# A STUDY ON HYBRIDIZATION OF SPRINGBACKED CARBON FIBER REINFORCED THERMOPLASTICS

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## ABSTRACT

Carbon fiber reinforced thermoplastics (CFRTP) have increasingly attracted attention with their outstanding advantages of short molding cycle time, energy absorption capacity and formability for multiple times. In relation to fabrication of CFRTP, there is a characteristic phenomenon, called springback. Springback is the deformation of randomly oriented short fiber reinforcement thermoplastic resulting from deconsolidation. Springback phenomenon decreases the density of CFRTP and expected for weight reduction of component design. However, after springback, there are some problems (degradation of mechanical properties and interlayer bonding properties, and so on) for practical application. In this paper, we managed to solve these problems and apply springbacked CFRTP for making lightweight composites by several hybridization combinations.

## 1 INTRODUCTION

As the ideal material for lightweight products, CFRTP (carbon fiber reinforced thermoplastics) have recently been paid attention to, because of its advantage in suitability for lightweight applications. CFRTP application leads to reduction of energy use and solution of some environmental issue such as global warming. Moreover, CFRTP is useful not only for lightweight products, but also for multiple times formability. Regarding the formability, there is a characteristic phenomenon, called springback. This is a deformation of randomly oriented short fiber reinforcement thermoplastic resulting from deconsolidation [1]. After the springback, the density becomes lower, which gives an advantage in weight reduction. However, after springback, there are many problems for practical application due to the degradation of mechanical properties and interlayer bonding properties between the layers which are fabricated by stacking short fiber reinforced sheets. Moreover, springbacked CFRTP had poor adhesion with adhesives because of its porous structure [2]. To solve these problems, hybridization is introduced in this study. Hybridization aims to take an advantage of the merits of each component material without introducing the relative weakness [3]. And we examined whether springbacked CFRTP have the potential for practical application.


Figure 1: A typical hybrid specimen with springbacked core material
after three point bending test [2].

## 2 MATERIALS

In this study, we used three types of CFRTP as follow for making hybrid CFRTP plates.

### 2.1 UT-CTT

UT-CTT (ultra-thin chopped carbon fiber tape reinforced thermoplastics: Fig.2) were made from unidirectional CF/PA6 prepreg sheet with the thickness of 44 µm, and the $V_f$ is about 55%. Carbon fiber was provided by Mitsubishi Rayon Co., Ltd. This sheet was made by using two spreading technology of Industrial Technology Center of Fukui Prefecture [4].

First, in order to make prepreg sheet into chopped tapes, an automated tape cutter and Tomson cutter were used. The tape length was 19 mm and the width is 5 mm. The chopped tapes were dispersed by wet dispersion process and then heated with compressing under 1 MPa and 260℃ for 90 sec to make fixed and portable sheets. This procedure can prevent chopped tapes from orientating out-of plane direction. In this study, UT-CTT was used for skin material because of its high mechanical properties.

Figure 2: The appearance of UT-CTT.

### 2.2 CPT

CPT (carbon fiber paper reinforced thermoplastics: Fig.3) are made from the recycled carbon fibers (RCF) and PP (Polypropylenes) or PA6 (Polyamide-6) fibers [5]. RCF originally provided by Toray Industries Co. was recycled by means of depolymerisation technique of Hitachi Chemical Co., Ltd. CPT can be made by RCF without degradation of the mechanical properties [6]. The length of RCF, PP and PA6 fibers were 6 mm. Each carbon fiber volume fraction was 19.4% (PP) and 24.1% (PA6). In this study, we selected CPT (PP) as springback material. That’s because the melting point of polypropylenes is lower than PA6. Therefore, we can induce core materials which made of carbon fibers and polypropylenes to springback without influencing except for CPT (PP).

Figure 3. The appearance of CPT.

### 2.3 THICK CPT (T-CPT)

In this study, we made thicker CPT (PP) as usual to aim for improving flexural properties of CPT composites after springback. After springback, CPT plate which was made by stacking CPT sheets delaminates easily between layers [7]. Therefore, we tried to make thick CPT which has enough thickness not to need to stack CPT (PP) sheets to get target thickness. Thick CPT (T-CPT) was made by wet dispersion process. First, stirred CPT (PP) sheets by mixer and dispersed it by wet dispersion process with binder (0.05 cc/l) and dispersing agent (1 cc/l). Then, squeezed the T-CPT by metal plates for fixing it and evaporated water by drier, and then pressed it under 1 MPa with 190℃ for stability (Fig.4).

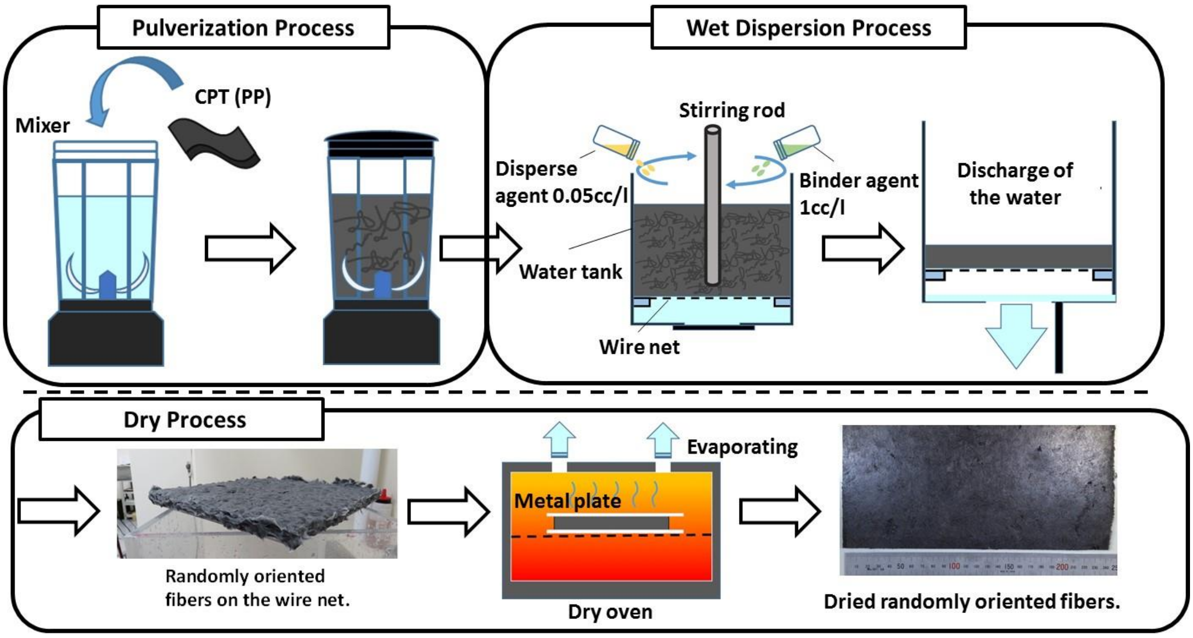


Figure 4: The schematic images of making process of T-CPT.

## 3 EXPERIMENTS

### 3.1 CORE CONDITIONS

In order to examine the flexural rigidity of hybrid composites with springbacked CPT (PP) as core materials in hybrid composites. We introduced 4 types of core conditions like Fig.1 (Exp1-4). The skin layers were consisted of UT-CTT with the thickness 0.4 mm in every condition. In Exp.1, CPT (PP) sheets were just stacked as core layers. In Exp.2, core layer was stacked same as Exp.1, but CPT (PA6) sheets were interposed between core and skin layer for adhesive agent. Former study suggested that this kind of adhesive agent is useful for improving interlaminar bonding properties between skin and core layers [2]. In Exp.3, we applied T-CPT for core material. In Exp.4, we used T-CPT and CPT (PP) as Fig.5. After compression molding, the thickness of the CPT (PP) and T-CPT were 1 mm (in Exp.1-4) and the thickness of the CPT (PA6) was 0.2 mm (in Exp.2 and 4).

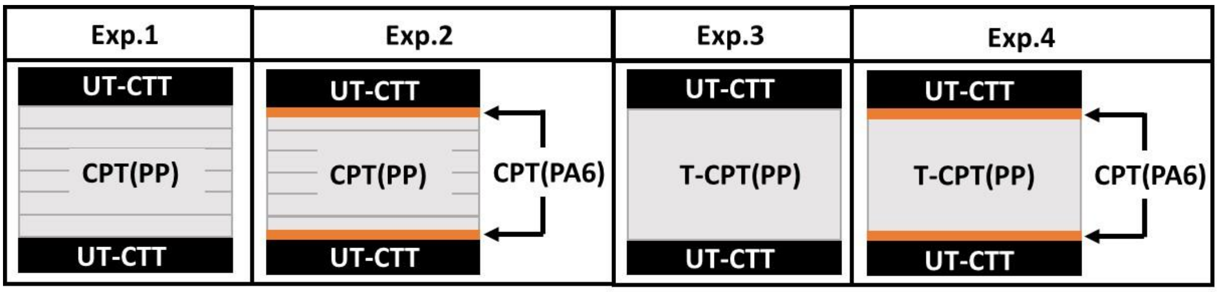


Figure 5: The schematic images of Exp.1-4.

### 3.2 COMPRESSION MOLDING

To make hybrid composites with springbacked CPT, in this study, we made hybrid composites first by compression molding with high pressure, and then reheated it to induce core materials to be springbacked with low pressure. First, UT-CTT and CPT sheets were cut into required size (25.0 mm ×12.5 mm), and stacked the sheets into the mold. The compression molding process was accomplished by a hot press machine (Pinette Emidecau Industries). The molding pressure was set at 5 MPa and the molding temperature was constant 260℃ for 5 min under the pressure.

### 3.3 INDUCE SPRINGBACK

To make hybrid composites induce springback, hot press machine was introduced. First, put specimens into hot press machine. Considering melding temperature of PP (about 160℃), the temperature was set at 190 ℃ and heating time was 10 minutes to induce springback. In order to control the springback ratio of the core materials, distance between platens of hot press machine was kept same position by using spacers. The platen was pressed with 5 MPa in order to prevent the distance between platens from moving by the pressure of springback (Fig.6).

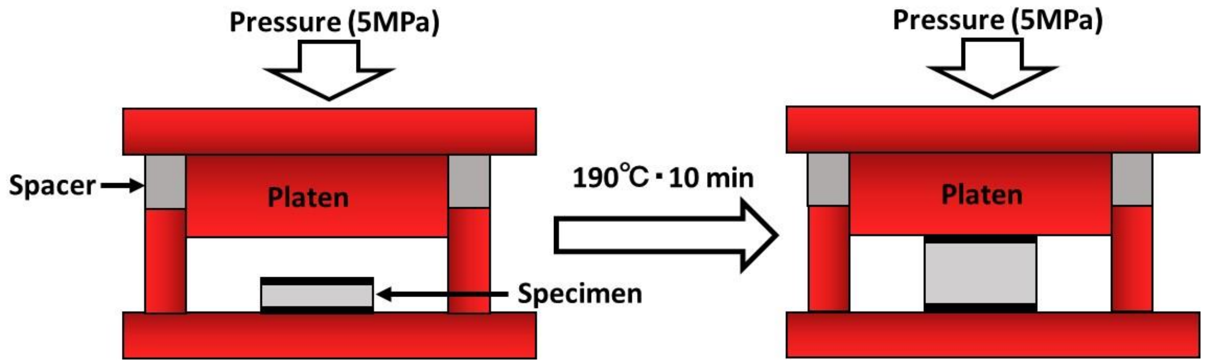

Figure 6: The schematic images of springback process by heat press machine.

### 3.4 FOUR POINT BENDING TEST

Four point bending tests were conducted to evaluate the flexural properties of hybrid CFRTP plates with springbacked core materials. Dimensions of specimens were decided based on ISO standards. Table 1 shows dimensions of the specimens used for four point bending tests. Springback ratio (SB ratio) was calculated by below equation.

$$\text{SB ratio} = \frac{\textit{the thickness of CPT (PP)}\ \boldsymbol{after}\ \textit{springback}}{\textit{the thickness of CPT (PP)}\ \boldsymbol{before}\ \textit{springback}}$$

Regarding the aspect flexural modulus, we compared the experimental values and the calculated values to examine practicality for component design. The Calculated values were led by Euler-Bernoulli beam equation and the parameters of these experiments are shown in Fig.7 and Table 2.

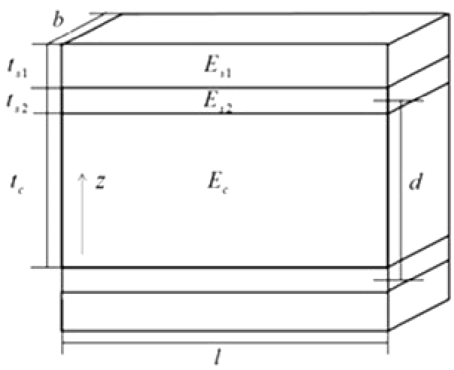

Figure 7: The definition of hybrid plate dimensions.

Table 1: Specimen dimensions for four point bending test.

| | Dimension of specimen | | | SB ratio | Span length | Stroke speed | Number of specimen | Reference standard |
|---|---|---|---|---|---|---|---|---|
| | Length [mm] | Width [mm] | Thickness [mm] | | [mm] | [mm/min] | | |
| Exp.1 | 144 | 23 | 3.6 | 2.8 | 120 | 8.4 | 5 | ISO 14125 |
| Exp.2 | 148 | 22 | 3.7 | 3.2 | 120 | 8.4 | | |
| Exp.3 | 124 | 23 | 3.1 | 2.5 | 105 | 7.3 | | |
| Exp.4 | 128 | 23 | 3.2 | 2.5 | 105 | 7.4 | | |

Table 2: The parameters for calculated values of the aspect flexural modulus.

| | | Exp.1 | Exp.2 | Exp.3 | Exp.4 |
|---|---|---|---|---|---|
| $t_{s1}$ | [mm] | 0.40 | 0.40 | 0 | 0 |
| $t_{s2}$ | [mm] | 0.20 | 0.20 | 0.40 | 0.40 |
| $t_{s3}$ | [mm] | 3.0 | 3.0 | 3.0 | 3.0 |
| $E_{s1}$ | [GPa] | 35.2 | 35.2 | 0 | 0 |
| $E_{s2}$ | [GPa] | 21.1 | 21.1 | 35.2 | 35.2 |
| $E_c$ | [GPa] | 3.5 | 2.4 | 3.5 | 2.4 |
| b | [mm] | 25 | 25 | 25 | 25 |
| l | [mm] | 139 | 139 | 125 | 125 |
| Aspect modulus | [$\sqrt{GPa}$/( g/cm$^3$)] | 4.0 | 4.0 | 4.3 | 4.3 |
| Experimental value | [$\sqrt{GPa}$/( g/cm$^3$)] | 3.8 | 3.8 | 4.3 | 4.2 |
| Standard deviation | [$\sqrt{GPa}$/( g/cm$^3$)] | 0.040 | 0.040 | 0.14 | 0.067 |
| Coefficient of variation | [%] | 1.2 | 1.2 | 3.3 | 1.6 |
| P | [g/cm$^3$] | 0.62 | 0.62 | 0.62 | 0.62 |
| $\alpha$ | | 1.15 | 1.09 | 0.970 | 1.10 |

## 4 RESULTS

The results of four point bending tests are shown in Fig.8-11. First, the observation of failure mode is discussed. The failure mode divided into two types (Fig.8 and 9). In cases of Exp.1 and Exp.3, interfacial out-of plane delamination was occurred. In case of Exp.2 and Exp.4, interfacial shear delamination was occurred.

Based on flexural strength, the coefficient of variation of formers was larger than that of later. Considering the effect of CPT (PA6) sheets for adhesive agent, it can restrain the coefficient of variation in specific flexural strength (Fig.10). The specific flexural strength was improved by using T-CPT. It presumed that T-CPT have more fibers which have out-pf plane directions than stacking CPT. The out-of plane fibers strengthen the core properties, because that fibers has resistance to vertical load.

In the specific flexural strength and stiffness, the condition of Exp.4 had the highest values in every conditions (Fig.10 and 11). The value of Exp.4 remarked eight times as high as steel in the specific flexural strength and six times as high as steel in the specific flexural stiffness. Moreover, especially in specific flexural stiffness, the calculated values were in good agreement with the experimental values of that.

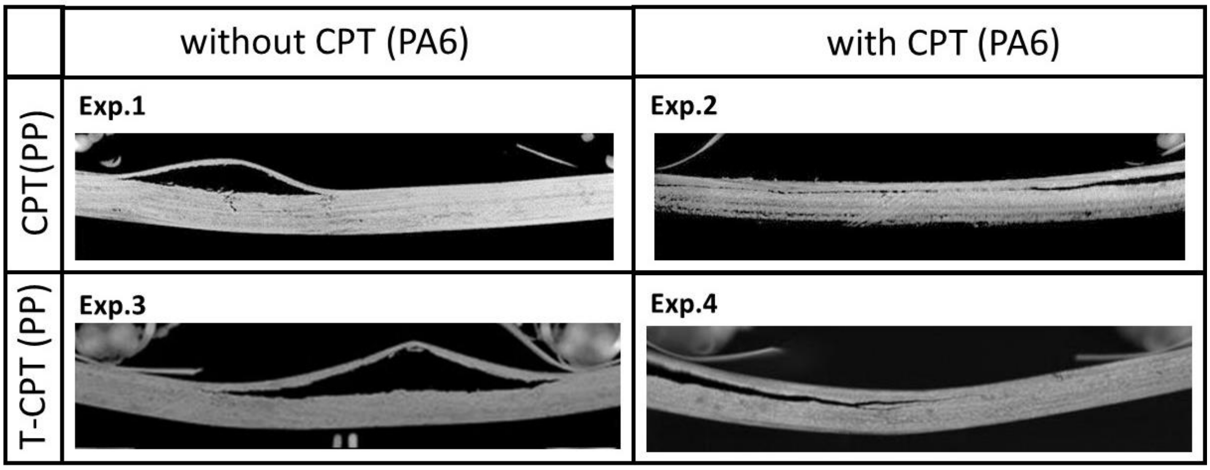


Figure 8: Observation of initial failure process by high speed camera.

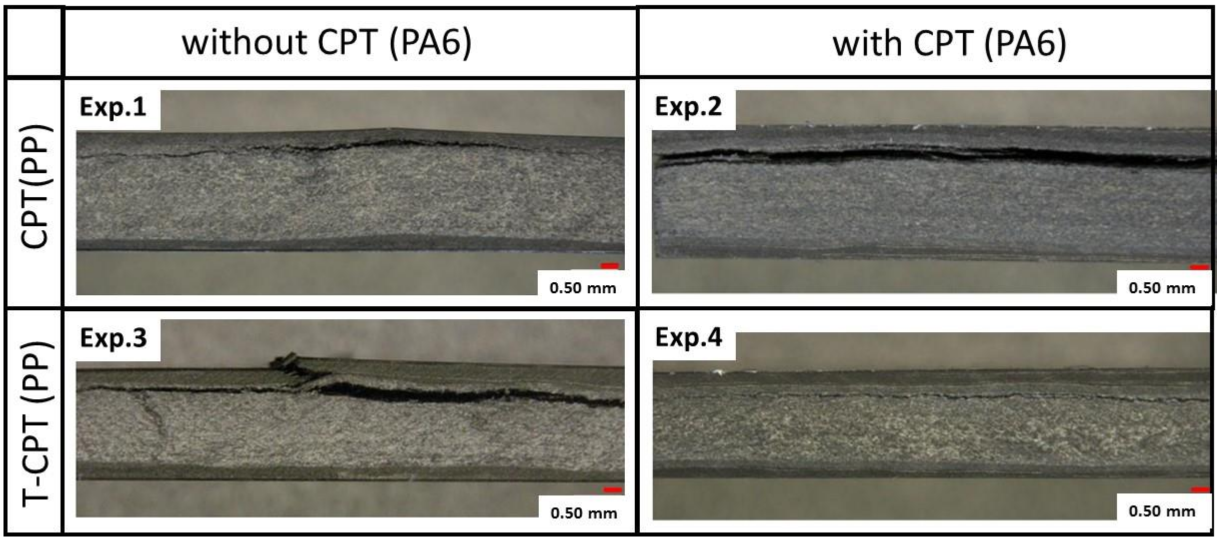


Figure 9: The cross section of the specimens after four point bending tests.

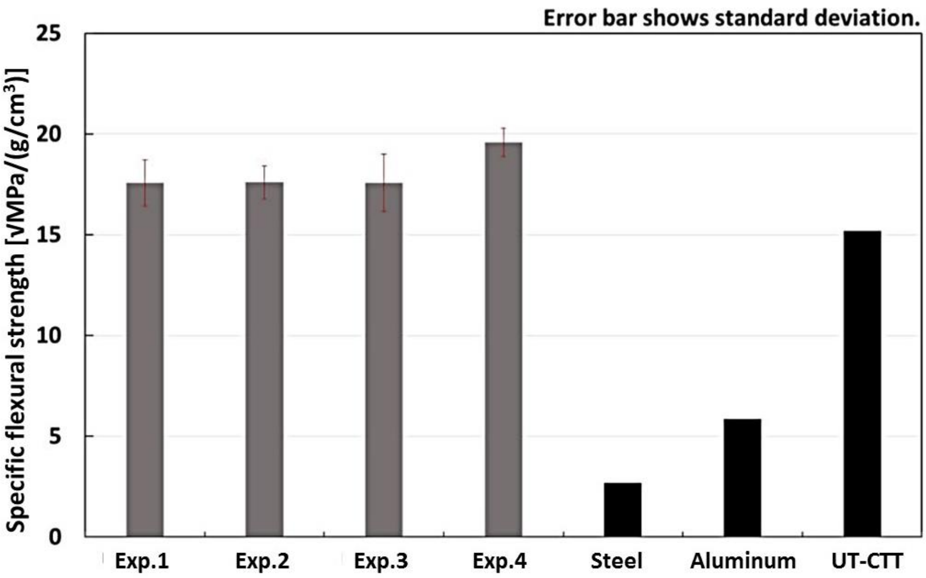


Figure 10: Specific flexural strength (Exp.1-4, steel, aluminum, UT-CTT).

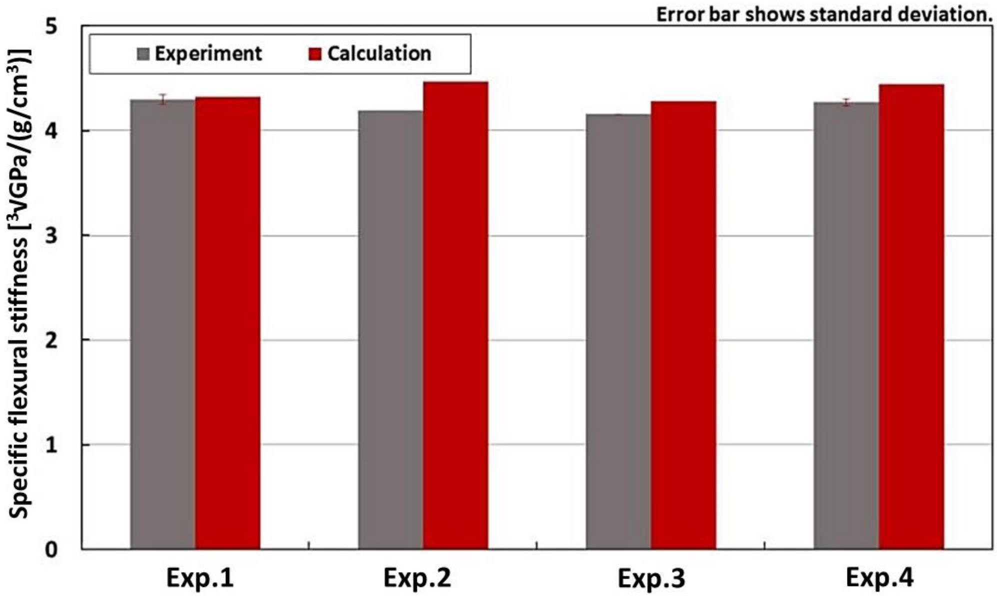


Figure 11: Specific flexural stiffness (Exp.1-4, steel, aluminum, UT-CTT).

## 5 CONCLUSION

In this study, we investigated the effect of hybridization on the mechanical properties and practicality of CFRTP plates with springbacked CFRTP. The conclusion of this study is summarized below.

- The flexural properties of springbacked core material partly depend on its fiber structures.
- We could make hybrid CFRTP plates with high flexural properties by imposing CFRTP sheets which have similar structure with core material between skin and core layer. Specific flexural properties of hybrid CFRTP were much higher than those of aluminum. Moreover, the calculated values of specific flexural stiffness were in good agreement with the experimental values.

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