

Development of GF RTP Crush Box with Consideration of Use Environment and Effect of Fiber Orientation

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ABSTRACT

Regulation of automotive CO₂ emissions is becoming increasingly stringent throughout the world in response to global warming. For automakers, this means a focus not only on increasing the fuel economy of powertrains, but also on reducing automotive driving resistance. High expectations are held for thermoplastic fiber-reinforced plastics (FRP) for the realization of automotive weight savings while also offering high levels of productivity and recyclability.

Thermoplastic FRP crush boxes display a higher level of energy absorption performance than metal (steel, aluminum, etc.) crush boxes. This will contribute to automotive weight savings and improved package design. In the case of automotive front bumper beam systems, it is necessary to realize stable load characteristics irrespective of the use environment. It is therefore necessary to consider the effects of temperature and thermoplastic resin degradation. The molding process for discontinuous fiber-reinforced FRP produces disordering of the fiber orientation. Research concerning the performance of thermoplastic FRP crush boxes produced findings that assisted in the design of a thermoplastic FRP crush box that would maintain a stable load characteristic in all use environments.

It was found that the temperature-dependency of the compression load characteristic of thermoplastic FRP crush boxes in progressive crushing mode in compression tests is low, and that it is necessary to realize an Euler buckling load higher than the progressive crushing load in order to produce a stable crushing mode. This paper discusses a design method for a thermoplastic FRP crush box based on the above-mentioned conditions in order to realize a stable compression load characteristic, with consideration of the use environment and the effect of fiber orientation.

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INTRODUCTION

With regulations targeting CO₂ emissions produced during vehicle operation increasing in stringency worldwide as a means of addressing the issue of global warming, it is no longer possible to respond simply by increasing the fuel efficiency of automotive powertrains. The reduction of the overall operating energy of vehicles is now an urgent task for automakers, one means of which is to reduce overall weight.

Manufacturers are responding to the need to reduce weight by applying a variety of high-cost materials, including ultra-high-tensile, hot-stamped, and aluminum materials, to mass-produced vehicles(1). Today, fiber-reinforced plastics (FRP) are beginning to be used in the bodies of some limited-production models as a next-generation material for the achievement of weight savings. FRP is an even more high-cost material than the metal materials mentioned above, but it is

considered that the rate of use of FRP in automotive body parts will increase in response to the increasing need for weight savings. Because thermoplastic FRPs, which use thermoplastic resins as the base material, display a higher level of productivity than conventional thermosetting FRPs, and are also suited to recycling, extensive research is today being conducted on these materials(2),(3).

The bumper beam is a part positioned at the foremost and rearmost extremities of the vehicle. An increase in the weight of this part not only affects the weight of the vehicle as a whole, but also affects the yaw inertia moment of the body, resulting in a decline in dynamic performance. The need for the realization of weight savings in this part is therefore high. The front bumper beam is made up of the beam and a crush box. Because the crush box is employed to increase collision safety performance, it is essential that it is designed to satisfy load reaction force demands.

With regard to the failure load mechanism of FRP crush boxes, S. Solaimurugan, R. Velmurugan, H. Hadavinia, and H. Ghasemnejad systematized wall surface failure modes in the direction of sheet thickness, and examined the buckling of the wall surfaces of standard parts, broadly divided into three constitutive modes (bending, shearing, and detachment); they then conducted performance design using CAE reflecting integral equations based on these modes(4),(5),(6). However, predicting loads using CAE at the initial stage of structural design when parts models do not exist is challenging.

It is known that loads are continuously generated by the breaking of the fibers in the ridge sections of crush boxes(7). The authors therefore focused on the loads generated in the ridge sections of crush boxes, and conducted research on a method of setting loads in relation to target performance at the initial stage of structural design without relying on CAE, ultimately proposing a design method(8).

However, because the base material of thermoplastic FRPs is thermoplastic resin, changes in performance depending on the use environment (e.g., the degradation of the resin due to the effect of temperature or chemical resistance) represent a concern. In addition, while the compression molding of thermoplastic FRPs using discontinuous fibers offers a high degree of freedom of formation by producing a compressive flow in the material, local decline in performance due to deviation in the orientation of the fibers when the material flows is also a concern. Research on the prediction of orientation during molding is being conducted from a variety of perspectives(9), but high-accuracy prediction remains a challenge.

The research discussed in this paper experimentally verified the effect of projected use environments and the orientation of the fibers during molding, studied thermoplastic FRP crush boxes with consideration of these findings, and proposed a design method.

PROCESS OF DESIGNING GFRTP BUMPER BEAM

Required Performance

It is necessary for the bumper beams fitted at the front and rear of the vehicle to possess sufficient stiffness and strength to clear differing national low-speed crush regulations. Figure 1 shows test modes. Due to design considerations and the need to increase cabin space, it is currently necessary to absorb the regulation crush energy with a small stroke, demanding higher stiffness and strength in the bumper beams, which is tending to increase the weight of the parts(8).

In order to boost crush safety performance in a variety of projected crush modes, in addition to the operation of safety devices, it is necessary for the bumper beam at the front of the vehicle to realize a variety of set load characteristics. Figure 2 shows an example of the performance demanded from the front bumper beam and a test method. As Fig. 2 shows, the performance demand is the realization of a stepped load characteristic in relation to the displacement of the

bumper beam during the test. The contribution of the load characteristic of the crush box has a greater effect on this performance parameter than that of the bumper beam.

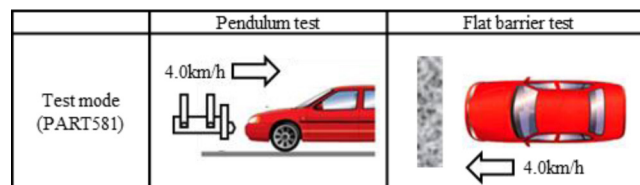


Figure 1. FMVSS PART58.

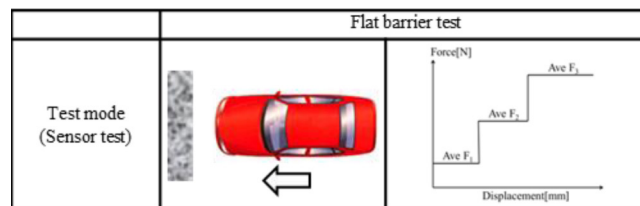


Figure 2. Load characteristic test.

Progressive Crush Failure of FRTP Crush Box

As Table 1 shows, FRP crush box structures display greater energy absorption efficiency than metal structures. As shown by case (A) in Fig. 4, metal crush box structures undergo buckling deformation, as a result of which the structure is not completely crushed, and the uncrushed section impinges on the crush space. By contrast, a thermoplastic FRP crush box, depending on its shape, will undergo buckling collapse, as shown in (B), or undergo progressive crushing from the extremity, as shown in (C). Figure 3 compares the load characteristics in cases (B) and (C). Looking at the deformation in case (C), there is minimal fluctuation in the load due to buckling, and high-efficiency energy absorption is therefore possible with complete crushing of the structure. If it were possible to design a crush box to make the phenomenon occurring in case (C) dominant, the target energy absorption in crush tests could be achieved with a small amount of deformation. This would not only reduce the weight of the crush box, but also contribute to the packaging of the vehicle as a whole.

In seeking to design a thermoplastic GFRP crush box, the authors proposed a method of prediction of the crushing load characteristic, and a method of design that would stabilize a mode promoting a progressive crushing mode(8).

Table 1. Comparison of energy absorption for various materials

Material	Molding	SEA	Cost
		J/g	-
JSC270C	Press +weld	6	1
A6063-T7	Extrusion	17	3
GF/PA6 Organo sheet	Thermoforming	45	5
CF/Epoxy Organo sheet	RTM	57	30

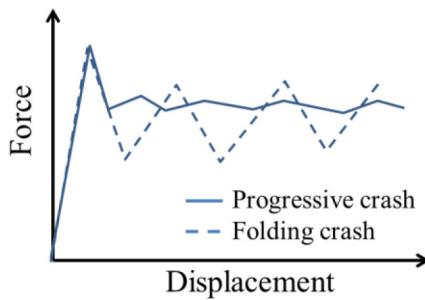


Figure 3. Comparison of folding crush and progressive crush for GFRTP crush box.

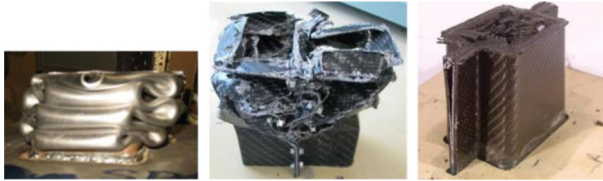


Figure 4. Crush rail failure : (A)Folding crush (steel), (B)Folding crush (GFRTP), (C)Progressive crush (GFRTP) .

However, these methods did not take the use environment or the disordering of the fiber orientation during molding into consideration. It was therefore necessary to understand the changes in the properties of the material and load characteristic of the crush box resulting from these factors. After gaining an understanding of these changes, it was necessary to consider a design method that incorporated responses.

Research conducted by Ishizuka has shown that progressive crushing loads in crush boxes formed from injection-molded materials incorporating short fibers are not dependent on the strength of the materials, but tend to be constant for the same base materials(10). This suggested the possibility that the same tendency might be displayed by materials reinforced by continuous fibers and materials reinforced by long discontinuous fibers. If this were the case, it would be possible to ignore changes in the strength of the material due to the factors mentioned above when it undergoes progressive crushing.

The condition for the stabilization of the progressive crushing mode was that the buckling load should be sufficiently greater than the progressive crushing load. The contribution of the corner ridge sections of the crush box to the progressive crushing load is high. Because loads on the corner ridge sections are proportional to the surface area, they can be predicted. Given this, by managing the position of the corner ridge sections and the number of contact points, it would be possible to conduct crush box design with consideration of the load characteristic demanded in a high-speed crush(8).

The buckling load is not related to the strength of the material, but is dependent on its shape and modulus of elasticity. By considering the modulus of elasticity, which changes as a result of various factors, and designing the buckling load to be greater than the progressive crushing load, it would be possible to stabilize the collapse morphology and the loads generated, even given the condition mentioned above.

Material and Molding

Material

Table 1 shows the specifications of the materials used in this research (manufactured by LANXESS).

1. LANXESS Tepex® Dynalite 102-RG600(x)/47%
2. LANXESS Tepex® Flowcore 102-RGR2400/47%
3. LANXESS Tepex® Dynalite 102-RGUD6000(x)/47%

Table 2. Mechanical property of material by supplier material data sheet.

		(a)Dynalite102 RG600(x)/47%	(b)Flowcore102 RGR2400/47%	(c)Dynalite102 RGUD600(x)/47%
Resin	-	PA6	PA6	PA6
Fiber	-	Glass	Glass	Glass
Fabric	-	Twill 50/50	Random mat	Twill 80/20
Fiber contents	%	47	47	47
Flexural Strength	MPa	620	480	840
Flexural modulus	GPa	19.2	17.7	26.5

Molding

Compression molding, employed for the thermoplastic GFRP bumper beams used in Honda limited-production models, was used as the molding method. Figure 5 shows the molding process. This method allows simultaneous molding of continuous fibers and compression flow of discontinuous fibers(10).

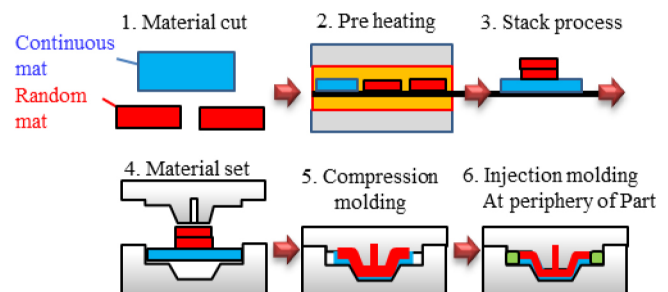


Figure 5. Molding process.

EFFECT OF USE ENVIRONMENT ON GFRTP MATERIAL

Because the base material for the FRP employed in this research was a thermoplastic PA6 resin, the effect of temperature was taken into consideration. The effect of the characteristic water absorption of PA6 resins, and, from the perspective of chemical resistance, the effect of the calcium chloride used as a standard snow-melting agent, also represented concerns. Each of these effects was determined in materials tests, and the dynamic compression load characteristics of the materials under these conditions were studied. The test materials were LANXESS Tepex® Dynalite 102-RG600(x)/47%, a continuous fiber-reinforced material, and LANXESS Tepex® Flowcore 102-RGR2400/47%, a discontinuous fiber-reinforced material.