High-speed compression molding of continuous carbon fiber-reinforced polypropylene

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Abstract

Polypropylene (PP) is a typical thermoplastic and a superior material due to its low specific gravity, good moldability and low impact on the environment; therefore the rate by which PP is being used has increased remarkably and it is expected to be used as a matrix of carbon fiber-reinforced plastic (CFRP). However, since PP has poor interfacial adhesion to carbon fiber (CF), improvement of interfacial properties is necessary. In this study, maleic anhydride-modified polypropylene was used to improve the interfacial adhesion between carbon fiber and matrix resin. Continuous carbon fiber-reinforced polypropylene was fabricated by the high-speed compression molding method and the effect of maleic anhydride-modified polypropylene on the mechanical properties of CFRP was examined. As a consequence, the mechanical properties of CF/PP were improved by supplying 12.5wt% of maleic anhydride modified PP to PP.

Keywords: carbon fiber, polypropylene, maleic anhydride.

1 Introduction

Carbon fiber-reinforced plastics (CFRPs) are expected to be used for manufacturing car component parts because of their superior mechanical properties and light weight. Automotive structures are expected to become lighter by using CFRP. In addition, considering process time and recyclability, thermoplastic resins are desirable for use as matrices. As polypropylene (PP) is a typical thermoplastic and a superior material due to its low specific gravity, good moldability and low impact on the environment, the proportion of total volume of materials for automobiles occupied by PP has reached about 20% after

2000 [1]. However, since PP does not have a polar group and its adhesion to the reinforcing fiber is poor, it has not yet been able to take full advantage of the strength of the reinforcing fibers [2]. As a method for increasing the interfacial adhesion of CF/PP, maleic anhydride-modified polypropylene (m-PP) having polar groups such as unsaturated carboxylic acid was added to PP [3]. It is reported in past studies that the strength of the molded specimens increased, with increased interfacial strength between fibers and matrix resins [4, 5], when PP becomes a material with polarities after m-PP is added to it [6]. However, in molding of the continuous carbon fiber-reinforced polypropylene, the influence of m-PP on its mechanical properties has not been discussed. In this study, continuous carbon fiber-reinforced polypropylene was fabricated by the high-speed compression molding method and the effect of the presence of maleic anhydride-modified polypropylene on the mechanical properties of CFRP was examined.

2 Materials and experimental procedures

2.1 Material

Polypropylene (PP, SA08, Japan Polypropylene Corporation) and maleic anhydride-modified polypropylene (m-PP, Yumex, Sanyo Chemical Industries, Ltd.) were used as matrix materials. They were processed into non-woven fabrics (Kuraray Co, Ltd.) by the melt blown method with a weight per unit area of 50 g/m² and 9.4 g/m², respectively. As reinforcing fabrics, non-crimp stitched carbon fabric (NCF, 300 g/m² [0°/90°]) and PAN-based carbon fibers stitched together by polyester sewing thread, were used.

2.2 Molding method

Specimens were molded by the high-speed compression molding method [7]. Table 1 shows the melt flow rate (MFR) of PP and m-PP [8]. Table 2 shows the molding conditions: the molding temperature was set at 200°C and the molding pressure at 2 MPa. CF/PP-0, CF/PP-12.5, CF/PP-25 and CF/PP-100 represent the

Table 1: Melt flow rate of PP and M-PP [8].

Temperature (°C)	MFR (g/10 min)	
	Polypropylene (PP)	maleic anhydride-modified Polypropylene (m-PP)
160	<0.1	48.4
180	18.9	>100
200	25.1	
220	58.1

cases in which the content rate of m-PP is 0%, 12.5%, 25% and 100%, respectively. As for the molding of composite laminates, NCF and resin non-woven fabrics were laminated so that the fiber volume fraction was 50% and the thickness of the specimens was 2 mm. The temperature history during the molding process is shown in fig. 1. The holding time for the maximum 200°C temperature of the mold surface was set at 90 s. It took only about 50 s to heat up the specimen from 50°C to 200°C; the cooling process from 200°C to 50°C required only about 130 s. As a whole, the molding was completed in 270 s.

Table 2: Molding conditions of CF/PP.

Specimen	Content rate of m-PP	Temperature (°C)	Pressure (MPa)	Holding time at maximum temperature (s)	Stacking sequence
CF/PP-0	0	200	2	90	NCF(0°/90°) _{3s} (300 g/m ²)
CF/PP-12.5	12.5				
CF/PP-25	25				
CF/PP-100	100

Figure 1: Temperature history of mold surface.

2.3 Tensile tests

Tensile tests were conducted using a universal testing machine (Autograph AG-100kN, Shimadzu Corporation) based on JIS-K7164 and the displacement rate was set at 1 mm/min. Aluminium tabs were glued to both ends of the specimens in order to diffuse stress concentrations and their gauge lengths were 70 mm, their width 10 mm and their thickness 2 mm. Extensions between the marked

points of the specimens were measured by video-type non-contact extensometer (DVE-201, Shimadzu Corporation).

3 Results and discussion

The tensile strength and elastic modulus of CF/PP obtained by the tensile tests are shown in figs 2 and 3. CF/PP-12.5 has the highest tensile strength. This shows a limit to the reinforcing effect on the interface adhesive property caused by m-PP. This is because even if m-PP is added over a certain amount, the component of low molecular weight is increased in the matrix and the tensile strength is decreased [9]. On the other hand, CF/PP-100 has the highest tensile modulus. As shown in table 1, MFR for maleic anhydride-modified PP is

Figure 2: Tensile strength of CF/PP.

Figure 3: Tensile modulus of CF/PP.

extremely high compared to PP. Due to the flow out of the resin during the molding process, the actual fiber volume fraction V_f could be higher than the desired V_f resulting in the specimen showing a higher tensile modulus.

4 Conclusion

Continuous carbon fiber-reinforced polypropylene was fabricated by the high-speed compression molding method and the effect of maleic anhydride-modified polypropylene on the mechanical properties of CFRP was examined. The mechanical properties of CF/PP were improved by supplying 12.5wt% of maleic anhydride-modified PP to PP.

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