STUDY ON OPTIMAL AUTOMOTIVE STRUCTURE MADE BY CFRTP

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1 Introduction

CFRTS (carbon fiber reinforced thermosetting resins) are lightweight and strong materials. Because of these properties, CFRTS has been used in F1 cars, airplanes, and so on. And some luxury passenger automobile have adopted CFRTS to enhance driving performances. However CFRTS's application field has been limited because of high cost, low productivity, difficulty in recycling, and so on. Hence, it is difficult to apply CFRTS to mass production automobile [1] to reduce global oil consumption and CO_2 emission. Then Japanese government decided to develop technologies to apply CFRTP (carbon fiber reinforced thermoplastics) to mass production automobile. So that CFRTP will have not only similar mechanical properties as CFRTS but also have more ductile fracture property than CFRTS [2]. And this technological development will also help to promote electric vehicles by decreasing materials of secondary battery and motor [3].

From this standpoint, optimal automotive BIW structure made by CFRTP are discussed in this study. Although there were a lot of FEM study for applying CFRP to automotive structure [4, 5], we couldn't know about actual optimal CFRTP BIW structure form these case studies. Since specific stiffness and specific strength of CFRTP are quite different from those of steel [6], the optimal steel BIW structure may not be the optimal CFRTP BIW structure. Then we, in this primary work, simply divide BIW structure into frame and panel parts, and the optimal combination of them are investigated by using FEM.

2 Method of analysis

In this research, finite element model as shown in Fig.1 (this model is referred from [7]) which is composed of panel and frame members is used, and the following three structural properties are calculated by using LS-DYNA.

(1) Normalized torsional stiffness (NTS)

Torsion is given to the model, while two points are fixed not to move. In this condition, displacement is calculated as shown in Fig.2. Then NTS is given as following equation [8].

$$\frac{GJ}{L^3} = \frac{WR}{L^2 \arctan\frac{\delta}{R}} \qquad (1)$$

Where, δ is calculated displacement, W is applied load for torsion, R and L are width and length of car model respectively. When NTS is higher, better driving performances can be provided.

(2) Normalized bending stiffness (NBS)

Bending is given to the model, while four points are fixed not to move. In this condition, displacement is calculated as shown in Fig.3. Then NBS is given as following equation [8].

$$\frac{EI}{L^3} = \frac{wb^2(L^2 - 2b^2)}{6L^4 y} \qquad (2)$$

Where, y is calculated displacement, w is applied load for bending, b is the length between the front of the model and the load point, L is length of car model, respectively. When NBS is higher, better driving performances can be provided.

(3) Resistance to collision (RC)

The model is fixed not to move and an object is given an initial velocity to collide with the model. Different from the above two models, doors are closed during collision as shown in Fig.4. When the deformation of the model is smaller, better occupant protection performances can be provided.

2.1 Analysis of panel and frame structure

In order to understand roles of both panel structure and frame structure, these two structures are firstly modeled and analyzed respectively. The weight of body is adjusted by changing the thickness of panels or frames. Relationships between weight of the body and the three structural properties are studied, so that roles of panel and frame can be clarified.

2.2 Calculation of weight-lightening ratio

In this paper weight of the body made by steel and CFRTP are compared with the properties of NTS, NBS and RC. Firstly, the body made of steel is analyzed. Weight is fixed and NTS, NBS and RC are analyzed respectively. These values are plotted on graphs. In this analysis, weight of the body is fixed at 350 kg. Stiffness of steel is 210 GPa, and density of steel is 8 g/cm^3. The body made of CFRTP is also analyzed by the same method. In this analysis, weight of body is changed. Stiffness of CFRTP (with 47% of carbon fiber volume fraction) is 34 GPa, and density is 1.35 g/cm^3. Relationship between stress and strain is shown in Fig.7. These values are obtained from mechanical test of CFRTP. By comparing graphs of the properties of steel body and CFRTP body with a same level, weight-lightening ratio of CFRTP body to steel body can be calculated.

3 Results and discussions

3.1 Analysis of panel and frame structure

Relationship between NTS and weight of the body is shown in Fig.8. NTS of the panel model is higher than that of the frame model. So it is realized that torsional stiffness of the body can be increased by increasing the thickness of panel more efficiently than increasing the thickness of frame.

Relationship between NBS and weight of the body is shown in Fig.9. Similarly, NBS of the panel model is higher than that of the frame model. So it is realized that the bending stiffness of the body can be increased by increasing the thickness of panel more efficiently than increasing the thickness of frame.

Fig.10 shows a relationship between displacement by collision and weight of the body. The frame model has higher resistance to collision than the panel model. So it is realized that resistance to collision of the body can be increased by increasing the thickness of frame more efficiently than increasing the thickness of panel.

Considering these results, panels and frames play different roles in actual structure. And their optimal weight should be determined respectively from the crashworthiness and rigidity needed for the body. Hence, optimal weight ratio of panel and frame, this is indeed automotive structural design, of CFRTP automobile must be different from that of steel automobile.

3.2 Calculation of weight-lightening ratio

Fig.11 shows the analytical result of steel body at 350 kg. If the rate of panel increases, both NTS and NBS increase. And displacement by collision increases if the rate of panel increases to more than 40%. If the rate of panel is determined at 40%, the NBS is about 300 N/mm, and displacement by collision is 230 mm.

Fig.12 shows the analytical result of CFRTP body with a weight of 160 kg, 180 kg and 200 kg respectively. This graph also shows the same tendency of the steel's one. However, displacement by collision has nothing to do with stiffness, comparing to the steel body.

If the criterion is determined as a steel body with 40% of panel (displacement by collision is 230 mm), CFRTP body of which weight is 180 kg and the rate of panel is 75% can fulfill this criterion. So if this body is employed, weight of the body can be reduced to as much as 40%. If this body is disseminated, it can reduce the energy consumption of transportation and bring us a better vision which is friendlier for the environment.

Though anisotropy is not considered in this paper, if it is considered, smarter and lighter weight automotive structure can be expected by above results and discussions.

4 Conclusions

If a structure is divided into panels and frames, panels mainly contribute stiffness of the structure. On contrast, frames mainly contribute resistance to collision of the structure. So consideration of the balance of these two parts is important for designing the optimal structure against external loads.

If the body made of CFRTP is designed with the same stiffness and resistance to collision of the steel body, its weight can be as much as about 40% of

steel body. And the ratio of panel member in CFRTP body is higher than that of steel body. This is because CFRTP is stronger than steel and is not as brittle as CFRP.

Future automobile will be required more fuel efficiency and more safety. Form this study, we know that automobile becomes more lighter by using anisotropy of CFRTP, and occupants become more safety by using more frame parts. Furthermore, light-weight automobile is not only safe for pedestrians, CFRTP is known to be effective in reducing head injury of pedestrians because of its long elastic strain.

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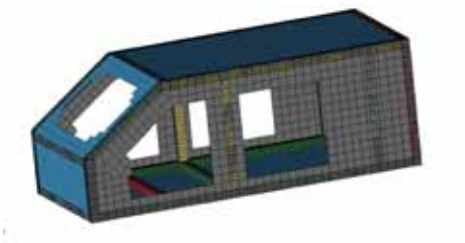

Fig.1 Finite element model used in this study.

Fig.2 Deformation subjected to torsional load.

Fig.3 Deformation subjected to bending load.

Fig.4 Displacement by collision.

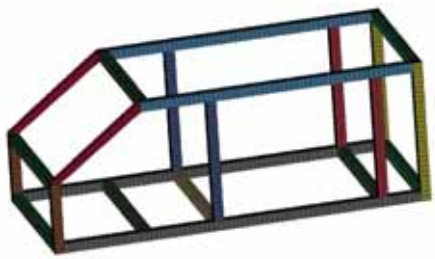

Fig.5 Frame model used in this study.

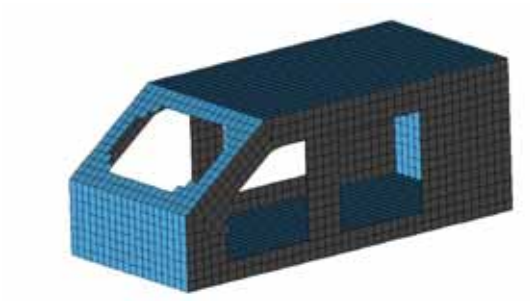

Fig.6 Panel model used in this study.

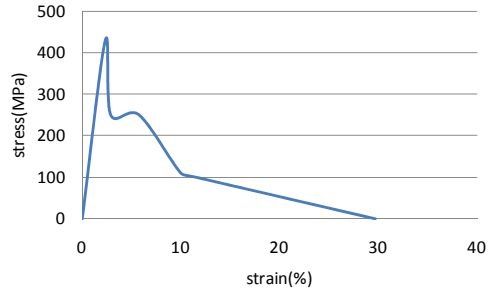

Fig.7 Strain and stress relationship of CFRTP.

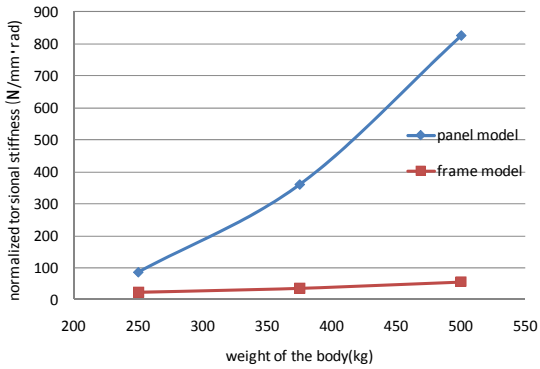

Fig.8 Changes of normalized torsional stiffness according to the weight of the body.

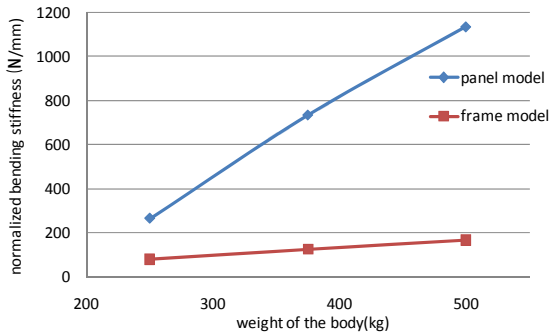

Fig.9 Changes of normalized bending stiffness according to the weight of the body.

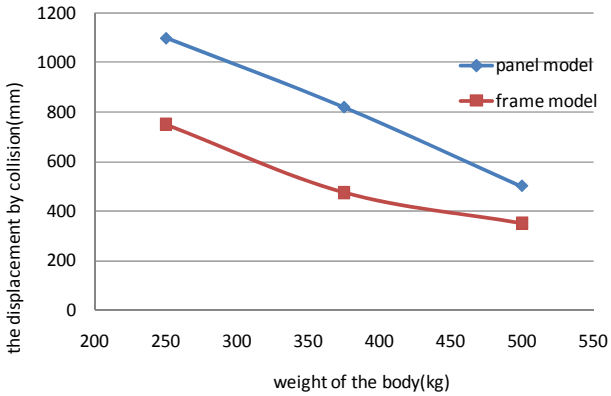

Fig.10 Changes of displacement by collision according to the weight of the body.

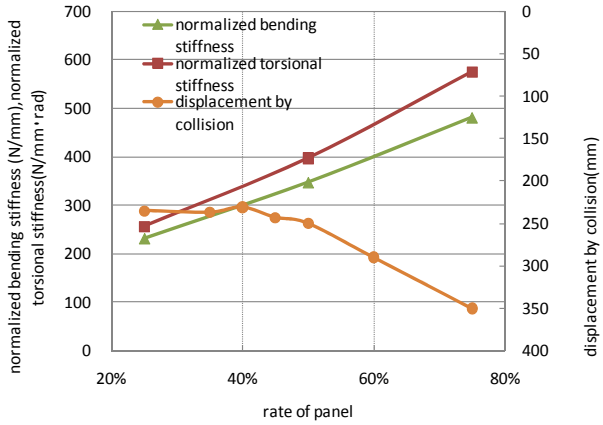

Fig.11 Influence of weight ratio of panel to frame on structural properties of steel automobile.

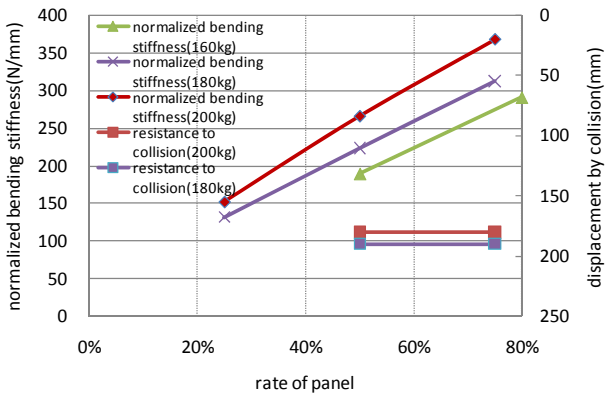

Fig.12 Influence of weight ratio of panel to frame on structural properties of CFRTP automobile.