EFFECT OF SPRINGBACK RATIO ON BENDING AND IMPACT PROPERTY OF CARBON FIBER REINFORCED THERMOPLASTICS SANDWICH STRUCTURES

Yunqian Zhang[*1], Yi Wan[1], Taro Nakamura[1], and Jun Takahashi[1]

[1] Department of Systems Innovation, School of Engineering, The University of Tokyo
7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan
*Email: zhang-yunqian@cfrtp.t.u-tokyo.ac.jp

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ABSTRACT

In this study, carbon fiber paper reinforced thermoplastics (CPT), which regarded as sandwich core materials, were manufactured with out of panel thermal deformation------so called 'springback'. The impact tests were conducted using the both springbacked CPT with different springback ratios and the springback-core sandwiches to evaluate energy absorption property. In addition, the statistical flexural properties were also investigated by conducting three-point bending experiment using the same materials. The results shows that the impact energy and flexural rigidity increase first and decrease later with the growth of CPT core springback ratios. The critical springback ratio of CPT indicated the saturation point of mechanical properties in the corresponding tests. The impact experiment results show that the critical springback ratio is around 250% and 300% considering specific strength, specific rigidity and energy absorption. For static fracture, the critical springback ratio appeared around 250%. These results reveal the effect relationship between the springback ratio and the strain rate dependence of CPT under flexural loading, also different failure modes were observed on CPT under static and dynamic fractures. An optimal springback ratio is given refer to these experiments.

1 INTRODUCTION

Driven by the trend of energy saving and environmental protection, fuel consumption of automobile is attracting attentions from all over the world. The ultra-lightweight design for automobile is an effective method to achieve environmental friendly goals. Recently, CFRTP(Carbon Fiber Reinforced Thermoplastic) materials are gaining interest from automobile manufacturers because of its high specific mechanics. The application of CFRTP on automobile regarded as an effective method to reduce fuel energy consumption [1]. In addition, CFRTP can provide superior specific energy absorption performance over conventional metallic structures [2]. As the material science developed, structure development also appeared with the demand of multifunctional application. Sandwich panel has a long history of application to structural elements [3] and the research for optimizing sandwich materials have been conducted hitherto. Sandwich structures may provide a reasonable solution for fiber reinforced materials since a soft core can support the stiff laminated skin to absorb energy and reduce the weight at the same time [4].

For sandwich structure, they can provide superior energy absorption performance over conventional metallic structures compared on weight basis [5]. The use of composite materials as energy absorbers, however, is still limited as they crush in a more unstable manner than their metallic counterparts [6]. Nevertheless, sandwich structure may open up a new load for application for automobiles since it may provide a stable impact properties for fiber reinforced materials by adjustment of structure.

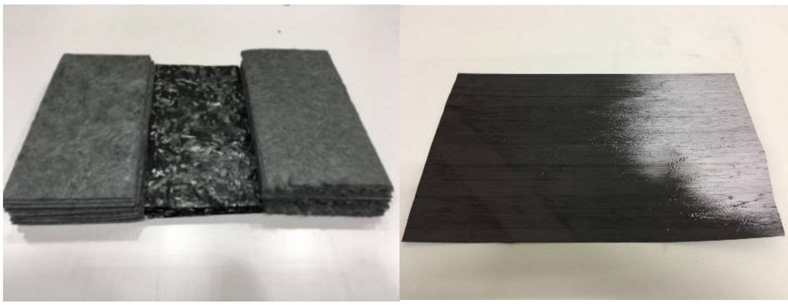
A thermal deformation called ''deconsolidation'' or ''springback'' is often observed during the heating process of randomly oriented short fiber reinforcement thermoplastic [7]. Heating process were conducted to increase the thickness and the ratio of changed thickness were measured as the springback ratio [8]. In this study, a kind of springbacked sandwich is investigated. The inner layer of a sandwich is called "core" and the core is made by CPT (carbon fiber paper reinforced thermoplastic) in this study. The outer layer of a sandwich is called "skin" and UT-CTT (ultra-thin chopped carbon fiber tape reinforced thermoplastics) is designed as skin in the structure. A springbacked core may stabilize the impact properties but the interface may cause new interlaminar fracture. This study focusing on the impact test on CFRTP sandwich structure. The results archived from bending test are also compared to give a guide to the optimal springback ratio in dynamic and static situations.

2 EXPERIMENT PROCEDURE

To characterize the properties of CFRTP sandwich structure, different springback ratios (100%, 150%, 200%, 250% and 300%) of core and the same skin is manufactured. The ability of energy absorption is carried out by high-speed puncture impact tester. Impact strength, rigidity and energy absorption is investigated in this dynamic fracture.

2.1 Material

CPT material, CARMIX CFRTP-PP (polypropylene) as shown in Fig. 1(a) (except the middle part), is employed as a core material provided by Awa Paper Mfg. Co., Ltd. 18 layers are overlapped to consolidate a 2mm core by hot press machine. The CF/PA6 UD sheet (Polyamide-6) material from the Industrial Technology Center of Fukui Prefecture in Japan shown in Fig.1 (b) is used for sandwich skin. The thickness of UD sheet is 44μm and the V_f is 54 here.



(a) (b)

Figure 1 (a) CPT material (b) UD sheet

2.2 Springback of the core

The original cores are consolidated by a hot press machine (Pinette Emidecau Industries). The PP layers are set in the mold and original springback ratio cores are manufactured by panel and panel. After original cores are consolidated, one panel is kept for 100% springback ratio core and the others are heated in the same mold again to springback. For PP core, the molding temperature is set as 265°C and hold-in time is 10 minutes. For making springback core, the gap in the mold is calculated and a rigid stopper is placed to keep the distance. The structure is shown in Fig. 2.

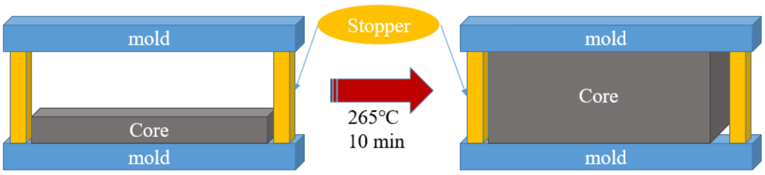


Figure 2 Springback procedure for PP core by hot press machine

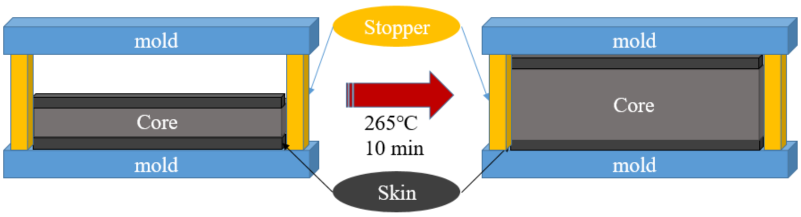
The distance between molds is decided by springback ratio. For example, if the thickness of original core is 2mm, when making springback ratio 200% core, the height of the stopper is $2 \times 2 = 4$mm.

2.3 Sandwich manufacturing

During this study, the sandwich skin is made by UT-CTT (ultra-thin chopped carbon fiber tape reinforced thermoplastics) cut from original UD sheet. The tape length used here is 18mm and the width is 5mm. After cutting the UD sheet into several $18mm \times 5mm$ tapes, a kind of randomizing distributed method is taken by water agitation like Fig. 3(a) shows. After dehydration, the randomly scattered tapes are consolidated by a hand press (Fig. 3 (b)) at the temperature of 260℃ and the pressure of 5MPa. For making sandwich, the core is not consolidated first like the procedure in 2.2. In this study, the PP layer for core and UT-CTT layer which is consolidated as above is overlapped directly like Fig. 3(c) shows.

For making original sandwich, the overlapped layers are set in the same hot press machine (Pinette Emidecau Industries) introduced in 2.2. The consolidating temperature is 265℃ 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(d) present. However, the calculating of the height of stopper is a little different from simplex core. Take a 3mm sandwich as an example, the skin is 0.5mm×2 here, and core is 2mm. When making 200% springback ratio sandwich, the height of the stopper is $2mm \times 2 + 0.5mm \times 2 = 5mm$.

(a) (b) (c)



(d)

Figure 3(a) Randomizing distributed method by water agitation (b) Hot hand press
(c) Sandwich layers (d) Springback procedure for sandwich by hot press machine

After fetching out the panels from hot press mold, a diamond cutter (MARUTO Testing Machine Company AC-500CF) is used to cut the edges to reduce reliability. Then, the panels are cut into various sizes due to the specimen sizes. Before impact test, the specimen are kept in the vacuum drying machine for at least 2 hours to eliminate moisture inside.

2.4 Impact test

Impact tests are proceeded for both core and sandwich structure in this study. The springback ratios conducted here are 100%, 150%, 200%, 250% and 300%. Dimensions for specimen are based on ISO standard-ISO14125-class 4. Number of specimen for each test is 6 and calculating number is 5 after getting rid of an unstable one. Table 1 and Table 2 describe the dimension for core and sandwich used for impact test in this study.

Dimension(mm)	SB100%	SB150%	SB200%	SB250%	SB300%
Thickness	2	3.2	4	4.5	5.6
Width	35	35	35	35	35
Length	55	55	55	55	55
Span length	40	40	40	40	40

Table 1 Dimension of specimen for core

Dimension(mm)	SB100%	SB150%	SB200%	SB250%	SB300%
Thickness	2.7	3.3	4.2	4.8	5.7
Width	35	35	35	35	35
Length	55	55	80	95	115
Span length	40	40	70	84	96

Table 2 Dimension of specimen for sandwich

3 RESUCLTS

The impact test of springback ratio 100%-300% sandwiches and single cores have been conducted. High-speed puncture impact tester (Shimadzu Corporation HITS-P10) is used here. The impact speed is set 3.8m/s in this study. Results for impact test is shown in this section.

3.1 Impact load-Deflection of core and sandwich

Fig. 4(a) shows a typical impact load-deflection diagram of CPT core and Fig. 4(b) shows a representative impact load-deflection diagram of multiple sandwich structure.

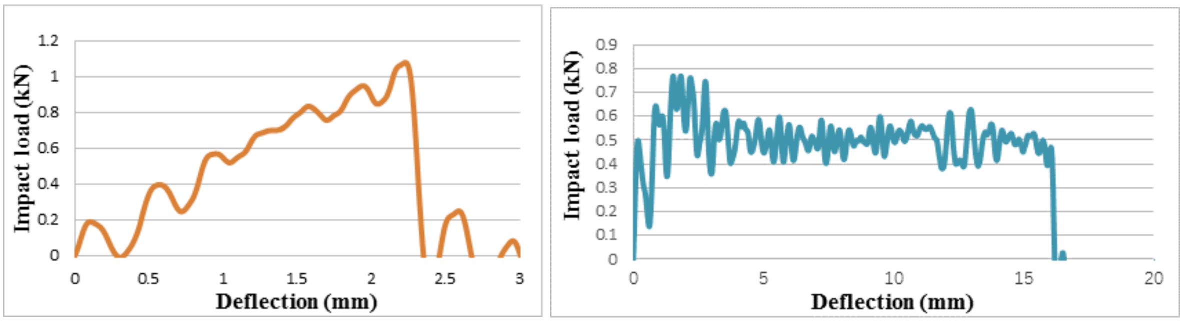


Figure 4(a) A typical impact load-deflection diagram of CPT core
(b) A typical impact load-deflection diagram of multiple sandwich structure

3.2 Impact strength of core and sandwich

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

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

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

The impact strength for core and sandwich in this experiment is shown in Fig. 5.

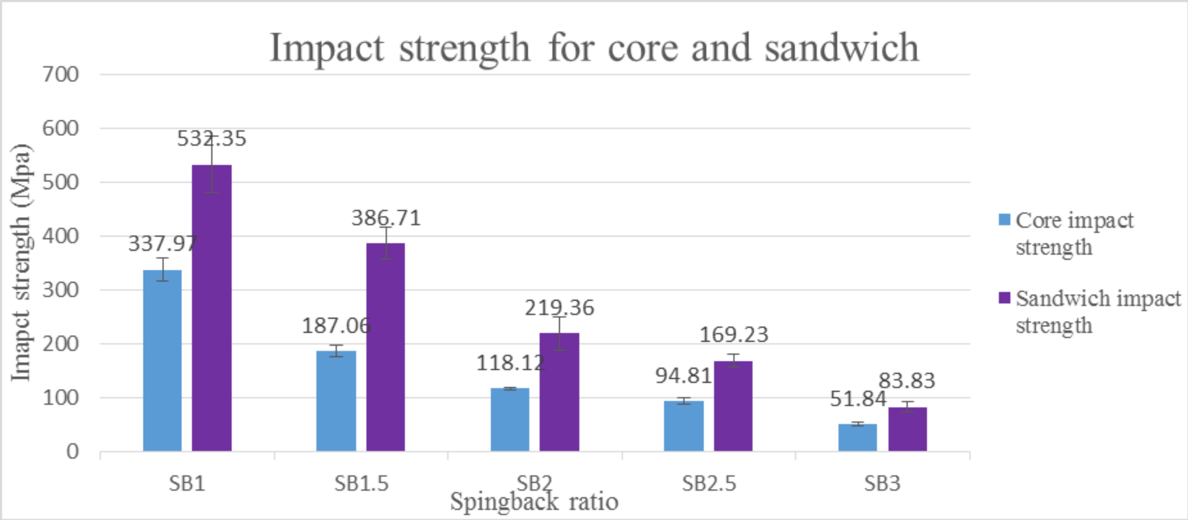


Figure 5 Impact strength for core and sandwich

3.3 Specific impact strength and rigidity of core and sandwich

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

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

Where, $E_b: impact\ modulus\ of\ elasticity$

$L: Span\ length$

$b: Specimen\ width$

$h: Specimen\ thickness$

$\frac{\Delta P}{\Delta \delta}: \frac{load}{deflection}$

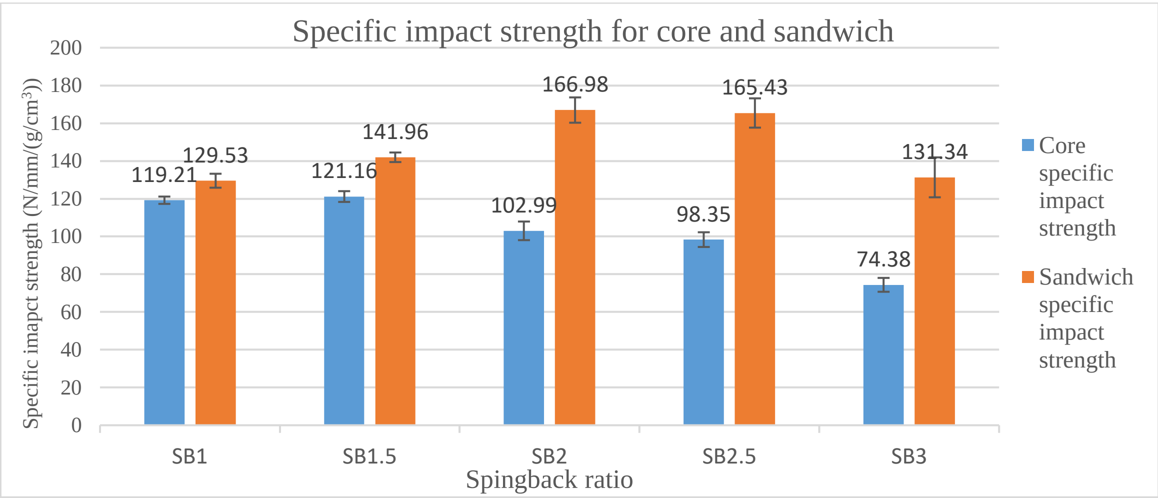
Specific impact strength and rigidity is calculated as:

$$Specific\ strength: \sqrt{E_b}/\rho \quad (3)[10\text{-}11]$$

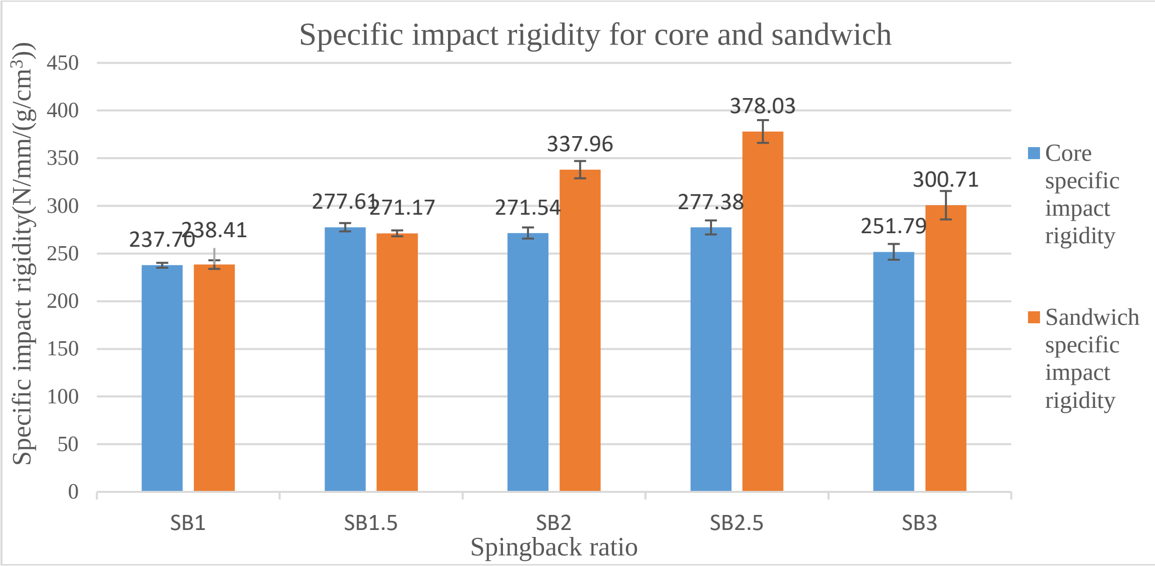
$$Specific\ rigidity: \sqrt[3]{E_b}/\rho \quad (4)[10\text{-}11]$$

Where, $\rho: Density$

Fig. 6(a) shows the specific impact strength and Fig. 6(b) shows the specific impact rigidity of core and sandwich.



(a)



(b)

Figure 6(a) Specific impact strength for core and sandwich
6(b) Specific impact rigidity for core and sandwich

3.4 Energy absorption of core and sandwich

Energy absorption for core and sandwich is divided as elastic and total energy for every gram. The density and volume are measured for each specimen before impact test. The results for energy absorption of core and sandwich are shown in Fig. 7.

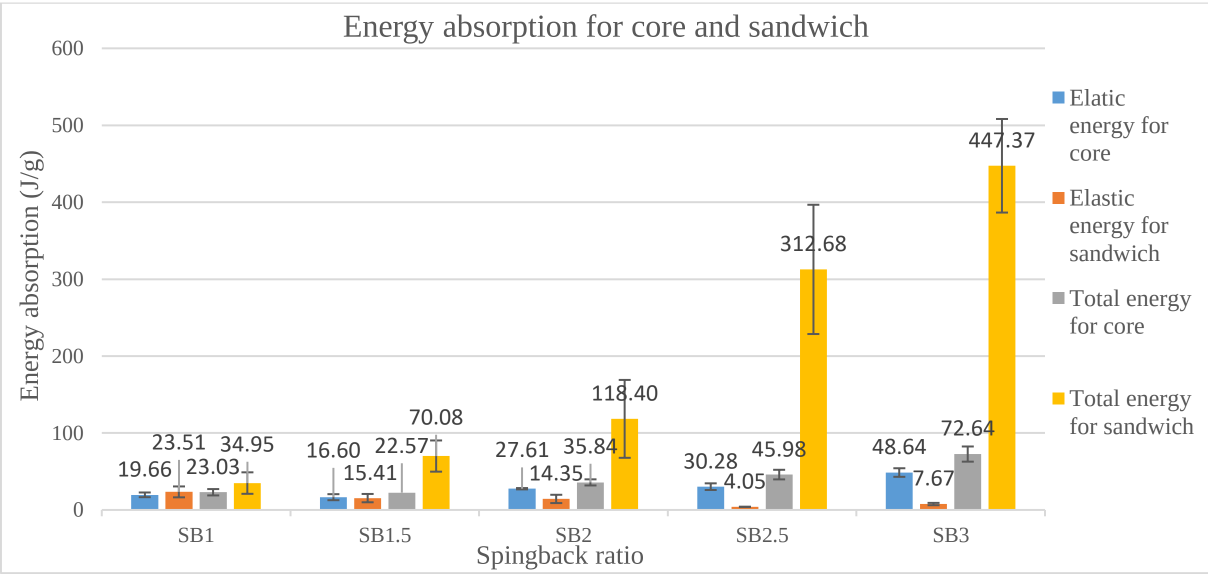


Figure 7 Energy absorption for core and sandwich

4 DISCUSSION

The results obtained by impact test are illustrated in this section. The results of three-point bending done by Taro Nakamura are also compared here. The effect of springback ratios on the strain rate dependence of CPT are observed and different fracture modes are present.

4.1 Impact strength, specific impact strength and specific impact rigidity.

For original impact strength, the PP core and compound sandwich present the same tendency------ the impact strength decreases as the springback ratio increases. However, one of the important goal of applying CFRTP into vehicle is to gain higher mechanical properties without sacrificing the weight. Specific impact strength and specific impact rigidity are taken into account in this situation. For simplex CPT core, the specific strength decreases little after springback. While, for specific impact rigidity, the tendency increases first and decreases later. It indicated that the optimal springback ratio for PP core is around 200%-250% in this aspect. The sandwich structure shows the same tendency and demonstrates that the optimal springback ratio for CPT sandwich structure is around 200%-250% when considering the dynamic strength and rigidity.

4.2 Energy absorption

Energy absorption for every gram shows diverse results. Before maximal impact load, the energy absorption is calculated as elastic energy. The PP core shows an increase as the springback ratio raise. However, for sandwich structure, the elastic energy absorption is not so good which may be explained by the rigidity of skin before plastic fracture. When comes to total energy, the advantage of sandwich structure appear. The total energy increase a lot with the growth of springback ratio. This phenomenon may be interpreted by the voids in the core and stability of the skin together. For sandwich structures, they didn't break at once and the fracture process lasted longer time since the soft core absorbed much energy and the tough skin played a reinforced role. Also, the deviation of energy absorption is increased with the increase of springback ratio due to different junction surface properties between core and skin.

4.3 Comparison between dynamic and static fracture

Refer to Taro Nakamura's three-point bending test results shown in Fig 8, the critical springback ratio appears in the 250% springback ratio situation. CPT sandwich got improved flexural feature as a structural material especially at optimal springback ratio 250%. For specific strength and specific rigidity during impact experiment, the critical springback ratio appears around 250%, too. At the same time, for total energy absorption, springback ratio 250% and 300% are the optimal options.

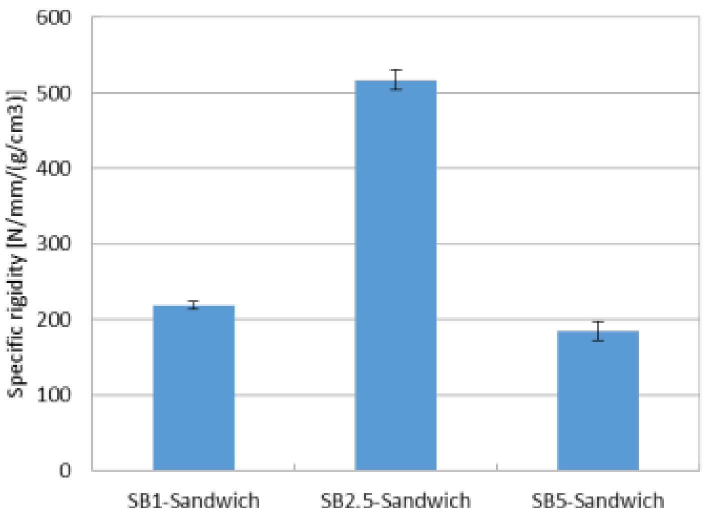
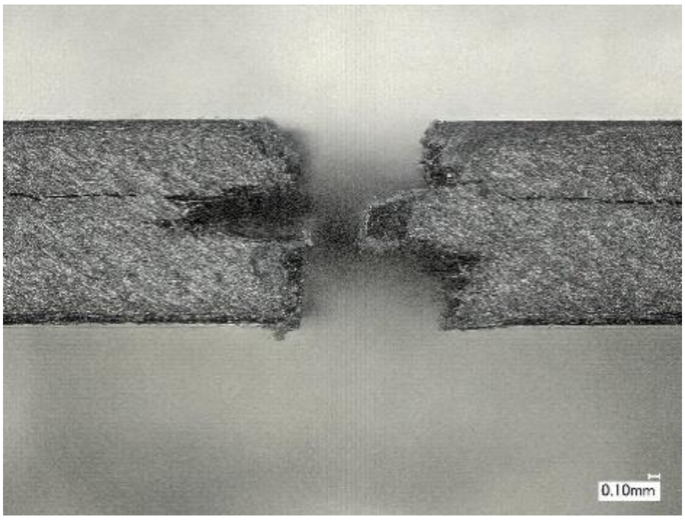


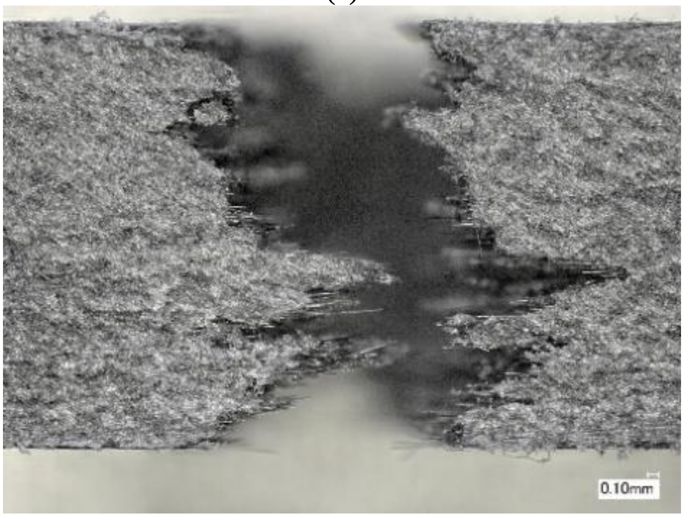
Figure 8 Specific flexural rigidity of each sandwiches [8].

4.4 Fracture models observed

Fig. 9 and Fig. 10 are taken by digital microscope. Fig. 9(a) is taken by a springback ratio 100% core and Fig. 9 (b) is a springback ratio 250% core. The fracture modes for core are even same although different springback ratio is applied. The more obvious interlaminar fracture appeared in the springback ratio 100% core.



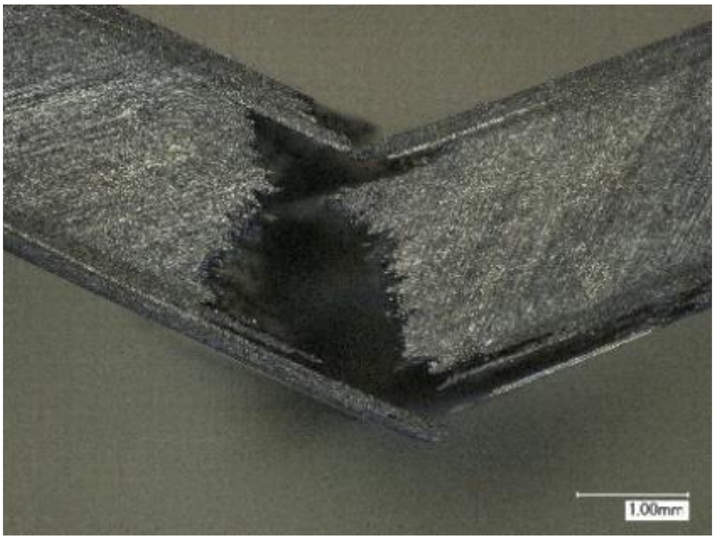
(a)



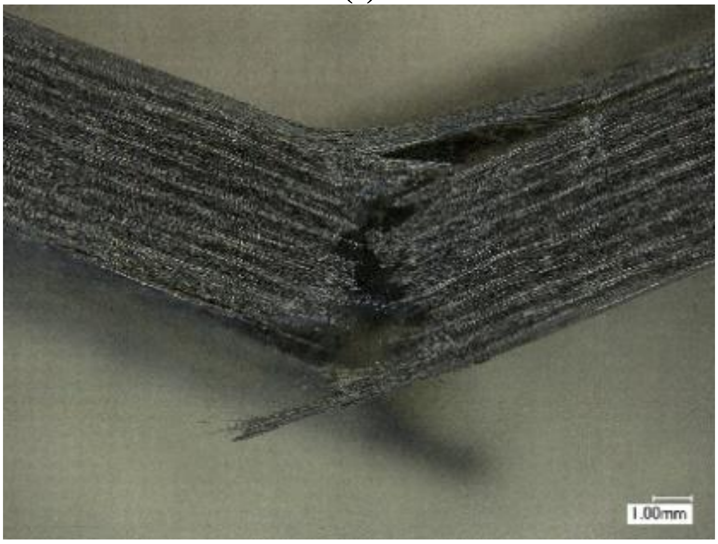
(b)

Figure 9(a) The fracture surface of a springback ratio 100% core
(b) The fracture surface of a springback ratio 250% core

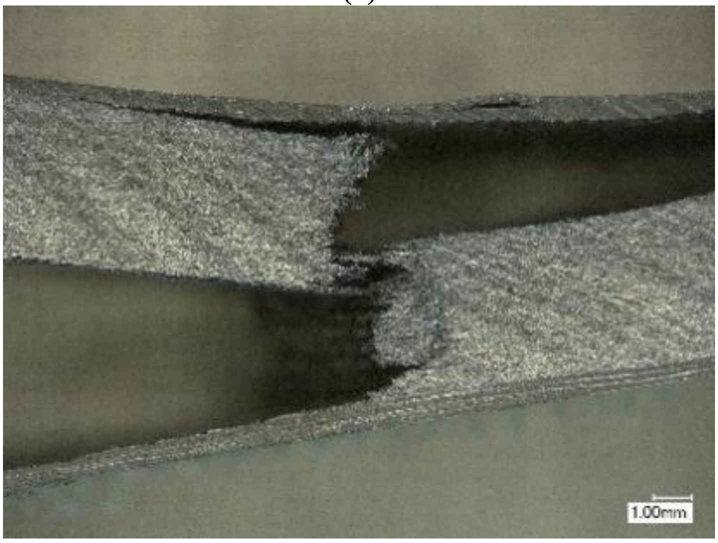
Fig. 10(a) is observed from a springback ratio 100% sandwich. Fig. 10(b) and Fig. 10(c) are two sandwich panels of the same springback ratio------250%. Different fracture modes can be observed from this set of photos. For springback 100% sandwich structure, it breaks totally and the fracture between CTT skin and PP core is not obvious. For springback ratio 250%, fracture in junction surface influences the impact process a lot. When the junction surface properties are superior, the fracture mainly appeared in fibers break. However, when the junction surface properties are poor, the fracture appeared not only in fibers break, but also in interlamination surface. Layer gliding ever appeared in high springback ratios.



(a)



(b)



(c)

Figure 10(a) The fracture surface of a springback ratio 100% sandwich
(b) The fracture surface of a springback ratio 250% sandwich
(c) The fracture surface of another springback ration 250% sandwich

5 CONCLUSION

CPT sandwich structure is a practical method to increase the mechanical properties and energy absorption abilities in the CFRTP applications. The springback ratios influence the properties both in dynamic and static fracture. Finding the critical springback ratio of CPT indicated the optimal springback ratio which can be applied in corresponding situation. When applying CPT into vehicle field, flexural properties such as strength, rigidity and energy absorption ought to be considered. On account of the results and discussion, the springback ratio 250% is considered as the optimal springback ratio for CPT sandwich structure for automobile application.

The appearance of different fracture modes also should be considered further. Better adhesion between the sandwich core and skin may reduce the fracture between layers hence improve the mechanical properties. Additional approaches should be carried out for a better understanding of the fracture of this kind of sandwich.

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