DEVELOPMENT OF NOVEL HEAT EFFICIENT PREHEATING PROCESS FOR HIGH CYCLE THERMOFORMING OF DISCONTINUOUS CFRTP

T. Hayashi [a*], K. Hasegawa [a], H. Wataki [a], J. Takahashi [a]

[a] *The University of Tokyo, Department of Systems Innovation, School of Engineering,7-3-1, Hongo, Bunkyo-ku, Tokyo 113-8656, Japan*

Keywords: carbon fiber, thermoplastics, impregnation, preheating

Abstract

Weight reduction of automobile is one of the urgent developmental subjects for automotive industries to reduce CO_2 emission. Carbon fiber reinforced plastics (CFRP) has been investigated as a promising material to reduce car weight significantly. Meanwhile, thermoplastic polymer is investigated as a matrix resin for composites because it has some advantages over thermosets, regarding impact resistance, short molding cycle, weldability, recyclability and economy. Therefore carbon fiber reinforced thermoplastics (CFRTP) based on common thermoplastic polymers such as polypropylene or polyamide, which is widely used for automotive applications, have great potential to be used for weight reduction of mass production automotive products. However conventional high-cycle CFRTP thermoforming processes are not so affordable because fully impregnated prepreg and its blanking are not efficient for mass production. Therefore we are developing new preheating machine which have the functions of blanking and preheating with impregnation by using semi-preg (semi-impregnated prepreg) for total heat efficiency. In this paper, we investigated CFRTP impregnation mechanism to know the relationship between preheating conditions and thermoforming molding conditions. Moreover, we discuss the efficiency of fiber morphology of discontinuous CFRTP and preheating conditions to get fully impregnated CFRTP products.

1. Introduction

Carbon fiber reinforced plastics (CFRP) have high specific stiffness and strength and are used in various industrial applications. Recently, carbon fiber reinforced thermoplastics (CFRTP) are gaining attentions because of its short molding cycle. So far, super-engineering plastics such as PEEK and PPS are mainly used as matrices ([1], [2] and [3]), but too expensive to be used for mass-production cars. Hence we developed discontinuous CFRTP with polypropylene (PP) matrix, and investigated mechanical properties by changing their flow-molding condition.

2. Materials and Testing methods

2.1 Materials

In this study, we used polypropylene matrix carbon fiber prepregs which Mitsubishi Rayon Co., Ltd. manufactured by using TR50S (tensile modulus: 240GPa, tensile strength: 4900MPa). Volume fraction (V_f) of carbon fiber is 45% and we call this fully impregnated prepreg as UD75A. And also Mitsubishi Rayon Co., Ltd. produced two special semi-pregs (not fully impregnated prepreg) for basic research of impregnation. One is produced with two times faster speed than UD75A and called UD75B. The other is produced with four times faster speed than UD75A and called UD75C. The specifications of these prepregs are shown in Table 1.

Table 1. Specification of 3 types of prepregs investigated in this study.

Name	Type	FAW (g/m2)	Vf (%)	Thickness (mm)	Processing (production) speed
UD75A	UD	75	45	0.093	Normal speed for fully impregnated prepreg
UD75B	UD	75	Depends on impregnation degree		2 times faster than UD75A
UD75C	UD	75	Depends on impregnation degree		4 times faster than UD75A

2.2 Composites

The composites and their fiber morphology and properties investigated in this study are shown in Table 2. UD composites were prepared by laminated UD prepregs along single direction. And QISO composites were prepared by lamination pattern: $[+45/0/-45/90]_{s2}$ of UD prepregs. SCT-Qs (semi-continuous carbon fiber reinforced thermoplastics quasi-isotropic laminate) were prepared with semi-continuous fabricated prepreg (SCT-prepreg) and laminated as the same pattern as QISO composites.

Table 2. Composites and their fiber morphology.

Name	Name (specific)	tape(fiber) length	tape width	isotropy (tensile)	isotropy (flexural)
UD composite	uni-directional composite	continuous (uncontrollable)	uncontrollable	orthotropic	orthotropic
QISO composite	quasi-isotropic laminated composite	continuous (uncontrollable)	uncontrollable	isotropic	anisotropic
SCT-Q	semi-continuous CF reinforced thermoplastics quasi-isotropic laminated	discontinuous (controllable)	controllable	anisotropic	anisotropic
CTT	chopped CF tape reinforced thermoplastics	discontinuous (controllable)	controllable	isotropic	isotropic

2.2 Sample preparation

200 mm × 200 mm composite panels were molded by 100kN hand-press machine with simple steel mold as shown in Figure 1. Molding condition is shown in Figure 2. Tables 3 to 5 are the molding conditions of UD, QISO and SCT-Q, respectively.

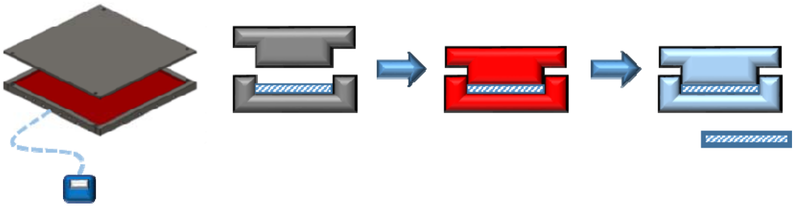

Figure 1. Steel mold for preparation of composite and its mold process.

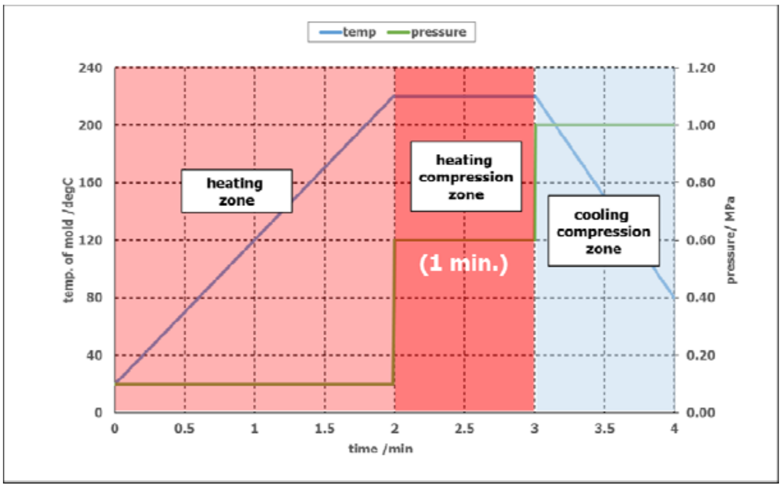

Figure 2. Schematic diagram of temperature and pressure for preparation of composite.

Table 3. Preparation conditions for UD composites.

material	Heating condition			Cooling condition	
	temperature	pressure	time	pressure	time
UD75A	180℃	0.3MPa	1min	1.0MPa	180 to 80℃(3min.)
UD75B	180℃	0.3MPa	1min	1.0MPa	180 to 80℃(3min.)
UD75C	180℃	0.3MPa	1min	1.0MPa	180 to 80℃(3min.)

Table 4. Preparation conditions for QISO composites.

Prepreg	Heating condition			Cooling condition	
	Temperature	Pressure	Time	Pressure	Time
UD75C	180℃	1.0MPa	1min	2.0MPa	to 80℃(3min.)
UD75C	200℃	0.5MPa	1min	2.0MPa	to 80℃(3min.)
UD75C	200℃	1.0MPa	1min	2.0MPa	to 80℃(3min.)
UD75C	200℃	2.0MPa	1min	2.0MPa	to 80℃(3min.)

Table 5. Semi-continuous fabrications and the preparation conditions for SCT-Q.

Prepreg	**Semi-continuous fabrication**			**Heating condition**			**Cooling condition**	
	Fiber length	**Cut width**	**Cut angle**	**Temperature**	**Pressure**	**Time**	**Pressure**	**Time**
UD75C	25mm	5mm	90°	200℃	1MPa	1min	2.0MPa	to 80℃ (3min.)
UD75C	25mm	5mm	90°	200℃	2MPa	1min	2.0MPa	to 80℃ (3min.)
UD75C	25mm	5mm	30°	200℃	1MPa	1min	2.0MPa	to 80℃ (3min.)
UD75C	25mm	5mm	30°	200℃	2MPa	1min	2.0MPa	to 80℃ (3min.)

2.3 Density measurement

We measured the densities of composites by electronic densimeter (Alfa Mirage MDS-300) based on Archimedes' principle as shown in equation (1). Specimens were sized 100mm long and 25mm wide. Composite specimens were dried at least 12 hours. After that densities of composite were measured.

$$\rho = \frac{W_A}{W_A - W_B} \times (\rho_0 - d) + d \tag{1}$$

ρ : density of composite
W_A : weight of composite in air
W_B : weight of composite in liquid
ρ_0 : density of liquid
d : density of air (≒0.001 g/cm^3)

2.4 Evaluation of flexural strength and modulus

To measure flexural properties of the prepared composites, 3-point bending test were conducted by testing machine (SIMADZU AGS-X) with following conditions; distance of supports was 80 mm, cross-head speed of testing machine was 5 mm/min. Size of specimens was 100mm by 25mm.

3. Results and discussions

3.1 Effects of processing (production) speed of prepreg

We molded UD composites by using prepregs produced by three different processing speed as shown in Table1. Figure 3 is the result of 0° directional flexural modulus and strength. The composite of UD75A produced by the lowest processing speed showed the highest flexural modulus and strength. By contrast, the composite of UD75C produced by the fastest processing speed showed the lowest flexural modulus and strength. Before bending test, we had measured the densities of composite. Figure 4 is the result of density measurement of UD composite. Same as flexural properties, the composite of UD75A showed the highest density and that of UD75C showed the lowest density. Considering with these results, flexural properties of UD75B and UD75C were smaller than those of UD75A because UD75B and UD75C prepregs contained voids due to their production process.

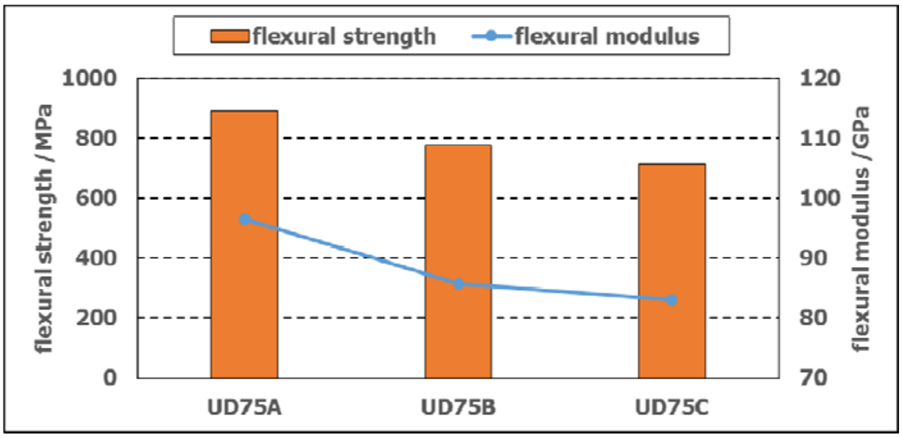

Figure 3. 0°directional flexural strength and modulus of UD composite (prepreg: UD75A, UD75B, UD75C).

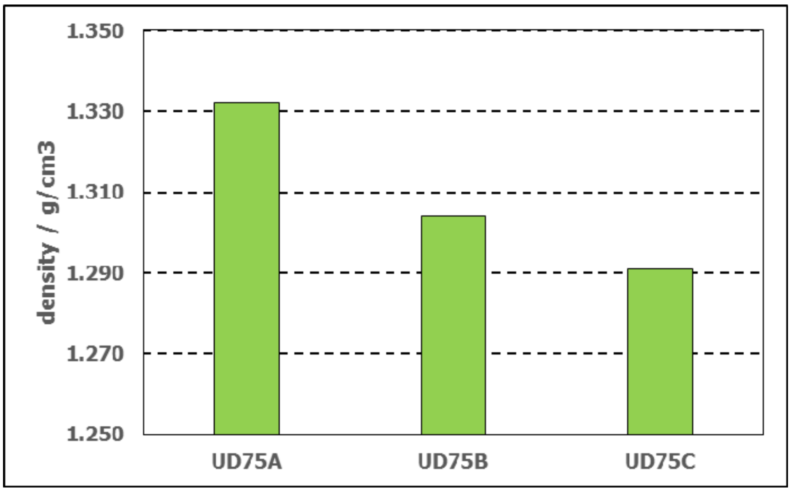

Figure 4. Densities of UD composite specimen (prepreg: UD75A, UD75B, UD75C).

3.2 Effects of molding condition for QISO composite

We measured the mechanical properties and densities of QISO composites by changing the maximum temperature and pressure during its heating process. Table 4 is the molding condition of QISO composite of UD75C. Figures 5 to 7 are the flexural modulus, flexural strength and density of this material. As shown in these figures, both higher molding temperature and higher molding pressure causes higher mechanical properties. The reason of the big scatter shown in the flexural strength of the specimen molded by 2 MPa may be caused by the flow of fiber. Hence this phenomena can be controlled by the proper combination of molding temperature and pressure. Considering with these results, the difference of mechanical properties of composite was mainly caused by the difference of void content in composite.

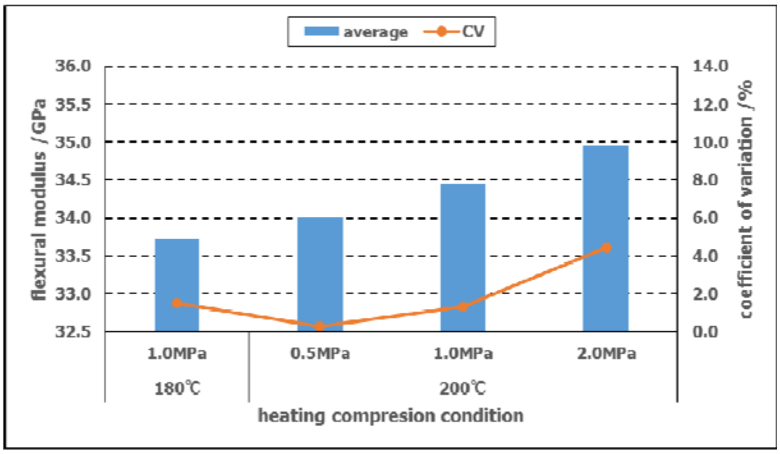

Figure 5. Flexural modulus of QISO composite (prepreg: UD75C).

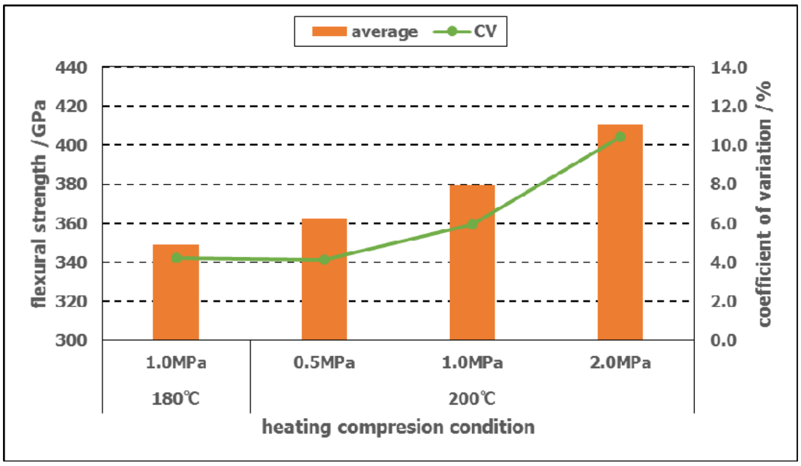

Figure 6. Flexural strength of QISO composite (prepreg: UD75C).

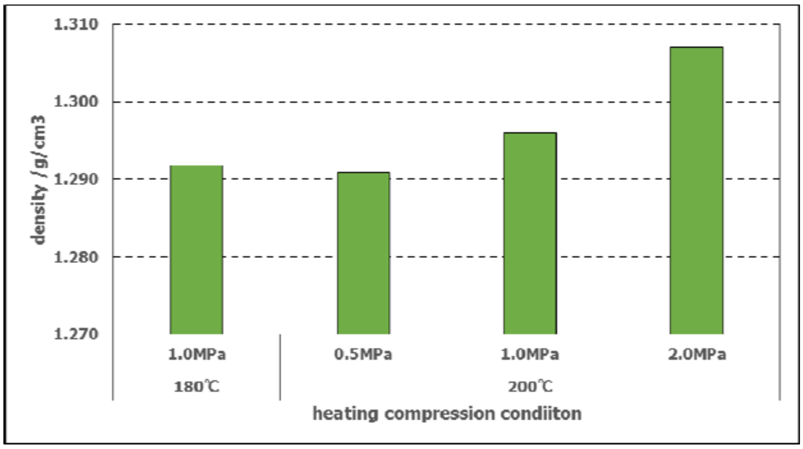

Figure 7. Densities of QISO composite specimen (prepreg: UD75C).

3.3 Effects of molding condition for SCT-Q

Semi-continuous fabrication and their preparation condition is shown in Table 5. Figure 8 is the comparison of flexural modulus of SCT-Q and QISO. In this figure, the flexural modulus of SCT-Q was a few percent smaller than that of QISO, which is sure to be the influence of the cutting part. But the influence of molding pressure and cut angle was almost nothing. Figure 9 is the flexural strength of SCT-Q and QISO. In this figure, the flexural strength of SCT-Q was 15-25 % smaller than that of QISO, which is caused by the same reason of the flexural modulus. The difference of flexural strength was much bigger than that of flexural modulus. However the scatter of the flexural strength of SCT-Q did not increase in the higher molding pressure, because only cut part flowed during molding.

SCT-Q by 30° cut semi-continuous fabrication showed higher mechanical properties than SCT-Q by 90° cut semi-continuous fabrication. Because the fabricated part in SCT-Q with larger cut angle was easier to open and move during molding and contained more defects than that with smaller cut angle, observing the two molded panels in Figure 10.

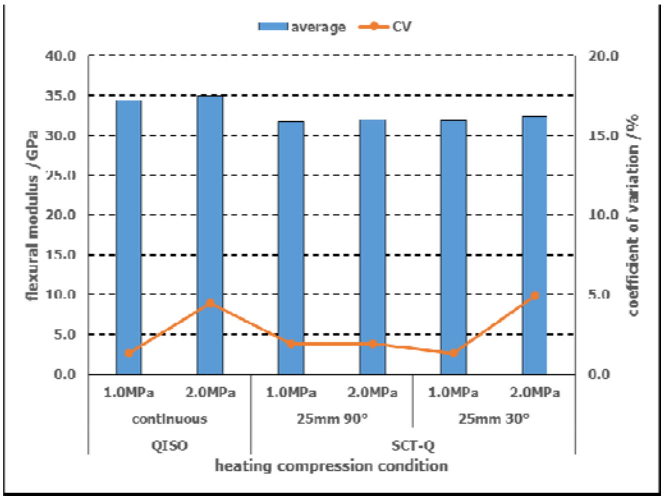

Figure 8. Flexural modulus of QISO composite and SCT-Q (prepreg: UD75C).

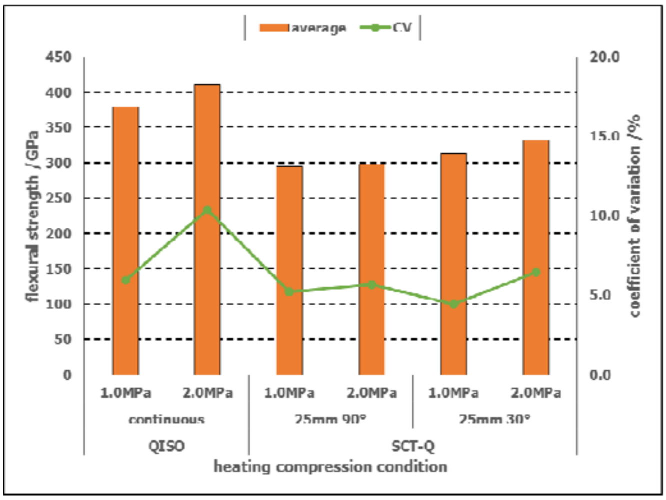

Figure 9. Flexural strength of QISO composite and SCT-Q (prepreg: UD75C).

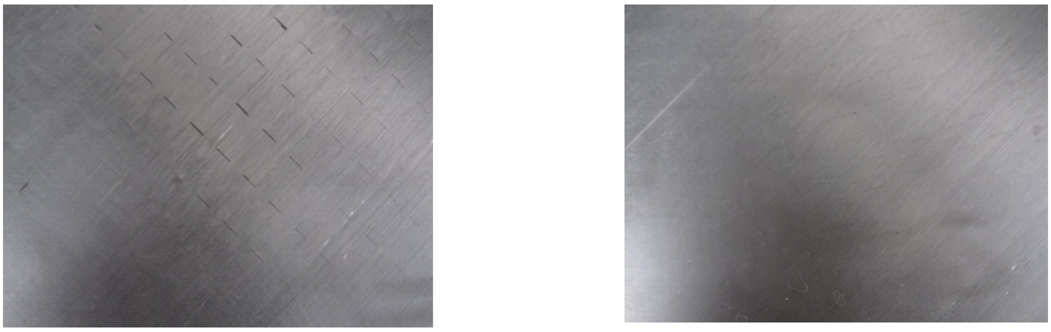

Figure 10. Pictures of SCT-Q panel (left: 90°cut, right: 30°cut).

Conclusions

We investigated continuous and discontinuous fiber reinforced thermoplastic composite by using 3 types of prepregs with different production speed. Composites were more impregnated by higher pressure or by higher temperature independent of fiber morphology. The composite of semi-continuous fabricated prepreg (SCT-prepreg) were prepared and the mechanical properties of SCT-Q with small cut angle (ex.30°) were higher than that with large cut angle (ex.90°) because the fabricated area in SCT-Q with large cut angle was easy to open and move.

Acknowledgement

This study was conducted as a part of Japanese METI project "the Future Pioneering Projects / Innovative Structural Materials Project" since 2013fy. Authors would like to express sincerely appreciation to the project members who have provided valuable information and useful discussions.

References

[1] M. Buck Continuous fiber thermoplastic composite materials & processing technologies. *SAMPE JISSE 10* (2007).
[2] J. Fox-Rubin Considerations for thermoforming continuous fiber reinforced composites. *SAMPE JISSE10* (2007).
[3] A. Offringa. Continuous fiber reinforced thermoplastics and aerospace applications. *SAMPE JISSE10* (2007).