Mechanical properties of FRTP using hybrid fabrics and \textit{in situ} polymerizable polyamide6 with VaRTM

In this paper, a fabrication method of hybrid fibers reinforced with thermoplastics using \textit{in situ} polymerizable polyamide 6 is presented. The carbon/glass hybrid FRTP (referred as HFRTP hereinafter) by fabrication a method of VaRTM has no voids and unfilled parts because ε-caprolactam has very low viscosity before polymerization. This HFRTP not only exhibits superior bending properties, but also is suitable for high-speed molding, namely within one minute process time because it can be released from the mold without a cooling process.

Introduction

Thermoplastics can be re-melting and re-molding by heating. This means that they can be easily remanufactured and remolded into a higher strength of fibers reinforced thermoplastic (FRTP), it must be developed by using continuous fibers and increasing their content. However, such FRTP cannot be easily fabricated. The thermoplastic resins as the matrix of FRTP, are high polymers that remain highly viscous even at a higher temperature than their melting points. As a result, they need a higher temperature, a higher pressure and longer process time to allow them to bond with fibers.

The methods of the FRTP containing a larger amount of continuous fibers have been studied\cite{1} . One approach for this purpose is using \textit{in situ} polymerizable polyamide 6 as the matrix. This \textit{in situ} polymerizable polyamide 6 was obtained by using aromatic ring opening polymerization, \textit{ε}-Caprolactam. One of authors in this paper developed a system by using \textit{in situ} polymerizable polyamide 6. They had no voids and unfilled parts because the caprolactam had very low viscosity before polymerization. Furthermore, these FRTPs not only exhibited superior mechanical properties, but also was suitable for high-speed molding, namely within one minute process time because it could be released from the mold without a cooling process. In order to apply the HFRTP for the wider area, carbon/glass hybrid fabrics were used as the reinforcement and the \textit{in situ} polymerizable polyamide 6 as the matrix were fabricated with the VaRTM. Moreover, the relationships of their mechanical properties with the process conditions were reported here.

Fabrication

Matrix and Reinforcement

The used matrix was the \textit{ε}-caprolactam opening polymerizing a monomer of \textit{ε}-Caprolactam with a sodium salt of \textit{ε}-Caprolactam as a catalyst and methylhexyl disioccurate (HMDS) as an activator. Table 1 shows a viscosity of the \textit{ε}-Caprolactam and the initiator. The reinforcements were made of carbon fibers and plain woven textiles of glass fibers. The carbon fabric had 125 tex / 25 mm in both the directions of the warp and the weft and its thickness was 0.21 mm. The thickness of the glass fabric was 0.23 mm and the fabric density was 25 tex per 25 mm for both directions of the warp and the weft. The carbon fabrics were washed with acetone in order to remove Cabosil of the binding agent before the molding because this agent gave the bad effect on the hardening of \textit{ε}-Caprolactam.

Molding method

The catalyst for \textit{ε}-caprolactam polymerization is a sodium salt of \textit{ε}-Caprolactam. In the case of \textit{ε}-Caprolactam molding, the \textit{ε}-Caprolactam is opened with a catalyst and the monomer was polymerized. This study selected the VaRTM method. Figure 1 show a schematic view of the VaRTM molding system and a photograph of the experimental apparatus.

Experiment

Axis flow testing

In order to investigate the relationship between the molding temperature and the reinfow distance until the curing, the resin flow test was executed under the temperatures (140, 160, 180, and 200°C). In the Figure 4, the flow distance in the HFRTP became smaller according to an increase of molding temperature because a reaction of the resin became to be quickly cure state due to the higher temperature.

Three point bending test

In order to evaluate the bending properties of the HFRTP, a three point bending test was executed. The specimen had a thickness of 3 mm, a width of 10 mm and a span length of 80 mm. Figure 5 shows the representative stress-strain relations of the C/FRTP, the GR/FRTP and the HFRTP at the molding temperature of 140°C. Both of the C/FRTP and GR/FRTP were also fabricated with CF fabrics alone and GF fabrics alone, respectively. The stress of the HFRTP increased approximately linearly with the strain and the value of failure strain was same as of the C/FRTP. The experimental results of the bending strength and modulus (450MPa and 20 GPa) approximately agreed with the theoretical values (450MPa and 33.66 GPa) depend on the rule of mixture and the laminate theory. Furthermore, the experimental standard deviations for the bending strength and modulus of the HFRTP at 140°C, were smaller values of 13.6% and 0.725%. Figure 6 shows the bending properties of the HFRTP at the molding temperature of 120°C to 200°C. This figure expressed that both the bending strength and modulus had the higher values at the molding temperatures from 140°C to 160°C.

Table 1. Viscosity of \textit{ε}-Caprolactam

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<thead>
<tr>
<th>Temperature (°C)</th>
<th>Viscosity (Pa·s)</th>
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<tr>
<td>110</td>
<td>300</td>
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<td>140</td>
<td>130</td>
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Figure 6 Bending properties of HFRP at various molding temperatures

1) The hybrid fibers reinforced thermal plastic (HFRTP) fabricated here not only exhibited superior bending properties, but also was suitable for high-speed molding, namely within one minute process time because it can be released from the mold without a cooling process.

2) The bending properties of the HFRTP were changed to the molding temperature and the best molding temperature was from 140°C to 160°C.

3) The experimental results of the bending strength and modulus of the HFRTP approximately agreed with the theoretical values. This result meant that the interlaminar strength of the HFRTP was larger.

REFERENCES


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