Development of the Electro-Friction Effect in the Semiconductor Particles / Thermoplastic Resin Composite Film

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ABSTRACT

Electrorheological particles (ERP) as the semiconductor particulate were distributed into polypropylene (PP) resin and formed into composite films by vacuum-press. The ERP had the cluster structures in PP matrix resembling those formed in electrorheological fluids (ERF) in an electric field. When an electric field was applied to the films, electric flux lines dragged into the clusters leading to a suction force between the electrode and the clusters. The effect was named "Electro-Friction" (EF) effect.

The friction force increased with increasing the amount of filling ERP. When the ERP content was 50 wt%, the particles were considered to reach the percolation threshold, providing the continuous particle cluster in ER fluids. It was found that some addition of nano-needles of tin oxide (TO) to the film increased the electroconductivity with enhancing EF effect. A very strong friction force as much as 19.3 N was observed at the applied voltage of 1400 V for the film composed of PP 47% / ERP 47% / TO 6%.

Keywords: electro-friction effect, electrorheological particle, polypropyrene, tin oxide, applied voltage

1 INTRODUCTION

Over the past few decades a great deal of research has been carried out on smart materials. These are generally materials that respond in a predictable and controllable way to an external stimulus. Smart fluids in the form of electrorheological (ER) fluids are among the most spectacular of the smart materials. They are capable of changing viscosity (rheology) reversibly by an order of up to 100,000 in response to an electric field. For example, a typical ER fluid can go from the consistency of a liquid to that of a gel, and back, with response times on the order of milliseconds, which is called the ER effect. The ER effect was discovered in the late 1940s by Winslow [1]. In response to the electric field, ER fluids rapidly solidify, or at least increase their viscosity dramatically. Such a millisecond response of ER fluid is a subject of great interest because of many possible industrial applications, especially in the automotive and aerospace industries, for field-controllable fluids such as practical fast electro-mechanical actuators.

ER fluids usually consist of fine dielectric particles suspended in a liquid of low dielectric constant. The large contrast of dielectric constant between the particles and the liquid makes the ER system easily polarizable in an electric field. When an electric field is applied to ER fluids the induced particle dipoles create a long-range interaction that causes them to chain along the field direction and form complex column-like clusters [2]. Meanwhile, electric flux lines dragged into the clusters leading to a suction force between the electrode and the clusters. In this study, the cluster structures have been formed in a polymer matrix providing a novel "Electro Friction" (EF) effect material that gives variable friction force at the interface with electro-conductivity material under the controlled applied voltage.

In this study, ER particles (ERP) as the semiconductor particulate are distributed into polypropylene (PP) resin and formed into composite films by vacuum-press. The obtained films were exposed to an electric field to examine the change in frictional force.

2 EXPERIMENT

2.1 Preparation of PP-ERP composite powder

In order to distribute the semiconductor particles into the resin, the particles were mixed with the polymer solution and dried up. At first, polypropylene (PP) was heated in xylene with stirring at the concentration of 15 wt% so that PP can be dissolved. The oil bath temperature was 135 ºC. After PP was dissolved, the electrorheological particles (ERP) which was supplied by Fujikura Kasei Co. Ltd. were added into the solution (the contents of ERP were 40, 45 and 50 wt% of the composites) and stirred for two hours. In case the ERP content was 50 wt%, the third component, i.e. nano-needles of tin oxide (TO) were also added. TO was ca. 2 μm in length, nanometers in diameter, with density of 6.51 g/cm^3 and resistivity of 1 Ωm. The suspension was poured into trays and dried up. Finally, the dry films were pulverized into fine powder.

2.2 Preparation of PP-ERP composite film

The composite powder was set between polyimide sheets and formed into films by vacuum-press. First of all, the temperature of the upper plate and lower plate of the vacuum-press was set to 210 ºC. The composite powder was loaded in the frame (70 × 40 × 0.3 mm) and inserted between polyimide sheets. They were placed on the lower plate of vacuum-press and the chamber pressure was reduced to 0.1 MPa. The powder was immediately melted and pressed at 10 MPa to eliminate the internal gas in the composite, and soon the pressure was released. Then the pressure was maintained at 30 MPa for 5 minutes followed by the cooling with keeping the pressure at 30 MPa. After the temperature of the plate decreased to 50 ºC (about 3 minutes), the vacuum was released.

2.3 Measurement of friction force

To investigate the EF effect, the friction force of the film was measured. The films were placed between the electrodes on the horizontal board. The friction force was measured by sliding the upper electrode with varying the applied voltage from 0 to 1500 V. The DC power source was Glassman HighVoltage EL50P08. The friction measurement conditions were as follows: the contact area between the upper electrode and film was 40 × 55 mm, the load on the upper electrode was 50 g. The current values were also monitored with using a Sanwa digital multimeter CD772.

3 RESULTS AND DISCUSSION

The increment of friction force with applied voltage is shown in figure 1. The friction force increases with increasing the amount of filling ERP. When the ERP content is 50 wt%, the particles are considered to reach the percolation threshold, which is the formation of long-range connectivity in random systems. Then the ERP are contacted with each other to a certain extent depending on the content producing the electro-conducting path, which corresponds to the particle cluster in ER fluids.

According to ER fluids literature, conductivity of particles also has a strong influence on ER performance. H. Tian studied that the strongest ER effect was found to occur at the conductivity about 10^{-7} S/cm [3]. The effect of the particle conductivity on the ER activity was also theoretically analyzed. A conduction model was presented for understanding ER mechanism [4]. This explanation lead to an assumption that the composite film with many electro-conducting paths will show a strong EF effect. The composite film composed of ERP, PP and SnO_2 needle powder (TO, 2 μm long with nanometer order diameter) was prepared. The composite film composed of 4.7 g ERP, 4.7 g PP and 0.6 g TO showed a very strong friction force as much as 19.3 N at the applied voltage of 1400 V as shown in figure 1. It was also proved that the electric current under applied voltage increased remarkably for the composite films with TO as shown in figure 2.

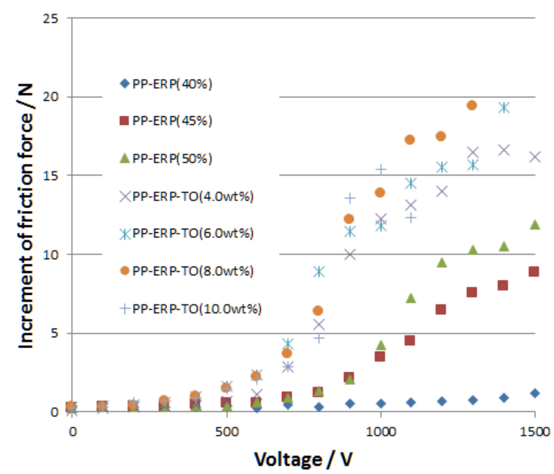

Figure 1: Increment in electro-friction of ERP/PP composite film with applied voltage.

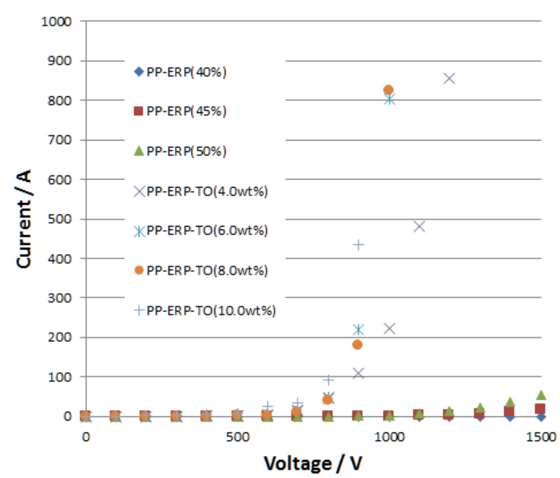

Figure 2: Increment in current value of ERP/PP composite film with applied voltage.

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