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Electrostatic properties and characterization of two-layer paper sheets

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ABSTRACT

The aim of the research is to determine the electrostatic properties of two-layer paper sheets composed of laboratory filter paper and polyethylene. The volume resistivity and conductivity in a filter paper sheet, polyethylene film and a two-layer sheet consisting of them were studied. The experiment was done using two techniques. The investigated samples were exposed to static electric field and the surface and volume conductivity were measured in accordance with ASTM D257 standard. The same samples were also exposed to positive and negative air ion flux that allows a periodical deposition of a dosed amount of charge in order to measure electrostatic properties of the samples, i.e. to measure maximum surface voltage, sheet capacitance, surface voltage decay half time, volume resistivity, et cetera. A study of a two-layer sample consisting of laboratory filter paper and polyethylene film superimposed on the conductive surface in one position when the polyethylene film is on top and in other when the sample is in turned over position shows that the electrostatic properties of the top layer become dominant. The obtained results appear to be useful for more precise understanding of the phenomena occurring in multilayer sheets and to find a way to improve the multilayer sheets features.

1. Introduction

Paper is one of the most commonly used visualization tool for transferring the image from electronic media onto a physical medium and is used in various types of printing machines [1]. The main features of paper are determined by the materials used for its production, by the manufacturing process and by the paper sheet final structure. When the image is created on a paper sheet by electrophotographic printing technology, the paper sheet's electrical properties become particularly important [2–4]. The increasing use of paper, ranging from daily printing, packaging and to its application as a carrier in printing electronics leads to deeper knowledge of electric and dielectric properties not only about paper sheets but also of complex structures containing low conductive plastic materials.

Sheets of paper can be homogeneous or multilayered. Homogeneous paper sheets are those that consist of the uniform mass of substance (pulp) across the sheet volume. In order to modify mechanical, optical or electrical properties of the pulp mass, which is usually some variant of cellulose, various additives are added [5]. Properties of homogeneous paper sheets are highly dependent on environmental conditions, especially on the ambient humidity and temperature. In some cases, in order to achieve different mechanical, electrical and optical properties of paper, one or both sides of the sheet of paper are covered by different materials. Such a type of a paper sheet becomes a stratified structure and is usually referred to as a multilayer paper sheet [6–8]. A multilayer part composed of thin layers of metal and a dielectric material on a paper sheet, similarly to those proposed in Ref. [9], can also become a passive element for printing electronics.

Some tests with a two-layer sample composed of paper and polyethylene placed on a conductive plate have been performed. Whereas significant differences in surface and volume conductivity and volume resistivity depending on the orientation of the sample were observed, a detailed study of this phenomenon was carried out.

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2. Experimental

2.1. Measurement technique

The experiment was performed using two techniques. The investigated samples were affected by static electric field and by air ion flux in order to measure electrostatic properties of samples.

Test sample affected by static electric field (contact method). A test method for conductivity measurement in accordance with ASTM D257 [10] with the measuring instrumentation described in Ref. [11] is applied. It consists of two types of electrodes: one is adapted for measuring surface conductivity of sheets or films and made using rake-type electrodes [11] (Fig. 1a), and the other, for measuring volume conductivity, is made using a circular conductive plate and ring electrodes [10] (Fig. 1b). The test samples, depending on the quantity measured, together with the same electrodes are pressed against a conductive plate. The test sample pressure was 1.5 kN/m^2.

For a rake-type electrode system, $N = 34$, $g_s = 400$ μm and $L = 36$ mm. For a circular conductive plate, $d = 30$ mm and the distance between the circular electrode and the ring is $g_v = 13$ mm.

The surface conductivity σ_{surf} was obtained by placing a rake-type conductive electrode system on the tested sample (Fig. 1c). In this case, the conductive plate electrode is grounded and a direct current voltage $+U_s$ to the electrode 1 is applied, and then a voltage U_m on the resistor R connected to the electrode 2 is measured.

The sample surface conductivity is calculated using the equation

$$\sigma_{surf} = (U_m/U_s)\cdot(g_s/RL)\ [S],$$

where U_m is the measured voltage, U_s is the applied voltage, g_s is the distance between two adjacent lines of the rake-type electrode, R is the resistance of the external resistor, and L is the overall length of the rake-type electrodes ($L = l\cdot N$, see Fig. 1a).

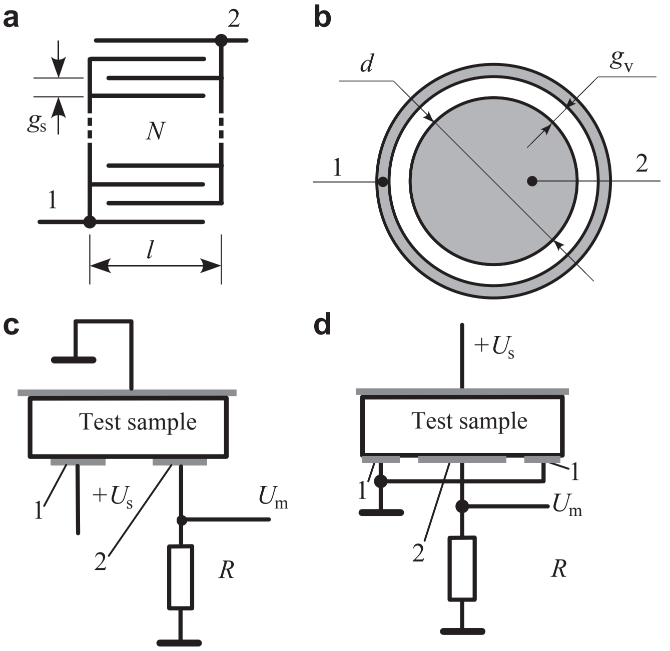

Fig. 1. Electrode shape and circuit diagrams: a – rake-type electrode, b – circular conductive plate and ring electrodes, c – equivalent diagram for surface conductivity measurement with grounded conductive plate electrode, d – equivalent diagram for volume conductivity measurement with a connected conductive plate electrode to a direct current voltage.

The volume conductivity σ_{vol} was measured by placing a circular conductive plate and ring electrodes on the tested sample (Fig. 1d). In this case, the conductive ring 1 is grounded and a direct current voltage $+U_s$ is applied to the conductive plate electrode, and then a voltage U_m on the resistor R connected to the electrode 2 is measured.

The sample volume conductivity is calculated using the equation

$$\sigma_{vol} = (U_m/U_s)\cdot\left(4h/\pi d^2 R\right)\ [S/m],$$

where U_m is the measured voltage, U_s is the applied voltage, h is thickness of the test sample, d is the diameter of the circular electrode, and R is the resistance of the external resistor.

In both cases it is assumed that the resistance of the resistor R is much smaller than the sample resistance.

Test sample affected by ion flux (non-contact method). Another test method is based on measurement of dielectric parameters when the test sample is placed on a conductive plate electrode and exposed to ion flux [12–14]. Detailed description of the measurement technique, the circuit diagrams and the action sequences for computing the main parameters of the investigated objects are presented in Ref. [12]. The measurement technique allows periodical deposition of a dosed amount of charge on a test sample and makes it possible to measure instantaneous values of deposited electric charge Q [C/m^2] and surface voltage U_{surf} [V] (see Fig. 2). By measuring simultaneously the surface voltage and the deposited electric charge, the time dependence of surface voltage, the surface voltage dependence on deposited charge, the electric capacitance and the volume resistivity dependence on the surface voltage are obtained. From the obtained data the main parameters of the investigated test samples are calculated (maximum surface voltage U_{max} [V], sample capacitance per unit area C [F/m^2], surface voltage decay half time $t_{0.5}$ [s], volume resistivity ρ_{vol} [$\Omega\cdot m$]).

The measurement process consists of two stages. The first stage is deposition of electric charge. The deposited charge and the surface voltage are increasing. When the surface voltage stops to increase, the maximum surface voltage $U_{s\ max}$ is measured. In the initial part of this stage, i. e., at lower surface voltages, the sample capacitance C is calculated as follows: $C = \Delta Q/\Delta U$, where ΔQ is the increment of the deposited charge, and ΔU is the corresponding change of the surface voltage.

In the next stage the charge deposition is suspended. In this interval of time the surface voltage naturally begins to diminish and the surface voltage decay half time and the volume resistivity (also called specific insulation resistance) are calculated.

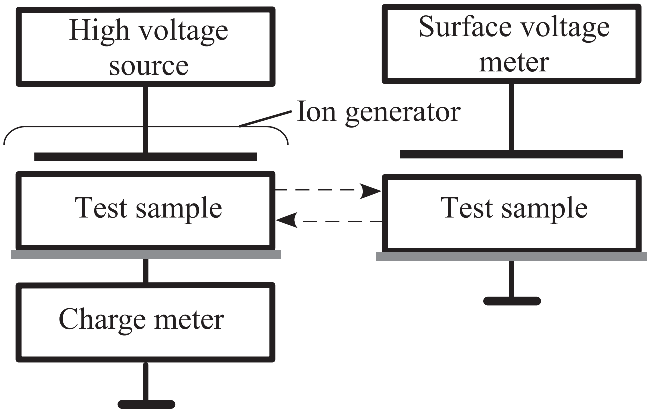

Fig. 2. The circuit diagrams for volume resistivity measurement when the test sample is exposed to ion flux.