

Cold-Rolled and Galvannealed (GA) High Strength Steel Sheets for Automotive Cabin Structure[†]

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Abstract:

JFE Steel has developed and commercialized a series of cold-rolled and galvannealed (GA) high strength steel sheets which are suitable for automotive body structural parts. High strength steels are required a wide variety of strength grades and the superior formability, such as stretch-formability, stretch-flangeability and bendability, which meets a forming method and the shape of forming parts. Adequate spot-weldability and corrosion resistance after painting are also necessary for them. Besides, anti-hydrogen embrittlement property is important especially to those of higher tensile strength grade than 1 180 MPa. JFE Steel's sheet products for automotive body structural parts have met the various demands by optimal material design and precise process control with featured production facilities. Developed cold-rolled and GA high strength steels have been widely applied to great numbers of automotive parts and are expected to serve further weight reduction of car bodies in future.

1. Introduction

Recent trends in automotive steel sheets include the use of thinner gauge materials and weight reduction in order to reduce CO₂ emissions with the aim of protecting the global environment, and adoption of higher strength materials to improve vehicle crashworthiness. In particular, extremely high strength materials sufficient to prevent deformation during a collision are demanded for the cabin structural parts in order to protect the pas-

sengers. For this reason, steel sheets with tensile strength (TS) of 980 MPa and higher are frequently used in the cabin structure.

JFE Steel has developed continuous annealing equipment¹⁻³⁾, which is necessary in the manufacture of high strength steel sheets, and was among the first to commercialize and expand the use of ultra-high strength steel sheets in the 1970s⁴⁻¹⁰⁾. These materials were adopted successively in bumper reinforcement (bumper R/F) parts, door impact beam, seat frame, and body parts, and contributed to auto body weight reduction. Improvement of forming technologies utilizing FEM (Finite Element Method) analysis¹¹⁾, and the development of products with the optimized formability for the forming parts, such as elongation, stretch-flangeability, bendability, etc. of ultra-high strength steel sheets played a large role in expanding the application of these products. More recently, application of ultra-high strength steel sheets to underbody parts has also begun; as corrosion resistance is required in underbody parts, development and commercialization of high strength, high formability galvannealed (GA) steel sheets for this application is progressing¹²⁾.

This paper presents an overview of the design of the metal microstructure to impart various properties required in cold-rolled and GA high strength steel sheets, focusing on the JFE Steel series of cold-rolled and GA high strength steel sheets which are applied to the cabin structure of the automotive body. This is followed by an introduction of the features of JFE Steel's product lineup and respective products, together with

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examples of their use.

2. Concept of Material Design for Property Improvement

2.1 Necessary Features of Steel Sheets for Automotive Body

Based on the necessity of absorbing energy during collisions and protecting the automobile passengers, high strength steel sheets of TS590 MPa grade and higher are now mainly used in automotive body structural parts. The properties which are considered necessary in these steel sheets for automotive body structural parts are (1) formability, (2) spot-weldability, (3) corrosion resistance after painting, (4) resistance to hydrogen embrittlement fracture, etc.

Where formability is concerned, the necessary steel sheet properties depend on the forming method and the shape of the part in which the sheet is applied. For example, sheets with high elongation are suitable for press-formed parts in which stretch-forming is the main deformation mode, as represented by the center pillar, while sheets with both elongation and stretch-flangeability are suitable for parts which are manufactured by combined forming, i.e., a combination of stretch-forming and stretch-flange forming, such as front side members. Stretch-flangeability is generally evaluated by the hole expanding ratio (λ value) in the hole expanding test (The Japan Iron and Steel Federation Standard, JFS T1001-1996). Since crush forming, which mainly involves bending, is frequently applied to ultra-high strength steel sheets of 980 MPa grade and higher, appropriate bendability is necessary in order to prevent surface cracking of the steel sheets under severe bending forming. Bendability is evaluated by the ratio of the limiting bending radius, R , which is defined as the minimum bending radius without occurrence of cracks, and the sheet thickness, t (R/t).

Together with suppressing cracks and fracture, another critical issue in forming is the shape accuracy of parts. Springback occurs when high strength steel sheets are press-formed, and the poor shape accuracy of parts resulting from this phenomenon has a negative impact on the following assembly and welding processes. As a countermeasure for springback, auto makers design dies so as to compensate for springback in advance in the forming process. However, if there are large scattering of material strength values, deviations will occur in formed-part shape, and it will not be possible to solve the problem of shape accuracy. Accordingly, in order to improve the shape accuracy of parts, it is necessary to supply high strength steel sheets with minimal scattering of strength values.

Because many auto body parts are assembled by

spot-welding, appropriate spot-weldability is required in high strength steel sheets. As a problem in the spot-weldability of high strength steel sheets, if the amount of added alloying elements in the steel is increased to secure high strength, hardness of spot-welds will be excessive and ductility will be lost. In this case, weld strength against stress in the peeling mode, for example in the cross tension strength (CTS) test, will be reduced by fracture at the nugget¹³⁾. Thus, an alloy design with a low carbon equivalent is necessary in order to secure adequate weld strength. On the other hand, to secure ultra-high strength and high elongation characteristics, use of a high C steel is effective. When high C steel with a C content exceeding 0.15% is used, reduced weld strength is a concern in ordinary spot-welding, as mentioned above. Use of the newly-developed JFE Steel "Pulse Spot™ welding method"¹⁴⁾ in spot-welding is an effective solution to this problem.

To meet ever-increasing requirements for corrosion resistance in the automobile body, anti-corrosion steel sheets applying GA, etc. can be used in the underbody. Although cold-rolled steel sheets are normally used in the upper body, appropriate paintability and corrosion resistance after painting are required in the respective parts.

One concern when using ultra-high strength steel sheets of TS1180 MPa and higher is hydrogen embrittlement. This is a phenomenon in which hydrogen enters the steel in steel sheet production and automobile body manufacturing stages or during use due to corrosion, and diffused hydrogen in the steel causes delayed fracture, namely hydrogen embrittlement. In order to avoid hydrogen embrittlement, optimization of the material, and at the same time, use technologies that secure proper levels of strain by forming and residual stress, are considered necessary.

2.2 Improvement of Elongation (Work-Hardenability)

Total elongation, which is evaluated by the tensile test, can be divided into uniform elongation before occurrence of necking and local elongation after necking. Of these, because press-forming is generally performed within the range of uniform elongation, improvement of uniform elongation, i.e., work-hardenability is necessary. Based on the total balance of strength, formability, weldability, and other properties, the main stream in high strength steel sheets for forming applications is dual phase steels consisting of ferrite and martensite phases (hereinafter, DP steel).

The main factors of microstructure which influence work-hardenability in DP steel are the strength and volume fraction of the respective phases. Therefore, a fundamental study was carried out to separate these factors

of microstructure and investigate the influence of the each factor on work-hardenability¹⁵). **Figure 1(a)** shows the effect of the martensite fraction on tensile properties. When the martensite fraction is high, the work-hardening rate is high in the initial stage of deformation. However, since this property displays strain dependency, conversely, the work-hardening rate is low in the later stage of deformation. On the other hand, when the martensite fraction is low, the work-hardening rate is low in the initial stage of deformation, but a higher work-hardening rate is maintained until the later stage of deformation. **Figure 1(b)** shows the effect of the strength of the martensite phase. When the hardness of the martensite phase is high, the work-hardening rate increases over the entire strain region. The results of a detailed analysis of the microscopic deformation behaviors of these steels revealed that the average strain of the respective phases after 5% stretching increased in both the ferrite and martensite phases when the fraction of the martensite phase is high¹⁶). Based on this fact, when the martensite fraction is high, that is, when the ferrite fraction is low, it was estimated that strain concentrates on the soft ferrite phase, and this phase undergoes greater work-hardening. At the same time, deformation of martensite is promoted by the action of internal stress, and as a result, the material displays high work-hardening as a composite material in the initial stage of deformation. In the later stage of deformation, it is considered that the average strain increases in both phases, and as a result, the work-hardening capacity is reduced, resulting in a decrease in the total work-hardening rate. Furthermore, when the hardness of the martensite phase is high, it is thought that plastic deformation increases near the interface between ferrite and martensite phases. In this case, the density of geometrical necessary (GN) dislocations introduced as a result of this plastic deformation increases, and this also contributes to work-hardening through internal strain distribution in both phases¹⁷). In DP steels, a high balance of strength and elongation is

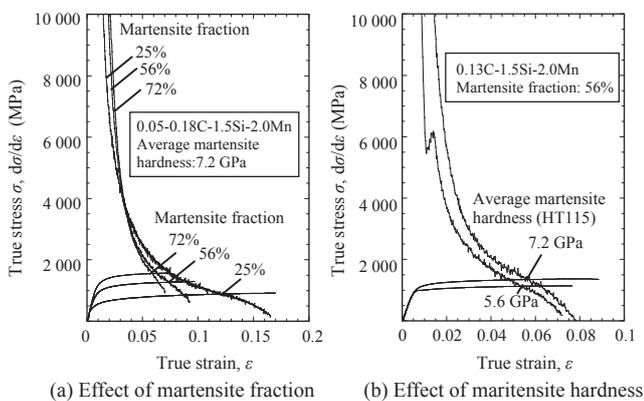


Fig. 1 Stress-strain curve and work-hardening rate of dual phase steels

achieved by controlling the fraction and strength of the martensite phase, utilizing the basic understanding described above.

Further improvement in work-hardenability can be achieved by use of transformation induced plasticity (TRIP phenomenon) by the retained austenite phase. The work-hardenability of TRIP steels is influenced by the stability of the austenite phase by concentration of C in the austenite phase¹⁸). JFE Steel has completed the development of 590 MPa grade and 780 MPa grade TRIP steel sheets with both cold-rolled steel sheets and GA steel sheets. In TRIP steels of 980 MPa grade and higher, consideration is necessary in order to secure spot-weld strength, as an increased C content in the steel is unavoidable.

2.3 Improvement of Stretch-Flangeability

One fracture mode which becomes a problem in press-forming of high strength steel sheets is stretch flange fracture. Since the main controlling factor in stretch flange fracture is the ease of crack propagation by the coalescence of microvoids generated at phase boundary, stretch-flangeability can be improved by increasing the uniformity of the microstructure. **Photo 1** shows a comparison of the condition of crack propagation in two different types of 980 MPa grade steel sheets with different stretch-flangeability. In the low λ steel shown in (a), a process was observed in which voids formed, mainly at the boundary between ferrite and martensite, and these ultimately coalesced to form a crack even under low strain. On the other hand, in the high λ steel, it was considered that formation of voids was suppressed due to the easily deformed martensite. As shown in **Fig. 2**, it has been clarified quantitatively that the stretch-flangeability of DP steels is controlled by the difference in the hardness of the ferrite and martensite phases, and stretch-flangeability improves as this difference decreases¹⁹). From the viewpoint of homogeneity of the microstructure, a single phase of martensite has

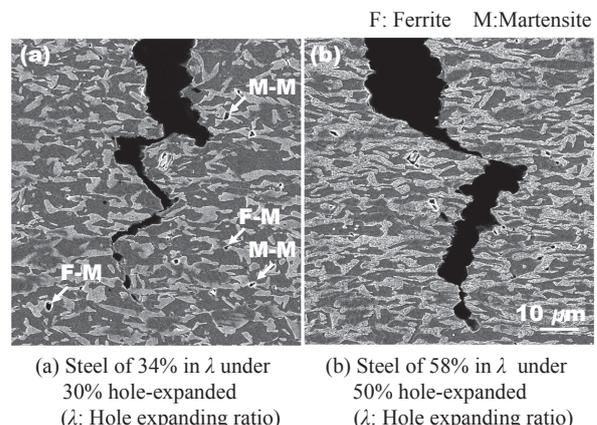


Photo 1 Microstructures beneath punched edge surface

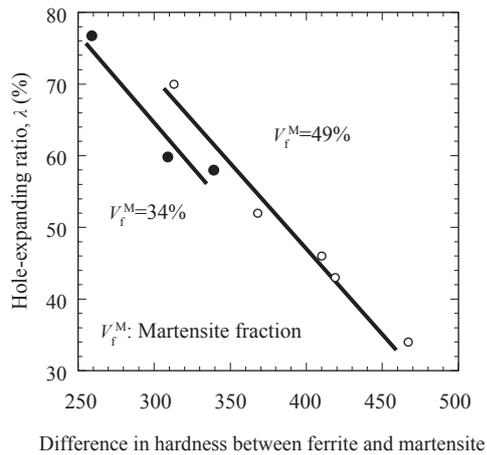


Fig. 2 Relationship between the difference in hardness between ferrite and martensite and hole-expanding ratio

the greatest superiority and thus displays extremely high stretch-flangeability.

2.4 Improvement of Bendability

The process which results in fracture in bending comprises the uniform elongation limit (necking limit), and the limit for development of fracture from this necking (fracture limit). The former is controlled by uniform elongation, and the latter, by the local elongation²⁰⁾. Accordingly, improvement of the balance of these two properties is considered necessary in order to improve bendability.

On the other hand, deformation is localized in bending forming in comparison with tension and stretch-flange forming. Thus, as a distinctive feature, bending is easily influenced by local inhomogeneity in material properties. The conceivable inhomogeneous material properties indicated here are distribution of a fibrous structure, nonmetallic inclusions, etc. elongated in the rolling direction. These inhomogeneous material properties, if present in a steel sheet, promote cracking in the direction parallel to the rolling direction. Therefore, JFE Steel uses a manufacturing method which considers the effects of these conditions when producing high strength steel sheets.

2.5 Hydrogen Embrittlement Property

Delayed fracture (hydrogen embrittlement) is a phenomenon in which embrittlement and fracture of the steel occur due to hydrogen entering the steel. During the 1960s and 1970s, there were cases in which high strength bolts (F13T: Withdrawal of Japanese Industrial Standards (JIS)) used in bridges failed as a result of this type of fracture. Although there have been no reports of hydrogen embrittlement failure of automotive steel sheets as of this writing, consideration to prevent delayed fracture is necessary responding to the recent

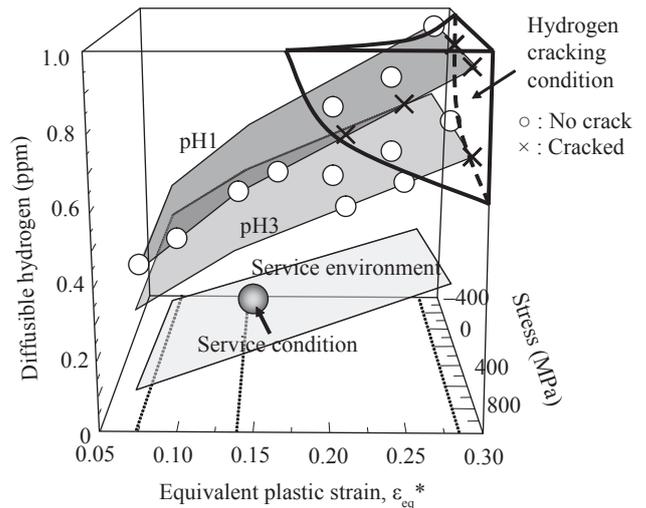


Fig. 3 Hydrogen cracking condition of a 1 180 MPa grade cold-rolled high strength steel

growing applications of ultra-high strength steels.

The controlling factors in hydrogen embrittlement are considered to be material-related factors such as strength, microstructure, etc., loading stress (applied stress), and diffusible hydrogen content. In the case of thin sheet products, the necessity of considering damage occurring in the forming process has been pointed out, and a material evaluation method using a 3-dimensional map of loading stress, plastic strain, and diffusible hydrogen was proposed²¹⁾. The conditions for occurrence of hydrogen embrittlement can be clarified experimentally by performing immersion tests with different plastic strain, applied stress, and HCl concentration conditions using U-bending bolt-tightened test pieces. JFE Steel has prepared 3-dimensional maps of this type for all ultra-high strength steel sheet products of 1 180 MPa grade and higher.

Figure 3 shows a map of the hydrogen embrittlement cracking conditions for a low yield ratio (YR) type 1 180 MPa grade cold-rolled steel sheet. Although hydrogen embrittlement occurs when any of stress, strain, or hydrogen is high, a quantitative evaluation of the risk of occurrence of hydrogen embrittlement is considered possible by fitting the conditions under which the steel is to be applied to this diagram²¹⁾. By clarifying the region of concern for hydrogen embrittlement, this is considered to provide guidelines for designing parts so as to avoid hydrogen embrittlement.

3. JFE Steel High Strength Steel Sheet Product Series and Their Features

3.1 High Strength Cold-Rolled Steel Sheets

3.1.1 Development concept

JFE Steel provides a line of products which includes

high YR type (precipitation strengthening steel), low YR type (DP steel), high ductility type (TRIP steel), high λ type (DP steel, martensitic steel), etc., responding to the strength and other properties required in high strength cold-rolled steel sheets.

JFE Steel's DP steels and martensitic steels are manufactured mainly using the continuous annealing line equipped with water quenching bath (WQ-CAL), and have the following features.

- (1) Line of TS780–1 470 MPa grade high formability steel sheets responding to needs for high strength and formability by precise microstructure control
- (2) Excellent spot weldability and resistance to hydrogen embrittlement by low C equivalent composition design
- (3) Excellent stability of material quality by uniform cooling by WQ and feed-forward control

With the WQ-CAL, the microstructural morphology (martensitic steel or DP steel) can be controlled utilizing the temperature conditions in annealing. Control of the volume fraction and hardness of the hard second phase over a wide range is also possible by optimizing the quenching and tempering temperatures, and as a result, it is possible to produce specific target material properties corresponding to a wide range of strengths and applications.

Using WQ-CAL, it has also become possible to secure strength and formability with minimized alloying elements, beginning with C. Thus, the fact that it is possible to maintain the soundness of welds, which had been a concern with ultra-high strength steel sheets, is also an important feature of the WQ-CAL technology.

Moreover, this technology is also effective for improving the hydrogen embrittlement property of martensite single phase type ultra-high strength steel sheets⁸⁾.

As another feature, the WQ-CAL is effective in improving the poor shape accuracy of products due to springback, which becomes an issue in press-forming of high strength steel sheets. Rapid and uniform cooling control suppresses scattering of strength within an individual coil, making it possible to obtain stable strength and material quality in both the coil longitudinal direction and transverse direction. Scattering of strength between coils is suppressed by steelmaking technology that controls the steel composition with high accuracy, and control of factors which cause strength variations in the integrated process from hot rolling through continuous annealing.

3.1.2 Product line

Table 1 shows JFE Steel's lineup of high strength cold-rolled steel sheet products.

In the TS590 MPa grade, which has been widely used up to now, JFE Steel has commercialized 3 types conforming to the Japan Iron and Steel Federation Standard, JFS A2001-2008.

As 780 MPa products, high λ type for use in seat frames, which require high stretch-flangeability, and low YR type for use in the auto body frame, which has drawability and stretch-formability, have been commercialized. For high elongation needs, TRIP type steel sheets utilizing the transformation induced plasticity of retained austenite have been commercialized.

Against the background of progress in forming tech-

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

TS grade	Type	JFS Standard	Mechanical properties					Application
			YS (MPa)	TS (MPa)	El (%)	λ (%)	R/t	
590	High YR	JSC590R	470	610	27	65	<1.0	All purpose
	Low YR	JSC590Y	390	640	31	50	<1.0	All purpose
	TRIP	JSC590T	420	610	36	75	<1.0	All purpose
780	Low YR	JSC780Y	500	810	22	50	<1.0	Cabin structure
	High λ	JSC780Y	600	830	19	80	<1.0	Seat frame
	TRIP	JSC780Y	520	840	27	35	<1.0	Cabin structure
980	Low YR	JSC980YL	610	1 010	17	30	1.0	Cabin structure
	El- λ balance	JSC980Y	740	1 020	16	45	1.0	Seat frame
	High λ	JSC980YH	820	1 030	14	60	<1.0	Seat rail
	Super λ	—	900	1 020	7	100	2.0	Seat frame (TOX applicable)
1180	Low YR	JSC1180Y	860	1 210	14	30	1.5	Door beam, Bumper R/F
	High λ	—	1 030	1 230	7	60	2.0	Bumper R/F
1320	—	—	1 160	1 330	7	50	2.0	Bumper R/F
1470	—	—	1 200	1 510	7	40	2.5	Pipe door beam

JFS: Japan Iron and Steel Federation Standard
 λ : Hole expanding ratio R/t: Radius/Thickness

YS: Yield strength YR: Yield ratio (YS/TS)

TS: Tensile strength

El: Elongation

TRIP: Transformation induced plasticity

R/F: Reinforcement

nology in recent years, high expectations are placed on 980 MPa as the strength grade which will become the main stream in high strength steel sheets for the auto body frame of the future. The 980 MPa grade has a long history of use and is widely applied to the bumper R/F, door impact beams, seat frames, and auto body frames. By application, mainly low YR is applied in auto frame applications. The low YR type not only has elongation and good bendability as types of formability required in steel sheets for the auto body structure, but also provides corrosion resistance after painting, spot-weldability, and other properties. In seat frame related parts, mainly the elongation (El)-hole expanding ratio (λ) balance type and the high λ type are applied. The ultra-high λ type is a type that was developed in order to apply the mechanical clinching method (TOX method) to assembly of seat frames, and has high local ductility, showing an extremely high hole expansion property. The features of this sheet provide excellent resistance to fracture under severe forming such as TOX clinching²²⁾.

In the 1 180 MPa grade, JFE Steel supplies low YR type and high λ type. Since the low YR type has high elongation for a product in this strength grade, and draw forming is also possible, door impact beams with the same performance as hot-stamped parts can be manufactured at high productivity by cold-forming^{23,24)}. Although hydrogen embrittlement is a concern at this and higher strength levels, this is avoided by the above-mentioned hydrogen embrittlement prediction technology, making it possible to apply these ultra-high strength sheets without problems.

The 1 320 MPa and 1 470 MPa grades, which are manufactured making maximum use of the features of WQ-CAL, possess the highest levels of tensile strength

(TS) among steel sheets in practical application. Bendability, satisfactory weldability, and resistance to hydrogen embrittlement are realized by adopting a martensite single phase microstructure. Mass production of these sheets for bumper R/F and steel tube door beams is continuing.

3.2 High Strength Galvannealed (GA) Steel Sheets

3.2.1 Design concept

In automobile cabin structural parts, simultaneously with the trend toward high strength materials, the use ratio of coated steel sheets is also increasing with the aim of extending the period of the corrosion life guarantee. GA steel sheets are widely used to meet this need, particularly because the manufacturing cost is low and heavy coating weights can be achieved easily, enabling production of sheets with high corrosion resistance. Corrosion resistance is also required in cabin structural parts for the cabin structure in parts positioned below the belt line. Therefore, high strength GA steel sheets are necessary in main structural parts such as side members, side sills, pillars, etc. As these parts are frequently difficult to press form due to the design shape of the automobile body, development of high strength steel sheets with both high strength and high formability has been desired. In response to this requirement, in addition to conventional high strength steel sheets, JFE Steel developed a line of high El type high strength GA products with improved stretch-formability, and a line of high El- λ type high strength GA steel sheets with improved local formability, e.g., stretch-flangeability, bendability, etc. In the high El type high strength GA product line,

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

TS grade	Type	JFS Standard	Mechanical properties					Application
			YS (MPa)	TS (MPa)	El (%)	λ (%)	<i>R/t</i>	
590	High YR	JAC590R	455	635	26	45	<1.0	All purpose
	Low YR (Conventional)	JAC590Y	385	620	29	45	<1.0	All purpose
	Low YR (High El)		395	615	32	60	<1.0	All purpose
	High El- λ	—	400	620	34	90	<1.0	All purpose
	TRIP	—	410	630	32	45	<1.0	All purpose
780	Low YR (Conventional)	JAC780Y	560	815	19	35	<1.0	Cabin structure
	Low YR (High El)		450	825	24	25	<1.0	Cabin structure
	High El- λ	—	640	815	24	80	<1.0	Cabin structure
	TRIP	—	450	800	26	25	<1.0	Cabin structure
980	Low YR (Conventional)	JAC980Y	705	1 015	15	25	1.5	Cabin structure
	Low YR (High El)		645	1 015	18	30	1.5	Cabin structure
	High El- λ	—	800	1 000	17	65	1.5	Cabin structure
1180	Low YR	—	870	1 200	9	40	2.5	Side sill, Door beam

JFS: Japan Iron and Steel Federation Standard YS: Yield strength TS: Tensile strength El: Elongation
 λ : Hole expanding ratio *R/t*: Radius/thickness YR: Yield ratio (YS/TS) TRIP: Transformation induced plasticity

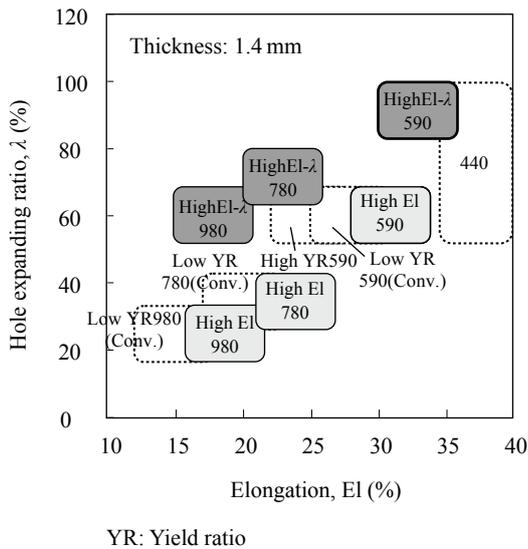


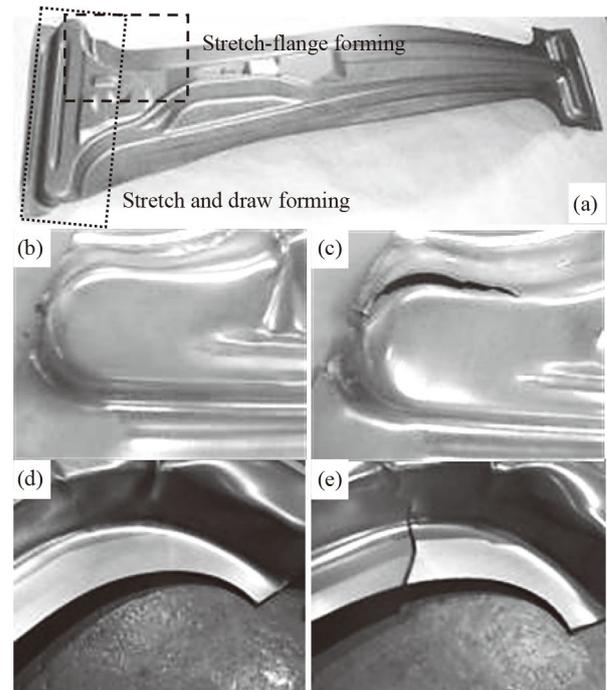
Fig. 4 The elongation and hole expanding ratio (λ) of a series of galvannealed (GA) high strength steel sheets

excellent ductility is achieved by increasing the work-hardening ability of the ferrite phase in the DP microstructure. In the high El- λ type high strength GA steel sheet line, in addition to increasing the work-hardening ability of the ferrite phase, the strength difference between the phases is reduced by optimizing the microstructure. As a result, local formability is increased, and stretch-flangeability and bendability are improved.

3.2.2 Product line

The lineup of high strength GA steel sheets supplied by JFE Steel is shown in **Table 2**. This product lineup includes low YR type (conventional), low YR type (high El), and high El- λ products which are suitable for various forming modes, covering a wide range of TS grades from 590 MPa to 1 180 MPa. The relationship of TS, El, and λ in these high strength GA steel sheets is shown in **Fig. 4**. The total elongation values of the high El type are on a level 3–5% higher than those of the conventional type, while showing ductility on substantially the same level as the conventional type at a TS level one grade lower. While maintaining ductility on the same level as the El type, the high El- λ type has a hole expanding ratio 40–50% higher than that of the conventional type, and the 590 MPa grade and 980 MPa grade display high stretch-flangeability comparable to that of the conventional 440 MPa and 590 MPa grades, respectively.

The following presents the results of a formability evaluation of the equivalent of an actual part using dies simulating the center pillar shown in **Photo 2**(a) for the conventional type, high El type, and high El- λ type steel sheets of the TS 980 MPa grade. **Table 3** shows the mechanical properties of the test materials. The effect of



(a) Appearance of press-formed parts and evaluated positions (b), (c) Stretch and draw forming, (d), (e) Stretch-flange forming, Steels press-formed: (b) Low YR(High El), (d) High El- λ , (c), (e) Low YR(Conventional)

El: Elongation λ : Hole expanding ratio YR: Yield ratio (YP/TS)

Photo 2 Press-forming results of 980 MPa grade galvannealed (GA) ultra high strength steels using experimental stamping tools of center pillar

Table 3 Mechanical properties of 980 MPa grade ultra high strength galvannealed (GA) steel sheets used for press-forming test

Type	YS (MPa)	TS (MPa)	El (%)	λ (%)
Low YR (Conventional)	680	1 020	15	25
Low YR (High El)	620	1 010	19	25
High El- λ	819	997	17	69

YS: Yield strength TS: Tensile strength El: Elongation
 λ : Hole expanding ratio YR: Yield ratio (YP/TS)

elongation was evaluated at the drawing and stretching combined forming position of the lower part of the center pillar, and stretch-flangeability was evaluated at the flange of the pillar side position. The results of the formability evaluation of the 980 MPa grade high El type GA steel sheet are shown in Photos 2(b) and (c) in comparison with the conventional type. With the conventional type, fracture occurred near the punch shoulder, whereas the improved ductility of the high El type enabled forming without fracture. The results of the formability evaluation of the 980 MPa grade high El- λ type GA steel sheet are shown in Photos 2(d) and (e) in comparison with the conventional type. With the conventional type, fracture occurred from the flange edge toward the verti-

cal wall part. In contrast, no fracture was observed in the high EI- λ type due to the improved stretch-flangeability of this sheet. Since it is possible to apply high strength GA steel sheets even to structural parts with complicated shape by selecting the most appropriate material for the forming mode as illustrated in this example, high strength GA sheets are expected to contribute to both corrosion resistance and crashworthiness in frame parts of the cabin structure.

4. Examples of Application

The high strength cold-rolled steel sheets and GA steel sheets introduced up to this point are already widely used in automobile frame parts. The following presents examples of application of high strength grade products.

Photo 3 shows a door impact beam made of a 1 180 MPa grade cold-rolled steel sheet. This is an example in which cost reduction was achieved by substituting a cold-pressed part for the hot-stamped part in former model, which was possible because the high elongation of the developed material enables forming of this complex part shape^{23,24}). **Photo 4** shows a 1 320 MPa grade bumper R/F part which was produced by roll forming. This is an example of use of a steel sheet of the highest strength level applied in forming applications.

Among high strength GA steel sheets, the applications of the 590 MPa grade are expanding rapidly. The 980 MPa grade is in mass production for applications such as belt line R/F parts, side sill R/F parts, etc., and further expansion of applications is expected in the future.

5. Conclusion

This paper introduced the basic principles by which properties are realized in the ultra-high strength cold-rolled steel sheets and galvannealed steel sheets developed recently by JFE Steel, together with the product lines and features, and examples of applications. These products are making an important contribution to automobile weight reduction and improved crashworthiness.

In order to expand the applications of high strength materials, continuing development of use technologies such as forming, welding, etc. beyond their current levels is necessary. Therefore, JFE Steel plans to develop and propose use technologies integrated with material development.

JFE Steel will promote further development while continuing to deepen its collaborative relationships with customers, with the aim of realizing low fuel consumption contributing to the solution of global environmental problems and to safe, comfortable and “people-friendly” automobiles.



Photo 3 Door impact beam made of the low yield ratio (YR) type 1 180 MPa cold-rolled ultra high strength steel

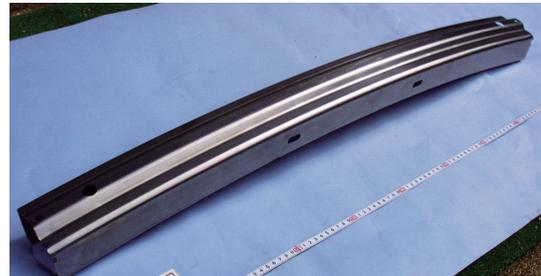


Photo 4 Bumper reinforcement made of the 1 320 MPa grade cold-rolled ultra high strength steel

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