ENERGY ABSORPTION EVALUATION ON CFRP STRUCTURE STRENGTH BY CF/AL HYBRIT MATERIAL

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Abstract

The purpose of this research is to examine the possibility of using carbon-fiber-reinforced plastic (CFRP) structures for vehicle components with respect to crashworthiness. An evaluation was conducted using the amount of bending energy absorbed by the structure as the evaluation criterion. Test pieces were fabricated by placing a CFRP/Al hybrid material inside a CFRP component having a constant cross section. The test pieces were then subjected to weight-drop tests and the results were compared with the test data for the existing steel structure. It was observed that the amount of energy absorbed was increased by dispersing the load transmitted to the hybrid material and by the deformation of the entire test piece. The tested specification absorbed 1.3 times more energy than the steel test piece, demonstrating its effectiveness as a vehicle structural component.

1. Introduction

The vehicle weight has increased in recent years due to measures taken to improve crashworthiness. However, there are strong needs to reduce the vehicle weight because of its impact on fuel consumption. In this regard, carbon-fiber-reinforced plastic (CFRP) has attracted interest as a weight reduction material owing to its excellent strength and specific rigidity. However, since CFRP is susceptible to damage under an impact load due to its brittle nature, it is difficult to apply this material to areas of the vehicle body that absorb crash energy in side impacts. The focus of this study was a CFRP/Al hybrid material with superior bending energy absorption. Test pieces incorporating the CFRP/Al hybrid material as reinforcement were manufactured, and their effectiveness as a side impact absorbing component was tested by measuring the level of absorbed energy.

The CFRP/Al hybrid material consists of CFRP with high tensile strength on the tension side and aluminum, which can absorb a large amount of energy by plastic deformation, on the compression side. This material can absorb significantly more energy than either CFRP or aluminum alone.

2. Test pieces and method

2.1 Test pieces

Figure 1 shows a test piece manufactured of the CFRP/Al hybrid material (referred to as the hybrid material here). The test piece consists of inner and outer parts with the hybrid material used as reinforcement inside the CFRP structure. In this study, the plate thickness of the inner/outer parts, aluminum geometry, and foam material were used as the factors, and two levels were defined for each factor. Based on previous findings [1], [2], [3], [4],a hybrid material with high energy-absorbing capacity was selected. For the purpose of comparison, a steel test piece was also fabricated that simulated the existing steel structure applied to the energy-absorbing area of the vehicle body.

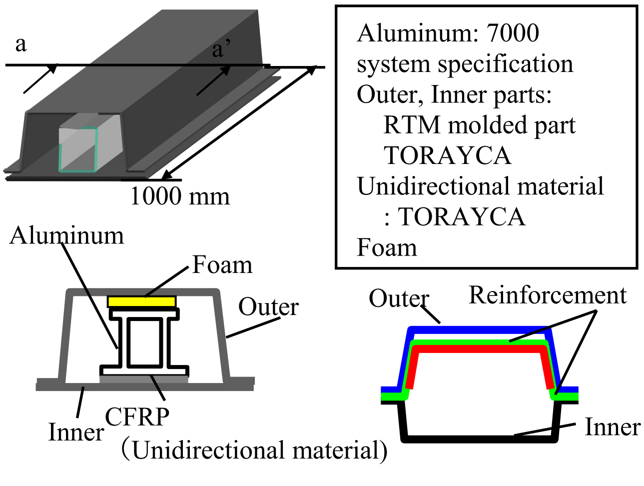


Fig. 1. Test piece specification

2.2 Experimental method

As shown in Fig. 2, a test piece was placed on two support jigs spaced at a distance of 800 mm. A weight-drop test was conducted by dropping an impactor from a height of 12 m, thereby applying a load to the outer side of the test piece equivalent to an impact at a collision speed of 55 km/h.

Displacement of the test piece was measured with a laser displacement gauge. The loading on the test piece was measured with load cells attached to the support jigs. The energy absorption level of the test piece was calculated based on the load-displacement graph thus obtained. Additionally, the fracture condition of the test piece was observed.

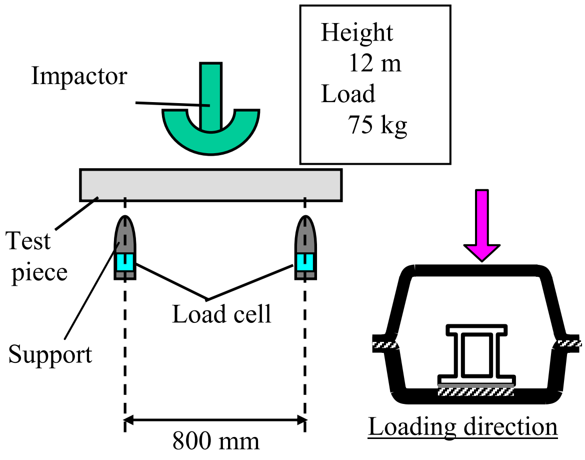


Fig. 2. Outline of impact test

3. Results and discussion

3.1 Preliminary experiment

The test piece was composed of the inner and outer parts, with the hybrid material as reinforcement. First, the location of the hybrid material was examined in a preliminary experiment. As shown in Fig. 3, the test piece was fabricated by placing the hybrid material on either the outer part or the inner part.

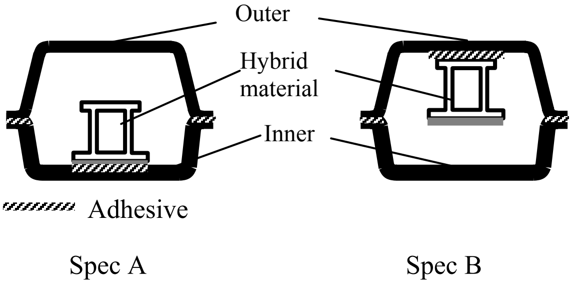


Fig. 3. Test pieces after impact test

Impact tests were conducted on these test pieces, and Table 1 shows the energy absorption level of each specification.

Table 1. Comparison of energy absorption levels

	Steel test piece	Spec A	Spec B
Hybrid material Position	—	Inner part	Outer part
Energy (%)[*1]	100	89	87

[*1] Compared by assuming energy absorption of steel test piece equals 100

Figure 4 shows the fracture condition of the test pieces. Detachment was seen in the bonded area of the outer/inner parts and between the outer part and the hybrid material for the test piece with the hybrid material on the outer part. In this experiment, the impactor load was transmitted in the order of the outer part, hybrid material, and the inner part. It is assumed that local deformation of the loaded area of the outer part prevented the hybrid material and the inner part, which were bonded with an adhesive, from following the deformation of the outer part, thereby causing the detachment in the bonded area.

For the test piece with the hybrid material on the inner part, the load was applied in the order of the hybrid material and the inner part, after the outer part was damaged. Accordingly, the whole structure absorbed the impact energy, which prevented the detachment of the component parts.

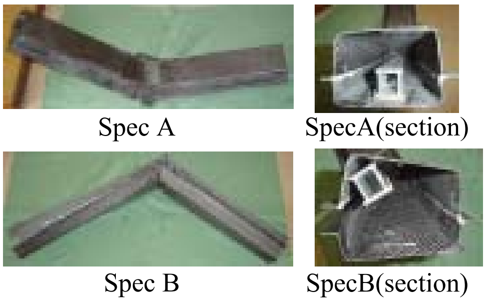

Spec A
SpecA(section)
Spec B
SpecB(section)

Fig. 4. Test pieces after impact test

Figure 5 is a load-displacement graph of the test results. The graph shows higher initial reaction force for the test piece with the hybrid material on the outer part compared with the steel material. This is because the load was initially applied to the highly rigid hybrid material. The test piece with the hybrid material on inner part initially sustained the load only with outer part. After the loaded area of the outer part was damaged, the load was transmitted to the hybrid material. The results in the graph match the actual fracture condition.

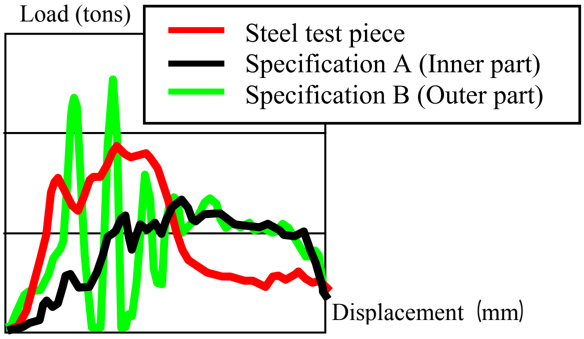
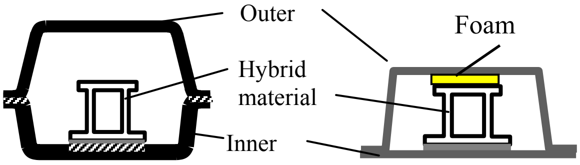


Fig. 5 Load-displacement curves in impact test

No large difference in energy absorption levels was found between the two test pieces. However, it was concluded that placing the hybrid material on the inner part was better, considering that there was no detachment of component materials.

3.2 Experiment

In addition to the test piece with the hybrid material on the inner part, which was used in the preliminary experiment, test pieces with a smaller cross-sectional area were also examined, as shown in Fig. 6.



Nos. 2 & 3 Nos. 4 & 5

Fig. 6. Test pieces after impact test

Table 2 shows the energy absorption levels of typical specifications used in this experiment.

Table 2. Comparison of energy absorption levels

	No. 1	No. 2 [*3]	No. 3	No. 4	No. 5
aluminum [*1]		A	B	B	B
Foam				○	○
Outer part thickness (mm)	1.2	1.2	1.2	1.2	1.2
Inner part thickness (mm)	1.2	1.2	1.2	1.2	1.8
Energy (%) [*2]	11	87	101	133	137

[*1] Cross-sectional coefficient(aluminum) A＜B

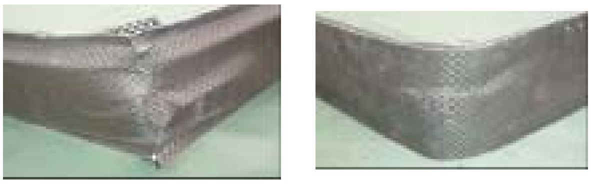
[*2] Compared by assuming energy absorption of steel test piece equals 100

[*3] The same as spec B in the preliminary experiment

Energy absorption of the test piece with the hybrid material having aluminum geometry B exceeded that of the steel test piece. In addition, the component parts of all the test pieces with the hybrid material did not come off or fly into the air after the impact, as Fig. 7 shows. These results indicate that the structure with the hybrid material specification can be applied to body locations that absorb impact energy.

No. 1 (Inner part) No. 1 (Outer part)

No. 3(Outer part) No.4(Outer part)



No. 3(Inner part) No. 4(Inner part)

Fig. 7. Test pieces after impact test

A comparison of the individual factors indicates that test piece No. 1 without any hybrid material on either the outer part or the inner part had a noticeably lower energy absorption level of 11% compared with the steel test piece. However, the whole structure did not break off, and after unloading, the shape recovered, as No. 1 in Fig. 7 indicates.

With regard to different aluminum specifications, a comparison of test pieces No. 2 and No. 3 shows an increase in energy absorption of nearly 1.2 times. The cross-sectional coefficient differed between spec A and spec B, with aluminum B having a higher coefficient. It was also revealed that the hybrid material alone improved the energy absorption level.

By comparing test pieces No. 4 and No. 5 for different inner part specifications, it was found that an increase in plate thickness led to a higher energy absorption level. The inner part material is the area where the tensile load is applied, and it also serves to promote plastic deformation of the aluminum in the same way as the CFRP (Unidirectional material), which is one component of the hybrid material. Thus, improvement of the inner part material strength can prevent a reduction in load sustainability in the latter half of the displacement phase. It is regarded as one of the factors for improving energy absorption.

A simple comparison cannot be made of the test pieces with and without the foam material because of the difference in their cross-sectional structures. Nonetheless, the results indicate an increase in energy absorption and differences in deformation between test pieces No. 3 and No. 4. Test piece No. 4 with the foam material did not have a sharp bending angle. As No. 3 in Fig. 7 indicates, a crack occurred in the inner part of test piece No. 3, and it fractured and was deformed. Test piece No. 4 did not have any distinct damage and was deformed. An examination of test pieces with and without foam and having the same cross-sectional structure as No. 4 confirmed the same increase in energy absorption and the same overall shape deformation as that of No. 3 and No. 4. Consequently, it is assumed that the entire test piece absorbed energy, because No. 4 with the foam material had a wide deformation area.

Figure 8 is a load-displacement graph of the major specifications tested in this experiment.

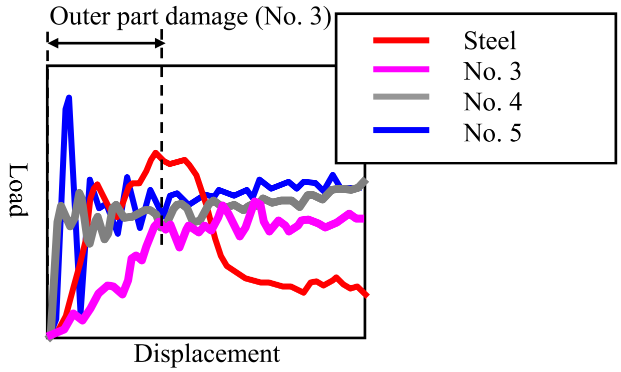


Fig. 8. Load-displacement curves in impact test

For test piece No. 3 without any foam material, the load was applied to the outer part at the beginning of the displacement phase. Subsequently, after the outer part was damaged, the load was transmitted to the hybrid material and was sustained in a stable manner. Compared with No. 3, the load-displacement curves of test pieces No. 4 and No. 5 increased immediately, as they had no clearance for deformation of the outer part owing to the absence of foam between the outer part and the hybrid material. The results suggest that the load level at the beginning of displacement was mainly sustained by the hybrid material in these test pieces. The difference in the sustained load at the beginning of the displacement phase appeared as the difference in the energy absorption level. It can be assumed that the foam dispersed the local load applied to the hybrid material at the beginning of the displacement phase, resulting in pervasive deformation that absorbed the load. This load dispersion is considered to be a factor that increased energy absorption.

Thus, it was found that the applied load must be conveyed to the hybrid material efficiently in order to improve the energy absorption level of this structure. The outer part does not need to have high strength or rigidity. For instance, it is preferable to have the outer part transmit the load in the surface direction as much as possible by making this part thinner.

Therefore, it is assumed that the increase in energy absorption of 1.3 times obtained by adding foam between the hybrid material and the outer part is attributable to the energy absorption mode of the test piece, even though it had a low cross-sectional coefficient. Since the hybrid material of the test piece mainly sustains the applied load, if a similar hybrid material is applied and the load is easily transmitted to the hybrid material, the outer part can presumably absorb a certain level of energy even with a low cross-sectional coefficient.

4. Conclusion

The conclusion drawn from the experimental results is summarized below.

- The CFRP structure composed of an outer part, an inner part and a CFRP/Al hybrid material absorbed as much or more energy than the steel test piece, indicating that it can be used as a vehicle structural material.

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