FLOW BEHAVIOR OF COMPLEX SHAPED HYBRID CFRTP DURING COMPRESSION MOLDING

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ABSTRSCT

The flowability of hybrid CFRTP made by ultra-thin chopped carbon fiber tape reinforced thermoplastics (UT-CTT) and carbon fiber paper reinforced thermoplastics (CPT) was investigated in this paper by using rib formation mold. Hybridization of different structures of CFRTP materials aims to take advantage of the merits of each component without introducing the weaknesses. Three types of UT-CTT/CPT composites were molded with a specially designed mold: two sharp ribs (height of 3 mm and 8 mm). Various lengths of chopped tapes (6 mm, 18mm and 30 mm) were prepared to fabricate three types of UT-CTT preforms. In order to fully charge the rib cavities in the mold, 10 MPa, 15 MPa and 20 MPa were applied to investigate the proper molding pressure. In the case of hybrid CFRTP, the fiber distribution of the CPT plate part under the charging port of ribs was relatively kept successfully and the flexural rigidity was improved in comparison with that made by only UT-CTT.

1 INTRODUCTION

Carbon fiber reinforced thermoplastics (CFRTP) are an excellent material for lightweight applications and are suitable to be applied in automotive manufacturing industry. CFRTP has increasingly attracted attention of researchers and engineers because of the advantages of short molding cycle time and high energy absorption capacity. Manufacturing CFRTP for lightweight vehicles plays an effective role in saving energy consumption and decreasing the CO_2 emission amount. Different from conventional CFRTP materials compared by continuous carbon fibers (CF), discontinuous CFRTP requires much lower molding pressure than continuous CFRTP and has higher flexibility to form more complex shape [1-2]. Therefore, discontinuous CFRTP is expected to apply to complex parts of production vehicle.

In future, recycling carbon fiber is very important for solving problems about the inadequate disposal of relevant carbon fiber waste. However, the application of recycled carbon fibers (rCF) is still in development because of the discontinuous length distributions of rCF. Different manufacturing techniques for discontinuous CFRTP may render a way to improve the real application of rCF in production vehicle. In this study, ultra-thin chopped carbon fiber tape reinforced thermoplastics (UT-CTT) and carbon fiber paper reinforced thermoplastics (CPT) are used as two scales of discontinuous CFRTP classified by the intrinsic fiber structures, the former is composed by aligned CF reinforced chopped tapes and the latter is composed by randomly oriented CF.

In this paper, UT-CTT and CPT are combined to investigate a possible hybrid structure to mitigate the disturbance of the fiber distributions in forming complex shape parts. Hybrid CFRTP aims to take an advantage of the merits of each component material without introducing the relative weaknesses. A very important benefit to hybridize the UT-CTT with CPT is to decrease the material cost without sacrificing the stiffness, which is enhanced by hybrid structures [3]. However, in real manufacturing UT-CTT/CPT hybrid structures, some problems, such as resin impregnation, temperature durability, disturbance of the fiber alignment, need to be investigated primarily.

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UT-CTT has both good mechanical properties and formability, so it is desirable for complex shape automotive primary structure [1]. However it is difficult to conduct numerical simulations because deformations of the tapes during molding (Figure 1), which can also lead the decrease of mechanical properties [5]. On the other hand, CPT shows lower mechanical properties of final products and flowability during molding process due to lower fiber volume fraction and more random fiber orientations compared to those of CTT, so there is difficulties for the materials to fill the mold cavities with more complex geometries, as the unfilled rib shown in Figure 1 [6]. However, CPT also has the certain superiority since it is light and can be made by recycled CF without degradation of the mechanical properties [7]. UT-CTT in melt state is easy to flow despite of its high volume fraction. In this study, it is expected to balance and control disturbance of the fiber alignment by using CPT in core layer, because CPT prevents UT-CTT flow behavior adequately.

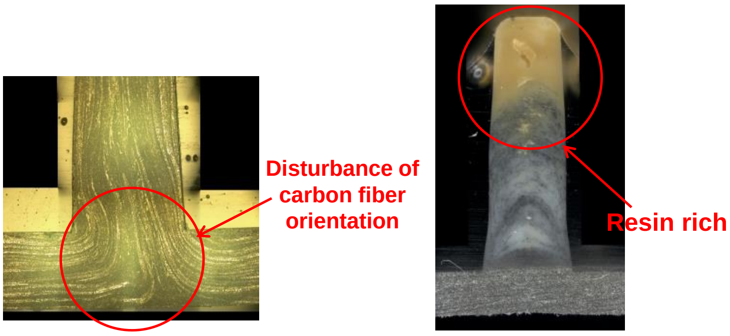

Figure 1. Cross section of the ribs (Left: made by only UT-CTT, Right: made by only CPT).

2 MATERIALS

In this study, we used two different types of discontinuous CFRTP for making hybrid CFRTP as follows.

2.1 UT-CTT

UT-CTT was made by unidirectional CF/PA6 (Polyamide-6) preimpregnated sheet with the thickness of 44 μm, and carbon fiber volume fraction (V_f) is approximately 55%. Carbon fiber was provided by Mitsubishi Rayon Co., Ltd, and PA6 was provided by Mitsubishi Plastics, Inc. This sheet was made by using tow spreading technology of Industrial Technology Center of Fukui Prefecture [8].

First, in order to make prepreg sheet into chopped tapes, an automated tape cutter and Tomson cutter were used. The tape length has 3 types: 6 mm, 18 mm and 30 mm. The tape has the width of 5 mm. The chopped tapes were dispersed by wet dispersion process and then heated with compressing under 5 MPa and 260 °C for 90 sec to make fixed and portable sheets. This procedure can prevent chopped tapes from orientating in out-of-plane direction.

2.2 CPT

CPT material (CARMIX® [9]) were manufactured by Awa Paper Mfg. Co., Ltd. The average length of CF and PA6 fiber are closed to 6 mm. The Vf of CF is about 24%. These fibers are carefully dispersed by a continuous paper-making process.

3 EXPERIMENTS

3.1 Compression molding

In this study, in order to examine the flow behavior and flexural rigidity of hybrid CFRTP, we used CPT for core layer to moderate disturbance of the fiber alignment during charging the ribs. First, UT-CTT and CPT sheets were cut into required size (12.5 mm × 12.5 mm), and stacked the sheets into the mold. The compression molding process was accomplished in Sanko Gosei Ltd. The molding pressures were set at 10 MPa, 15 MPa, 20MPa respectively and the proper molding

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pressure will be discussed in latter sections. The molding temperature is constant as 260°C for 5 min under each molding pressure. The mold is used to form two ribs of the heights of 8 mm and 3 mm respectively and of the length of 30 mm, the details of the geometries are further shown in Figure 2. Both ribs have thickness of 2 mm at the top, but the different thicknesses at the bottom are determined by the same gradient of 0.05, which are 2.8 mm for the taller one and 2.3 mm for the shorter one.

In this study, we conducted two experiments (Exp. 1 and Exp. 2) to investigate flow behavior and mechanical properties of hybrid CFRTP. The purpose of Exp. 1 was to observe the flow behavior during charging the ribs in different pressures and tape lengths. Therefore, the specimens for Exp. 1 were made by one-side hybridization as shown in Figure 3. Meanwhile, in Exp. 2, our purpose was to examine the flexural rigidity of hybrid CFRTP influenced by the ribs. Therefore, the specimens were prepared as sandwich panel for practical utility as shown in Figure 3. The parameters of these experiments are shown in Table 1 and Table 2.

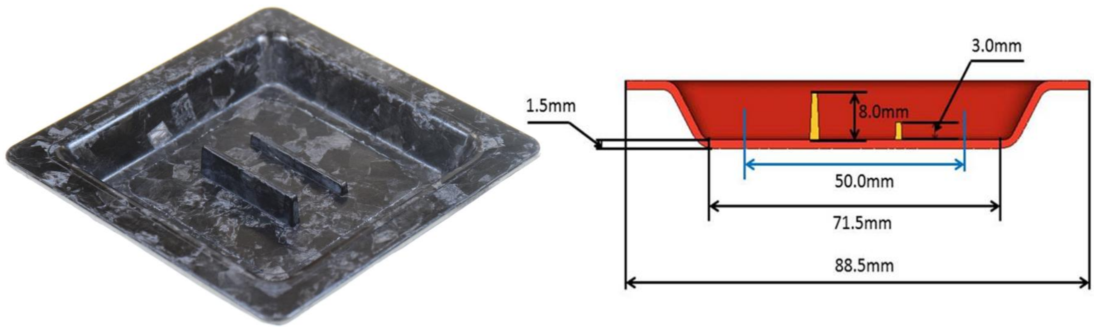

Figure 2. Representation of mold and its geometry.

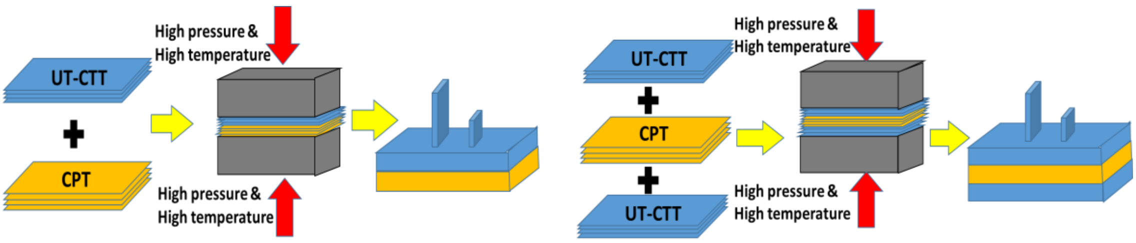

Figure 3. Schematic diagram of molding process (Left: Exp. 1 Right: Exp. 2).

Table 1. Molding variables in Exp. 1 for observation of cross sections.

No.	Tape length (UT-CTT)	Molding pressure	Molding time	Thickness	
				UT-CTT	CPT
	[mm]	[MPa]	[min]	[mm]	[mm]
1-1	6	10	5	0.67	0.75
1-2	6	20			
1-3	18	15			
1-4	18	20			
1-5	30	20			

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Table 2. Molding variables in Exp. 2 (sandwich panel) for 3-point bending tests.

No.	Tape length (UT-CTT)	Molding pressure	Thickness	
			Skin layer (UT-CTT)	Core layer (CPT)
	[mm]	[MPa]	[mm]	[mm]
2-1	6	15	0.67	0.17
2-2			0.50	0.50
2-3			0.33	0.80
2-4	18	20	0.67	0.17
2-5			0.50	0.50
2-6			0.33	0.80
2-7	30	20	0.67	0.17
2-8			0.50	0.50
2-9			0.33	0.80

3.2 Observation (Exp. 1)

In order to observe the flowability of hybrid CFRTP, observation on the cross sections by digital microscope (KEYENCE: VHX-1000) was conducted. Polishing rough surfaces of the cut sections with successively finer mediums was performed prior to the observation.

3.3 Mechanical testing and observation (Exp. 2: sandwich panel)

To investigate the flexural rigidity of the plates with ribs, we conducted 3-point bending tests in two ways, 0° direction and 90° direction (Figure 4). In 0° direction test, the supports and indenter were vertical to the ribs. In the 90° direction test, they were parallel to the ribs. The specimens were cut into a certain dimension (45 mm × 45 mm) to demonstrate the stiffening effects caused by ribs clearly. The other parameters are shown in Table 3. The number of tests was 3 for each samples. In case of tape length 18 mm, additional experimental conditions were used because of the previous research [5]. In this study, we calculated the values by considering the plate with ribs as shown in Figure 5. Material properties for calculation, Young's modulus of UT-CTT and CPT, were referred from the values of previous researches [10]. At last, to confirm validity of the flexural rigidity, we observed on cross sections of the specimens as Exp. 1 Calculated values ware led by lamination theory (Eq. 1) and elastic curve equation (Eq. 2).

$$\mathrm{EI} = 2\mathrm{b}\left\{\int_{0}^{\frac{h}{2}-t} E_c\eta^2 d\eta + \int_{\frac{h}{2}-t}^{\frac{h}{2}} E_s\eta^2 d\eta\right\} \tag{1}$$

$$\mathrm{EI}\frac{d^2y}{dx^2} = -\mathrm{M(x)} \tag{2}$$

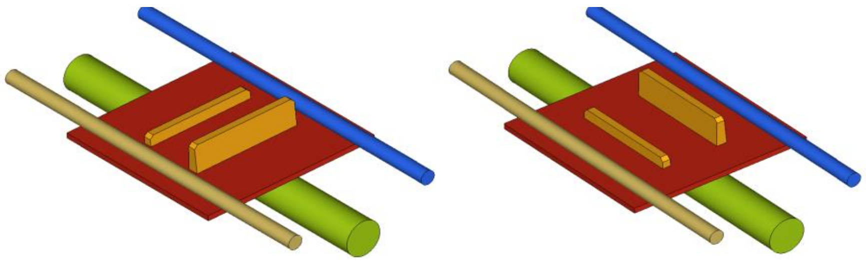

Figure 4. Schematic diagram of 3-point bending test (Left: 0° type, Right: 90° type) [5].

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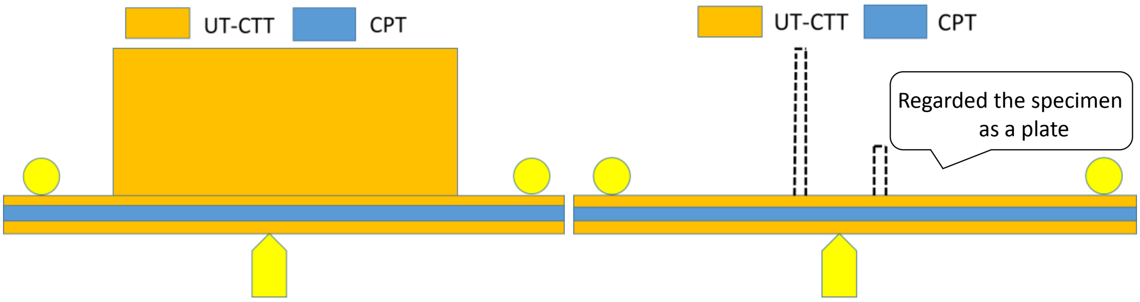

Figure 5. Schematic diagram of plate with ribs in calculation (Left: 0° type, Right: 90° type).

Table 3. Configurations in 3-point bending test of Exp. 2.

Span length [mm]	40
Support radius [mm]	2.0
Loading nose radius [mm]	5.0
Loading speed [mm/min]	0.5

4 RESULTS

4.1 Results of observation (Exp. 1)

The ribs of the specimens had been fully charged under the pressure imposed; the cross sections of the samples were observed as shown in Figure 6 and 7. The tapes could flow into the ribs as expected, and the fiber alignment of the CPT plate part under the charging part of ribs were not disturbed. However, UT-CTT became difficult to charge into the rib with the increase of the tape length. Consequently, more resin were flowed into the ribs as illustrated in Figure 1 (left).

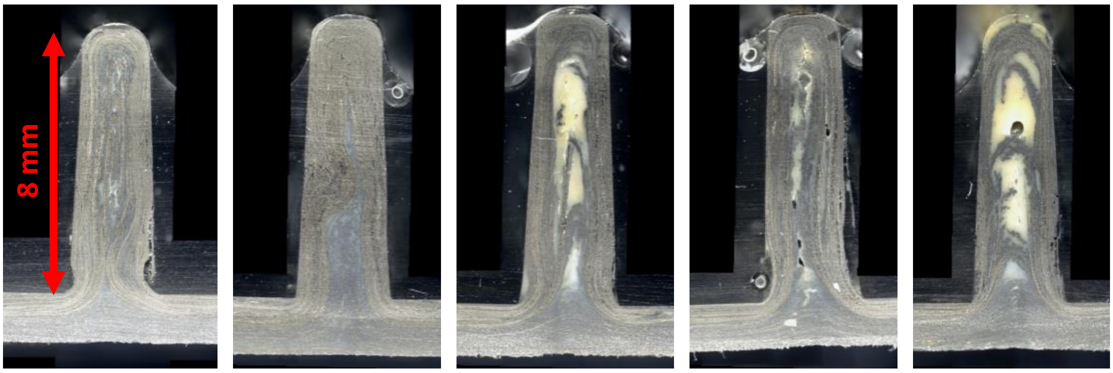

Figure 6. Cross sectional view of the tall ribs in Exp. 1 (In order from left: 6 mm/ 10 MPa, 6 mm/ 20 MPa, 18 mm/ 15MPa, 18 mm/ 20 MPa, 30 mm/ 20MPa).

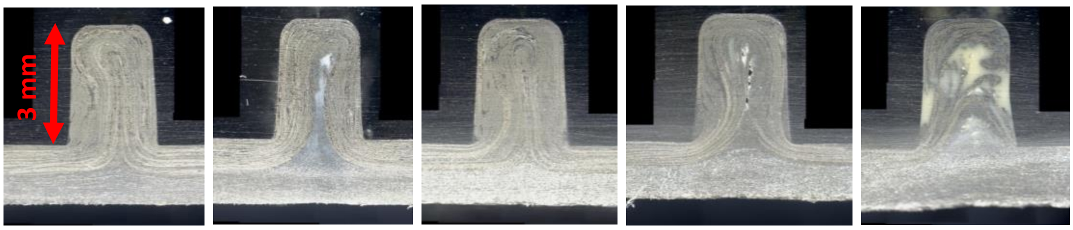

Figure 7. Cross sectional view of the short ribs in Exp. 1 (In order from left: 6 mm/10 MPa, 6 mm/20 MPa, 18 mm/15MPa, 18 mm/20 MPa, 30 mm/20MPa).

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4.2 Results of 3-point bending tests and observation (Exp. 2: sandwich panel)

Figure 8-10 represent the cross sections of the sandwich CFRTP. These figures show that the layer under the charging port of tall rib could not be molded as we expected. CPT layer was pulled up by upper UT-CTT and pushed up by lower UT-CTT. However, the disturbance of lower UT-CTT layers under the charging port was more in-plane moderately oriented in comparison with Figure 1.

Figure 11-13 represent the results of 3-point bending test. In 0° direction tests, in most case of every tape length, theoretical values were higher than those of experiments, since the ribs could not be filled with rCF as we expected. On the other hand, in 90° direction tests, theoretical values were lower than experimental values because ribs strengthen the flexural rigidity of plate. It's just because we calculated flexural rigidity as there was no reinforcement effect by ribs in 90° direction tests, as shown in Figure 5. The results of 18 mm tapes show that hybrid CFRTP has higher flexural rigidity than CFRTP which made by only UT-CTT, which indicates that the alignment under the charging port of ribs was not disturbed relatively. Moreover, samples of 18 mm tapes marked highest flexural rigidity in all tape length. It seemed 30 mm tapes could not be charged into ribs completely because of its lower flowability and the ribs did not strengthen the flexural rigidity of its plate efficiently.

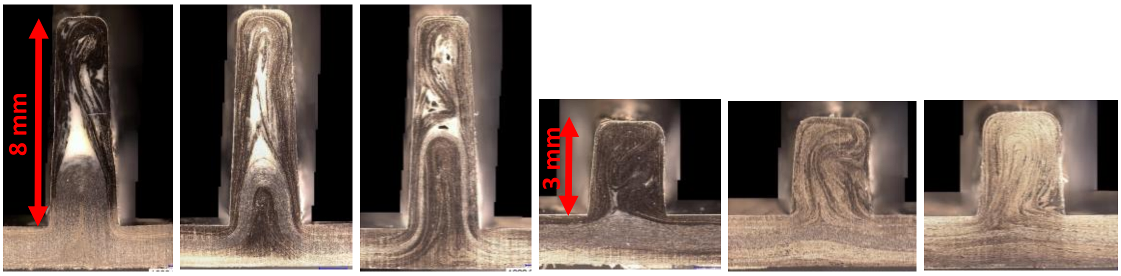

Figure 8. Cross sectional view of the tall and short ribs with the tape length of 6 mm in Exp. 2 (In order left side: No.2-1~2-3).

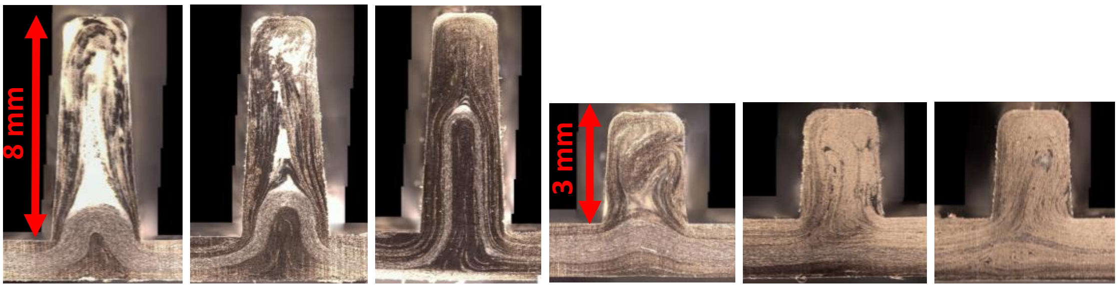

Figure 9. Cross sectional view of the tall and short ribs with the tape length of 18 mm in Exp. 2 (In order left side: No.2-4~ 2-6).

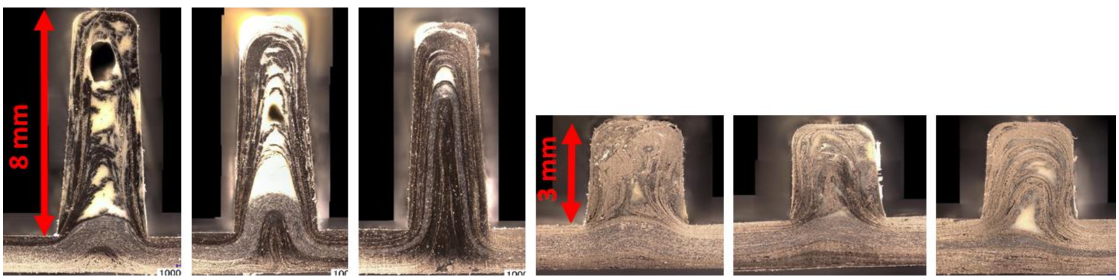

Figure 10. Cross sectional view of the tall and short ribs with the tape length of 30 mm in Exp. 2 (In order left side: No.2-7~ 2-9).

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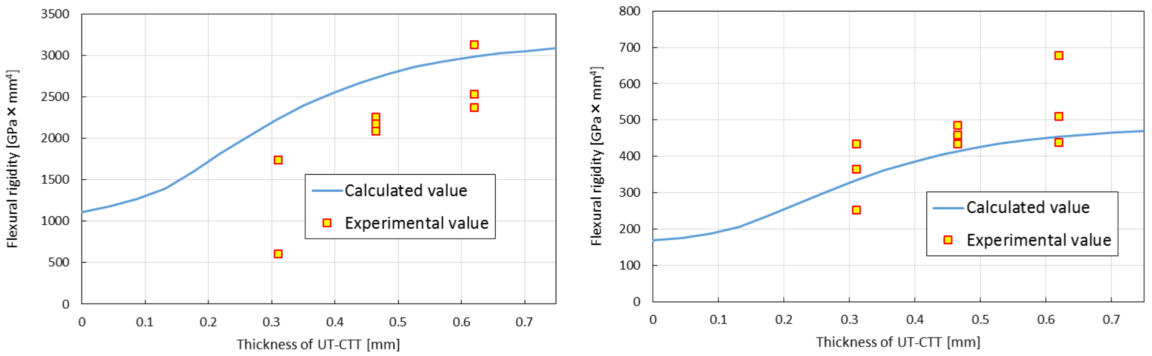

Figure 11. Flexural rigidity of the hybrid CFRTP with the tape length of 6 mm in Exp. 2 (Left: 0°, Right: 90°).

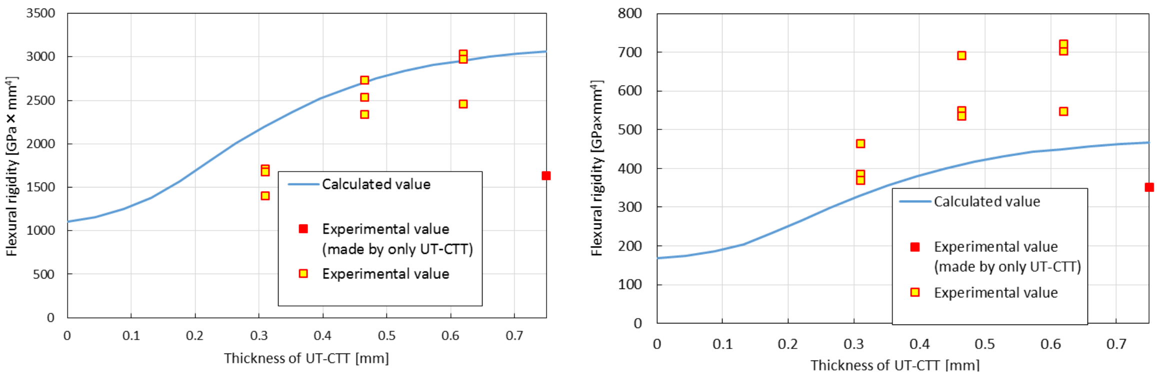

Figure 12. Flexural rigidity of the hybrid CFRTP with the tape length of 18 mm in Exp. 2 (Left: 0°, Right: 90°).

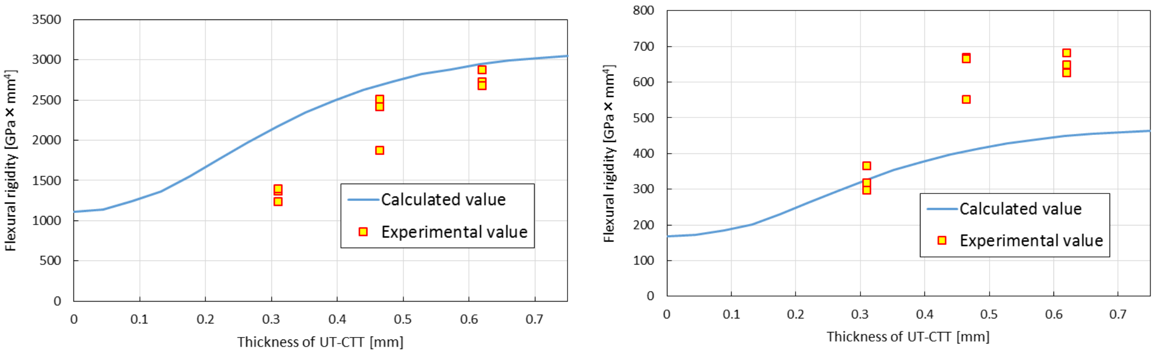

Figure 13. Flexural rigidity of the hybrid CFRTP with the tape length of 30 mm in Exp. 2 (Left: 0°, Right: 90°).

5 CONCLUSION

In this study, we investigated that we could control and balance the disturbance of the fiber alignment using flow characteristics of two different materials. The conclusion of this study is summarized below.

1) The one-side hybrid CFRTP can mitigate the disturbance of fiber orientation of UT-CTT around the charging port.
2) In the sandwich CFRTP, the fiber alignment of the UT-CTT layers under the charging port was relatively kept in-plane oriented compare with the sample made by only UT-CTT.

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3) In terms of the flexural rigidity, the calculated values of hybrid CFRTP were closer to the experimental values than those of CFRTP which was made by only UT-CTT.
4) The tape length of UT-CTT affected the flexural rigidity. When the tape length was 18 mm, the flexural rigidity marked the highest value and the calculated values were closest to the experimental values.

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