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Simulation of electric field on a polypropylene slice between high voltage electrodes

Jieyu Liu¹, Wenyu Cheng¹, Jianning He¹, Qiming Zhuang², Yan Zhao² and Donglai Wang^{2,3}

¹ State Grid Liaoning Marketing Service Centre, Shenyang, Liaoning 110006, China;

² Shenyang Institute of Engineering, Shenyang, Liaoning 110136, China.

³ donglai.wang@hotmail.com

Abstract. The dielectric strength of insulating slice in the high voltage apparatus can be changed by doping the nano clay. In order to test the breakdown time of nano clay-doped polypropylene slices in different temperatures, an experiment has been carried out. In this article, the model of electric field simulation for the experiment is studied. Influences of the thickness and relative permittivity of polypropylene slice on electric field strength are considered. The simulated results can be used as reference for analysing the experimental phenomena of the breakdown of polypropylene slices.

1. Introduction

With the increase of transmission voltage level, higher and higher requirements are put forward for the insulation reliability of insulating dielectrics [1]. Polypropylene (PP) film, as a thermoplastic obtained by polymerization of propylene monomers, has the advantages of regular structure, high crystallinity and low price [2,3]. PP has excellent recyclability, processability and has good mechanical strength and machining performance [4].

Adding the nanoparticles to the polymer is able to improve the overall properties of the composite. Nano clays are widely used in the modification of polymer dielectrics [5]. In order to better understand various phenomena in nanocomposites and make them be used effectively in many applications, scholars have greatly strengthened the research on polymer-based nanocomposites as dielectrics and insulators [6,7].

Under the influence of environmental temperature and electric field, dielectric materials are often affected by electrical aging and thermal aging, which seriously accelerates the deterioration of dielectric materials and even leads to equipment failure or complete damage [8]. The higher the voltage amplitude applied to the dielectric, the longer the charging time and the greater the polarization degree of the dielectric. With the increase of the degree of polarization, a large number of hot electrons are produced in the dielectric, which break down the macromolecular chain in the polymer, produce a large number of small molecules and free radicals, increase the dielectric loss and reduce the breakdown field strength and withstand voltage time.

The electric field strength of PP film is the decisive factor of breakdown. However, in the high temperature withstand voltage experiment, the electric field distribution in PP film cannot be measured directly, so it needs to be obtained by simulation [9]. This paper studies the electric field simulation model of the experiment. The influence of thickness and relative dielectric constant of PP sheet on electric field strength is considered.



2. Simulation model

The high temperature withstand voltage experiment of PP slice is shown in figure 1. The slice is sandwiched between two electrodes and fixed by a bracket. The bracket is placed in the beaker, and the voltage is led in by the high-voltage cable. By heating the bottom of the beaker, the ambient temperature of PP film is changed. The whole experimental system is insulated by Teflon board.

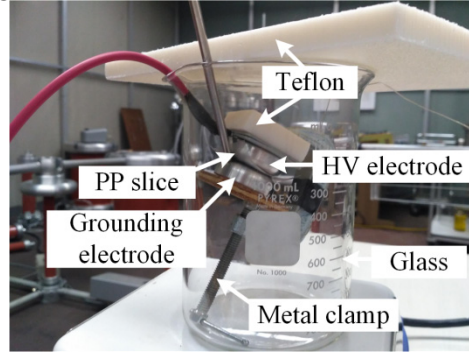


Figure 1. Experimental setup

According to the experiment, three 2D symmetrical models are built in FEM (Finite Element Method) simulation software, as shown in figure 2. φ_1 and φ_2 are Dirichlet boundary conditions. The voltage on the high voltage electrode is V . The relative permittivities of Teflon, wood, rubber and glass are 2.0. The relative permittivity of air is 1.0. The governing equation in power frequency electric field is the Laplace equation

$$\nabla^2 \varphi = 0 \quad (1)$$

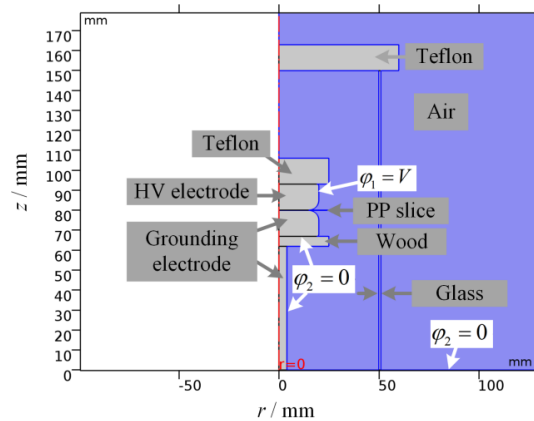
The boundary conditions are

$$\begin{cases} \varphi_1 = V \\ \varphi_2 = 0 \end{cases} \quad (2)$$

The electric field strength E can be obtained by

$$E = -\nabla \varphi \quad (3)$$

The model in figure 2(a) is named as theoretical model. This model reflects the original aim of experiment and the influence of metal clamp is not considered. The model in figure 2(b) is called as practical model. In this model, the actual fixed bracket structure in the experiment is fully considered. The metal clamp and the rubber gasket are assumed to be surrounding the electrodes. That is to say, the impact of the metal clamp on the electric field should be stronger than the actual situation. In addition, to simplified the simulation, a simplified model is presented in figure 2(c). In the simplified model, all of the structural supports are neglected. Depending on the symmetry, the voltage on the plane $z=0$ is $V/2$.



(a) Theoretical model

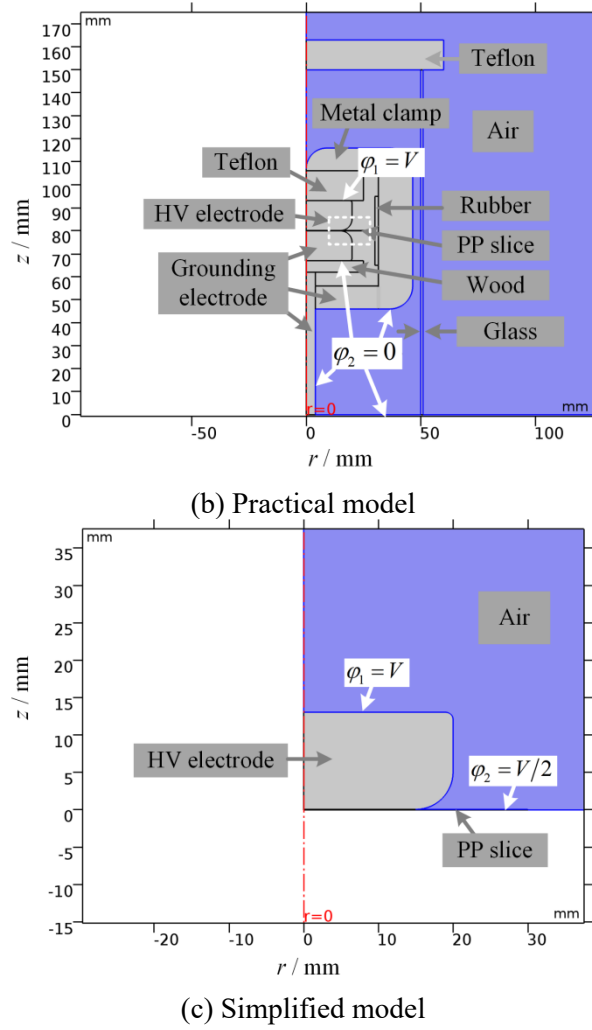


Figure 2. 2D symmetrical models

In FEM, the equivalent variable problem of Laplace equation (1) is

$$J[\varphi] = \iint \frac{\varepsilon}{2} \left[\left(\frac{\partial \varphi}{\partial x} \right)^2 + \left(\frac{\partial \varphi}{\partial y} \right)^2 \right] dx dy = \frac{1}{2} [\varphi]^T [K] [\varphi] = \min \quad (4)$$

where $J[\varphi]$ is the second-order energy functional, $[K]$ is the coefficient matrix of the total electric field energy. According to the extreme value theory of function, there is

$$\frac{\partial J}{\partial \varphi} = 0 \quad (5)$$

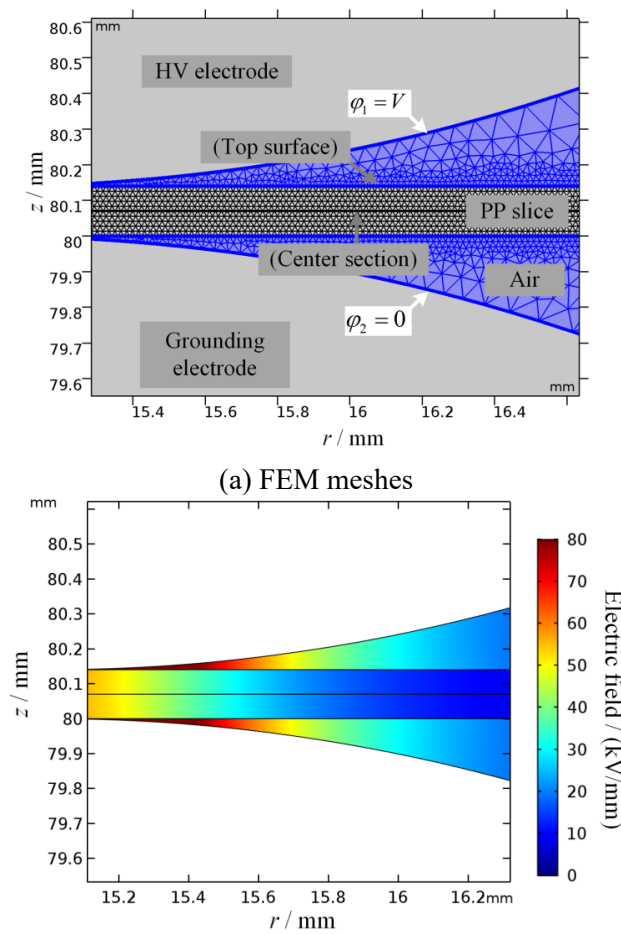
and the discrete form is

$$[K][\varphi] = [f] \quad (6)$$

where f is the energy source in the electric field. In the FEM analysis, the space is meshed by second order triangular element.

3. Results

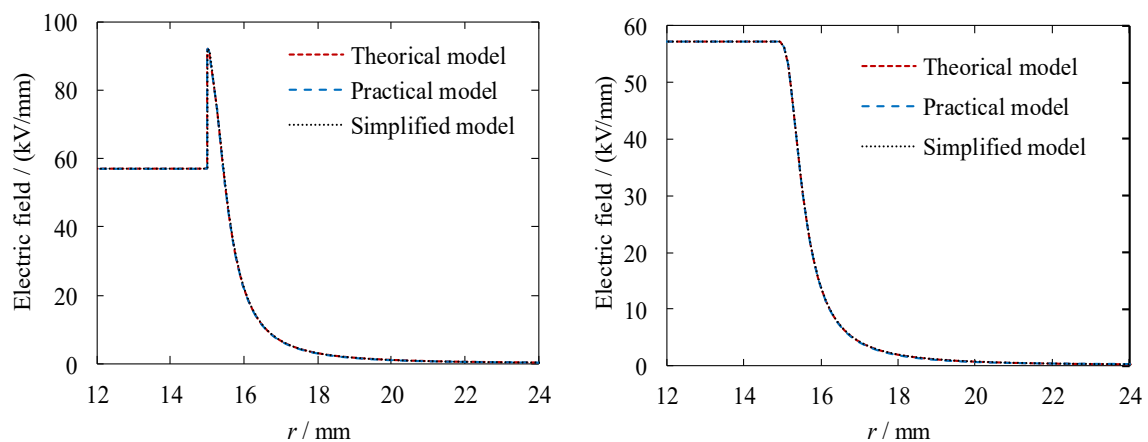
The FEM meshes in the dotted white box area, as depicted in figure 2(b), are shown in figure 3(a). In the following calculation, the relative permittivity of PP slice $\varepsilon_r=2.2$, the voltage on the electrode $V=8$ kV, the thickness of PP slice $d=140$ μm .



(b) Electric field distribution
Figure 3. Details in the air gap area.

The calculated electric field distribution using practical model is shown in figure 3(b). The relative permittivity of air is lower than PP. Therefore, the electric field in the air near the tangential position of the PP and the curved shape electrode edge is very large.

The calculated electric fields on the top surface and the center section of PP slice with three different models are presented in figure 4(a) and figure 4(b), respectively.



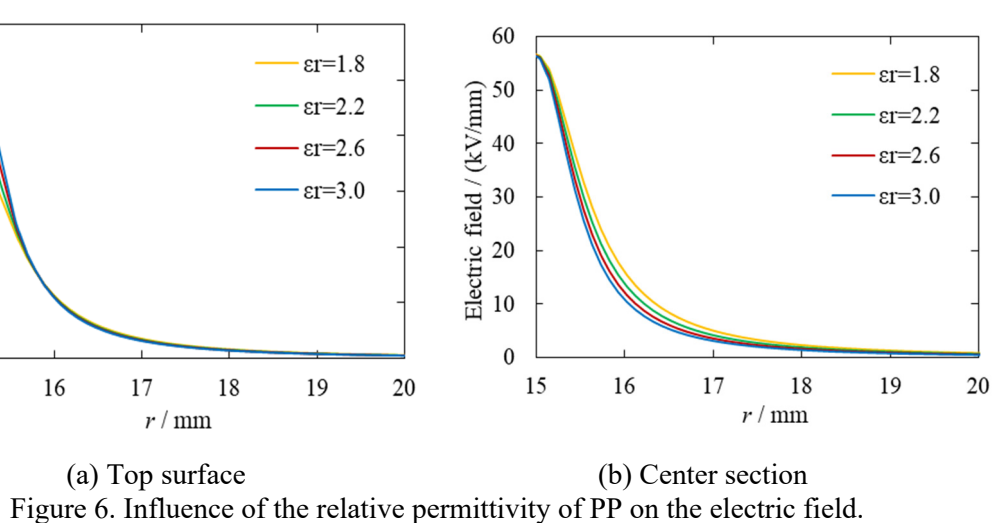
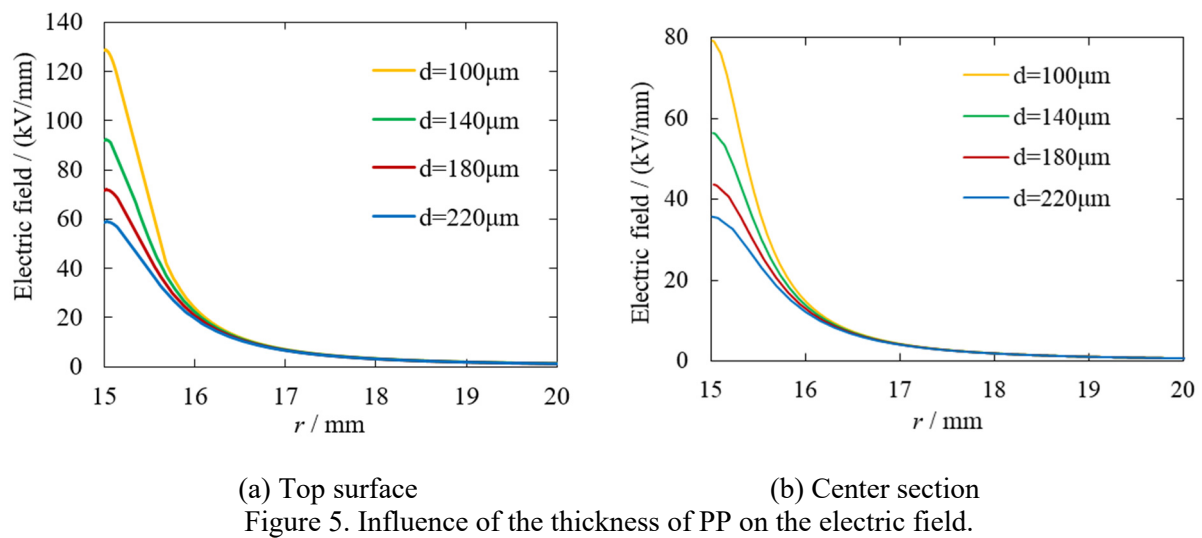
(a) Electric field on the top surface of PP (b) Electric field on the center section of PP
Figure 4. Comparison of the simulation models.

The positions of top surface and the center section are illustrated in figure 3(a). When the surface of PP slice is connected to the electrodes, the electric field E can be considered to be produced by an infinite parallel-plate capacitance, i.e., $E=V/d$. When the small air gap appears, the electric field on the surface of PP is suddenly increased. Then, the electric field is reduced with the increase of the value of r coordinate.

The electric field in the center section is also decreased with the increase of r coordinate, but the maximum value will not exceed V/d . Comparison of the electric fields in figure 4 indicates the three models are equivalent in the analysis of electric field near the PP slice. Thus, the simplified model is applied in the following calculation.

4. Discussion

The influence of thickness of PP slice on electric fields is shown in figure 5. With the increase of thickness d , the electric fields are decreased. The influence of relative permittivity of PP slice is shown in figure 6. With the increase of ϵ_r , the electric fields on the top surface are increased, but the electric fields on the center section are reduced. When voltage on the high voltage electrode is 8 kV, the thickness of PP slice is 140 μm , and the relative permittivity of PP slice is 2.2, the maximum electric field on PP slice is 92.2 kV/mm.



5. Conclusion

A simplified electric field simulation model on PP slice is presented. Electric fields on the top surface and the center section of the PP slice are calculated. The center area of the high voltage electrodes can be considered as a parallel-plate capacitor. On the top surface of PP slice, the electric field intensity reaches the maximum at the tangent of the surface and the electrode. With the increase of thickness and the decrease of the relative permittivity, the maximum electric field on the top surface of PP slice will be reduced.

Acknowledgements

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