Development of Aluminum Alloy Extrusion Products with Improved Vehicle Energy Absorption

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This article describes examples and features of aluminum alloy extrusion products used for vehicle bumper beams. A bumper system design, which satisfies the latest safety performance standards, is described in relation to future trends in the industry. Also discussed is a newly developed aluminum stay, which is produced using an electro-magnetic forming method, and its strength characteristics.

Introduction

Aluminum extrusions, in addition to their lightness, have an advantage of being formable into complex cross-sectional shapes with various wall thickness distributions, shapes which are difficult to be formed by steel. Because of this advantage, many automobiles use aluminum[1)] extrusions of 6000 series (Al-Mg-Si) and 7000 series (Al-Mg-Zn) alloys for their bumper beams[1)]. Recent automotive bumpers employ structures having several components. A bumper system may have components such as a bumper cover (design surfaces), bumper beam and a piece of foam material fixed in-between the cover and beam. Bumper beams, in many cases, are fixed to an automotive body through attachments such as bumper stays. In recent years, bumper systems constructed with bumper beams and stays are used more commonly because of their improved crash energy absorption[2)].

Methods for forming aluminum extrusions into such components include hydroforming which has been used to form relatively large, three dimensional shapes having varying cross sections. However, an effective method for forming small to mid-sized components has not yet been established. Kobe Steel has focused on electromagnetic forming[3)] of tubular aluminum alloy extrusions as a feasible method for forming products with varying cross-sectional shapes. The company has conducted various researches to put the forming technology into practice[4)].

This paper describes the technical trend in aluminum bumper beams. Also explained is the production of aluminum bumper-stays using electromagnetic forming and the characteristics of the bumper systems employing such stays.

1. Bumper system

1.1 Aluminum alloys for bumper beams

Automotive bumper beams are made of either high-strength steel or extruded aluminum alloy. The following describes the aluminum alloy developed for automotive bumpers. Kobe Steel has developed a new 7000 series aluminum alloy for automotive bumpers. The alloy is featured by its high proof stress of about 350 MPa and a deformation resistance comparable to that of 7003 alloy which has conventionally been used. The properties are achieved by adjusting the Mg and Zn content.

In general, extruding aluminum alloy becomes more difficult as its strength increases. The 7003 alloy is easier to extrude compared to other 7000 series alloys, such as 7N01, which are extruded for higher strength products. However, the wall thicknesses of the extrusions made of 7000 series alloy tend to be thicker due to their difficult extrudability. Meanwhile, the 6000 alloys have an advantage in their extrudability but with relatively lower strengths compared to 7000 series alloys. Thus 6N01 alloy is typically used for extrusions. The new 7000 series alloy developed has the high strength of the 7000 series and extrudability comparable to that of 6000 alloys.

1.2 Performance requirement for bumper systems

Bumper systems generally have structures as shown in **Fig. 1** The outermost layer is a resin shell, in which a piece of resin foam is disposed to absorb crash energy. Disposed further inside the resin foam is a metallic bumper beam, or a reinforcing member, which is attached to the body frame, e.g., through bumper stays. Most vehicles employ bumper stays made of metals, although some do not have any stay. The main function of bumper systems is to absorb energy at the time of crash. The system also adds stiffness for improving drivability and has other functional features, such as to provide a platform for mounting towing brackets and sensors. **Table 1** summarizes the impact test standards applied by several countries to the testing of bumper systems.

For low speed collisions of 8km/h or lower, bumpers are intended to protect body parts, such as hoods, trunk lids and lamps, from losing their functions. Bumpers are designed to plastically deform at the time of collision under these speeds, so as to absorb crash energy and protect automotive bodies. The newly revised standard of Insurance Institute for Highway Safety (IIHS) adopts new, low-speed collision tests which assume collision between vehicles having different heights[5)]. The IIHS is legally nonbinding, however, their ranking based on the repair cost incurred after collisions affects the sales of automobiles indirectly. With the revision of the IIHS standard, automobile manufacturers will need to assess collisions offset in the height directions. Thus, the cross sectional sizes of bumpers are envisaged to become even larger.

The offset barrier crash test (crash against an oncoming vehicle with body-width overlap of 40%) at 15 km / h requires prevention of damage to automotive bodies with even larger crash energy absorption. This is achieved by plastically deforming not only bumper beams, but also bumper stays. When designing a bumper to meet the requirements, the crushing load of the bumper system should be kept lower than the crushing loads of any other body members. In addition, the energy absorption efficiency of the system should be improved in such a way that the load displacement curve at the time of crash exhibits a rectangular-shaped waveform, an indicative characteristic of high energy-absorption efficiency.

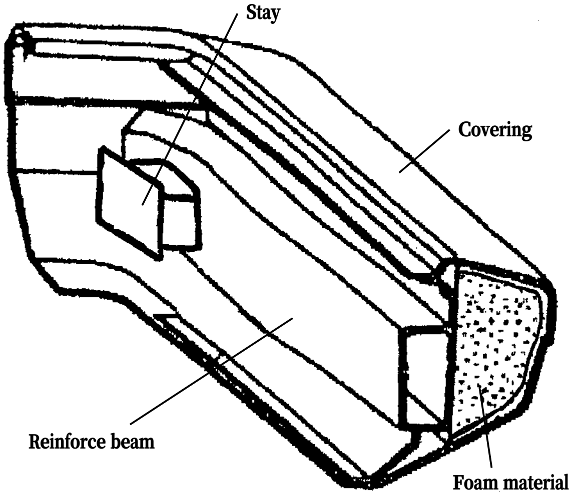

Fig. 1 Example of bumper structure [2)]

Most conventional low-speed crash tests, as shown in Table 1, evaluate deformations of automotive bodies and the cost of repairing the crashed bodies. Bumpers, in these tests, are regarded to function as mere protectors of automotive bodies. In recent years, bumpers are required to absorb energy at high-speed crash, as the collision regulations for vehicles become more stringent. Although a bumper may not be able to absorb all the collision energy exerted on the whole vehicle, higher energy absorption characteristics are strongly required of the bumper.

For example, bumper stays, which used to merely attach bumper beams to automotive bodies, are now regarded as important components in improving the energy absorption characteristics of bumper systems.

In addition to vehicle protection, a technical standard for protecting pedestrian's legs[6)] was developed against presumed personal injury accident and has already been applied in Europe. **Fig. 2** illustrates a method for evaluating pedestrian's leg protection, in which a leg form, simulating a knee and thigh potions of a leg, is brought into collision against a bumper system. The energy absorbing characteristics of the bumper system is evaluated by the physical load and moment exerted on the leg form.

A high stiffness is required for a bumper to protect the automotive body, while a low stiffness is required for pedestrian protection. Bumper systems are required to satisfy these two conflicting factors, making their design more challenging.

Table 1 Bumper impact test standards [2)]

Enforce country	Name of standard	Pendulum impact		Barrier impact	Evaluation points
		Center	Corner		
USA	(former) Part 581	5mph (2times)	3mph (2times)	5mph	No body damage No functional damage
	Part 581	2.5mph (2times)	1.5mph (2times)	2.5mph	No body damage No functional damage
	IIHS	3mph (corner barrier) 6mph (full barrier)			Repair costs
Canada	CMVSS215	5mph	3mph	5mph	No functional damage
Europe Union	ECE No.42	4.0km/h (2times)	2.5km/h (2times)	—	No functional damage
Gulf countries	G.S.41	4.0km/h (2times)	2.5km/h (2times)	—	No functional damage
All country	RCAR	15.0km/h (40% offset barrier)			Repair costs

mph : mile/h

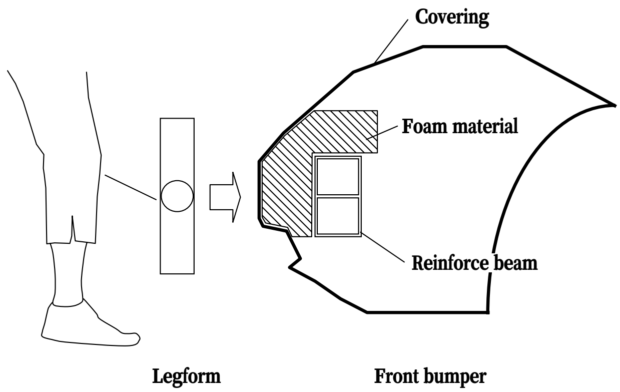

Fig. 2 Evaluation of leg protection performance

2. Electromagnetically formed bumper stay

2.1 Electromagnetic forming of bumper stay

New aluminum alloy bumper stays have been developed using electromagnetic forming. The stays are featured by their high energy-absorption characteristics. The following describes the details of the electromagnetic forming of the stays.

Conventional bumper stays have been made by welding together materials, e.g. press formed steel sheets or aluminum alloy extrusions. However, stays made of steel has disadvantage in their heavy weight, while aluminum stays tend to be expensive because of their welding cost.

Kobe Steel has been focusing on electromagnetic forming, a high-speed non-contact forming method, and successfully developed non-welded, aluminum alloy stays which are more than 50% lighter than conventional steel stays. **Photo 1** shows external views of the aluminum stays.

Electromagnetic forming is a metal forming process, originally developed in the USA in 1960s, and uses impact energy caused by electromagnetic field. **Fig. 3** illustrates the principle of electromagnetic forming. The forming method is well suited for the forming of highly conductive materials, such as aluminum and copper, because the current induced by an inductor, or an electromagnetic coil, causes the force (electromagnetic force) to form the material. The method has an advantage of forming materials in non-contact manners, however, the inductor, which is subject to electromagnetic reaction force during forming, tends to fail because of dielectric breakdown. Prolonging the life of the inductor is one of the keys in making the method industrially feasible. Coil shapes are known to affect coil lives[7].

Fig. 4 shows four forming methods using electromagnetic forces. Recently reported applications of electromagnetic forming include bore flanging of aluminum[8] and electromagnetic seam welding between aluminum and steel sheets[9]. In the development of new aluminum stay, an electromagnetic forming method was adapted to perform bulge forming and flange forming at a tube end simultaneously. The parts subject to the forming are extruded aluminum tube and plates with a hole as shown in Photo 1. **Fig. 5** schematically illustrates the forming method. An aluminum tube is inserted into a hole in an aluminum plate. An inductor is then inserted into the interior of the aluminum tube. Applying a large current to the inductor exerts an electromagnetic force on the aluminum tube, making the tube expand outwardly into contact with the plate hole. Thus the tube contacts with the inner surface of the plate-hole tightly, while the tube portion projecting out of the plate-hole bulges outwardly, making the tube swage locked to the plate. A mold is disposed at the end of the tube without a plate so that the end portion is formed into a flange.

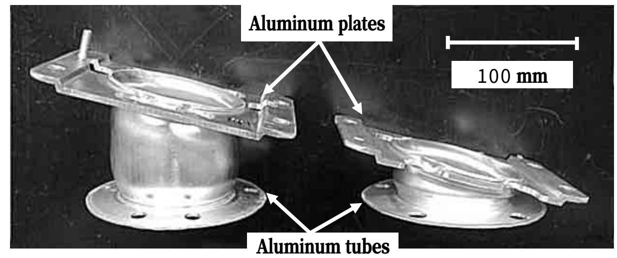

Photo 1 Example of electromagnetic formed stays

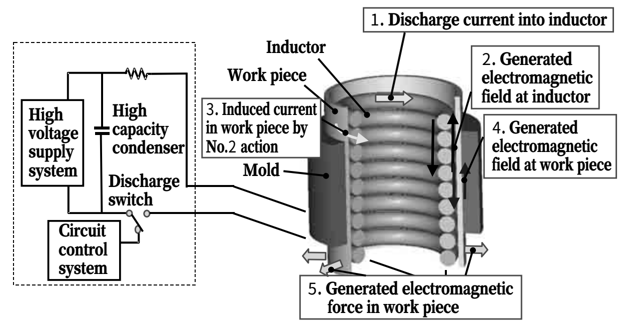

Fig. 3 Typical configuration of electromagnetic forming apparatus

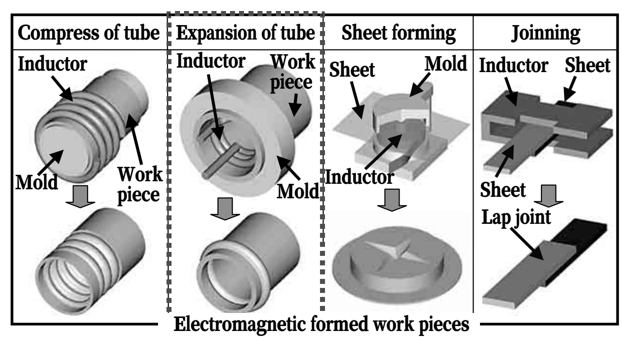

Fig. 4 Types of electromagnetic forming

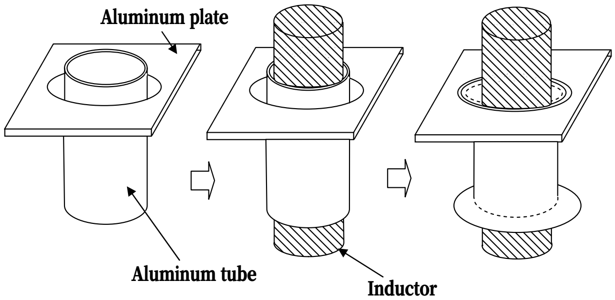

Fig. 5 Process method of electromagnetic forming

2.2 Features of electromagnetically formed stay

Conventional stays made of steel suffer from drawbacks in that they require welding steps in manufacturing and distortions caused by the welding remain in the final products. Electromagnetic forming involving bulge forming and swage locking reduces process steps, depending on shapes, to almost a half. The reliability of the product increases since the process does not involve any welding which can cause distortion. In addition, only two pieces of parts are required to form a stay by electromagnetic forming.

As a result, an electromagnetically formed stay weighs only about a half of a stay made of steel having a same crashing load. The electromagnetically formed stay exhibits similar energy absorption characteristics against loads applied from different directions and thus is considered to deliver sufficient performance in actual collisions. These characteristics respond well to the recent standards requiring not only bench test results, but also good performance in actual collisions.

Two types of collision tests are required by standards, i.e., barrier collision and pendulum collision. In either case, a bumper system is brought into a collision with either one of the barrier or pendulum for the evaluation of its collision performance. More specifically, for an input of collision energy, outputs are obtained in quantities such as deformation amount and reaction force. For example, smaller deformation amount is considered to be better for a given input of collision energy. In actual collision, however, the input value does not necessarily remain constant. The characteristic of providing a constant output against such varying input is called "robustness" which provides versatility and stability of performance. Stays for bumper systems are required not only of energy absorption characteristics, but also such robustness.

The following describes an example in which robustness of an electromagnetically formed stay against input loads from various directions was examined. Energy absorption characteristics were evaluated for applied load directions of 0º (axial direction), 13º, 30º and 45º. **Photo 2** shows the actual testing set-up for 30º angle and the test result is given in **Fig. 6**. The electromagnetically formed stay exhibits an almost constant maximum load bearing capacity regardless of the applied load directions. It should be noted that a straight tube, when crushed in the same manner, exhibits a highest load bearing capacity for the 0º angle direction and a lowest load bearing capacity for 45º angle. The higher robustness of the electromagnetically formed stay is attributable to its shape. The electromagnetically formed stay has a body section which is bulged to a near spherical shape. This shape is considered to provide stable energy absorption characteristics against loads from various directions. The electromagnetically formed stay is also featured by the load bearing capacity which does not drop rapidly after passing its maximum capacity. Therefore, electromagnetically formed stays are well suited for bumper systems with their low manufacturing costs and energy absorption characteristics. The applications of the stays are now expected to grow.

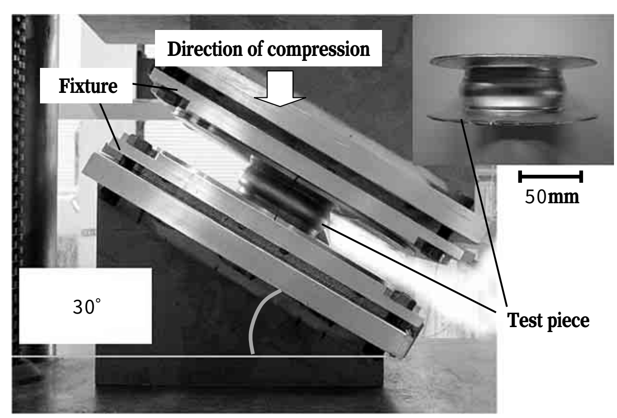

Photo 2 Typical robustness evaluation

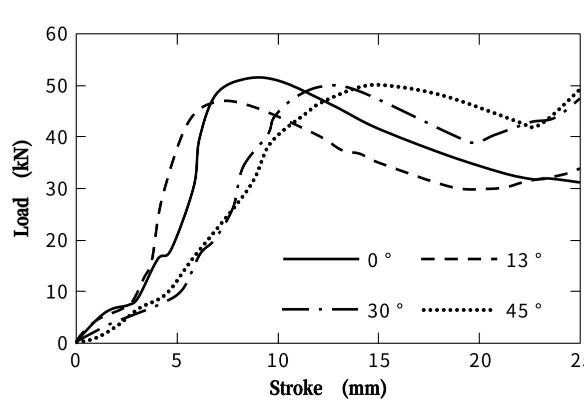

Fig. 6 Compression test results of electromagnetic formed stays

Conclusions

As described above, aluminum alloy extrusions are widely used for automotive bumper systems. The properties required for automotive applications are expected to become more advanced with tightening regulations and the diversification of components used. To meet such requirement and to promote the use of aluminum alloy extrusions to automotive bumper systems, rapid developments are required for their materials, forming process and optimum structures. Kobe Steel will continue to strive for the design and development of bumper systems to contribute to automotive weight reduction.

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