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Development of Aluminum Alloys and New Forming Technology for Automotive Parts.

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Automobiles tend to become heavier as the safety and comfort features are improved. Meanwhile, automobiles have to meet more stringent regulations for exhaust emissions, including CO_2 and NO_X, to protect the environment. The European Commission has announced a policy to reduce CO_2 emissions down to 140 g/km or less by 2012. Therefore, carmakers are pushing forward development of light weight automotive technology. Especially, aluminum alloys have started to be used for various automotive parts for its low specific gravity. Now the aluminum alloy for automotive parts is being extended to hoods, trunk lids, a bumper systems and suspension arms. This presentation will be report on the latest trends and the developmental status of aluminum alloys and new forming technology for automotive parts.

Keywords: *Automobile, Fuel economy, Light weight, Aluminum alloy, forming technology.*

1. Introduction

Automobiles are becoming heavier in order to satisfy requirements such as safety (e.g., collision safety and pedestrian protection), drivability, comfort and larger interior space. Meanwhile, automobiles have to meet more stringent regulations against exhaust emissions, including CO_2 and NO_X emissions, to protect the environment. The European Commission, for example, has announced a policy to reduce CO_2 emissions down to 140g/km or less by 2008 and to 120g/km or less by 2012. Japanese regulations to reduce CO_2 emission will also be tightened to a level comparative to that of the European Commission by 2012. Thus, improving fuel economy is now imperative for all the automobile manufacturers.

Various measures are taken to reduce fuel economy including new power trains involving hybrid systems or advanced diesel engines. Above all, automotive weight reduction is regarded as one of the most effective means for decreasing fuel economy. One hundred kilograms of weight reduction improves fuel economy by 1km/L, according to the Japanese 10-15 mode measurements[1). Automotive weight reduction has been achieved traditionally by reducing thickness of steel-sheet body panels by increasing the strength of the steels, however, this approach is limited because of the resultant reduction in panel stiffness. For this reason, lighter materials are being studied extensively to replace the steels. Especially, aluminum alloys have started to be used for various automotive parts for its low specific gravity (approximately 1/3 of steel). Now the use of aluminum alloy is not limited to conventional castings such as engine blocks, but extends to body panels (engine hoods, trunk lids and doors etc.), bumper systems and suspension arms[2)~5)]. This presentation will be report on the latest trends and the developmental status of aluminum alloys and new forming technology for automotive parts.

2. Light weight automobile trend.

2.1 The fuel economy regulations of the automobile.

Fig. 1 shows the target for fuel economy in the world (Europe, Japan and USA). The Europe's target is the highest in the world. The European Commission, for example, has announced a policy to reduce CO_2 emissions down to 140g/km or less by 2008 and to 120g/km or less by 2012. Japanese regulations to reduce CO_2 emission will also be tightened to a level comparative to that of the European Commission by 2012.

2.2 The aluminum technology for light weight automobiles

In 1985, the MAZDA RX-7 applied aluminum alloy sheet for its body panel (hood) for the first time in Japan. Since then, aluminum panels have been used mostly for sporty and luxury cars until early 1990s. The HONDA Motor Co., Ltd. presented the all aluminum body NSX for the first time in the world. Table 1 lists the automobile models in Japan using aluminum panels as of 2009. More recentry, aluminum panels are being used for wider variety of models, such as the TOYOTA Crown and Prius, NISSAN Infiniti M37/M45, G37 and Fairlady Z. The many aluminum panels are used for hoods. Recent models employ aluminum panels for trunk lid, doors and roof[6),7)].

In Europe, automobile used of aluminum raised sharply between 2000 and 2002. For examples of high volume models include the Mercedes-Benz E class and BMW 5series, both of which are produced in volumes greater than twenty thousand a month. Audi presented, as early as 1992, an all-aluminum body car, the Audi A8, having a space frame structure and is regarded as a forerunner in the use of aluminum panels for automobiles. In 2006, after presenting the Audi A2 and new Audi A8, the company started using a hybrid material structure for the Audi TT model, in which the aluminum space frame and partial steel plates are joined together. The expanding automotive use of aluminum in Europe seems relevant to the more stringent regulation on CO_2 emissions which becomes compulsory in 2012.

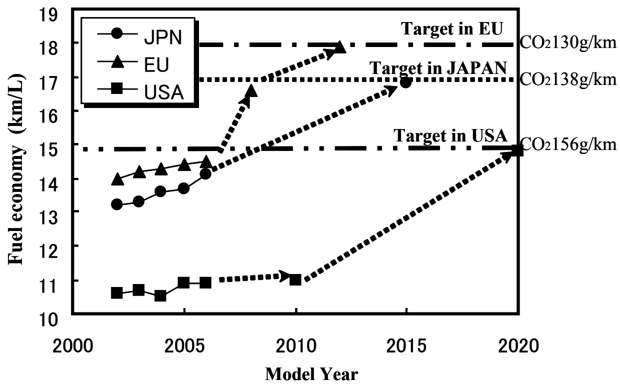

Fig.1 Target of the fuel economy in JAPAN, USA and EU.

Table 1 Examples of Aluminum Closure Panels in Japan.

Car Makers	Models	Application Parts
TOYOTA	CROWN	Hood
	CROWN MJ	Hood
	PRIUS	Hood, Back-Door
TOYOTA(LEXUS)	LS	Hood
	GS	Hood
	SC	Hood, Roof
	HS	Hood
	IS	Hood
DAIHATSU	COPEN	Hood,Roof
NISSAN	FUGA (Infiniti M37/M45)	Hood,Door
	GT-R	Hood,Door,Trunk-Lid
	CIMA	Hood,Trunk-Lid
	SKYLINE Coupe	Hood
	SKYLINE (Infiniti G37)	Hood
	Fairlady Z	Hood,Door,Back-Door
MAZDA	RX-8	Hood,Rear-Door
	ROADSTER	Hood,Trunk-Lid
HONDA	LEGEND	Hood,Trunk-Lid
MITSUBISHI	LANCER Evo.	Hood,Roof,Trunk-Lid
	PAJERO	Hood
	OUTLANDER	Roof

3. The developmental status of aluminum alloy sheets for automotive panels

Table 2 shows the development history of aluminum alloy sheets for automotive panels [8)]. In Japan, Al-Mg alloys with minor addition of Zn were first used when aluminum alloy sheets were practically applied to automobiles in 1985. Around the same time in EU and USA, either 2000 series (Al-Cu) alloys or 6000 series (Al-Mg-Si) alloys with minor addition of Cu were used to serve the purpose. Currently, as the requirements for automotive panels has diversified, 6000 series (Al-Mg-Si) alloys are predominantly used worldwide with a few exceptions of 5000 series (Al-Mg) alloys. This is because the requirements for the material properties now include not only strength and

Table 2 Development history of aluminum sheets for automotive panels

	1985～1990	1990～1998	1999～2005
JAPAN	●Al-Mg Series Alloy High Strength & High Formability	○Al-Mg Series Alloy AA5022,AA5023 ○Al-Mg-Si Series Alloy High Bakehardability High Formability	◎Al-Mg-Si Series Alloy High Bakehardability High Formability Hemming SS mark free ○Al-Mg Series Alloy
US & EU	●Al-Cu Series Alloy AA2036, AA2008 ●Al-Mg-Si Series Alloy AA6009, AA6010	○Al-Mg-Si Series Alloy AA6022, AA6016 ○Al-Mg-Si Series Alloy AA6111	◎Al-Mg-Si Series Alloy AA6022, AA6016

formability, but also corrosion resistance, hemming formability, surface characteristics and weldability. Table 3 presents the compositions and properties of typical aluminum alloys used for automotive panels [7]. The 6000 series alloys constitute the mainstream of alloys used for automotive panels because they are heat-treatable and their strengths can easily be controlled by heat treatments. In addition, the 6000 series alloys may also be adapted to exhibit bake hardening which occurs during the baking step after painting in the automotive manufacturing process. The bake hardening features of the alloys improve dent resistance and enables reduction of the sheet thickness and weight. The bake hardenability depends on the baking conditions which differ slightly by countries. The baking process is treated at higher temperatures, around 180 to 200 ºC, in EU and USA, while the treatments at lower temperatures for short period (e.g.,170ºC x 20 min) are preferred in Japan. The alloys for outer panels are required to harden under the baking conditions described above, however, conventional 6000 series alloys were unable to harden sufficiently under such conditions. Extensive studies [9)-11)] revealed that pre-aging steps as shown in Fig. 2 provides bake hardenability at low temperatures, which otherwise has been difficult to achieve. A short period process of reversion treatment at a low temperature is also reported to provide bake hardening[12)-14)].The yield strength of a 6000 series alloy depends on the distribution (size and density) of fine precipitates (intermediate β': Mg_2Si; see Fig. 3) formed during aging treatment. The distribution is largely affected by the content of Mg and Si, major alloying elements, as well as by aging treatment conditions. A dense distribution of fine precipitates as depicted in Fig. 3 is required to achieve high proof strength. The figure represents the microstructure of a low temperature, bake hardening type alloy developed.

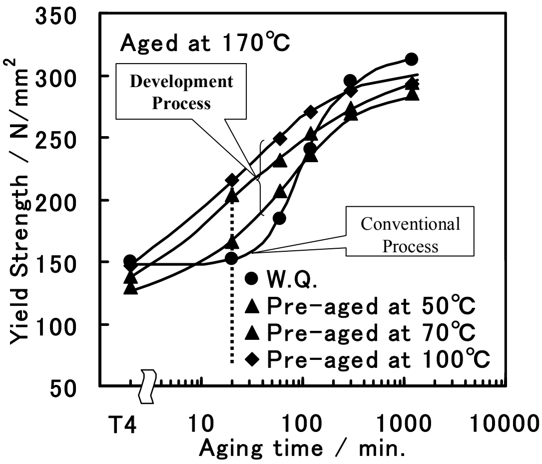

Fig.2 Effects of pre-aging on bake hardenability in 6000 series alloys

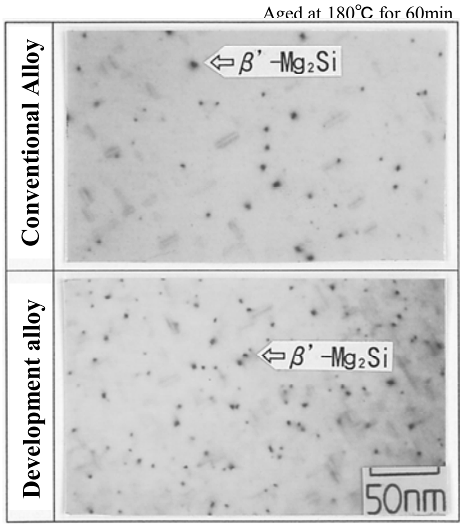

Fig.3 TEM microstructures of aged 6000 series alloys (aged at 180℃ for 60min.)

Such distribution can be obtained by an excessive addition of Si which is the major alloying element. Thus, excessive amounts of Si are added to the aluminum alloys practically used for automotive panels, such as AA6022 and AA6016. Most of the 6000 series alloys for automotive panels developed in

Table 3 Chemical compositions and mechanical properties of aluminum alloys for automotive panels

Alloy		Chemical Compositions (wt%)								Mechanical Properties				
		Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	TS N/mm²	YS N/mm²	EL %	n-Value	r-Value
6000 series	AA6022	0.8～1.5	0.05～0.20	0.01～0.11	0.02～0.10	0.45～0.7	0.10	0.25	0.15	275	155	31	0.25	0.60
	AA6016	1.0～1.5	0.50	0.20	0.20	0.25～0.6	0.10	0.20	0.15	235	130	28	0.23	0.70
	AA6111	0.7～1.1	0.40	0.5～0.9	0.15～0.45	0.50～1.0	0.10	0.15	0.10	290	160	28	0.26	0.60
5000 series	AA5022	0.25	0.40	0.20～0.50	0.20	3.5～4.9	0.10	0.25	0.10	275	135	30	0.30	0.67
	AA5023	0.25	0.40	0.20～0.50	0.20	5.0～6.2	0.10	0.25	0.10	285	135	33	–	–
	AA5182	0.25	0.35	0.15	0.20～0.50	4.0～5.0	0.10	0.25	0.10	265	125	28	0.33	0.80
	AA5052	0.25	0.25	0.10	0.10	2.2～2.8	0.15～0.35	0.10	–	190	90	26	0.26	0.66

Japan also contain Si in excessive amounts. In addition, Cu is also effective in making the precipitate distribution fine and homogenous [15].The alloys in 6000 series are naturally aged to increase their yield strength when left at room temperature for a long period of time. The increase in yield strength may adversely affect workabilities such as press formability and bendability. To prevent such change in strength over time, a process has been developed involving a reversion or stabilization treatment. As shown in Fig. 4, the process yields only minimal hardening after elapsing of several hours [14].

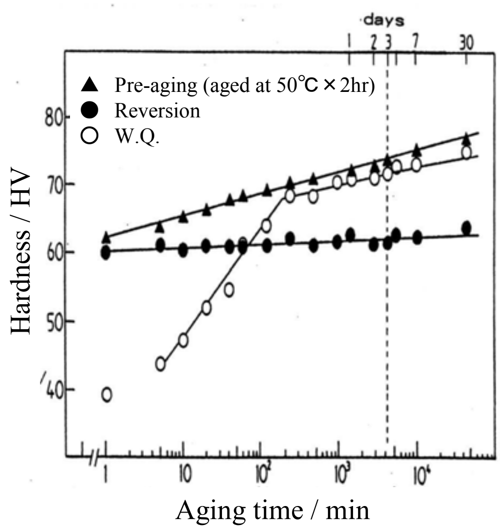

Fig.4 Effect of reversion process on natural aging in 6000 series alloys

4. Forming technologies of aluminum alloys for automotive parts

Aluminum alloy sheets are less formable than steel sheet because of their low elongations, n-values, r-values and modulus of elasticity. A shape that could be formed by steel sheet may not be formed by aluminum alloys without causing cracking, wrinkling, or spring back. Thus, aluminum alloy sheets may impose restrictions on the design of shapes with their less degree of freedom in forming. When compared to steel sheets, aluminum alloy sheets exhibit proof and tensile strengths almost equivalent to that of mild steel, however, their elongations are much smaller. Fig. 5 shows stress-strain curves of typical aluminum alloy sheets (5000 and 6000 series) for automotive panels. Also included is the curve for a mild steel. As can be seen from the figure, the aluminum alloys have significantly smaller elongations after maximum loads are reached (the elongations called “local elongations”) compared to the steel. The difference in local elongation is considered to be the cau se of the different formabilitites between aluminum alloys and steel. The following describes the measures taken to improve the formabilitites of aluminum alloy sheets.

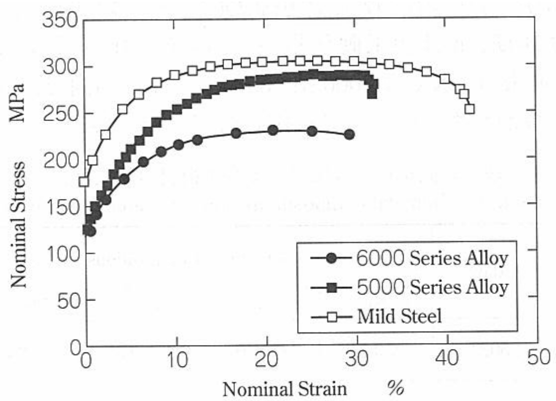

Fig.5 Stress-Strain curves of aluminum alloys and mild steel

Fig. 6 depicts the relation between the LDH_0 (LDH : Limiting Drawing Height) and tensile strength for aluminum alloys and steels. The LDH_0 is defined as the height at which a fracture occurs when a rectangular blank is press-formed using a spherical head punch. The vicinity of the fractured portion is in a plane strain region. The results indicate that the stretchability of aluminum alloy

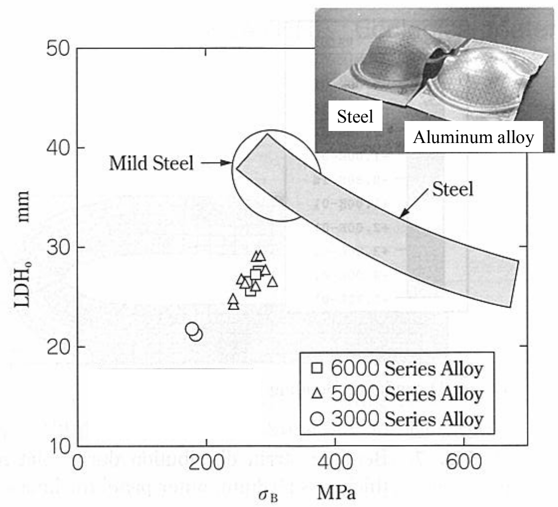

Fig.6 Relationship between LHD0 and tensile strength of typical aluminum sheets and mild steels

sheets are inferior to that of steel sheets.

5. New forming technology of aluminum alloys for automotive parts

The temperature dependence of superplastic deformation is also utilized in the forming of aluminum alloy sheets. Some aluminum alloys have unique characteristics of exhibiting significantly large elongations at temperatures either higher or lower than room temperature. The characteristics may be exploited in the forming of aluminum alloys. Fig. 7 depicts the temperature dependence of the mechanical properties of a 5000 series (Al-Mg) alloy. Hot-blow forming utilizes the large elongation of aluminum alloy sheet at elevated temperatures. The method is practically used in forming complex shapes which may be difficult to form even with steel sheets. However, the approach takes long process time and its application has been limited. Recent development has shorten the process time of hot-blow forming. Honda Motor Co., Ltd., adopted the process to the forming of front fenders and trunk lids for the Honda Legend[1]. On the other hand, a low temperature forming technology has also been developed utilizing the large elongation at lower temperatures, a unique characteristics of aluminum alloy.

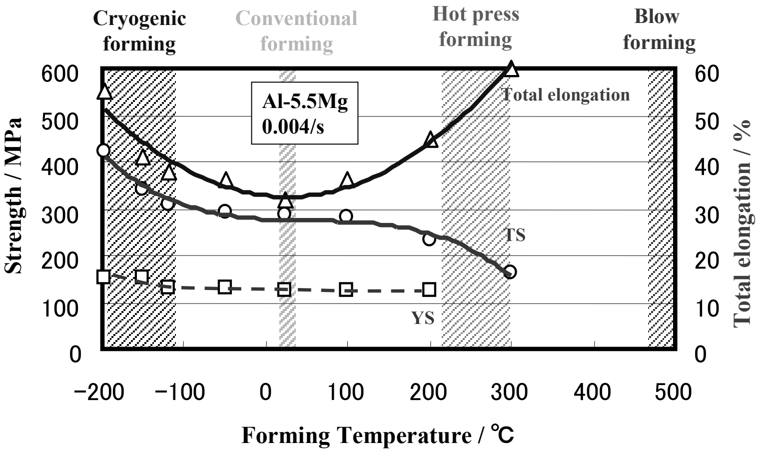

Fig.7 Effects of forming temperature on mechanical properties in 5000 series alloys

Fig. 8 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 the electromagnetic coils, causes the force (the 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 the 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. The coil shapes are known to affect coil lives[16].

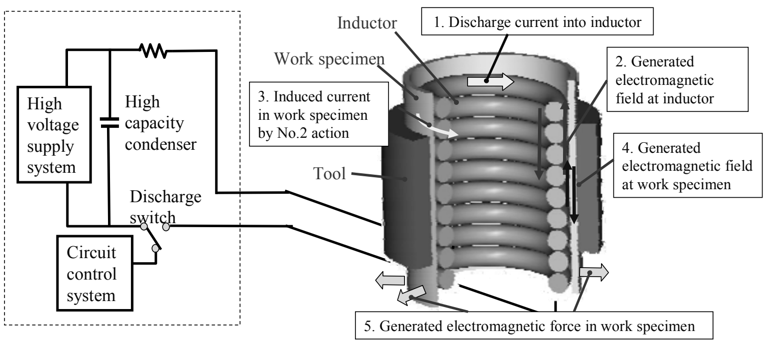

Fig.8 Typical configuration of the electromagnetic forming apparatus

Fig. 9 shows four forming methods using the electromagnetic force. Recently reported applications of the electromagnetic forming include bore flanging of aluminum[17] and electromagnetic seam welding between

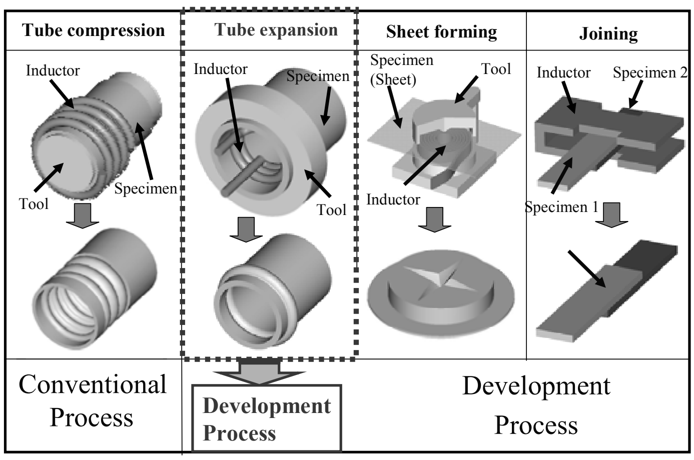

Fig.9 Types of the electromagnetic forming

aluminum and steel sheets[18]. In the development of new aluminum stay, the electromagnetic forming method was adapted to perform bulge forming and flange forming at tube end simultaneously. The aluminum tube is inserted into a hole in the aluminum plate. The inductor is then inserted into the interior of the aluminum tube. Applying a large current to the inductor exerts the 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. The mold is disposed at the end of the tube without a plate so that the end portion is formed into a flange.

6. Conclusions

The latest trend and new technologies of aluminum alloys have been reviewed with major focus on automotive panels. In the needs for automotive weight reduction, aluminum will continue to be a major candidate for a lighter substitute material. Functional properties, as well as the weight reduction effect, will be required for aluminum alloys to be used for various automotive parts. To expand the use of aluminum for automotive panels, forming technologies should be further improved to provide more degree of freedom to automotive design. Also important subject to reduce the cost of aluminum parts for them to be used for various parts of mass produced vehicles. The cost reduction may involve the development of process technologies which simplifies process steps and simultaneously achieve the required quality. Unification and recycling of parts will also be needed.

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