EVALUATION OF FLOWABILITY OF THERMOPLASTIC CARBON FIBER COMPOSITES FOR COMPRESSION MOLDINGS

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Abstract

The design of thermoplastic carbon fiber composites which have high flowability is presented. The composite consists of the regularly piled unidirectional prepregs which have slits to cut the continuous fibers. The flow pattern is observed by the originally developed press machine which is equipped with a glass window. The flowabilty is defined by the small scale compression molding and the apparent viscosity is measured by the conventional compression viscometry. The specific slit design improves the flowability and the compression molding requires low pressure in comparison with the conventional stampable sheets.

1. Introduction

Many industrial sectors desire to reduce greenhouse gas emission due to concerns regarding global warming. For automotive industries, decreasing fuel consumption is a primary issue from the environmental point of view and weight reduction is one route to improve the gas mileage.

Carbon fiber reinforced plastic (CFRP) has been a recent focus because of their outstanding strength and modulus, given their weight, compared with conventional material. However, the long molding time due to the cure of thermoset matrix sometimes prevents CFRP from being used in automobile assembly lines.

The technique to improve the cycle time is the adoption of thermoplastic as matrix resin. Carbon fiber-reinforced thermoplastic (CFRTP) has not only a good mechanical performance but a short molding time because of no curing time. In addition to the balance of molding time and structural performance, the flowability is essential because many applications for vehicles require the component to be formed into complex geometries, such as a rib structure.

In this paper, we propose a composite design which induces high flowability. By regularly piling the UD prepreg sheets which have well designed slit to cut the continuous fibers, the composite requires a low pressure in compression moldings even at high-fraction fibers. This CFRTP is named slit carbon prepreg based thermoplastic composite (SPTC). This type of composite design was already proposed in Japanese patents [1, 2], and several papers have primarily discussed the properties of the thermoset matrix resins [3-6]. Therefore, we focus on the slit pattern’s effect on the flowability of the thermoplastic matrix resin.

2. Experimental setups

2.1. Preparation of SPTC

The carbon fiber TR50S-15L (Mitsubishi Rayon Co. Ltd.) was opened to an area weight of 72 g/m^2 and was sandwiched by a cast film of 40 μm thickness that consisted of maleic-anhydride-grafted polypropylene (m-PP), which was produced by the Mitsubishi Chemical Corp. This laminated sheet was passed through a roll gap under a specific pressure and was heated to 260ºC and a UD prepreg volume fraction of 33% was produced.

The slits were inserted into the UD prepreg using a ZUND G3 L-2500 cutting plotter to cut the continuous fibers into a specific length. The design of the slits was achieved by controlling the slit angle and the fiber length (slit interval), as observed in Fig. 1. The slit UD prepregs were plied in a quasi-isotropic manner $[(0/45/90/-45)s]_2$ and were then consolidated using a press molding machine at a force of 50 kN and at a temperature of 210ºC for 7 minutes. The size of the mold cavity, which is a square that is 300 mm on each side, was the same as the slit UD prepreg; therefore, no deformation was observed after molding. The thickness of the SPTC was approximately 2.0 mm. Our target design of slit in this study was summarized in Table 1.

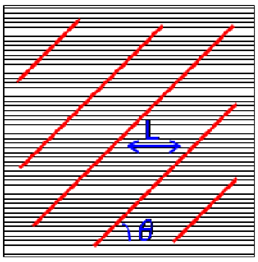


Figure 1. Slit design by slit angle θ and fiber length L (Black lines show the CF orientation and the red lines the slits).

	θ [deg]		
L [mm]	Small	Middle	Large
Small		Middle_θ, Small_L	
Middle	Small_θ, Middle_L	Middle_θ, Middle_L	Large_θ, Middle_L
Large		Middle_θ, Large_L	

Table 1. Matrix of experimental targets.

2.2. Observation of flow behavior

The flow behavior of SPTC was observed by the originally designed press machine which was equipped with glass-prism window as it was seen in Figure 2. The press stage was moved up and down by rotating the shaft with screw thread as the torque was monitored. The machine was heated at 230 ºC by the cartridge heaters which were inserted into the holes in the press stage. A CCD camera (HAS-220, Direct Ltd.) and zoom lens (VH-Z00R, Keyence Ltd.) were used to take snapshots of the flow with a frame date of 50 frames-per-second.

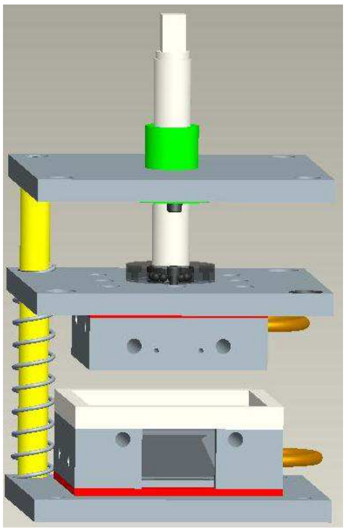


Figure 2. Schematic view of the press machine with the visualizing window.

2.3. Measurement of flowability

The moldability was defined as the ratio of the initial thickness to the final thickness after the compression molding process. The conditions of pressure and sample size were determined from the real production process of certain automobile parts using a theoretical scale-down model. The SPTC samples, squares that were 78 mm on each side with a thickness of 2 mm, were plied doubly and preheated at 230 ºC for 5 minutes until a uniform temperature was achieved. After the preheating step, the SPTC was moved to the low temperature press of 145 ºC and was pressed with a force of 17 and 33 kN for 30 seconds.

The apparent viscosity was measured according to the basic compression viscometric theory [7]. The disk shape of SPTC samples were pressed under the specific temperature and force. The obtained thickness-time curve was fitted by the equation below and the apparent viscosity was estimated

$$\frac{1}{h^4} = \frac{8\pi F}{3\eta V^2} t + C \qquad (1)$$

where h=thickness, F=force, η=viscosity, V=volume, t=time, and C=constant.
The size of CFRTP disk and the experimental conditions were summarized in Table 2.

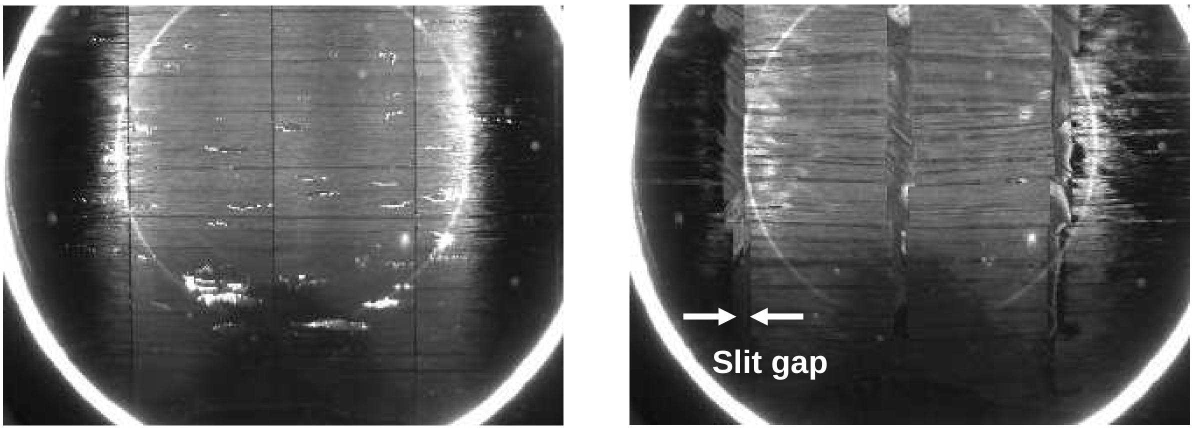
Disk size	Diameter [mm]	74.0
	Thickness [mm]	2.0
Measurement condition	Temperature [ºC]	180
	Force [kN]	10.0

Table 2. Experimental conditions of the apparent viscosity.

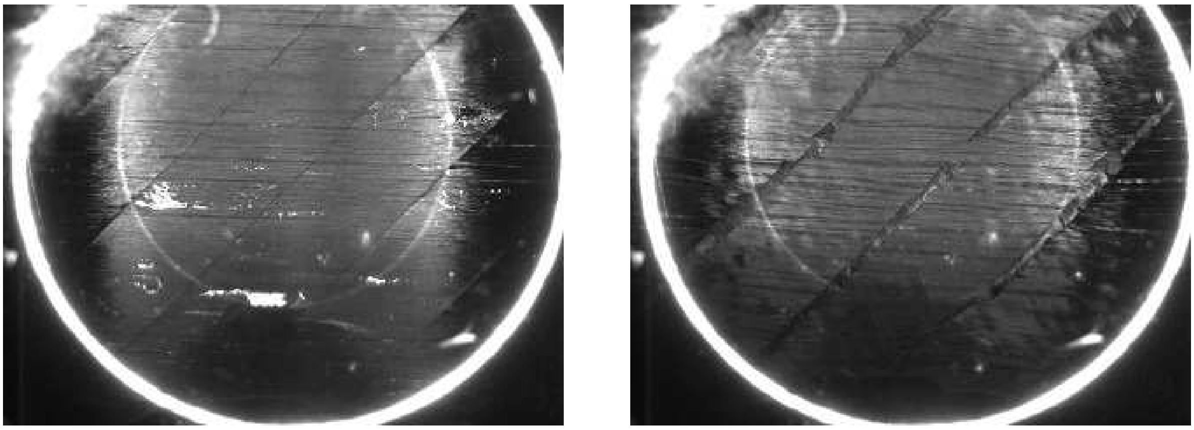
3. Result and discussion

3.1. Observation of flow behavior

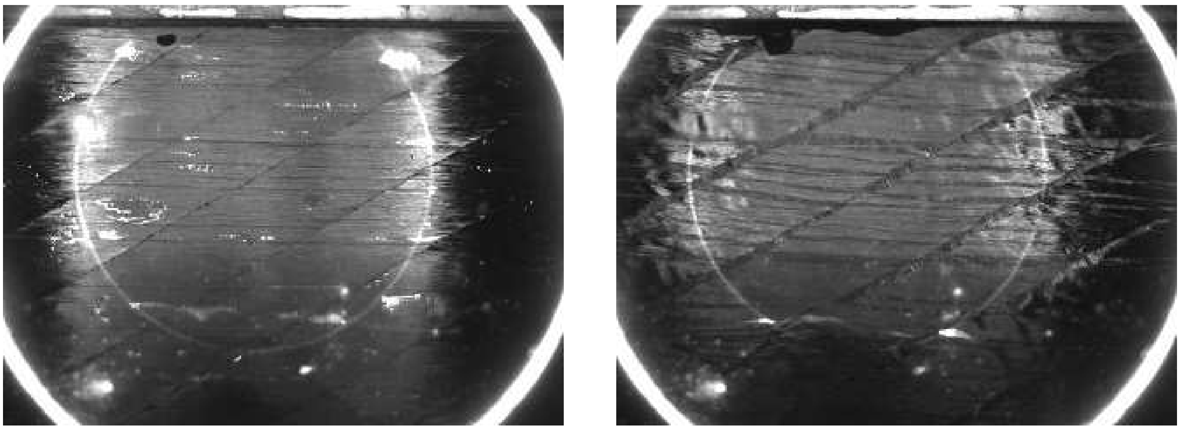
The snapshots of the flow behavior under the certain force are shown in Figure 3. The flow pattern depends on the slit angle and the 90 degree slit angle widen the slit gaps as it is seen in (a). On the other hand, small slit angle keeps slit gaps small and the uniform flow is expected as in (b) and (c).



(a) Large slit angle; initial condition; final condition



(b) Middle slit angle; initial condition; final condition

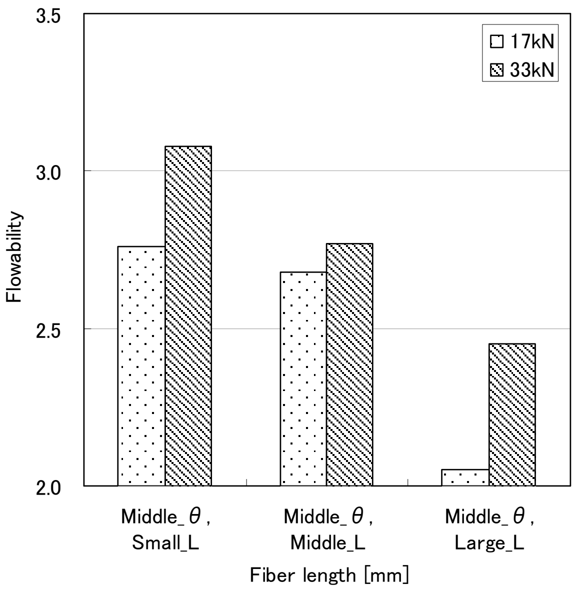


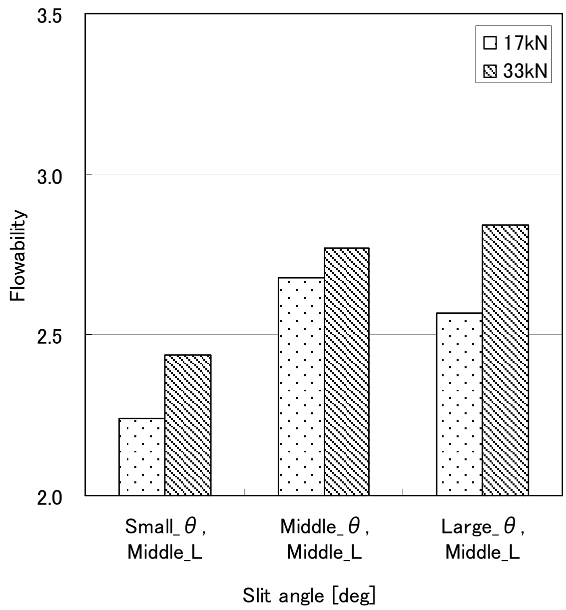
(c) Small slit angle; initial condition; final condition

Figure 3. Snapshots of the flow behavior under the compression molding.

3.2. Flowability and apparent viscosity

Flowability of CFRTP samples are shown in Figure 4. The flowability is defined as the ratio of initial thickness to final thickness through the compression molding. Therefore the large value stands for good flowability. This figure shows not only the short fiber length but small slit angle improve the flowability. The effect of fiber length is reasonably acceptable. The small slit angle widens the slit gap and this flow pattern improves the flowability.

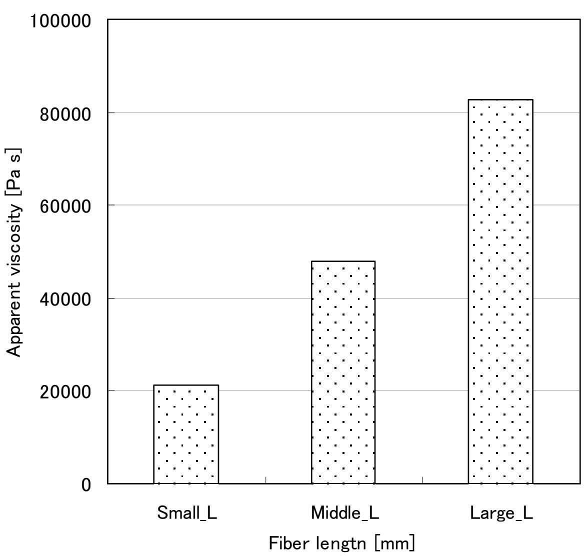




(a) Effect of fiber length (b) Effect of slit angle

Figure 4. Flowability of CFRTP samples which have different fiber length and slit angle.

The apparent viscosity measured by above mentioned technique is summarized in Figure 5. The viscosity depends on both slit angle and fiber length as same as the flowability and the short fiber and the great angle shows low viscosity.



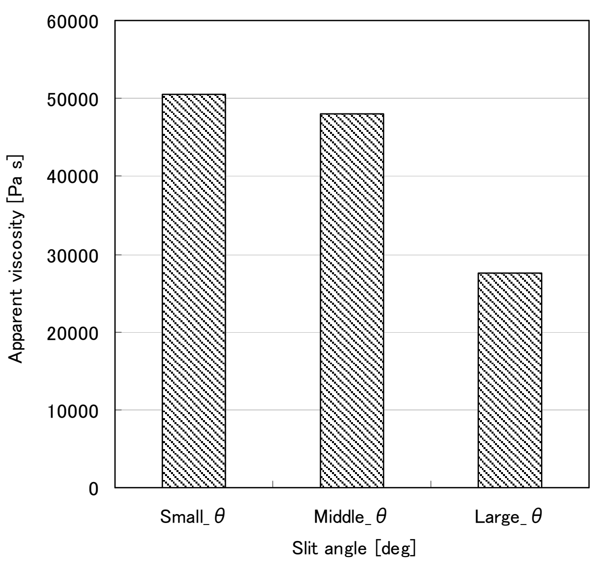


Figure 5. Apparent viscosity of CFRTP samples which have different fiber length and slit angle.

4. Conclusion

We have proposed the design of a carbon fiber-reinforced thermoplastic with good flowability as the primary goal. For this purpose, SPTC shows good property when the optimized slit pattern is imposed. The short fiber length and the great slit angles induce good flowability. Even though the mechanical properties improved when using a smaller slit angle [8], we recommend the great slit angle due to the reasons described above. The composite material that has this slit design can be shaped by compression molding at low pressure.

On the other hand, mechanical property oriented design is also possible in SPTC. Thus, a tailor-made composite that has flexible design of moldability and mechanical property can be achieved.

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