Characteristics of 780MPa and 980MPa Grade Hot-dip Galvannealed Steel-sheets

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Hot-dip galvannealed steels of 780MPa and 980MPa grades have been developed which exhibit low yield point (YP) and excellent formability. These steels are being increasingly incorporated in automotive bodies to improve fuel economy through body weight reduction. These newly developed 780MPa and 980MPa grade steels also exhibit higher spot-welded joint strengths. Crash tests show that these newly developed steels can effectively absorb more energy both for axial-crash and bending-crash conditions compared to conventional steels. These results indicate that the newly developed steels can replace conventional low strength steels currently used for automotive bodies.

Introduction

With growing awareness of global environmental issues, automobile manufacturers are striving to reduce automotive weight and thus decrease exhaust emissions. Concurrently, automakers are pursuing higher automotive impact resistance to protect vehicle occupants. This has led to more extensive use of high tensile-strength (hereinafter called “Hi-Ten”) steel-sheets, especially for automotive body frames[1]. Hot-dip galvannealed (hereinafter “GA”) Hi-Ten steel, among others, is extensively used for lower pillar portions and other frame members which require corrosion resistance. As the application of Hi-Ten steel expands, a higher-level balance is desired for its properties[2), 3)]. For example, a Hi-Ten steel having superior formability is strongly required for forming complex-shaped parts such as automotive body frames, and much R&D effort has focused on developing forming technology for such materials[4)-9)]. This paper introduces the characteristics of low yield point (YP)-type Hi-Ten steels of 780 MPa grade and 980 MPa grades, both developed by Kobe Steel.

1. Design concept of developed steels

GA steel-sheets are produced generally through continuous hot-dip galvanizing lines. The galvanizing lines, however, impose restrictions on the property improvement of GA steel-sheets compared to the continuous annealing lines (CALs) used for cold-rolled steel-sheet products. The restrictions, mainly on heat cycles, arise from the temperatures required for the galvanizing baths and galvannealing treatment. Under such restrictions, Kobe Steel has already established production technologies for low YP-type GA steel-sheets of 590 MPa grade[6), 8)]. The technologies are adapted for the production of GA steel-sheets of 780 MPa grade and 980 MPa grade. To satisfy properties, especially elongation required for such high-strength steel-sheets, the yield points must be lowered by controlling their microstructures to dual phase (DP), i.e., ferrite + martensite, while suppressing the bainitic transformation during the cooling step after annealing. The basic concept of alloy design is as follows:

1) Addition C and/or Mn makes the microstructure dual phase, suppressing bainitic transformation and improving strength/elongation balance. Excessive addition of C and/or Mn, however, may deteriorate spot-weldability. The addition should be kept to a minimum, with just enough to maintain the strength/elongation balance.
2) Addition of Si is highly effective in improving elongation, however, it may deteriorate coatability.
3) Phosphorous impurity should be avoided as much as possible to ensure weldability.
4) Addition of either Cr or Mo facilitates the formation of DP structure as in the case of C and/or Mn. If added independently, however, Cr may deteriorate coatability and Mo may lower elongation. Thus, the elements should be added in combination within a range which satisfies other property requirements.

Based on the above concept, new steels have been developed for sheets which exhibit stable properties even in a mass production scale.

2. Characteristics of the developed steel

2.1 Formability and dimensional accuracy

Table 1 shows the mechanical properties of the developed steels compared to reference cold-rolled (CR) sheet-steels. The reference steels are of the same strength grade and, in particular, the reference CR980 is known to have a good property balance between elongation and bending characteristics. Generally, GA steel-sheets tend to have properties

Table 1 Mechanical properties of steels

Steel	Category	TS grade	YP (MPa)	TS (MPa)	El. (%)	λ (%)
Developed steel	Galvannealed	980MPa（GA980Y）	724	1,022	15	27
		780MPa（GA780Y）	456	837	21	33
Conventional steel	Cold-rolled	980MPa（CR980Y）	690	1,030	15	30
		780MPa（CR780Y）	502	833	21	45

- Specimen thickness : 1.4mm
- Tensile test : JIS Z 2241 (JIS No. 5 specimen in transverse direction)
- Stretch flanging (Hole expanding) test : Hole expansion ratio : λ-value obtained by method of JFST1001

inferior to those of CR sheets produced through CALs, due to the restrictions on the heat cycles. The developed GA steels, however, have elongations similar to those of CR sheets, exhibiting good strength-elongation balances. This is due not only to the alloy design and microstructural control of the cooling step after annealing described above, but also to an optimized volume fraction of ferrite which ensures uniform deformation. Regarding local deformation, each of the developed steels has a good hole-expandability (λ), an index for stretch flangeability, similar to that of the corresponding CR steel-sheet. Each of the developed steel also has an excellent bendability according to the U-bending test, which resulted in a minimum bend radius smaller than twice the sheet thickness (**Table 2**). The excellent local deformation is considered to be the result of a homogeneous microstructure which minimizes local stress concentrations. With those new GA steels having well balanced elongation and λ, Kobe Steel has a wide range of both CR[7] and GA steel-sheets that meet various needs of its customers. The company has already completed the development of high-elongation type steels[14] and is now working on the improvement of high-λ type steels having excellent local deformation.

Table 2 Bendability for U-bending test in developed steels

Steel		Thickness (mm)	Limited bending radius 〈Transverse direction〉 (mm)
Developed steel	GA980Y	1.2	2
	GA780Y	1.2	1.5

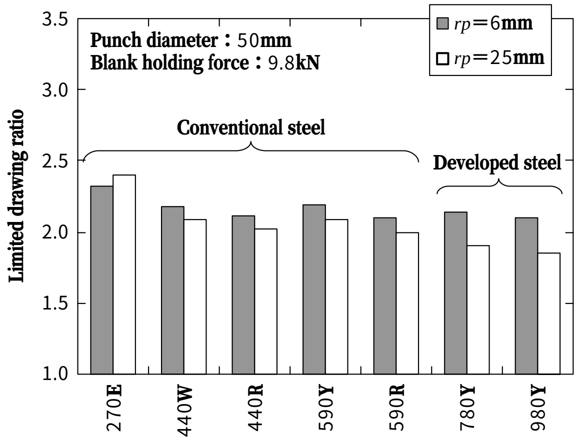


Fig. 1 Limited drawing ratio (LDR) of various GA steels[12]

Evaluation was also performed on the drawability of the developed steels. **Fig. 1** [12] shows the limit drawing ratio (LDR) of the developed steel-sheets drawn by a column-shaped punch having a 50 mm diameter. It should be noted that the reference materials consist of low strength GA steel-sheets having good formabilities. Each steel-sheet was subjected to two drawing tests using different punches; i.e., one with a punch with shoulder radius (r_p) of 6 mm and the other with a spherical head having radius of 25 mm. In the case where r_p = 6 mm, the developed steels have drawabilities similar to those of precipitation-hardened type steels, 590R and 440R, and a C-Mn steel, 440W. Interstitial free (IF) steels, such as 270E, exhibit high drawability because of their high r-value. On the other hand, the developed steels exhibit excellent drawabilities even though their texture is less developed. It is well known that drawabilities are more affected by work hardening behaviors[15]. The excellent drawabilities of the developed steels, despite their higher tensile-strengths and lower r-values, is attributable to their high work hardening property.

The GA steel-sheets of Fig. 1 were formed into hat channels using 48 mm wide punches having different die shoulder radii (r_d = 3 mm, 7 mm and 10 mm). The amount of spring back was measured for each sheet sample and was plotted against its tensile strength, as shown in **Fig. 2** [12]. Due to large strain introduced during forming, the amounts of spring back relate more strongly with tensile strength rather than with yield stress. It has also been found that smaller die

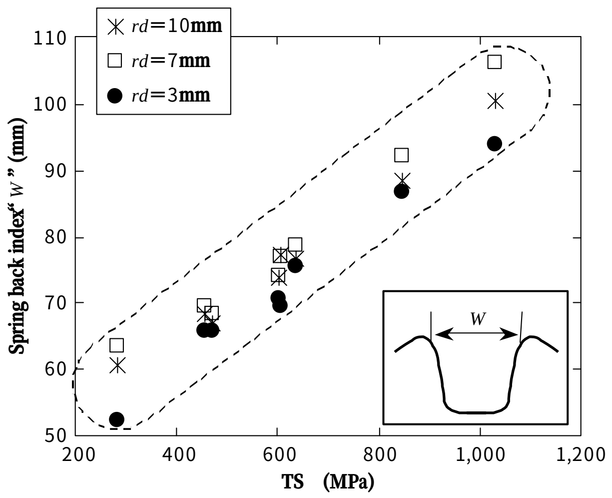


Fig. 2 Relation between spring back index : W and TS for various GA steels[12)] (W determined by a hat channel draw tool as shown in the figure)

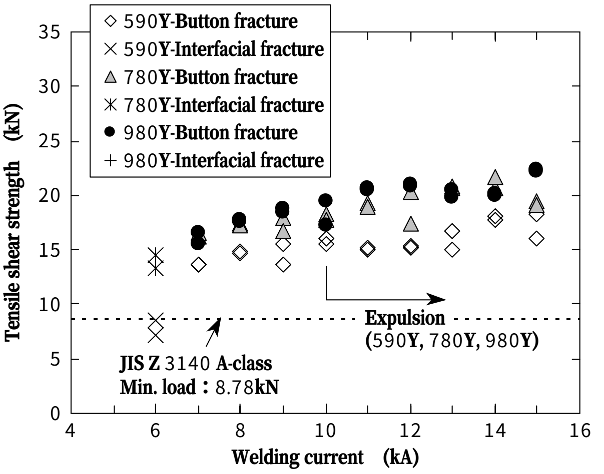
shoulder radii, r_d, tend to advantageously improve dimensional accuracies.

2.2 Spot weldability

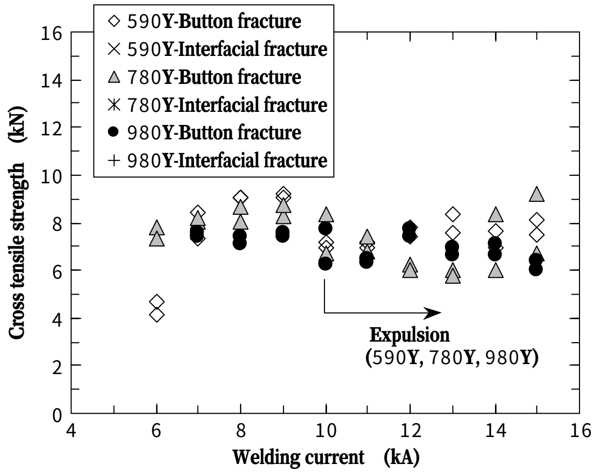
Spot weldabilities were evaluated for steel-sheets of 1.2 mm thickness. The evaluation was performed under the conditions as shown in **Table 3** with varying welding current. **Fig. 3** a) shows the tensile-shear strengths and Fig. 3 b) shows the cross-tensile strengths, respectively of welded joints plotted against the welding currents. The welded samples include a reference steel, GA590Y[8)], and the newly developed steels. The reference GA590Y is known to have a good spot-weldability. The tensile shear strengths of joints tend to increase with increasing base material strengths, as previously known[16)-18)]. The developed steels have strengths well exceeding the requirement of JIS Z 3140A at the welding currents which yield button-fractures, indicative of a sound joint. Regarding the cross-tensile strengths, none of the welded sheet caused brittle fracture in the welded zone (nugget), and no significant decrease in strength was confirmed even after expulsion. These results indicate excellent joining performance of the developed steels. A wide current range of about 4 kA was secured for the welds which exhibit button-fracture without expulsion. The wide range enables the developed steels to have stable joint strengths. The excellent weldabilities described above are attributable to the Cr/Mo combined additions that reduce addition of C which otherwise may deteriorate weldability. Recently, Kobe Steel has developed a steel having further improved weldability with even less carbon content.

Table 3 Spot welding conditions

Electrode tip	Dome type Cu-Cr
Tip diameter	6 mm
Electrode force	3,720 N
Welding time	23 cycle (60Hz)
Welding current	6-15 kA
Cooling water	2 L/min



(a) Tensile shear strength



(b) Cross tension strength

Fig. 3 Effect of welding current on tensile shear strength (a) and on cross tension strength (b) for the developed and GA590Y steel

2.3 Impact resistance

Structural members made of 780 MPa and 980 MPa grade Hi-Tens are required to have high impact resistance since they are widely used for collision safety purposes. To evaluate the impact resistance of the developed steels, crash tests were conducted using hat-shaped specimens having a cross section as shown in **Fig. 4**. Each specimen was spot-welded to a back plate (1.4 mm thick) made of GA 440W steel

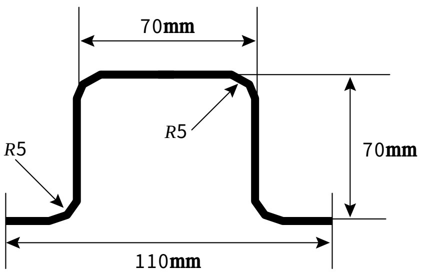
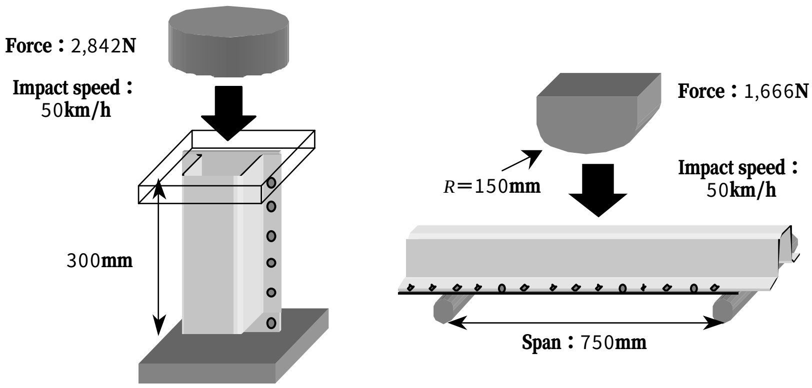


Fig. 4 Cross sectional geometry of crash test specimen



Axial crash test specimen

Crash bending test specimen

Fig. 5 Axial and bending crash tests

Table 4 Crash test results for the developed steels and conventional steel (440W)

Steel		Thickness (mm)	Axial crash test		Crash bending test	
			Maximum load (kN)	Absorbed energy 〈0-150mm〉 (kJ)	Maximum load (kN)	Absorbed energy 〈0-100mm〉 (kJ)
Developed steel	980Y	1.4	502	12.88	29.7	1.29
	780Y	1.4	428	10.72	23.4	1.05
Conventional steel	440W	1.4	261	6.24	15.5	0.58

at welding intervals of 50 mm. The lengths of the specimens were set to 300 mm for axial-crash test and 1000 mm for crash-bending test. For each test, a weight was dropped from a height onto each specimen as shown in **Fig. 5**. The shock-loads were measured by a load-cell underneath the specimen. The strains were measured by a laser displacement meter. **Table 4** shows the maximum loads and absorbed energies determined from the load-strain curves obtained in the crash-tests for GA440W steel and developed steels. For each test, the absorbed energy was calculated for the range from the beginning of the deformation until the weight hit the stopper of the crash tester. The average of three tests for each steel was used as the result. In both the cases of axial-crash and crash-bending tests, the maximum load increases with increasing tensile strength of the base material, i.e., the developed steels show higher deformation resistances compared to the conventional GA440W. The developed steels also have higher absorbed energy values, enabling them to be used for the shock absorbers of structural members.

3. Future development

The newly developed steels are now used mainly for auto body frames and are highly regarded by customers. Kobe Steel is proactively transferring the technologies to USA and EU to ensure the global availability of the steels for auto makers all over the world. Especially in the USA, Kobe Steel has established Pro-Tec Coating Company, a joint venture with U.S. Steel, and started supplying the steel-sheets in volume mainly to the local Japanese automobile manufacturers. Kobe Steel is gaining high respect for the GA Hi-Tens, because of their high performance[11)-13)], from U.S. automobile manufacturers. Therefore, applications of the GA Hi-tens to mass produced cars are expected to grow rapidly.

Conclusions

A series of tests has been conducted on the developed steels may advantageously be applied to automotive body frames, replacing conventional lower-strength steel-sheets. On the other hand, Hi-ten steel-sheets are required to be even more formable so that they can be adopted to more complex shaped parts. Based on the above development, Kobe Steel has already established technologies for high yield-ratio (YR) type steels in order to better meet overseas standards. The company has developed high weldability type steels and, more recently, high elongation type steels[14)]. Kobe Steel now has a line of steel products fulfilling customers' variety of needs. The company will keep striving not only to develop and provide materials, but also to develop products from user's perspective by working even more closely with the customers. Our goal is to provide excellent quality steels adapted for various application, which includes delivering a line of Hi-Ten products. Our corporate mission is to develop unique products “only one of the kind”, and KSL will continue technological development of more value added products and thus contribute to the reduction of environmental burdens of the automobile industries.

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