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Effect of the cooling rate on the mechanical properties of glass fiber reinforced thermoplastic composites

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ABSTRACT

For the manufacturing of the polymer based composite materials, the understanding of appropriate manufacturing process is important to improve the productivity and manufacturing process. In this study, the effect of cooling rate on the mechanical properties of glass fiber reinforced polypropylene (GFPP) composite was investigated including the tensile, interlaminar shear strength (ILSS), fracture toughness and also the impact properties. To observe the crystallinity of the polypropylene (PP), the X-ray diffraction (XRD) and the differential scanning calorimetry (DSC) analysis were employed. Based on the experimental results, it was found that the tensile strength of GFPP was decreased in the higher cooling rate due to the insufficient adhesion strength between the glass fiber and PP. Nevertheless, the fracture toughness, ILSS and impact properties of GFPP were much improved as the cooling rate increased because the adhesion strength between PP spherulites could be enhanced due to the higher crystallinity. It is expected that the investigated relationships between the cooling rate and the mechanical properties of GFPP will be widely used to optimize the manufacturing process.

1. Introduction

The selection of appropriate materials for automotive components is an important issue in related research fields because weight reduction is very important for both the fuel efficiency and the environmental issues. In recent years, the development of polymer-based composite materials has resulted in remarkable properties such as the weight reduction, the design flexibility, and also the rapid manufacturing processes. For these reasons, polymer-based composites have received much attention from the automobile industry. There are two main types of polymer-based composites: thermoset composites and thermoplastic composites. In the case of the thermoset composites, the carbon fiber (CF) or glass fiber (GF) reinforced epoxy composites have been widely applied in the various industry due to their excellent mechanical properties compared to the traditional metallic materials [1]. However, especially for the automotive industry, the use of thermoplastic composites has been increased in recent years because of their many advantages such as the simple manufacturing process, low material cost, elimination of complicated storage conditions, and the possibility of recycling compared to the thermoset composites [2].

In the various thermoplastic composites, the polypropylene (PP) has been widely used as the matrix due to its high thermoformability, convenience for machining, low material cost, high impact resistance and fracture toughness [3]. For these reasons, the mechanical properties and manufacturing process of glass fiber reinforced polypropylene (GFPP) composites have been investigated in depth to replace the conventional metallic automotive components. From the experimental reports, it has been reported that the GFPP composite has outstanding impact properties and tensile/compressive strength compared to its low weight [4,5]. Also, the optimal consolidation temperature, pressures or dwelling time for the manufacturing of GFPP composites have been investigated in many ways [6]. However, the influences of cooling rate during the manufacturing process of GFPP on the various mechanical properties such as the tensile strength, fracture toughness or impact properties have not yet been reported.

In this study, the effect of the cooling rate on the mechanical properties of GFPP composites was investigated with considering of the microstructural changes of PP matrix. The tensile strength, fracture toughness, and impact properties of GFPP composites

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were evaluated experimentally with respect to the cooling rate during the manufacturing process. The differential scanning calorimetry (DSC) and X-ray differential (XRD) analysis were employed to investigate the microstructural change of PP matrix and the scanning electron microscope (SEM) was used to observe the interface between the fibers and matrix.

2. Experimental methods

2.1. Fabrication of the GFPP composite

In this study, the unidirectional GFPP composite prepreg was used which has the 17.5 μm of fiber diameter. The GFPP prepreg has the 0.3 mm thickness and 34.5% of fiber volume fraction under the 10 bar of manufacturing pressure, which is the standard pressure condition for the GFPP fabrication. In this work, the GFPP prepregs and compositional information with standard pressure condition were supported from the automotive composite part manufacturing company (LG HAUSYS, South Korea). In this work, the hot-press machine was used in order to apply the heat and pressure on the prepreg laminates. The GFPP prepregs were pressed under the 10 bar after the heating up to 220 °C with the 5 °C/min of rate. Then, the 3 min of dwelling time was used at 220 °C for the consolidation of GFPP prepregs. This is because the 3 min of dwelling time has been practically used to manufacture the automotive part for the rapid mass production in the automotive composite part manufacturing company. After the 3 min of dwelling time, the GFPP composites were cooled by the water cooling system in hot-press machine with the different cooling rates as 1, 10 and 20 °C/min. During the cooling process, the 10 bar of pressure was applied until the temperature of GFPP composites cooled down close to the room temperature. Additionally, the temperature of specimen was measured directly during the manufacturing process by using the data acquisition system (DAQ9211, National Instrument, USA) with the thermocouple which was inserted inside the prepregs. During the fabrication process, the hot-press machine could be controlled based on the temperature monitored from the data acquisition system. Fig. 1 shows the measured temperature profiles and pressure condition during the heating and cooling cycles with respect to the different cooling rate.

2.2. Mechanical property tests

In this work, the tensile tests were performed for the GFPP composites with respect to the cooling rate. The unidirectional GFPP specimens were prepared based on the ASTM D 3039 with dimensions of $250 \times 15 \times 1.2\ mm^3$ [7]. The tensile tests were performed by using a universal testing machine (RB 301, UNITECH-M, R&B, South Korea) with a tensile speed of 2 mm/min. Additionally, a scanning electron microscope (SEM, FE-SEM S4800, Hitachi, Japan) was used in order to observe the interface between the GF and PP after the tensile tests.The fracture toughness test was also performed for the GFPP composites to measure the strain energy release rate, which is dominated by the adhesive strength of the PP matrix itself [8]. In this work, the modes I, II and mixed mode bending (MMB) fracture toughness tests were performed with respect to the cooling rate. To measure the mode I fracture toughness, the double cantilever beam (DCB) test was performed based on ASTM D5528 [9]. As shown in Fig. 2a, the DCB test was performed by using a micro tensile testing machine (LLOYD, USA) with a piano hinge tab. The polytetrafluoroethylene (PTFE) film was inserted inside the specimen to prepare the initial delamination before the consolidation. After the test, the mode I fracture toughness (G_{IC}) was calculated using the following equation:

$$G_{IC} = \frac{3P\delta}{2ba} \quad (1)$$

where P is the applied load, δ is the displacement of the crosshead, b is the width of the specimen, and a is the delamination length of the specimen. In the case of mode II fracture toughness, the end notched flexural (ENF) test was performed [10]. The load was applied to the specimen which had an initial crack length of 30 mm by using a universal testing machine. The load was applied downward on the midpoint of the specimen with a 2 mm/min of test speed, as shown in Fig. 2b. Then, the mode II fracture toughness (G_{IIC}) could be obtained as follows:

$$G_{IIC} = \frac{9a^2P\delta}{2B(2L^3 + 3a^3)} \quad (2)$$

where B is the cross-sectional area of the specimen and L is the specimen length.

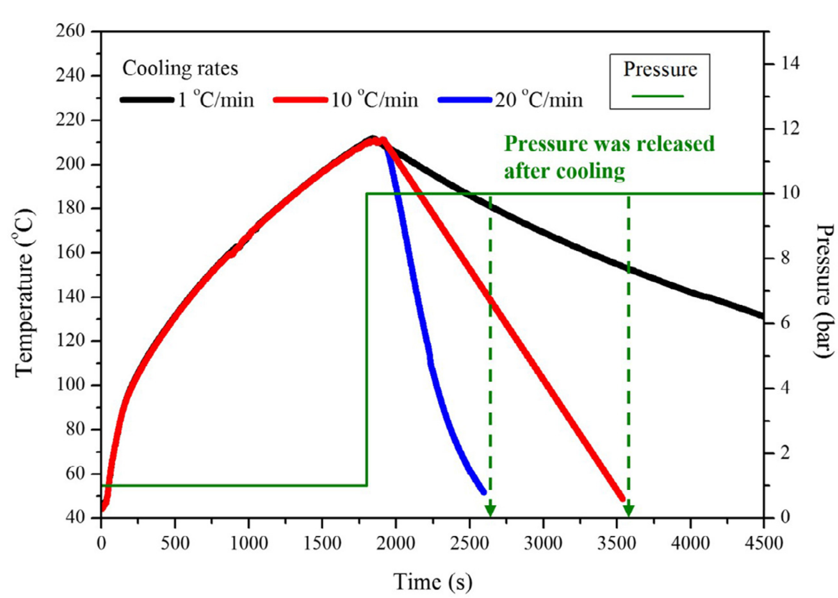

Fig. 1. Pressure condition and temperature profile during the fabrication of GFPP composite with respect to the cooling rate.