Weight Reduction Study for Side Panel of Formula One Monocoque

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ABSTRACT

This paper describes the research conducted on Carbon Fiber Reinforced Plastic (CFRP) for the side panel of a Formula One monocoque.

The elongation ratio of a matrix resin was increased, thus increasing intrusion load 30% by load distribution. This enabled weight reduction by 1.1 kg for only a segment of the side panel.

In addition, weight reduction research was further conducted on single-sheet side panel, an alternative option to aluminum-honeycomb sandwich side panel, and the resulting technical issues were clarified.

1. Introduction

A several-mm-thick material called CFRP is used for the Formula One monocoque. CFRP is made by laying up multiple 100 µm-thick "prepreg" sheets, which is a carbon fiber fabric impregnated with matrix resin, and hardening the layered sheets. In addition, sandwich structures in which an aluminum honeycomb is sandwiched between CFRP increased strength and rigidity, and weight reduction is further required.

The Federation Internationale de l'Automobile (FIA) sets regulations for intrusion resistance in side impacts to help ensure side panel safety(1).

The FIA updates side panel regulations every few years in order to enhance safety, and each time the monocoque weight is increased.

Weight increases are expected to continue in the future following regulation updates, so the mechanism of intrusion resistance was studied, a matrix resin for side panels was developed, and weight reduction research using optimized panel structures was initiated.

2. Side Panels and Intrusion Regulations

In Fig. 1, the side panel is shown as the shaded portion. The side panel takes up over 50% of the surface area of the monocoque, thus it is a component that benefits greatly from weight reduction technology.

Figure 2 shows the setup for the intrusion test of the side panel.

For the intrusion test, a test panel is used to simulate a laminate on the side panel section of the monocoque. This test panel, which has a 550 mm x 550 mm outer dimension framed with a 25 mm wide metal frame for affixing bolts, is penetrated at a rate of 2 ± 1 mm/min. The FIA stipulates three regulation parameters: intrusion load, energy absorption, and fracture morphology. In 2005, all three of these parameters were increased to the following: intrusion load: "during the first 100 mm of displacement by the penetrator, the load must exceed 250 kN"; energy absorption: "during the first 100 mm of displacement by the penetrator, energy absorption must exceed 6 kJ"; and fracture morphology: "after the penetrator displaces 150 mm, there should be no damage to the border or to the fixture."

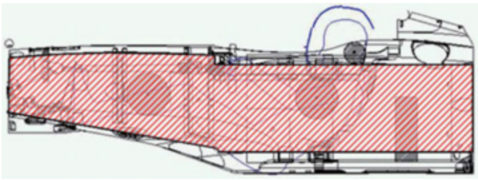

Fig. 1 Side panel area of monocoque

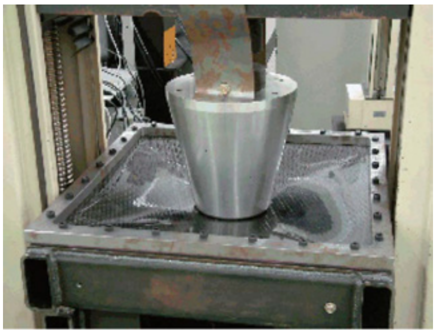

Fig. 2 Intrusion test setup

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Table 1 Side panel regulation transition

Year	Maximum load; first 100 mm of displacement (kN)	Energy absorption; first 100 mm of displacement (kJ)	Destructive morphology; after 150 mm displacement	Others
2001-2004	150	6	No destruction to frame	–
2005-2006	250			–
2007-				Additional extra secondary panel

Each racing team is conducting research to clear these regulations by weight reduction applications. Moreover, since 2007, the FIA has ordered the addition of FIA-designated, 6.2 mm-thick laminates to portions of the exterior side panels that satisfy the above requirements[(2)] (Table 1).

3. Technology Elements

The impact of carbon fiber-type, panel structure, aluminum honeycomb density, matrix resin of CFRP was confirmed.

3.1. Carbon Fibers

Intrusion tests were conducted on CFRP made from commercial carbon fibers. The carbon fiber series T1000G manufactured by Toray Industries, Inc. was confirmed as offering the highest tensile strength and best intrusion resistance among available carbon fibers.

3.2. Panel Structures (Sandwich Panel and Single Sheet)

Formula One monocoque is designed to receive the highest intrusion load when the inner wall of the panel is penetrated. Figure 3 shows intrusion test results for the sandwich panel and single sheet. For the sandwich panel, the top panel that corresponds to the outer wall panel of the monocoque was penetrated with 142 kN of load. Then, the bottom panel that corresponds to the inner wall panel of the monocoque was penetrated with 261 kN of load. Also, the single sheet was penetrated with 200 kN of load, 61 kN less than the bottom panel of the sandwich panel, despite being 1.3 mm thicker than the bottom panel of the sandwich panel. Furthermore, if the 10 mm thickness of the honeycomb is subtracted, the displacement of the single sheet is found to be 4 mm less than bottom panel penetration.

For the sandwich panel, the top panel and aluminum honeycomb is considered to disperse the load in the in-plane direction, so less stress would be generated at the bottom panel under the same load. In other words, the load distribution was expected to be an integral technical element for increasing intrusion resistance.

3.3. Aluminum Honeycomb Density

With sandwich panels that use low-density aluminum honeycomb for weight reduction, the intrusion load is decreased. That is, honeycombs with low density have low compressive strength and shear strength, and consequently, is unable to distribute the load acting on the top panel over a wide area of the bottom panel (Fig. 4). Technology is required that supports reduced intrusion loads for low-density honeycomb.

3.4. Matrix Resin

Pre-impregnated matrix resin, used as CFRP materials, takes full advantage of the special characteristics of carbon fiber, including high strength and high elastic modulus. However, the high strength and high elastic modulus characteristics of CFRP were expected to adversely affect intrusion resistance because of low load distribution. Therefore, CFRP trials were made with two kinds of epoxy resins, one with a high elastic modulus and another with a high elongation ratio. Then, intrusion resistance tests were conducted on the side panel. As anticipated, the results showed that matrix resin with high elongation ratio has greater intrusion resistance (Fig. 5).

Thus, it was confirmed that low-density honeycombs and matrix resin with excellent load distribution

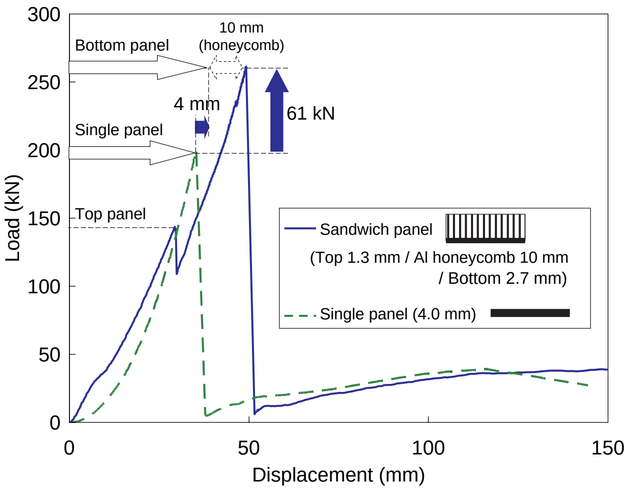

Fig. 3 Intrusion test results of sandwich / single panel

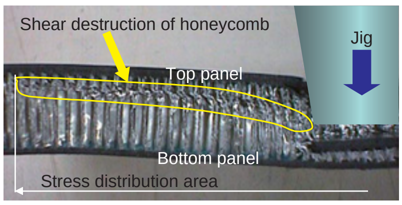

Fig. 4 Side panel section before bottom panel intrusion

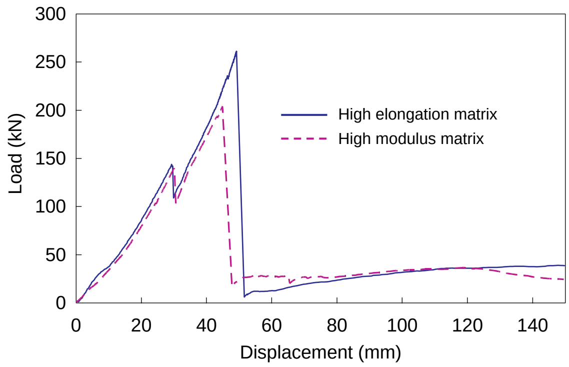

Fig. 5 Intrusion test results of high modulus/ elongation matrix CFRP panel

properties are a necessary technical element for side panel weight reduction.

4. Research on Matrix Resin for High Intrusion CFRP

An aluminum honeycomb with a density of 10 lb/ft^3 has been used for the side panel and weight reduction was conducted by using 8 lb/ft^3 of material. Research was then conducted under the concept of compensating for reduced intrusion loads due to decreased load distribution by increasing the elongation ratio of the matrix resin.

By optimizing the resin components, RH421 epoxy resin with a 4% elongation ratio manufactured by Nagase ChemteX Corporation was obtained for the final specification. Figure 6 shows the mechanical properties.

An intrusion resistance test was conducted on a test sandwich panel that used RH421 and an aluminum honeycomb with a density of 8 lb/ft^3. The results showed a 30% increase in intrusion load over the existing Cycom2020[(3)] product specification.

Figure 7 shows the panel intrusion holes. The Cycom2020 specification shows breaks at sharp angles around the intrusion hole area as opposed to the gentle bends exhibited by the RH421 specification.

It is thought that, because of reduced CFRP bending and the reduced compression elastic modulus (Fig. 8), bending and compression stress concentration, which are CFRP weak-points, did not occur and these stresses were successfully converted into tensile stresses. Thus, the high elongation ratio of the matrix resin allowed weight reduction of the aluminum honeycomb and the increased intrusion load to be achieved simultaneously.

5. Research on Single-sheet Side Panel

Research was conducted on further weight reduction with the goal of conforming single-sheet side panels to regulations without using aluminum honeycombs.

5.1. Verification of Composite Results for Low Elastic Modulus Layers

Figure 9 shows the intrusion load for single-sheet CFRP. When the panel thickness was increased, the intrusion load increased but the intrusion load efficiency, obtained by dividing intrusion load by the panel thickness, decreased. This was thought to be caused because load distribution was decreased together with the increase in panel rigidity.

Functional materials similar to the aluminum honeycomb of the sandwich panel were researched to help distribute the load. Single-sheet side panels were made for trial purposes (Fig. 10). For the panels, an organic fiber layer with an elastic modulus less than that of carbon fiber was arranged in between the CFRP layers or on the CFRP outer layer. As a result, the intrusion

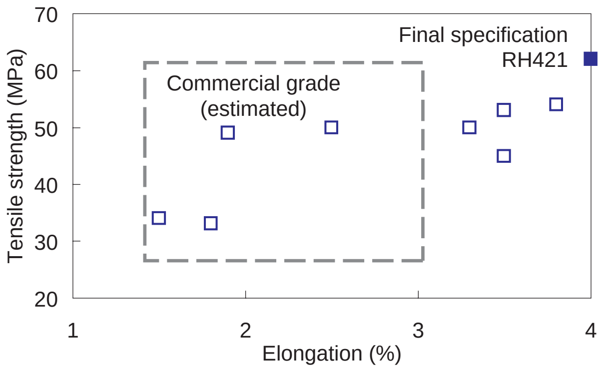

Fig. 6　Physical properties of trial epoxy resin

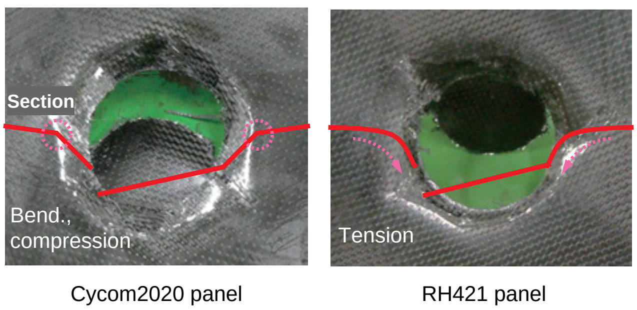

Fig. 7　Panel appearance after intrusion test

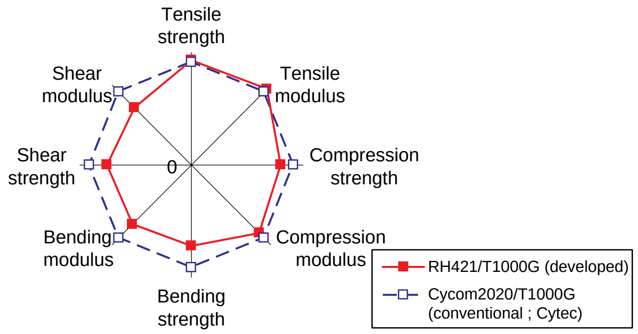

Fig. 8　Mechanical properties of CFRP

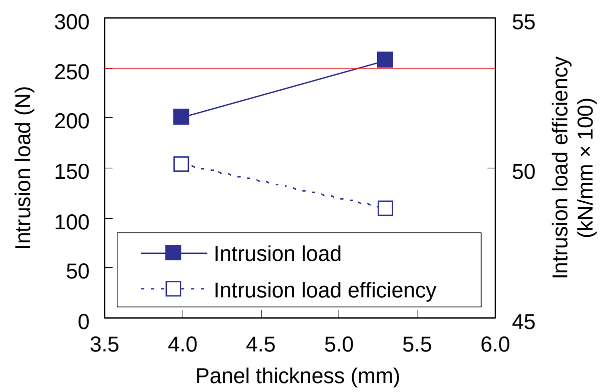

Fig. 9　Intrusion load and intrusion load efficiency of single panel

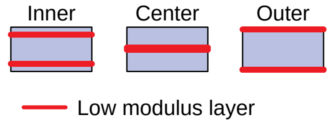

Fig. 10　Example of low modulus layer arrangement

load was increased more than for the single-sheet CFRP panel, with the exception of one specification, even though there was variation depending on the difference in the kind of organic fiber and arrangement (Fig. 11).

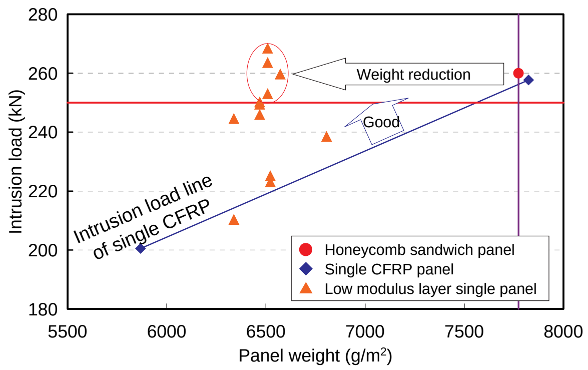

Fig. 11 Effect of low modulus layer arrangement for intrusion

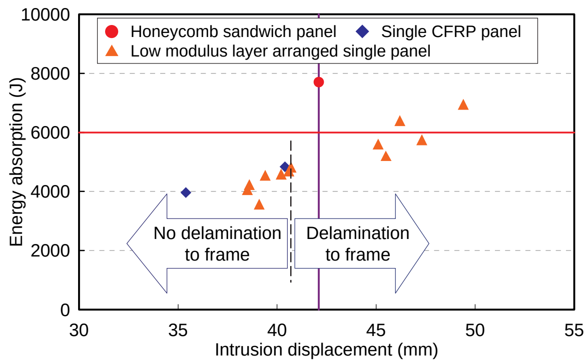

Fig. 12 Energy absorption of low modulus layer single panel

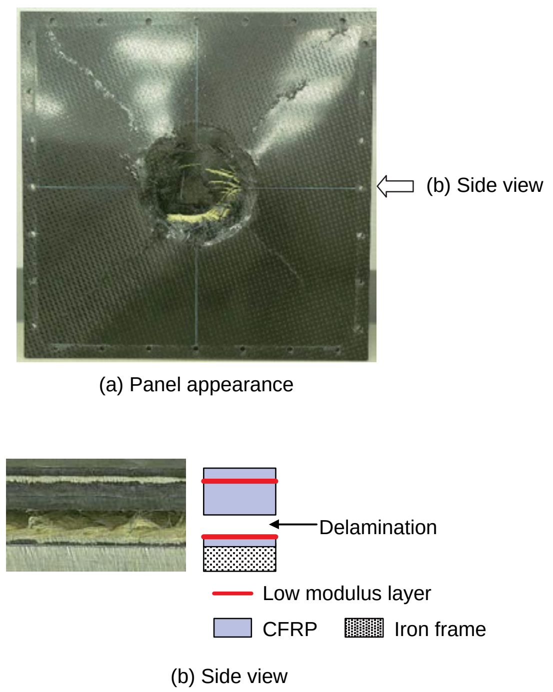

Fig. 13 Appearance after intrusion test of low modulus layer single panel

5.2. Issues of Single-sheet Low Elastic Modulus Composites

Figure 12 shows the remaining issues related to energy absorption and the fracture morphology for the side panel. As the amount of the energy absorption increases the intrusion displacement increases; however, because single sheets do not undergo a two-stage intrusion like the sandwich panel, the amount of the energy absorption is low. Also, when intrusion displacement increases, delamination is generated at the organic fiber layer and the carbon fiber layer interfaces and extends to the edge of the panel (Fig. 13). Because of this fracture morphology, regulations have not been achieved. Additional control technology for interface delamination is required in single-sheet manufacture for side panels.

6. Conclusion

The technology that maintains intrusion resistance with sandwich panels having low-density aluminum honeycomb was established by producing a high elongation ratio CFRP matrix resin.

Side panels with RH421 applied allowed the bottom panel to be thinner, and in combination with a low-density aluminum honeycomb achieved a total weight reduction of 1.1 kg. These specifications were officially approved by the FIA.

An actual test using a real vehicle with these side panels was performed and verified with no decrease in driving stability performance.

On the other hand, it was clear that interface delamination control technology is necessary regarding single-sheet construction that will allow further weight reduction.

References

(1) Federation Internationale de I'Automobile (FIA): Side intrusion test procedure, Appendix to the 2007 FIA Formula One Technical Regulations, Article 18. 6, p. 34-35 (2006)

(2) Federation Internationale de I'Automobile (FIA): Additional side intrusion panels, Appendix to the 2007 FIA Formula One Technical Regulations, Article 15. 4. 7, p. 26-27 (2006)

(3) http://www.cytec.com/

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