FLEXURAL BEHAVIOR OF CF/PP HOLLOW BEAM MADE BY CONTINUOUS AND DISCONTINUOUS UD TAPE

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Keywords: CF/PP, Hollow beam, Flexural behavior, Uni-directional tape.

Abstract

We fabricated 400mm long Carbon fiber/Polypropylene hollow beams consisting of impregnated uni-directional tape and they showed higher strength than steel beam in three point flexural test. The composite beams were made by thermoforming followed by vibration welding. Strength and modulus increased further by means of rib reinforcement and continuous tape reinforcement.

1 Introduction

Carbon fiber reinforced plastics have high relative stiffness and strength and are used in various industrial applications. Recently, carbon fiber reinforced thermoplastic (CFRTP) is gaining attentions because of its short molding cycle. So far, super-engineering plastics such as PEEK and PPS are mainly used as a matrix ([1], [2] and [3]), but too expensive to be used for mass-production cars. We developed polypropylene (PP) matrix CFRTP and its molding/welding technologies. Based on these technologies, we made strong CF/PP hollow beams, evaluated their characteristics and compared with those of steel beam.

2 Materials and testing methods

2.1 Materials

Carbon fiber for thermoplastic matrix (referred as TP-CF) and acid-modified PP (referred as modified-PP) were provided by Mitsubishi Rayon and Toyobo, respectively. Special surface-treatment of carbon fiber was designed to enhance the adhesiveness to modified PP. Uni-directional (referred as UD) tape was made by impregnating TP-CF with modified PP. Volume fraction of TP-CF was 50%.

2.2 Sample preparation

By using this tape, 3 types of blank were prepared.
Blank A-1: UD tape was cut, dispersed and consolidated to make a 5mm thick sheet. Length 380mm, width 50mm, weight 0.13kg.
Blank A-2: UD tape was cut, dispersed and consolidated to make a 7mm thick sheet. Length 380mm, width 50mm, weight 0.18kg.
Blank B : This blank consisted of two layers. The lower layer was cut-tape composite like A-1 or A-2. Its thickness, length, width and weight were 6mm, 380mm, 50mm and 155g, respectively. The upper layer was continuous tape composite. It consisted of 5plies; 0/90/0/90/0, and its thickness, length, width and weight were 1mm, 380mm, 50mm and 25g,

respectively. The total dimension was length 380mm, width 50mm and thickness 7mm and total weight was 0.18kg.
Two types of stamping molds were used to make a hat –channel shape part by blank A-1, A-2 and B.
a) Hat-channel shape mold without rib
b) Hat-channel shape mold with rib, rib height 10mm
Each blank was heated up to 230 degree C in infrared heater and afterwards placed on a mold. Mold temperature was controlled at 130 degree C. Two hat-channels were welded by vibration welding (Branson, M624) to make hollow beams A-1, A-2 and B.

2.3 Evaluation of flexural strength and modulus
Strength and modulus of each hollow beam was evaluated by 3 point flexural test (Shimadzu, Autograph). Support span was 300mm and cross head speed was 5mm/min. The radius of loading nose was 75mm. As a comparison, steel beam (electrolytic zinc-coated steel) was also evaluated. Its thickness was 1mm and weight was 0.63kg.

Sample Name		Steel Beam	Beam A-1 Discontinuous Tape Composite, without rib	Beam A-2 Discontinuous Tape Composite, with rib	Beam B Hybrid Composite, with rib
blank		-	A-1	A-2	B
Mold		-	a	b	b
Thickness	mm	1	2	2	2
Length	mm	400	400	400	400
Cross section	mm x mm	50 x 50	50 x 50	50 x 50	50 x 50
Rib height	mm	-	-	10	10
Weight	kg	0.63	0.26	0.36	0.36

Table 1. Hollow beams employed.

3 Results
3.1 Effects of surface treatment of CF and modification of PP
2 mm thick UD sheet was prepared by using UD tape consisting of TP-CF and modified PP. For a comparison, the combination of conventional carbon fiber and conventional PP was also employed. Each sample was broken and its cross section was observed by optical microscope. As shown in Figure 1, in the case of conventional CF/ conventional PP, they did not adhere with each other at all, and for TP-CF/ modified PP, they adhered well.

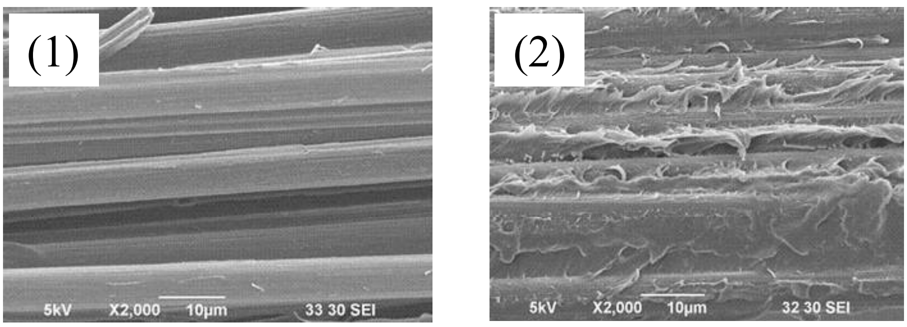

Figure 1. Comparison of adhesiveness between CF and PP.
(1) Conventional CF/ conventional PP, (2) TP-CF/ modified PP

0 and 90 degree flexural strength of 2mm thick UD sheets of conventional CF/ conventional PP and TP-CF/ modified PP were measured by Shimadzu Autograph based on JIS K 7017. As

shown in Table 2, due to enhanced adhesiveness between CF and PP, the latter had higher strength. For this reason, only TP-CF/ modified PP tape was used to fabricate hollow beams.

	Conventional CF/ conventional PP	TP-CF/ modified PP
0 degree Flexrual Strengh	400MPa	800MPa
90 degree Flexural Strength	8MPa	50MPa

Table 2. 0 and 90 degree strength of conventional CF/ conventional PP and TP-CF/ modified PP.

3.2 Vibration welding of discontinuous tape composite

Two hat channels were welded by vibration welding machine to form a hollow beam. Each hat channel was equipped with 10mm wide and 400mm long flange, and each flange of two hat channels were faced with each other and welded. Welding conditions were as follows; frequency 240Hz, amplitude 1.5mm, welding pressure 1MPa and penetration depth 0.5mm. Holding time after vibration welding was 5 sec. Figure 2. shows cross section of welding zone of beam A-1. The same welding method was used to make beams A-2 and B.

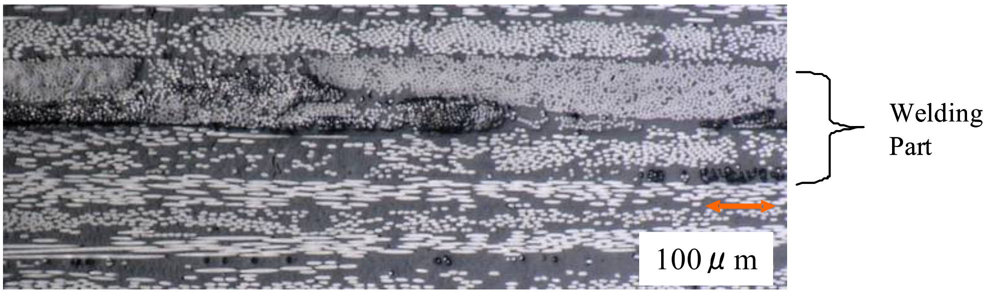

Figure 2. Welding zone observation of beam A-1 by optical microscope.

3.3 Flexural test of hollow beams

For each hollow beam sample, flexural test was conducted. The results are shown in Figure 3. Steel hollow beam showed highest modulus among all samples; however its strength was the lowest. In the case of steel beam, loading nose penetrated into the upper surface of the beam.
Beam A-1 was stronger than steel beam, but its stiffness was lower. In order to enhance the stiffness, beam A-2 was fabricated by using mold b. Because of rib installation shown in Figure 4, beam A-2 was heavier than beam A-1 by 0.1kg. Both strength and modulus increased by the effect of 10 mm height ribs as shown in Figure 4.
Strength and modulus were improved further by continuous tape reinforcement. Heated blank B was placed on mold b and pressed. By doing so, cut tape composite flew into cavities and ribs were formed. In the meantime, continuous tape composite formed the roof of the hat channel. By dual effects of rib installation and continuous tape reinforcement, very strong and stiff hollow beam was fabricated by using blank B. Flexural behavior of beam B and steel beam was shown in Figure 5. The upper part of beam B was partially broken, but lower part didn’t break. So, when the loading nose was removed, the beam became almost straight.

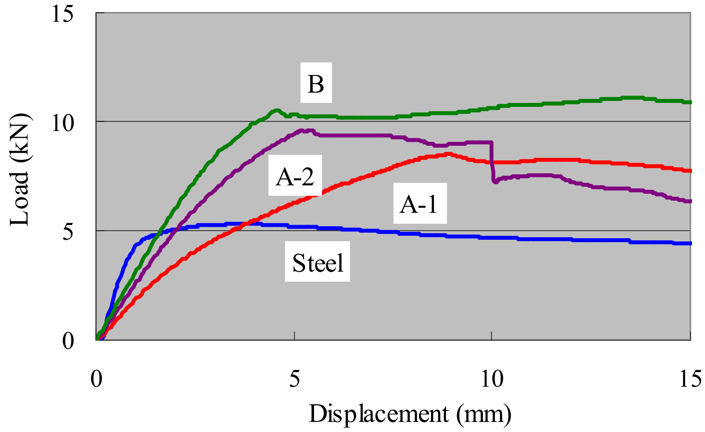

Figure 3. Flexural behavior of steel and CF/PP composite.
(A-1) Discontinuous tape composite without rib, (A-2) Discontinuous tape composite with rib, (B) Hybrid composite with rib.

Figure 4. CF/PP hat-channel reinforced by 10 mm high ribs.

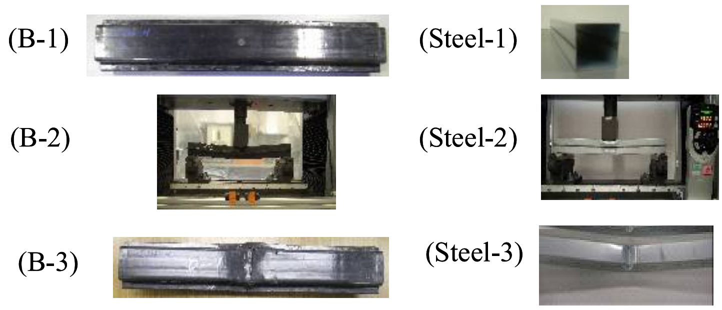

Figure 5. Flexural test of beam B and steel beam.
(1) Before test, (2) During test, displacement 15mm, (3) After test, displacement 50mm.

3.4 Effect of flexural rate

For beam A-2, the effect of flexural rate was evaluated. Instead of 5mm/min, flexural test was conducted at cross head rate 50mm/min. As shown in Figure 6, both strength and modulus were a little higher at 50mm/min than 5mm/min. We are planning to conduct flexural test at wider range of flexural rate.

Figure 7 shows the samples after flexural test up to displacement 50mm. For both samples of 5mm/min and 50mm/min, compression side and tensile side broken.

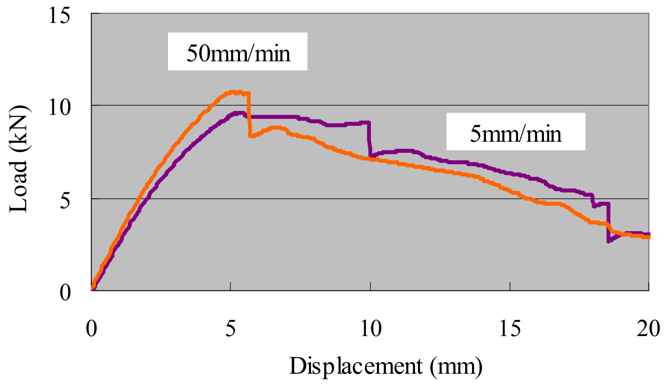

Figure 6. Flexural behavior of beam A-2.
Flexural rate: 5mm/min and 50mm/min.

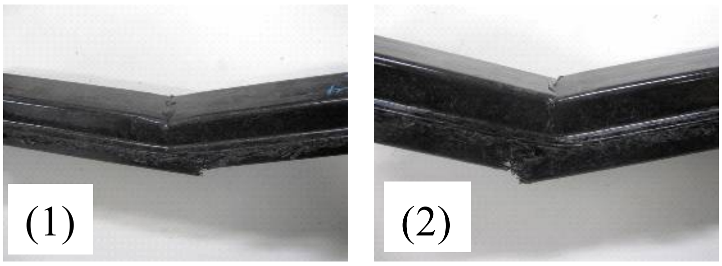

Figure 7. Samples after flexural test up to displacement 50mm of beam A-2.
(1) 5mm/min, (2) 50mm/min.

3.5 Experimental summary

From Figure 3, maximum load (σ) and displacement at 3kN (d) were obtained. In this table, σ (kN)/W(kg) and 3(kN)/(d(mm)xW(kg)) were considered as relative strength and relative modulus, respectively. Table 3 and Figure 8 summarize the results. All composite beams A-1, A-2 and B had higher relative strength than steel beam. Relative modulus of beam A-2 was almost same as that of steel beam. Beam B had higher relative strength and modulus than steel beam. Beam A-1 had the highest relative strength. Beam A-2 had higher strength than beam A-1, but it was heavier than beam A-1 by 0.1kg, so relative strength was lower. Beam B had the well balanced characteristics.

Sample Name		Steel Beam	Beam A-1 Discontinuous Tape Composite, without rib	Beam A-2 Discontinuous Tape Composite, with rib	Beam B Hybrid Composite, with rib
Blank		-	A-1	A-2	B
Weight (W)	kg	0.63	0.26	0.36	0.36
Maximum load (σ)	kN	5.3	8.5	9.6	10.5
σ /W	kN/kg	8.4	32.7	26.7	29.2
Displacement at 3kN (d)	mm	0.64	1.73	1.14	0.94
Initial Modulus (E)	kN/mm	4.7	1.7	2.6	3.2
E/W	kN/(mm.kg)	7.4	6.7	7.3	8.9

Table 3. Flexural characteristics (Cross head rate: 5mm/min).

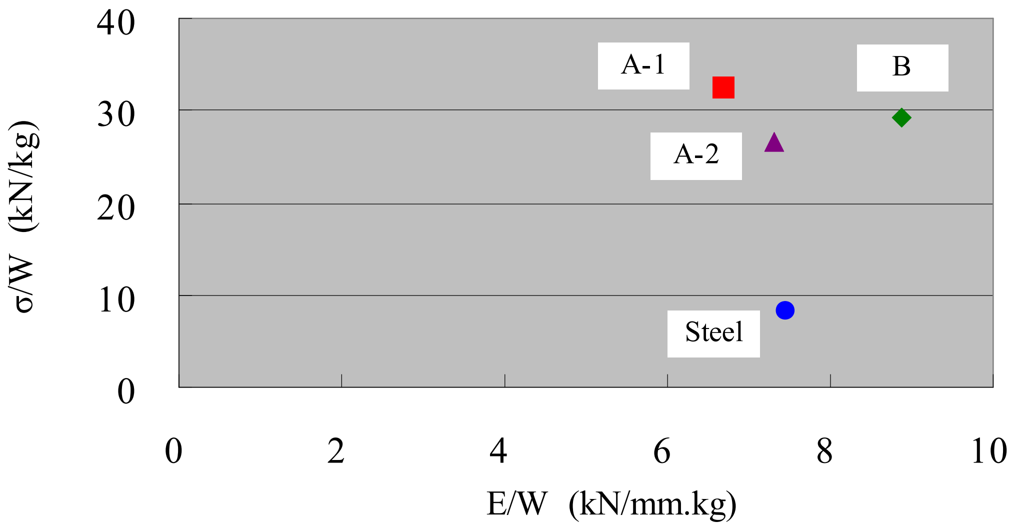

Figure 8. Relative strength and modulus of hollow beams.

4 Simulation of CF/PP hollow beams

Flexural behavior of beams A-1 and A-2 was simulated by using LS-Dyna. Figure 9 shows the deflection of each part in Z-direction (Load direction) at displacement of cross-head 2mm. In the case of beam A-1, The area beneath the loading nose deforms locally, because there is no rib reinforcement. In the case of beam A-2, the beam bends overall, because the beam is stiffer than beam A-1 due to rib reinforcement. These simulation results matched with experimental data well.

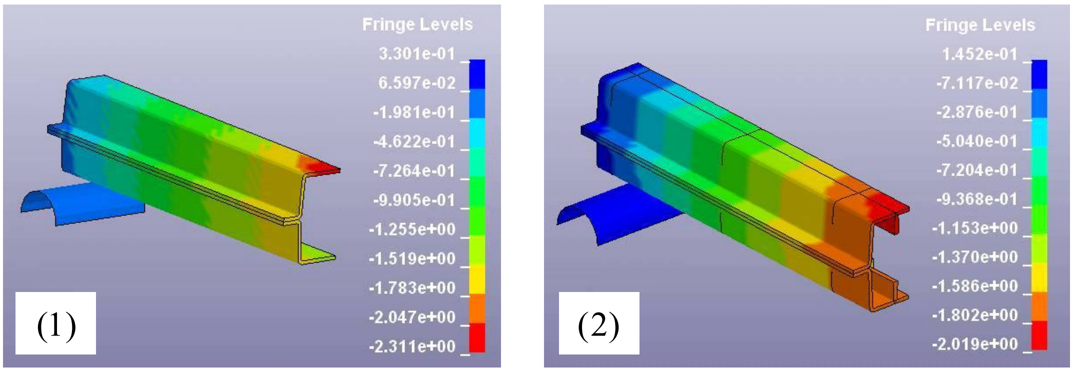

Figure 9. Displacement of Z-direction of CF/PP hollow beams.
(1) beam A-1, (2) beam A-2.

Acknowledgement

This work belongs to Japanese METI-NEDO project "Development of sustainable hyper composite technology" since 2008fy.

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