EVALUATION OF SOFT-SKIN EFFECT PERFORMANCE OF CARBON FIBER REINFORCED THERMOPLASTICS

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Keywords: soft-skin effect, lateral impact test, light impact, body-contacting product design, lightweight materials, CFRTP

Abstract

This research evaluated the advantages of carbon fiber reinforced thermoplastics (CFRTP) in design of body-contacting product with developed apparatus and indexes. Experimental analogy was adopted to investigate the characteristics of contacting force on human body during the impact events and following conclusions could be obtained. In the case that human body collides with the products directly, because of lower inertia, CFRTPs show better performance in reducing the contacting peak force and fluctuant level of the contacting force history exerted on human body, comparing with traditional metallic materials. In the case that human body is protected by the products, the experiment results shows that the body-protecting performance is determined by the stiffness of the products and no apparent additional advantage could be found by applying CFRTP in design of body-protecting products except for reducing the weight of products.

1. Introduction

Carbon fiber reinforced plastics (CFRP) are novel materials which have been widely applied in many industries over the past decades. In Japan, several kinds of CFRTPs have been developed for application of lightweight structures for mass-production of automobiles. With continuing cost decreasing and innovation of molding technology, CFRTP are promising to be applied in not only the automobile structures but also various daily products in near future. However, many basic material properties related to functionality, like shock reduction, have not been clarified yet and these are the obstacles in expanding application of CFRTP.

Shock is a kind of usual mechanical phenomenon in daily life. In many cases, shock transferring to human body is the phenomenon undesired because it would bring human pain or discomfort. The degree of pain and discomfort varies depending on material of what humans collide with. For materials used in body-contacting structures, we named the effect of reducing the degree of pain and discomfort during the colliding events “soft-skin effect” [1]. To lighten the pain and discomfort, proper material selection is one of key points for design of body-contacting products.

Ref. [2, 3] investigated HIC (head impact criterion) value of the accidents that pedestrians crash into bonnets made in different materials, including steel, aluminum, and composite. The results show that the bonnet made in composite is not only lightweight but also showing better performance in pedestrian safety protection. Yamashita, et al. [1] performed drop weight impact test and finite element analysis on CFRTP, compared with steel, aluminum, and polypropylene. The results showed that CFRTP is more human friendly when human body crash into CFRTP objects or is protected by

CFRTP products. Many literatures related to application of composites materials in body-contacting product designs could be found, but few of them deeply investigated the mechanism of better performance in body-contacting product designs for composite materials.

As the extension of previous study [1], the soft-skin effect of CFRTPs will be evaluated in details and the related mechanism will be investigated by improved experimental conditions and testing system.

2. Materials and testing methods

2.1. Materials

Two kinds of CFRTPs were used in this research, sheet molding carbon fiber tape reinforced thermoplastics (CTT) and carbon fiber paper reinforced thermoplastics (CPT). CTT (Fig. 1) is made from chopped tape sheet, which was provided by Industrial Technology Center of Fukui Prefecture, Japan. The unidirectional carbon fiber polyamide 6 (PA6) prepreg tapes were dispersed by air and a layer of PA6 film was inserted between the tapes to temporarily fix the position of tapes. The volume fraction of carbon fiber for chopped sheet is around 50%. By cutting the chopped sheets into assigned size and molding under specific high temperature and pressure, the CTT plate could be fabricated.

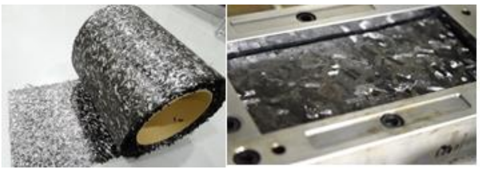


Figure 1. Fabrication of CTT

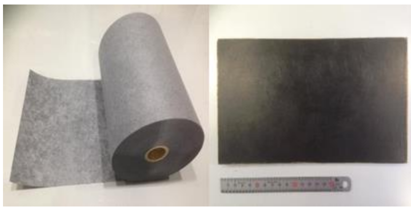


Figure 2. CPT sheet and specimen

CPT (Fig. 2) manufactured from CARMIX made by Awa Paper Mfg. Co., Ltd, Japan. CARMIX sheet used in this study is composed of carbon fiber and PA6 fiber dispersed by a continuous paper-making process. The average length of carbon fiber and PA6 fiber are 6 mm. The Vf of CPT is about 24%.

The soft-skin effect of CTT and CPT were evaluated by comparing with steel and aluminum. Two groups of specimens for test were prepared, as shown in Table 1. In order to evaluate the performance of different materials fairly, the three point bending stiffness of the specimens for each group was controlled almost same by control of thickness and adjusting the width of specimens.

Table 1. Parameters of specimens for group-1 and group-2

	Material	Width × span× thickness (mm)	3-point bending stiffness (N/mm)	Weight (g)
Group-1	Steel	15 × 80 × 1.35	61.4	12.9
	Aluminum	15 × 80 × 1.95	59.1	6.47
	CTT	15.3 × 80 × 2.45	59.4	4.38
	CPT	16.2 × 80 × 2.72	58.5	4.74
Group-2	Steel	15 × 80 × 1.64	104	15.6
	Aluminum	15 × 80 × 2.4	108	7.51
	CTT	14.6 × 80 × 2.95	106	5.29
	CPT	15 × 80 × 3.45	108	5.56

Same as the previous study [1], experimental analogy was adopted to represent the cases that human body collides with objects directly, and human body is protected by objects from outside impact source, called impact pattern-1 and impact pattern-2, respectively.

Figure 3. Lateral impact equipment

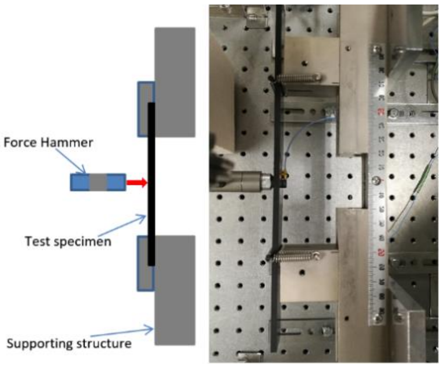


Figure 4. Equipment for pattern-1

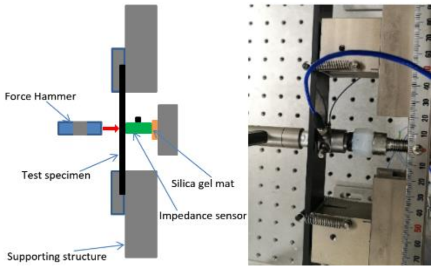


Figure 5. Equipment for pattern-2

2.2. Testing methods

In the previous study [1], the drop steel rod impact test apparatus was applied, which was rough and the impact force history could not be measured. To improve reliability of the impact test results, the force hammer (Model 086c03, PCB Piezotronics, Inc., USA) used for vibration test was applied to measure the impact force history. To remove the influence of the gravity during the impact tests, the lateral impact apparatus was developed, as shown in Fig. 3. Different impact speeds could be achieved by changing the original position of the hammer. The laser displacement sensor (LK-G85, KEYENCE Corporation, Japan) was applied to measure the impact speeds of the force hammer. Special fixture was designed to fix the tested specimens. The simply supporting boundary condition could be realized and the span of specimen can also be adjusted. Same as the previous study [1], experimental analogy was adopted to represent the cases that human body collides with product directly, and human body is protected by product from outside impact source, called impact pattern-1 and impact pattern-2, respectively.

2.2.1. Impact pattern-1 tests

When human crash into some products accidentally, the reaction force exerted on human body is desired to be controlled as low as possible. Fig. 4 shows the equipment for pattern-1. The force hammer represents the human body and the specimen represents the products that human body collides with. Based on measured data, the soft-skin effect of different materials for impact pattern-1 could be evaluated by comparing impact force history.

2.2.2. Impact pattern-2 tests

When human wear product for body protection, the level that the force exerted on human body are also desired to be controlled as low as possible. Fig. 5 shows the equipment for pattern-2. Different from pattern-1, force hammer here represents the outer impact source. An impedance sensor (Model TLD288D01, PCB Piezotronics, Inc., USA) used for measuring the compression force represents the protected human body. The silica gel mat is used to weaken the supporting stiffness so that human body could be better simulated. The specimen represents product. Based on impact force history measured by force hammer and impedance sensor, the soft-skin effect of different materials for impact pattern-2 could be evaluated.

3. Results and discussion

3.1. Impact pattern-1

3.1.1 Characteristics of impact force history

For each specimen and each experiment condition, the tests were conducted for 5 times. Figure 6 shows the impact force history of group-2 specimens for 5 tests under the impact speed of 0.8 m/s. Because the well control of the experimental conditions, the results were stable for each tests.

In the previous study [1], the force exerted on human body was used as an index to evaluate the soft-skin effect of the materials. Higher contacting force on human body means more undesirable feeling or worse influence on human body. The impact peak force for two groups of the specimens under different impact speeds are shown in Fig. 7. With the increasing the impact speeds, the impact peak forces of different materials in different sizes also go increasing. Except for the results of steel specimen in group-1 under the impact speed of 2.8 m/s, it is clear that the average impact peak forces of CTT and CPT were always lower than steel and aluminum specimens in same experimental conditions.

In the tests of steel specimen of group-1 under 2.8 m/s impact speed, apparent plastic deformation was observed during the tests and the impact peak force decreased gradually within 5 tests. This is reason why the average impact peak force changed a little from impact speed of 2.2 m/s to 2.8 m/s and why the standard deviation become bigger. It seems that the materials with lower yield stress have the better soft-skin effect. Since the current evaluation was conducted within elastic stage of materials, the influences of lower yield stress of material on soft-skin effect will be discussed in future job.

Impact peak force could serve as an effective index to evaluate the soft-skin effect, however, this index just capture the characteristic of one moment in the whole impact event. From the Fig. 6, it can be vividly seen that the impact force history of steel was the most irregular and fluctuant during the impact events. For the impact tests, the impact contacting force are always fluctuant due to relative vibration between the two colliding objects. In this study, the impact force fluctuant ratio (FR) is proposed to evaluate the fluctuant level of the impact force history. Fig. 8 is one of the test results used for illustration. The original impact force result and the corresponding impact force after filtering (cutoff frequency is 1600 Hz) is shown Fig. 8 (a). The area encircled by original result line and the filtered result line is defined as are A. The area between filtered result line and x axis is defined as area B. The FR is defined as the ratio of are A to are B.

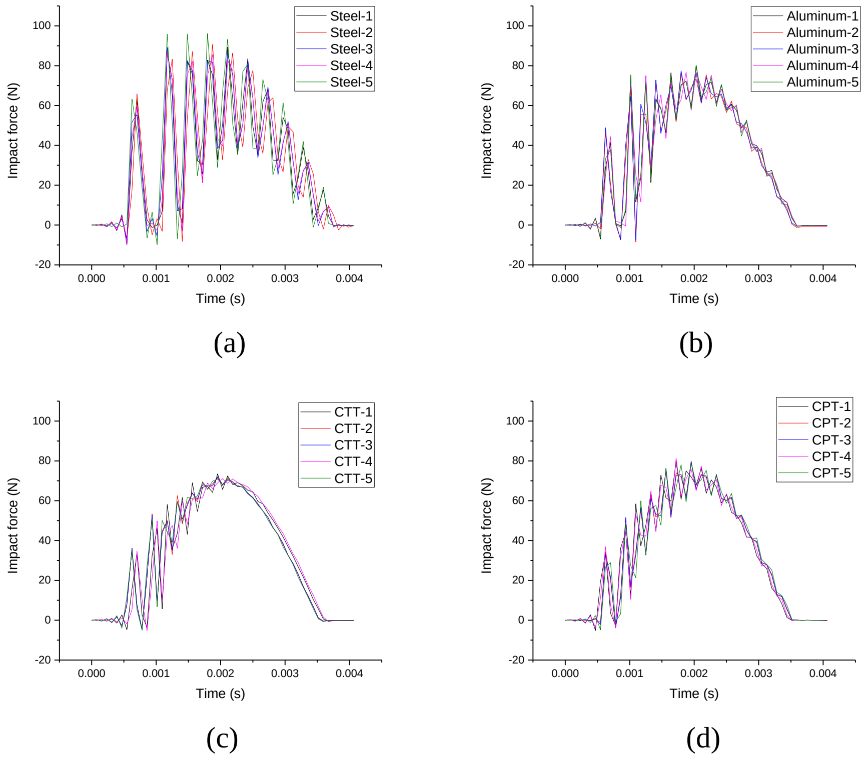


Figure 6. Impact force history of (a) steel, (b) aluminum, (c) CTT, (d) CPT specimens in group-2 under impact speed of 0.8 m/s.

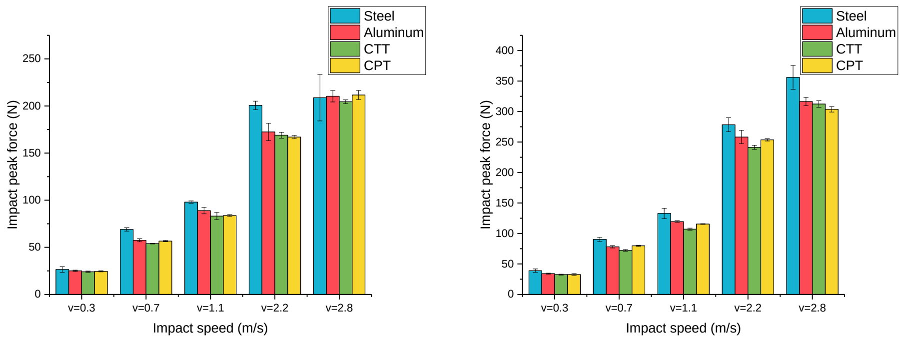
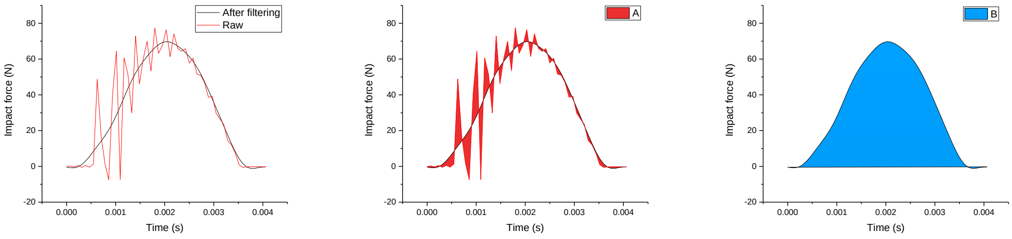


Figure 7. Impact peak force of group-1 (left) and group-2 (right) specimen.

Following this definition, the FRs of specimens in group-2 under three different impact speeds are shown in Fig. 9. It is clear that the impact force of steel specimen is the most fluctuant, which is consistent with the direct observation. And the impact force of the CTT specimen shows the least fluctuant. The higher FR is, the higher impact peak force would appear during the impact events, and also more sharp force peaks would appear. When the FR of structure become lower, the better soft-skin effect of structure for impact pattern-1 could be expected.



(a) (b) (c)

Figure 8. Impact force results of aluminum specimen in grou-2 under impact speed of 0.8 m/s. (a) the raw results and results after filtering, (b) area A, (c) area B.

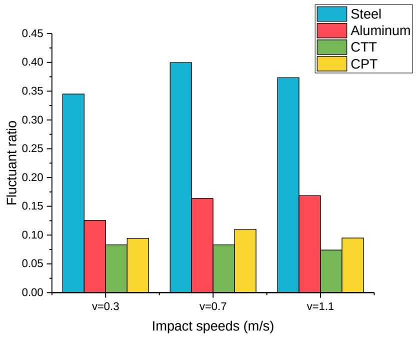


Figure 9. FR of impact force history for specimens in group-2 under different impact speeds.

3.1.2 Influence of inertia of the specimens

It can be seen that the FRs of aluminum, CTT, and CPT are all great lower than steel from Fig. 9. The common characteristic of these three materials is lower weight and lower inertia, as can be seen from the Table 1. To check the influence of inertia, the specimens with attaching mass were designed to check the influence of the inertia, as shown in Fig. 10. Three different masses were prepared, 2.96 g, 5.1 g, and 6.85 g. The CTT specimen in group-2 was used for this validation. The masses were fixed to the center of specimen by cyanoacrylate adhesive. The impact speed was 0.8 m/s.

Fig. 11 shows the impact peak force and FR with different attaching masses. It is apparently shown that the structure with higher inertia could exert higher impact peak force on the force hammer and the whole impact force history become more fluctuant.

Figure 10. CTT specimen in group-2 with attaching mass.

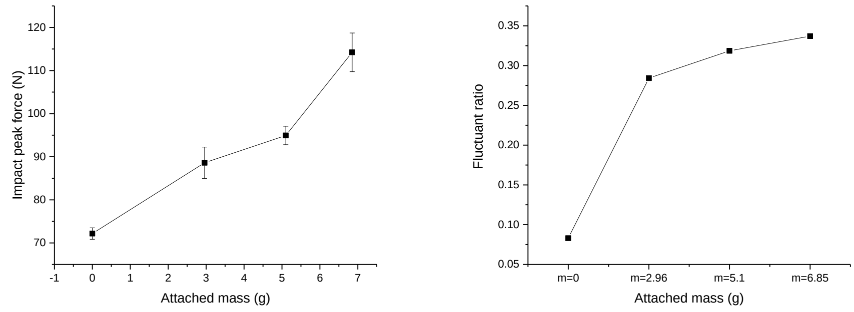


Figure 11. Impact peak force with different attaching mass (left) and FR of impact force history with different attaching mass (right).

3.2. Impact pattern-2

In the impact pattern-2 tests, the impedance sensor was fixed behind of the tested specimen with about 0.5 mm distance between the specimens. Because the specimens were not absolutely flat and the contacting compressing force measured by impedance sensor was sensitive to the distance between sensor and tested specimens, the impact tests were conducted for both sides of the specimens, 3 times for each sides under each experimental condition.

Fig. 12 shows the compression force history of two group specimens during the impact tests. Due to inertia of the impedance sensor and original static motion state, the first compression peak forces were relatively high for all tests. It is found that the first compression peak forces were not sensitive to the bending stiffness of the specimens. Even though the bending stiffness of group-2 specimens is two times of the bending stiffness of group-1, the values of first compression peak force for two groups under the same impact speeds were in same level, which could also be validated by comparing the results of group-1 and group-2 specimens in Fig. 13. From the first compression peak force of specimens in different materials shown in Fig. 13, it is hard to say which material has better performance in impact pattern-2. The results of specimens in different materials were in same level and both CPT and steel sometimes showed the lowest first compression peak force under certain impact conditions.

After first collision between the specimen and the sensor, the sensor would continue to be compressed if the force hammer continue going forward. As can be seen from Fig.12, the compression forces were in lower level in this stage for the specimens with higher bending stiffness. This is the reason why the stiffness of body-protecting products should be designed at high value.

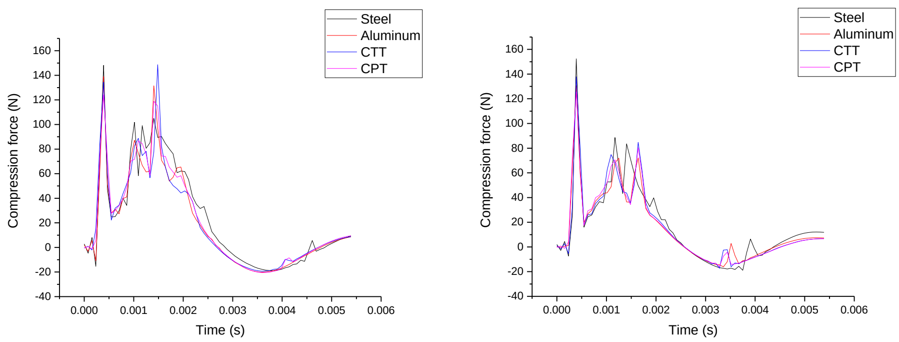


Figure 12. The compression force on the impedance sensor for the group-1 (left) and group-2 (right) specimens under the impact speed of 2.2 m/s.

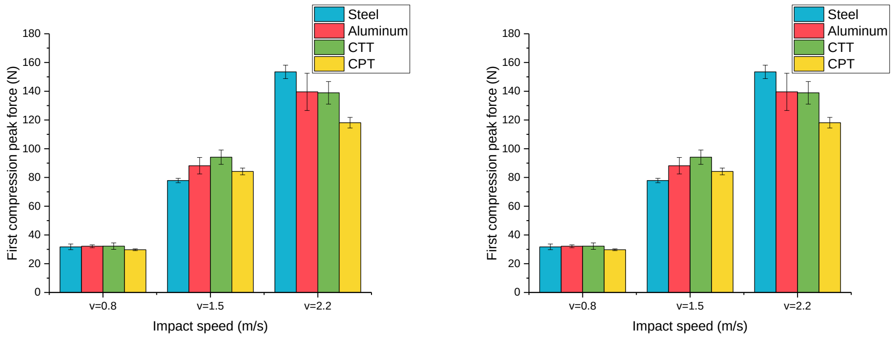


Figure 13. First compression peak force of the group-1 (left) and group-2 (right) specimens.

4. Conclusions

In this study, the soft-skin effect of steel, aluminum, CTT, and CPT were evaluated by improved experimental conditions and mechanisms of soft-skin were investigated further. Following conclusions could be obtained:

1) In the impact pattern-1 tests, the impact peak forces of CTT and CPT under certain impact speeds are always lower than those of steel and aluminum if the specimens in different materials are controlled in same stiffness. The influence of inertia has been proved directly related the soft-skin effect for impact pattern-1. The FR was defined to describe the fluctuant level of impact force history. It was found that the higher the inertia of structure would result in the more fluctuant the force history. For real application, if the structures in different materials are designed in same stiffness, the lightweight structures have better performance in reducing the human's pain or discomfort when human collide with the structures.

2) In the impact pattern-2 tests, no apparent advantage could be found from compressing force history of CTT and CPT, comparing with steel and aluminum. The overall compressing force level is directly determined by the stiffness of the structure. The structure with higher stiffness has better performance in reducing the overall compression force level. In real application scenarios, CTT and CPT are suitable for design of body-protecting products because the same performance could be achieved with great light weight.

References

[1] S. Yamashita, I. Ohsawa, Y. Matsuo, J. Takahashi. Research on soft skin effect of carbon fiber reinforced thermoplastics. *15th European Conference on Composite Materials, Venice, Italy*, 24-28 June 2012.

[2] A. Masoumi, M. H. Shojaeefard, A. Najibi. Comparison of steel, aluminum and composite bonnet in terms of pedestrian head impact. *Safety Science*, 49.10:1371-1380, 2011.

[3] A. Ahmed, W. Li. Introducing CFRP as an alternative material for engine hood to achieve better pedestrian safety using Finite element modeling. *Thin-Walled Structures*, 99:97-108, 2016.