

Development of Smart Design Process for Light Weight Body in White

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ABSTRACT

This paper describes a new approach and specific design procedure for more lightweight automotive Body in White (BIW) design.

For a BIW structure with a target value for static stiffness, joints with high stiffness sensitivity are selected and a lightweight BIW joint design chart is produced from calculations combining topology optimization and thickness optimization.

Using this chart made it possible to theoretically assign an optimum spring value to the BIW structure for the purpose of lightweight design, enabling substantial weight reduction in the base model while maintaining the same stiffness performance.

Moreover, we found that by applying other load cases together with static stiffness, such as dynamic stiffness and local stiffness, and following a design procedure that utilizes their interactions, significant weight reduction can be achieved in comparison with the conventional design process that adds each product characteristic individually to a BIW structure satisfying static stiffness.

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INTRODUCTION

With increasing automobile ownership on a global scale driven by growth in the world economy in recent years, demand for greater automotive environmental performance, in particular greater energy efficiency, is increasing in intensity year by year [1].

In order to increase the energy efficiency of an operating vehicle, in addition to increasing the efficiency of the motor, it is essential to reduce the running resistance of the vehicle. Methods of reducing running resistance are extremely simple, and in fact only three are available: 1) reduction of the weight of the vehicle; 2) reduction of air resistance; and 3) reduction of rolling resistance. Of these, reduction of the weight of the vehicle, that is, design of lightweight vehicle bodies, also enhances the dynamic performance of the vehicle and reduces the load on the brakes, tires, and other parts related to dynamic performance, ultimately leading to reductions in the weight of these parts as well. In addition, in the area of crash safety performance, reduction of the weight of the vehicle reduces the amount of energy that it is necessary to absorb, and can contribute to reductions in the weight of the structural members that absorb crash energy. The design of lightweight bodies is therefore extremely important in increasing automotive energy efficiency.

While the figure varies with the size of the vehicle, in the breakdown of the weight of a passenger vehicle, the body in white (BIW) accounts for approximately 25% of the total weight, and determining how to design this structure to be lightweight is a strong demand on automotive body designers. In order to design a lightweight BIW, it is

necessary to achieve a more rational structural design and to select appropriate materials based on the characteristics of the product. In the case of passenger vehicles, steel is the main material selected to be used when the BIW is designed due to its superior mechanical properties and from considerations of economic rationality [2]. The development of methods for more rational structural design, without reliance on the specific weight of the material, is therefore essential to the realization of lightweight vehicle bodies.

A number of commercial software packages are available for use in reviewing designs during the development process as a means of reducing the weight of the completed BIW structure. The optimization of sheet thickness using NASTRAN is an example [3]. However, while these tools offer designers hints, they do not go so far as setting out rational procedures for the design of a complex structure like the BIW. In addition, while designers might want, for example, to employ straight members rather than bending the frame in order to make more efficient use of structural members, there are limitations on the desired design space. Because there will necessarily be restrictions on the package - for example, the direct link between attempting to offer increased space for passengers and product competitiveness, or the necessity of ensuring space in order to absorb energy from considerations of crash safety performance - even if it is rational from the perspective of reducing weight to use a frame member straight rather than bending it, there are many cases in which it is challenging in practice to freely position structures. The creation of lighter BIW structures therefore necessitates design procedures that allow for more rational design within the given package limitations.

Seeking to make it possible to design more lightweight automotive BIW structures, the research discussed in this paper therefore proposed a new lightweight BIW design method that can be employed regardless of model, shape, or materials. This method comprises 1) a joint design method that rationally allocates weight resources in structural joints and standard cross-sections, and 2) a design procedure that makes use of interaction between members when it is necessary to satisfy multiple stiffness demands.

BASIC PRINCIPLE OF WEIGHT REDUCTION

Procedure for Determination of Body Specifications

Ensuring body stiffness and ensuring adequate crash safety performance to protect the lives of vehicle occupants are representative functions demanded from vehicle bodies. Both of these functions are essential, and neither can be sacrificed in designing a lightweight body. Normally, however, there is a strong tendency when designing the BIW to develop specifications with the priority on crash safety performance. One reason for this is that it is necessary to destroy vehicles in order to verify the crash safety performance of the designed vehicle in real vehicles, and this has a significant impact on the development schedule in terms of both time and expense. In addition, during the process of reinforcing the vehicle in order to ensure crash safety performance, the stiffness of the body also naturally increases.

While body stiffness tends to be related to aspects of the commercial appeal of the vehicle, including handling stability and the acoustic characteristics of the interior, the grounds for performance demands in this area are of limited persuasiveness in comparison to the type of direct target values employed in the case of crash safety. In other words, despite the fact that an increase in stiffness tends to make it possible to achieve certain aspects of commercial appeal, for example sporty handling, it is also a fact that there are products with sufficient commercial appeal among vehicles with low body stiffness. Open-top sports cars are a typical example. The static stiffness values of the BIW for vehicles of this type are overwhelmingly lower than those for vehicles with roofs, but they possess the necessary level of handling performance for sports cars, and many are highly regarded in the market. As this indicates, the fact that indicators for the demanded performance are challenging to determine can be considered related to the tendency to prioritize the design of crash performance, for which indicators are simple to determine.

Condensing the discussion above, in the case of crash safety performance, it is simple to determine effects when specifications are reflected because tests are available in which actual vehicles are destroyed, making it easy to understand the demands of crash safety performance during the development process. However, there are cases in which prioritizing crash safety performance in design causes issues in attempting to ensure body stiffness.

A method of reducing the weight of the vehicle body while enhancing crash safety performance that makes extensive use of high-tensile strength steel sheets has recently become entrenched. The more that the yield points of high-tensile strength steel sheets increase, shaping technologies advance, and the scope of their use broadens, the thinner it will be possible to form the sheets, and it is thought that the use of this method will reduce the weight of vehicles. This is therefore becoming the mainstream in approaches to reducing the weight of steel bodies. However, because the stiffness of members declines when steel sheets are made thinner, the higher that the yield points of the material become, the greater the need to recover the amount of this decline. In other words, the increased application of high-tensile strength steel sheets produces a significant contradiction in the design of BIW, for which both stiffness and crash safety performance are demanded. Today's rapid advancements in materials and production technologies make the effect of this impossible to ignore.

Based on these facts, the researchers in the present project decided to judge whether to formulate specifications from crash safety performance or stiffness performance based on the principle of whether or not the material could be relied on to fulfill the performance demands. In the case of the material characteristics demanded for crash safety performance, it is possible to ensure a specific level of energy absorption, namely to increase the yield point of the material in order to satisfy performance demands. By contrast, in terms of ensuring stiffness, changes in Young's modulus cannot be foreseen at a stage when the material is fixed, and there is no choice but to attempt to maintain performance via shape and thickness. In this case it is not possible to rely on the material characteristic.

For these reasons, the authors decided on a simple procedure for the design of the BIW: after ensuring stiffness performance via shape and thickness, the material is relied upon to ensure the energy absorption required for crash safety performance.

The development of preventive safety technologies as one aspect of automotive safety technologies is proceeding rapidly. The ultimate outcome of these technologies will be cars that do not crash. If these vehicles go into use, there will be no need to use high-tensile strength materials with high yield points in order to help ensure the absorption of crash energy, and it is thought that the role of high-tensile strength materials will decline. However, as long as the action of running the vehicle does not change, the need to ensure stiffness in the BIW will remain. This is another reason that stiffness was prioritized in the design procedure.

Work and Potential for Reduction of Weight of Each Body Component

Based on the design policy of prioritizing and maintaining stiffness performance in BIW design, a method of reducing the weight of the BIW structure first giving consideration to stiffness alone was examined. In the development of the BIW, emphasis is conventionally placed on how to ensure the cross-sectional size of the frame. Considering a simple cross-beam model of the type shown in Fig. 1, it is obvious that increasing the geometrical moment of inertia would be effective in realizing stiffness. However, overemphasizing

structure such as a BIW features multiple groupings of beams, and the overall stiffness of the structure is realized through interaction between the members.

Given this, in order to proceed with reducing weight, it is first necessary to understand the amount of work performed by each component of the body. The amount of work performed by each component when loads for evaluation of static bending stiffness and static torsional stiffness were applied to the BIW was therefore verified by means of strain energy. Figure 2 shows the distribution of strain energy. Difference in strain energy is expressed by the size of the spheres. Figure 2 indicates that the strain energy that expresses the work of the BIW is not concentrated in the standard cross-sections of the frames, but rather in the joint sections that connect frame to frame.



Figure 1. Example of a simple cross-section beam.

Therefore, despite the fact that increasing the geometrical moment of inertia of the frame members contributes to enhanced stiffness of the BIW overall, when the distribution of strain energy is considered, there is the possibility that the joint sections may deform before the size of the cross-section can be fully made use of, and it will not be possible to make complete use of the cross-section.

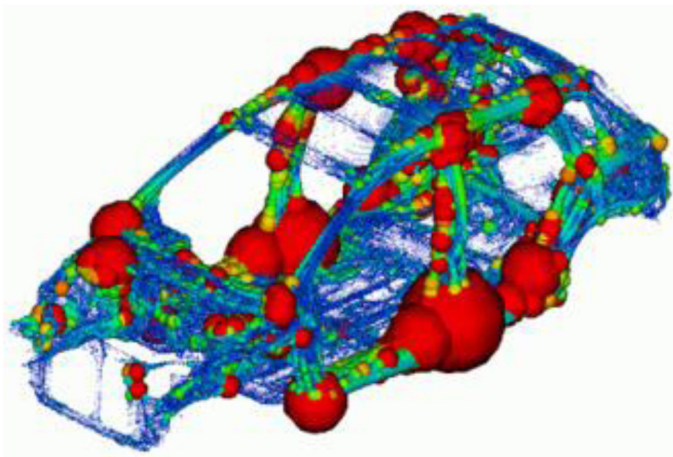
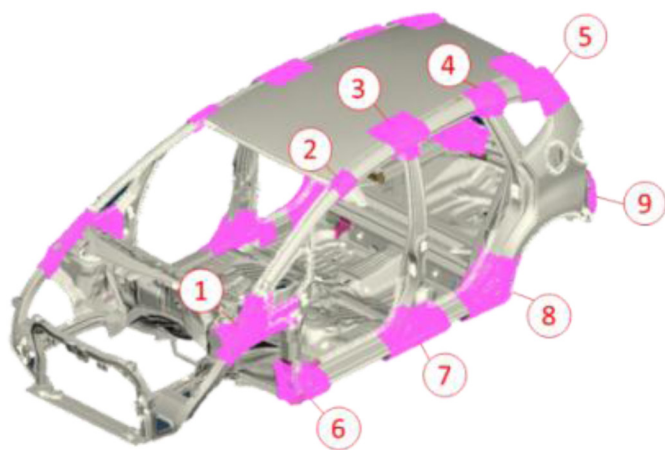


Figure 2. Example of the distribution of strain energy.

The potential possessed by the frame of the BIW was therefore verified. Values for static bending and static stiffness when rigid elements were employed at 9 sites on one side of the joint and 18 in total on the left and right were calculated and compared with stiffness values for the base model. The results are shown in Figure 3. It was found that controlling deformation of the joint section using rigid elements increases values for static bending stiffness and static torsional stiffness by twofold or more.



	Static Bending Stiffness	Static Torsional Stiffness
BASE	1	1
RIGID JOINT	2.13	2.23

Figure 3. Stiffness values when rigid elements were employed.

This indicates that as long as the deformation of the joint section can be controlled, the size of the cross-section is redundant. Because a twofold increase in stiffness is unnecessary, the lowering of stiffness values to their original levels following control of deformation in the joint section was therefore considered. In order to reduce stiffness, it is necessary to make a variety of changes, including reducing the thickness of redundant frame members and reducing the size of the cross-section. It was postulated that if the mass produced when stiffness values were returned to their original levels in this process were greater than the mass necessary for the control of deformation in the joint sections, it would be possible to reduce the weight of the BIW.

The following test was conducted in order to verify this hypothesis. Figure 4 shows a comparison of mass balance in a BIW when weight resources were reallocated from the roof sides to the center pillars. The reduction of the thickness of the roof side sections to achieve a weight reduction of approximately 2.1 kg reduces bending stiffness by approximately 1.1%. When the thickness of the joint sections of the center pillars was increased in order to make up for this performance decline by recovering the original stiffness, an increase in weight of approximately 0.7 kg was found to be necessary. The mass balance was -1.4 kg, representing a reduction in weight against the original BIW and demonstrating the rationality of reallocating weight resources from the cross-sections to the joints.

Based on the above, the basic concept developed for lightweight BIW design that satisfies the required stiffness demands was to create the capital to prioritize the allocation of weight resources in the joint sections, which perform a significant amount of work, and transfer weight resources from sections that perform little work to the joint sections, as well as create reduced weight.