Electrical Properties and Temperature Effects of PET Films with Interface Layers

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In this paper, PET (Polyethylene Terephthalate) films with semiconducting and interface layers were investigated. The electrical properties, such as volume resistivity, tanδ (dissipation factor), and breakdown strength at various temperatures were measured. Thermal analyses of PET and semiconducting films were measured and compared by differential scanning calorimeter (DSC) of each film. It is found that the volume resistivity of film (dependence on semiconducting/interface layers) and electrical properties of PET films are changed. Breakdown strength and dissipation factor of PET film with semiconducting layer (PET/S/PET) are decreased more greatly than PET and PET/PET films, due to the increase of charge density or charges at two contacted interfaces between PET and semiconductor. The dissipation factor of each film is increased with temperature. For PET/S/PET film, it is depended on temperature more than PET or PET/PET. However, the breakdown strength is increased up to 85°C and then decreased over 100 °C. The electrical properties of PET films with semiconducting/interface layer are worse than without it. It is due to a result of temperature dependency, which deeply affects thermal resistance property of PET film more than semiconducting/interface layers.

Keywords: *Polyethylene Terephthalate, Breakdown Strength, Dissipations Factor, Thermal Properties.*

1. INTRODUCTION

The insulation structures of power cable, joint boxes and terminations have many inhomogeneous materials and interfaces of insulation system such as cross-linked polyethylene, semiconductor, ethylene-propylene rubber and epoxy. Most failures of insulation system material are appeared at the interfaces between two insulating layers with high stress and temperature. It is well known that the weak points of insulating system lie in the interface [1-2].

Researches for the interface mechanism of insulation system have been thoroughly investigated on electrical breakdown, dissipation factor, and capacitance. Many papers have been reported the results on the space charge effect at interfaces between two kinds of polymers or laminated polymers [3-6]. Recently, it is reported on the behavior of two layer films in high electric field and on breakdown strength of the boundary region between layers [7]. Therefore, it is important to investigate the electrical properties of insulation system in power cable, its accessories, and polymer insulator with the interface between two polymers for its improvement. Also, thermal analysis technique has been used for the evaluation of degradation, the tree propagation property on insulation materials and the relation between electrical and thermal properties of polymer. [8-10]

The scope in this work is to investigate the thermal and electric properties of PET films with semiconducting /interface layers and thermal properties of each film. The results were compared by DSC analysis of each film. It was observed that the relation between electrical and properties in PET films, such as volume resistivity, dissipation factor, and breakdown strength and interface effects, etc.

2. EXPERIMENTS

The three specimen films were used in this paper. They are PET(Polyethylene Terephthalate, SKC, Type SR-01), PET/PET and PET/semiconducting layer/PET (PET/S/PET). The thickness of PET films is 50 μm, a PET/PET film is 50 μm, and a PET/S/PET film is 130 μm. The thermal properties of PET and semiconducting films was analyzed by DSC(Mac science, DSC3100). The conducting current was measured at a constant electric field (0.2 MV/cm) by Electrometer (Keithley 617). The dissipation factor and capacitance were measured by Capacitance Bridge (Tettex 2881) at constant electric field (0.1MV/cm) and under a given pressure (2 N/cm^2) between the upper and the lower electrodes. For the conducting current, the dissipation factor and capacitance test, a three electrode systems were adopted as the upper electrode (100.4 mm). And the guard electrode was used as the lower electrode (49.5mm).

For AC breakdown strength, sphere upper-electrode of 9.5mm diameter and plane lower-electrode were used. The electrodes and samples were immersed in silicone oil bath for keeping at a given temperature varied from 25°C to 100°C. AC voltage applied at the rate of 500 V/sec until the breakdown. The breakdown voltage of each specimen was determined by the mean-value obtained by 10 samples.

3. RESULTS AND DISCUSSIONS

3.1 Thermal Analysis

The thermal analysis for PET and semiconducting films were studied by the differential scanning calorimetry (DSC). Fig. 1 shows the DSC curve of semiconducting films. It is clear from this curve that melting point and glass transition temperatures are around 110°C and 60 °C, respectively.

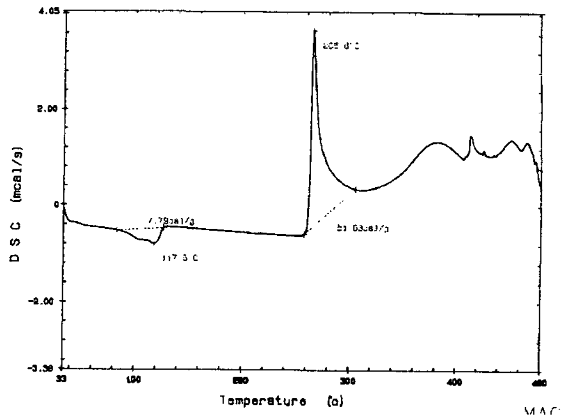

Fig.1 DSC curve of semiconducting film

It was considered that the peak at 117°C was due to re-crystallization at a temperature below the melting point. The semiconducting films were consisted of carbon black, LLDPE and LDPE pellets. The second peak occurred at 260°C was due to a paralysis and oxidation of carbon black/polymers.

Fig. 2 shows the DSC curve of PET films. The first peak at 257°C in Fig. 2 shows a melting point and the second peak, increasing broadly from 360°C to 441.1°C, is due to an oxidation of PET film. The glass transition temperature of PET occurred at 80°C due to moving a molecular chain of polymer.

In this paper, the relationship between the electrical and thermal properties of polymers is investigated. The charge activity dependency on glass transition temperature is obtained by thermal analysis through DSC and will affect to electrical properties of films. Through Fig. 1 and 2, it was identified that PET has a thermal stable than semiconducting film.

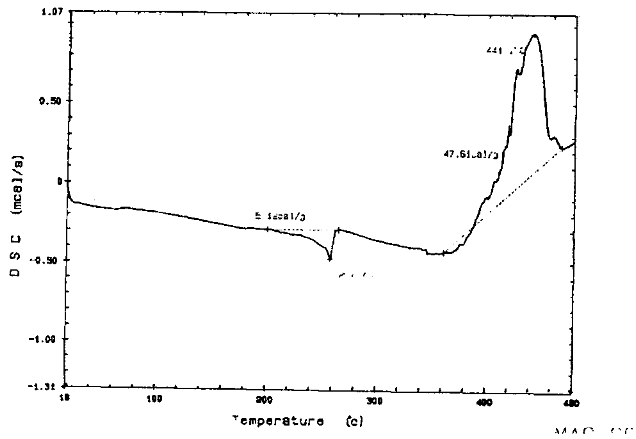

Fig.2 DSC curve of PET film

3.2 Volume resistivity

The volume resistivities of PET, PET/PET and PET/S/PET films are shown in Fig.4. The volume resistivities of PET, PET/PET and PET/S/PET were 1.1×10^{16}, 9.3×10^{15} and 1.0×10^{15} Ω m, respectively. The volume resistivities were decreased with the existence of interfaces, especially in semiconductor. The volume resistivity of PET/S/PET films is lower than that of PET/PET. The high charge density in interface layer of PET films affects PET films, and it probably has a role of a charge injection on the surface between PET films. The volume resistivities of PET/PET and PET/S/PET films were decreased. Especially, the volume resistivity of PET/S/PET was the lowest. It is considered that the decrement of volume resistivity of PET/PET and PET/S/PET is due to change of charge density on the interface between layer and reduction of the electric field by the semiconducting.

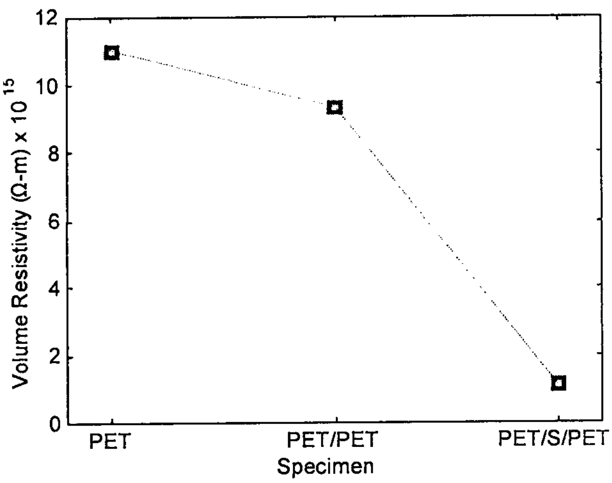

Fig.3 Volume resistivity of each specimen

3.3 Dissipation factor and capacitance

The volume resistivities are affected by the capacitance and dissipation factor of PET films. Therefore, the relationship between dielectric properties as the effect of interface or semiconducting layer was investigated. At room temperature, the dissipation factor and capacitance of each PET, PET/PET and PET/S/PET film were measured as a function of temperature. The capacitances of each specimen are 515, 574 and 580pF, respectively. The results show that capacitance is higher than that for PET and PET/PET films. The volume resistivity of PET/S/PET is decreased whereas the capacitance of PET/S/PET is increases. The dielectric constants for PET, PET/PET and PET/S/PET film were calculated as 2.4, 2.45 and 4.42, respectively. The dielectric constant of PET/S/PET was higher than PET and PET/PET films.

The dissipation factors of each specimen are $9.0\text{X}10^{-4}$, $1.0\text{X}10^{-3}$ and $3.2\text{X}10^{-3}$, respectively. The dissipation factor for PET/S/PET films with semiconduction layer is more prominent increment than that with interface layer, because of interfacial phenomenon Both dissipation factor and capacitance of PET films increased with semiconducting or interface layers more than those without them. This result indicates that the dielectric properties deeply depend on semiconducting more than interface layers between PET films. These results show that dissipation factor and volume resistivities are more sensitive to semiconducting layer than interface layer between PET films. It is assumed that dissipation factor and capacitance of PET films are increased because of the increased relaxation of polarization or charge under highest tangential field in surface between two PET films.

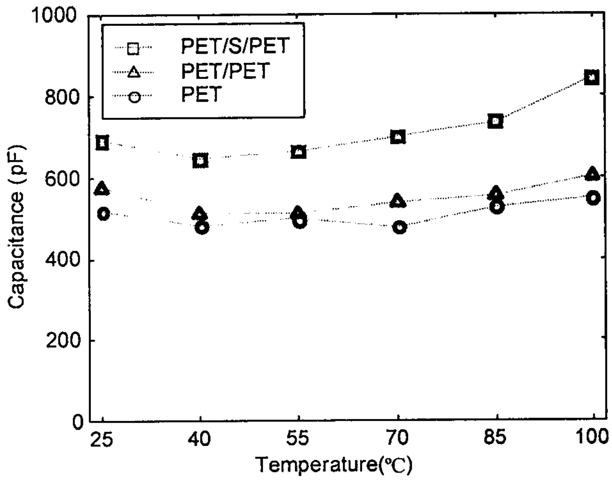

Fig.4 Capacitances as a function of temperature

The dielectric properties are an important parameter to evaluate the dissipation factor and capacitance of the insulating material. The dielectric properties are strongly depended on temperature. The aged insulating materials will change the dielectric properties. Therefore, it is necessary to investigate the temperature effect for dissipation factor and capacitance. The temperature dependency of each specimen is shown in Fig 4. and 5.

Fig.4 indicates the capacitance is a function of temperature and slightly increased with temperature. In this case, actually capacitance is different for PET and PET/PET films at various temperatures. For each specimen, it was observed a deeply dependence on interface layers in PET films.

The capacitances for PET, PET/PET and PET/S/PET films were 549, 604 and 842 pF, respectively. The dielectric constant for each specimen at 100 °C is 2.61, 2.77 and 6.42, respectively. The capacitance of PET/S/PET film was higher than PET and PET/PET films at various temperatures. The dielectric constant of PET/S/PET films was considerably increased in comparison to that of PET and PET/PET films, and was affected by the semiconducting layer as an interface. It was found that dielectric constant and dissipation factor of specimen with a semiconducting layer were increased.

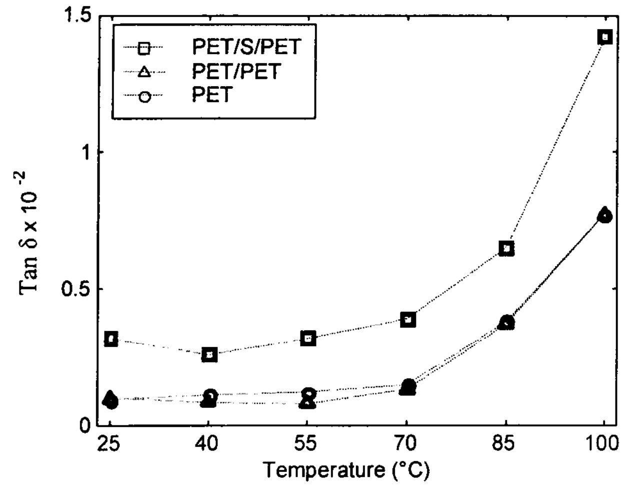

Fig.5 Dissipation factor as a function of temperature

Fig.5 shows the dissipation factor as a function of temperature. The dissipation factor is drastically increased at the temperature increased above 70°C. The dissipation factor of PET/S/PET films is higher than PET and PET/PET films. The reason is that the charge activities are increased in semiconducting layer. However, the change of dissipation factor for PET/PET films is similar with PET films.

The dissipation factors of PET/S/PET films are affected more than that one with only interface layer. The reason is that dissipation factors at high temperature are increased due to an effect of a resistant factor or electric dipole in semiconducting layer. These results of volume resistivity and dielectric properties of PET film with semiconducting/interface layer have affects on breakdown strength.

3.4 Breakdown Strength

The breakdown strength of PET, PET/PET, and PET/S/PET films were 2.0, 1.7 and 0.49 MV/cm, respectively. The breakdown strength of films with semiconducting and interfaces layer was lower than that of PET films. The breakdown strength is decreased due to contaminants or voids on surface between two films.

Fig.6 shows the breakdown strength characteristics as a function of temperature. The breakdown strength for all specimens were increased with the temperature to 55 °C, and showed a tendency to decrease at 100°C. The breakdown strength of PET and PET/PET films have affected at below 85 °C, whereas those of all films with semiconducting layer are influenced above 100 °C. These results suggest that temperature dependency of breakdown strength is more related to PET film than to semiconducting or interface layer.

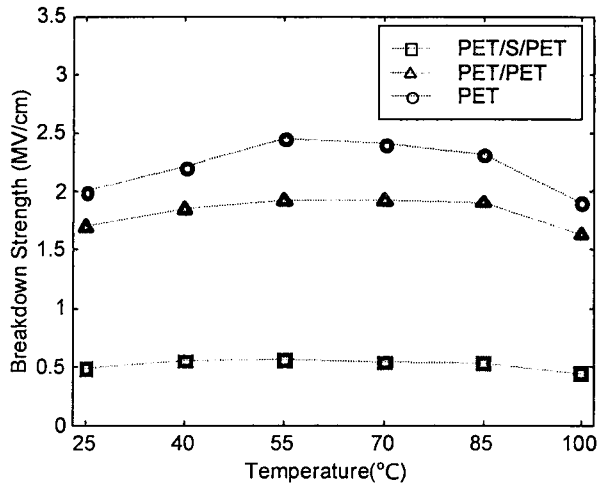

Fig.6 Breakdown strength as a function of temperature

4. CONCLUSIONS

The thermal and electrical properties of PET films with semiconducting/interface layer have been investigated, and the conclusions can be summarized as follows.

It is observed that the melting points of semiconducting and PET films were 110°C and 255 °C, respectively. The glass transition temperature of each film was obtained at the melting point. At high temperature above melting point, it is considered that the occurrence of the second peak is due to a paralysis and oxidation of carbon black/polymers.

An interfacial phenomenon of semiconducting/ interface layer in films was observed and is related to the changes of volume resistivity. Dissipation factor of PET/S/PET film has been increased comparing with PET and PET/PET films. The breakdown strength of PET/S/PET film decreased more than that of PET/PET films. The dissipation factor of PET films with semiconducting layer is dramatically increased compared with PET and PET/PET films and the dissipation factors are increased smoothly with the increase of temperature.

The changes of electrical properties might be explained by the increase of charge density, caused by void and contaminants in the surface between two films. From the results, it could be concluded that the semiconducting or interface layers between two films have affected on electrical properties.

ACKNOWLEDGMENT

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