Effect of the Electrical Conductivities of Corona Discharge Ground Rolls on Surface Treatment

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Abstract

Corona treatment surface modification utilizes a corona discharge (air plasma) to change the surface properties of low polarity materials to improve surface wettability and adhesion. This air-based discharge is generated by the application of high voltage to an electrode which is positioned over the material to be treated, with this material typically supported by a ground plane or roll. Ground planes can be 1) bare metal and suitable for treating both conductive and nonconductive materials, 2) covered with a conductive coating, or 3) covered with a non-conductive coating and also suitable for treating both conductive and nonconductive materials. The latter type of "universal" roll coverings is, for example, prevalent, but can be inherently inefficient in treating varying materials and thicknesses.

Due to their chemical composition, many low polarity materials are insulators and require considerable electrical current to increase their surface tension. The low conductivity of these materials is also the cause for the collection of very high electrostatic charges on their surfaces. This study examines the physical, thermal and electrical properties of various conductive ground roll coverings of corona treatment systems common to the polymer film converting industry, and their respective effects on film surface tension levels and surface tension longevity.

Introduction

In an electric insulating material (or dielectric) such as many polymer packaging films, electrons are bound to atoms and molecules and there is a high resistance to electric current. This means that the film has a near zero electrical conductivity. When breakdown occurs during corona treatment, the present electric field releases the electrons. If the corona discharge is strong enough, the freed electrons can accelerate and liberate other electrons when they collide with neutral atoms or molecules. To calculate how much the voltage an insulating polymer film can hold before breaking down, the dielectric strength of the film must be determined, which is measured in volts per unit length. The higher the electric strength, the more insulating the film will be. There is, therefore, an important interrelationship between a film's electrical properties and the electrical design of the corona treater, the latter of which can play a significant role in the surface performance of films after the corona surface modification process.

Dielectric strength is a key property of an insulating polymer film and it is defined as the ratio of the breakdown voltage to the film's thickness. Breakdown voltage is the maximum voltage a polymer film can withstand before a conducting path forms through it. Low density polyethylene (LDPE), for example, is a tough and relatively inexpensive polymer made of long carbon chains attached with hydrogen atoms. It has good electrical properties with its low moisture absorption. However, as its temperature increases and it softens (as crystallites melt), the polymer's dielectric strength will decrease. To counteract this effect, it is well known that incorporating inorganics such as silica nanoparticles into polymers can increase the breakdown strength and voltage endurance significantly.

If a polymer film were to be used for strictly insulating purposes, it would be better to have a lower dielectric constant. However, it is advantageous for packaging films to hold energy at their surfaces for the purpose of ink, coating, or lamination adhesive wetting and adhesion. As such, a higher dielectric constant would be favorable. For reference, the dielectric constant relates to the permittivity of the polymer film and its ability to polarize in response to an applied field such as a corona discharge. Physically, this means that the greater the polarization incorporated into a polymer film from a corona discharge at a defined watt density, the greater the dielectric constant will be.

Table 1. Electrical Properties of ECTFE and LDPE polymers

Properties	ECTFE	LDPE
Volume resistivity (Ω·cm)	$> 10^{15}$	$> 10^{15}$
Surface resistivity (Ω)	$> 10^{14}$	$> 10^{15}$
Dielectric strength at 1mm thickness (kV/mm)	30-35	20-160
Relative dielectric constant at 1kHz	2.5	2.3
Dissipation Factor at 1kHz	0.0016	0.0003

For this study, we have chosen ECTFE and LDPE, two polymers with similar resistivity, dielectric strength and dielectric constants, but with vastly different dissipation factors. Dissipation factor is the percentage of electrical energy absorbed and lost when electrical current is applied to an insulating material such as polymer films. ECTFE has a five-fold higher dissipation factor than LDPE.

The objective of this study was to determine, given the electrical properties of these two films, 1) what effect the dielectric properties of different conductive ground roll coverings have on the initial surface energy achieved at various watt density corona treatments, and 2) what the relative dissipation (or conversely retention) of surface energy is when employing these roll covering types.

Description and Application of Equipment and Processes

The subject films were exposed to corona discharges using a roll-to-roll process employing ITW Pillar Technologies' ceramic electrode technology in combination with either 1) a plasma-sprayed conductive ceramic (over steel) ground roller provided by American Roller, or 2) a conductive sleeve (over steel) provided by Jemmco. Mechanical roll covering properties are provided in Table 2. Trial watt densities ranged from 2 to 5 Wmin/ft^2. The corona discharge frequency was fixed so as to preclude changes in the dissipation factor (loss factor), as it is well known that higher frequency corona discharges can decrease the dissipation factor.

Table 2. Corona System Dielectric Roll Covering Properties

	Plasma-Sprayed Conductive Ceramic	Conductive Sleeve
Shore A Hardness		65
Rockwell C Hardness	70	
Nominal Thickness Range - mils	40-120	.080-.082"

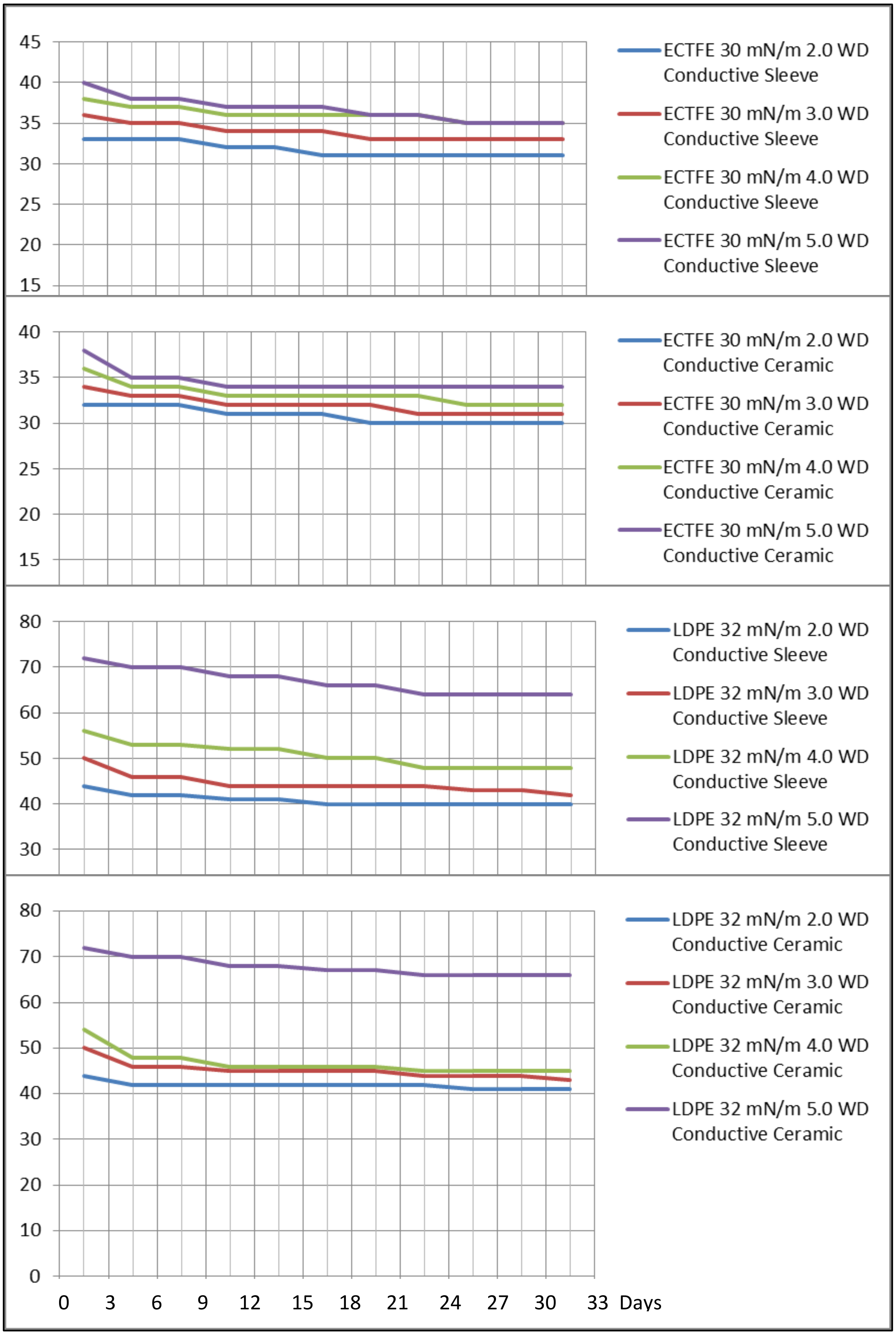
The trial films were treated and analyzed within the ITW Pillar Technologies surface modification laboratory for surface energy dissipation within a controlled climate of 70°F and 50% relative humidity. Data was collected over a thirty day period.

It was expected that both film surfaces would be etched and oxidized, yielding hydrophilic surface states. When an air-based discharge is used, the degree of oxygen incorporation at the surface is well known to increase linearly with increases in applied power density. A spectrum of oxygen-containing groups including peroxide, hydroxyl, ketone / aldehyde, carboxylic acid, and ester groups are introduced at the surface. Among these oxygen functionalities, carboxylic acid (approximately 14-16% of the oxygen present), ketone/aldehyde **(**24-26%), and hydroxyl/epoxide (6-10%) groups were expected to be introduced at the surface by corona treatment.

Regarding corona treatment aging effects, it is common understood that free radicals make up approximately 20% of the species generated in a RF corona discharge, and are therefore a major constituent of the discharge. In many cases, a large number of free radicals remain trapped in the treated film and cannot recombine rapidly. The existing free radicals can react with water vapor and oxygen in exposed air, or they can recombine. These processes lead to a gradual rearrangement of the surface network of species and are sometimes described as aging. The aging effect is influenced in part by sustained exposure to variations in ambient temperature and humidity. Aging is therefore more specifically a result of the extraction of polar and dispersion components of the surface free energy imparted to polymer films by corona treatment. Aging effects were expected as inherent processing effects following corona treatment.

Experimental and Results

Figure 1. Corona Treatment and Aging Effects of ECTFE and LDPE Using Conductive Sleeve and Conductive Ceramic Roll Coverings



An analysis of the data in Figure 1 above indicates several key findings. First, it can be observed that the corona treatment aging effect is prevalent with both films and when using both ground roll covering variants, and that ECTFE is less polar than LDPE. Secondly, conductive sleeve technology provided higher initial surface energies to the ECTFE film within the 2-5 Wmin/ft^2 range, as opposed to the conductive ceramic roll covering. This advantage did not present itself within the LDPE trials. Thirdly, ECTFE films treated with conductive sleeve technology stabilized at higher surface energy levels after the trial period than the ECTFE films treated with a conductive ceramic roll covering. Fourthly, LDPE films treated by either conductive roll covering achieved the same initial surface energy level. Lastly, LDPE treated at the highest power density level of 5.0Wmin/ft^2 stabilized within the range of 64-66 mN/m considering both ground roll coverings, a significant step change from 4.0Wmin/ft^2 which stabilized within the range of 45-48 mN/m. Stabilization surface energy values for both roll covering variants of the LDPE trial materials under 4.0Wmin/ft2 were similar.

Discussion and Conclusion

It was apparent from the study that for partially fluorinated, non-polar polymers such as ECTFE, the dielectric properties of conductive ground roll coverings influences the initial surface energy attainable with these materials. A noticeable improvement in initial surface free energy accompanied the use of conductive sleeve (over steel) technology when compared to plasma-sprayed conductive ceramic technology. Higher level surface energy stabilization of ECTFE was also improved with conductive sleeve technology. This advantage was not evidenced in any of the LDPE trials, although moderate discharge power densities to the conductive sleeve covering provided higher average surface energies to LDPE vs. ECTFE. It was also observed that the higher dissipation factor for ECTFE did not manifest itself when comparing the aging of both film types and their respective conductive roll coverings.

LDPE treated at a power density level of 5.0Wmin/ft^2 stabilized at a level significantly higher than lesser applied power densities. It is theorized that a breakdown voltage threshold was crossed by which the LDPE polymer surface became significantly overpopulated with low molecular weight oxidized materials. A further study would seem warranted to examine certain electrical property and current distribution differences between conductive ground roll coverings to discern how surface treatment improvements can be optimized.

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