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Development of Ultra-High-Strength Cold-Rolled Steel Sheets for Automotive Use

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Abstract

In automotive body designing, high strength steels are applied in order to achieve weight reduction and high crashworthiness. 980MPa class ultra-high strength steel is recently applied to seat parts. However, it has less formability than that of conventional high strength steels. To meet this demand, three types of 980MPa ultra-high strength steels are developed, which are good elongation type, high stretch flangeability (high hole-expandability) type and balanced type.

1. Introduction

As a measure for suppressing the global warming, the Government of Japanese has laid down an official plan[1)] to improve the fuel consumption of gasoline-fueled automobiles to a target of 15.3 km/l by the fiscal year 2010 (see **Fig. 1**); this means an improvement by approximately 20% from the actual value (12.6 km/l) in the fiscal year 1995. On the other hand, more collision-safety-related regulations are legislated and safety standards are revised and as a result, car components are required to have higher strength.

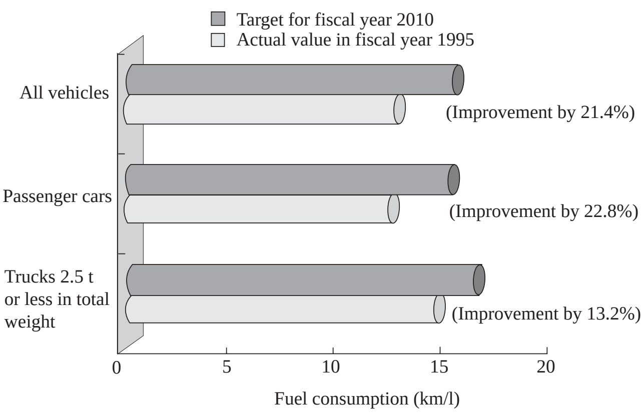

Fig. 1 Fuel consumption targets of gasoline-fueled automobiles

Increasing the strength of a steel sheet is essential for reducing the weight of an automobile and improving its collision safety at the same time. Various kinds of high-strength steel sheets have so far been applied to automobile parts; whereas 980 to 1,180MPa class ultra-high-strength steel sheets have been used in a limited scale for members where high strength is required such as bumpers and door beams, most of the steel sheets used for main structural members have had a tensile strength up to 440 to 590MPa. Application of the ultra-high-strength steel sheets has expanded over the last years for further reduction in the weight of the overall vehicle. The use of a 980MPa class ultra-high-strength steel sheet for the structural members of an automobile seat is being promoted as a new field of application. However, an ultra-high-strength steel sheet cannot be applied easily to a wide variety of car components because its formability is comparatively poor. In this background, to offer a wide freedom of choice according to the characteristics required for fabricating different car components, Nippon Steel Corporation developed three types of ultra-high-strength steel sheets: one having excellent total elongation, another having enhanced local elongation for intensive bending deformation, and the third in which the two characteristics are combined in a balanced manner. This paper reports the characteristics of these three types of cold-rolled steel sheets of a 980MPa class, and some examples of their applications to the structural members of a car seat.

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2. Required Characteristics of Automobile Components for Which Ultra-high-strength Steel Sheets Are Used

Ultra-high-strength steel sheets are used mainly for bumper reinforcements, door impact beams and seat components. Generally, the formability (elongation, local elongation, and so on) of a steel sheet becomes poor as its strength increases. On the other hand, users of steel sheets are inclined to design a car component in a complicated shape so as to minimize its weight; thus, the workability required of a steel sheet becomes increasingly demanding.

Fig. 2 shows the components of an automobile seat, one of the fields where the use of ultra-high-strength steel sheets of a 980MPa class is increasing lately. The characteristics required of a steel material are explained below using seat components as examples. For a seat back side member, a good strain diffusion property is required for preventing warping of a work after forming; for realizing this, low yield strength, high elongation and a high n-value are effective. Stretch-flanging forming is also applied in its fabrication and for this reason, good local elongation is also required of a steel material, in a manner balanced with other properties. Excellent local elongation is important especially when a mechanical clinch is involved. For a seat rail where the forming is mainly bending, a material steel sheet must have an extremely good local elongation.

Both stretch forming and burring are employed for fabricating a lower seat arm and for this reason, a good balance between total elongation and local elongation is essential. When hole expanding is involved, excellent local elongation is required. As discussed above, simply having a high strength is not enough for an ultra-high-strength steel sheet; several other properties are also required of it depending on the final product for which it is used.

3. Assortment of Ultra-high-strength Steel Sheets According to Required Characteristics

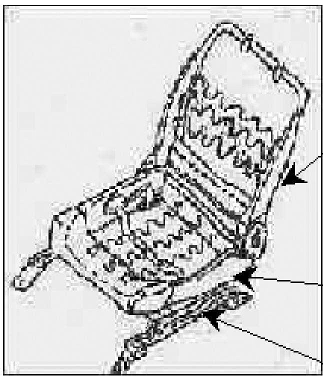
Nippon Steel Corporation improved the characteristics of ultra-high-strength steel sheets of a 980MPa class to realize the several different properties that are required for different automobile components and as a result, established a lineup of three different types of the product: an elongation type, a hole expandability type (bendability type), and a balanced type (see **Table 1**).

In the case of an ultra-high-strength steel sheet, if total elongation is increased the properties governed by local elongation such as hole expansibility (stretch flangeability) and bendability are deteriorated; this indicates that total elongation and local elongation are incompatible with each other. For this reason, different measures have to be taken to enhance each of these characteristics.

In the elongation type, it is necessary that the metallographic structure be a dual-phase structure containing ferrite, which is excellent in ductility, as the main phase for securing good total elongation, and a hard phase as the second phase. For this end, ferrite-forming elements are added to the steel and an optimum annealing temperature pattern is adopted at the processing on a continuous annealing and processing line (C.A.P.L.).

Regarding the hole expansibility type, on the other hand, it has been made clear that if the metallographic structure is not uniform and if strain concentrates locally, then the local strain concentration occurs at a soft phase near a hard phase and as a consequence, hole expansibility and bendability are deteriorated[2,3]. Based on this finding, measures are taken such that the hardness difference between the ferritic phase and the second phase is decreased and the heating temperature at the processing on a C.A.P.L. increased to homogenize the microstructure[3].

In the balanced type, the measures employed for the above two types are combined for realizing a good elongation and a high hole



Seat structure (schematic)

Typical component	Required workability
Seat back side member	Ductility Good strain diffusion Stretch flangeability
Mechanical clinch type (TOX mechanical clinching method)	High stretch flangeability (for securing mechanical clinch joint strength)
Seat lower arm	Ductility Bendability Hole expansibility (burring workability), etc.
Seat rails (lower/upper)	High bendability

Fig. 2 Required characteristics according to applications (Examples of seat components)

Table 1 Product assortment of 980-MPa class cold-rolled steel sheets

Material properties	High performance (low yield strength, high elongation, high n-value)	⟷	High local elongation (high hole expansibility, high bendability)
Product type	Elongation type (low yield strength)	Balanced type (balanced elongation and hole expansion ratio)	Hole-expansibility type (high hole expansion ratio)

expansibility in a balanced manner. The values of the total elongation and hole expansion ratio of the balanced type are intermediate between those of the above two types.

The application of ultra-high-strength steel sheets is expected to expand by appropriately choosing the most suitable type from among the three types, each having its properties featured as explained above, according to the properties required for the fabrication of different car components.

4. Material Properties of Ultra-high-strength Steel Sheets and Examples of Their Applications

Fig. 3 shows the relationship between the elongation (El) and hole expansion ratio (λ) of the developed three types of 980MPa class steel sheets.

The hole expansibility was measured through a hole expanding test, wherein a punch having an apex angle of 60° was forced into a punched hole 10 mm in diameter as shown in **Fig. 4**[4]. The hole expansion ratio (λ) is calculated as follows:

$$\lambda\ (\%) = \{ (d - d_o) / d_o \} \times 100$$

where, d is the diameter of the hole at the time when a crack propagates across the thickness of a specimen sheet, and d_o its original diameter.

The elongation type shows a total elongation of roughly 17%, considerably higher than that of the other two types. The hole expansibility type, on the other hand, displays a hole expansion ratio of roughly 90%, demonstrating its high hole expansibility (burring workability). The El and λ values of the balanced type are intermediate between the respective values of the elongation and hole expansibility types; thus it is suitable for applications where both ductility (El) and hole expansibility (λ) are required.

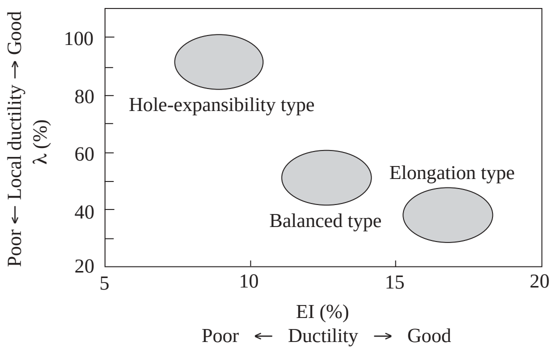


Fig. 3 Relationship between elongation and hole expansion ratio

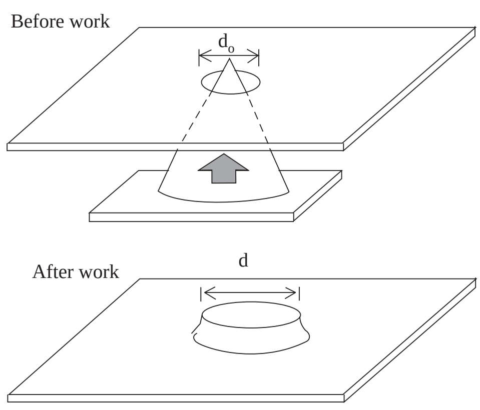


Fig. 4 Hole expanding test

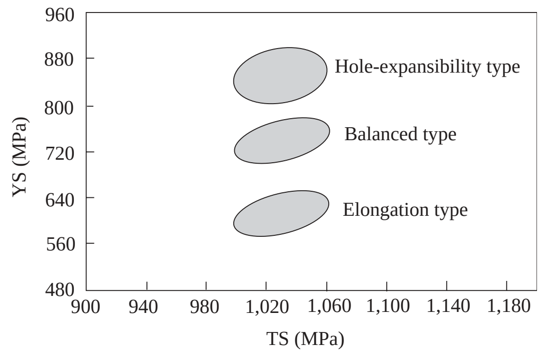


Fig. 5 Relationship between yield stress and tensile strength

Table 2 Property figures (thickness: 1.4 mm)

Product type	YS (MPa)	TS (MPa)	El (%)	λ (%)
Elongation type	624	1,008	17	43
Balanced type	737	1,012	13	55
Hole-expansibility type	843	1,011	10	92

Photo 1 Press-formed seat arm

Fig. 5 and **Table 2** show the relationship between the yield stress (YS) and tensile strength (TS) of the developed three types of products. It is clear from them that a steel sheet that has the most suitable yield stress can be chosen in accordance with envisaged application from among the products that have the same level of tensile strength.

Photo 1 shows an example where a steel sheet of the balanced type was used for a seat arm component. Here, there was no cracking during forming work, and shape freezing was good.

5. Summary

The characteristics and applications of 980MPa class ultra-high-strength steel sheets developed by Nippon Steel have been briefly presented in this paper.

An ultra-high-strength steel sheet was viewed as difficult to use, but its applicability has been expanded with the lineup of three types of the product: the elongation (low-YS) type suitable for applications such as bumper reinforcements; the hole expansibility type excellent in local formability and suitable for seat rails and a burring-worked component; and the balanced type suitable for a seat lower arm. The authors intend to continue contributing to the weight reduction and enhancement of collision safety of an automobile by further improving the product and expanding its applications through close cooperation with carmakers and component manufacturers.

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