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Influence of corona charging in cellular polyethylene film.

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Abstract. Cellular polymers have recently attracted attention for their property of exhibiting a piezoelectric constant when they are electrically charged. The electrostatic charge generated in the voids by the internal discharges creates an internal macrodipole which is responsible for the piezoelectric effect. Charging by corona discharge is the most used method for cellular polymers. Many works have been published on polypropylene and polyethylene films mainly focused on the required expansion process or on the results obtained for raw cellular materials electrically activated. Our work is based on commercial polyethylene cellular films which have been physically characterized and electrically activated. The effect of thermal treatment, physical uniaxial or biaxial stretching and corona charging was investigated. The new method of corona charging improved the piezoelectric constant under other activation conditions.

1. Introduction.

Piezoelectricity in polymers based on their oriented crystalline structure is known at least since 1950 [1]. Recently some new piezoelectric polymers have been developed from polymer foams [2][3]. They are not based on the same physical property since electrical dipoles in polymer foams are created at the micron scale whereas in conventional piezoelectric polymers dipoles are due to the molecular structure [4][5]. Polymer foams are not initially piezoelectric but after a corona charging treatment piezoelectricity is developed in the material from a macroscopic point of view. Corona charging is applied on the surface of a flat polymer foam sample creating a high internal electric field [6]. This induces air breakdown inside the polymer foam cells and an electrostatic charge appears in the inner surface of the cells generating a macroscopic dipole at each cell where the discharge occurs [7]. Piezoelectric properties are then related to both polymer electrostatic properties and corona discharge physics.

The electric model of the charge polymer foam can be simplified into two layers of polymer and air, where σ is the equivalent surface charge density, ϵ is the permittivity of the material, S_1 is the thickness of polymer and S_2 is the thickness of air and Y the Young modulus of the polymer foam [8]:

$$d_{33} = \frac{\epsilon\sigma}{Y} \cdot \frac{1 + (S_2 / S_1)}{(1 + \epsilon(S_2 / S_1))^2} \quad (1)$$

In this work we present results obtained on commercial polymer foams thermally modified and charged by means of different corona charging methods. The new contribution is the use of cellular polyethylene instead of cellular polypropylene and the reversal of the corona-poling polarity to achieve higher effects. The d_{33} static constant measurements show the influence of material modification and corona charging system on piezoelectric properties.

2. Experimental.

Samples were cut from commercial closed cell polyethylene foams 0.48mm in thickness (Alveolit TA 0.48 density 180kg/m³). Thermal stretching is then applied by heating the sample and pulling it in particular directions. Uniaxial stretching is performed in a single step and biaxial stretching is carried out by means of two perpendicular stretches. The heating temperature is 100°C and the stretching ratio for uniaxially stretched samples was 50% and 30% for biaxially stretched samples (in both directions). Although thickness is reduced to 60µm in the case of uniaxial stretching and to 50µm for the case of biaxial stretching, cell shape is different in both cases and that gives very different results. After thermal stretching, samples are metalized by silver sputtering on the grounded side, then corona discharge is applied and finally the other side is also metalized.

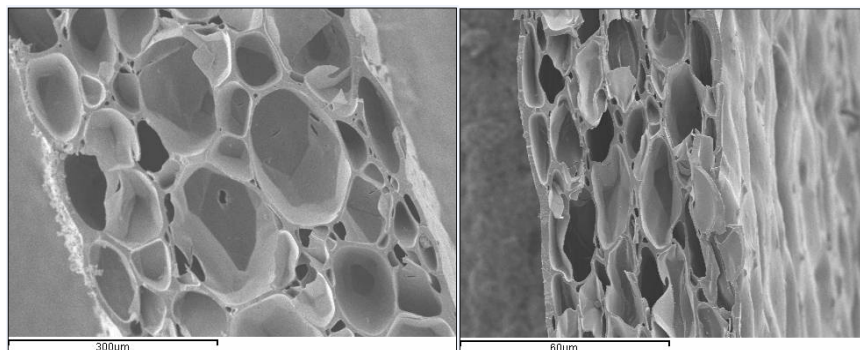


Figure 1. Foam before thermal stretching (left) and after uniaxial thermal stretching (right).

To determine the influence of the corona charging method, samples were not thermally treated, thickness was 0.48mm and 12kV positive corona discharge was applied for 5 min.

3. Results and discussion.

3.1. Influence of thermal stretching

Thermal stretching improves the piezoelectric constant of the material. As can be seen in figure 2, the piezoelectric constant d_{33} of biaxially stretched samples is up to 5 times higher than uniaxially stretched samples, although thickness is similar in both cases (170 pc/N vs. 25 pc/N). However, it may be noticed that internal charge stability is shorter than in the case of non-thermally treated samples probably because of the morphological changes induced in the material during heating. Reaching the glass transition temperature (50°C) may lead to conductivity modifications and it can be seen that piezoelectric constant decreases with time faster than in the case of non-treated samples. Besides, in the thermally stretched samples it can be expected that the internal electric field is higher and some charge injection and neutralization phenomena happen helping to dissipate static charge.

The increase of d_{33} constant may be due both to the increase of the internal poling field because of the sample thickness reduction and the modification of the cell shape. The poling field is nearly one order of magnitude higher for the stretched samples but the breakdown happens at relatively close values of corona discharge voltage for both kind of samples (≈ 15 kV corona discharge for the non-stretched samples and ≈ 14 kV for the stretched samples). This is probably due to the irregular internal field distribution on the samples. Thus it is not possible to apply the same high poling field for both samples. But, on the other hand, the modification of the cells shape induces important mechanical and electrical changes in the material and this is probably the main reason for d_{33} constant increase [9]. From the internal discharges point of view, flatter cells with closer walls allow to a higher electrical charge to be stored since several breakdowns can occur inside the same cell. (In spherical cells one discharge may prevent further discharges from happening since an opposite electric field is generated by the static charge). Charge density is increased and, according to equation (1), the piezoelectric

constant increases. From a mechanical point of view, the Young modulus is reduced thus improving the d_{33} coefficient [7].

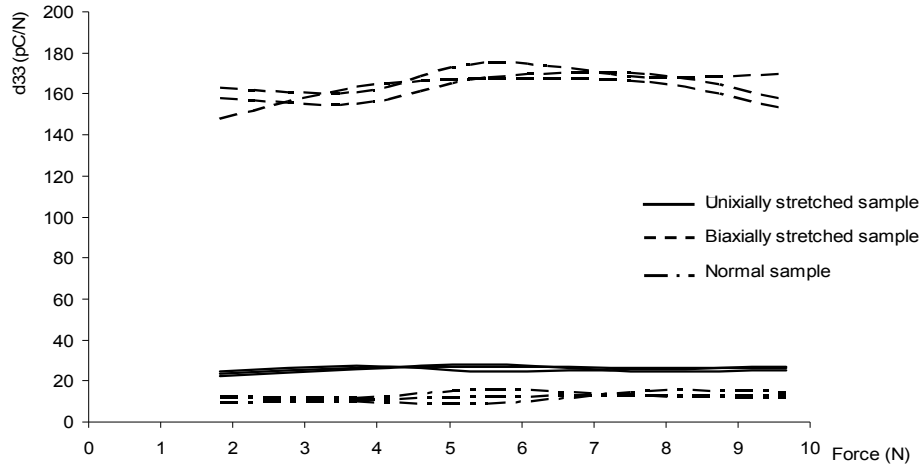


Figure 2. Piezoelectric constant for uniaxial or biaxially stretched samples.

3.2. Influence of corona charging system

The corona charging system is based on the well known point-to-plane arrangement but applying a new methodology. Samples are charged twice reversing their position under the corona discharge. A first corona discharge is applied for 5 minutes and the exposed side to the corona discharge is metallized. This operation also neutralizes surface charges but preserves the internal charges. Then the sample is placed again upside down under a corona discharge of the same polarity and intensity, that is, the firstly exposed and metallized side is now the grounded side of the sample. This reverses the internal electric field in the cells which now is added to the external applied electric field. (Reversing the polarity of the corona discharge instead of the sample orientation could have led probably to the same results).

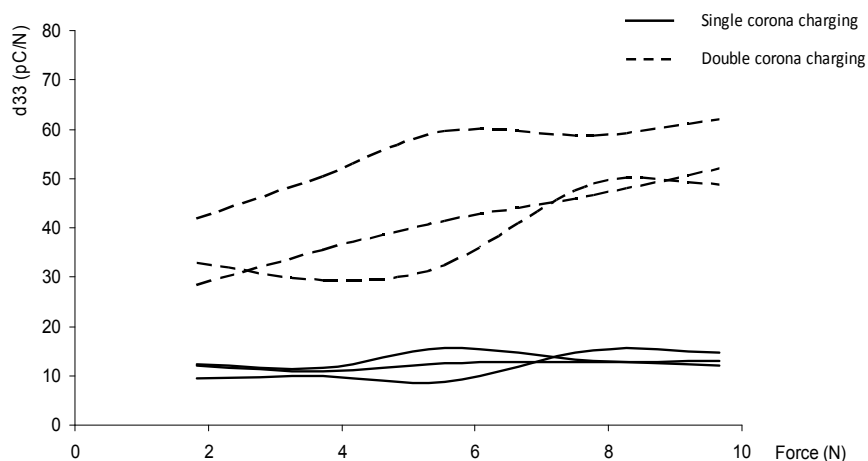


Figure 3. Effect of the corona charging method on the piezoelectric constant.

This new charging method provides good results as can be seen in figure 3 with no need to apply thermal stretching to the samples. This method simplifies the development of polymer foams for their application as piezoelectric materials without modifying charge stability as happen when thermal

treatment is applied. Although thicker samples are used and cell geometry is more spherical, electric breakdown inside the cell is enhanced by the internal electric field reversing. In the spherical cells previous discharges will probably prevent further discharges from happening in the same cell. Of course, a flat cell will give better results and more charge density storage but thermal treatment in our samples reduced charge stability. It can be noted that longer application of the corona discharge does not provide further improvements in the piezoelectric constant.

4. Conclusions.

Piezoelectric properties from available polymer foams treated by corona discharge have been investigated. Two main factors have been considered: thermal stretching and corona discharge application methodology. The piezoelectric d_{33} constant obtained directly from corona discharge application and sample metallization can be improved significantly (up to 170 pC/N) by thermal biaxial stretching but charge stability drops. A reversal, two-step application of corona discharge also improves the piezoelectric constant (70 pC/N) while keeping charge stability. This is probably due to modification of the air breakdown dynamics in the cells of the material inducing stronger internal discharges and higher surface charge. This charging method could be easily applied to the production of larger samples.

5. Acknowledgements.

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