

## Mechanical and Electrical Properties of Biodegradable Plastics

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### Abstract:

We examined the mechanical and electrical properties as well as physicochemical analysis of PLA and PET copolymer that is biodegradable plastics. The decreasing rate of tensile strength of PET copolymer became a tendency to look like PP, and was more gradual than the decreasing rate of PLA. The rise of  $\sigma$  of PLA according to the rise in heat was not caused easily from PET copolymer. Dielectric breakdown strength of PLA was high within the range of the temperature that was wider than that of the PET copolymer and LDPE.  $\epsilon_r'$  was LDPE < PLA < PET copolymer  $\approx$  PET, and the maximum value of the peak of  $\epsilon_r''$  was PET copolymer > PLA > PET.

### INTRODUCTION

Production of synthetic plastics including cross-linked polyethylene and epoxy resin has been rapidly boosted as a result of development in the petrochemical industry. Nowadays, the products prevail in all fields of daily life and industry. Synthetic plastics are light weight, easily processed, and have viscoelastic material features such as mechanical properties, electric insulation, insulation characteristics, and corrosion resistance, so that they are widely used as an electric insulation material. In addition, because consumer electronics equipment and digital assistants quickly became widely available along with the development of recent electric/electronic and network industries, synthetic plastics will be increasingly used as an electric insulation material. However, most of these instruments are disposed of after use and damage the environment, causing a large social problem.

A biodegradable plastic is a plastic that is decomposed via germs and decomposition enzymes in nature to give water and carbon dioxide. Thus, it can be buried in the ground for waste treatment. The plastic generates only a small amount of heat during combustion and does not release poisonous materials such as dioxins. Therefore, when biodegradable plastics are used instead of synthetic plastics, the environment is protected [1]. However, the example of reporting on the research on the electrical characteristics of the biodegradable plastics is very few including authors; thus, the plastics are not yet in actual use as an electrical insulation material [2-5].

A present main current is a synthetic polymer though the biodegradable plastic is greatly classified into three

(bio polymer, synthetic polymer, and modification of natural polymer) depending on the manufacturing method. Moreover, the synthetic polymer is classified into "Plant base" and "Mineral oil base". In this research, polylactic acid (PLA) that was "Plant base" and polyethylene terephthalate copolymer (PET copolymer) that was "Mineral oil base" were selected. Both of these are high production capacity, and materials to be able to expect the price cutting. Each sample is a thermoplastic resin.

In this research, it examined the mechanical and electrical properties as well as physicochemical analysis of PLA and PET copolymer that is biodegradable plastics.

### EXPERIMENTAL METHODS

**Samples** The sample used was biaxially oriented PLA and PET copolymer films (trade name: Palgreen LC and BO, thickness of 25  $\mu\text{m}$  and 20  $\mu\text{m}$ ) of Tochello Co, Ltd [6]. Fig. 1 and Fig. 2 shows chemical structure of PLA and PET copolymer. Moreover, the film of low-density polyethylene (LDPE), polypropylene (PP) and polyethylene terephthalate (PET) films were used as comparison samples. The thickness of comparison samples are all 25  $\mu\text{m}$ .

**Thermal analysis** A differential scanning calorimetry (DSC) instrument (SHIMADZU, DSC-60) was used for thermal analysis. With  $\alpha$ -Alumina as a reference material, DSC spectra were observed for PLA with a rise in temperature from 30°C to 230°C at a rate of 10°C/min. in a nitrogen atmosphere.

**Tensile strength** The sample was cut like the strip of

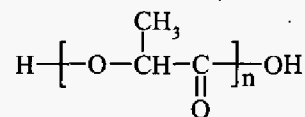


Fig. 1 Chemical structure of PLA.

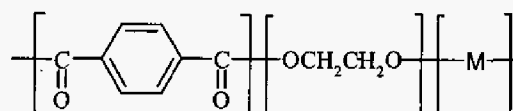


Fig. 2 Chemical structure of PET copolymer.

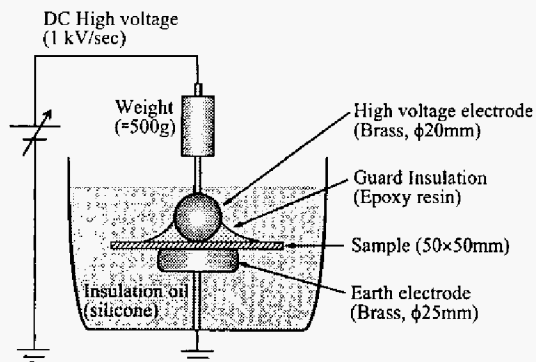


Fig. 3 Experimental system for measuring dielectric breakdown strength.

paper of 150×10mm. The tensile speed set to 100mm/min, and the tensile strength was measured while changing the sample from room temperature to 120°C, and measured specific conditions five times or more.

**Electric conduction** The sample was cut out into 50×50 mm squares, and the aluminum was vacuum-deposited on both sides of the sample to form electrodes φ25 mm at the center and guard electrodes around them. The conduction current was measured by using the high resistance meter (Agilent Technologies, 4339B) while applying the DC electric field ( $E=0.2$  MV/cm), and it was measured while the sample was heated in dry air from 30 to 150°C at 1°C/min. Afterwards, the electric conductivity was evaluated from measurements.

**Breakdown strength** Fig. 3 shows experimental system for measuring dielectric breakdown strength. The sample was cut out into 50×50 mm squares. The high voltage side was made the ball electrode of φ 10 mm, and the earth side was made the disk electrode of φ 25 mm that rounded the edge, and to prevent creeping discharge in addition, the guard insulation was done by epoxy resin the contact surrounding of the high voltage electrode and the sample. The sample and the electrode system were soaked in the silicone oil, and a positive direct current high voltage was applied at the rate of increase of 1kV/sec. The temperature of the sample changed from the room temperature to 120°C, and measured specific conditions ten times or more.

**Dielectric properties** A precision LCR meter (Agilent Technologies, 4284A) was used to determine dielectric properties. Capacitance ( $C$ ) and the dielectric loss tangent ( $\tan \delta$ ) were simultaneously measured. The signal voltage was set to 1 Vrms and the measurement frequency ( $f$ ) was set to 1 kHz. The range of the measurement temperature and the measurement environment are similar to the measurement of electric conduction. The relative permittivity ( $\epsilon'$ ) and the relative dielectric loss factor ( $\epsilon''$ ) were evaluated from measurements.

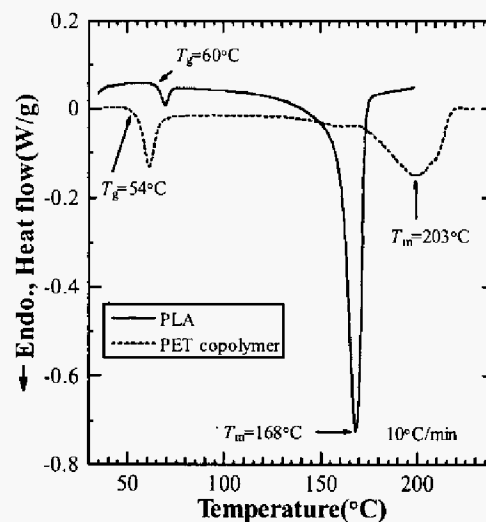


Fig. 4 DSC spectra of PLA and PET copolymer.

## RESULTS AND DISCUSSION

**Thermal properties** Fig. 4 shows DSC spectra of PLA and PET copolymer. The DSC curves shifted toward heat absorption starting at around 50°C or 55°C. In glass transition, step-shaped signals specific to the transition appear. For glass transition temperature ( $T_g$ ), extrapolation front temperature ( $T_f$ ) or mid temperature of the step ( $T_m$ ) are generally used. However,  $T_f$  is used as  $T_g$ , since use of  $T_f$  is recommended in D 3418-82 by the American Society for Testing and Materials (ASTM). In the  $T_g$  values derived from the DSC spectra, PLA was about 60 °C, and PET copolymer was about 54 °C. Thus,  $T_g$  of PLA was a little higher temperature than PET copolymer. In addition, a large absorption peak appears at a temperature of 150°C or higher. The peak is attributed to the melt transition, the temperature of which corresponds to the melting point ( $T_m$ ). In the  $T_m$  values derived from DSC spectra, PLA was about 168 °C, and PET copolymer was about 203 °C. Therefore, it was seen that PET copolymer with the aromatic ring is more excellent thermal stability than PLA.

**Tensile strength** Fig. 5 shows the temperature dependence of tensile strength at break. Tensile strength of PLA and PET copolymer at the room temperature became about 100 MPa, and was the same as PP. It was tensile strength that is four times nearer than LDPE. Tensile strength has decreased when the temperature rises in each sample, and PLA became LDPE and the same at the case of 100°C. The decreasing rate of tensile strength of PET copolymer became a tendency to look like PP, and was more gradual than the decreasing rate of PLA. Therefore, it was thought that mechanical strength of PET copolymer at the high temperature is more excellent than that of PLA.

**Electric conduction** Fig. 6 shows the temperature

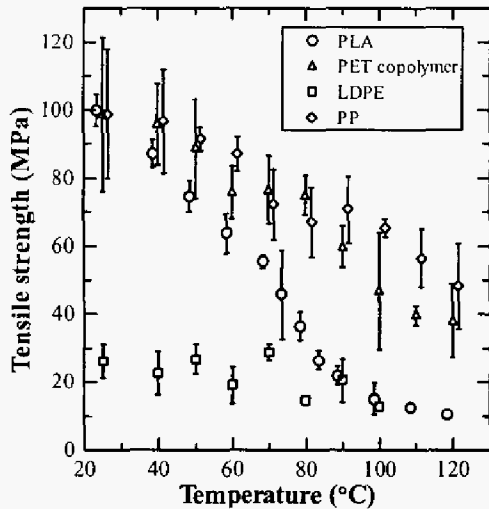


Fig.5 The temperature dependence of tensile strength at break.

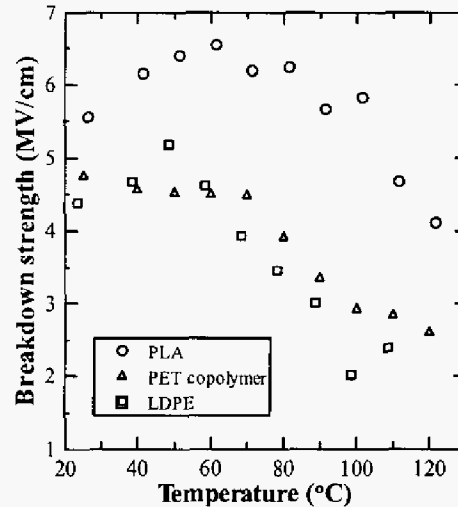


Fig. 7 The temperature dependence of dielectric breakdown strength.

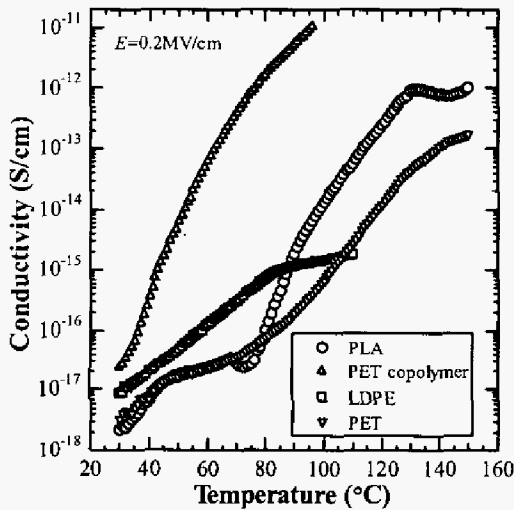


Fig. 6 The temperature dependence of electric conductivity.

dependence of electric conductivity ( $\sigma$ ).  $\sigma$  of PLA at the room temperature was about  $10^{-18}$  S/m, and it was almost the same as PET. Moreover, it was a tendency to look like  $\sigma$  of PET up to about 70°C. When becoming a high temperature any more,  $\sigma$  of PLA increased rapidly, and the rate of increase was higher than PET. From the DSC spectra in Fig. 4,  $T_g$  of PLA was found to be about 60°C. That is,  $\sigma$  of PLA rises more than  $T_g$  in the high temperature region, and was considered that it became easy to cause the ionic conduction by micro-Brownian motion of a molecular chain [5]. However,  $\sigma$  of PLA was lower than that of LDPE from the room temperature to about 80°C. On the other hand,  $\sigma$  of PET copolymer at the room temperature was  $2 \times 10^{-17}$  S/m, and it was a little higher than the one of LDPE, and was an excellent value when

thinking about use to the insulating material. However,  $\sigma$  of PET copolymer increased rapidly with the rise of the temperature, and it became about  $10^{-11}$  S/m in about 100°C. Therefore, it was considered that it is easy to flow to the leakage current in PET copolymer than PLA.

**Breakdown strength** Fig. 7 shows the temperature dependence of dielectric breakdown strength (BDS). BDS of PLA at the room temperature became about 5.5 MV/cm, and was higher than that of PET copolymer and LDPE. Moreover, BDS of PET copolymer was a tendency to look like LDPE. When it became the high temperature of  $T_g$  ( $=60^\circ\text{C}$ ) or more, BDS of PLA was higher than that of other samples though it decreased. From the temperature dependence of tensile strength in Fig.5, tensile strength was decreased when the temperature rises, and from the temperature dependence of  $\sigma$  in Fig.6,  $\sigma$  of PLA rises more than  $T_g$  in the high temperature region. That is, it was guessed that a molecular movement in an amorphous region is opened by becoming the high temperature of  $T_g$  or more and it changes into the state of rubber, and the rise of the electric conductivity and the decrease in mechanical strength are caused. Therefore, it was considered that the free volume breakdown. In addition, the softening point ( $=60^\circ\text{C}$ ) of PLA is exceeded and it was thought that electromechanical breakdown is caused because the Maxwell stress acts easily [8]. The influence of the heat breakdown caused by locally the temperature of the sample rising by the energy injected by the electric field, and melting and resolving it is thought, too. On the other hand, BDS of PET copolymer was a tendency to look like LDPE from the room temperature to the high temperature region. Therefore, insulating properties of PLA was superior to that of PET copolymer and LDPE within the wide range of the temperature, and it was thought that PET copolymer is like to LDPE. It is

reported that the impulse breakdown strength of PLA was 1.3 times that of XLPE [9].

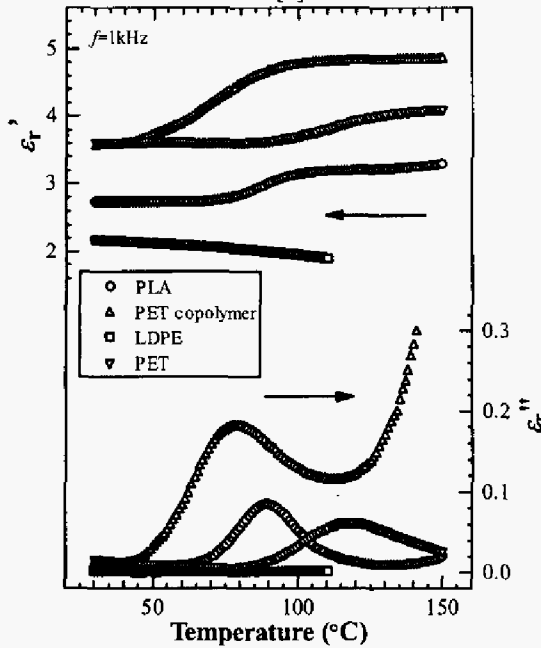


Fig. 8 Temperature dependence of  $\epsilon'$  and  $\epsilon''$

**Dielectric properties** Fig. 8 shows the temperature dependence of  $\epsilon'$  and  $\epsilon''$ . In the case of the room temperature,  $\epsilon'$  of PLA was about 2.7, and it was lower than that of PET and PET copolymer though it was higher than LDPE. On the other hand, the  $\epsilon'$  of PET copolymer became about 3.6, and was almost the same as PET. Therefore, it was thought that the amount of the polarization at the room temperature is LDPE < PLA < PET copolymer  $\approx$  PET.  $\epsilon'$  of PLA began to increase from about 70°C, and the rate of increase became gradual from about 100°C.  $\epsilon'$  of PET copolymer began to increase from about 40°C, and the rate of increase became gradual from about 100°C. That is, because  $\epsilon'$  increases about  $T_g$ , the change is thought to be attributable to dipole orientations resulting from the micro-Brownian motion, and thermal orientations seem to be disturbed by thermal agitation at about 100°C or higher. Moreover,  $\epsilon'$  of PET copolymer increases from about 40°C more than PET, and is thought to be a rapid increase of the amount of the polarization of PET copolymer when the temperature rises.

$\epsilon''$  of PLA hardly changes from room temperature to about 60°C, but it increases from 60°C and an absorption peak appears at about 90°C.  $\epsilon''$  of PET copolymer increases from 40°C and an absorption peak appears at about 80°C. Since this peak appears above  $T_g$ , it may be due to  $\alpha$  absorption. In addition, the maximum value of the peak ( $\epsilon''_m$ ) was PET copolymer > PLA > PET, and it was thought that the energy loss

when the AC electric field is applied to the dielectrics is small in this order.  $\epsilon''$  of PET copolymer increased rapidly from about 120°C again. From the temperature dependence of  $\sigma$  in Fig.6,  $\sigma$  of PET copolymer increased rapidly with the rise of the temperature than other samples. That is, PET copolymer was guessed that the ionic conduction is caused easily, the ion is accumulated on the electrode field side more than 120°C at the high temperature, and the space charge polarization is caused.

## CONCLUSIONS

We examined the mechanical and electrical properties as well as physicochemical analysis of PLA and PET copolymer that is biodegradable plastics. The results are as follows:

1. From the DSC spectra,  $T_g$  of PLA derived was about 60°C, and PET copolymer was about 54°C. In addition,  $T_m$  of PLA derived was about 168°C, and PET copolymer was about 203°C.
2. The decreasing rate of tensile strength of PET copolymer became a tendency to look like PP, and was more gradual than the decreasing rate of PLA.
3. The rise of electric conductivity ( $\sigma$ ) of PLA according to the rise in heat was not caused easily from PET copolymer.
4. Dielectric breakdown strength of PLA was high within the range of the temperature that was wider than that of the PET copolymer and LDPE.
5.  $\epsilon'$  was LDPE < PLA < PET copolymer  $\approx$  PET, and the maximum value of the peak ( $\epsilon''_m$ ) was PET copolymer > PLA > PET.

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