Experimental and theoretical investigation of surface discharges for charged dielectric materials

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Abstract: The paper presents experimental investigations of electrostatic discharges for charged dielectric materials. The aim of the work is to develop a model that allows the calculation of the dissipated power and energy during brush and surface discharges.
For a higher surface charge density, the discharge pattern changes from brush- to surface discharge. An important point is to find the transition value of the surface charge density. The decisive parameter for the development of surface discharges is the tangential electric field strength. Therefore, the tangential electric field strength on the surface was simulated. Parameter for this are the *initial surface charge density* and the *discharge length*.

Introduction

An easy model for the charge and discharge phenomena of insulating materials could facilitate the ESD-dimensioning of devices and systems. On the one hand, the conditions influencing the size of the discharged area have to be determined. On the other hand, an easy model is needed to estimate the dissipated power and energy during the discharge process. A part of these aspects have been already presented and discussed in previous papers [4,5].

Two kinds of discharges can appear depending on the value of the surface charge density. Brush discharges occur especially for thicker plates and a smaller value of the surface charge density. A limited area around the discharge point is discharged. Figure 1a shows a typical charge distribution on the surface at a 1 mm PVC-plate after the discharge by a sphere with a diameter of 30 mm. For thin plates or foils a higher value of surface charge density is possible and surface discharges can occur. By these discharges a much larger surface area can be almost completely discharged (see figure 1b).

The condition for a surface discharge is a brush discharge. A limited area around the discharge point is discharged. The discharge shorts the charged surface to the grounded backplane. At the boundary between the discharged and still charged area a high tangential electric field strength on the surface arises. If the electric field strength is higher than a critical value a surface discharge follows.

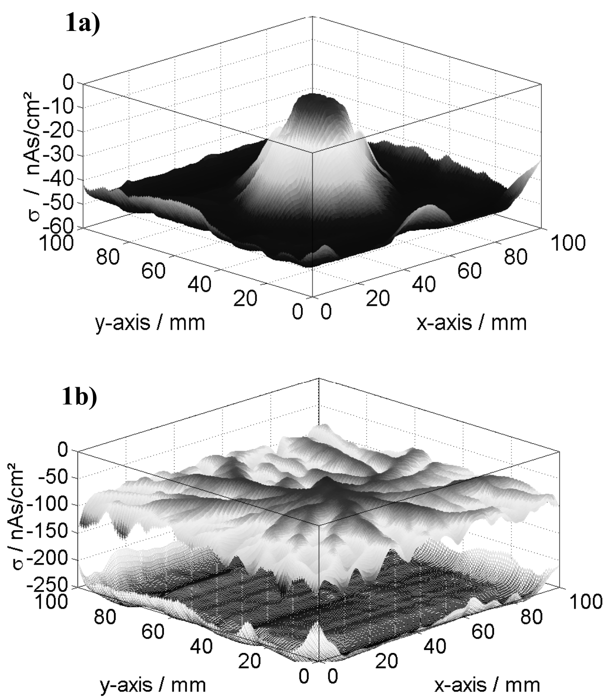

Figure 1: Typical charge distribution for a brush- and a surface discharge.

Measurement set-up

The charging and discharging of insulating materials depend on the climatic conditions, like relative humidity and temperature. Therefore, the experimental arrangement is set-up in a climatic chamber for constant climatic conditions. The conditions for all measurements are 25%-30% of relative humidity and 21°C of temperature. The measurement set-up are shown in figure 2 and have been presented in [4].

The plates and foils can be charged using corona discharges. It is possible to measure the charge distribution on the surface using a scanning system. Then, a grounded electrode is moved to the charged surface until a discharge occurs and the new charge distribution can be measured. From the acquired charge distribution values the transported charge and the area of the discharged surface can be determined.

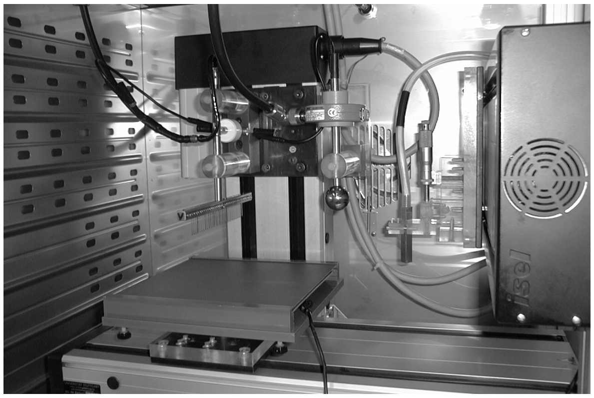

Figure 2: Measurement set-up.

The theoretical maximum value of the surface charge density is 2.7 nAs/cm² for an one-sided charged layer [3]. Due to a conductive layer on the back side the surface charge density can be much higher, because an electric double layer arises. Due to the higher charge density a higher danger potential is possible. Therefore, only these types of plates and foils are investigated. Up to now, only negative corona voltages have been studied.

Transition from the brush to the surface discharge (measurements)

An important point is the value of the initial surface charge density where the brush discharge changes to the surface discharge. Figure 3 shows the transition from the brush discharge to the surface discharge for three PVC-foils of different thickness (measurement results).

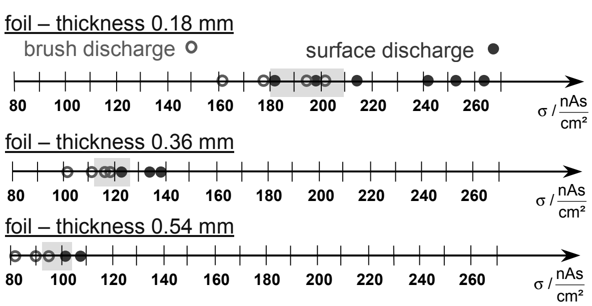

Figure 3: Transition from the brush discharge to the surface discharge for three PVC-foils of different thickness.

For thicker foils the transition point from brush- to surface discharge is at lower surface charge as for thinner foils. The decisive parameter for the propagation of the surface discharges is the tangential electric field strength on the surface. For thicker foils, the critical value of this field strength is reached at a lower value of charge density.

Tangential electric field strength on a brush discharge

Principle of the simulation of the tangential electric field strength after the discharge

The basis for the simulation of the tangential electric field strength on the surface is the measured surface charge density distribution after the discharge. Figure 4 shows the geometrical set-up.

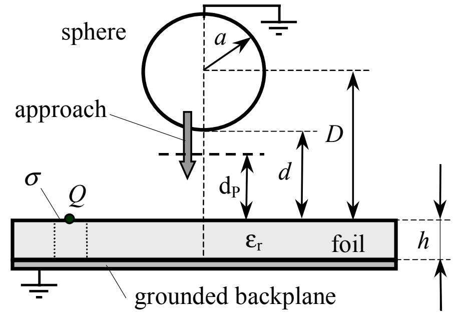

Figure 4: Geometrical set-up

A virtual grid is laid over the surface and the charge density in each grid element is represented by a point charge. The effect of the sphere and the ground plane is taken into consideration by the induced charge in the sphere and in the ground plane.

Determination of the discharge gap length

For the further investigations the determination of the discharge gap length is needed. Here, the basis for the simulation is the constant initial surface charge density.

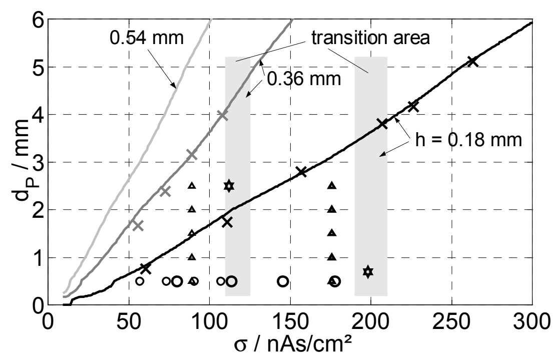

Figure 5: Simulated (solid line) and measured (x) discharge gap length d_P as a function of the surface charge density. The gray boxes, circles, triangles and stars refer to the next chapter.

For a higher radius a of the sphere electrode (> 10 mm) and smaller gap distance (< 10 mm) the electric field is rather uniform. For uniform fields Paschen's law [2] of breakdown defines the breakdown voltage respectively field strength.

For the sphere-plane set-up the maximum field strength arises on the vertex of the sphere. At this point the value of the electric field strength E_s is simulated for different gap lengths d. The curve E_s as a function of d is compared with the curve of the breakdown field strength of 'Paschen'. The point of intersection of both curves indicates the discharge gap length d_P. At this gap length the breakdown condition is met. The values of the discharge gap length d_P are determined as a function of the initial charge density. This function with thickness h as parameter is plotted in figure 5 (solid line).

For some values of the surface charge density the discharge gap length are measured (figure 5 crosses). The measured values show a good agreement with the simulated values.

The start condition of a discharge is that an initial electron in the gap area exists. When the sphere arrives at the distance d_P (where according to Paschen the discharge should occur) and no initial electron exists, the sphere can continue to approach, until the discharge starts. In this case, a value $d < d_P$ (d up to 0.1 mm - 0.5 mm, dependent on the thickness h) and a higher value of field strength E_s is possible.Measurements carried out with a UV-lamp confirm this fact. Here, the discharge always occurs at d close to d_P. Therefore, the calculated values for d_P are maximum values.

Tangential electric field strength as a function of the surface charge density

By a brush discharge, a limited area around the discharge point is discharged. The discharge shorts the charged surface to the ground plane. At the boundary between the discharged and still charged area a high tangential electric field strength on the surface arises.

Along a cut line across this discharged area the tangential electric field strength is considered. Aim of this investigation is to determine the tendency of the maximum value of the tangential electric field strength along this cut line by increasing the value of the initial surface charge density σ_i.

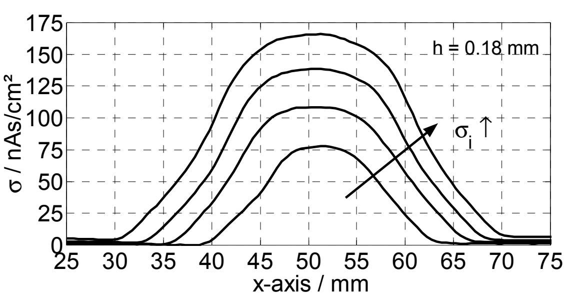

Figure 6: The discharged charge density for increasing value of σ_i

Therefore, some measurements with a constant gap length $d = 0.5$ mm and an increasing value of σ_i are carried out (circles in figure 5). For these measurements, a cutaway view of the discharged charge density distribution (difference between the distribution before and after the discharge) is shown in figure 6 (foil thickness $h = 0.18$ mm). For a higher value of σ_i a larger area is discharged.

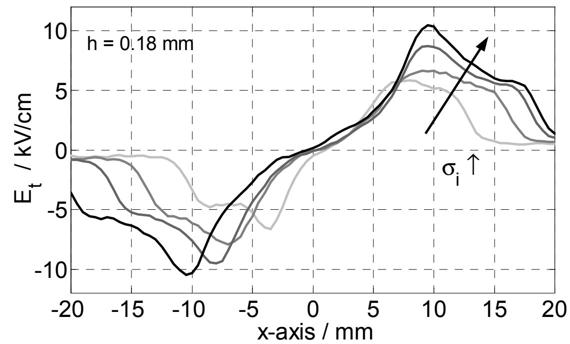

Figure 7: E_t along the cut line for increasing value of σ_i .

For some examples, the calculated tangential electric field strength along the cut line is plotted in figure 7. The discharge point is at position zero and corresponds to the position of about 50 mm in figure 6. The maximum values of the electric field strength are located on both sides in the zone where the rise of the surface charge density is highest.

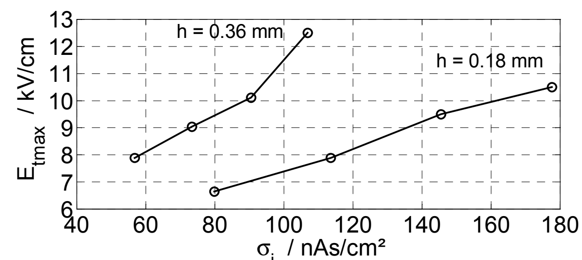

Figure 8: E_{tmax} as a function of the initial surface charge density σ_i

The maximum values of the tangential electric field strength E_{tmax} as a function of the initial surface charge density σ_i with h as parameter are shown in figure 8. For an increasing value of σ_i the maximum value of the tangential field strength E_{tmax} increases.

Tangential electric field strength as a function of the discharge gap length

As already mentioned, a lower value of the gap length $d < d_P$ is possible. The effect of this is a higher value of electric field strength. This fact influences the brush discharge. The size of the discharged area and the shape of the surface charge density distribution after the discharge is varying. Therefore, the influence on the tangential electric field strength along the described cut line is investigated.

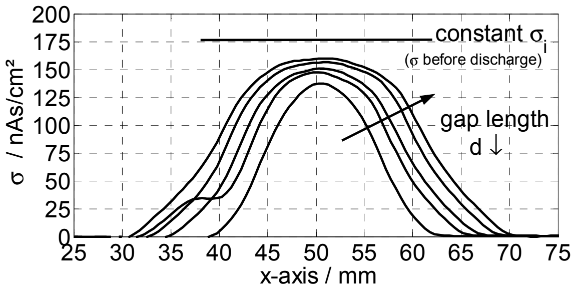

Figure 9: The discharged charge density for decreasing value of *d*

Here, some measurements with a constant value of σ_i and different gap length *d* are carried out (triangles in figure 5). A cutaway view of the discharged charge density distribution of the measurements (foil thickness *h* = 0.18 mm) is shown in figure 9. For a lower value of the discharge gap length *d* a larger area is discharged.

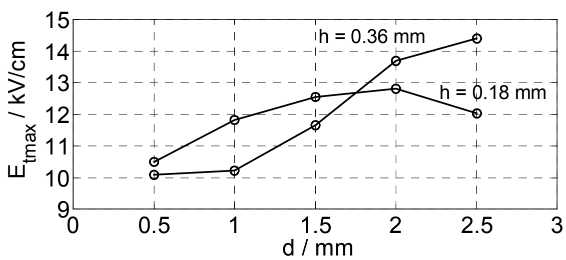

Figure 10: E_{tmax} as a function of the discharge gap length *d*

For this measurements the tangential electric field strength along the cut line is calculated. The maximum values of E_{tmax} as a function of the discharge gap length with *h* as parameter are shown in figure 10.

An important effect is that for a decreasing value of the discharge gap length the values of E_{tmax} decreases. For a lower value of *d* the shape of the discharged charge density distribution is more flat.

Example for the critical value of E_{tmax}

The tendency of the maximum value of the tangential electric field strength E_{tmax} was determined. Now, the critical value of E_{tmax} is investigated. Therefore, two examples of brush discharges for different thickness *h* are chosen. In these cases, σ_i is close to the transition area (stars in figure 5).

For this measurements the tangential electric field strength along the cut line is also calculated and plotted in figure 11. The maximum value of the tangential electric field strength E_{tmax} is about 14 - 15 kV/cm. After the brush discharge no surface discharge follows, because the value of E_{tmax} is very close under the critical value. The result of this is that the critical value of the tangential electric field strength which initiates a surface discharge is about 15 kV/cm for the presented set-up.

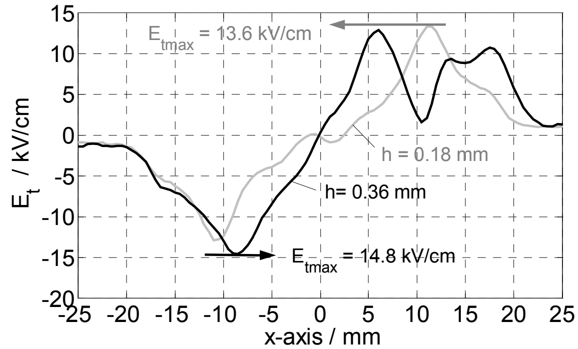

Figure 11: The tangential electric field strength along the cut line.

Conclusion

In this paper, the transition from the brush to the surface discharge was investigated. The decisive parameter for the propagation of the surface discharges is the tangential electric field strength on the surface. For this, the field strength was estimated. The main results are:

- The transition value of the surface charge density is dependent on the thickness of the charged foil.
- Along a cut line across the discharged area of a brush discharge the tangential electric field strength was calculated. The maximum value of these field strengths increases as a function of the initial surface charge density.
- These maximum value of the tangential electric field strength are also dependent on the gap length in the moment of the discharge.
- The critical value of the tangential electric field strength which initiates a surface discharge is about 15 kV/cm for the presented set-up.

References

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