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Cold-Rolled and Galvannealed (GA) Ultra-High Strength Steel Sheets for Automobile Structural Parts

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Abstract:

JFE Steel has developed and commercialized a variety of cold-rolled and galvannealed (GA) high strength steel sheets which significantly contribute to weight reduction of automobiles. In order to reduce the thickness of automotive parts through the application of 980 MPa or higher grade ultra-high strength steel sheets, it is necessary that they have the same level of press formability to that of lower strength steels. In addition to increase the elongation of ultra-high strength steel sheets, it is important to improve the stretch-flangeability, depending on manufacturing processes and part shapes. It is also necessary to consider the spot weldability and delayed fracture properties. These problems associated with ultra-high strength steel sheets have been solved by sophisticated microstructure control technology and unique manufacturing processes. Based on reasonable material design, ultra-high strength steel sheets have been commercialized for automotive structural parts. These cold-rolled and GA ultra-high strength steel sheets, which lined-up as JEFORMA™ series, provide excellent formability. The application of these steel sheets is expected to be further increased in the future.

1. Introduction

Development and application of high strength automotive steel sheets for the purpose of satisfying both reduction of CO_2 emissions by weight reduction of automobiles and improvement of crashworthiness by increasing car body strength are progressing steadily, and a series of new laws and regulations have also been introduced. To meet these requirements, ultra-high strength steel sheets of tensile strength (TS) 980 MPa grade and higher are increasingly used in the main structural parts of the automobile cabin in order to increase car body strength. Conventionally, these ultra-high strength steel sheets had been used only in reinforcement parts with simple shapes, but recent years have seen expansion to structural parts with complex shapes, and this has heightened the need for ultra-high strength steel sheets with excellent formability.

JFE Steel Corporation made practical application of the continuous annealing line[1–4], which is indispensable for manufacturing ultra-high strength steel sheets, and commercialized ultra-high strength steel sheets ahead of the times. Since then, JFE Steel has also improved the elongation, stretch-flangeability, bendability and other formability properties of ultra-high strength steel sheets which are necessary to expand their application, and has developed steel sheet products with the various types of formability needed in application to automotive parts[5–11]. Moreover, when ultra-high strength steel sheets are applied to underbody parts, a galvannealed zinc coating is essential for securing high corrosion resistance. To address this need, the company has also commercialized ultra-high strength galvannealed (GA) steel sheets[11, 12]. At present, various types of cold-rolled and GA steel sheets of 980 MPa to 1 180 MPa grade are used in actual automotive parts and are making an important contribution to weight reduction and high strength in car bodies[13].

This paper first presents an overview of material

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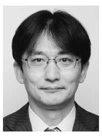

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design for imparting various excellent properties to ultra-high strength steel sheets, beginning with high elongation, and then introduces JFE Steel's product line of high formability high strength steel sheets (JEFORMA™), for which the company offers as a product series to enable customers to select the optimum steel sheet corresponding to the elongation, stretch-flangeability and other formability requirements of each part. The features of the respective products and examples of application are also discussed.

2. Material Design of Ultra–High Strength Steel Sheets for Automobile Structural Parts

2.1 Properties Required in Automobile Structural Parts

When using ultra-high strength steel sheets, the process of plastic forming to a specified shape by press forming and assembly into a car body by resistance spot welding is unchanged from the past. Thus, as in the case of conventional steel sheets, excellent formability and spot weldability are also demanded in ultra-high strength steel sheets as materials for automobile structural parts. In addition, although resistance to delayed fracture and resistance to LME (Liquid Metal Embrittlement) during spot welding were not considered problems with low strength steel sheets, these properties are also increasingly required in steel sheets with higher strength levels.

Where press formability is concerned, the most necessary steel sheet property varies depending on the shape of the applied part and the forming method. For example, steel sheets with high elongation are applied in parts in which the main forming method is stretch forming, as in the box-shaped part of the center pillar lower, while steel sheets with excellent stretch-flangeability are suitable for the flange part of the center pillar upper. The hole expansion ratio (λ) obtained by the hole expanding test (JIS Z 2256) is generally used as an index of stretch-flangeability[14]. If both elongation and stretch-flangeability can be improved while maintaining an appropriate balance of the both properties, a large increase in the degree of freedom in formability can be expected.

In forming of parts, dimensional accuracy is a critical issue, on the same level as whether forming is possible without fracture or cracks. Deformation due to springback occurs when shape constraints are released after press forming of a steel sheet, and the decreased dimensional accuracy of the part due to springback reduces production efficiency in the following car body assembly processes. Since springback is caused by the release of the elastic deformation component generated during forming, higher strength sheets are disadvantageous, as they display larger flow stress during working. To maintain the same dimensional accuracy as with conventional steel sheets in parts in which ultra-high strength steel sheets are applied, together with forming technology[15], it is also essential to suppress springback of ultra-high strength steel sheets.

Because many parts used in automobile bodies are assembled by spot welding, proper spot welding of ultra-high strength steel sheets with various steel sheets is required. If addition of alloying elements is increased in order to achieve higher strength, fracture toughness decreases due to excessive hardening of the weld metal, and in some cases, the strength of the welded joint is reduced by fracture in the nuggets[16]. Thus, in ultra-high strength steel sheets, a low carbon equivalent (C_{eq}) composition design that reduces the amount of alloying elements to the minimum necessary to achieve the required strength is essential.

One concern which is peculiar to ultra-high strength steel sheets is delayed fracture due to absorption of hydrogen into the steel sheets. This is a brittle fracture phenomenon caused by the hydrogen which evolves in the corrosion reaction that proceeds under the automobile use environment, and it is generally thought that susceptibility to delayed fracture increases significantly when the tensile strength of steel sheets reaches a level that exceeds 980 MPa. Recently, moreover, the occurrence of intergranular cracking (LME crack) due to diffusive intrusion of zinc from the Zn coating layer into grain boundaries at the steel sheet surface has been confirmed when spot welding of ultra-high strength Zn-coated steel sheets was performed[17–19]. Because the same type of cracking can also occur in ultra-high strength cold-rolled steel sheets, which do not have a coating layer, if the welded joint includes a Zn-coated sheet, LME is viewed as a problem in all types of ultra-high strength steel sheets. Thus, when applying ultra-high strength steel sheets to automobile structural parts, it is also necessary to consider delayed fracture in the use environment and LME cracking depending on the combination of steel sheets being welded.

2.2 Guidelines for Improvement of Elongation

Because ultra-high strength steel sheets for use in press forming must have a good total balance of properties such as strength, formability, weldability, etc., the main stream is DP (Dual Phase) steel sheets which have a dual-phase structure consisting of a soft ferrite phase and a hard martensite phase. With expanded application of ultra-high strength steel sheets to structural parts in recent years, steel sheets with higher elongation than DP steel sheets are now strongly required. Since

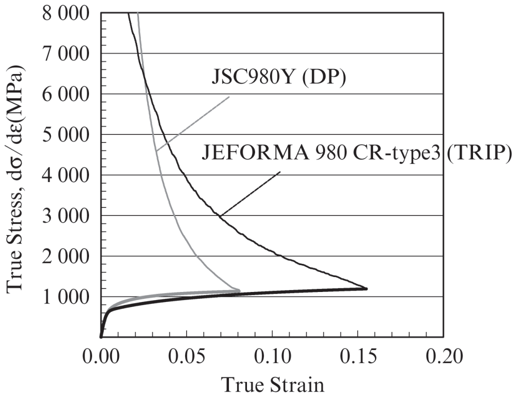

Fig. 1 Stress-strain curve of JSC980Y (DP) and JEFORMA 980CR-type3 (TRIP)

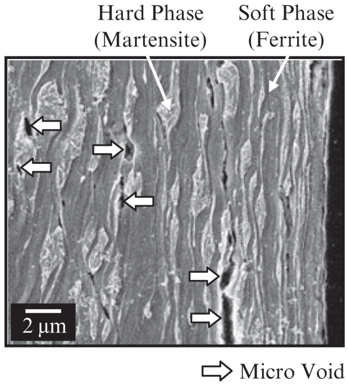

Photo 1 Microstructure at the punched edge of conventional DP steel

use of the TRIP (TRansformation Induced Plasticity) effect of retained austenite is an effective solution for this need, development of ultra-high strength TRIP steel sheets with a composite structure that contains retained austenite is being promoted.

TRIP steel sheets are produced by heating and holding the steel sheet in the $\alpha + \gamma$ intercritical region or in the γ single-phase region in the annealing process after cold rolling, followed by austempering, in which the steel sheet is cooled to the bainite transformation region and held. During this austempering process, the stability of the austenite is increased by promoting discharge of solid-solution C from the transformed phase to the untransformed austenite, thereby increasing the C concentration in the austenite. It is possible to realize higher elongation in comparison with conventional DP steel sheets because this stabilized austenite is retained until room temperature and the TRIP effect is effectively demonstrated during deformation (**Fig. 1**). Moreover, in order to stabilize the elongation of TRIP steel sheets at a high level in ultra-high strength steel sheets, which have a large content of alloying elements, control of not only the amount of retained austenite and amount of C in the retained austenite, but also the partition of Mn and Si[20] between the ferrite and austenite phases during annealing in the $\alpha + \gamma$ intercritical region is also a key factor governing the elongation.

2.3 Guidelines for Improvement of Stretch–Flangeability

Since some automobile structural parts have complex shapes that include a mixture of stretch forming parts and stretch-flange forming parts, improvement of these properties is required when applying ultra-high strength steel sheets to such structural parts with complex shapes. Here, stretch-flange forming refers to a forming mode in which the flange length is extended so that the edge of a flat sheet is raised. The main controlling factor for stretch-flangeability is the ease of initiation and propagation of cracks when tensile stress is applied to the punched edge of the steel sheet. Flange parts of steel sheets normally undergo shearing. Therefore, when a dual-phase steel sheet is used, the micro voids shown in **Photo 1** form at the interface between the soft phase and hard phase at the sheared edge, and these micro voids become a cause of cracking during flange forming. It is known that, at this time, the stress concentration at the phase interface can be reduced and the hole expansion property of the dual-phase steel sheet can be improved by reducing the hardness difference between the phases that make up the DP

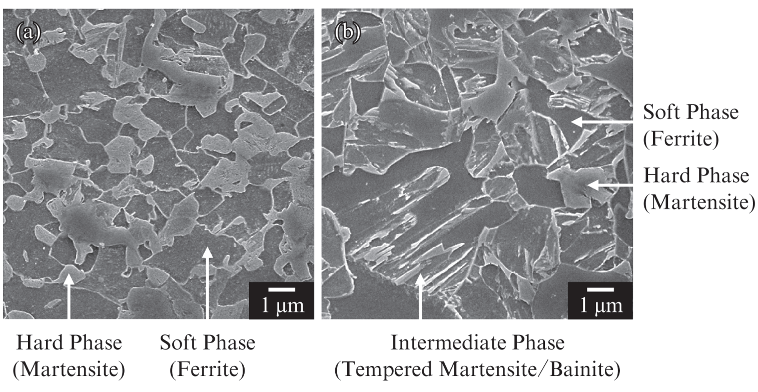

Photo 2 Microstructures of JSC980Y and JEFORMA 980CR-type2

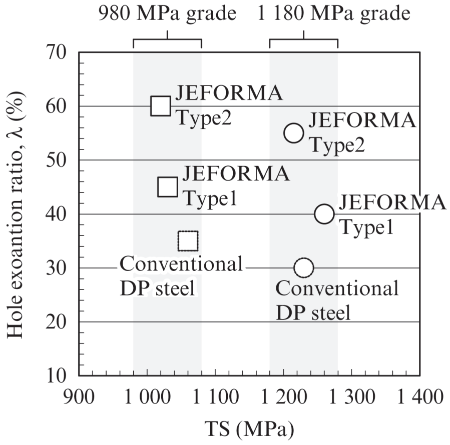

Fig. 2 TS-λ balance of conventional DP, high Eltype (JEFORMA Type1) and high El-high λ type (JEFORMA Type2) steels

steel sheet[21, 22]. Thus, it is considered possible to suppress the formation of micro voids at the interface between the soft phase and the hard phase by using a complex phase structure containing a third phase, or intermediate phase, with strength and ductility between those of the soft phase and the hard phase, as shown in **Photo 2**(b). As shown in **Fig. 2**, high stretch-flangeability can be achieved even in ultra-high strength steel sheets, by creating this kind of new complex phase structure.

2.4 Maintaining Spot Weldability

In composition design for achieving both ultra-high strength and high elongation in steel sheets, increased addition of alloying elements is unavoidable. Because the hardness of martensite depends on the content of C, 0.15 mass% of C or more is frequently added to ultra-high strength steel sheets, and the carbon equivalent increases together with other alloying elements. In this case, reduced welded joint strength is a concern under normal spot welding conditions. Reduction of impurity elements such as P and S, which adversely affect joint strength, is a possible measure based on the steel composition, but since there are limits to that approach, some other solutions are also necessary.

Welding-based measures include control of the fracture toughness and hardness distribution of the nuggets. A new current pattern utilizing a pulsed current was designed to optimize these properties. This technique, called Pulse Spot^{TM} welding[23], is effective for securing joint strength. Pulse Spot^{TM} welding is a spot welding technology utilizing repeated application of cooling and a pulsed current pattern having high current conduction with short periods after the main current for nugget formation. Because the pulsed current pattern enables effective reheating treatment of the area around the nuggets, improvement of joint strength is possible, even with ultra-high strength steel sheets with a high C content. As spot welded joint characteristics on the same level as those with conventional steel sheets are frequently required when ultra-high strength steel sheets are applied to automotive parts, JFE Steel proposes customer solutions which include state-of-the-art welding technologies.

2.5 Prevention of Delayed Fracture

In ultra-high strength steel sheets of 1 180 MPa grade and higher, delayed fracture during use is a concern[24]. Delayed fracture is an embrittlement and fracture phenomenon of steel which is caused by hydrogen absorbed into the steel. During the 1960s and 1970s, delayed fracture occurred in F11T bolts (TS 1 100 MPa grade) and F13T bolts (TS 1 300 MPa grade) for bridges. Although no cases of delayed fracture during the use period have been reported in automotive steel sheets to date, it is necessary to consider prevention of delayed fracture in order to expand the application of ultra-high strength steel sheets to automobile parts.

There are three controlling factors for the occurrence of delayed fracture in parts produced by press-forming steel sheets: strain introduced by working, tensile residual stress due to working and the applied tensile stress associated with assembly of the car body, and the diffusible hydrogen content absorbed from the use environment. A limit diagram for the delayed fracture susceptibility of a steel sheet can be prepared by using a space in which the coordinate axes represent the respective elements of strain, tensile stress and diffusible hydrogen content, by confirming whether delayed fracture of the steel sheet occurs under conditions corresponding to various coordinate positions, and mapping the results[25]. When applying ultra-high strength steel sheets to parts, it is necessary to confirm in advance that the part to which the steel sheet is to be applied and its use environment are on the safe side of the limit line or limit plane. It is thought that expanded application of ultra-high strength steel sheets can be encouraged by incorporating appropriate safety factors based on judgments by this kind of mapping.

In actual automotive parts, press forming is performed after blanking the base material steel sheet by shearing, without performing face grinding or other mechanical processes. In the shearing process, the sheared edge is subjected to plastic forming until fracture occurs. Therefore, among the three above-mentioned factors, strain and stress reach extremely high levels in the sheared edge, and as a result, the sheared edge is an extremely disadvantageous weak part from the viewpoint of delayed fracture. In order to evaluate the delayed fracture behavior of ultra-high strength steel sheets under a more realistic environment, JFE

Steel investigated the hydrogen embrittlement resistance in the vicinity of the sheared edge[26] and developed a hydrogen absorption monitoring system that enables quantitative evaluation of the amount of hydrogen absorbed in steel sheet due to corrosion under an actual vehicle environment[27].

In order to prevent delayed fracture of ultra-high strength steel sheets, a material design which reduces the inclusions and impurity elements that cause delayed fracture to the absolute minimum, and at the same time, a quantitative understanding of the risk of delayed fracture in the application environment of ultra-high strength steel sheets are both important. Therefore, JFE Steel is promoting study toward the establishment of design guidelines for automotive parts which avoid delayed fracture of ultra-high strength steel sheets, including application technologies for limiting plastic strain and residual stress to within the safe range.

2.6 Prevention of LME Cracks

LME is a phenomenon in which embrittlement of a solid metal occurs when the solid metal is in contact with a liquid metal. In Japan, it is known that LME cracks have occurred during hot-dip galvanizing of high strength steel for power transmission steel towers[28], and research to prevent cracking due to LME has been carried out since the 1980s. In the case of automotive parts made from steel sheets, welding of Zn-coated steel sheets creates a condition in which dissimilar metals (solid steel sheet and molten zinc) coexist. Since it is thought that susceptibility to LME increases in ultra-high strength steel sheets accompanying their higher strength and higher alloy composition, preventing LME cracks is one of the most critical issues.

In recent years, much research has been done on LME cracks in automotive steel sheets, and it has been reported, for example, that cracks caused by LME occurred in the heat affected zone (HAZ) in spot welds of ultra-high strength Zn-coated steel sheets under a condition in which the angle of the electrode axis was misaligned with respect to the perpendicular direction of the steel sheet[17]. If misalignment of the electrode angle exists during welding, flexural stress is generated in the steel sheet between the electrodes, and compressive stress acts on the HAZ, which has a designated positional relationship. If molten Zn is present, it is estimated that LME cracking will occur when the electrodes are released and the tensile stress generated by the recoil of the steel sheet acts on the compressed HAZ[18].

The controlling factor for LME cracking in spot welds of ultra-high strength steel sheets are thought to include material-related factors such as the strength, microstructure and alloy composition of the steel sheets, the melting point of the Zn coating layer, etc., and also factors related to the welding conditions, such as the magnitude of the above-mentioned tensile stress which is generated when the electrodes are released after welding. It has been found the increasing the electrode force holding time is effective[19] for suppressing LME cracks in spot welds. In order to avoid LME cracks, suppression measures in the welding process have been proposed simultaneously with optimization of the above-mentioned factors.

3. Recent Ultra-High Strength Steel Sheet Products

3.1 High Strength Steel Sheets with Excellent Formability Series

JFE Steel has created a series of high strength steel sheets with excellent formability for use in automotive parts under the tradename “JEFORMA™.” The high strength steel sheets in the JEFORMA™ Series are classified in three types, a high El type with higher elongation than conventional steel sheets (Type 1), a high El-high λ type with high elongation and stretch-flangeability (Type 2) and a super- high El type with even higher elongation than the high elongation (Type 3). The line-up includes 590, 780, 980 and 1 180 MPa grades of both cold-rolled steel sheets and GA steel sheets. In particular, this paper presents details of the 980 MPa and 1 180 MPa grade products.

3.2 Ultra-High Strength Cold-Rolled Steel Sheets

3.2.1 Product line-up of ultra-high strength cold-rolled steel sheets

In addition to the conventional DP type, JFE Steel has commercialized cold-rolled steel sheets of both the 980 MPa and 1 180 MPa grades in the above-mentioned three types in the JEFORMA™ Series.

The steel sheets classified as the high El type are based on a conventional ferrite-martensite dual-phase (DP) steel sheet and have a microstructure design that secures elongation with the soft ferrite phase and strength with the hard martensite phase. DP steel sheets are manufactured by quenching after annealing in the $\alpha + \gamma$ intercritical region to transform austenite into martensite. As annealing equipment suitable for manufacturing this kind of DP steel sheets, JFE Steel uses the water quench process in the continuous annealing line (WQ-CAL). Because water quenching enables uniform cooling at a rapid cooling rate, it is possible to produce steel sheets with excellent spot

Table 1 Mechanical properties of cold-rolled ultra high strength steel sheets of JFE Steel

TS grade	Type	Name	Mechanical properties				Development stage
			YS (MPa)	TS (MPa)	El (%)	λ(%)	
980	Conventional DP	JSC980Y	690	1 060	14	35	Commercial production
	High El (DP)	980CR-type1*	750	1 030	15	45	Commercial production
	High El-high λ	980CR-type2*	820	1 020	16	60	Developed
	Super high El (TRIP)	980CR-type3*	640	1 030	23	30	Commercial production
1 180	Conventional DP	JSC1180Y	890	1 230	10	30	Commercial production
	High El (DP)	1 180 CR-type1*	910	1 260	12	40	Commercial production
	High El-high λ	1 180 CR-type2*	1 060	1 215	15	55	Developed
	Super high El (TRIP)	1 180 CR-type3*	950	1 240	16	40	Commercial production
1 320	–	–	1 160	1 330	7	50	Developed
1 470	–	–	1 270	1 510	7	40	Developed

*JEFORMA series
YS: Yield strength TS: Tensile strength El: Elongation
λ: Hole expanding ratio TRIP: Transformation Induced Plasticity

weldability as a result of a low carbon equivalent design and high material property stability with minimal strength variations. High El type DP steel sheet products are used as the base material for steel sheets with excellent formability for automotive parts and are already applied to a large number of automotive parts.

High elongation steel sheets with extremely high elongation utilizing the TRIP effect of retained austenite are classified as the super- high El type. This type of steel sheet has higher elongation than high El type DP steel sheets and is being developed targeting a larger number of automotive parts, namely, parts with more complex shapes with which application of ultra-high strength steel sheets was difficult.

TRIP steel sheets that contain retained austenite are manufactured through a process of holding in the bainite transformation temperature region of around 400°C in the cooling process following annealing, as it is necessary to concentrate alloying elements in the austenite phase during annealing and stabilize the austenite until room temperature. JFE Steel manufactures these steel sheets by using the gas jet cooling process in the continuous annealing line, which enables accurate control of the thermal history of cooling after holding in the annealing process, making it possible to produce products with excellent mechanical property and shape stability.

Products which have high stretch-flangeability in addition to high ductility are classified as high El-high λ type steel sheets. Conventionally, there was a strong contradiction between the product design principles of high El type steel sheets, which prioritize uniform elongation in practical use, and high λ type steel sheets with high stretch-flangeability, which has a strong correlation with local elongation, and for this reason, it was considered difficult to satisfy both high ductility and high stretch-flangeability simultaneously. JFE Steel succeeded in commercializing steel sheets that simultaneously satisfy both high ductility and high stretch-flangeability in ultra-high strength steel sheets by optimizing the phase composition and distribution of those phases in complex phase steels, together with the alloy composition, and realizing the ideal manufacturing conditions for achieving those properties. These products are used commercially as materials for automotive parts.

3.2.2 Mechanical properties and condition of development of ultra–high strength cold–rolled steel sheets

Table 1 shows JFE Steel's ultra-high strength cold-rolled steel sheets and their representative property values. In the 980 MPa class and 1 180 MPa class strength grades, JFE Steel offers a product line-up of three types of steel sheets with different property balances in addition to the low yield ratio (YR) type conventional steel grades, supporting the most appropriate use over a wide range corresponding to the needs of specific applications.

Super- high El type cold-rolled steel sheets are already in the mass production stage in both the 980 MPa class and 1 180 MPa class strength grades, and expansion of production volume is also foreseen in the future. In addition, commercialization of high El-high λ type cold-rolled steel sheet products has already been completed, and application to automotive parts in response to the requirements of customers is being studied.

1 320 MPa grade and 1 470 MPa grade steel sheets are steel sheets consisting of a single martensite phase and have the world's highest levels of strength as steel

Table 2 Mechanical properties of galvannealed (GA) ultra high strength steel sheets of JFE Steel

TS grade	Type	Name	Mechanical properties				Development stage
			YS (MPa)	TS (MPa)	El (%)	λ(%)	
980	Conventional DP	JAC980Y	630	1 030	14	25	Commercial production
	High El (DP)	980GA-type1*	650	1 020	18	30	Commercial production
	High El-high λ	980GA-type2*	800	1 020	16	60	Developed
1 180	Conventional DP	JAC1180YL	830	1 230	11	20	Commercial production
	High El (DP)	1 180GA-type1*	800	1 220	13	20	Commercial production
1 320	−	−	980	1 330	9	40	Developed
1 470	−	−	1 070	1 510	9	30	Developed

*JEFORMA series
YS: Yield strength TS: Tensile strength El: Elongation
λ: Hole expanding ratio TRIP: Transformation Induced Plasticity

sheets for cold forming. Fully utilizing the advantages of the WQ-CAL process, these products have excellent bendability and satisfactory weldability and delayed fracture characteristics, and are used as materials for automotive collision resistant parts.

3.3 Ultra-High Strength GA Steel Sheets

3.3.1 Product line-up of ultra-high strength GA steel sheets

In the car body, anti-corrosion performance is required in structural parts arranged below the beltline, mainly comprising the underbody, from the viewpoint of corrosion resistance. As materials for parts of this type, all Japanese-affiliated auto makers use GA steel sheets, which are produced by the hot-dip galvannealing process. Accordingly, ultra-high strength GA steel sheets are necessary for further weight reduction of anti-corrosion specification parts.

The side sill and floor cross member are representative examples of structural parts in which anti-corrosion performance is necessary. When high strength steel sheets are applied, the forming difficulty of these parts is low, as the parts have linear shapes, but as a distinctive feature, stretch-flangeability is required in many parts of these automotive components. As in the case of ultra-high strength cold-rolled steel sheets, a line-up of multiple types of products with different formability balances is desirable for expanding the applications of ultra-high strength GA steel sheets in various automotive parts.

3.3.2 Mechanical properties and condition of development of ultra-high strength GA steel sheets

In continuous galvanizing lines for GA steel sheets (CGLs), a molten zinc pot is generally installed in the cooling process after annealing, and immersion of the traveling strip in the zinc bath and alloying treatment (galvannealing) of the Zn coating layer are performed continuously. Accordingly, the cooling rate tends to be lower than in production of cold-rolled steel sheets, in addition to the interruption of cooling of the steel strip after annealing. Because it is necessary to form the required amount of a low temperature transformation phase even at a low cooling rate, increasing hardenability by increasing the amount of added alloying elements is indispensable in high strength GA steel sheets. However, increasing the amount of alloying elements not only decreases the weldability of the steel sheets but also deteriorates the wettability of the zinc and the reactivity of the Zn coating layer during galvannealing, and thus tends to deteriorate coatability. For this reason, it is more difficult to realize ultra-high strength in GA steel sheets than in cold-rolled steel sheets, and freedom of material design is also lower.

Under these restrictions, JFE Steel commercialized high El type and high El-high λ type ultra-high strength GA steel sheets in the 980 MPa grade and high El type GA sheets in the 1 180 MPa grade by making full use of a microstructure control technology that enables precise control of the microstructure of the steel sheets by an original heat treatment process. **Table 2** shows the line-up of these products. JFE Steel has also developed super high El type GA steel sheets in both strength grades and is conducting actual mill trials for commercialization. Moreover, as with cold-rolled steel sheets, the company has also completed development of 1 320 MPa grade and 1 470 MPa grade GA steel sheets with the aim of commercializing these materials as GA steel sheets for automotive parts for the first time in the world.

4. Examples of Applicable Parts

Practical application of the ultra-high strength cold-rolled steel sheets and GA steel sheets introduced

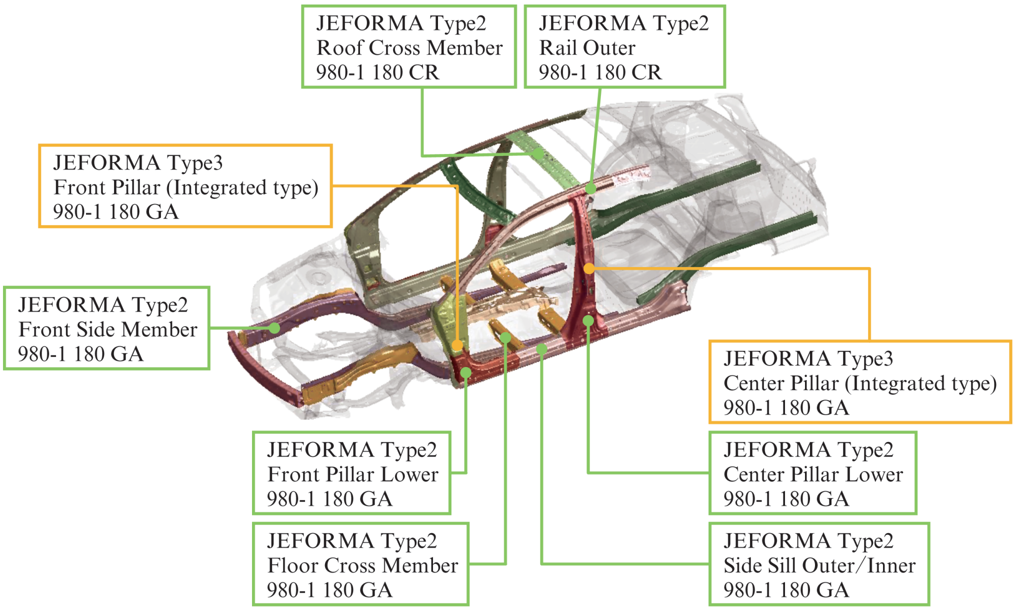

Fig. 3 Suitable parts for ultra high strength steel sheets of JFE Steel

Photo 3 A pillar upper reinforcement made of JEFORMA 1 180CR-type1

in the previous chapters as automobile structural parts is already progressing, centering on high El type products. As one example, **Photo 3** shows an A pillar upper reinforcement part produced using a 1 180 MPa grade cold-rolled steel sheet (JEFORMA 1 180 CR-type 1). An auto body weight reduction effect has been obtained in parts having shapes with comparatively low forming difficulty by substituting ultra-high strength steel sheets for the conventional material.

As materials for further auto weight reduction, application of high El-high λ type and super high El type products, which have higher formability, to next-generation vehicles to be commercialized in the 2020s is also being studied widely. Examples of the applicable parts for these ultra-high strength steel sheets are shown in **Fig. 3**. Although steel sheets of 590 MPa to 780 MPa grade are used in parts for current automobiles due to formability limitations, substitution of 980 MPa and higher grade steel sheets is assumed, and a number of auto makers are conducting evaluations with the aim of application in commercialized automobiles.

5. Conclusion

In an overview of ultra-high strength steel sheets for use in automobile structural parts, this paper has introduced the basic principles for realizing properties in cold-rolled steel sheets and GA steel sheets which achieve further improvements in formability, contributing to additional weight reduction of automobile bodies, together with the line-ups and features of the products and assumed examples of application. When actually applying these ultra-high strength steel sheets to automotive parts, it is necessary to solve not only problems in connection with press formability, but also a variety of related problems such as spot welding in the auto body assembly process, delayed fracture in the use environment, etc. While deepening its cooperation with customers, JFE Steel will propose comprehensive solutions which include application technologies, and will promote development with the aim of supplying steel sheets that contribute to the development of human- and environment-friendly advanced automobile bodies.

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