ALUMINUM ALLOYS FOR AUTOMOBILE APPLICATIONS

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ABSTRACT Nowadays, importance of vehicle weight reduction is growing because of fuel economy. To apply aluminum is a highly effective way to reduce vehicle weight. But, mechanical properties per material cost, such as specific Young's modulus / cost, are not so good than any other materials. Therefore, it is important to consider all aspect of material use for auto parts and to manage smart applications.

Key word : *vehicle aluminum weight reduction engine body*

1. Introduction

In these days, there are not many aluminum auto parts being used. The amount of aluminum currently used for automobiles is only 5mass% of entire automobile materials. This situation is greatly different from the cases of aircraft and bullet trains. Recently, however, automobile industry has begun to take a great interest in application of aluminum. It is because of increasing requirement to improve fuel economy triggered by concern about global warming and energy security. Accordingly, successful result from such effort is expected.

In this paper, current activities to apply aluminum to automobiles will be summarized. The future prospects of auto aluminum application will be also discussed.

2. Improvement in Fuel Economy

In order to reduce CO_2 emission, fuel economy should be improved further. To meet this requirement, auto manufacturers are making efforts to improve conventional engine efficiency, to develop new power train such as hybrid system and also to reduce vehicle weight. Especially, importance of vehicle weight reduction is growing since average vehicle weight these days is gradually increasing to improve vehicle safety. Safety equipments such

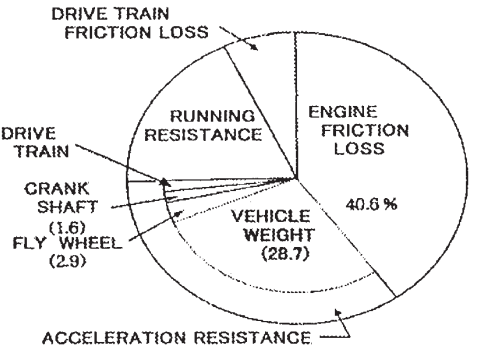

Fig. 1 Energy Consumption of Vehicle [1]

as ABS, air bag etc., and high strength body structure contribute to vehicle weight gain.

The effect of weight reduction on fuel economy is shown in Fig. 1. From this figure, It is obvious that weight reduction is as effective as engine efficiency improvement and friction loss reduction. The important fact is that weight reduction has a ripple effect on fuel economy. For example, weight reduction enables us to obtain exactly the same vehicle performance with a smaller engine, and such a smaller engine enables us to use a smaller transmission and a smaller fuel tank. With this ripple effect, it is said that 1% of vehicle weight reduction results in 0.8 to 1.0% of fuel economy improvement.

To apply aluminum is a highly effective way to reduce vehicle weight, and total amount of aluminum applied to automobiles is gradually increasing. Fig. 2 shows the changes in material content per Mid-Size vehicle in Japan. The amount of sheet steel is decreasing, and the amount of aluminum and organic materials is gradually increasing instead.

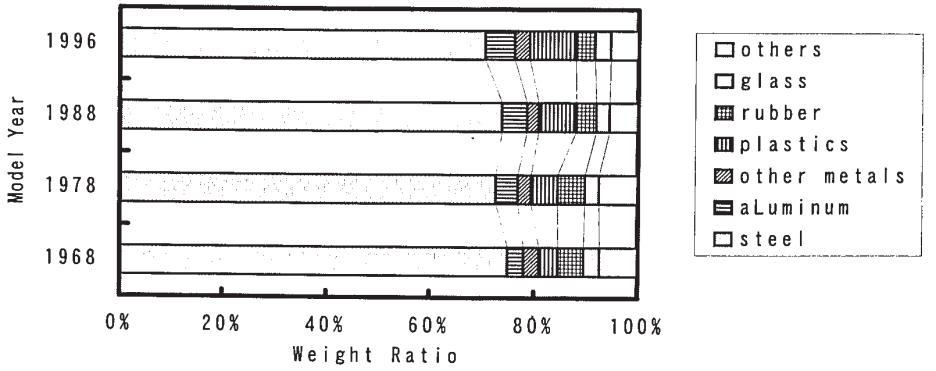

Fig. 2 The Changes in Material Content of Vehicle

3. Current Status of Aluminum Application

Fig. 3 shows recent examples of aluminum application to vehicles. In addition to conventional application such as engine cylinder head and disc wheel, engine block and radiator application have been increasing.

Fig. 4 shows aluminum consumption by each manufacturing process of aluminum auto parts in Japan. Regarding total increase of the consumption, aluminum castings takes higher rate than wrought aluminum parts. While this is mainly because aluminum casting parts are generally larger and heavier than wrought aluminum parts, this may be also because of the difference between cost performance of casting parts and that of wrought parts. In the following section, the difference of the cost performances will be discussed.

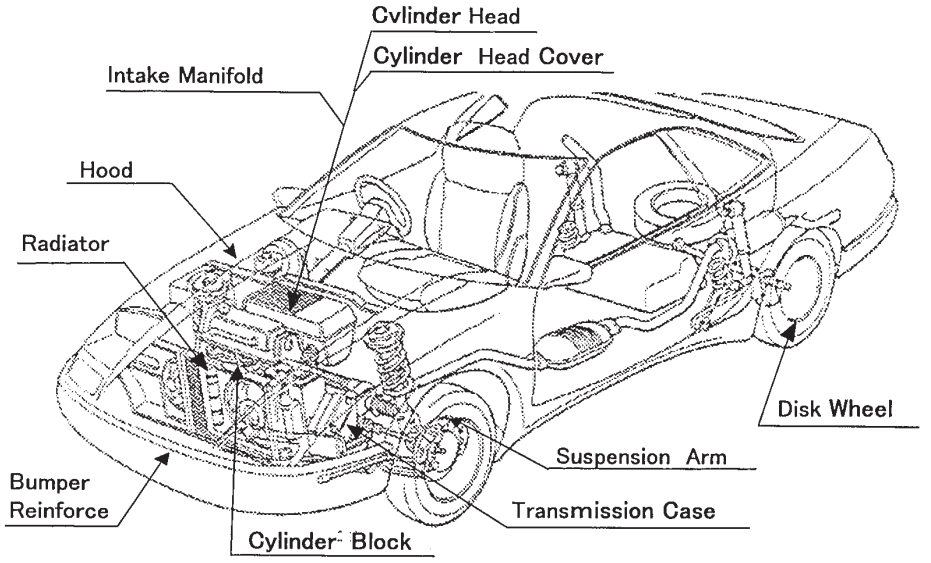

Fig.3 Recent Examples of Aluminum Application to Vehicle

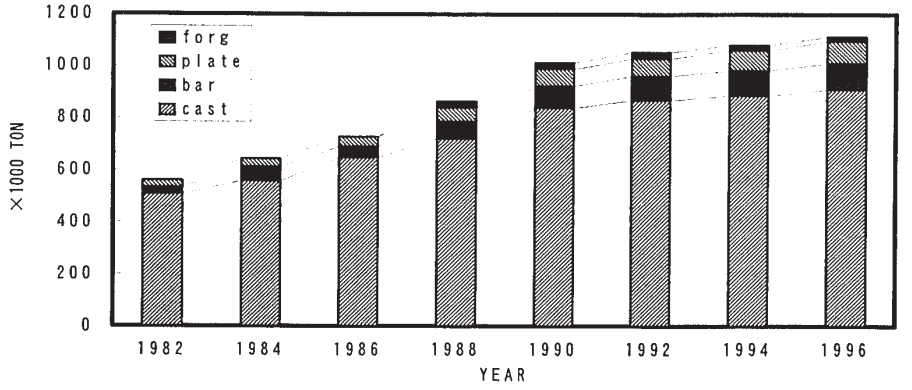

Fig. 4 Aluminum Consumption for Auto Parts in Japan

3. 1 Characteristics of Aluminum

Fig. 5 shows specific moduli of casting / wrought aluminum and other materials. Specific modulus of aluminum is slightly advantageous since cross sectional area of aluminum parts can be wider than those of other materials due to its light specific gravity.

In Fig. 6, the values shown in Fig. 5 are converted to per each material cost basis. From the view point of specific modulus per material cost, aluminum, especially wrought aluminum, has no

advantage over other materials. Therefore most aluminum parts are being used because of not only its mechanical properties but also its other characteristics such as high thermal conductivity and machinability etc.

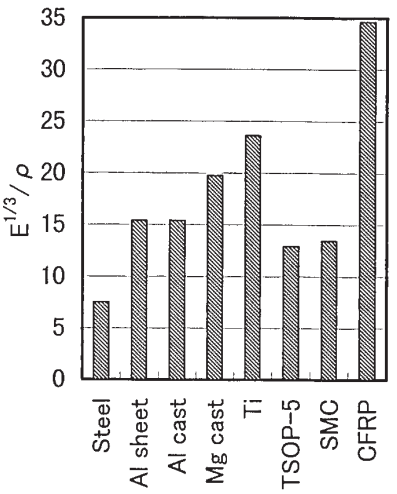

Fig. 5 Specific Moduli of Materials

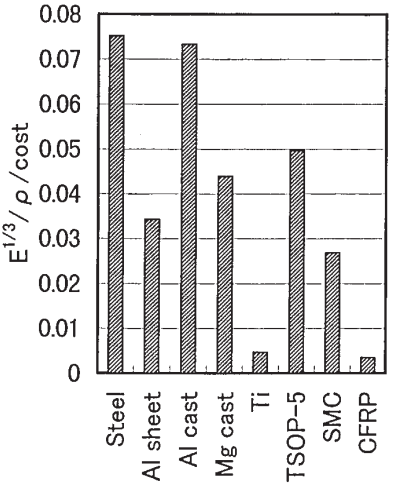

Fig. 6 Specific Moduli / costs

3.2 Use and Effect of Aluminum Castings

As shown in Fig. 6, the cost performance of aluminum castings is as good as that of other materials. Therefore, aluminum castings have been applied to various automobile parts for a long period. As a remarkable trend, the material of engine block, which is one of the heaviest auto parts, is being switched from cast iron to aluminum with significant weight reduction.

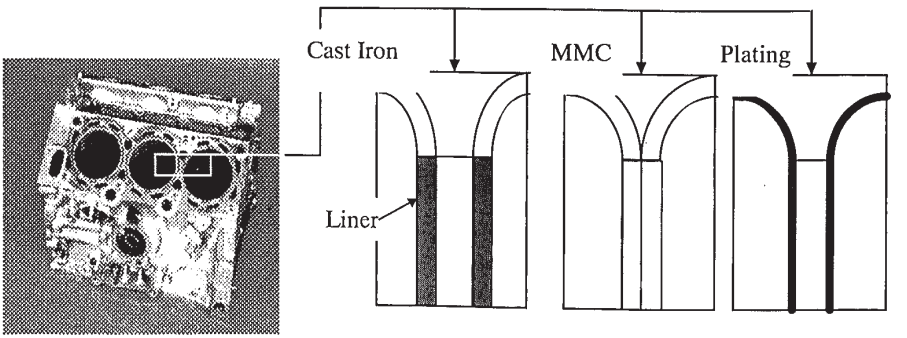

Fig. 7 Structures of Aluminum Cylinder Block

On the other hand, aluminum blocks need to be embedded with cast iron cylinder liners due to aluminum low wear resistance against piston rings. As a result, bore pitch of aluminum blocks becomes greater than that of cast iron blocks and total length of aluminum blocks becomes longer than that of cast iron blocks. In order to solve this problem, new technologies such as anti-wear plating and metal matrix composite are under development. This examples are shown in Fig. 7. In the field of aluminum castings, those developments are equally important as aluminum alloy materials.

3.3 Use and Effect of Wrought Aluminum

Recently, developmental effort to apply wrought aluminum is becoming more active rather than to apply aluminum castings.

In the field of heat exchanger, brazed aluminum-tube structure is becoming popular by replacing the conventional soldered copper structure. Fig. 8 shows an example of aluminum radiator structure. In the case of aluminum-tube structure, fin material is also changed to secure corrosion resistance of aluminum tube. In other words, fin material works as sacrificial anode for aluminum tube. Aluminum radiator is preferable not only for the purpose to reduce weight but also to reduce the amount of lead used for vehicles. Like this case, it is important to consider all aspects including recyclability for material selection of auto parts.

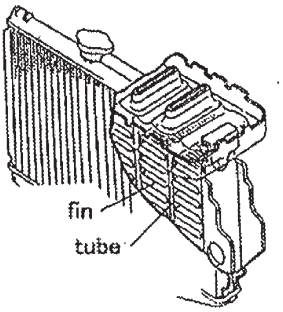

Fig. 8 Aluminum Radiator[2]

4. Future Application of Aluminum

Aluminum body structure is one of potential auto application which can reduce vehicle weight drastically with using large amount of aluminum. There are generally two types of structure to apply aluminum to body structure. One is monocock-body structure represented by ALCAN-Ford Aluminum Intensive Vehicle (AIV), and the other is space frame structure represented by ALCOA-Audi A8. These examples are shown in Fig. 9 and

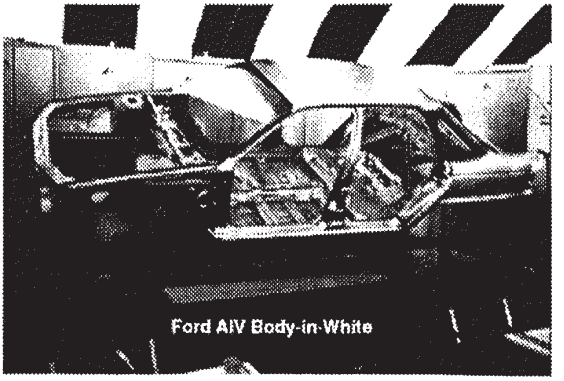

Fig. 9 ALCAN-Ford AIV[3]

The updated examples of these two types are Ford P2000 and Audi AL2. Both of them could reduce weight about 40 % on Body-in-White basis.

Ford P2000 is basically designed with monocock-body structure which is being developed by ALCAN. This structure is based on two technologies which are to improve press formability of aluminum sheets and special pretreatment for excellent performance with both paints and adhesives. Key feature of this structure is applying adhesives to many portions. On the other hand, the structure of Audi AL2 is progressed space frame with aluminum extrusions from the space frame already developed for A8 by ALCAN. In the AL2, there are few aluminum cast joints which were extensively applied to A8 since they are replaced with direct bonds. And also aluminum extrusions are made into as straight shape as possible. From these aspects in AL2, it is easily understood that various challenges to reduce production costs have been made.

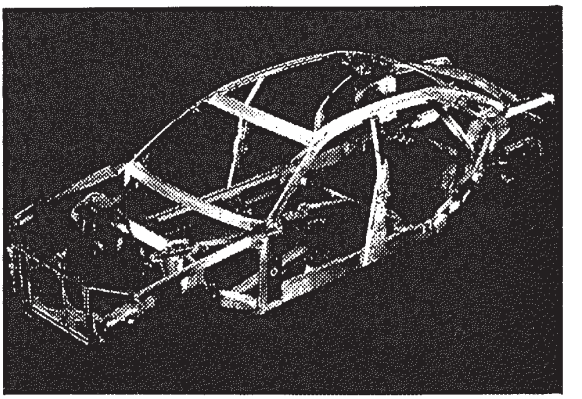

Fig. 10 ALCOA-Audi A 8 [4]

As shown in Fig. 6, aluminum sheet doesn't has no specific advantage compared to sheet steel from the viewpoint of cost performance. Accordingly, when we consider applying aluminum to body structure, it is important to improve cost performance. Regarding outer panel application, low Young's modulus of aluminum is improved by increasing sheet thickness without sacrificing weight reduction. This is because panel rigidity improves in proportion to the square of sheet thickness (t^2) and thicker aluminum sheet which has the same characteristics as thinner sheet steel is still lighter than the sheet steel. Regarding internal structural members, however, various characteristics ,including impact energy absorption at the time of crash, fatigue strength, and Young's modulus , determine the shape and consequently the weight of each member. Therefore, the issue of internal structural members is not as simple as the issue of outer panels. Application of aluminum extrusion is one of solutions to meet various requirements of internal structural members. In the case of press aluminum sheets for body structure, it has been challenged to meet strength requirement with using adhesive bonding .

As discussed above, aluminum is applied to body structural members with optimizing their shapes. However, this approach makes production cost significantly increase and it seems to be too expensive only for fuel economy improvement. In fact, commercialized vehicles which have

all aluminum body structure are limited to highly distinctive vehicles produced in relatively small numbers such as Audi A8.

To compete with aluminum-related R&D, steel-related R&D for light weight body structure has been conducted. Fig. 15 shows an example of such body structure developed in Ultra Light-weight Steel Auto Body (ULSAB) project which is collaborative project to study light-weight steel body structure by thirty five steel makers in the world. In this project, extensive use of high tensile strength steel, hydroforming process, and laser welding process, etc. have been studied.

Several new developments are in progress in both aluminum and sheet steel fields. It seems to continue the competition between aluminum and sheet steel for a while in the future. We believe that highly cost effective ways including developmental costs will survive and also will direct future auto body structure.

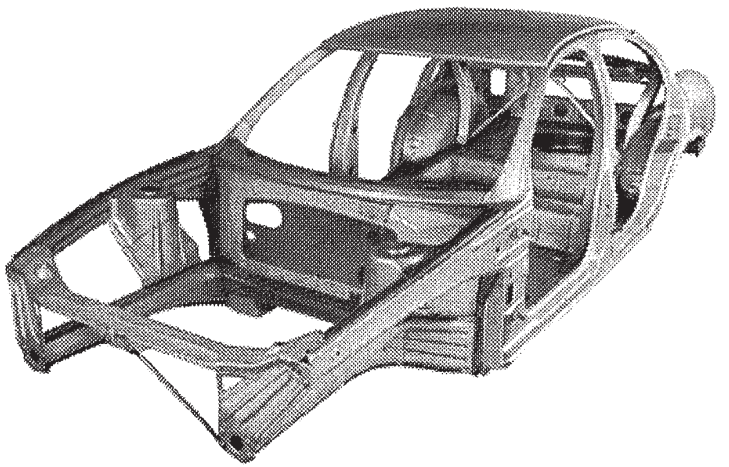

Fig. 11 ULSAB Body in White [5]

5. Conclusion

There are many factors to be considered for material selection to automotive application. For example, characteristics, raw material cost, production cost and mass-productivity as components, and supply stability, etc. The most important factor is, however, superior cost performance compared with competing materials. As discussed above, aluminum is in severe competition with other materials with regard to structural designing and process engineering, aiming at better cost performance. We expect that such competition will accelerate each development of whole automotive materials.

It is also important these days to consider environmental aspects. From such viewpoint, it is

necessary to minimize energy consumption and environmental burden in terms of automobile life cycle. Accordingly, even in the automotive field, not only production- related technologies, but also environmental technologies, such as recycling technology of scrap vehicles, need to be developed.

There are only a couple of years remaining before the 21st century. Although roads in Japan seem to be filled with automobiles, there are still large number of people in the world who are not enjoying the benefits from automobile use. We can say aluminum application to automobiles is just at the beginning. We hope that by the highly advanced use of aluminum, automobiles will be accepted by people across the world as environment-friendly and fun-to-drive transportation.

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