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High Strength Steel Sheets for Weight Reduction of Automobiles

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Abstract:

Requirements to fulfil fuel efficiency regulation are becoming strict year by year. The developing countries are also establishing strict regulations similar to developed countries. Body weight reduction is still important even in electric car which is effective to improve fuel efficiency. Applying high strength steel more than 980 MPa grade in tensile strength has progressed in recent ten years. Moreover, hot stamping also becomes applicable to automobile reinforcement members. Along with the situation, many issues to use ultra high strength steels and hot-stamped members are newly presented.

Since the increase in volume fraction of martensite makes steels strengthened, water quench process in the continuous annealing line is key to develop and produce new high strength steels. Very rapid cooling rate in JFE continuous annealing process realizes excellent welding properties in newly developed low alloy steels. Surface treatment also improves press formability of high strength galvannealed steel sheets and has been applied to automobiles.

1. Introduction

The concentration of carbon dioxide (CO_2), which has been a cause of global warming, is increasing significantly by the increase in economic activity. Especially, the amount of CO_2 from automobiles occupies about 20% in CO_2 emission[1)] so that reducing CO_2 emission from automobiles is one of the important issues to prevent global warming. Since the amount of CO_2 emission from driving an automobile is proportional to the weight of the vehicle with any drive system[2)], the weight reduction of automobiles is an important matter to reduce CO_2 emission. Even in the case of electric vehicles (EV), because a battery weighing from 100 kg to 200 kg has to be installed, the weight reduction is also necessary to extend the cruising distance further.

Use of high strength steels has been promoted for weight reduction since more than 60% of the weight of an automobile is the weight of steel parts. Considering cost and supply chain for multi-material structures, steel sheets will remain as the main automotive material. This article presents an overview of high strength steel sheets which contribute to automotive weight reduction from the past to the present, and in the near future.

2. Transition of Fuel Economy Regulations and Automobile Driving Methods

Figure 1 shows the change in fuel economy regulations[3)] and stricter regulations are going to be employed in the near future in various countries. In particular, even in China and India, which will be motorized, tightening of the regulations is planned in keeping with those in well-motorized countries. These regulations indicate that it will become necessary to supply automobiles with the same fuel economy performance globally as in Japan, North America and Europe. On the other hand, since the weight of automobiles is also increasing annually to satisfy new collision safety regulations by adding automatic driving devices, etc., it is necessary to reduce the weight.

Figure 2 shows the prediction of automobile production in Japan for each drive system[4)]. Recently, Europe and China announced shifts to the production of electrical vehicles without gasoline engines. However, the hybrid system (HEV) is expected to be the

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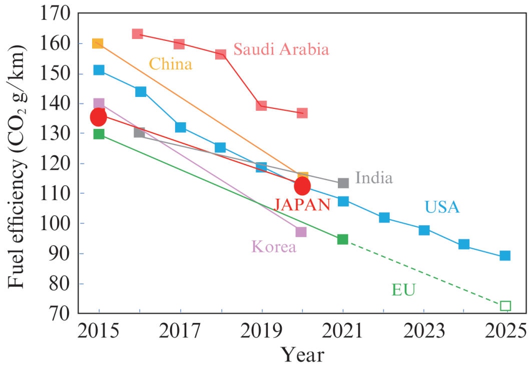

Fig. 1 Change in mileage regulations[3)]

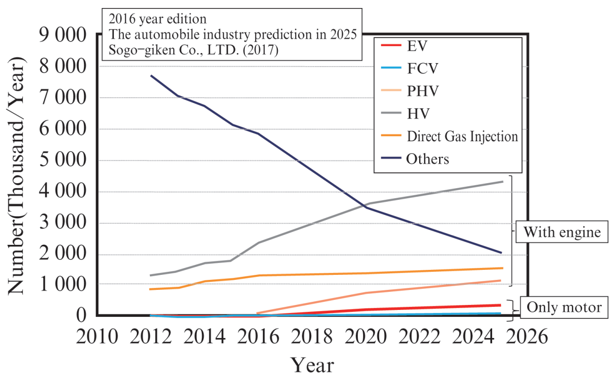

Fig. 2 Automobile production number prediction in each driving system[4)]

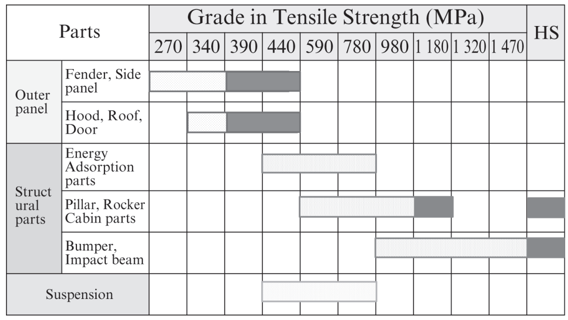

Fig. 3 Strength of steels in each automobile parts

standard in 2025. The hybrid system body structure will be similar to that of the conventional gasoline engine automobiles. This indicates that the requirement for high strength steel of structural bodies should be the conventional type. In EVs without a gasoline engine, the weight distribution will change due to a decreased volume of excess space in the front of the cabin and extra weight due to the installation of a battery weighing over 100 kg. As a result of these changes, the requirements for automobile body parts are as follows.

(1) Higher strength to support and protect the battery.
(2) Weight reduction in the rear part of vehicles to optimize the weight distribution for improvement of steering performance.
(3) Weight reduction of undercarriage (suspension) parts to reduce the weight of the lower body.

JFE Steel plans to supply materials suited to the needs described above.

3. Strength of Automotive Steel Sheets and Issues for Use

Figure 3 shows the tensile strength of steel sheets applied to the automobile parts. The hatched areas in Fig.3 show the strength of the steel sheets used in 2007, and the darker areas show the strength newly applied in the last 10 years. In the outer panels, which are directly seen in automobile parts, while steel sheets in the tensile strength of 340 MPa was used to form complex shapes, the use of 440 MPa grade steel sheets has begun. In the case of the use of 440 MPa grade steel sheets, maintaining both dent resistance and rigidity performance were huge issues, since 0.6 mm thickness sheets have already been applied.

In energy absorbing members, 440 to 780 MPa class steel sheets are used because of stable crush deformation by high work-hardening performance. Applying high strength steel sheets with a tensile strength higher than 780 MPa will be realized.

In pillars, rockers and other parts that protect the passengers in the cabin, the use of high strength steel sheets has progressed with the aim of preventing deformation even under the large load of a collision. Steel sheets from the conventional 590 MPa grade to 1180 MPa grade are now used. In addition, parts produced by hot stamping (HS) are also increasing. In the HS technique, high strength parts are obtained by heating the steel sheet to around 950°C and pressing with a die for quenching.

In bumper and impact beam parts, which directly receive the impact of a collision, higher strength steel sheets had been applied from an early date and the above-mentioned HS parts have now started to be used.

In the tensile strength from 590 to 780 MPa grade hot-rolled steel sheets have been used in suspension parts. In recent years, applying high strength steel sheets at a tensile strength higher than 780 MPa has not progressed compared to the body structural parts. The reason for the remaining strength in suspension parts is attributed to the lack of definitive technical solutions to the difficult problems of decreased rigidity accompanying gauge reduction, securing a corrosion allowance, the fatigue strength of welded joints, etc., which are different from upper body structural parts. Nevertheless, with the development of technologies for suppressing slag generation in arc welding and controlling the shape of the weld metals, etc., JFE steel Corporation continues to find new solutions to those problems.

In Fig. 3, it was mentioned that the use of high strength steel sheets for cold-stamping had started. In the HS process, high strength is also obtained by heating a sheet to a high temperature and pressing the sheet with a die. Although the HS process is able to obtain a good shape more easily, it involves issues that are different from those in cold-stamping of high strength steel sheets. **Table 1** shows the issues both of the cold-stamping process and of the hot-stamping process.[5] In the cold-stamping process, the issues are: (1) forming of low ductility steel sheets, (2) increase in the press load accompanying high strength and (3) remarkable increase in springback. The issues arising in the HS process are: (a) production efficiency, (b) piercing (shearing/cutting method), (c) shape constraints, (d) anti-corrosion property, (e) ductility after forming and (f) guarantee strength. It should be noted that liquid metal embrittlement (LME) in spot welding [6], delayed fracture and die life are common issues of the two processes.

In LME, the penetration of zinc into the grain boundaries in the matrix of the steel at the heat affected zone by resistance spot welding is sometimes observed in Zn-coated steel sheets[6]. The LME occurs when high tensile stress is applied to the steel under the melted zinc coating during the resistance spot welding process. To prevent these phenomena, technical development in both steel sheets and welding methods is required.

Table 1 Issues of steels applying to automotive parts[5]

Press	Issue	Technique
Cold stumping	(1) Press formability	Development of high ductility steels
	(2) Press load	Process analysis
	(3) Spring-back, (Twist and camber)	Change in press sequence
	(4) Welding/LME	Leaser welding, Change in spot welding conditions
	(5) Delayed fracture	Defense of hydrogen, sharing method, improvement of microstructure
	(6) Galling/Die life	Hardening method
Hot stumping	(a) Production efficiency	Cooling method of die
	(b) Piercing	Hot piercing, Laser cutting
	(c) Shape constrains	Indirect hot stamping
	(d) Anti-corrosion property	Development of anti-corrosion plate
	(e) Ductility of parts	Development of new steels
	(f) Welding/LME	Leaser welding, Change in spot welding conditions
	(g) Delayed fracture	Defense of hydrogen, sharing method, improvement of microstructure
	(h) Galling/Die life	Release of the adhesive metal
	(i) Strength ensuring	Guarantee of strength

4. Manufacturing Method and Features of Automotive High Strength Steel Sheets

Figure 4 shows the thermal history of producing high strength steel sheet in a continuous annealing line (CAL)[7–9]. In the CAL, rolling oil on the cold-rolled sheet is removed and heated to the ferrite-austenite region or austenite region. In the case of reheating to the ferrite-austenite region, ductility is recovered by recrystallization of the ferrite, and the austenite forms martensite in the subsequent quenching process. There are several cooling techniques from high temperature: roll quench cooling, gas jet cooling and water quenching. Among these techniques, water quenching is the most superior process for manufacturing low alloy high strength steel sheets, as it realized the fastest cooling rate and uniform cooling in the sheet. The martensite generated by quenching is then tempered by reheating, and hardness is adjusted simultaneously with the appearance of toughness. This technology makes it possible to manufacture dual-phase (DP) high strength steel sheets in which the martensite secures strength whereas the ferrite provides formability. Moreover, it is possible to promote the bainite transformation and retained austenite by austempering at 500°C or less. Steel that contains the retained austenite exhibits large elongation by the TRIP effect (TRIP: TRansformation Induced Plasticity). However, in order to retain a large quantity of austenite, large amounts of Si and Mn are added to prevent cementite from being generated. Moreover, to achieve higher strength such as 1320 or 1470 MPa grade, the austenite fraction should be

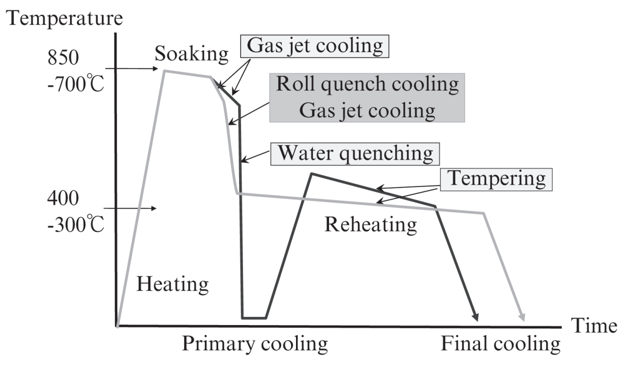

Fig. 4 Thermal history of continuous annealing line

increased by adding austenite forming elements and in the annealing process with higher temperature.

JFE Steel Corporation is actively engaged in the development of technology applications for various high strength steel sheets. The following presents a brief review of the newly developed high strength steel sheets.

4.1 High Strength Cold–Rolled and Galvannealed Steel Sheets for Panels (440BH)

Figure 5 shows the change in the yield strength of BH (bake-hardening) steel sheets for automotive panels. These steel sheets show work hardening as a result of press forming and hardening by aging due to the heat of paint baking. In press forming, excellent surface quality can be obtained by lowering yield strength (0.2% poof stress). In comparison with the conventional 340 BH and general 440 W steel sheet, the yield strength of 440 BH is lower than that of 440 W and approximately the same as that of 340 BH, while the yield strength of 440 BH after paint baking is higher than that of 340 BH and approaches that of 440 W. Considering dent resistance is proportional to the 1/2 power of thickness, the reduction of the thickness of 0.05mm can be obtained by utilizing 440 BH steel instead of 340 BH steel. The low yield strength of 440 BH steel is attributed to the small amount of martensite in the ferrite matrix[10].

However, rigidity is not improved by applying high strength steel since rigidity is determined only by the sheet thickness and Young's modulus. Therefore, JFE Steel also developed a new technology for improvement of the rigidity of panels and provides solution technologies of light weight high performance panel parts[11, 12].

4.2 Cold–Rolled Steel Sheets for Structural Parts

In structural parts, high formability is necessary in order to prevent in-plane cracking of steel sheet and cracking from sheared edges when manufacturing automotive parts. These properties of high strength steel sheets can be expressed by elongation and the hole expanding ratio. Elongation (EL: %) is an index of formability when a steel sheet is formed in a bulge shape (called stretch forming or bulge forming). The hole expanding ratio (λ: %) is an index of the formability of the sheared edge of a steel sheet and presents as the amount of increase in the hole diameter after the punched hole is expanded until a crack occurs through the sheet thickness. With both indexes, higher values indicate higher formability.

JFE Steel realized steel sheets with high formability for the stretch forming and flange forming by fine microstructure control and completed a lineup tradenamed JEFORMA™. **Figure 6** shows the concept of JEFORMA™ lineup. Type 1 has higher elongation (EL) than the general type steel sheet and realizes excellent stretch forming (deep drawing). Type 2 has a higher hole expanding property (λ) than Type 1 and enables excellent stretch flangeability. Type 3 realizes higher elongation than Type 1, and deeper drawing is available. This lineup is developed in order to realize complex automobile parts.

4.3 Surface Treatment for Improved Formability

The elongation of high strength steel is unavoidably lower than that of low strength steel. A high lubricity, hot-dip zinc-coating (JAZ™) was developed[13] as a technology that compensates for the reduced formability caused by the lower elongation. JAZ™ is a high lubricating film that was developed to improve the formability of mild steel. It is already widely used and can also be applied effectively to high strength steel sheets. **Figure 7** shows the stretch forming property of galvannealed high strength steel sheets with JAZ™. In the relationship between the elongation of steel sheets and spherical stretch forming height, the stretch forming height increases linearly as the elongation of the steel sheets increases. The stretch forming height of the

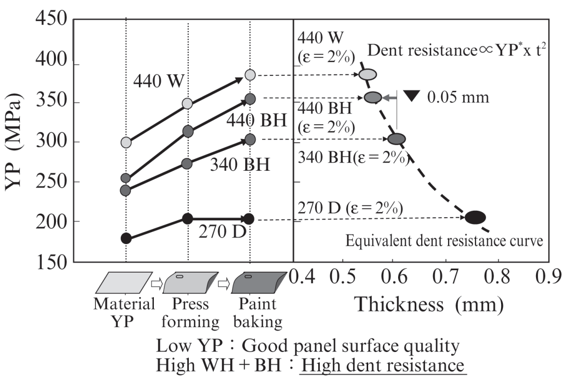

Fig. 5 Reduction of sheet thickness by increase in yield strength of 440BH after bake handering

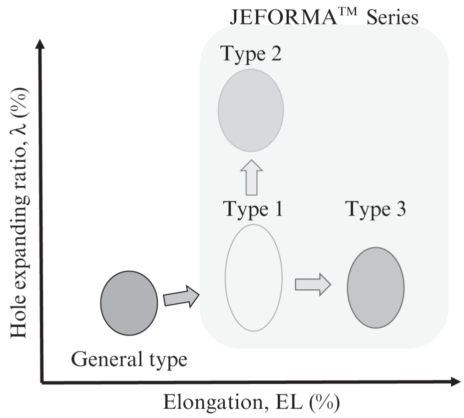

Fig. 6 Schematic illustration showing concept of JEFORMA™

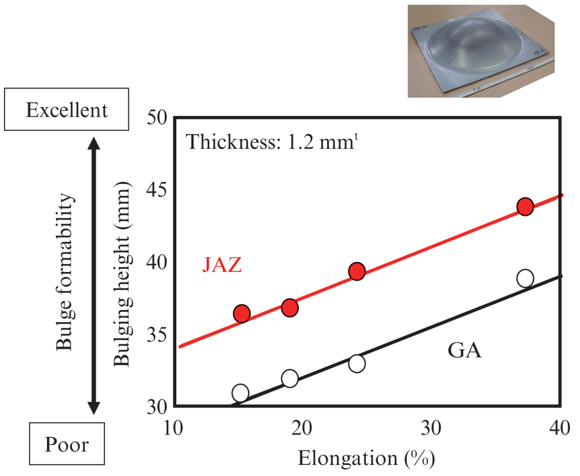

Fig. 7 Effect of JAZ™ on bulge forming height of high strength steels

galvannealed hot-dip zinc-coated steel sheets with JAZ™ is higher than that without JAZ™. Because the high lubricating film reduces frictional resistance with die, even when forming high strength steel sheets, it is possible to obtain higher stretch formability than that expected from the elongation of the steel sheet. Thus, JAZ™ is an effective surface treatment for improving formability of high strength steel sheets.

5. Conclusion

In response to the stricter regulations in the future, the strength of steel sheets has increased in the last 10 years. However, with the large trend toward EVs, higher performance will be required in automotive structures. In order to realize the high requirements industrially, social expectations will be on high strength and high ductility steel sheets with a better LCA. In the future, JFE Steel will continue to work energetically to develop new high performance high strength steel sheet and technologies.

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