Application of Aluminum Extrusions to Automotive Parts

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Recent automobiles have problems of increasing body weight due, for example, to enhanced structural strength for improving collision safety, an increase in the number of parts such as sensors and installation of large batteries. Meanwhile, it is also necessary to respond to the strengthening of fuel-efficiency regulations, and aluminum materials are being increasingly used for the purpose of weight reduction. In particular, aluminum extrusions, which enable complicated cross-sectional shapes to be obtained with relative freedom, are being increasingly applied to automotive parts such as automotive bumper systems and frame members. This paper reports on the current status and future trends of automobile parts adopting aluminum extrusions, with its main focus on a 7000-series alloy that is our main product.

Introduction

In recent years, environmental issues, such as global warming due to CO_2 emissions and the depletion of fossil fuel oil, have been drawing attention, and efforts are being made in various fields. In the field of automobiles, efforts are being continued to suppress CO_2 emissions by improving fuel economy through the development of vehicle bodies with reduced weight, as well as electric vehicles, fuel-cell vehicles, etc. For example, automotive structures with reduced weight are being developed using steel with tensile strength higher than that of conventional steels. Aluminum alloys are also being increasingly used to reduce the weight of structural parts conventionally made of steel. Aluminum alloy is characterized by a low specific gravity approximately one third that of steel and a high specific strength. Its quality and mass production technologies have been proven by their actual applications, in motorcycles, aircraft and Shinkansen cars, for instance.

One of the major advantages of aluminum alloy is that its stock material can be made by hot extrusion, in addition to casting, forging and rolling, the conventional means for producing steel. Wrought aluminum alloys can be hot-extruded into strips with complicated cross-sections relatively freely, and these extrusions are increasingly being used for bumper systems, frame members and other automobile parts.[1), 2)]

This paper introduces the case examples of automotive parts based on aluminum extrusions.

1. Background of automotive weight reduction

Regarding automotive fuel economy, there are a number of legal regulations and standards that have been around for many years, and various efforts have been made to achieve it. Since the Kyoto Protocol, adopted at the third meeting of the Conference of Parties to the United Nations Framework Convention on Climate Change in 1997, the fuel economy improvement policy, aiming at reducing CO_2 emissions, which are considered to be the cause of global warming, has been one of the major driving forces for regulating fuel economy.

In terms of global trends, Europe and North America are leading the world in strengthening their regulations for automotive fuel economy and curbing CO_2 emissions. Fuel economy regulations have also been implemented in Japan and China, and similar regulations are planned for the next decade in the Middle East, Southeast Asia and South America. The corporate average fuel efficiency (CAFE) regulations in North America and the emission standards in Europe are very strict; non-compliance can be fined. **Fig. 1** shows the transition and future target values of fuel economy regulations in Japan, Europe, China and North America from 2015 to 2030.[3)] By 2025, each automobile manufacturer must reduce CO_2 emissions to a level lower than 2/3 of the current level. Automotive weight reduction is regarded as the best solution for the current gasoline engines, and weight reduction is essential for vehicle models with a greater production volume. For example, the F-150 (Ford), 760,000 units of which were produced

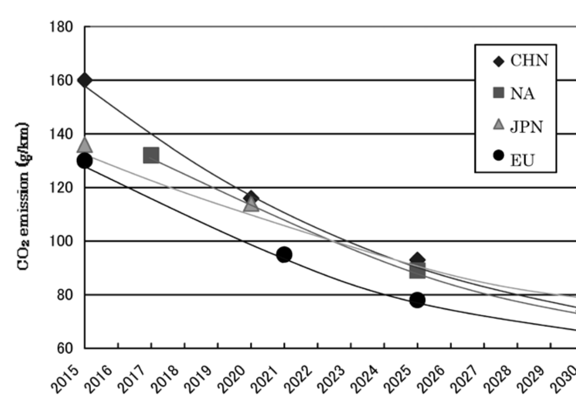
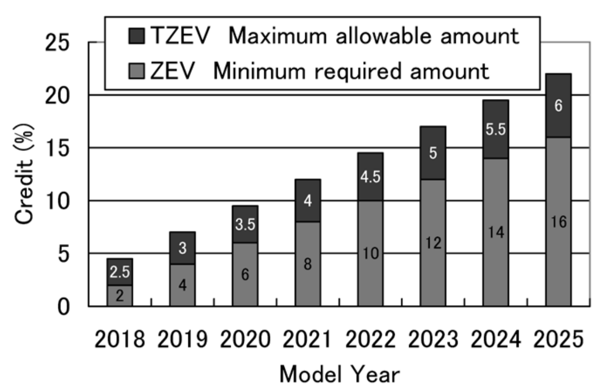


Fig. 1 Transitions of standards being strengthened for fuel economy and CO_2 emission (fuel economy converted into CO_2 emission)[3)]

in North America in 2014, uses a much greater amount of aluminum than its previous version, and has achieved a weight reduction of approximately 320 kg/unit. The CT-6 (GM) also uses aluminum at an increased rate that accounts for 62% of its vehicle body weight.

Other than these fuel economy regulations, there are the Zero Emission Vehicle (ZEV) program in California[4)] and the New Energy Vehicle (NEV) program that China plans to implement after 2020. In these programs, automobile manufacturers are obligated to produce automobiles with no CO_2 emissions: electric vehicles and fuel-cell vehicles. Fines are to be imposed if this cannot be achieved, or else the makers must purchase credits from automobile manufacturers like Tesla, which produce only electric vehicles. The state of California stipulates a coefficient called "credit" for each vehicle on the basis of the ZEV types, such as EV, PHEV and HEV, and has established credit criteria to be achieved against their sales volumes. **Fig. 2** shows the credit that will be allocated for environmental vehicles under the ZEV regulation of 2018-2026. It is stipulated that, in 2025, more than 15% of all the vehicles in the state of California must be ones with



●TZEV (Transient ZEV) : Plug-in hybrid vehicle

●ZEV (ZERO emission vehicle) : Battery Electric Vehicle, Fuel cell vehicle

Fig. 2 ZEV credit allocated for LVMs [4)]

zero CO_2 emissions, such as electric vehicles.

Against the background described above, the weight reduction needs for automobile structural materials have continued to increase, and serious attempts are being made not only to replace cast iron and steel with higher-strength steel, but to replace them with light-weight materials such as aluminum and FRP.

With the aim of reducing vehicle body weight, Kobe Steel has been working on technologies for both material and processing; these efforts include improving the forming limit of aluminum alloy sheets used for panels and the performance of forged aluminum products. As described in this paper, Kobe Steel has also been promoting the development of high-strength alloys for aluminum extrusions and has launched various automotive safety members made of aluminum extrusions. This paper introduces the product family of such aluminum extrusions.

2. Aluminum extrusions

The application of aluminum extrusions has been expanding since the 1960s; it began with extrusions having small cross-sections, such as extruded tubes and multi-hole profiles for engine heat-exchangers. In the 1980s, aluminum alloys in the form of sheets and extruded hollow profiles began to be applied also as the structural materials of vehicle bodies, for which steel had been the main material. As aluminum applications expanded, the reduction of parts-processing costs and cold workability became issues, which have been addressed by improving the chemical compositions and microstructures of the aluminum alloys. Since the 1990s, hydroforming using hydraulic pressure has emerged to make two dimensional extrusions into 3D shapes.

Unlike steel, aluminum can be extruded in complicated cross-sectional shapes with a varying

Table 1 Applications of aluminum alloy extrusions to automotive structures

Part name	Alloy	Adoption	Required characteristic
Door beam	7000 Series	1993～	Bending strength, Energy absorption
Instrument panel reinforce		2003～	Rigidity, Bending strength
IPU guard		2012～	Bending strength
Seat back bar		2015～	Axial strength
Front side rail		2016～	Axial compressibility
Locker		2016～	Bending strength
Bumper system (Fr. Rr.)		1992～	Bending strength, Energy absorption
Side step	6000 Series	2007～	Rigidity
Back step		2014～	
Knee bolster		2005~	Compressibility in cross section
Sub flame	5000 Series	2005～	Rigidity

wall thickness distribution. With their light weight, they are attracting attention as an effective means of reducing the weight of automobiles.

Kobe Steel began to apply aluminum extrusions to bumper systems and door beams in 1990 and has expanded the application to the structural members of vehicle bodies. **Table 1** summarizes the examples of applications in the past.

3. Bumper system

3.1 Overview of bumper system

Recent bumper systems mostly have structures as shown in **Fig. 3**.[2] Such a system comprises a thin shell made of resin, providing the outermost portion, and a foam resin placed therein. Inside the foam resin, a metallic bumper reinforcement is attached to the vehicle body via stays (mounting supports). Some types of vehicles have bumper reinforcing material attached directly to the vehicle bodies; however, as the collision safety standards have become more stringent, stay members are often required to have energy absorbing characteristics.[5]

The main role of a bumper system is to receive impact force first and absorb energy through its deformation. Another role is to transfer the energy that cannot be absorbed by bumper beams to stays and rear members. High-strength materials and cross-sectional shapes have been developed to absorb more energy in the light-weight structure. Recently, high-strength alloys (proof stress of 300 MPa or higher) of the 7000-series (Al-Zn-Mg system) alloys have begun to be used,[6] and there are designs of this sort that have realized a weight reduction of approximately 30% compared with the conventional 6000-series (Al-Mg-Si system) alloys. Furthermore, in response to the strengthening of collision standards, some materials with even higher strength (proof stress of 400 MPa or higher) are also being pursued.

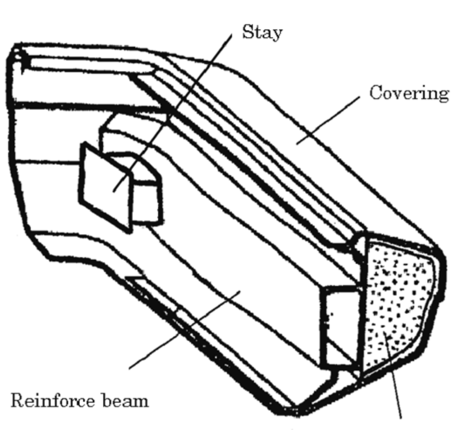


Fig. 3 Example of bumper structure

In addition, the energy absorbing members of bumper systems and the like require aluminum alloys that are immune to crack propagation upon crush. Kobe Steel has revealed that grain size and intragranular precipitates are greatly involved in such crush-cracking resistance[6] and exploits this fact in the material development.

3.2 Bumper beam

The cross-section of a bumper beam is based on a square hollow section without, or with one or more partition(s). **Fig. 4**. shows typical cross-sectional shapes. The shapes (curvatures) are diversified, including both-end curves. **Fig. 5** shows an example of overall shape. There is also a need to process variable cross-sections as shown in **Fig. 6** to ensure conformability to the vehicle body design. Variable cross-sections are required to address the issues of smaller overlap between barriers and vehicle bodies at the time of collision testing, as in the case of narrow offset collision.

Bumper systems are also designed to allow the attachment of hooks for towing vehicles. Their designing has become more challenging not only because of the bending compression upon collision, but also because they must incorporate functions against the tension and fatigue caused by towing.

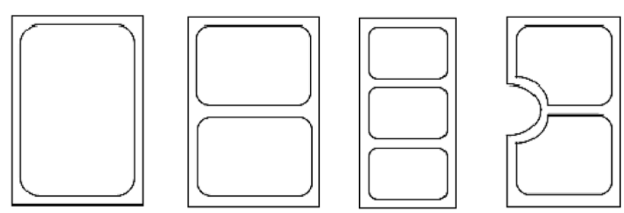


Fig. 4 Typical section type of bumper beam

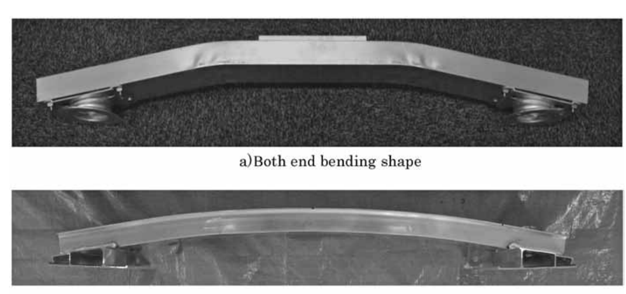


Fig. 5 Typical bending shape of bumper beam


Fig. 6 Both-ends-formed bumper beam

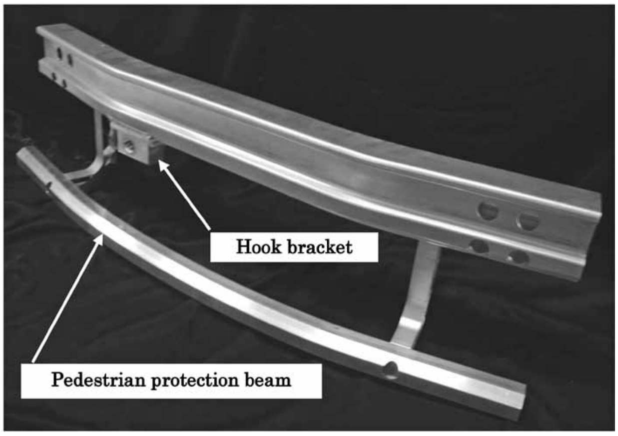


Fig. 7 Example of front bumper system

Lately, another small beam may be attached under a bumper beam for pedestrian protection (**Fig. 7**). The multi-functionalization of bumper systems is expected to be further accelerated in the future.

3.3 Bumper stay

With the strengthening of safety standards, bumper stays are required to have energy absorbing characteristics, and their collapse behavior upon collision must be controlled.

Steel stays have box-like shapes, welded together and mechanically fastened to aluminum bumper beams. Welded structures are mainly adopted also for commonly used aluminum stays; however, it is difficult to guarantee their strain and quality after welding, and they become costlier than the ones made of steel.

Against this backdrop, Kobe Steel has developed bumper stays made by a swaging method based on electromagnetic forming.

3.4 Bumper system utilizing electromagnetic forming

Electromagnetic forming is a technology for processing subject material and utilizes high magnetic field generated instantaneously when high-voltage, charged in a capacitor with a large capacitance, is discharged at once into an electromagnetic coil. This technology is suitable for forming highly conductive materials such as aluminum and copper. The forming force is applied in a contactless manner, enabling a reduction in the number of dies compared with the press forming method. This technology is expected to enable process reduction, through the simultaneous processing of forming and bonding, and the forming of complex shapes. Hence, research has been conducted to put this technology into practical use.[7]

On the other hand, the coils are subjected to electromagnetic reaction forces, which are opposite to the forming forces, when forming the subject materials. Hence, increasing the lifetime of coils has been one of the challenges for mass production. Kobe Steel has advanced simulation technologies, such as a newly developed calculation simulator to predict the electromagnetic force distribution during tube expansion.[8] These technologies have been exploited in--to give one example-- developing a technique to increase the durability of coils and have been applied in the mass production process. As a result, a bumper system using electromagnetically formed stays has been put into practice.[9]

Conventional steel stays have parts welded together, a process requiring time and money; this method has the drawback of allowing the welding strain being retained in the final products. Each electromagnetically formed stay shown in **Fig. 8** has a body in the form of a hollow circular tube made of aluminum alloy. An end plate is attached to one end of the hollow circular tube, and the circular tube is electromagnetically expanded to swage-couple the plate. The other end of the circular tube is stretch formed during electromagnetic tube expansion, which simultaneously forms a mounting portion.

Although depending on the shapes of parts, the expansion and swaging of aluminum tubes with electromagnetic force eliminates the need for welding and approximately halves the number of processing steps. There is also no welding strain involved, and the number of parts for constructing a stay can be reduced. The electromagnetically formed stay has a mass approximately 1/2 that of the conventional steel stay with equivalent strength performance.

Fig. 9 shows an example of a bumper system, in which a bumper beam and stays are directly coupled

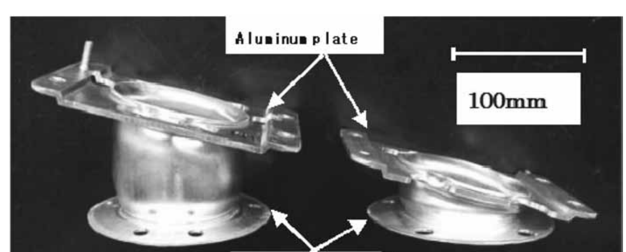


Fig. 8 Bumper stays produced by electro-magnetic forming

Fig. 9 Bumper system combining stay with beam

by electromagnetic forming without a plate. The bumper and stays are integrated by swaging, and further weight reduction has been achieved thanks to the reduced number of parts and the weldless structure.

4. Door beam

Door beams are one of the most important safety members for protecting passengers from the lateral collision of automobiles and are currently installed in most automotive doors. **Fig.10** shows an example of door beams.

Each door beam is required to have the ability to absorb energy upon collision and to prevent large deformation of the door. Although the final performance against lateral collision is evaluated by actual vehicle testing, each door beam is usually evaluated by a 3-point bending test with the beam simply supported at both ends. The shapes of door beams are designed with the required characteristics of maximum bending load and amount of energy absorption.

The door beams designed by Kobe Steel have a basic structure with Ⅱ-shaped cross-sections, the shape having the highest bending efficiency. For a given amount of energy absorption, a weight reduction of approximately 30% has been achieved compared with the high-tensile-strength steel pipe currently used.

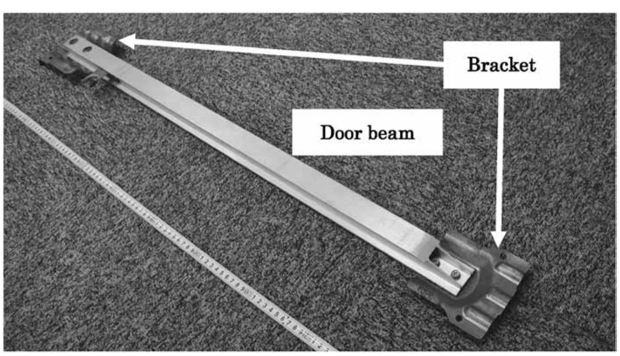


Fig.10 Aluminum door beam

The recent trends include door beams having large-R shapes to shorten the free running distance upon collision and door beams having crushed ends to improve their attachability to the door inner panel. Application of these processes means that considerable residual stress occurs. Kobe Steel reduces the risk of SCC by controlling the residual stress occurring in the process to lead to practical applications. In addition, door beams require high shape accuracy, and the improvement of processing accuracy has become a subject for the future.

5. Vehicle body frame member

The application of aluminum in bumper systems and door beams has been studied for approximately the past 20 years and is on the point of becoming established as a technique for reducing vehicle body weight. Future weight reduction, however, is considered to need the application of high strength aluminum extrusion in vehicle body frames.

The Cadillac CT6, unveiled at Euro Car Body 2015, applies a number of aluminum extrusions.[10] A Kobe Steel 7000-series alloy was adopted for its three components, namely, the crash can, front rail and rocker, which served as elements for reducing the body weight by approximately 100 kg. **Fig.11** shows the application portions.[10] Although 6000-series alloys were sometimes used for vehicle body frames in the past, this was the first case where a 7000-series alloy was applied.[10]

Its application in frame members arranged crosswise in vehicle bodies has also begun, in

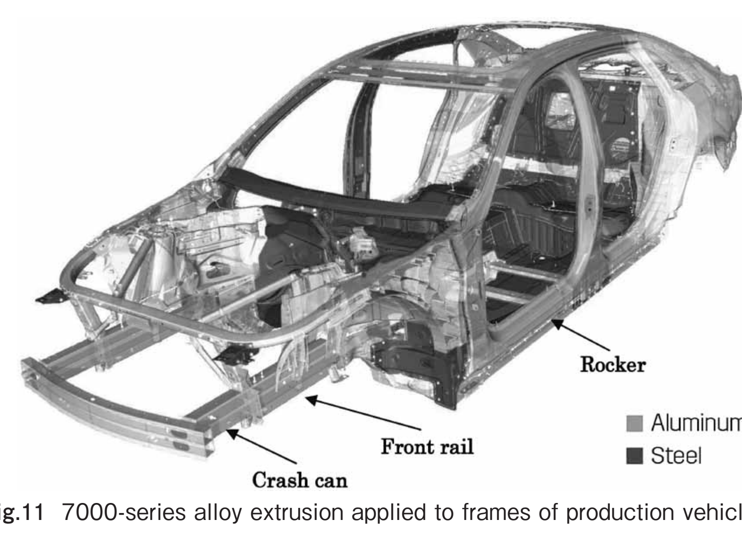


Fig.11 7000-series alloy extrusion applied to frames of production vehicles[10]

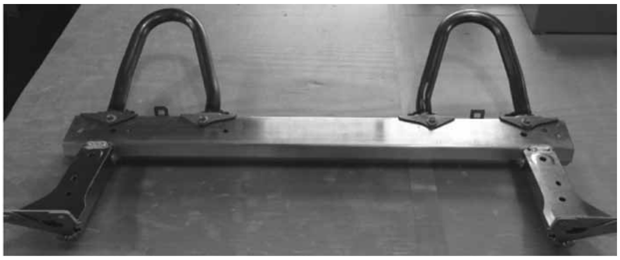


Fig.12 Seat back bar

addition to its use in the frame members of vehicle bodies arranged lengthwise, such as rockers. For example, there is a case in which a 7000-series alloy was applied to a cross member called a seat back bar (**Fig.12**). In addition to its offering more collision safety than the previous model, in which high-tensile-strength steel of 780 MPa was used, this alloy has realized a weight reduction of approximately 1.9 kg.[11)]

As large batteries are installed in vehicles, the battery frames have also begun to be made of aluminum. Kobe Steel has also manufactured a product called a guard frame. This is a type of battery frame and comprises a member for preventing the battery from penetrating into the rear seat upon rear end collision. A 7000-series alloy is adopted to achieve the strength required.

The 7000-series alloys have a strength that is 1.5 times or more higher than that of 6000-series alloy, which is advantageous for weight reduction. However, to further advance the application of 7000-series alloy in the future, it is important to solve issues such as the suppression of SCC by residual stress control, the joining of dissimilar materials and optimization of component structures.

6. Exterior parts

Kobe Steel manufactures side steps (**Fig.13**) and back steps for passengers getting on and off; these steps are exterior parts combining aluminum extrusion with resin and iron parts. They have structures in which PP resin is used for the appearance where design is considered to be important, and aluminum extrusions of the 6000-series are used to ensure the rigidity required for the step boards. These steps are mechanically attached by screws and/or clips.

The brackets are made of pressed iron, which is less costly, and the joints of dissimilar materials using aluminum extrusions are treated against electrolytic corrosion using cation painting. Each component requires different performance and has an arrangement of materials most suitable for each characteristic. The side step is an example of automotive parts designed on the basis of "specific types used in specific parts."

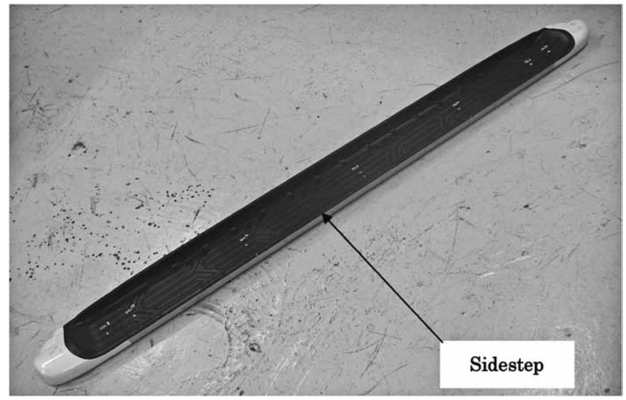


Fig.13 Side step

In order to simultaneously achieve weight reduction and minimum cost, components combining dissimilar materials are expected to increase in the future.

Conclusions

The 7000-series aluminum extrusions can be made into high-strength materials and be formed into profiles with hollow cross-section. Hence, they are being increasingly valued as a material suitable for high-strength members. On the other hand, they cannot be subjected to complicated forming, unlike the press forming of sheets, and it is difficult in many cases to apply them by simple material replacement, imitating appearance configurations. Thus, it is important to understand the function required for each part first and optimize its shape to suit aluminum extrusion.

As the applications of aluminum extrusions to automotive parts increase in the future, there may be combinations with various materials. Hence, technologies such as joining and surface treatment will become even more important.

Kobe Steel will strive to continue to develop the application of aluminum extrusions by combining the technologies of materials, processing, designing, simulation and bonding of aluminum alloys. Aiming at a further reduction of weight and cost, Kobe Steel will continue to develop one-of-a-kind technologies to please its customers.

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