoň
Department of Physics, FEIT
University of Žilina
Žilina, Slovakia
hardon@fyzika.uniza.sk

***Abstract*—Dielectric materials are an essential part of any electrical device. These materials are under constant development to optimize and improve their insulating properties and adjust them for specific applications. The recent trend of nanocomposites opens new possibilities for these materials via new kinds of modifications not possible in the past. Furthermore, with the increasing trend of HVDC applications, it is of rising importance to further study the effects of DC voltage stress on dielectric materials, as the phenomenon of space charge accumulation has a considerable impact on the longevity of the dielectric system. In this article, a cold-cure epoxy resin was used as a base material and MgO nanoparticles were incorporated in various weight percentages (0, 10, 20, and 30 wt.% of MgO) to create samples. The electric field distribution and space charge accumulation under a high voltage DC stress were measured via the pulse electro-acoustic (PEA) method.**

***Keywords*—Electric field, Epoxy resin, MgO, Nanocomposite, PEA, Space charge**

I. Introduction

Epoxy resin is one of the most widely used insulation materials in many both DC and AC applications. It is due to its chemical stability and both great electrical and mechanical properties [1]. Due to the nature of DC applications, it is necessary to take in an account the space charge accumulation, as it has a significant effect on the functionality of dielectric systems used in these types of applications [1] [2]. Also, with the rising trend of HVDC applications usage, it is of even more significant importance nowadays, especially as the space charge mechanics in the insulation materials are not so well understood as the mechanics in the materials under AC electric stress [3]. Though the space charge is a significant factor, it is not the only factor affecting the lifetime of the DC insulation system, as the temperature is also a significant factor, even more than in AC applications [4]. This is due to the strong relation between polarization mechanisms and the temperature of the material [4], [5]. With the rising temperature, the movement of the particles and, and thus the polarizability of the material is increasing. Due to this, it is important to consider the temperature of the system during the examinations and testing. All the measurements done in this experiment were made under the room temperature of 25°C.

With the constant need for improvement and adaptation of insulation materials for specific applications, nanoparticles offer an interesting new way of material modifications [6] [7]. In some applications, it was already proved, that the modification of MgO nanoparticles can affect, and even decrease the charge density thorough the material [7].

The PEA diagnostic method offers an opportunity to observe the inner mechanics of the insulating material under the electrical stress. Thus, it is not just possible to observe the response to electrical stress from the surface of the sample as the whole, but a graphic map of the value end exact position of the accumulated charge in time can be gained.

II. Experiment

This paper presents the results of an experiment, in which an epoxy resin with different weight percentage of nanoparticles is put under a HVDC stress. The goal of this experiment is to gain insight into how the amount of the added nanoparticles affects the space charge accumulation and electric field distribution thorough the inner structure of the samples.

A. Samples description

The samples received for this experiment are made from epoxy resin ELAN-TECH EC 141 and varying percentage of MgO nanoparticles 20 nm in size. The exact percentage of nanoparticles is 0, 10, 20, and 30 wt. %. The thickness of the samples varies from 1 mm to 1,5 mm and the edges were cut to a round shape with a diameter of approximately 80 mm. The permittivity for each sample was measured under the room temperature of 25°C, voltage 1000 V, 50Hz. The sound velocity inside the samples was calculated by the PEA software. The parameters of each sample are summarized in Table I.

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TABLE I
PARAMETERS OF THE SAMPLES

MgO (wt. %)	Thickness (mm)	Permittivity (-)	Sound velocity (m/s)
0	1.1578	3.27	$2.85 \cdot 10^3$
10	1.198	3.25	$2.71 \cdot 10^3$
20	1.5323	3	$2.78 \cdot 10^3$
30	1.4732	3.6	$2.77 \cdot 10^3$

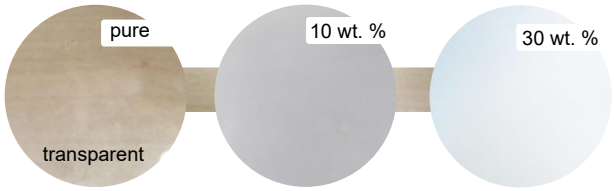

Fig. 1. Tested samples with different MgO content

B. Diagnostic method

The samples were measured via the Pulse Electro-Acoustic method (or PEA in short) on Techimp PEA Flat system. The scheme can be seen in Figure 2. The pulses generated had an amplitude of 250 V and pulse width of 10 ns. Pure silicone oil was used during the placement of the sample to avoid any interference of reflected signal or air bubble creation between the sample and the surface of the device. The HVDC was set according to the thickness of the sample to achieve the value of applied electric field of 21 kV/mm. This value should be sufficient for tested samples, as there is a confirmed accumulation of space charge in epoxy at electric field of 15 kV/mm [8]. There is also a limitation in the form of power source with the upper limit of 30 kV. The samples were under the influence of the electric field for the duration of 1200s. The data gathered during the measurement were evaluated via Techimp PEA software.

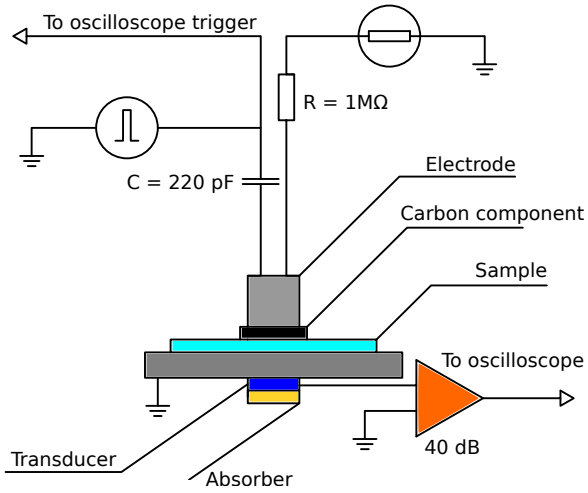

Fig. 2. Techimp PEA Flat system scheme

III. RESULTS

The results are divided in three sections. The first set of results presents the graphic maps of space charge accumulation in time. In addition, the exact values of accumulated space charge in time of 15 s, 60 s, 600 s and 1200 s are shown for the investigated sample modifications. In the second part, the exact electric field distribution is shown in correlation to the previously chosen times of measurement. The last part then shows the electric field maximum measured in time from 60 s to 1200 s with basic statistical evaluation.

A. Space charge accumulation

The first set of results represents the graphic map of charge density thorough the material in time. As can be seen from Figure 3, it is interesting that the area with hetero-charge near the HV electrode increases with increasing MgO concentration. The absolute space charge increases slightly with time, but these changes are not very pronounced in the observed time interval (see Figure 4).

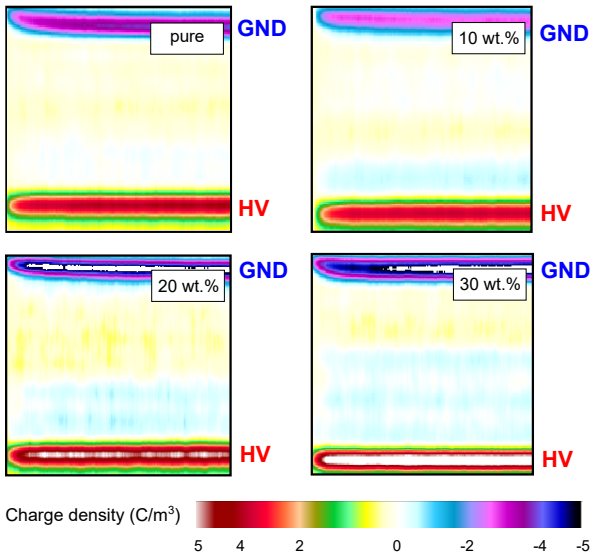

Fig. 3. PEA space charge patterns for different wt.% of EP/MgO composites in comparison with pure EP.

From the previously shown results, it can be safely assumed, that the increasing percentage of MgO nanoparticles added into the epoxy resin propagates the accumulation and mobility of the space charge. With the adding of a conductive component to the amorphous epoxy resin, the hopping polarization became strongly pronounced in the sample. This may be due to the increased possibility of tunnel formation between two points in the inner structure of the material [4] [9]. This cause an increased mobility of the trapped charge and its' deeper penetration into the structure of the material. This, together with the amorphous structure of the epoxy resin, may be the cause of the charged layer creation, as the barrier between two separate traps is weakened by the presence of the nanocomposite.

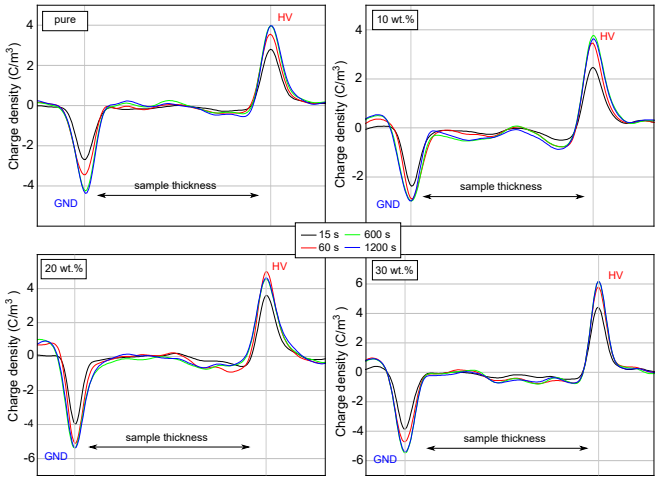

Fig. 4. Space charge distribution for different wt.% of EP/MgO composites in comparison with pure EP.

B. Electric field distribution

In this part, the figures of an electric field distribution thorough the samples are shown. As can be seen, the pure sample is the closest to the theoretical model of linear distribution.

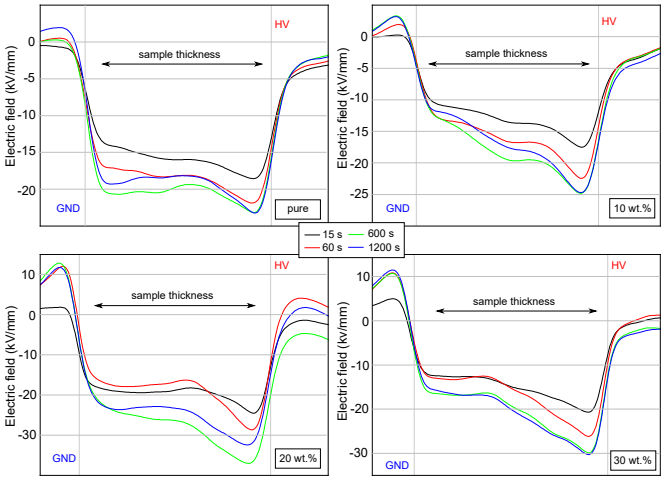

Fig. 5. Electric field distribution for different wt.% of EP/MgO composites in comparison with pure EP.

The electric field distribution thorough the samples is directly affected by the space charge accumulation. As can be seen in Figure 5, the positions of the distortions correspond with the accumulated charges in Figure 4. This uneven distribution creates a higher localized stress in the material. This stress on the material can have a negative effect of the integrity of the whole dielectric system, as it can cause damage of the material structure and can lead to the electrical breakdown, destroying the dielectric system. Because of this reason, it is important to monitor the electric field thorough the material and evaluate the maximal electrical stress from the inner distribution, instead of the value of applied outer electric field.

C. Electric field maximum

The electric field maximum provides interesting information about the behaviour of material stressing in time. From the Figure 6 is visible, that the there is an increase of maximum electric field in comparison with the theoretical case (21 kV/mm). This increase is more pronounced for the higher filling levels. Also, a relatively great variability of this parameter is visible. For this reason, the statistical analysis is presented in Table II.

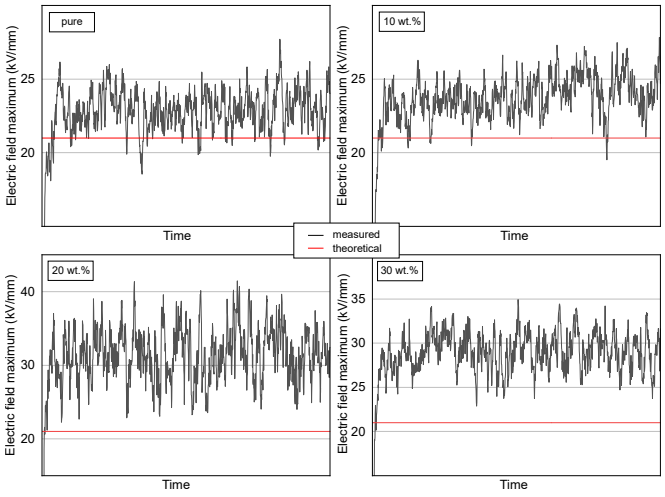

Fig. 6. Maximum electric field in time for different wt.% of EP/MgO composites in comparison with pure EP and with theoretical electric field.

TABLE II
STATISTICAL ANALYSES OF ELECTRIC FIELD MAXIMUM IN TIME

MgO (wt. %)	Mean (kV/mm)	Median (kV/mm)	Min (kV/mm)	Max (kV/mm)	Variance (kV/mm)
0	22,98	22,97	18,54	27,70	1,69
10	23,87	23,83	19,51	27,82	1,69
20	31,58	31,49	22,27	41,44	12,34
30	29,13	29,21	22,89	34,94	4,23

As discussed previously, uneven distribution of the electric field causes the localized maximum of electrical stress in the sample. From the data gained during the measurement, it can be seen, that even in the pure sample, the local stress is higher even in the pure sample by approximately 1,9 kV/mm from the outer applied electric field (21 kV/mm). This localized stress is increased by relatively small margin for the the sample with 10 wt.% of MgO, but there is a drastic increase in the last two samples. The increase of the electric field maximum is more than 25 % from the value of the pure sample as can be seen from Table II. It can be safely assumed, that the percentage of MgO nanoparticles in the material over 10 wt.% has a negative impact on the integrity of the dielectric system, as the increased localized stress cause the higher possibility of an electrical breakdown.

IV. Conclusion

The results presented show the pure epoxy resin sample as the least affected by the space charge creation and thus with least deformed electric field distribution. This is according to the initial expectation, as there is no conductive component, which would propagate the accumulation of the space charge in the inner structure of the material. With the rise of the nanoparticles percentage, there can be seen a trend in widening of the space in which the hetero charge is accumulated. It was already confirmed, that the nanoparticles may not have a negative effect on the accumulated space charge release up to the 10 wt.%, but reaching over this value, the material starts to accumulate more charge, than the pure epoxy resin [10]. The cause for this increase of trapped charge penetrating deeper into the structure of the material may be the higher probability of the conductive tunnel forming between two charge traps in the material, weakening the barrier between the two traps and increase the mobility of the trapped charge. With the rising percentage of filling and the trapped charge in the material, there is also more prominent distortion of the electric field, affecting the local electrical stress in the material. Confirming the assumption of the negative impact of higher percentage of filling discussed in [10], the distortion and localized electrical stress is higher by significant margin in the samples of 20 wt.% and 30 wt.% of MgO nanoparticles, compared to the other two samples. From this can be assumed, that the higher filling has a negative impact on electrical properties of the dielectric system and creates a higher risk of electrical breakdown. For further research, the impact of filling percentages under 10 wt.% should be investigated, and most optimal amount of wt.% of MgO should be decided.

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