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Technical Report

Present Situation and Future Trend of Ultra-High Strength Steel Sheets for Auto-Body

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Abstract

Application of ultra-high strength steel sheets is one of the most important methods to satisfy weight reduction and crash safety of a vehicle. Recently, there is a trend to apply ultra-high strength steel sheets widely to auto-body parts. In this report, present situation of ultra-high strength steel sheets, especially with tensile strength more than 980MPa and 1,470MPa by hot-stamping, have been introduced.

1. Introduction

Amid ever-growing concern about global warming, strenuous efforts have been made to improve the fuel efficiency of automobiles. For example, the average fuel efficiency of automobiles in Japan is expected to be 16.8 km/l by 2015, more than 20% better than the 2004 figure.[1] Reducing car body weight is an effective means of improving fuel efficiency. However, the tightening of regulations on crashworthiness[2] has made it necessary to add features such as reinforcing parts to car bodies, leading to an inevitable increase in car body weight.

The use of higher strength steel is one of the most effective ways to reduce car body weight while securing the required crashworthiness. Therefore, steelmakers have been pressing ahead with development of high-strength steel sheets. In recent years, reports have been presented regarding the development of ultrahigh-strength steel sheets for cold press forming (tensile strength: 980 MPa or more), the hot stamping of steel materials to obtain 1,470 MPa-class structural members by hot forming, and the application of such steel sheets to car body skeletal members.[3-10] In future, regulations for crashworthiness will become increasingly stringent. Therefore, it is expected that the application of steel sheets of higher strength to strengthen members of car bodies will expand, allowing improvements in the fuel efficiency of automobiles through further reduction of car body weight.

This report outlines the current status of development of ultra high strength steel sheets for cold press forming and hot stamping steel sheets, describes their properties, and touches upon the future trend.

2. Ultrahigh-strength Steel Sheets for Cold Press Forming

2.1 Steel sheet composition and concept of microstructure control

As the hardness of a steel sheet increases, its formability and weldability tend to deteriorate.[11, 12] In order to restrain such a tendency, it is useful not only to increase the steel strength but also to control the steel microstructure, thereby ensuring adequate formability in the forming mode of interest.[11, 12]

In the forming of ultrahigh-strength steel sheet, if the total elongation that is effective in bulging is enhanced, the properties that are governed by local ductility (e.g., hole expansibility) and are effective in stretch flanging and bending deteriorate. Thus, the total elongation and the local ductility are incompatible (**Fig. 1**). Therefore, it is necessary to employ a different method of microstructure control in order to improve both of these factors simultaneously.

When total elongation is considered important, a composite structure incorporating soft ductile ferrite as the base and, for example, hard quenched martensite dispersed within the base is effective. In this case, it is necessary to add a ferrite-forming element and optimize the annealing heat treatment pattern in the continuous annealing equipment.

When importance is attached to hole expansibility, special atten-

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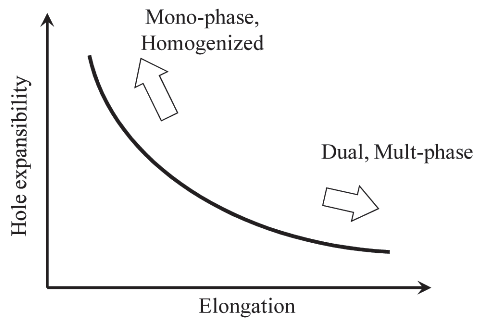

Fig. 1 Schematic illustration of relationship between elongation and hole expansibility for ultra-high strength steel sheets

tion should be paid to the fact that steel sheet is subject to local strain concentration and the occurrence of voids and microcracks if it does not have a uniform microstructure; this can cause the hole expansibility and bendability of the steel sheet to deteriorate.[13)] Therefore, it is necessary to implement appropriate measures in order to ensure a uniform microstructure; such measures can include reducing carbon content to restrain the formation of hard, coarse carbides and heating the steel sheet to a high temperature to homogenize its microstructure.

In order to obtain a good combination between total elongation and hole expansibility, it is important to reduce the difference in hardness between the soft phase and the hard phase while ensuring the required total elongation by employing a steel sheet of composite structure.

By widening the variety of steel sheets with unique characteristics, as mentioned above, it has become possible to choose steel sheets according to specific parts requirements and apply ultrahigh-strength steel sheets in the right situations.

2.2 Various properties of steel sheets

2.2.1 Main chemical compositions and microstructures

Table 1 illustrates the main chemical compositions and microstructures of various ultrahigh-strength steel sheets. The cold-rolled steel sheets shown in the table were manufactured by a continuous annealing line and the galvannealed steel sheet was manufactured by a continuous hot-dip galvanizing line.

The basic chemical compositions of the sheets are C–Si–Mn and C–Mn for the cold-rolled steel and galvannealed steel sheets (whose Si content has been reduced to ensure the desired surface quality), respectively. Steel sheets that are required to possess good hole expansibility have a comparatively low carbon concentration (which helps to restrain the formation of hard carbides) and consist entirely of hard bainite. Conversely, steel sheets that are required to exhibit good elongation are composed mainly of soft ferrite and hard martensite. The hardness of martensite is determined by its carbon content: martensite is harder for higher carbon contents. For steel sheets requiring good elongation, the carbon content is made comparatively high to promote the formation of a composite structure of soft ferrite and hard martensite. To obtain a good combination between hole expansibility and elongation, the volume fractions of ferrite, bainite, and martensite are optimized to control differences in hardness at the nano-scopic level.

2.2.2 Mechanical properties

Table 2 shows the mechanical properties of the steel sheets described above.

For 980 MPa-class steel sheets, both the cold-rolled and galvannealed steel sheets for which elongation is important exhibit total elongation of 16 - 17%, higher than that of other types of steel sheet. Conversely, steel sheet for which hole expansibility is important exhibit hole expansibility (λ) of more than 90%, indicating that it has good burring formability. Steel sheet of balanced type has material properties lying somewhere between those of the above two types; therefore, it is useful when both ductility (El) and hole expansibility (λ) are required.

Steel sheet exhibiting good elongation displays a comparatively low yield point (YP), while that exhibiting good hole expansibility displays a comparatively high YP. This corresponds to the difference in hardness between their microstructures. Thus, by choosing between different types of steel sheet it is possible to obtain an optimum steel material that has the desired yield stress, formability, and corrosion resistance, even if the tensile strength (TS) is the same as that of other types.

The 1,180 MPa-class steel sheet also shows a strength-ductility combination comparable to that of 980 MPa-class steel sheets (**Fig. 2**).

2.2.3 Spot weldability

Fig. 3 illustrates the strengths of spot-welded joints of cold-rolled steel sheet and galvannealed steel sheet with good elongation. The spot-welding conditions were such that the nugget diameter became $5\sqrt{t}$ (t: sheet thickness) under the applied force of 500 kgf. The joint strengths measured were as follows: a) tensile shear strength (TSS) and b) cross-tension strength (CTS). TSS increases with increasing strength of the base metal, whereas CTS remains the same regardless of increases in base metal strength. Under the present welding conditions, all of the welded joints fractured at their

Table 1 Chemical compositions and microstructure of ultra-high strength steel sheets

Type		Main chemical compositions	Main microstructure
Cold Rolled (CR)	Hole-expandability: λ	C-Si-Mn	Bainite
Cold Rolled (CR)	Balanced λ and El	C-Si-Mn	Ferrite, bainite, martensite
Cold Rolled (CR)	Elongation: El	C-Si-Mn	Ferrite, martensite
Galvannealed (GA)	Elongation: El	C-Mn	Ferrite, martensite

Table 2 Mechanical properties of ultra-high strength steel sheets

Type		YP (MPa)	TS (MPa)	El (%)	λ (%)	Yield ratio
Cold Rolled	Hole-expansibility: λ	843	1011	10	92	0.83
Cold Rolled	Balanced λ and El	737	1012	13	55	0.73
Cold Rolled	Elongation: El	624	1008	17	43	0.62
Galvannealed	Elongation: El	632	1013	16	35	0.62
Galvannealed	Elongation: El	777	1199	13	32	0.65

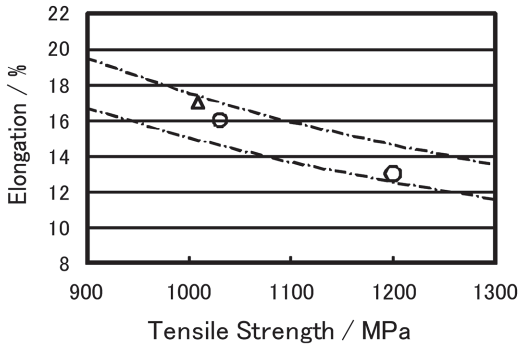

Fig. 2 Combinations between tensile strength and elongation

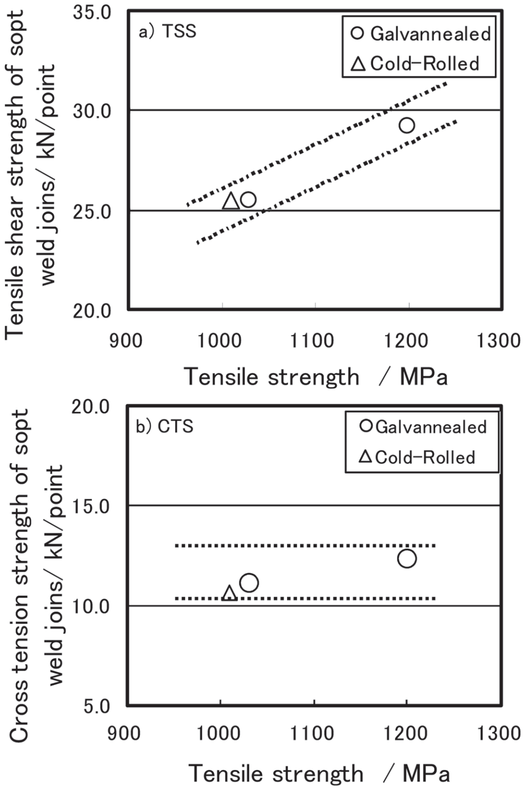

Fig. 3 Relationship between tensile strength and spot weld joint strength of ultra-high strength steel sheets

base metal.

2.2.4 Impact characteristics

The impact characteristics of the steel sheets were measured by drop weight tests. Test pieces with cross-sections of 70 mm × 60 mm and spot-welded flanges were tested in bending mode to measure and evaluate absorbed energies. The weights used were 75 - 160 kgf and the falling height was 4 - 9 m. As shown in **Fig. 4**, the amount of absorbed energy increased in proportion to the increase in steel sheet strength. Thus, the amount of absorbed energy in a collision increases when an ultrahigh-strength steel sheet is applied. Therefore, it is expected that the ultrahigh-strength steel sheet will help to reduce car body weight through reduction of the thickness of strength members.

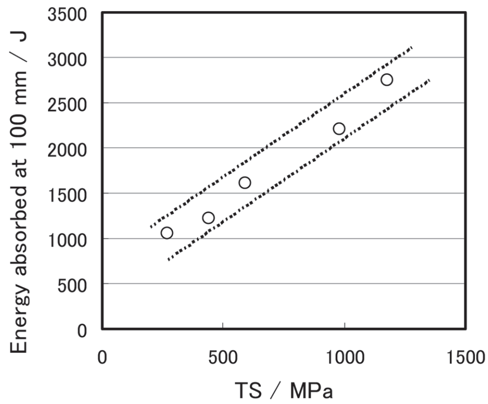

Fig. 4 Changes in the absorbed energies of galvannealed steel sheets with tensile strength evaluated by bending mode drop tests

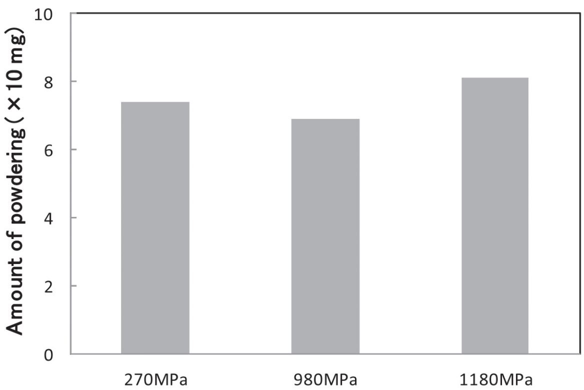

Fig. 5 Amount of powdering of steel sheets

2.2.5 Adhesive resistance of coatings

Fig. 5 illustrates the amounts of powdering required for mild and high-strength steel sheets in V-bending test. The amounts of powdering depends little on the strength of steel sheet. It is also clear that the ultrahigh-strength steel sheet requires almost the same adhesive resistance of coatings as that of the mild steel sheet.

3. Steel Sheets for Hot Stamping

3.1 Hot stamping steel sheet and the manufacturing process

To obtain steels with strength as high as 1,470 MPa, a forming method known as hot stamping has been put into practical use.[5] In this method, the steel sheet is heated to about 900°C (austenite region) before being formed by water-cooled dies. Therefore, this method has the advantages of increasing steel sheet strength through quenching and offering good shape fixability through hot stamping.

Table 3 presents the chemical composition and properties before and after quenching of a hot-stamping steel sheet to obtain 1,470 MPa-class components. The strength of the steel sheet before hot stamping was 490 - 590 MPa; after quenching, its strength was 1,470 MPa or more.

Fig. 6 shows the relationship between cooling rate and hardness obtained for a steel sheet for hot stamping; Mn and B have been added to improve hardenability. When the heating temperature is 950°C, the hardness of the steel sheet can be controlled within the

Table 3 Chemical compositions and mechanical properties before and after hot stamping

C	Mn	Cr	B
0.22	1.2	0.15	0.0015

	YP (MPa)	TS (MPa)	El (%)
As coated	394	615	26
As formed	1280	1530	8

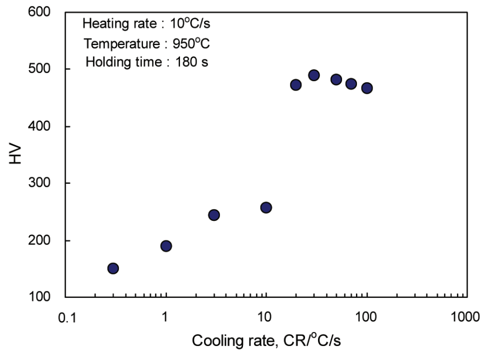

Fig. 6 Relationship between cooling rate and hardness (HV) for steel sheets for hot stamping

range HV 450 to HV 500 at a cooling rate of about 20°C/s or higher. The cooling rate depends on the conditions implemented to prevent the transformation of ferrite, pearlite and bainite during the cooling process.

3.2 Spot weldability

Fig. 7 shows the influence of welding current on a) tensile shear strength and b) cross-tension strength. Joint strength tended to increase with increasing welding current and growth of the nugget. Cross-tension strength was low compared to the tensile shear strength. Similar tendencies can also be observed in existing high-strength steels.[14]

3.3 Shape fixability

Fig. 8 compares the shape fixability of hot-stamped material with that of cold-pressed material at a forming start temperature of 800°C. The measured clearance between the flange end and the flat face of a hat-shaped part was used as the shape fixability. It is clear that hot stamping offers much better shape fixability than conventional cold press forming.

4. Future of High-strength Steel Sheets and Concluding Remarks

So far, we have described ultrahigh-strength steel sheets for cold press forming and the present status of hot stamping. However, amid the rapidly increasing social demand for reduction of environmental impacts, it is necessary to further reduce the weight of car bodies. On that basis, efforts have been made to develop new steel sheets with still higher strengths.

In recent years, highly formable 980 MPa steel sheets for cold press forming have been developed.[15] More recently, reports have detailed the development of a 1,180 MPa steel sheet that is comparable in formability to 780 MPa steel sheets.[16] The development of

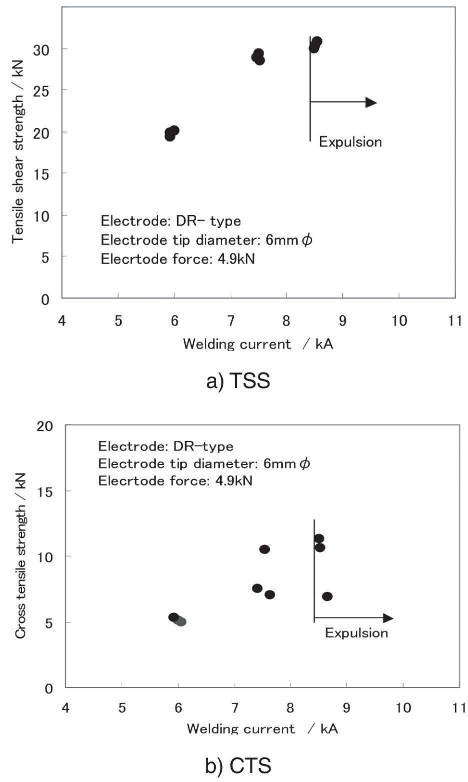

Fig. 7 Relationship between spot weld joint strength and welding current for steel sheets for hot stamping

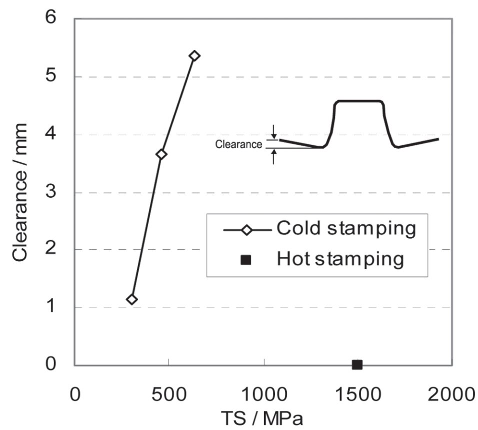

Fig. 8 Comparison of shape fixability between hot stamped material and cold-pressed material

members using a new steel sheet exceeding 1,470 MPa in strength has also been reported for hot stamping.[17]

In developing new steel sheets of higher strength, it will become increasingly important not only to enhance steel strength but also to test the application and evaluation of such steels. It is also important to address problems such as weldability and hydrogen embrittlement. Such research must be conducted simultaneously with the development of new materials.

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