ADHESIVE PROPERTY OF INSERT-INJECTION MOLDED GLASS FIBER REINFORCED THERMOPLASTICS

C. Wang\textsuperscript{1}, Y. Nagao\textsuperscript{2}, Y. Yang\textsuperscript{3*}, and H. Hamada\textsuperscript{1}

\textsuperscript{1}Advanced Fibro Science, Kyoto Institute of Technology, Kyoto, Japan  
\textsuperscript{2}Yamamoto Co., Ltd, Hiroshima, Japan  
\textsuperscript{3}College of Textiles, Donghua University, Shanghai, China  
* amy_yuqiu_yang@dhu.edu.cn

ABSTRACT

In this research, a new kind of joint method called “insert-injection moulding” is presented and the adhesive dumbbell samples with different length of adhesive interface were obtained. The Instron universal test machine with temperature chamber was adopted in order to investigate the effect of test temperature on the mechanical property of adhesive samples. And the samples were tested at three kinds of temperature i.e. 40, 60 and 80 °C. Surfaces morphology of FRP part of adhesive samples before and after tensile were observed by scanning electron microscope (SEM). It is found that the tensile strength shows increasing trend with increasing the length of adhesive interface. When the test temperature increases, the maximum load of both PP and PC shows the decreasing trend. But for the failure displacement, PP samples show increasing trend while PC samples does not show the significant changes.

Keywords: insert-injection molding, adhesive property, adhesive length, test temperature,

Introduction

Fibre-reinforced polymer (FRP) composites are applied more and more widely such as in automobiles, aerospace, marine and many other industries due to the advantages they provide in performance, structural efficiency and cost. During usage process of fiber reinforced polymer composites, joints are usually needed to connect different parts of structure. The joint can be divided into 3 types: pinned or bolted joints known as mechanically fastened joint, adhesively bonded joints and the combination one [1-4]. Mechanical fastening remains the primary means of joining composite components in modern aircraft structures, even though bolted joints are relatively inefficient. The stress concentration due to the hole causes a considerable reduction in both the notched tensile and compressive strength of a composite laminate. Experience with bolted joints in composite structures for aerospace applications has indicated a high level of complexity in joint design, due to the almost unlimited combinations of composite materials and fibre patterns and the fact that bolted joints in composites fail at loads that are not predicted by either perfectly elastic or perfectly plastic assumptions[5]. Bonded joint has advantage in low weight and good sealing to the structure, but it needs good condition of connecting surface and brings out some negative effects on environment.
In this study, a new kind of joint method called “insert-injection molding” is established. Firstly, the dumbbell samples of injection molded fiber reinforced polymer were cut into half dumbbell shape. Secondly, the cross-sections of half dumbbell parts were polished to get the slope of different length. Thirdly, the half dumbbell parts were inserted into cavity of dumbbell shape and then melt polymer was injected. After cooling down, the adhesive dumbbell samples were obtained. The Instron universal test machine with temperature chamber was adopted in order to investigate the effect of test temperature on the mechanical property of adhesive samples. And the samples were tested at three kinds of temperature i.e. 40, 60 and 80 °C. The surface morphology of FRP part before and after tensile was observed by scanning electron microscope (SEM).

**Fabrication of Samples**

In this research, the glass fiber reinforced polypropylene (GF/PP, R250G, Prime Polymer Co., Ltd) and glass fiber reinforced polycarbonate (GF/PC, GS2020MN1, Mitsubishi Engineering Plastic Co., Ltd) were used to fabricate dumbbell samples by injection molding technology. As shown in the figure 1, the dumbbells were cut into half dumbbell shape. And then different length of adhesive interface i.e. 5mm, 10mm and 15mm was polished by the polishing machine. Subsequently, the half dumbbell of GF/PP was pre-inserted into the mold cavity and the melt polypropylene (PP, J2021GR, Prime Polymer Co., Ltd) resin was injected into the cavity. After cooling, the adhesive dumbbell was obtained. Using same method, the half dumbbell of GF/PC was pre-inserted and the melt polycarbonate (PC, S3000, Mitsubishi Engineering Plastic Co., Ltd) resin was injected into cavity. POYUEN 55T injection molding machine was used to mold dumbbell samples and the barrel temperature is 250 °C for PP and 300°C for PC, mold temperature is 50°C for PP and 90 °C for PC, holding pressure is 44MPa for PP and 88MPa for PC, respectively. The cooling time of all samples is 15s. The samples were shown in figure 2.

Fig.1 Schematic of insert injection molding
Experiments

The Instron universal test machine with the temperature chamber was used to carry out tensile test. Temperature of chamber was set as 40, 60 and 80°C separately and samples were kept in the chamber for 1 hour and then tensioned at the speed of 1mm/min. The thermal property of neat PP and neat PC was measured by the differential scanning calorimeter (DSC, Instrument 2920 MDSC V2.6A). Temperature rank of heating is from 25-200°C for PP resins and 25-330°C for PC resins. The surface morphology of FRP part before and after tensile was observed by scanning electron microscope (SEM).

Results and Discussions

Effect of Length of Adhesive Interface on the Adhesive Property

Fig. 3 Load-displacement curves of adhesive samples at different test temperature
After tensile test, the tensile results were shown in figure 3 and 4. The tensile strength was calculated by the following equation

$$\sigma = \frac{L}{A}$$ (1)

where $L$ is maximum load; $A$ is area of cross-section of samples; $\sigma$ is the tensile strength.

In figure 4, it is found that the tensile strength of both PP and PC samples shows increasing trend and PC samples shows more significant increase when increase the length of adhesive interface. It was thought that with increasing the length of length of adhesive interface, the area of adhesive interface also increased and there would be more interaction effect of molecular such as Van der Waals’ Force in the interface. As a result, the tensile strength increased with increasing the length of adhesive interface. Comparing to PP molecular, PC has more branch molecular and higher molecular weight, which lead to more molecular entanglement and molecular attraction, as a result, the maximum load of PC shows much higher improvement than that of PP.

In fact, both shear effect and stretch effect exist in the interface of the adhesive dumbbell samples and the schematic of load analysis in the adhesive interface is shown in figure 5. The adhesive normal strength and adhesive shear strength can be calculated with following equation:

$$\sigma_n = \frac{L_n}{S} \quad (3) \quad \sigma_s = \frac{L_s}{S} \quad (4)$$

$\sigma_n$, $\sigma_s$ is the adhesive normal strength and adhesive shear strength, respectively. $L_n$, $L_s$ is the adhesive normal load and adhesive shear load. $S$ is the area of adhesive interface.

Fig.5 The schematic of load analysis in the adhesive interface
As shown in figure 6a, the adhesive normal strength decreases significantly for both PP and PC samples with the increasing of adhesive length. As shown in figure 6b, when the length of adhesive interface increased, the adhesive shear strength increases for PC but decreases for PP, which may result from better resistant property of PC samples to shear effect.

Effect of Test Temperature of Adhesive Interface on the Adhesive Property

Maximum load and failure displacement at different test temperature are shown in the figure 7. When the test temperature increases, the maximum load of PP and PC (Fig. 7a and b) shows the decreasing trend. At the same time, the failure displacement of PP (Fig. 7c) shows increasing trend while the failure displacement of PC (Fig. 7d) does not show the significant change. It is thought that the glass transition temperature (Tg) of polymer plays important role on the displacement of samples when test temperature increases and polymer would become soft and show viscoelastic property when the temperature increases over the glass transition temperature. Therefore, the thermal property of PP and PC resins used for the adhesive part were measured by DSC test and the results were shown in figure 8. It is found that The Tg point of rigid PP cannot be seen from the curves, which indicates that the Tg point of the PP resin is lower than 25°C (room temperature). As a result, the displacement of PP samples increases a lot when test temperature increases from 40 to 80°C. However, the Tg point of the PC resin is up to 150°C. That is the reason why the displacement of PC samples hardly change when test temperature increases from 40 to 80°C.
Observation of Fracture Surface after tensile test

The surface of FRP part of samples before tensile test and after tensile test was observed by the SEM observation. As shown in the figure 8, there are some gaps in the surface of both GF/PP (Fig.9a) and GF/PC (Fig.9c) before test due to the polishing effect, which could contribute to the adhesive strength by producing interlock effect. After tensile test, a lot of residual PP resins in the
surface of GF/PP (Fig. 9b) part but very few residual PC (Fig. 9d) resin can be seen in the surface of GF/PC part.

Fig. 9 Surface morphology of FRP part: a) GF/PP before test; b) GF/PP after test; c) GF/PC before test and d) GF/PC after test

**Conclusions**

In this research, a new kind of joint method i.e. “insert-injection molding” is established. The adhesive samples PP-GF/PP and PC-GF/PC were fabricated by the insert-injection molding technology. The effect of different length of adhesive interface and test temperature on the mechanical property was investigated based on the tensile test and SEM observation and conclusions can be summarized as following:

1) It is found that the tensile strength of both PP and PC samples shows increasing trend and PC samples shows more significant increase when increase the length of adhesive interface.

2) When the test temperature increases, the maximum load of PP and PC shows the decreasing trend. At the same time, the failure displacement of PP shows increasing trend while the failure displacement of PC does not show the significant change.

3) SEM observation shows different morphology of PP-GF/PP and PC-GF/PC after tensile test. There is a lot of residual PP resins in the surface of GF/PP part but very few residual PC resin can be seen in the surface of GF/PC part.

**References**


