COMPARISON BETWEEN SPRINGBACKED CARBON FIBER CARD WEB REINFORCED THERMOPLASTICS AND CARBON FIBER PAPER REINFORCED THERMOPLASTICS SANDWICH STRUCTURES ON BENDING AND IMPACT PROPERTY

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Abstract

In this research, a kind of sandwich structure made by out of panel thermal deformation------so called "springback" is manufactured. Carbon fiber card web reinforced thermoplastics (CWT) and carbon fiber paper reinforced thermoplastics (CPT) are implied as the core part and the uni-directional carbon fiber reinforced thermoplastics (UD CFRTP) is designed as the skin part. Molding parameters are set and sandwich structures with different springback ratios using CWT and CPT cores were manufactured. High-speed puncture impact tester was utilized to get the impact properties of these sandwich structures. At the same time, the statistical flexural properties were also investigated by conducting three-point bending experiment using the same materials. The critical springback ratios of core and sandwich structures indicated the peak points of mechanical properties in the corresponding tests. Diverse results were acquired and the optional impact strength, specific impact strength, flexural strength, specific flexural strength and specific flexural stiffness were given during various situations in details. Fracture models appeared during the research were also showed in the final part.

1. Introduction

Carbon fiber is attracting more and more attention in the automobile industry. Even though the cost is still high, most automobile companies are putting their efforts into active pursuit of "carbon fiber-reinforced polymers (CFRP) — a key means to lightweight production passenger vehicles and light trucks — as they seek to comply with impending CO_2 emission and fuel-economy regulations" [1]. At the same time, CFRTP materials can provide preferable specific energy absorption performance over conventional metallic structures [2]. With the development of material science, structure development also appeared with the growing demand of multipurpose applications. Sandwich panels have been used for structural elements for a long time [3] and the researches for pursuing better sandwich materials have been conducted hitherto. Sandwich structures may offer a suitable solution for fiber reinforced materials since the soft core part can contribute to absorb energy and reduce the weight at the same time [4]. Therefore, sandwich structure may open a new road for application of automobiles since it may provide stable impact properties for fiber reinforced materials by adjustment of structure.

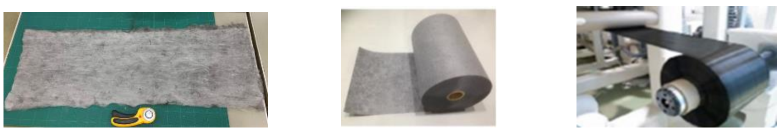
A thermal deformation called ‘‘deconsolidation’’ or ‘‘springback’’ is often observed during the heating process of randomly oriented short fiber reinforcement thermoplastic [5]. The springback ratio of the material indicates the deformation degree of the internal structure and the ratio of changed thickness was measured as the springback ratio. Former research has proved that the springback ratio influences the bending and impact properties of CFRTP a lot. In my master study, a kind of springbacked sandwich is investigated. The inner layer of a sandwich is called "core" and the cores are made by carbon fiber card web reinforced thermoplastics (CWT) mainly in this research. Carbon fiber paper reinforced thermoplastics (CPT) was also tried as core material with once molding. The outer layer of a sandwich is called "skin" and uni-directional carbon fiber reinforced thermoplastics (UD CFRTP) is designed as skin in the structure. This study mainly conducted the impact test and three-point bending tests on CFRTP sandwich structures. The results achieved from dynamic and static fractures were compared to guide the optimal springback ratio in various situations.

2. Experiment procedure

2.1. Material

CWT, (carbon fiber card web reinforced) from Ehime Institute of Industrial Technology Paper Technology Center in Japan is shown in Fig.1 (a), this material is manufactured by a novel carding process. Carding process is the vital process in non-woven sheet producing procedure, hundreds of needles were set in the front part and fibers were fed into this part, then CF and matrix fibers were mixed [6]. Card web with 20% of V_f which were manufactured by carding process was used during this research. This material was designed as an approach for reusing recycled carbon fiber. However, TORAYCA®T700S fresh carbon fiber and polyamide (PA) was used in real fabricating process to avoid negative influence of degenerated carbon fiber in recycled materials [7]. Another core material used in this research is CPT, CARMIX CFRTP-PP (polypropylene) as shown in Fig. 1(b). This material is provided by Awa Paper Mfg. Co., Ltd. The length of carbon fiber is 6 mm here.

The CF/PA6 UD sheet (uni-directional carbon fiber reinforced thermoplastics) material from the Fukui Prefecture in Japan shown in Fig.1 (c) is used for sandwich skin. The thickness of CF/PA6 UD sheet here is 132 μm.



(a) **(b)** **(c)**

Figure 1. Material used in this research (a) CWT (b) CPT (c) UD

2.2. Molding process for core

The manufacturing process for original core is just to cut the sheet from the original roll and then put into a hot press machine (Pinette Emidecau Industries). After original cores are consolidated, one panel is kept for 1 springback ratio core and the others are heated in the same mold again to springback. For making springback core, the gap in the mold is calculated and a rigid stopper is placed to keep the distance as Fig. 2 shows. The molding temperature for CWT Core used here is 280℃ and holding time is 10 minutes. However, the molding temperature for CPT PP core is 195℃.

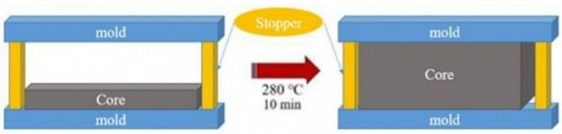


Figure 2. Springback procedure for individual CWT core by hot press machine

2.3. Manufacturing process for sandwich structures

Overlapped CWT and CPT PP layers are set in the same hot press machine (Pinette Emidecau Industries) with 3 pieces of UD sheet in both sides to make an original sandwich structure. The consolidating temperature for CWT and CPT PP sandwich is 280℃ and the duration is 10 minutes. After the original sandwich is consolidated, springback procedure is the same as stated in 2.2 like Fig. 3 shows.

Figure 3. Manufacturing process for springback sandwich structures

2.4. Specimen preparation

Due to the manufacturing process of CWT sheets, the fiber orientation distribution is influenced by the moving direction of carding machine [8] like Fig. 4 presents. We defined the moving direction of the machine as the L direction of the material and the perpendicular direction as the T direction.

Figure 4. The carding process for CWT sheets [8]

As for CPT material, the manufacturing process is like paper making process which means stirring the mixture of carbon fiber in water. This material doesn't show directionality of the orientation of carbon fiber obviously so we don't define the direction of the specimen by overlapping the CPT sheet.

The springback ratios conducted here are 1, 1.5, 2, 2.5 and 3. Number of specimen for each test is 6 and calculating number is 5 after getting rid of an unstable one. Samples of specimen are shown in Fig.5. Table 1 and Table 2 describe the dimensions for cores and sandwiches used in this research both for L and T directions of CWT and PP of springback ratio 3 situation.

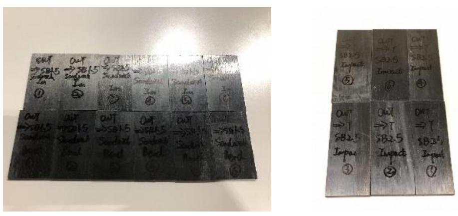


Figure 5. Samples of specimen

Table 1. Dimension of specimen for cores.

Dimension(mm)	SB1	SB1.5	SB2	SB2.5	SB3
Thickness	1	1.5	2	2.5	3
Width	35	35	35	35	35
Length	55	55	55	55	55
Span length	40	40	40	40	40

Table 2. Dimension of specimen for sandwiches

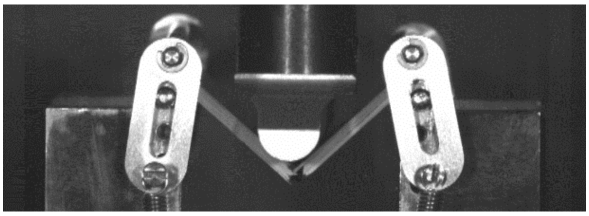
Dimension(mm)	SB1	SB1.5	SB2	SB2.5	SB3
Thickness	2	2.5	3	3.5	4
Width	35	35	35	35	35
Length	55	55	72	84	96
Span length	40	40	48	56	64

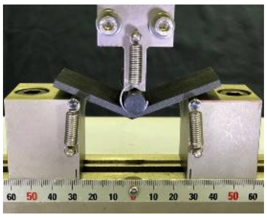
2.5. Impact test

Impact tests were proceeded by a high-speed puncture impact tester (Shimadzu Corporation HITS-P10) shown in Fig. 6 (a) for both core and sandwich structures in this study. The testing speed is 3.8m/s in this study.

2.6. Three-point bending test

Three-point bending tests are conducted by a universal testing machine shown in Fig. 6 (b). The testing speed is 1mm/min here.





(a) **(b)**
Figure 6(a). Impact test **(b).** Three-point bending test

3. Results and discussions

3.1. Impact strength for core and sandwich of CWT material

When the span and experimental condition is under $\left(\frac{\delta}{L}\right) \leq 0.1$, the impact strength σ_b is calculated as:

$$\sigma_b = \frac{3P_bL}{2bh^2} \quad (1)[9]$$

Where, $\frac{\delta}{L}: \frac{Deflection\ of\ max\ load}{Span\ length}$, $\sigma_b: Impact\ strength$(MPa),
P_b: Max $load\ (N), L: Span\ length$
$b: Specimen\ width, h: Specimen\ thickness$

Based on this equation, the impact strength for CWT core and sandwich in this experiment is shown in Fig. 7. For original impact strength, CWT L and T direction show the same tendency both for cores and sandwich structures. L direction is stronger than T direction due to the carding process which make the fiber array to some extent.

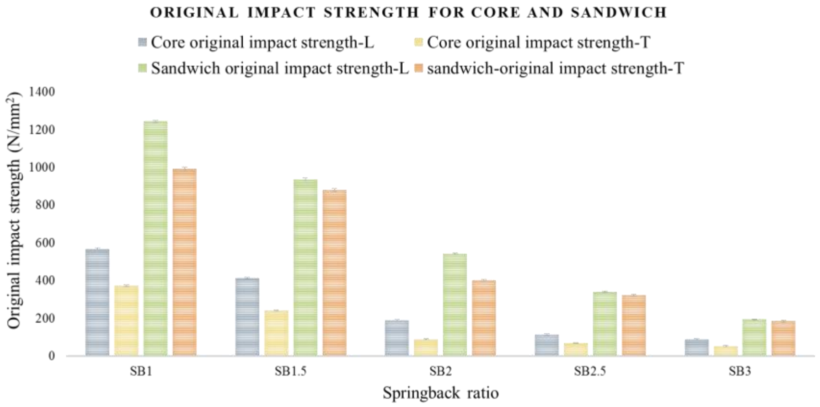


Figure 7. Original impact strength for core and sandwich structures

3.2. Specific impact strength for core and sandwich of CWT material

Specific impact strength is calculated based on the impact strength and material density. By analyzing impact load-deflection relationship, impact modulus of elasticity is obtained as follow:

$$E_b = \frac{1}{4} \times \frac{L^3}{bh^3} \times \frac{\Delta P}{\Delta \delta} \tag{2}$$ [9]

Where, E_b: *impact modulus of elasticity*, L : *Span length*, b : *Specimen width*
h : *Specimen thickness*, $\frac{\Delta P}{\Delta \delta}$: $\frac{load}{deflection}$

Specific impact strength and rigidity is calculated as:

$$Specific\ strength: \sqrt{\sigma_b}/\rho \tag{3}$$ [10]

Specific impact strength of core and sandwich of CWT material is shown in Fig. 8. The specific impact strength of core raises first and decreases later with the increase of springback ratios both in L and T direction. It demonstrates that springback process will increase the specific impact strength of CWT cores in some degree when finding the optimal springback ratio. When comes to sandwich structures, specific impact strength decreases a little with the increase of springback ratio. The distinctive between L and T directions is much lower than individual cores can also be observed. It reveals that the recycled carbon fiber may be suitable for make this kind of sandwich structures since the influence of fiber orientation is weakened in this structure.

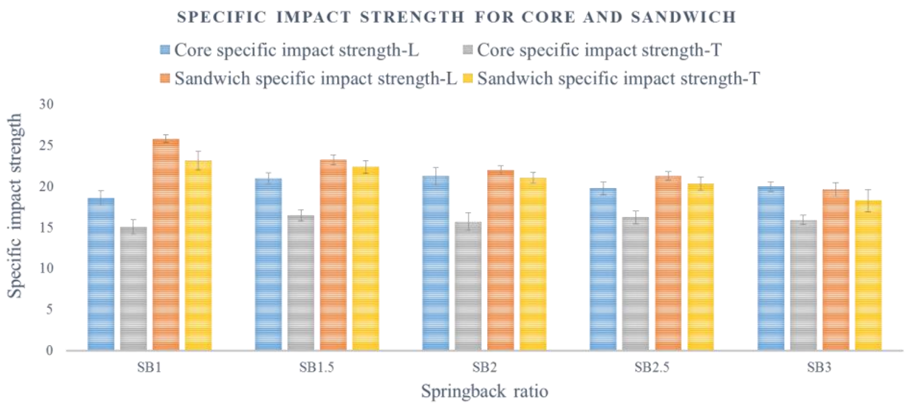


Figure 8. Specific impact strength of CWT

3.3. Flexural strength for core and sandwich of CWT material

Original flexural strength for cores and sandwich structures of CWT material is shown in Fig.9. This keep the same tendency as impact test in 3.1. However, the discrepancy between L direction and T direction sandwich is lower than impact test.

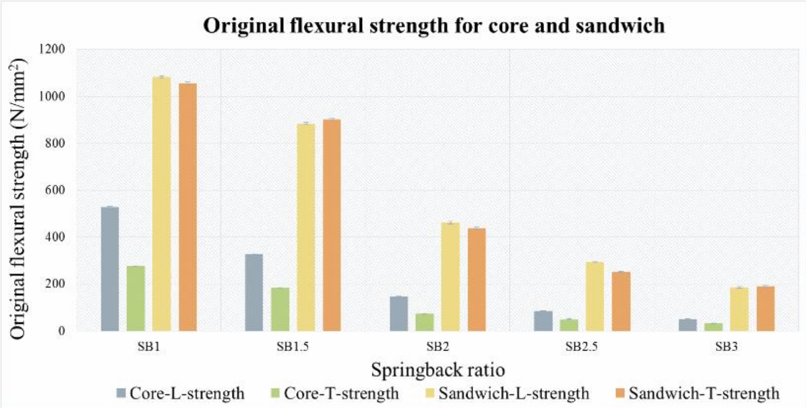
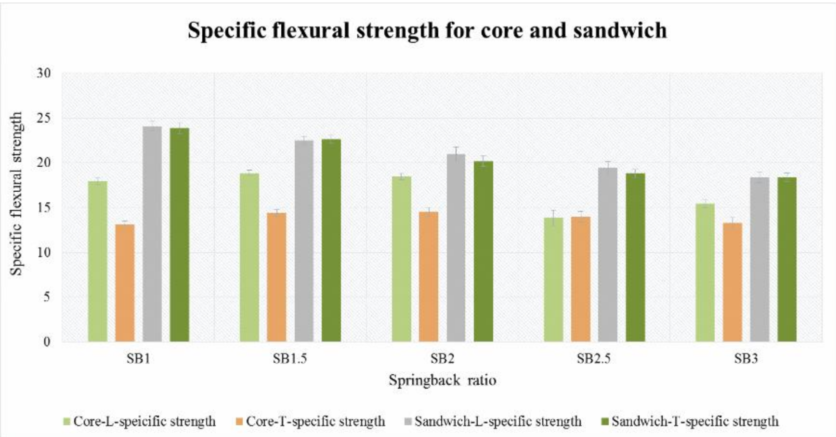


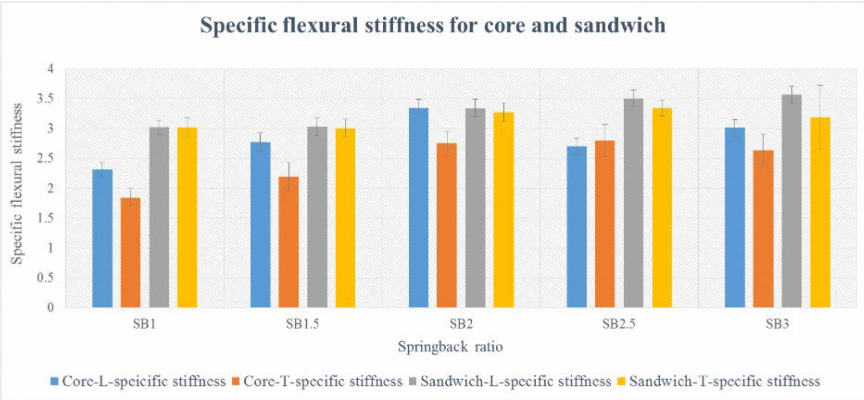
Figure 9. Flexural strength for core and sandwich of CWT material

3.4. Specific flexural strength and specific flexural stiffness for core and sandwich of CWT material

Specific flexural strength ($\sqrt{\sigma_b}/\rho$ [10]) and stiffness ($\sqrt[3]{E_b}/\rho$ [10]) for core and sandwich structures of CWT material is presented in Fig. 10. Specific flexural strength shows the same tendency in 3.2. However, the specific flexural stiffness shows different phenomenon. The springback ratio 2 is the optimal springback ratio for individual cores both in L and T direction. While the specific flexural stiffness of sandwich keeps raising until springback 2.5-3 situation. It proves that the optimal springback ratio for specific flexural stiffness is around 3 when considering the springback ratio from 1 to 3. Simultaneously, the influence of fiber orientation was weakened by sandwich structure in static fracture.



(a)



(b)

Figure 10(a). Specific flexural strength of CWT **(b).** Specific flexural stiffness of CWT

3.5. Impact and three-point bending test of CPT material

In my previous research, we found that the optimal molding temperature for CPT PP is around 195°C and CF/PA6 UD is around 265℃. While during this research, I set the molding temperature as 280°C to unify the CWT material. However, this temperature is too high for PP core and some obvious defects in PP core as Fig. 11 shows can be found after once molding. This demonstrates that PP core is not suitable for once molding with CF/PA6 UD sheet compared with CWT. Impact test and three-point bending test were both conducted on springback ratio 3 CPT PP sandwich situations but the results are unscientific. Separate molding with CPT PP and UD sheet may be investigated in the future.

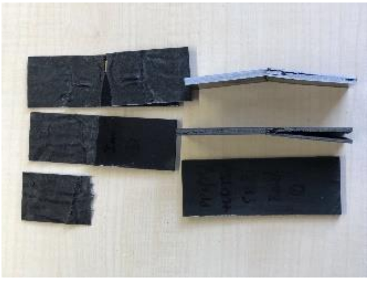


Figure 11. Springback ratio 3 CPT PP sandwich structures

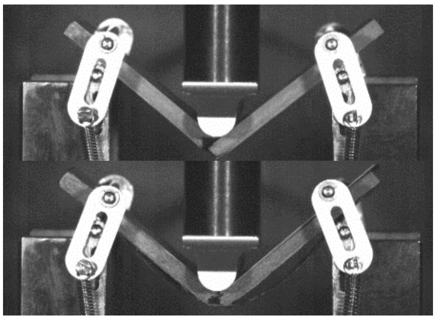


Figure 12. Different fracture models

3.6. Fracture models observed

For low springback ratio, the failure models are even the same both for core and sandwich structures during dynamic and static fracture process. However, different failure models can be found during high springback ratio sandwich structures like Fig. 12 shows. The more obvious interlaminar fracture appeared in high springback ratio situations. The soft core should absorb much energy by transferred into deformation and the rigid skin played the reinforced role at the same time. However, when the junction surface properties are poor, the fracture only appeared as fiber break of skin and the core cannot support the structure as normal ones then.

4. Conclusions

The springback ratio influence the properties of CWT material both in dynamic and static fracture. It is hard to achieve a constant springback ratio when considering various optimal properties. However, some rules can also be verified from this research. The original and specific strength for impact and three-point bending shares the same tendency with the change of springback ratios. Springback ratio 2 may be the optimal springback ratio when considering the specific strength since it balances the core and sandwich and the structure is stale at the same time. Springback 1.5, 2.5 and 3 can all be optimal springback ratio when in different situations. What's more, the weakened influence of fiber orientation may open a new road for the application of recycled carbon fiber. CPT PP is not suitable for once molding with UD sheet and separate molding should be investigated in the future.

The influence of fiber orientation can also be found during different failure models. The appearance of this phenomenon should be considered further. Better adhesion contributes to the properties of sandwich structures in some extent. Additional approaches should be carried out for making more stable springbacked sandwich structures.

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