STUDY OF PRODUCTION STABILITY IN DFFIM

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Abstract

Direct fiber feeding injection molding (DFFIM) process is an alternative method for producing long fiber reinforced polymer composites. The reinforcing fiber was feeding to compound with melted polymer at vented of injection molding barrel. In this research, two types of glass fiber (GF) were injected with recycled (polyethylene terephthalate) (RPET) matrix by DFFIM. The effect of GF types and matrix feeding speed on fiber content and mechanical properties of RPET/GF composites was investigated. Additionally, the effect of short and long term processing was researched. Fiber contents were varied according to types of GF and number of GF roving as well as controlling matrix feeding speed. Tensile modulus and tensile strength of the RPET/GF composites increased with increasing GF contents. It can be noted that the fiber content and tensile properties of the RPET/GF composites with DFFIM process were steadily with long term processing.

Introduction

Fiber reinforced thermoplastic composites (FRTP) is widely applied in construction, automotive and aerospace. Mechanical properties of FRTP are depended on fiber length, fiber contents, adhesion and dispersion of fiber on polymer matrix. It has been known that mechanical performance of the composites increase with increasing fiber length and fiber contents [1-3]. However, conventional injection molding is fabricated short fiber reinforced composites.

Direct fiber feeding injection molding (DFFIM) is a development process, which fiber is fed directly to injection barrel at vented hole as shown in Figure 1. Various parameters can be set in order to control fiber length, fiber content, fiber dispersion in the composites i.e. matrix feeding speed and number of fiber roving [4]. Vented hole of DFFIM is not only for feeding fiber but also used for releasing volatile gas during fabrication process. Hence, DFFIM process can be produced long fiber reinforced polymer composites with as well as prevented defects from volatile materials during polymer melted.

Figure 1: Schematic of direct fiber feeding injection molding (DFFIM) [4]
The stability of DFFIM process is focused for providing continuous production. In this research, recycled poly(ethylene terephthalate) (RPET) was used as the matrix resin. Glass fibers (GF) as reinforcement were fed to DFFIM process. The effect of fibers type, number of fiber roving and matrix feeding speed on properties of RPET/GF composites was carried out. Moreover, injected number and time for injection molded were investigated for understanding stability of DFFIM process.

**Experimental**

**Materials**

Recycled poly(ethylene terephthalate) (RPET) was provided by Negoro Sangyo Co., Ltd., Japan. Glass fibers (GF) (EX-1844) were supplied from Nippon Electric Glass Co., Ltd., Japan. Two types of GF were 1200 Tex and 2400 Tex, which are referred as L and H, respectively.

**Sample Preparation: step I Effect of Fiber Types and Feeding Speed**

RPET was dried before injection molding at 115 °C in an oven for at least 8 h. RPET and GF (L and H) were molded to dumbbell specimen with 4 mm in thickness using DFFIM (SE75DUZ-C110, Sumitomo Heavy Industries, Ltd., Japan). Vented screw (Nihon Yuki Co., Ltd., Japan) diameter was 28 mm. The barrel temperatures before vented area were 260-280 °C and after vented area were 250-270 °C. The molding temperature was 60 °C. Table 1 shows materials and processing conditions for fabrication.

**Table I: Materials and matrix feeding speed.**

<table>
<thead>
<tr>
<th>Matrix</th>
<th>Glass fiber</th>
<th>No. of roving</th>
<th>Matrix feeding speed (rpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPET</td>
<td>1200 Tex (L)</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>2400 Tex (H)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

**Sample Preparation: step II Stability of DFFIM Process**

1. DFFIM was cleaned and shutdown. The injection molding was restarted. Dried RPET and GF with 2400 Tex were injection molded using the similar condition of step I. 20 dumbbell specimens were collected from this step. The 20 specimens were collected again after 1 h.

2. Dried RPET and GF with 1200 Tex were process by DFFIM. 10 dumbbell specimens were collected every 1 h of 7 h processing.

**Characterization**

Fiber contents and fiber distribution was measured by using optical microscope and ImageJ program. Middle of dumbbell specimens were cut and burnt in an electric furnace at 600 °C for 6 h. The remaining of GF was spread on microscope glass slide and observed fiber contents and fiber dispersion.

Tensile test was carried out with according to ASTM D638 by Instron universal testing machine (Instron 4206, USA). The testing speed was 1 mm/min.

Scanning electron microscope (SEM) (JSM5200, JEOL, Japan) was used to observe morphology of specimens.
Results and Discussion

Step I Effect of Fiber Types and Feeding Speed

The effect of fiber types and matrix feeding speed on fiber content in the composites is shown in Table 2. The GF contents were about 16 wt%-55 wt% at different of matrix feeding speeds and types of GF as well as number of GF roving. The GF contents increased when increasing number of GF roving and decreased the matrix feeding speed with regardless on types of GF. After observing by optical microscope and ImageJ program, fiber contents and average length of GF in the composites were around 0.3 mm-0.6 mm in both L and H types of GF as presented in Figure 2. It can be seen that fiber length decreased with increasing content of GF in the composites as presented in Figure 2 (b). It indicated that fiber breakage was easily occurred at higher content of GF.

Table 2: Effect of types of fiber and matrix feeding speed on GF content in the composites.

<table>
<thead>
<tr>
<th>Matrix</th>
<th>Glass fiber</th>
<th>No. of roving</th>
<th>GF content (wt%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Matrix feeding speed (rpm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>RPET</td>
<td>1200 Tex (L)</td>
<td>1</td>
<td>34.9 (±2.4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>46.1 (±0.1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>55.2 (±1.1)</td>
</tr>
<tr>
<td></td>
<td>2400 Tex (H)</td>
<td>1</td>
<td>49.0 (±2.0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>52.7 (±1.4)</td>
</tr>
</tbody>
</table>

Figure 2: (a) Fiber length distribution and (b) fiber length and fiber content in the composites.

Figure 3 presented tensile modulus and tensile strength of the RPET/GF composites from DFFIM. Both tensile modulus and tensile strength significantly increased with increasing GF contents as shown in Figure 3 (a) and (b), respectively. It was attributed to stiffness of GF enhance tensile modulus of the composites. Likewise, GF exhibited reinforcing ability with resulting in increased tensile strength of the composites, which was due to good adhesion between GF and the REPT matrix. Figure 4 shows SEM photographs of the RPET/GF composites, which represented good adhesion between GF and RPET matrix. From the results, we would select type of GF and number of roving in order to obtain suitable GF contents in the RPET/GF composites with DFFIM process.
Figure 3: Effect of fiber contents on tensile properties (a) Tensile modulus and (b) Tensile strength.

Figure 4: SEM photographs of RPET/GF composites (a) GF 1200 Tex and (b) GF 2400 Tex.

Step II Stability of DFFIM Process

Short term stability

The effect of injected specimen on fiber content and tensile properties of the RPET/GF composites is presented in Figure 5 and Figure 6, respectively. At starting of DFFIM process, fiber contents were stable when specimens were injected around 5 specimens. On the other hand, the GF content was more stable after processing for 1 h. Figure 5 depicts tensile modulus and tensile strength of the composites after collecting specimens with different times. It can be seen that tensile modulus and tensile strength were unstable at the beginning of injection process while both values were almost unchanged after injected around 5 specimens and after processing for 1 h. Therefore, DFFIM specimen should be discarded about 5 specimens before continuous collecting specimens.

Long term stability

In this study, the composites were continuous injection molded for 7 h. After collecting the specimens every 1 h, it can be seen that fiber content was constant with long term processing as presented in Figure 7. In addition, tensile modulus and tensile strength were steadily as illustrated in Figure 8. It was informed that fiber contents as well as tensile properties of the composites were acceptable for long term process as well as for a mass production.
Figure 5: Fiber contents of short term stability in DFFIM.

![Graph showing fiber content (wt%)](image)

Figure 6: (a) Tensile modulus and (b) Tensile strength of short term stability in DFFIM.

![Graph showing tensile modulus and strength](image)

Figure 7: Fiber content of long term stability in DFFIM.

![Graph showing fiber content over time](image)
Figure 8: (a) Tensile modulus and (b) Tensile strength of long term stability in DFFIM.

Conclusions

This study provided information of DFFIM process for fiber reinforced polymer composites. The composunding was discarded. The content of GF was controlled by the matrix feeding speed and number of fiber roving as well as types of fibers. Tensile modulus and tensile strength of the composites significantly increased when increasing fiber contents. However, fiber breakage was found at higher fiber contents. The short term processing informed that 5 specimens should be rejected after starting DFFIM process. On the other hand, fiber content and tensile properties of the composites were stable after 1 h processing and with long term injection molded. Hence, DFFIM process is useful for fabricated long fiber reinforced composites and long term production.

Bibliography