EFFECT OF ALTERNATING ELECTRIC FIELD INTENSITY ON ADHESION OF THERMOPLASTIC RESIN

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ABSTRACT

This research shows adhesion strength of thermoplastic resin under different electric field. Usage of electric field is new solution in stamping manufacturing to control adhesion of Thermoplastic Carbon-Fiber-Reinforced Polymer. When AC 100 V was imposed to metal specimen, adhesion strength was 0.68 MPa to 1.37 MPa. The values varied from 0.72 MPa to 1.28 MPa when AC 300 V was imposed. Difference of adhesion force in same bias came from difference of frequency of electric field. This result indicates that lower intensity of alternating current field achieves same level adhesion strength despite lower energy power supply which is able to save energy cost.

Keywords: thermoplastic CFRP, CFRTP, alternating electric field, mold, stamping.

INTRODUCTION

It is strongly required to reduce weight of automotive vehicles which is one of the most effective way to improve fuel consumption because there will be new regulation for reducing CO\(_2\) gas emission. Carbon-Fiber-Reinforced Thermoplastic (Thermoplastic CFRP) is considered as next generation material in automotive vehicles because of its lightness as well as mechanical strength. Therefore new methods for producing Thermoplastic CFRP is being developed. Stamping is an effective method which is widely used in many industrial fields because it can achieve short-cycle time manufacturing. Long Fiber reinforced Thermoplastic by Direct compounding (LFT-D) method, which is one of stamping methods for Thermoplastic CFRP, have been developed for achieving one minute manufacturing (Oliver, 2006). In LFT-D method, controlling adhesion of thermoplastic resin is important to produce Thermoplastic CFRP which has smooth surface and high mechanical strength.

When thermoplastic resin and carbon fiber have week bonding, the Thermoplastic CFRP shows less strength than expected. On the other hand, when resin has strong adhesion on metal mold, surface quality and cycle-time of manufacturing is affected. Increasing adhesion between resin and carbon fiber generally makes adhesion between resin and mold strong. Methods using alternating current electric field has been developed in tribology field for controlling friction (Fujisawa, 1999). In the report, authors tested friction between mica surface and Si\(_3\)N\(_4\) imposed alternating current electric field. Their results indicated that electrical field changed electrical potential on surface and control friction. It is known that electrical potential energy on dielectric material could be changed by electrical field. There is possibility for controlling adhesion of thermoplastic resin. In this report, alternating current electric field was imposed on metal specimen for controlling adhesion of thermoplastic resin and we showed the possibility of using AC electric field in stamping process.
EXPERIMENT

Equipment and Material

Fig. 1 shows schematics of equipment which measures adhesion strength of thermoplastic resin in high temperature. A holder of metal specimens were set attached to the slider which moved upward or downward by the actuator. Temperature of metal specimens were controlled by applying constant electric current. Load on polymer specimens were detected by a load cell. Polymer specimens were fixed by the holder of polymer which shape was like clip.

Table 1 shows material properties of Acrylic resin of which adhesion strength was tested in this report. Polymer specimens were cleaned by ultrasonic cleaning in ethanol for one minute. SUS304 was selected as material of metal specimens. Metal specimens were cleaned by ultrasonic cleaning in ethanol for fifteen minutes firstly. Secondly, ultrasonic cleaning in acetone was applied for fifteen minutes.

![Fig. 1 - Schematic images of adhesion test equipment](image)

Table 1 - Properties of Acrylic resin

<table>
<thead>
<tr>
<th>Glassy-transition temperature $T_g$, °C</th>
<th>Young's modulus $E$, GPa</th>
<th>Tensile strength $t$, MPa</th>
<th>Density $d$, g/cm³</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>3.2</td>
<td>75</td>
<td>1.2</td>
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</table>

Method

As preparation of adhesion test, the heater was turned on and its power was controlled to keep temperature of metal specimens at 128°C. Then electric field was imposed on metal specimens. In next sequence, the actuator moved the slider downwards until a metal specimen was pushed to a polymer specimen. When the load cell detected 3 N press load, actuator stopped its rotation and kept slider position for 5 seconds. After 5 seconds, actuator rose slider up and detached the metal specimen from the polymer specimen. Speed of slider was 0.1
mm/s in all sequences. This equipment obtained reproducible results because every sequence were controlled by computers and electric circuits.

After finishing adhesion test, force-displacement curves like Fig. 2 were obtained. Adhesion strength was calculated from dividing maximum adhesion force by contact area. Contact area was considered as the area where color of polymer changed.

![Force-displacement curve](image)

**Fig. 2** - This is a force-displacement curve at 146°C. Minus and plus values of load indicates press force and pulling force on a polymer specimen, respectively.

**Electric Field**

Four types of electric fields were imposed on metal specimen. In one condition, there was no electric field which was conventional mold condition. Second type was DC -300 V condition under which -300 V bias was imposed on metal specimens. Third type was AC 100 V condition. The other type was AC 300 V condition. About AC 100 V and AC 300 V condition, frequency of alternating current was varied from 1 Hz to 2 MHz.

**RESULTS**

The results from the adhesion tests are shown in Fig. 3. In wide range of frequency, adhesion strength in alternating current field is higher than that of -300 V direct current field. The maximum adhesion strength under AC 100 V was 1.37 MPa when the current frequency was 900 Hz. The case of AC 300 V, maximum adhesion strength was 1.28 MPa when the frequency was 500 MHz. The minimum value under AC 100 V and AC 300 V were 0.68 MPa and 0.72 MPa which are same adhesion strength under DC -300 V, respectively.

**DISCUSSION**

Fig. 3 shows dielectric response of Acrylic resin at 128°C. Fujisawa showed that imposing stronger electric field was a domestic factor increasing surface interaction (Fujisawa, 1999). In our result, maximum and minimum adhesion force in AC 100 V and AC 300 V are same level, respectively, although both adhesion strength was varied as frequency changed. This result indicates that low bias can achieve same level of adhesion strength of higher bias if
frequency is controlled properly. Lower bias consumes less energy and requires smaller equipment which can save space in factories. This indicates that AC electrical field can control adhesion force effectively saving cost. In the future work, it is required to clarify the relation between alternating current frequency and dielectric constant which shows the mechanism of result in Fig. 3.

CONCLUSION

This study clarified effect of alternating current electric field on adhesion strength between Acrylic resin and metal. Adhesion strength varied in different frequency of alternating current and intensity of electric bias. Main results are following:

(i) Adhesion strength was varied from 0.68 MPa to 1.37 MPa under 100 V electric alternating current field in different frequency. The maximum and minimum adhesion strength were observed when frequency were 900 Hz and 50 MHz, respectively.

(ii) Adhesion strength was varied from 0.72 MPa to 1.28 MPa under 300 V electric alternating current field in different frequency. The maximum and minimum adhesion strength were observed when frequency were 500 MHz and 10 Hz, respectively.

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REFERENCES
