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Development of Future Automobile Design Concept, NSafe™-AutoConcept

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Abstract

Nippon Steel Corporation is developing NSafe™-AutoConcept, a design concept for next-generation automobiles that meet the future target of CO_2 emission reduction. Aiming at fully exploiting the potential of steel material for weight reduction, studies for the concept have confirmed that a 30% weight reduction is achievable with an all-steel body. The concept presently covering the body structure will be expanded to include the batteries, the drive motor and the traction system.

1. Introduction

The automotive industry is in a revolutionary time, and the entire concept of automobiles, which have been the means of transportation familiar to us all, is drastically changing; a key word is CASE standing for (1) connected, (2) autonomous, (3) shared, and (4) electric, and another is MaaS, or mobility-as-a-service. Since electric traction is effective at reducing CO_2 emission, it is widely and variously applied to many models. The 2012 Report on Energy Technology Prospect of the International Energy Agency (IEA) estimates the total number of battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEV), both of which require power charging, in 2020 at 8 million, that in 2030 at 37 million, and that in 2050 at 115 million.[1)]

The automobile structure is changing from the conventional type equipped with an inner combustion motor to another with an inner combustion motor, an electric motor, and batteries, or yet another with an electric motor and batteries only, and as a result, car weight will markedly increase because the batteries are heavy. Car weight reduction is essential for extending the cruising radius; this is true also with electric vehicles. In addition, it will be difficult to satisfy the fuel consumption restrictions in the main automobile markets of Japan, U.S.A, Europe and China by the above shift of the power system alone: to meet the fuel consumption regulations expected to be enacted in these markets, it will be necessary to reduce CO_2 emission by as much as 62 g/km (44%) from 2015 to 2025. Advances in inner combustion engines and the conversion to electric traction will be insufficient; the decrease in CO_2 emission achievable by these measures is estimated at 31 to 45 g/km at best, and the outstanding 17 to 31 g/km will have to be taken care of by measures such as intensive weight reduction of the car body other than the power train. Because a body weight reduction of roughly 15 kg is required to cut CO_2 emission by an estimated 1 g/km, car body weight will have to be cut by 200 to 300 kg to achieve the above figure.[2)]

To reduce car weight, the measures so far studied include replacing the steel material for body and chassis parts with aluminum, carbon fiber reinforced plastics (CFRP) or other lighter materials, but applicability of these materials is limited for reasons such as costs, recyclability, the ease of repair, and required part strength. For this reason, all-aluminum and CFRP bodies are still limited to some luxury models. Autonomous running technology is now in the development stage, and much time is still required to completely prevent collisions and accidents. On the other hand, collision safety is being requested increasingly strongly as it is evaluated under new conditions such as higher collision test speed and newly required protection of batteries.[3, 4)]

In consideration of the situation, Nippon Steel Corporation has been studying a new design concept for next-generation vehicles, systematically combining elemental technologies to solve the problems of efficiency enhancement of electric motors and batteries as well as those of size and weight reduction of body structure, drive system parts and batteries. This paper presents the full picture of

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weight reduction design of vehicle bodies and chassis. As for the details of the elemental technologies regarding different parts for body structure, electric motors, batteries and traction systems, other articles of this issue deal with them, and readers are kindly invited to refer to them. We hope this issue will help readers to better understand Nippon Steel's R&D activities for next-generation automobiles.

2. Conditions of Design Concept Study for Next-generation Automobiles

2.1 Design concept for future automobiles, "NSafe™-AutoConcept"

Nippon Steel's design concept for next-generation automobiles, "NSafe™-AutoConcept," is intended to best exploit the properties of the products of the company and its group to meet the design conditions of future automobiles. The studies were conducted in seven technical fields related to the following groups of automobile body parts: panels, structural frame parts, chassis parts, the electric motor and the power train, batteries, the internal combustion engine, and transmission parts.

2.2 Study on body weight reduction

The benchmark model for the study into body weight reduction was selected from the viewpoints of (1) versatility, (2) lightest weight, and (3) being composed of steel, and from among the models marketed at the time of the start of the study, Golf VII (2013 model) of Volkswagen was selected.

Studies were conducted on how to better equalize or lighten the weight of an all-steel body of this model compared to that of an all-aluminum one. First, body parts were divided into various types. **Table 1** lists the performance required for the different types of body parts, and the design factors for defining their material thickness.[5–7] The performance required for body parts differs depending on their types. Panel stiffness is required for outer panels for doors, etc., collision strength and durability for frame structural members such as B pillars and chassis parts such as suspension arms, and consequently, different material properties are selected and different thickness design conditions are applied depending on the required performance.

The performance aspects regarding which the material thickness can be decreased by increasing the strength are dent resistance, durability and collision strength, but with parts for which panel stiffness, torsional stiffness and bending stiffness are essential, it is impossible to decrease material thickness by increasing the strength only. In view of this, the parts were classified into categories, and the measures for their weight reduction were elaborated in consideration of the functions required for each of them. **Table 2** shows the categories of the parts. The outer panels (A) include the parts comprising them, and for this group, it is necessary to develop measures to decrease their weights without adversely affecting panel stiffness. The inner panels (B) are those not directly joined to outer panels;

Table 2 Categorization of body parts for weight reduction studies

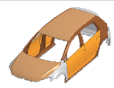
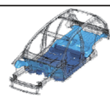
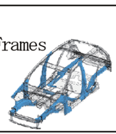
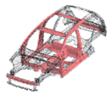
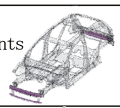
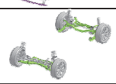
	Categorized name	Required Performance General Material Design	Weight (kg)
A	Outer Panels 	Appearance Designability Panel Stiffness e.g. 340MPa	116.7
B	Inner Panels 	Formability Noise Vibration Control e.g. 270～340MPa	37.8
C	Crash Energy Absorption Frames 	Energy Absorption Deformation Control e.g. 440～590MPaDP	41.7
D	Cabin Structural Members 	Cabin Protection Load Path Control e.g. 980～1180MPaDP Hot Stamp 1.5GPa	97.6
X	Bumper Reinforcements 	Energy Absorption Deformation Control e.g. 980～1180MPa Hot Stamp 1.5GPa	13.8
Y	Chassis 	Fatigue Strength Corrosion Resistance e.g. 440～780MPa	38.6
Z	Others	Reinforced Pasts Bracket etc.	34.2

Table 1 Required performance of body parts and thickness design factors[5–7]

Category		Example	Thickness design factor				
			Panel stiffness	Dent resistance	Bending, torsion stiffness	Fatigue strength	Crash resistance strength
Outer panel		Door outer panels Hood outer panel	◎	◎		△	○
Inner panel		Floor panel Dash panel	◎	△	○	○	○
Structural parts	A	B pillar Cross member			◎	○	◎
	B	Fr./Rr./Side member			○	◎	◎
	C	Door beam			○	○	◎
Chassis	A	Suspension arm			◎	◎	
	B	Wheel				◎	
Dominant mechanical properties			$k \times E \times t^{2\sim3}$	$k \times YS' \times t^{2\sim2.5}$	$k \times E \times t$	0.5TS	EA: $k \times TS^{0.5} \times t^{1.8}$

◎: Essential, ○: Important, △: Required, k: Shape factor, E: Young's modulus, t: Material thickness, YS'=YS+WH+BH, where YS is yield strength, WH work hardening, and BH bake hardening, TS: Tensile strength, EA: Energy Absorption

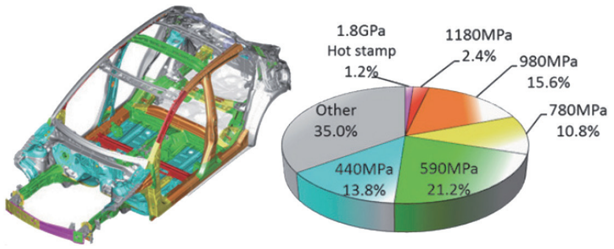


Fig. 1 Use of steel strength grades for white body[8)]

they include difficult-to-form parts such as rear floor panels; conventionally, they have not been used as required strength members. The collision energy absorbing frame parts (C) are designed to absorb energy in the event of a collision, and excellent energy absorbing capacity is essential. The cabin structural members (D) are the parts the deformation of which at a collision is controlled to be as negligible as possible to secure the cabin space. Other than the above, the chassis parts (Y) comprise suspension lower arms, subframes, etc., and durability is required. Others (Z) include brackets and miscellaneous accessories.

Table 2 also shows the strength level of material steel sheets commonly used for these categories of parts for the latest models including Golf VII. The material strength is highest with the cabin structural members (D) and the bumper reinforcements (X), followed sequentially by the chassis parts (Y), the collision energy absorbing frame members (C), the outer panels (A) and the inner panels (B). This indicates that high-strength steel is actively used for parts the required performance of which is governed by material strength. For the outer and the inner panels (A and B), the performance of which is governed by structural rigidity and not by material strength, however, the use of high-strength steels is not yet pronounced. It is also clear from the table that the collision energy absorbing frames (C) are designed for steels of lower strength than for cabin structural members (D).

Figure 1 shows the material design of Japanese car makers; steel materials are selected according to the criteria described above.[8)]

2.3 Technical viewpoints for body weight reduction and development of elemental technologies

To reduce car body weight making the most of the advantages of high strength-weight ratio and good ductility of steel, new design conditions are required for the outer panels (A), which account for the largest weight percentage as seen in Table 2, and the inner panels (B), for which low-strength sheets are used. With the collision energy absorbing frame parts (C) and the chassis parts (Y), for which lower-strength steel are used than for the cabin structural members (D), there is room for further weight reduction by using steel of higher strength. To make such new design conditions practically viable, new steel materials and new forming and joining methods will be required, and research and development for them are indispensable. Development of such new elemental technologies was conducted in parallel to the elaboration of NSafe™-AutoConcept; those elemental technologies are presented in other articles of the present issue, and readers are invited to refer to them.

3. Technical Viewpoints for Weight Reduction of Parts for NSafe™-AutoConcept and Study Results

3.1 Outer panels (A)

Panel stiffness is the resistance to out-of-plane deformation, or yielding under pressing force such as by fingers, the thicker the material sheet the better, and for this reason, there has been a certain lower limit to the sheet thickness for these parts. Consequently, it is essential for further weight reduction to devise new structural measures to prevent very thin sheets from yielding under pressing force. As a result of development studies, new structures have been developed, whereby an outer panel is reinforced by a foamed plastic sheet or a newly designed steel frame. **Figure 2** shows the newly developed panel reinforcing structure with a lattice frame.

3.2 Inner panels (B)

In the elaboration of NSafe™-AutoConcept, measures were pursued to improve the strength of difficult-to-form parts such as inner panels by advanced forming methods and alleviate the loads on the collision energy absorbing frames (C) and other structural parts. **Figure 3** shows the effects of strengthening of the rear floor panel on the body deformation at a rear collision. The figure shows that strengthening of the panel is effective at decreasing body deformation, which means that, by having an inner panel bear part of collision impact, it is possible to dissipate the loads on body structural members and better protect the cabin space.

3.3 Collision energy absorbing frame parts (C)

If a design condition for body frame members is established such that they deform under collision loads stably without fracture of the base metal or weld joints, it will be possible to use higher-strength sheets of thinner gauges for them. In the case of deformation by axial collapsing, the out-of-plane deformation of the side walls of the parts becomes greater with smaller wall thickness, its elastic deformation larger with increasing strength, and as a result of subsequent Euler bucking, deforming behavior becomes unstable. For weight reduction of such parts, therefore, it is essential to develop materials that do not fracture under collision impact and deformation control technology for thin sheets of high-strength steel.

3.4 Cabin structural members (D)

Regarding the cabin structural members (D), it was considered important to expand the use of thinner sheets by increasing steel

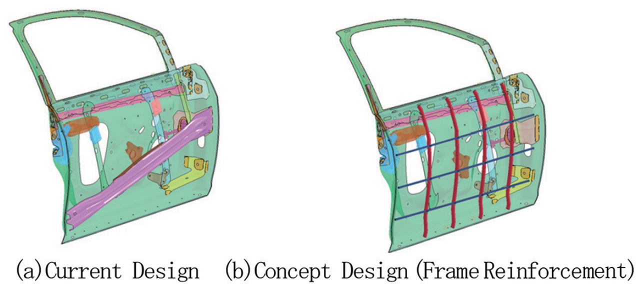


Fig. 2 Frame reinforcement for door outer panel

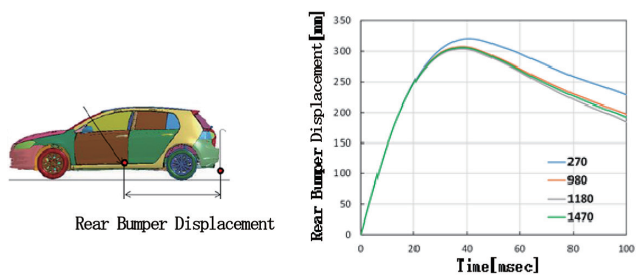


Fig. 3 Effect of rear panel strength on bumper displacement at rear collision

strength, and enhance local structural rigidity by improving load transmission efficiency of joints between parts. Following this philosophy, studies were focused upon development of the sectional design of parts and structure to take advantage of the material properties fully, and forming and joining methods for making parts using ultra-high-strength sheets. The same elemental technologies are applied also to the bumper reinforcements (X).

3.5 Chassis parts (Y)

In order to reduce weight of the chassis parts without adversely affecting durability, new structural designs have been developed to increase the strength and keep corrosion resistance and durability unaffected. The main target in the design development was how to control stress distribution under loads more homogeneously.

4. Potential of Body Weight Reduction by NSafe™-AutoConcept and Performance of Light-weight Body

4.1 Material and sheet thickness design based on concept model

The design conditions based on the views outlined above were applied to the parts of a Golf VII. **Figure 4** compares the current body design of the model and the concept design thus obtained in terms of steel strength and material thickness. In the concept design, 1 180 MPa class steel sheets were used for the collision energy absorbing parts (C), and 2.0 GPa class for the cabin structural members (D); the sheet thickness was around 1.0 mm for both these parts.

With respect to the inner panels (B), the sheet thickness of the rear floor panel was the same in both designs, but the steel strength of the concept model was increased to 1 180 MPa. **Figure 5** shows the sheet thicknesses of the outer panels (A) of both designs. The door panels of the concept model were designed to be 0.4-mm thick reinforced by the frame structure shown in Fig. 2 to secure stiffness.

4.2 Potential of body weight reduction and performance of light-weight body

Figures 6 and **7** show the weight reduction by the concept design based on the design conditions presented earlier herein by the part categories, and a comparison of the current and the concept designs with the all-aluminum design of an Audi A8, respectively. Although the weight reduction ratio of the inner panels (B) is comparatively low, use of high-strength steel for these parts significantly contributes to the weight reduction of the collision energy absorbing frames (C). All these point to the potential of the conceptual light-weight body for a weight reduction comparable to that of an all-aluminum body.

Figure 8 shows the deformation behavior of the concept model compared with the current model at a side collision. Although the

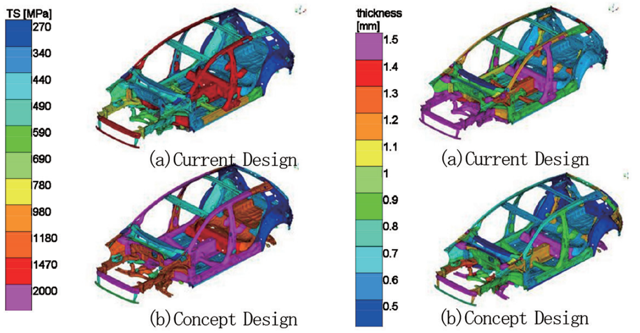


Fig. 4 Comparison of material design between current and concept models

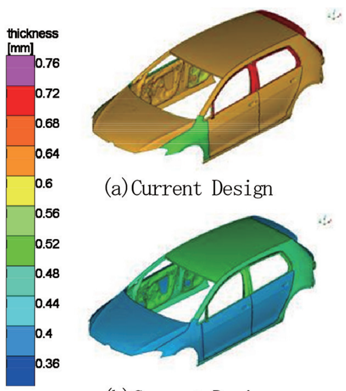


Fig. 5 Thickness design of outer panels

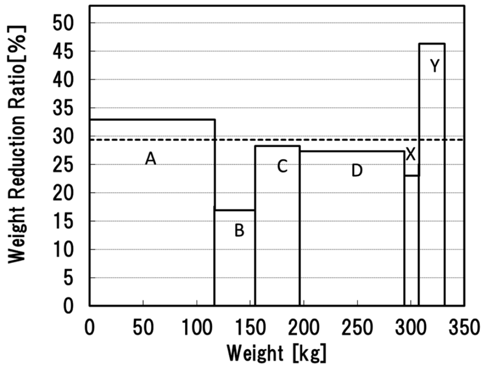


Fig. 6 Weight reduction ratio by part category

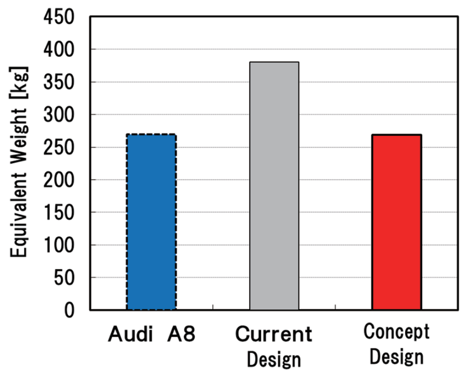


Fig. 7 Weight reduction potential of concept design

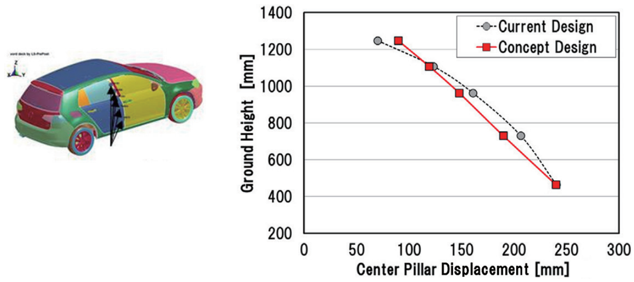


Fig. 8 Analytical results of the side crash performance with a new design concept model

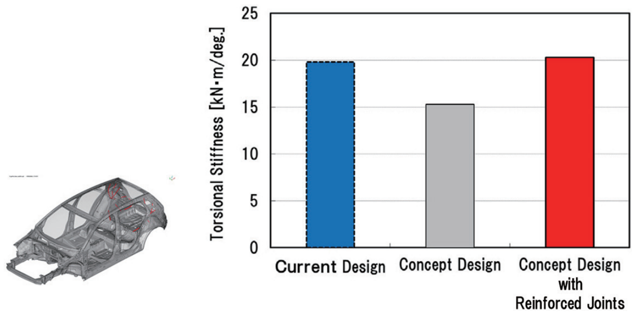


Fig. 9 Analysis of torsional stiffness

concept model is lighter in weight, its deformation behavior is substantially the same as that of the current model. Analytical results of torsional stiffness of the entire body are given in **Fig. 9**: although the value of the concept model is lower than that of the current model, it can be brought to the level of the current model by reinforcing the joints (marked in red) around the rear wheel houses with adhesives, etc.; the weight increase of the joint reinforcing measure is as small as 5 kg, approximately.

5. Conclusion

Nippon Steel is developing the conceptual model of a next-generation car body, NSafe™-AutoConcept, in consideration of a future target of CO_2 emission reduction.

The body components were classified into categories according to their structural functions, and the measures to reduce their weights were elaborated for each of the categories. Through such weight reduction measures and structural solutions devised to compensate for the reduction of part functions expected to result from the use of thinner materials, a body weight reduction of 30% from the current design has been attained with all-steel bodies; this potential weight reduction is equivalent to that of an all-aluminum body.

The new structural designs and the elemental technologies developed through the studies for NSafe™-AutoConcept show that, by actually applying them, the limit of body weight reduction can be further extended beyond what had previously been thought possible. Further efforts will be exerted for car body weight reduction to expand the concept to cover drive system parts and batteries.

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