JFE TECHNICAL REPORT
No. 10 (Dec. 2007)

High-Performance, High-Strength Steel Sheets for Exposed Auto Body Panels†

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Abstract:

JFE Steel has developed two types of high performance high-strength steel sheets for automobile body exposed panels. The SFG (super fine grain) HITEN, "SFGHITEN®," which is strengthened by fine grains, gives excellent press-formability with low yield strength and a large r-value. It is observed that the formation of PFZs (precipitate free zones) results in a mechanism in which yielding begins at low stress at an initial deformation stage. The UNI (uniform unique universal) HITEN, "UNI HITEN®" gives excellent press-formability and superior dent resistance which are obtained by increasing yield strength after paint baking.

1. Introduction

The steel sheets for automobile exposed body panels are required to excellent press-formability (e.g., deep-drawability and stretch-formability), high surface quality (resistance to surface distortions), and homogeneous coated surfaces after press forming. Steel sheets for inner panels are produced by adding solid-solution strengthening elements such as Si, Mn, and P to ultra low carbon IF steels in order to ensure simultaneous formability and strengthening. Sheets of this type with tensile strengths of up to 440 MPa are now available commercially. Weight reductions for the body-in-white through measures such as the addition of reinforcing parts, gauge reductions, and the application of high-strength steel sheets for exposed panels can only progress further with the realization of the need for high-strength steel sheets combining excellent press-formability and sufficient coated surface quality for exposed automobile body panels[1,2].

This paper describes two types of high-performance, high-strength steel sheets with excellent press-formability and high surface quality for the fabrication of exposed auto body panels.

2. SFG (Super Fine Grain) HITEN

2.1 Concept of Alloy Design[3]

Parts with complicated shapes such as the outer side panels and fenders must have the complex formability of deep-drawability and stretch-formability. **Figure 1** shows the concept of alloy design for SFG HITEN intended for use in these parts. The addition of large amounts of solid-solution strengthening elements is effective for strengthening deep-drawing high-strength steel sheets of IF steels (ultra low-carbon steels) with carbon content on the order of 20 ppm. SFG HITEN, in contrast, is produced with carbon content of 60 ppm, triple the value used in conventional IF steel, together with Nb in amounts high enough to achieve an Nb/C ratio of 1.0 or more (in order to precipitate and fix the interstitial solid-solution elements, carbon and nitrogen). The addition of solid-solution strengthening elements Si and Mo has drawbacks, however, as the former deteriorates the quality of the material and the latter is prohibitively expensive. Thus, the dispersion strengthening and grain refinement required for strength reinforcement can be achieved by using large amounts of Nb (C, N) precipitates in place of Si and Mo. Because of this, the following are expected from SFG HITEN: (1) excellent deep-drawability (high *r*-values) obtained by fixing C and N,

† Originally published in *JFE GIHO* No. 16 (June 2007), p. 12–15

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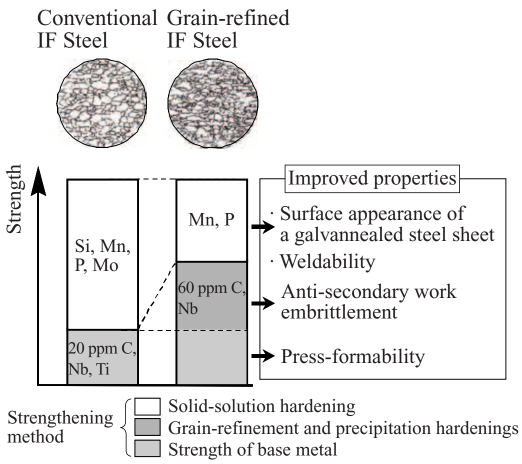


Fig. 1 Schematic diagram of the metallurgical concept for the SFG HITEN

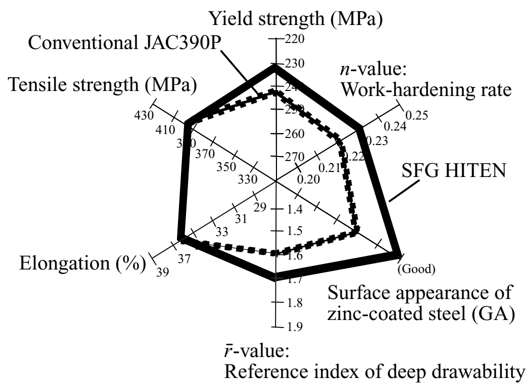


Fig. 2 Comparison of mechanical properties balance

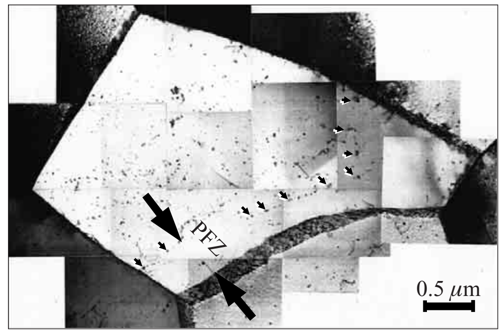


Photo 1 TEM micrograph of specimen annealed at 850°C

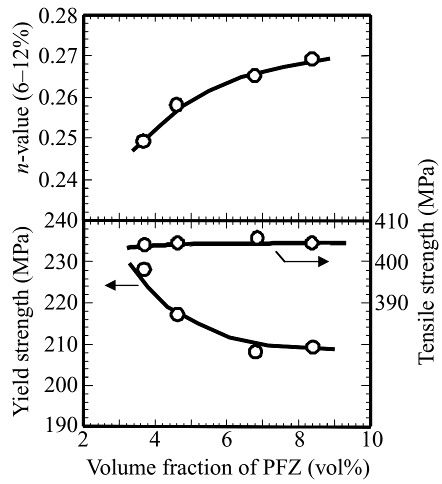


Fig. 3 Effect of volume fraction of PFZ on mechanical properties of annealed specimen

(2) a sufficiently good coated surface quality of galvannealed (GA) steel (which is suitable for use in exposed panels), and (3) strengthening by grain refinement and improved secondary-work embrittlement resistance.

2.2 Balances of Mechanical Properties

Figure 2 shows the balance of the mechanical properties of 390 MPa grade SFG HITEN. Newly developed steel has a low yield strength in spite of grain refinement. This substantially improves the surface distortion, a factor which can inhibit increases in strength. SFG HITEN performs outstandingly in complex formability and outdoes conventional steels in indices of press-formability (the n-value and r-value). The high r-value has been achieved by the development of a remarkable texture in the γ-fiber (<111>//ND recrystallization texture) in the annealed steel after cold rolling (enabled by grain refinement of the hot-rolled steel)[4]. Furthermore, the coated surface quality of galvannealed steel products is comparable to the quality of mild steels for use in exposed panels.

2.3 Low Yield Strength[5]

Grain refinement and precipitation strengthening generally increase the yield strengths of steel sheets. In SFG HITEN, a material with properties that defy the conventional knowledge, these treatments actually decrease the yield strength. **Photo 1** shows the result of an observation of the dispersion type of precipitates of a 390 MPa grade SFG HITEN steel performed under a transmission electron microscope (TEM). A zone depleted of precipitates (PFZ: precipitate-free zone) is formed in a region neighboring the grain boundary (indicated by the arrows). Micro yielding from the region neighboring the grain boundary is promoted in the initial deformation stage, and yield begins at low stress. This suggests that the yield strength can be controlled using a difference in the volume fraction of PFZ. **Figure 3** illustrates the relationship of the volume fraction of PFZ with YS, TS, and the n-value. The tensile strength TS is almost constant at 405 MPa irrespective of the volume fraction of PFZ. The yield strength decrease and the n-value increases significantly with increasing volume fraction of PFZ. Therefore, it could be inferred that the PFZ is the dominant factor for the yielding and work hardening behavior.

2.4 Secondary-Work Embrittlement [6]

IF steels have low grain boundary strength in comparison with intergranular strength because interstitial elements do not exist at the grain boundaries. In particu-

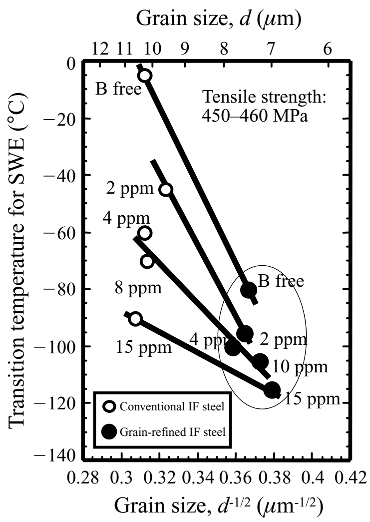


Fig. 4 Relationship between transition temperature, Tc and Ferrite Grain Size

lar, in high-strength steels based on IF steel, it is necessary to consider measures to prevent reduced resistance to secondary embrittlement caused by the strength difference between the grains and grain boundaries. This SFG HITEN was compared with the conventional IF high strength steel sheet, and the effects of both grain refinement and boron addition on the improvement of anti-secondary work embrittlement in IF steels were compared. The transition temperature of secondary work embrittlement was evaluated by flanging test of drawn-cup with the cup-height of 35 mm and the drawing ratio of 2.0.

Figure 4 shows how the grain size and the addition of B affects the resistance to secondary-work embrittlement of IF steels. The transition temperatures of both steels decrease as more B is added. The grain refinement and addition of B result in excellent resistance to secondary-work embrittlement in both steels.

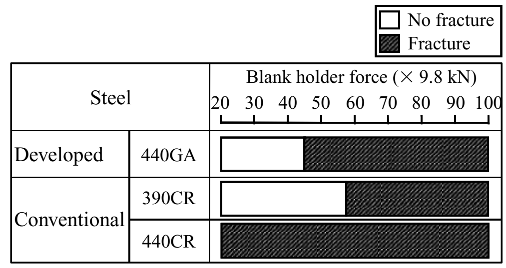
2.5 Press-formability [7)]

Press formability of SFG HITEN was compared to those of the conventional high strength steels by try-out-press with center pillar outer model. The press test was conducted using the test materials shown in **Table 1** and fractures were evaluated by changing the cushion force.

Table 1 Mechanical properties of steels used in press-forming test for a center pillar outer model

Steel		YS (MPa)	TS (MPa)	El (%)	Mean r-value
Developed	440GA	287	440	36.0	1.75
Conventional	390CR	243	402	39.5	1.62
	440CR	289	461	38.0	1.01

GA: Galvannealed steel sheet, CR: Cold-rolled steel sheet,
YS: Yield strength, TS: Tensile strength, El: Elongation



GA: Galvannealed steel sheet
CR: Cold-rolled steel sheet

Fig. 5 Press-formability for a center pillar model of the developed 440 MPa galvannealed steel sheets and the conventional cold-rolled IF-HSS

Figure 5 shows the result of the test. A fine-grained SFG440GA steel with a mean r-value of 1.75 resisted cracking and exhibited good formability at cushion pressures of up to 440 kN. In the conventional steel 440CR (JSC440W), having a mean r-value of 1.01 occurred under all of the cushion force conditions.

2.6 Examples of Application

SFG HITEN is now commercialized in the 340 MPa, 390 MPa and 440 MPa grades and adopted by multiple automakers. The 390 MPa grade SFG HITEN, among others, is applied to side outer panels[1)]. The resulting reductions in weight are considerable.

3. UNI HITEN

Among the exposed panels on automobile bodies, 340BH (bake hardening) steel sheets are used in large amounts for body outer part such as door, hood, roof and trunk-lid, in order to meet dent resistance requirements. To accomplish gauge reductions for these parts by increasing tensile strength, the surface quality (surface distortion) and coated surface quality of exposed panels become important for higher dent-resistance and stretch-formability, as well as decorative appearance and design. JFE Steel developed a 440 MPa grade UNI HITEN to meet these requirements. Control of the volume fraction and dispersion of the second phase with a dual-phase (DP) steel of ferrite + martensite ensures the low yield strength and high elongation, n-values, and bake-hardenability of UNI HITEN.

3.1 Mechanical Properties

Table 2 shows the mechanical properties of UNI HITEN compared to those of the 340BH steel. UNI HITEN has a yield strength about as low as that of 340BH in spite of its high tensile strength (440 MPa), and the surface distortion is expected to improve. The mean r-value is almost 1.0. The increase in yield stress in the plane strain area, a dominant deformation mode in door panels, is therefore suppressed, and uniform defor-

Table 2 Mechanical properties of TS 440 MPa grade UNI HITEN

Steel	YS (MPa)	TS (MPa)	El (%)	*n*-value	Mean *r*-value	△*r*-value	WH* (MPa)	BH** (MPa)	YS*** (MPa)
UNI HITEN	249	444	37	0.24	0.9	0.05	51	56	355
340BH	235	350	43	0.21	1.6	0.25	30	42	307

YS: Yield strength, TS: Tensile strength, El: Elongation
* Work-hardening, Increase in yield strength by 2% prestrain
** Bake-hardening, Increase in yield strength by again at 170°C for 20 min after 2% prestrain
*** YS' = YS + WH + BH

Fig. 6 Comparison between the conventional 440 MPa steel and the 440 MPa grade UNI HITEN on the surface distortion by optical method

mation is obtained. This gives UNI HITEN an excellent surface quality. The elongation, an index of stretch-formability, is equivalent to that of JAC390P and has been substantially improved compared to that of conventional 440 MPa grade steel. The *n*-value is 0.24, which is higher than that of 340BH.

Both work-hardenability (WH) and BH, the factors of dent-resistance, are higher than 50 MPa, and the values for YS (YS + WH + BH) exceed 350 MPa.

3.2 Surface Distortion

A press test was conducted on an area around the door handle to evaluate the surface distortion of UNI HITEN. **Figure 6** shows the result of the test. The conventional 440 MPa grade steel has a high YS and large distortion. In contrast to this, the YS of UNI HITEN is equivalent to that of 340BH and has an mean *r*-value of almost 1.0. Thus, a surface quality equivalent to that of 340BH steel was obtained through the effect of isotropy of $|\Delta r| < 0.1$.

3.3 Dent Resistance

To evaluate the performance in real panels, the dent resistance of an area around the handle was evaluated using a door model. **Figure 7** shows the evaluation results. The dent-resistance of UNI HITEN substantially surpassed that of 340BH steel in all door portions thanks to the high WH and BH, and the possibility of a gauge reduction was verified. The high *n*-value of UNI HITEN ensures excellent stretch-formability and good formability and panel quality comparable to those of 340BH steel.

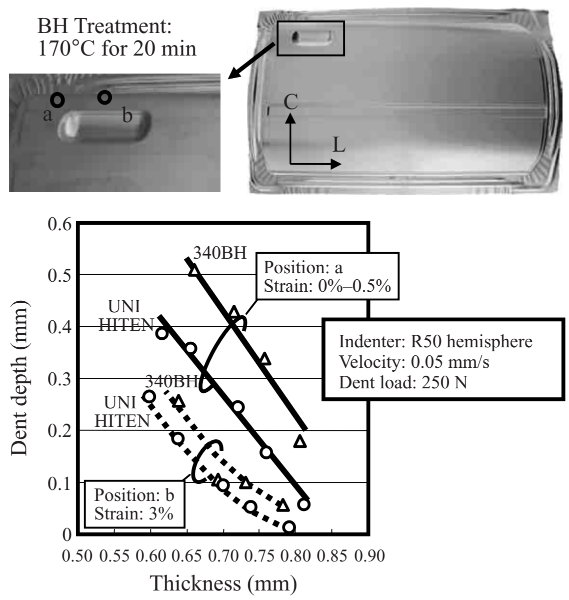


Fig. 7 Comparison between the conventional 340 MPa-BH steel and the 440 MPa grade UNI HITEN on the dent-resistance

4. Conclusions

Two types of high-performance, high-strength steel sheets suitable for use in exposed auto body panels were developed by JFE Steel to reduce the weight of automobile body panels.

(1) SFG HITEN: A fine-grained high-strength steel sheet strengthened by grain refinement, with high formability due to low yield strength, high *n*-values, and high *r*-values. SFG HITEN is expected to be applied to side outer panels.

(2) UNI HITEN: A low YR, 440 MPa grade BH steel

sheet with excellent surface quality, a high yield strength, high dent-resistance obtained by paint baking after press-forming, and good potential for gauge reductions as a consequence. UNI HITEN is expected to be applied to door, hood and trunk-lid.

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