THE MANUFACTURING OF CARBON-FIBER PAPER REINFORCED THERMOPLASTIC CORE SANDWICHED PANELS UNDER SEVERAL DEGREES OF CONSOLIDATION

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Abstract

In this study, carbon-fiber paper reinforced thermoplastics (CPT) was investigated with various degrees of consolidation as cores to be sandwiched with strong faces, unidirectional carbon fiber prepreg (UD). the sandwich was molded by one-step forming method which gets rid of the process of the face and core molding separately and the adhesion. And the comparison was made through the different consolidation levels on the flexural behavior and the impact property of the CPT core sandwich beams.

1. Introduction

In the past decades, thermoplastic composites have been attracting more and more attentions from researchers and widely used in automotive, infrastructure and biomedical [1]. Compared with thermosets, some incomparable priorities such as high speed molding availability, better environmental compatibility and higher impact toughness make it a prospective material for engineering development [2]. In particular, thermoplastic composites are reprocessable through post thermoforming, which reveals its potential to reuse and recycle. However, as will be addressed later, during the processing, there will be chemical shrinkage, thermal expansion, thermal contraction and other complex factors introducing lock-in stress inside [3]. And these stresses may result in low part quality and even render the part useless due to the release of the locked-in stresses and void content increase during the post thermoforming process, which can be called de-consolidation [4]. Xiao et al. found he content of voids due to de-consolidation may be over 10–20% of the whole volume of the composite [5]. Ye et al. proposed a void growth model to evaluate the degree of deconsolidation in a post-thermal operation on glass fiber-polyamide 12 composites [2]. Although high void content may lead to deterioration in mechanical property, it can be feasible to reduce the density of the composite and absorb unwanted energy like impact force, vibration, compressive stress and acoustical shock, thus, to take advantage of which, carbon-fiber paper reinforced thermoplastics (CPT) was investigated with various degrees of consolidation as core to be sandwiched with strong faces, unidirectional carbon fiber prepreg (UD). In general, sandwich structures consist of laminate face sheets and cores including polymers, aluminum, wood and composites where to minimize weight they are used in from of foams, honeycombs or with truss structures [6]. Allen gave a comprehensive introduction to sandwich structure and the theoretical analyses [7] which was updated by Zenkert [8]. Adhering is now considered as the most economic and relatively easy way for the joining of the honeycomb core or between faces and core [9], however, it is still inefficient to produce sandwich materials. In this study, the sandwich was molded by one-step method which gets rid of the process of the face and core molding separately and the adhesion. And the comparison was made through the different consolidation levels, the flexural behavior and the impact property of the CPT core sandwich beams. In addition, surface morphology of cross section was observed with optical microscope.

2. Materials and experiments

2.1. Materials

The core material is CPT where polyamide 6 (PA6) fibers and 6 mm-long carbon fibers were blended and processed by paper making technology into sheet.
The facing material is 132 μm-thick unidirectional CF/PA6 prepreg (CF, TR50S, Mitsubishi Rayon Co. Ltd.; PA6, Mitsubishi Plastics Co. Ltd.).
The detail information of the materials used is shown as Table 1.

Table 1. The information of the materials

	CPT	UD
Vf of CF[%]	23.1	54.0
Density[g/cm^3]	1.30	1.51

2.2. Manufacturing of the sandwich panels

In the core preparation, CPT sheets fit for the mold size were cut from carbon paper roll by both machine direction (MD) and transverse direction (TD) and then stacked by cross stacking sequence with MD and TD sheets to reach in-plane anisotropy because the mechanical performance is a little different between MD and TD.
In the facing preparation, UD sheets were cut from 132 μm-thick unidirectional CF/PA6 prepreg in 0° direction. Both the upper facing and bottom facing were made with same number of UD sheets to produce symmetric structure.
From previous work, it is found two-step forming method[10] is feasible to manufacture the UD/CPT sandwich because of its high production efficiency and better flexural behavior in sandwiches where in Two-step forming, both core and facings were stacked and placed onto the mold to manufacture sandwich panels directly with designated temperature and pressure; and then the panel was set onto molding die again to be reheated under thickness controllers for getting designated thick sandwich panels. In this study, a further improved forming method named One-step forming method was introduced to acheive higher production efficiency where both core and facings were stacked and placed onto the mold with thickness controllers directly under 5 MPa pressure, 270 °C. The processing schematic diagrams of Two-step forming method and One-step forming method are shown as Fig. 1.

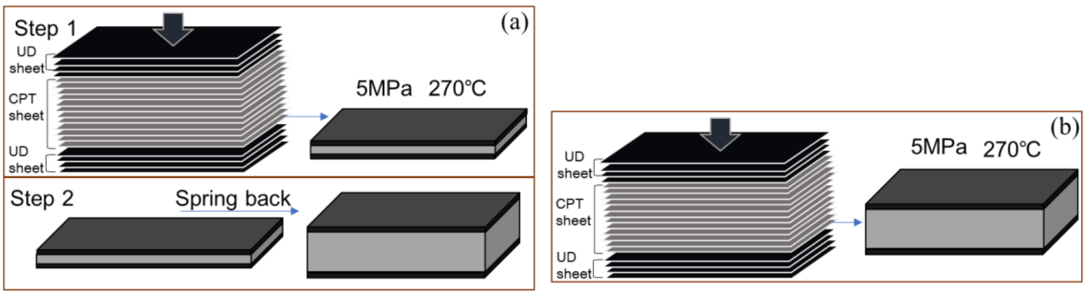

Figure 1. The processing schematic diagrams: (a) The process of Two-step forming; (b) The process of One-step forming

Consolidation ratio (CR) is the ratio of target core thickness to the full consolidated core thickness (under 5MPa pressure). The detail information of sandwich panels is shown in Table 2.

Table 2. The information of the sandwich panels

		Number of CPT sheets (Vf=20%)	Consolidation ratio	Forming method	Facing thickness [mm]	Core thickness [mm]	Sandwich thickness [mm]
A-1-CR3-a	8UD6CPT-CR3-a	12	3	Two-step	1	3	5
A-1-CR3-b	8UD6CPT-CR3-b	12	3	One-step	1	3	5
A-1-CR2.57	8UD7CPT-CR2.57	14	2.57	One-step	1	3	5
A-1-CR2.25	8UD8CPT-CR2.25	16	2.57	One-step	1	3	5
B-2-CR3	4UD8CPT-CR3	16	3	One-step	0.5	4	5
B-1-CR3	4UD6CPT-CR3	12	3	One-step	0.5	3	4
B-1-CR2.57	4UD7CPT-CR2.57	14	2.57	One-step	0.5	3	4

2.3. Three point bending test

Static three-point bending test of the sandwich beams were performed in accordance with the ASTM D 790 standard through a table-top precision universal tester from Shimadzu Corporation.

2.5. Three point impact test

Three point impact test was performed by a high-speed puncture impact tester from Shimadzu Corporation HITS-P10.

3. Results and discussion

3.1. Comparsion on One-step and Two-step forming methods

It was assumed that the flexural behavior of the sandwich panels by Two-step method would show better than the ones by One-step forming method because we supposed that the first step in Two-step would make sure the resin infiltrated well through the whole sandwich body and reduce the void content, however, it is obvious that the sandwich under One-step forming method share almost the same flexural property compared the one under Two-step forming as Fig. 2 shows. Therefore, it is considered that the facing suffered from the thermal heating twice with the high temperature which might probably cause thermal damage on the facing and affect the performance of the whole beam in the Two-step forming, meanwhile, in the case of One-step forming, although the designated thickness might lead to lack of pressure to mold the facings, stress release during heating on CPT sheets provide certain pressure to compact facings.

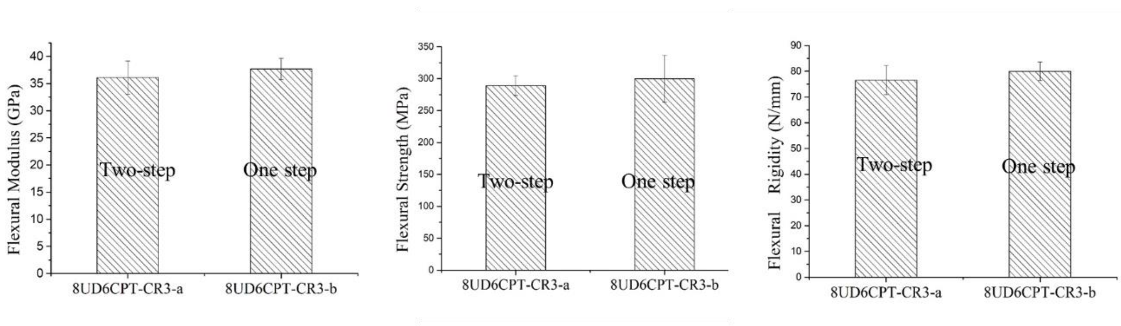

Figure 2. The flexural property comparison between One-step and Two-step forming methods

3.2. Flexural property of the sandwiches by One-step forming method

Fig. 3 represents the typical stress-strain curves for different consolidation ratio core and differet thick facing sandwich beams solicited in three point bending. The stress-streain curves of sandwich beams break up into three phases: the first phase shows initial linear elastic behavior which corresponds to the tension and compression of the facings and the first peak starts with the upper facing failure; and then the rest part of sandwich tends to suffer from core crushing and tension in the bottom facing where the second phase shows nonlinear behavior, which followed by a phase of a reduction in the load applied where the bottom facing fails. Therefore, the sandwiches show ductile behavior under flexural failure.

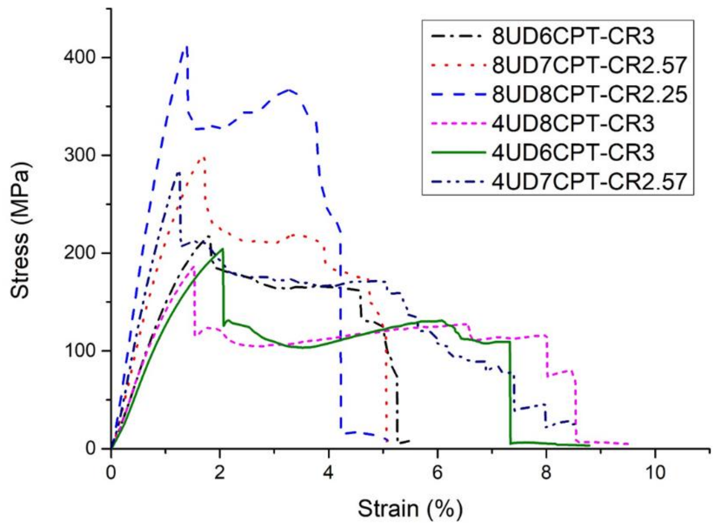

Figure 3. Stress-strain curves

3.3. Flexural property of the sandwiches by One-step forming method

Fig. 4 shows the comparisons on flexural modulus and flexural rigidity of the sandwiches. With the increase of the consolidation level where it means the decrease of consolidation ratio, both the flexural modulus and flexural rigidity increased. There is an assumption that the core property determines where the tendency of the flexural property goes. But referring to the case of A-1-CR2.57 and B-1-CR2.57, at the same consolidation ratio and core thickness, doubling the facing thickness, the flexural modulus and flexural stiffness didn't show superiority. Therefore, facing property also matters in different consolidation ratios. It is supposed to consider higher consolidation level produce better molding condition to facing, let's to say, the facing in lower CR sandwich get less defects than the one in higher CR. Because the earliest and highest peaks in S-S curves were caused by upper facing failure which means the critical failure is the compression failure type where the tension failure or core crushing didn't occur at the same time with the compression failure at the first phase. Therefore, according to ASTM C393, the facing strength was calculated as shown in Fig. 5. It is obvious that the facing condition on high CR is better. Furthermore, the sandwich of B-1-CR2.57 gets highest facing bending strength which is even higher than the sandwich with lower CR and thicker facing, A-1-CR2.25. That is because the outer UD sheets of thicker facing was not able to get enough pressure by the released pressure from the core and it has more defects.

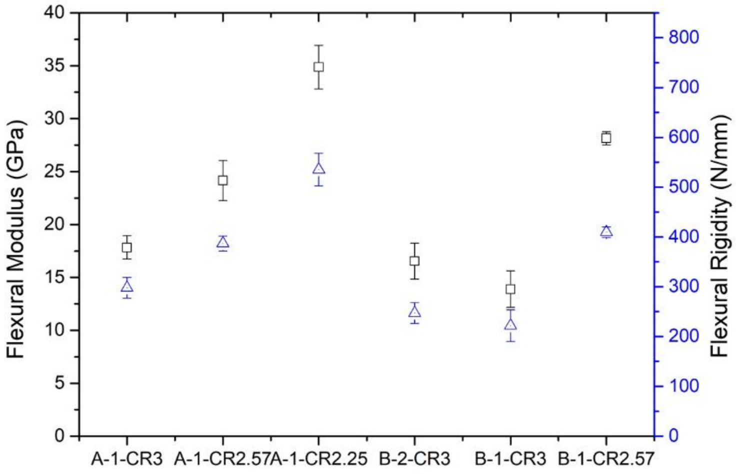

Figure 4. Comparisons on flexural modulus and flexural rigidity

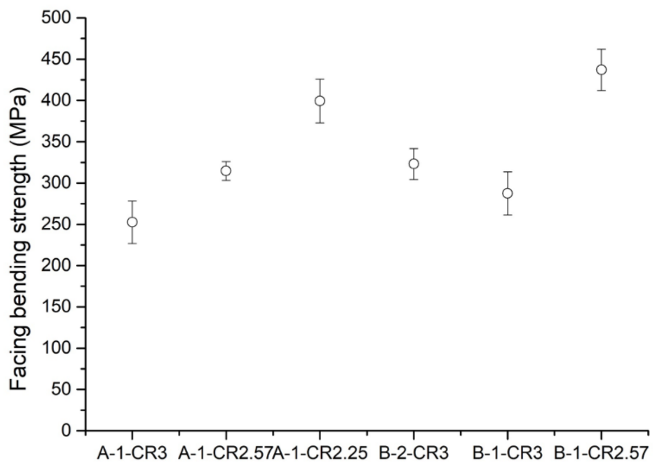

Figure 5. Facing strengths of the sandwiches

3.4. Energy absorption of the sandwiches by One-step forming method

Fig. 6 shows the load-displacement curves of the sandwiches under three point bending impact test. Like the tendency in the static test, the extended phase can also be seen after the first peak. And from the total energy absorption result, with the same CR and thickness, the thinner facing sandwiches absorbed more energy than the thicker one, which is because the core part contain higher air space and is durable to absorb more energy. When compared with UD and CPT, the sandwiches show superiority as shown in Fig. 7.

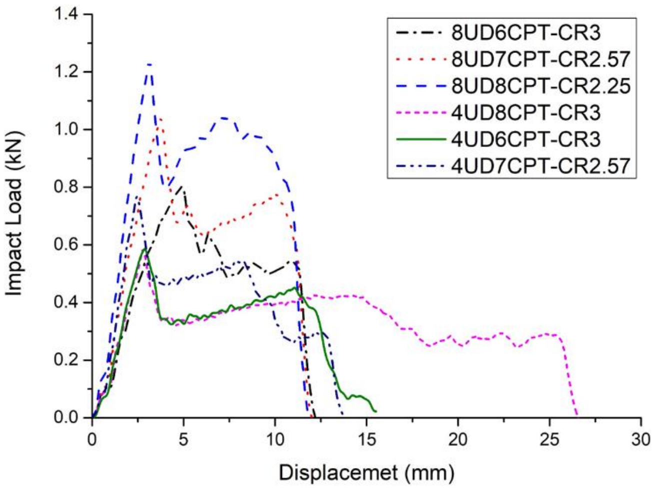

Figure 6. Load-displacement curves of three point bending impact test

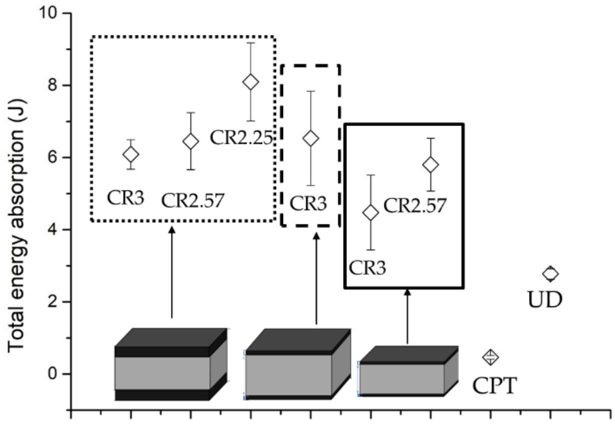

Figure 7. Total energy absorption

3.5. Specific flexural and energy absorption of the sandwiches by One-step forming method

As is known to us, sandwich composites are becoming more and more popular in structural design, mainly for their ability to substantially decrease weight, thus, the evaluation of weight lightening potential should be also discussed, which can be seen from Fig. 8 and Fig. 9.

In Fig. 8, the type B-1-CR2.57 sandwich has both the highest specific stiffness and specific strength. When it comes to the specific energy absorption, at the same consolidation ratio, thinner facing sandwich perform better compared with the thicker facing sandwich which is because thinner facing sandwich tends to have lower density.

From Fig. 8(b), compared with some steel and aluminum materials, the sandwiches have even more than four times higher specific flexural stiffness and strength. And the specific total energy absorption of the sandwiches are also higher than that of UD and CPT.

It is reasonably to get this kind of sandwich into further investigation and some real application.

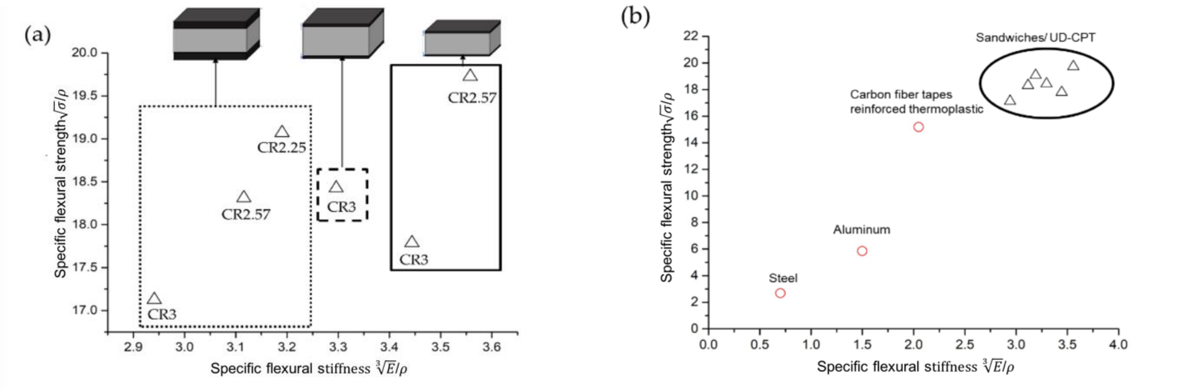

Figure 8. Comparison of weight lightening potential: (a) Specific flexural property of the sandwiches; (b) Comparsion with other materials

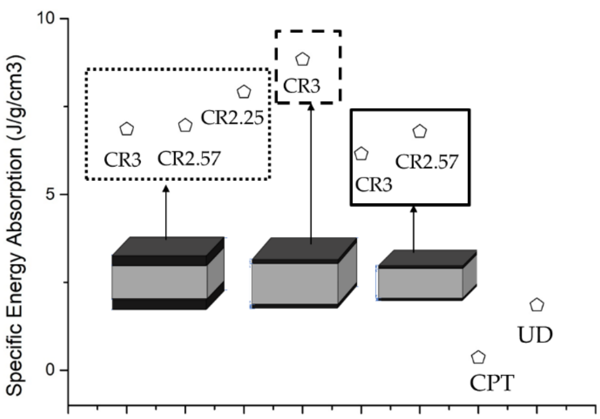

Figure 9. Specific energy absorption

4. Conclusions

At the current study, carbon-fiber paper reinforced thermoplastics (CPT) was investigated with various degrees of consolidation as cores to be sandwiched with strong faces, unidirectional carbon fiber prepreg (UD). And the comparison was made through the different consolidation levels on the flexural behavior and the impact property of the CPT core sandwich beams.

It is found that One-step forming method is feasible to manufacture the UD/CPT sandwich because of its high production efficiency and better flexural behavior in sandwiches compared with the Two-step forming method. At the same consolidation level and thickness, thinner facing sandwich show better performance on both flexural property and energy absorption property. Lastly, the UD/CPT sandwich shows excellent specific flexural property and energy absorption property when compared with other materials. For developing this kind of sandwich, it is necessary to design optimal facing thickness and consolidation ratio of the core to achieve balance between production high efficiency and engineering performance.

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