RESEARCH ON SOFT SKIN EFFECT OF CARBON FIBER REINFORCED THERMOPLASTICS

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Abstract

To make clear the soft skin effect of CFRTP, drop weight impact test and finite element analysis were performed and following conclusions were obtained. (1) In the case that human body collides with CFRTP products directly, developed CF/PP shows high ability to reduce human's pain and discomfort because of its surface softness. (2) In the case that human body is protected by CFRTP from impact loads by colliding object, developed CF/PP shows high ability to reduce back face force and its speed because of its excellent damping property. Therefore, such human friendly features of developed CF/PP are useful to expand its application.

1 Introduction

In recent years, environmental and energy problems have become serious, so measures in a transport sector, especially about automobile, have become more and more important. Among the various solutions to the problems, weight reduction by using CFRP (carbon fiber reinforced plastics) as a new alternative material has been expected to be an effective measure. In addition, super-aging society has continued to progress all over the world as shown in Figure 1, so social demand for weight reduction of personal belongings has also increased.
However, conventional CFRP has many problems about molding speed, cost, recyclability, and so on. Those problems have been obstacles in expanding application. In order to solve the problems, researches of CFRTP (carbon fiber reinforced thermoplastics) have been progress and a Japanese national project about it has started since 2008 fiscal year.
It is out of question that researches to solve these problems should be continued definitely, but many other basic material properties related to functionality of CFRTP have not been clarified yet unlike steel and this is one of the obstacles in expanding application range.
In this study, in order to expand the application of CFRTP, we evaluated the superiority about soft skin effect of CFRTP and also considered future tasks and development.

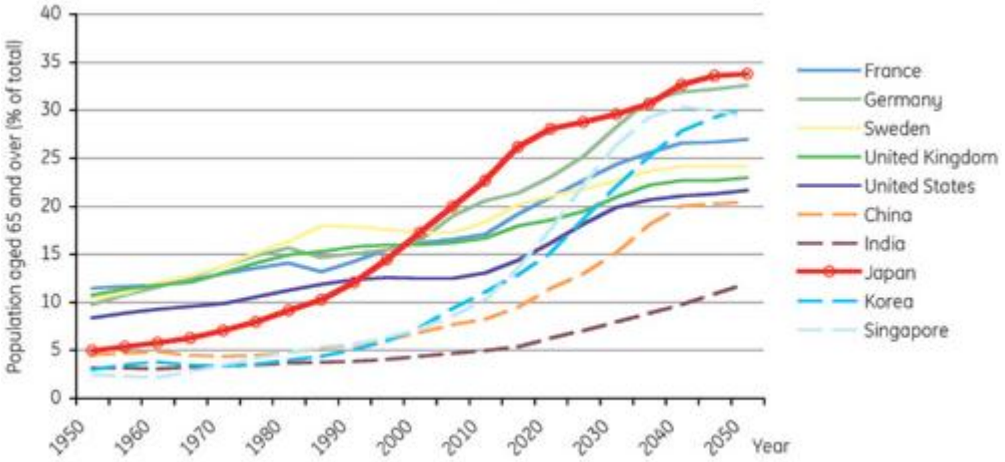

Figure 1. Pace of aging by country (1950-2050): growth in the proportion of the elderly population (65&over) in total population [1].

2 Soft skin effect and its evaluation index

2.1 About soft skin effect

When humans are colliding with something, or some kind of impact is applied to what humans are in contact with, if the impact energy is small, humans are not injured, but feel pains or discomfort. The degree of pain and discomfort varies depending on material of what humans collide with. We named the effect of reducing the degree of pain and discomfort "soft skin effect".

2.2 Evaluation index of soft skin effect

There are many factors that affect the degree of pain or discomfort [2]. So quantification of pain or discomfort is very difficult medically or in engineering. Therefore, evaluation index in material engineering has not been completely settled. Many indicators used in medical community currently do not eliminate subjective elements off. Indicators such as VAS (Visual Analog Scale) and MPQ (McGill Pain Questionnaire) [3] are some of the examples. In many indicators, we focused on the concept of pressure algometry [4]. Pressure algometry is a way of measuring degree of pain by the value of pressure applied to human body and used generally in medical community. Of course, subjective elements are not completely eliminated off in pressure algometry, but pressure (or stress in engineering) is almost certainly associated with degree of pain. In addition, if vibration applied to what human is in contact with is long-lasting, it is certainly uncomfortable and this is in common sense.
Therefore, we have defined the following three indexes to evaluate soft skin effect in this study. The first one is stress or force applied to human body, the second is speed of stress or force applied to human body, and the third is vibration damping property. Based on these three indexes, we performed a validation on soft skin effect in this study.

2.3 Impact patterns

In this study, we assumed two patterns in which light impact is applied to human body. As shown in Figure 2, pattern-1 is the situation that human body collides with product directly while pattern-2 is that human body is protected by product from impact loads by colliding object.

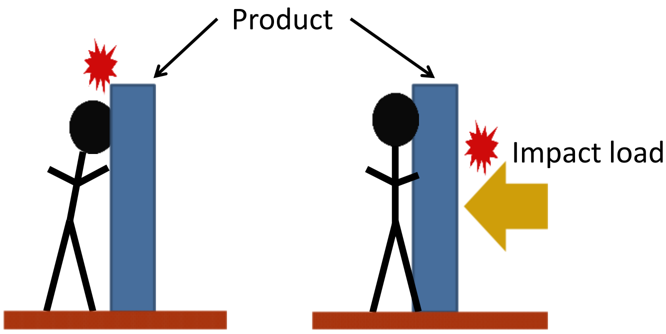

Figure 2. Image of impact pattern-1 (left) and pattern-2 (right).

3 Materials, testing methods and FEA

3.1 Materials

Two types of CF/PP were prepared and compared with steel, aluminum and polypropylene. As shown in Figure 3, one is chopped carbon fiber tape reinforced thermoplastics (CTT) with carbon fiber volume fraction (V_f) of 50 %, and the other is carbon fiber mat reinforced thermoplastics (CMT) with V_f of 20 %. These CFRTPs were provided by MITSUBISHI RAYON CO., LTD., TOYOBO CO., LTD and TORAY industries, LTD.

Thicknesses of these specimens were decided as shown in Table 1 to make flexural stiffness (*EI*) the same as possible as we could. Young's modulus (*E*) and second moment of area (*I*) were calculated by following two formulas [5].

$$E = E_f V_f + E_m(1 - V_f) \tag{1}$$

$$I = \frac{bh^3}{12} \tag{2}$$

Where, E_f and E_m are Young's modulus of carbon fiber and matrix resin. *b* and *h* are width and thickness of specimen, respectively.

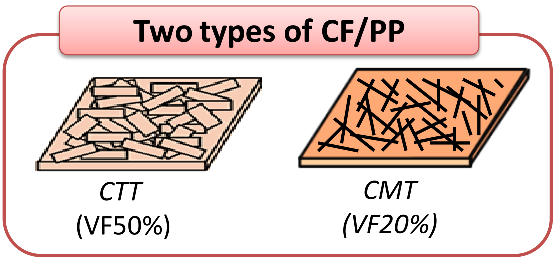

Figure 3. Images of two types of CF/PP.

Table 1. Test specimens for drop weight impact test.

	b: width [mm]	length [mm]	h: thickness [mm]	V_f [%]	EI: flexural stiffness [kN・mm^2]
steel	90	100	1.0	-	1575
aluminum	90	100	1.5	-	1772
CTT	90	100	2.0	50	2300
CMT	90	100	2.5	20	1797
polypropylene	90	100	5.0	0	1313

3.2 Testing methods

To perform light impact test, we made equipment for drop weight impact test as shown in Figure 4. Test specimens were fixed by steel base plate with toggle cramp as shown in Figure 5. In addition, experiments in this study are referring to the method of measuring CAI (compression after impact) that is a standard in SACMA (Suppliers of Advanced Composite Material Association) [6]. Because we assume two patterns (pattern-1 and pattern-2), two kinds of constraint were prepared as shown in Figure 6.

Table 2 shows conditions of drop weight impact test. Condition "A" corresponds to impact pattern-1 and deflection of the test specimen is allowed as shown in the left side of Figure 6. Condition "B" and "C" correspond to pattern-2 and the load applied to the opposite surface of collision side is observed directly by load cell in contact with a test specimen, so deflection of a test specimen is not allowed as shown in the right side of Figure 6. Mass of the impact bar is 0.15kg in condition "A" and "B" and 0.50 kg in condition "C". Because of the light mass of the impact bar, the tests can be performed at low energy level between 0.01J and 0.50J, so plastic deformation does not occur in test specimens basically. Metals are dented only in condition "C". Drop heights are 10mm, 30mm and 50mm in all conditions.

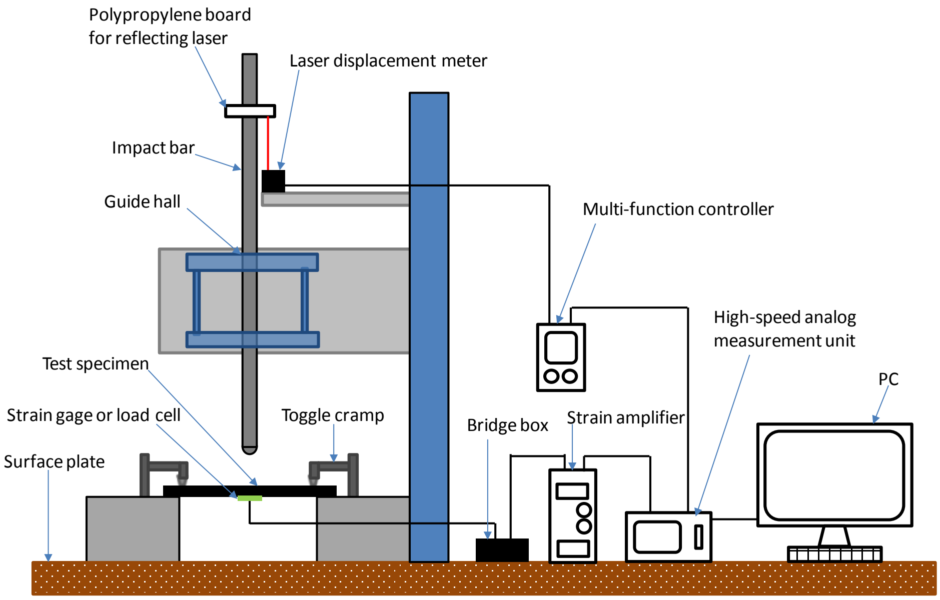

Figure 4. Schematic of drop weight impact test.

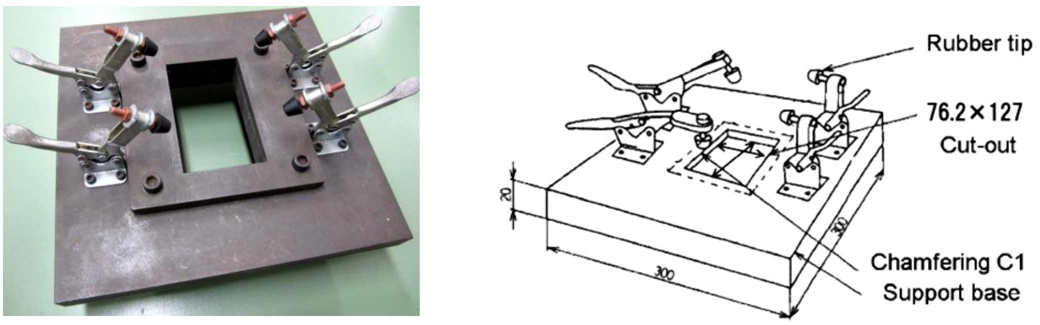

Figure 5. Steel base plate with toggle cramp organized by SACMA [7]

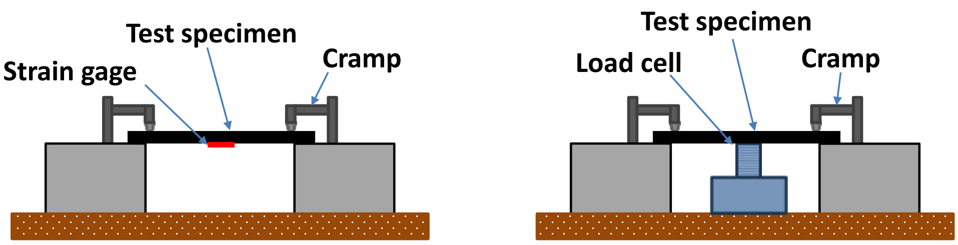

Figure 6. Schematic of constraints (left: pattern-1, right: pattern-2).

Table 2. Impact conditions of drop weight impact test.

Test No.	Constraint	ϕ [mm]	H[mm]	m[kg]	E_p[J]	V_0[m/s]
A-10	pattern-1	15	10	0.15	0.0147	0.44
A-30	pattern-1	15	30	0.15	0.0441	0.77
A-50	pattern-1	15	50	0.15	0.0735	0.99
B-10	pattern-2	15	10	0.15	0.0147	0.44
B-30	pattern-2	15	30	0.15	0.0441	0.77
B-50	pattern-2	15	50	0.15	0.0735	0.99
C-10	pattern-2	16	10	0.50	0.049	0.44
C-30	pattern-2	16	30	0.50	0.147	0.77
C-50	pattern-2	16	50	0.50	0.245	0.99

3.3 Finite element analysis

In order to know what happens on colliding interface such as stress-strain distribution, we performed FE analysis by plane-impact model. We used LS-DYNA Version971 as a solver. Because the model has a symmetry, we used 1/4 model as shown in Figure 7 for reducing calculation time. In order to reproduce the behavior of the actual impact phenomenon, the FE analyses were performed under the same geometrical and load conditions as those of the experiment in this study. Figure 8 shows comparison between the FE analytical results and the experimental results about displacement at the tip of the striker. Since these results show good agreement, we can discuss about a relationship between the degree of human pain and the stress distribution and its transition at collision area which can be obtained only by finite element analysis.

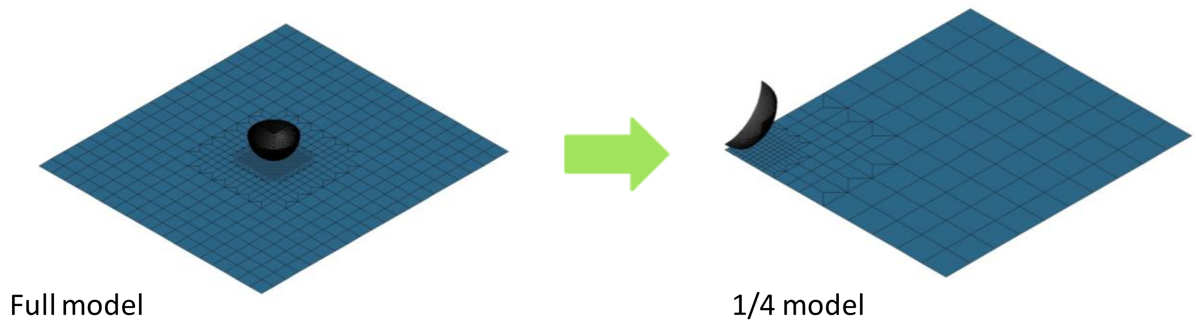

Figure 7. Schematic of plane-impact model.

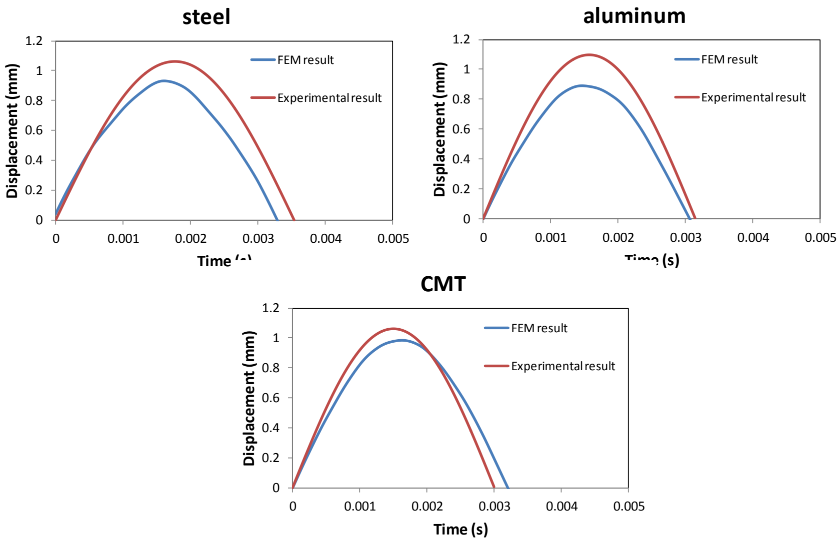

Figure 8. Comparison of FEA and experimental results (displacement curve).

4 Results and discussion

4.1 Pattern-1

The results of FE analysis in condition "A-50" is shown in Figure 9. This figure shows transition of the force applied to striker during contact. As shown in Table 3, the contact force of CMT specimen was about 1/2 of those of steel and aluminum specimen. It is because the contact area of CMT specimen was larger than those of steel and aluminum specimens. As shown in Figure 10 which shows the distribution of contact forces at the tip of striker and approximate contact area shown in red circle when contact forces are at their maximum value. Therefore, CMT has soft skin effect that reduces the level of pain. These phenomena are caused by the softness of the surface of CF/PP. In addition, self-excited vibration of CMT is smaller than those of steel and aluminum during contact. It is uncertain that human can identify the difference, but this difference may affect the level of discomfort that human feels in case of light impact.

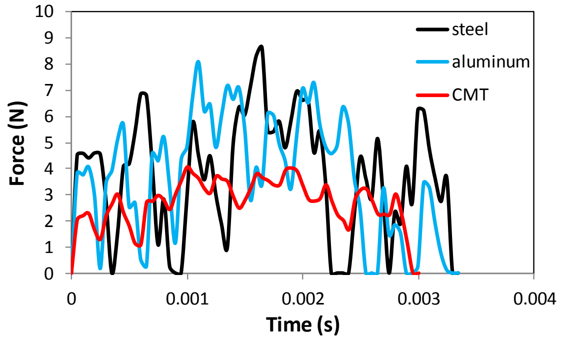

Figure 9. Time vs. forces applied to striker in plane-impact model.

Table 3. Maximum contact forces and approximate radius of contact area.

Materials	Maximum contact force [N]	vs. steel	Radius of contact area [mm]
steel	8.62	1	0.60
aluminum	8.08	0.94	0.60
CMT	4.08	0.47	0.75

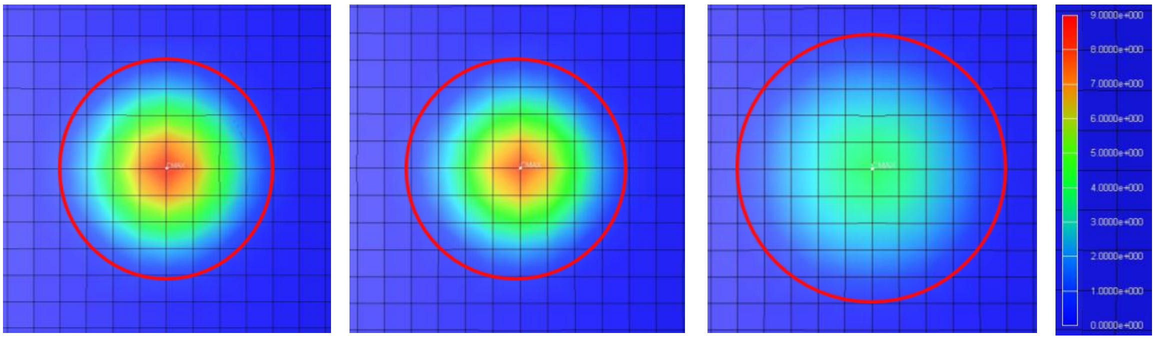

Figure 10. Distribution of contact forces at tip of striker (left: steel, center: aluminum, right: CMT).

4.2 Pattern-2

Concerning the back face force, which is the load observed at the opposite surface of collision side, the maximum values of CF/PP and PP become smaller than those of metals as shown in Figure 11. Figure 12 shows the maximum speed of back face force, and shows more significant deference than Figure 10. They are probably caused by the excellent damping properties of CF/PP and PP. However, in condition "B", these effects of CTT are smaller than those of CMT. It is probably because that flexural stiffness of CTT specimen was relatively higher as shown in Table 1. On the other hand, aluminum shows similar effect as CF/PP in condition "C". However, whereas an obvious dent occurred on the surface of aluminum specimen, dents did not occur at all on CF/PP and PP specimens observed by microscope. Therefore, it can be said that there is a superiority of CF/PP and PP.

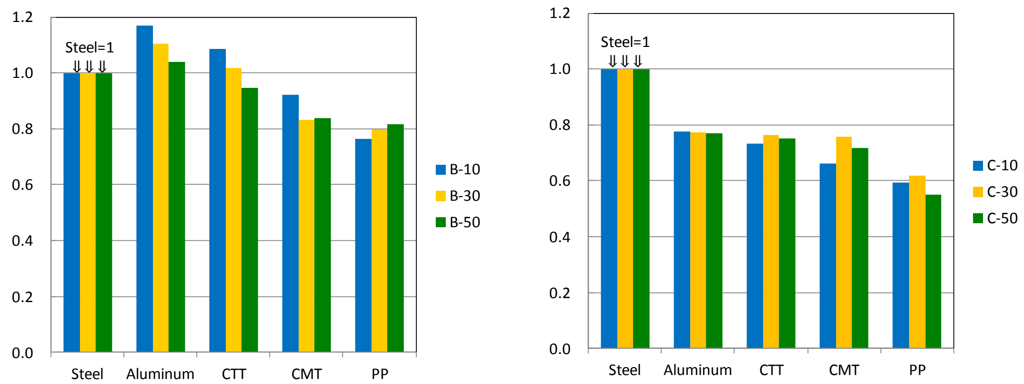

Figure 11. Comparison of maximum back face forces (left: condition B, right: condition C).

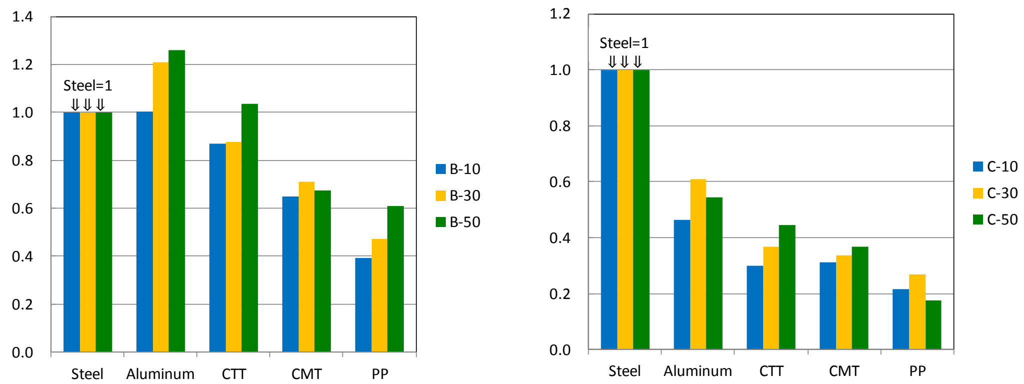

Figure 12. Comparison of the maximum speed of back face force (left: condition B, right: condition C).

Assuming that these materials are used to protect human body, according to previous results, larger force is sharply transferred to human body in the case of steel protector, while smaller force is slowly transferred to human body in the cases of CF/PP and PP protector.

5 Conclusions

We examined soft skin effect of CFRTP by drop weight impact test and FE analysis. In pattern-1, the contact force of CMT specimen was smaller than those of steel and aluminum specimen. It is probably because the surface of CF/PP is softer than metals and contact area of CMT was larger than those of metals. Therefore, CMT has soft skin effect that reduces the level of human's pain. In pattern-2, the maximum value of back face force, which is the load observed at the opposite surface of collision side, and its speed of CF/PP and PP specimens were smaller than those of metals. They are probably caused by the excellent damping properties of CF/PP and PP. Therefore, in both pattern-1 and pattern-2, superiority of CFRTP was confirmed according to the indexes of soft skin effect that we defined in this research.
Further studies has been continued, e.g., concerning an influence of V_f on soft skin effect (this information is important in order to balance soft skin effect and mechanical properties), thermal recovery of soft skin effect in the case that CF/PP is damaged by impact, etc.

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