

Development of a Lightweight CFRP Hood and Rear Spoiler

Yasuo YAMANE*

Tomohiro SAKURABA*

ABSTRACT

A carbon fiber-reinforced plastic (CFRP) hood and rear spoiler were developed to achieve weight reduction in vehicle body parts. In addition to its low weight, CFRP's moldability shared by other polymeric materials allows a high degree of styling freedom. It was possible to integrate undercut areas with sections of varying thickness to achieve the required functional characteristics without an increase in weight. Utilizing CFRP instead of aluminum for the hood has enabled integral molding of aerodynamic air ducts, and bonding of the skin and frame with adhesives has increased the section modulus of the entire hood, making it approximately 30% lighter. Forming the rear spoiler from CFRP rather than sheet molding compounds (SMC) has enabled the undercut section, composed of numerous curved surfaces, to be formed as a monolithic structure without the necessity of joining separate parts. Thus, a reduction in weight of approximately 40% versus the '93 model has been achieved, despite the increase in size.

1. Introduction

Reducing vehicle body weight is an effective means for reducing automotive fuel consumption which is one of many ways to address global environmental issues. In applying lightweight materials to vehicle bodies, efforts are being made to increase the application rate of high tensile strength steel sheets. On the other hand, the adoption of all-aluminum bodies has achieved significant weight reductions for some small-scale production vehicles that emphasize either lower fuel consumption or for dynamic driving performance. Amidst these circumstances, there have also been numerous cases of weight reduction using plastic body panels. Reports of outer panels using reinforcing fibers include a hood made of a sheet molding compound (SMC)⁽¹⁾ which is a type of glass fiber reinforced plastic (GFRP), and large-sized GFRP outer panels for small-scale production vehicles⁽²⁾. Thermoplastic fenders⁽³⁾ are reported as an example of outer panels using non-reinforced materials. Plastic materials thus far have had a small specific modulus, which has limited its scope of application compared to aluminum materials. Therefore, attention was given to the application of higher modulus carbon fiber reinforced plastics (CFRP) that are

widely used in the aerospace or racing car fields in which weight reduction ranks as one of the most important elements.

However, there are few successful applications of CFRP materials to automotive parts in the high production volume vehicle arena. Additionally, there are uncertainties regarding the weight reduction effects, collision safety, durability and product performance of CFRP based applications. This paper describes the development of a lightweight CFRP hood and rear spoiler which are superior to aluminum parts for small-scale production mass sales vehicles.

2. Development Aims and Approach

Materials with a superior specific modulus are applied as efficient materials for weight reduction of automotive parts. Figure 1 shows the weight reduction effects with equivalent surface stiffness for typical automotive materials. Using a steel sheet as a basis, this figure shows that weight reduction effects of approximately 40% can be expected for SMC, approximately 50% for aluminum, and approximately 67% for CFRP. Note that the flexural modulus of the CFRP laminate used in this figure is the value for a quasi-isotropic

* Tochigi R&D Center

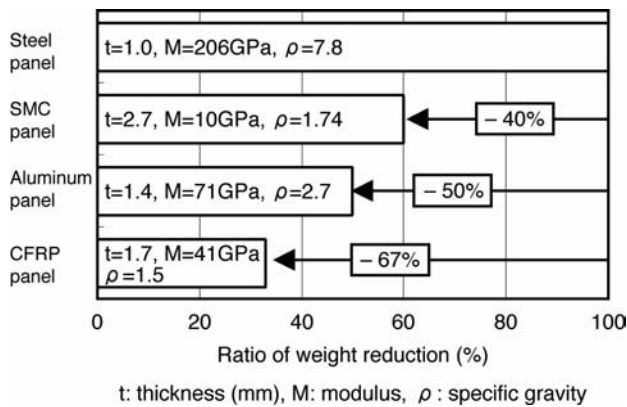


Fig. 1 Weight reducing effect with equivalent surface stiffness

laminate (in-plane isotropic of modulus)⁽⁴⁾.

In addition, although CFRP are plastic materials with a high degree of molding freedom, they also exhibit brittle failure. Therefore, the following goals were set for this development.

- 1) Achieving weight reduction by integrated molding without adding elements for joining other parts which are a factor increasing weights even for complex shapes such as hoods with aerodynamic air ducts and rear spoilers with multiple undercut sections.
- 2) Ensuring collision safety equivalent to metal parts.
- 3) Ensuring durability and marketability equivalent to metal parts.

3. Material Properties

3.1. Material Specifications

The molding materials used were HTA-3K plain fabric cloth W3101/Q195 comprised of carbon fiber (CF) as a reinforcing fiber and epoxy resin, and a W3802/Q195 prepreg (an intermediate base material consisting of reinforcing fibers impregnated with resin in the semi-hardened state) with aramid fiber (AF)⁽⁵⁾ which is resistant to shocks woven into the fabric. (Both materials were manufactured by TOHO TENAX Co., Ltd.)

The modulus of fiber direction (E11) of CFRP which is an anisotropic material exhibits the maximum value in the 0° direction and a value of approximately 10% in the 45° direction. Similarly, the shearing modulus (G12) exhibits the maximum value in the 45° direction and a value of approximately 10% in the 0° and 90° directions. Figure 2 shows an example of HTA-vf60% (volume fraction). Product development hypothesizes the load input from all directions, so a quasi-isotropic laminate is used as the basic structure, and a stack of reinforcing cloth materials are added in accordance with the required product functions.

3.2. Stacking Scheme and Material Properties

The hood used the stacking scheme described below to achieve both thinness for weight reduction and the required product functions.

The basic hood skin structure had a total of six layers, of which four layers were a quasi-isotropic laminate of CF cloth in order to ensure even surface stiffness for waxing and other work, and the center two layers were a 2-layer prepreg

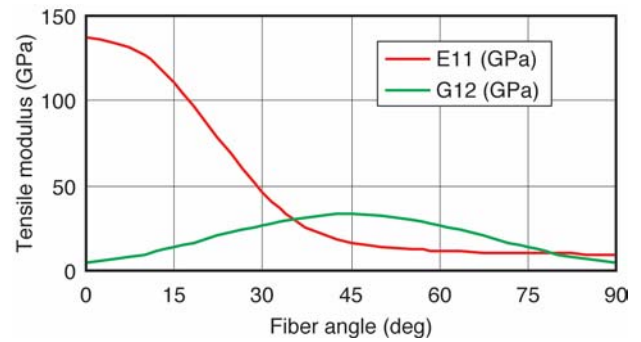


Fig. 2 Anisotropy of CFRP

laminate with AF woven in the $\pm 45^\circ$ direction. This stacking scheme was strong in the $\pm 45^\circ$ direction, but easily damaged by collision input from the front, so the AF layers prevented scattering in the event of collision. In addition, the hood frame had a total of four layers consisting of two CF cloth layers each in the 0° and 90° directions. This emphasized strength in the longitudinal direction to cope with light collision input, and the design shape ensured the optimum torsional rigidity when opening and closing the hood. In addition, an AF woven prepreg was also stacked for the same purpose as the skin.

The rear spoiler had a basic structure with a total 4-layer quasi-isotropic laminate, but 0° and 90° layers relative to the aerodynamic flexural direction were added to the center wing portion to increase the rigidity.

Table 1 shows the stacking scheme and basic properties of the hood and rear spoiler.

Table 1 Typical properties of several parts

		Hood skin	Hood frame	Rear spoiler
Stacking sequence		[$\pm 45/0,90/\pm 45$ (CF/AF)]S	[$0,90/\pm 45$ (CF/AF)]S	[$\pm 45/0,90$]S
0°, 90°	Flexural modulus (GPa)	30	26	45
	Flexural strength (MPa)	890	850	1300
$\pm 45^\circ$	Flexural modulus (GPa)	41	14	45
	Flexural strength (MPa)	1150	450	1300
Fiber content (vol %)		50	50	50

3.3. Material Properties of Stacking Overlaps

In laminates using cloth-woven prepreps, the textile width is approximately 1,000 mm, so when molding parts exceeding that width the prepreps must be lapped to avoid a drop in the physical properties. However, using a long lap length increases the amount of materials used, which leads to an increase in the weight. Therefore, the optimum lap length value was obtained by performing tensile shearing tests using a 25 mm wide test piece with varying lap lengths to minimize the increased weight. Figure 3 shows the stack section, and Fig. 4 shows the test results. Based on these results, the lap length in the stack was set in the range of 10 mm to 15 mm.

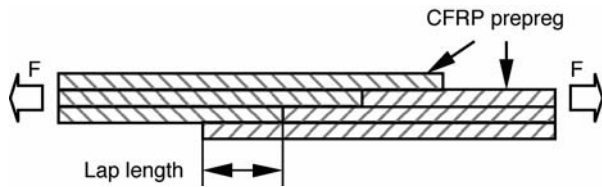


Fig. 3 Shearing testing

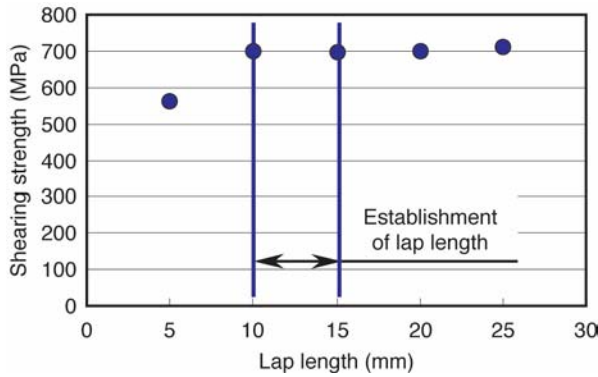


Fig. 4 Lap length vs shearing strength

3.4. Creep Properties of Metal Mounts

Composite laminate materials have a larger coefficient of thermal expansion than metal materials in the transverse direction (the direction perpendicular to the plate). Therefore, bolt loosening due to thermal creep is an issue when using steel bolts in the fastenings. Table 2 shows the coefficients of thermal expansion for metal materials and CFRP laminate.

Table 2 Coefficient of linear thermal expansion

Material	CLTE ($^{\circ}\text{C}^{-1}$)
Steel	$11.6 \times 10\text{E-}6$
Aluminum	$21 \times 10\text{E-}6$
CFRP (vf 50%)	(vertical) $40 \times 10\text{E-}6$
	(horizontal) $0.1 \times 10\text{E-}6$

CFRP laminate has a coefficient of thermal expansion approximately twice that of aluminum in the transverse direction. Therefore, the thermal creep performance of CFRP laminate and the corresponding portion of a mass produced aluminum hood frame were compared through the following test. CFRP laminates molded to a thickness of 2.0, 2.9 and 3.7 mm were clasped between $90 \times 25 \times 2.0$ mm stiffener plates which is the size that can be applied to parts in order to lower the surface pressure on the fastening, and clamped with M6 bolts at 7 N·m and 12 N·m which are the upper and lower limits of the prescribed torque. For comparison a 2.0 mm aluminum plate was clasped between 18 mm diameter washers for M6 and clamped in the same manner as the CFRP laminate. A hot-cold cycle load of -40°C and 80°C was then applied to both test pieces in this condition, and the residual axial force of the bolts was measured.

Figure 5 shows the CFRP test piece used in the test. In addition, the structure of a hood lock where a CFRP frame is

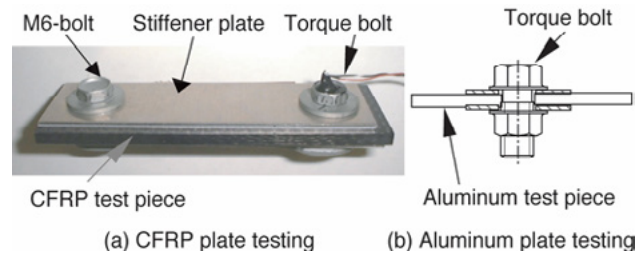


Fig. 5 Creep test piece

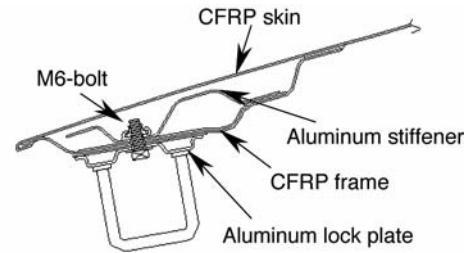


Fig. 6 Section of CFRP hood lock

clasped by an aluminum stiffener and locked by a bolt is shown in Fig. 6 as an example of a typical fastening.

Figure 7 shows the test results. Both the CFRP laminates and the aluminum plate finished the initial creep for the most part at the load for one cycle, and reached a steady creep range thereafter. In addition, the residual axial force increased as the CFRP laminates became thicker, and this is thought to be because the creep is absorbed by the surface layers of the laminate. These results showed that CFRP laminates which have the surface pressure lowered by a stiffener maintain a higher residual axial force than aluminum plates at the upper and lower limits of the clamping torque, and sufficient creep strength can be ensured with a plate thickness of 2 mm or more.

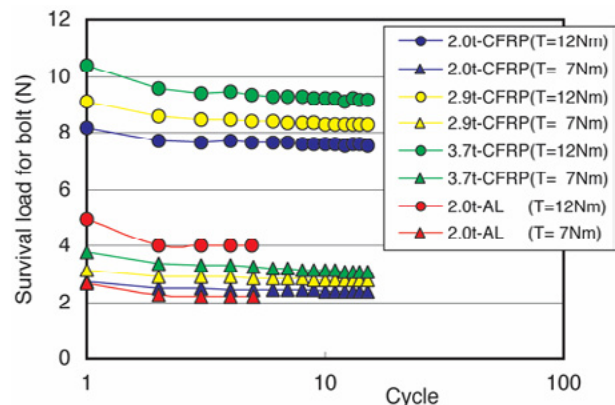


Fig. 7 Creep test results

4. Investigation of Manufacturing Methods

The hand lay-up (HLU) method which reduces die costs is an effective manufacturing method for creating parts for small-scale production vehicles⁽²⁾. The procedure for the autoclave (A/C) method using preregs, which is a type of HLU method, is presented below.

The basic procedure consists of the following six processes. Figure 8 shows a part of these work processes.

- (1) Prepreg cutting process in which the materials are cut to the prescribed specifications
- (2) Hand lay-up process in which the prepregs are stretched and stacked over a die that has been treated for die release
- (3) Bagging process for holding and transferring the materials between dies
- (4) Autoclave process in which the prepregs are pressurized and hardened
- (5) Part removal
- (6) Trimming

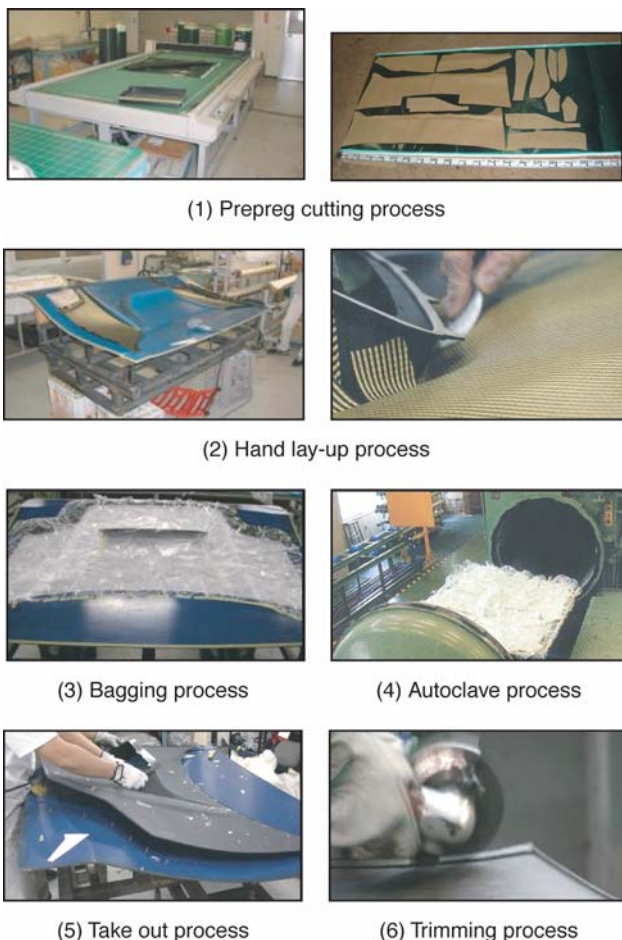


Fig. 8 A/C method

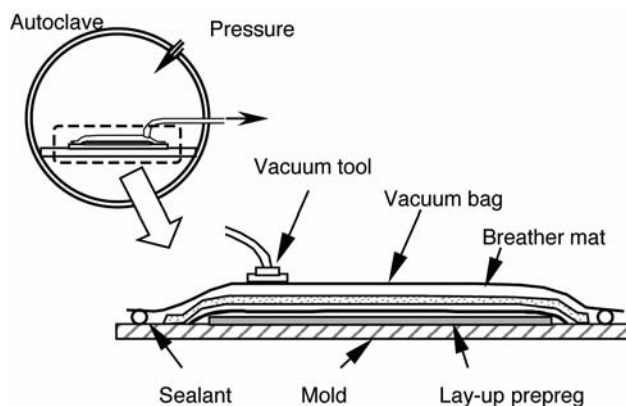


Fig. 9 Outline of A/C

Figure 9 shows an outline of the A/C process, and Fig. 10 shows an example of typical molding conditions. The A/C process generally stacks multiple thin prepregs to reach the prescribed thickness, hence some air becomes trapped between the layers. Therefore, all of the stacked prepregs are enclosed in heat resistant bag film, and the interior is depressurized using a vacuum pump to remove the air remaining air. Then, when the resin viscosity of the heated prepreg drops, the inside of the A/C is pressurized to further refine and disperse, or remove as much of the remaining air as possible. In addition, transfer performance can be improved by pressing the materials against the molding die using the A/C internal pressure.

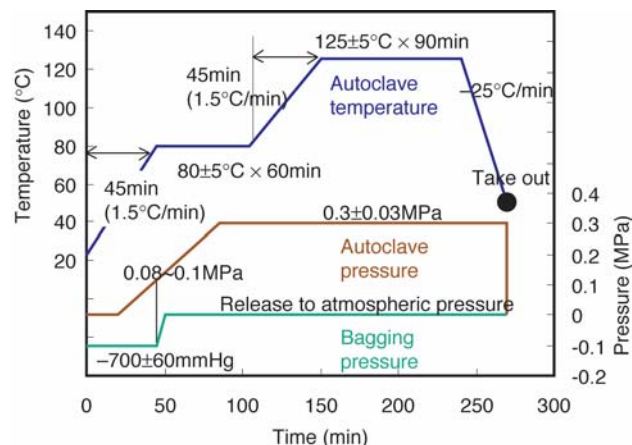


Fig. 10 Outline of cure cycle

5. Parts Structures

5.1. Hood

In addition to weight reduction, hoods require collision safety and marketability such as a rigid feeling when pressed and rigidity when opening and closing, etc.

Figure 11 shows the basic hood structure, and Fig. 12 shows an external view of the completed product. The basic thickness is 1.2 mm on the skin side, and 0.8 mm on the frame side. In addition, the thickness of the hinge and lock metal mount area is 2.2 mm for reinforcement purposes. The skin and frame flange were closely adhered to, to create a structure which raised the overall section modulus in order to improve the weight reduction efficiency compared to metal hoods. An air duct was also opened in the developed hood to generate front down force. When this type of hole is opened in conventional metal hoods using a press, plastic parts are generally added around the periphery of the hole as a garnish. However, dividing the molding die allowed an integrated structure that simultaneously achieved a beautiful, seamless finish and weight reduction.

In addition, to satisfy the requirements that the hood does not intrude into the cabin or split in the event of a collision, the hood must actively bend at the set locations. However, CFRP when compared to metals has an elastic characteristic, which means that it can undergo significant deformation and can accumulate a large amount of energy when subject to load input. Therefore, bend beads were located on the frame side in the same manner as metal hoods to create a structure that bends actively at the desired locations. In addition, bend beads cannot be located on the skin side for product

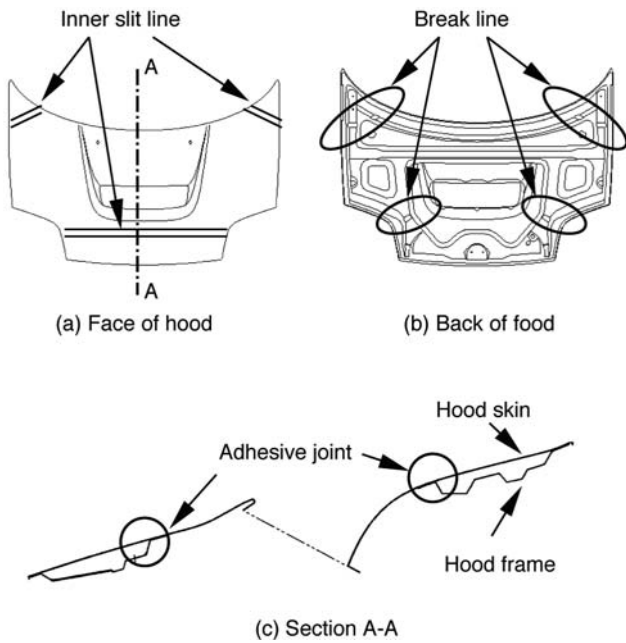


Fig. 11 Structure of CFRP hood



Fig. 12 External view of CFRP hood

appearance reasons, so slits were made in some of the surface layers near the frame bend beads to artificially reduce the skin strength in these locations and create an actively bending structure. AF which has strong anti-collision properties was also stacked in the inner layers of both the skin and frame to help prevent the hood from splitting in the event of a collision.

5.2. Rear Spoiler

In addition to improving the physical properties of the materials, eliminating the fastening bolts, flanges and adhesives also contributes greatly to reducing the structure weight. Rear spoilers are comprised of large numbers of minutely curved surfaces, so they are generally completed by creating individual parts which are then joined together. However, as the number of parts increases, the number of adhesive joints also increase, which in turn increases the weight. The developed rear spoiler used a FRP molding die which is lightweight and has excellent handing characteristics. This made the die easy to divide, and allowed a hollow integrated structure for the spoiler molded product that completely eliminated the unnecessary weight that was

formerly required to join the individual parts.

The basic structure was produced by molding CFRP into the final shape based on the blow-molded structure that is employed for most spoilers currently on the market. This technology allowed designs that were formerly impossible with a structure that joins individual parts, which both improved the aerodynamic characteristics and facilitated cutting edge designs.

Figure 13 shows the basic section structure of the spoiler and the insert bolt locking conditions, and Fig. 14 shows the completed product. The basic plate thickness is 0.8 mm, and 1.0 mm in the wing areas. Performance with respect to pull-out load and rotational torque is guaranteed by positioning the bolts used to attach the spoiler to the vehicle body in the molding die, and then clasp the square bolt heads with the molding base material.

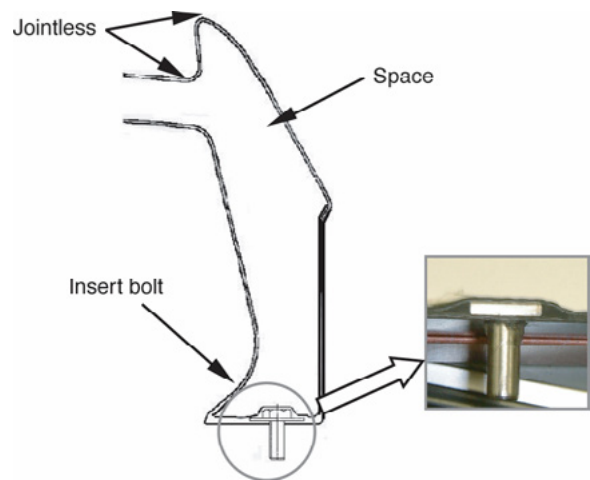


Fig. 13 Section of rear spoiler



Fig. 14 External view of CFRP rear spoiler

6. Parts Performance

The CFRP hood and rear spoiler experience almost no dimension change due to temperature, but the vehicle body side to which these parts are attached is made of aluminum which has a large coefficient of thermal expansion. Therefore, the following test was performed to confirm the effect of environmental temperature changes on the fit. The hood results are shown below as a typical example.

To simulate elevated temperature conditions an infrared lamp was set so that the surface temperature of the hood was around 80°C, and the amount of dimension change after four

or more hours was measured. Similar measurements were made at ambient temperature of -30°C . Points at a 100 mm pitch were also measured on the fender as a dimension change reference. Figure 15 shows the test conditions and measurement points.

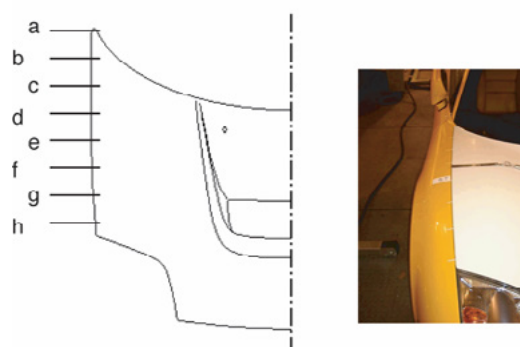


Fig. 15 Measurement points for dimension change

Figure 16 shows the results. The gap between the hood and fender reached a maximum of approximately 0.6 mm (point h) during the hot stage, and approximately 0.6 mm (point f) during the cold stage. This confirmed that dimension change was not a level that would be a problem in terms of product appearance.

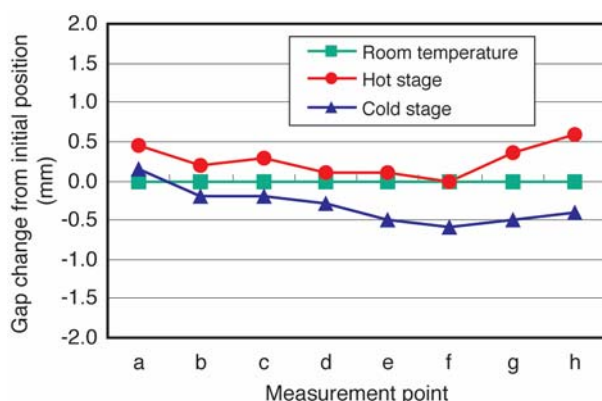


Fig. 16 Gap change in hot-cold cycle test of CFRP hood

7. Summary

Exterior parts were developed by effectively capitalizing on the anisotropy of CFRP materials and the degree of molding freedom of plastic as a means for reducing vehicle body weight. The hood product weight was 4.2 kg, which is a weight reduction of 30% compared to aluminum hoods, and the rear spoiler product weight could be kept to 2.3 kg, which is a weight reduction of 40% despite the increased size compared to the lightweight SMC spoiler for the '93 model.

At the same time, the following occurred through this development.

- 1) Regarding collision safety, bending initiation points were set using a bend bead shape on the frame side in the same manner as metal products. In addition, in locations where shape elements cannot be included for reasons of product appearance, bending start points were set without impairing the appearance by setting slits in the stacking

constitution to artificially reduce the material strength.

- 2) Mechanical fastening using metal bolts can be guaranteed even for stacked materials which exhibit large thermal expansion in the plate thickness direction.

8. Afterword

Carbon fiber reinforced plastics are extremely effective for the weight reduction of automotive parts. The use of CFRP parts as standard parts for the '02 model NSX type-R which, despite being a small-scale production vehicle, is a flagship car for Honda, and is thought to be a great leap forward for automotive weight reduction technology. How best to efficiently produce and use high priced carbon materials in mass production vehicles is a major issue, and it is the authors' hope that carbon materials will become widely used throughout the world as lightweight materials in the future.

Acknowledgement

The authors wish to express their deep thanks to all related in-house and outside parties including TOHO TENAX Co., Ltd. and YACHIYO INDUSTRY Co., Ltd. for their immense cooperation with this development.

References

- (1) Nomura, T., et al.: Present Status and Future Prospects of SMC Outer Panel for Vehicles, *Journal of Society of Automotive Engineers of Japan*, Vol. 43, No. 6, p. 32-38 (1989)
- (2) Nishiyama, K., Ei, R., Kato, Y., Ishibashi, K.: Development of Small-scale Production Method for Large-size Exterior Plastic Parts, *HONDA R&D Technical Review*, Vol. 11, No. 1, p. 173-178 (April 1999)
- (3) Takeuchi, A.: Development of ABS/PA6 Polymer Alloy for Body, *HONDA R&D Technical Review*, Vol. 12, No. 1, p. 183-188 (April 2000)
- (4) Fukuda, H., et al.: Chapter 5 Inplate Problems of Flat Plates and Inplate Rigidity of Laminates, *Introduction to Composite Material Dynamics*, Tokyo, Kokon Shoin, 1989 first edition, p. 91-98
- (5) Uemura, M., et al.: Chapter 1 Materials and Material Properties, *FRP Structure Design Handbook*, Tokyo, The Japan Reinforced Plastics Society, 1994 first edition, p. 1-12

■ Authors ■



Yasuo YAMANE



Tomohiro SAKURABA