Multi-material Automotive Bodies and Dissimilar Joining Technology to Realize Multi-material

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This paper introduces multi-material car body designs using ultra-high strength steel and aluminum alloy to realize an estimated weight reduction of 12 to 33% from the base body composed of conventional steel. Also included is an explanation of the dissimilar joining necessary for realizing multi-material car bodies as well as a dissimilar joining technology uniquely developed by Kobe Steel.

Introduction

As a measure for protecting the global environment, fuel efficiency regulations aimed at reducing CO_2 emissions are being increasingly strengthened in each country. In addition, the levels of fuel efficiency, environmental performance, motion performance, and safety performance required for automobiles are becoming increasingly higher every day. In addition to improving the efficiency of ICEV [Note 1)], there is a rapid movement toward electrification as seen in HEV, PHEV [Note 1)], EV [Note 1)], and FCV [Note 1)]. These electric vehicles are additionally equipped with heavy objects such as batteries and hydrogen tanks, and considering the movement performance and collision performance, it is said that the demand for weight reduction of the entire vehicle remains the same regardless of the type of powertrain.[1), 2)]

In recent years, aluminum has come to be used extensively for luxury cars. Examples include panels such as bonnet and trunk lids, as well as hang-on parts such as bumpers and door impact beams. To cope with weight reduction and strengthened collision safety regulations, high-strength steel sheets have come to be used for the body frames of popular cars, and multi-material including aluminum alloys combined with high-strength steel sheets has begun to be used for luxury cars and large vehicles. In the EU and U.S., some luxury cars have begun to adopt magnesium alloys, as well as resins such as CFRP, in addition to high strength steel sheet and aluminum alloys to further reduce their body weight.

In order to realize a multi-material structure, design and evaluation technologies are essential to maximize the effect of weight reduction by effectively combining materials with different physical properties. Furthermore, it is important to develop technologies such as dissimilar metal joining, which enables low-cost, high-strength joining of difficult-to-join materials such as high-strength steel sheets and aluminum alloys.

This paper focuses on multi-material bodies made of high-strength steel sheets and aluminum alloys, which are the current mainstream, and introduces the results of trial calculations of car body weights when the ratio of high-strength steel sheets and aluminum alloy is changed. Also introduced are existing dissimilar metal joining technologies to realize multi-material bodies and an example of low-cost dissimilar metal joining technology being developed by Kobe Steel.

1. Trial calculation of weight reduction effect of body frame based on steel-aluminum

In the EU and U.S., lightweight projects have preliminarily calculated the weight reduction effect of multi-material bodies.[3), 4)] There are, however, few publicly known cases where the relationship between the ratio of the applied materials and the weight reduction effect has been estimated for a given vehicle body. This section introduces examples of light weight designs with a changing ratio of steel and aluminum alloy for a given vehicle body, in which the effects of weight reduction and reduced number of parts are estimated.

An E-segment SUV was used as the base for weight reduction design. **Fig. 1** shows the main specifications of the vehicle, design requirements, body-in-white, and material compositions. The base car body is all made of steel, using approximately 40% high-tensile steel with a tensile strength of 590 MPa, and approximately 12.5% ultra-high tensile steel with a tensile strength of 780 MPa or higher. In order to examine the weight reduction from the base body, four cases were designed under different policies. Case 1 fully exploits ultra-high tensile steel, which is less expensive than non-ferrous materials, Cases 2 and 3 aim at reducing weight by combining steel and aluminum alloys, while aiming to reduce the number of parts by applying

Note 1) ICEV, Internal Combustion Engine Vehicle; HEV, Hybrid Electric Vehicle; PHEV, Plug-in Hybrid Electric Vehicle; EV, Electric Vehicle; FCV, Fuel Cell Vehicle

Dimension & Weight SUV (E segment)	
Length	4,826 mm
Width	1,885 mm
Wheelbase	2,785 mm
Height	1,710 mm
Curb Weight	2,150 kg
Weight of BIW	456.4 kg
Number of Parts	243

※ excluding doors and hood

Material constitution		Rate (%)
< TS590 MPa steel		41.4
≧ TS590 MPa steel		40.7
≧ TS780 MPa steel		12.5
hot stamping steel		4.5
Aluminum Extrusion		0.8

Fig. 1 Body-in-white, main specifications, and material constitution of base vehicle

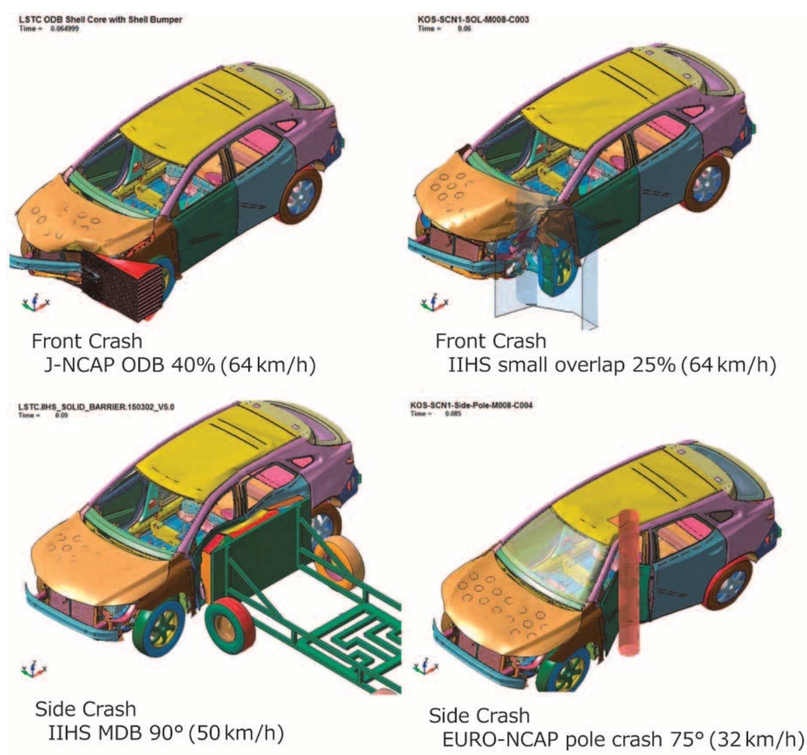

Fig. 2 Deformation of vehicle in typical cases of crash simulation

aluminum extrusions and die castings, and in Case 4, high-strength steel is applied only to the parts with severe collision requirements while making the best use of aluminum alloy.

The requirements for vehicle design are: (a) the amount of deformation at each part, evaluated by collision analysis, is to be evaluated as "Good" on the basis of the main collision criteria; and (b) the torsional stiffness and bending stiffness of the entire vehicle, evaluated by dynamic stiffness, are to be 50 Hz and 40 Hz or higher, respectively. **Fig. 2** shows the deformation of a vehicle body based on the crush simulation of typical collision cases.

Fig. 3 shows the calculated results of weight reduction, with the vertical axis representing the weight of the body-in-white and the horizontal axis representing the rough cost. The costs are based on relative comparisons that take into account the difference in material cost per weight of steel and aluminum alloy, as well as the cost reduction effect of machining and joining processes with the reduced number of parts. **Table 1** shows the weight ratio

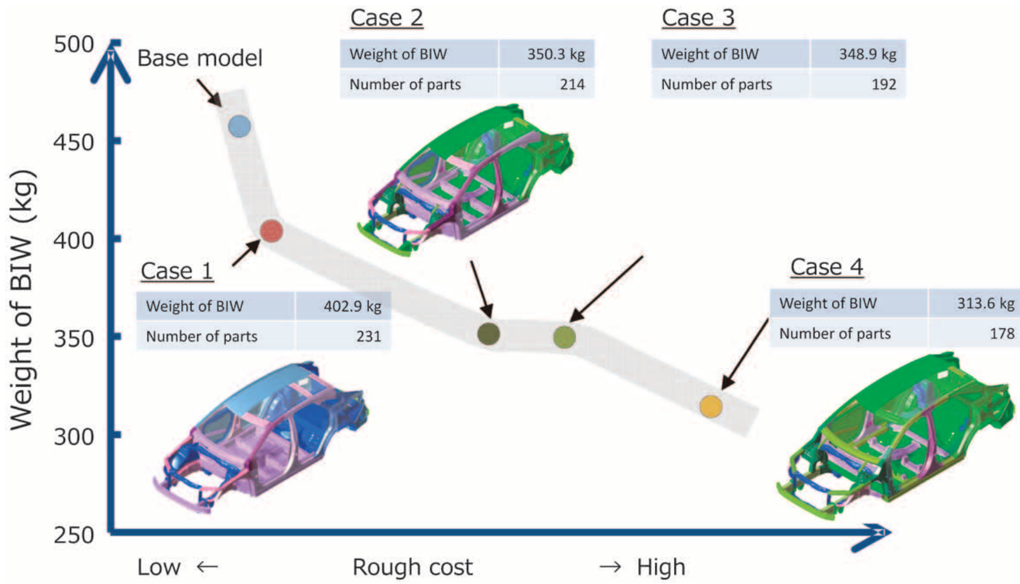

Fig. 3 Results of light weight design

Table 1 Material constitution ratio of each weight reduction case

Case 1

Material constitution	Rate (%)
< TS590 MPa steel	24.1
≧ TS590 MPa steel	32.9
≧ TS780 MPa steel	38.3
Hot stamping steel	3.8
Al Extrusion	0.9

Case 2

Material constitution	Rate (%)	
Steel		50.1
Al Extrusion	12.0	49.9
Al sheet	30.1	
Cast Al	7.8	

Case 3

Material constitution	Rate (%)	
Steel		61.4
Al Extrusion	4.8	38.6
Al sheet	26.2	
Cast Al	7.6	

Case 4

Material constitution	Rate (%)	
Steel		27.5
Al Extrusion	20.5	72.5
Al sheet	37.6	
Cast Al	14.4	

of steel and aluminum alloy used when sorted by steel strength class and the type of aluminum alloy. According to Kobe Steel's calculations, Case 1 results in a 12% (53.5 kg) weight reduction by the full exploitation of ultra-high-tensile material, Cases 2 and 3 result in a 22 to 24% (106.1 to 107.5 kg) weight reduction by the use of multi-materials, and Case 4 results in a 33% (142.8 kg) weight reduction by the proactive use of aluminum alloy. It should be noted, however, that an increase in cost associated with weight reduction is inevitable, as shown in Fig. 3. It is anticipated that not only the material cost, but also processing costs such as pressing and joining will increase.

Some of the materials used in this study are under development. It is necessary to make such efforts to put new materials into practical use for further reduced weight and lower costs. In addition, it is considered to be effective, for the sake of suppressing the cost, to reduce the number of parts by integrating parts by aluminum die-casting or extrusion, or to omit reinforcing members by increasing the strength of the steel. Developing technology for minimizing the capital investment in dissimilar material joining, which is a major issue for multi-materials, is also considered to be effective.

2. Existing dissimilar metal joining and low-cost dissimilar material joining technology

2.1 Issues in dissimilar metal joining and joining methods actually in use

Steel-to-steel joining is mostly accomplished by welding. Although there are differences between the resistance spot welding used for bodies-in-white and the arc welding used for the chassis, both mechanisms involve melting the base materials at

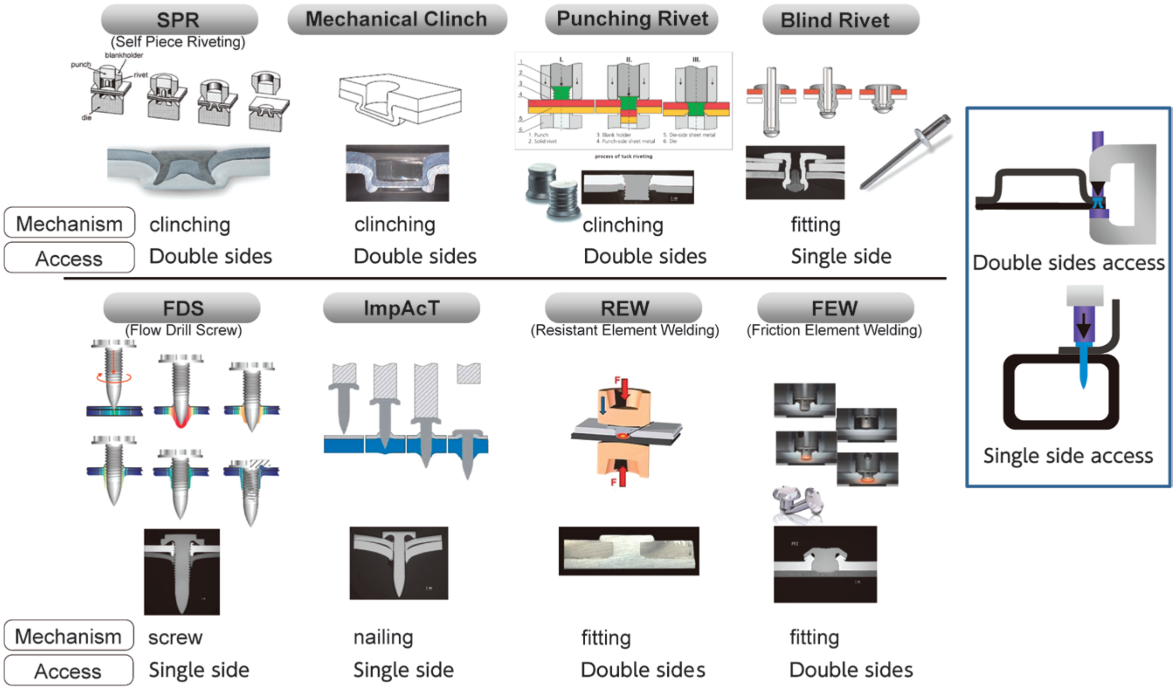

Fig. 4 Practically applied methods of joining dissimilar metals for car body structure

high temperatures to form metal bonds. However, weld joining between steel and aluminum alloy is impossible due to the formation of extremely brittle intermetallic compounds.

Hence, instead of melting and mixing the two metals, mechanical joining methods are mainly used for dissimilar metal joining, in which geometrical constraint or friction is used as a joining force. **Fig. 4** illustrates major methods of dissimilar metal joining for automobiles. To give just a simple explanation here, self-pierce riveting (SPR), which is the most popular clinching mechanism, involves more than 2,000 piercing points per vehicle. There also are some cars, each of which has more than 700 penetration points of a flow drill screw (FDS) mechanism.

2.2 Trends in adhesives

Another problem in joining dissimilar materials is electrolytic corrosion (galvanic corrosion). When different metals come into contact with each other, a local battery is formed, and one of the metals is selectively corroded. In the case of steel and aluminum alloys, the latter corrode. A practical way to prevent electrolytic corrosion is to keep moisture away from the joint surface. Most of the practical mechanical joining methods described above produce point joints and therefore lack the watertight seal function. The formation of a local battery can be prevented by applying an adhesive to the interface or surface in advance and then performing mechanical joining. This hybrid joining method is the de facto method of dissimilar metal joining taking into account the electric corrosion. In addition, since the adhesive forms a surface joint, it exhibits not only the above-mentioned sealing function but also high shear strength. On the other hand, there are many points to be considered, such as the quality control of the application state, as well as the deterioration of adhesive strength after exposure at low temperatures or for a long period of time. Despite this, the importance of adhesives has increased with the development of multi-material structures involving resins, and their use has increased.

2.3 Dissimilar material joining method for high strength steel and aluminum alloy [5), 6)]

As described in the previous section, aluminum alloys are more frequently being used with proactive application of high-strength steel sheets, which are relatively inexpensive and have a weight reduction effect, requiring dissimilar metal joining between high-strength steel sheets and aluminum alloy. However, the conventional mechanical joining method, in which a steel sheet is plastically deformed or penetrated, is becoming difficult as the strength of the steel sheet increases. On the other hand, although the adhesive can be applied to high-strength steel sheets, there is a disadvantage in that the cross tension strength (CTS) in the direction

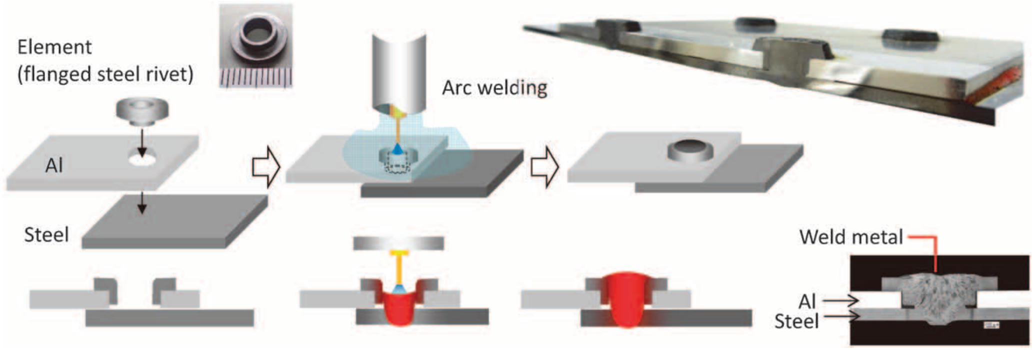

Fig. 5 Basic mechanism of EASW [7]

perpendicular to the shear strength is low, and the joint strength with adhesive alone is likely to be insufficient.

Hence, Kobe Steel uniquely developed "element arc spot welding (hereinafter referred to as "EASW")," a dissimilar metal joining method that enables the strong joining of high-strength steel sheets and aluminum alloys.[7] This mechanism is shown in **Fig. 5**. A hollow steel element (rivet) is inserted into an aluminum alloy sheet, and a steel welding wire is supplied to the hollow portion of the element by gas shielded arc welding and is casted. As a result, the steel element and the lower steel sheet are firmly welded together, while the aluminum alloy sheet is sandwiched between them to achieve fastening. Since the method requires no plastic deformation of the steel sheet, it is possible to join high-strength steel sheets involving hot stamping. **Fig. 6** compares the shear strength (TSS) and cross tensile strength (CTS) of conventional dissimilar material joining and EASW. It can be seen that EASW exhibits both TSS and CTS higher than those of the conventional joining methods. The features of EASW are as follows:

(1) Higher joining strength, irrespective of shearing or cross tensile, compared with the conventional dissimilar material joining methods (Fig. 6);
(2) No need to sandwich the base material from both its sides, allowing joining from one side and increasing the application range.
(3) Enabling the joining of a three-layer structure such as aluminum/steel/steel; and
(4) Simple and applicable to repairs.

In order to realize EASW on the actual production lines of automobiles, a robot system was jointly developed with FANUC, including necessary devices for automatically detecting the position of elements, inserting them, and automatically performing arc welding. Its prototype has been released lately (**Fig. 7**). Currently, its development for practical use is underway.

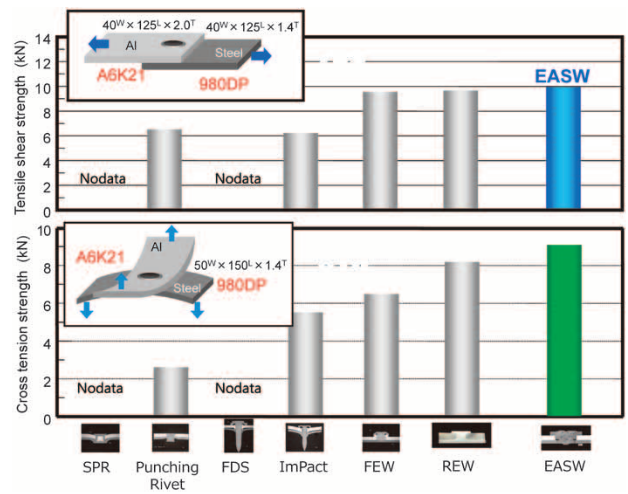

Fig. 6 Joining strength of EASW

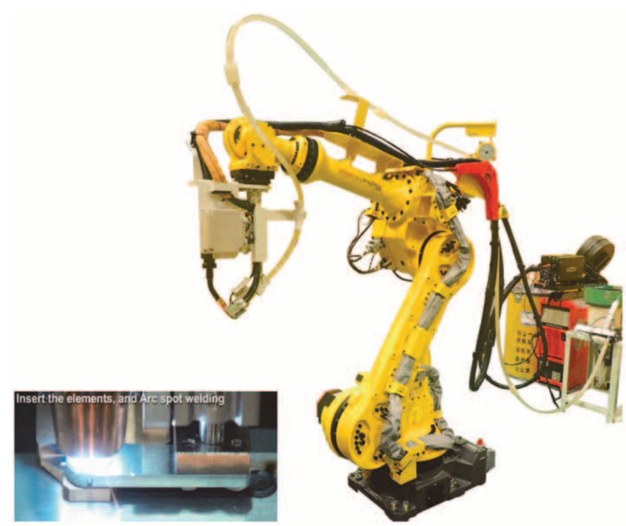

Fig. 7 Prototype robot system for EASW (right) and appearance of joining (left)

Conclusions

Continuous efforts are necessary to reduce the weight of automotive bodies in consideration of CO_2 emission and collision safety regulations; and the trend toward multi-materials, as a measure for weight reduction, is inevitable. The practical application of multi-material bodies has already progressed in the EU and U.S. In Japan, each company is increasing efforts toward realizing this application.

Since the automobile industry is a key industry that can be said to represent national power, it is expected that there will be greater efforts than ever before, including industry-government-academia collaboration and cooperation among different industries and supply chains. Kobe Steel will also continue to contribute its efforts toward reducing automotive weight.

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