Formability of TRIP Type Banitic Ferrite Steel Sheet

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In recent years, cold rolled steel sheets of 980MPa grade have been increasingly used for automotive parts to improve collision safety (crashworthiness) and to reduce body weight. Kobe Steel has developed a new 980MPa cold rolled steel sheet with elongation properties that are an improvement over conventional dual-phase (DP) steel sheets. This article focuses on the press formability of the newly developed steel sheet. Press formability testing was performed using a small-sized model die and a large-sized actual part die. The result clearly indicates that the developed steel sheet has a significantly improved press formability when compared with conventional DP steel sheets.

Introduction

The latest automobiles are required to have both improved collision safety and weight reduction and make wide use of high-strength steel sheets. However, steel sheets with higher strength tend to have poor elongation characteristics and are more prone to crack during press forming. Therefore, some auto parts must be made in separate pieces for ease of forming. To resolve the issue, several methods have been proposed, including multiple process steps for improving deep-drawing formability[1)] and dual punching to improve stretch flangeability[2)]. So far as the materials are concerned, the steel sheets that have been developed are of high strength and superior formability. Kobe Steel has developed a cold-rolled, transformation-induced-plasticity (TRIP) type, banitic-ferrite steel sheet of 980MPa grade (hereinafter referred to as the "developed steel"), which is suitable for auto body frames, with elongation characteristics that are an improvement over those of conventional dual phase (hereinafter referred to as "DP") steel sheets[3), 4)].

This paper describes the features of the developed steel and reports the results of formability tests conducted using a small laboratory scale die and a large die simulating actual parts.

1. Microstructure and mechanical properties of developed material

1.1 Microstructure

Steel sheets with improved workability have been needed as the applications of high tensile strength steel of 980MPa grade increase. In response, Kobe Steel aims at improving elongation characteristics, while maintaining stretch-flangeability in comparison with the conventional 980MPa grade DP steel sheet of a type focusing on elongation (hereinafter referred to as "980DP steel"). **Fig. 1**[3)] shows micrographs of the developed steel and 980DP steel. The developed steel contains a large amount of retained γ, which is morphologically controlled so as to be finely dispersed in elongated shapes to ensure elongation characteristics. The purpose of this is to increase the stability of retained γ such that the TRIP effect continues until the late stage of deformation.

1.2 Tensile properties

To evaluate the mechanical properties of the developed steel, tensile tests were conducted on specimens prepared according to JIS 5, using a 100kN autograph manufactured by Shimadzu Corporation. The cross-head speed was kept constant at 10mm/min. Comparisons were made with 980DP steel, as well as with 780MPa grade DP steel (hereinafter referred to as "780DP steel"). As shown in **Table 1**, the developed steel exhibits an elongation comparable to that of the 780DP steel and greatly exceeds that of the 980DP steel, implying its excellent formability. In addition, the developed

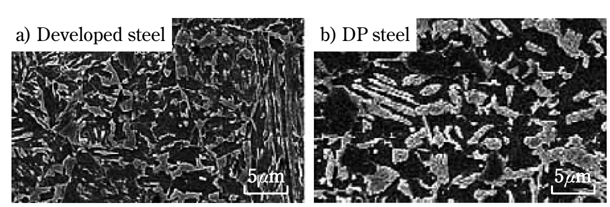


Fig. 1 Microstructure of 980MPa grade cold rolled steel sheets a) developed steel, b) conventional DP steel[3)]

Table 1 Mechanical properties of sample steels

(t : 1.4mm)

		YS (MPa)	*TS* (MPa)	*EL* (%)	*n* value 2-6%
a)	980 Developed steel	631	1,062	20	0.22
b)	980 DP steel	642	1,060	16	0.15
c)	780 DP steel	527	831	20	0.13

steel exhibits a n value (work hardening index) which is much higher than those of the reference steels, an indication of superior strain dispersibility. Thus, the developed steel advantageously suppresses the local reduction of thickness during press forming and is expected to enhance collision performance when used for parts in automobile body frames.

In order to verify the superior strain dispersibility of the developed steel, strain measurement using a non-contact strain measuring machine, ARGUS, manufactured by GOM mbH, was conducted in the longitudinal direction of the tensile specimens. A pattern of equally-spaced dots was provided on each specimen prior to the test. Each specimen was mounted on a tensile machine, elongated, and dismounted as soon as the strain reached 15%. After the deformation, the position relationships in the dot pattern were measured and the image was processed to evaluate the strain distribution. The measurement results, shown in **Fig. 2**, indicate that the developed steel exhibits less local strain concentration when compared with the reference steels, with the strain almost uniformly distributed within the specimen. The distributions in the thickness reduction rates of the specimens (**Fig. 3**) verify that local strain concentration is suppressed for the developed steel.

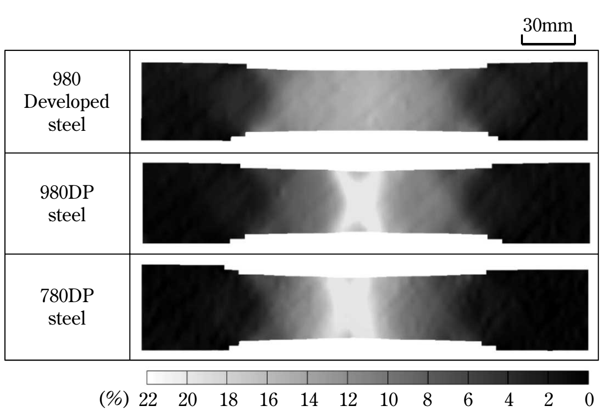


Fig. 2 Longitudinal strain distribution of tensile test specimen (strain：15%)

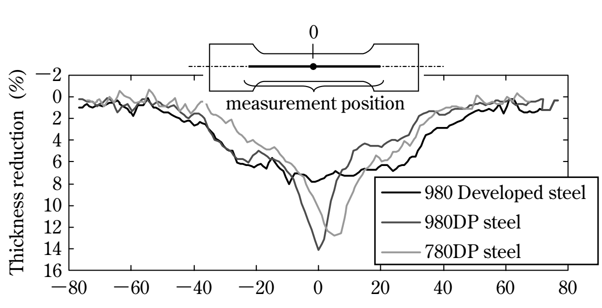


Fig. 3 Distribution of thickness reduction rate in tensile test specimen (strain：15%)

2. Formability of developed steel

The developed steel sheet was studied for its formability in terms of the four major forming modes of stretching, deep drawing, stretch flanging and bending. The thickness of the tested materials was 1.4mm.

2.1 Stretch formability

Fig. 4 depicts the testing apparatus. The stretch formability was evaluated by the maximum forming height, which is determined by the punch stroke, which causes failure with a rapid load drop in the load-stroke diagram. As a reference, the 980DP steel was also tested. The testing apparatus was a 500kN universal deep-drawing tester manufactured by TAKES-GROUP Ltd.

The maximum forming heights shown in **Fig. 5** verify that the developed steel has a formability superior to that of the 980DP steel. This result is as expected from the results of the tensile tests. The stretchability is reported to be affected by the elongation and n values of materials[5].

As in the case of the tensile test, the strain dispersion effect in the stretch formed samples was studied. Thickness reductions were measured on the developed steel and 980DP steel, both formed to a height of 17mm. As shown in **Fig. 6**, the thickness reduction rate for the developed steel is less than 30% even near the top where the reduction reaches the maximum. On the other hand, the 980DP steel exhibits a thickness reduction of about 35% for the same forming height, verifying the superior strain dispersibility of the developed steel in the stretching test.

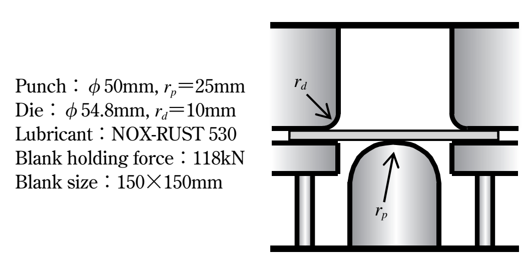


Fig. 4 Experimental apparatus for stretch formability

Fig. 5 Maximum forming height

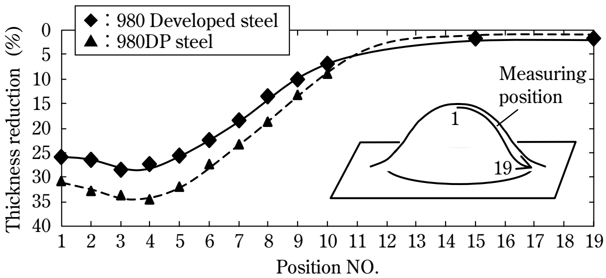


Fig. 6 Thickness reduction rate distribution of stretch test specimen (Forming height：17mm)

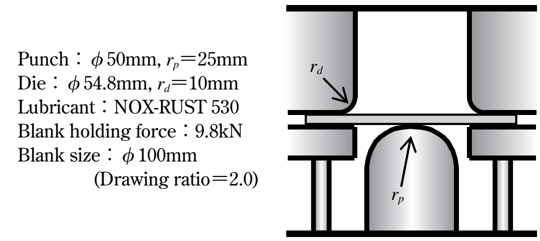


Fig. 7 Experimental apparatus for drawing formability

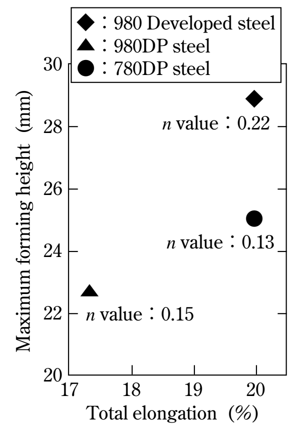


Fig. 8 Maximum forming height (Draw)

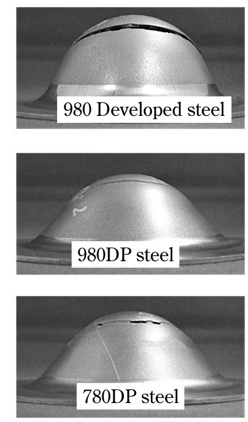


Fig. 9 Drawing test specimen

2.2 Deep drawing formability

Deep drawing tests were conducted using a punch having a spherical head with a head diameter of 50mm (**Fig. 7**). The maximum forming height at a drawing ratio of 2.0 was used as the evaluation index. The maximum forming height was determined by the punch stroke, which causes failure with a rapid load drop in the load-stroke diagram, just as in the case of the stretch formability test. Both the 980DP steel and 780DP steel were tested as reference materials. The tests were conducted using a 500kN universal deep-drawing tester manufactured by TAKES-GROUP. Ltd.

As shown in **Fig. 8**, the developed steel exhibits the best formability among the three types of steel tested. The difference can easily be seen in the photos of the formed samples (**Fig. 9**). The developed steel exhibits the highest total elongation and n value, the combined effect of which is considered to have led to its superior formability. As described above, the developed steel contains retained γ, which is considered to assure excellent strain dispersibility and to increase the strength at the punch shoulder portion by strain-induced transformation as well[6]. In other words, the excellent strain dispersibility is considered to allow the developed steel to have a larger thickness near the vertex in comparison with the DP steel. In addition, the greater strength increased by work hardening is considered to have enabled the developed steel to endure great resistance against the material flow into the flange. Another reason for the excellent formability is that, unlike conventional retained γ steel, the developed steel has finely dispersed retained γ in elongated shapes, such that work hardening continues until the late stage of the deformation. As for resistance against the material flow into the flange, the volume expansion associated with the strain-induced transformation of retained γ suppresses the transformation under the compressive stress generated by the drawn material. Furthermore, the strength increment due to work hardening, which is smaller than in the case of DP steel, decreases the flow resistance and contributes to the improved deep drawability of the developed steel.

2.3 Stretch flangeability

The stretch flangeability was evaluated by a hole-expanding test. The test was conducted according to the Japan Iron and Steel Federation Standard, JFST1001. The stretch flangeability of the developed steel is almost equal to that of the 980DP steel, as shown in **Fig.10**. In general, the stretchability and stretch-flangeability of a high-strength steel sheet are in a trade-off relationship. In other words, steel sheet having a superior stretchability tends to have poor stretch-flangeability and vice versa. The reason for the suppressed degradation of stretch-flangeability, despite the superior stretchability, compared with the 980DP steel, is that the developed steel has a fine and homogeneous microstructure that suppresses local cracking.

2.4 Bending formability

Bending formability is evaluated by the existence/nonexistence of a crack on the outer surface of a sample bent by V bending with a punch with a punch angle of 90 degrees. The punch tip radius, R, was varied from large to small. In this V bending test, each sample was placed such that the

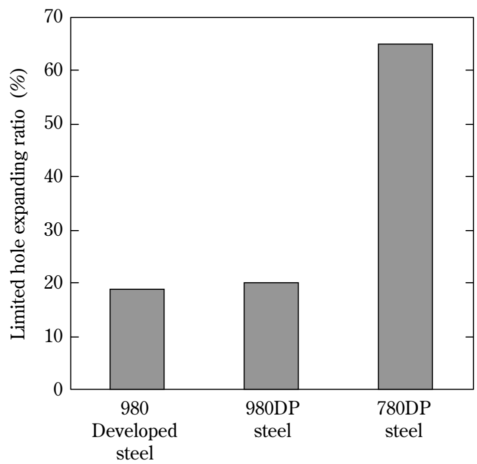
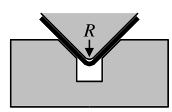


Fig.10 Limited hole expanding ratio of steels

Table 2 Bendability of steels

	90°V		
	R=0mm	R=0.5mm	R=1.0mm
980 Developed steel	△○	○○	○○
980DP steel	△△	○○	○○



○ : Good △ : Hair crack

rolling direction was parallel to the bending ridge line, and the punch was forced until the applied pressure reached 19.6kN. The test results are summarized in **Table 2**. They confirm that the developed steel has a bending formability almost equivalent to that of the 980DP steel. The developed steel sheet can be bent to the point where it is substantially U-shaped, which is considered to satisfy the bending workability required for body frame parts.

2.5 Formability evaluation using die simulating front pillar

As described above, the developed steel is superior in formability to the conventional type of DP steel sheet in all three of the aspects of stretchability, deep-drawability and bendability. Its stretch-flangeability has been confirmed as almost equal to that of the 980DP steel. To demonstrate the superior formability of the developed steel, an evaluation was conducted using a large-sized die simulating an actual part.

Kobe Steel once evaluated the formability of the developed steel using a die to simulate a B-pillar and confirmed the superiority of the developed steel[3]. The evaluation at that time, however, focused on the formability of deformation elements including only stretching and deep drawing, rather than the formability of an entire part, lacking the deformation element of stretch flanging; so this time the evaluation was conducted based on an A-pillar, which contains the deformation element of stretch flanging. A simulation die was used for evaluating the overall formability of the entire part.

Fig.11 is a photo showing the formed part. The A-pillars, currently in volume production, use steel sheets of either 440MPa grade or 590MPa grade steel sheets, and only a few employ the 980MPa grade. In many cases, this component is constructed in separate blocks, in which the pocket shape in the lower part of the vehicle is separated to avoid cracking during the press forming. The evaluation this time, on the other hand, was conducted by forming the part as a single piece without splitting. As shown in Fig.11, the press-formed shape requires a superb deep-drawability and stretchability, as well as a superior stretch-flangeability at the blank holder portion. As a reference, 980DP steel was also press-formed. The sheet thickness in either case was 1.4mm.

The blank holder force was varied from 800kN to 2,000kN, while checking for the existence/nonexistence of cracks and wrinkles. As shown in **Table 3**, the 980DP steel could be formed up to 1,300kN without cracking; however, wrinkling occurred in the seat surface facing the upper surface of the punch. These wrinkles, occurring inside the part, can be suppressed by increasing the blank holder force. The arrow in the table indicates the direction along which the wrinkle suppression

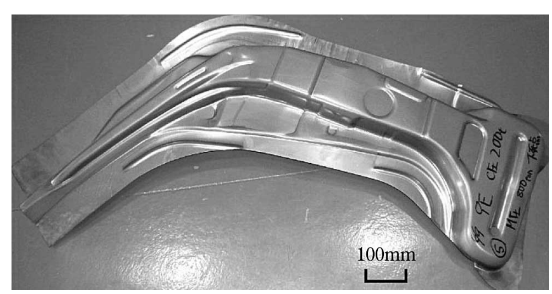


Fig.11 Shape of press test part

Table 3 Results of press test

BHF (blank holding force)	fracture		wrinkle
	980 Developed steel	980DP steel	
800kN	○	○	NG
1,000kN	○	○	
1,200kN	○	○	
1,300kN	○	○	
1,400kN	○	×	
1,500kN	○	×	
1,700kN	○	×	
2,000kN	○	×	Good

○ : Good × : fracture

becomes more advantageous. **Fig.12** shows an example of the wrinkles. A blank holder force greater than 1,400kN resulted in cracking in the stretch flange portion, as shown in **Fig.13**. The developed steel, on the other hand, was formable without causing any cracking up to the equipment capacity limit, a blank holder force of 2,000kN. Thus the developed steel can be used for increasing the strength of parts and for the reduction of production cost by single-piece forming. Furthermore, its excellent formability can be exploited to allow the product design of parts having deeper cross-sections and to improve collision performance.

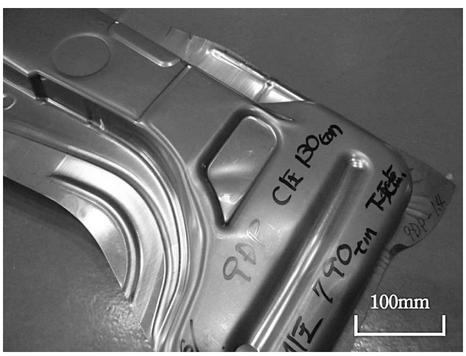


Fig.12 Example of wrinkle in test part (BHF=1,300kN 980DP steel)

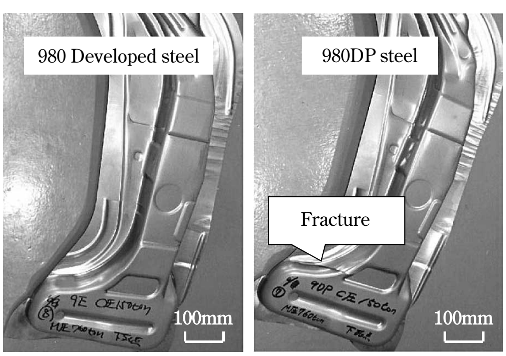


Fig.13 Example of press result (BHF=1,500kN)

Conclusions

A TRIP type, bainitic ferrite, 980MPa grade cold-rolled steel sheet with superior formability was introduced. This sheet has improved elongation characteristics, compared with conventional type DP steel.

The developed steel is superior in elongation characteristics and strain dispersibility compared with the conventional type DP steel and can be applied to body frame parts (forming).

A formability evaluation, using a small laboratory scale die, has confirmed that the developed steel has a formability exceeding that of conventional type DP steel in all the terms of stretching, deep-drawing and bending. It also exhibits a stretch-flangeability almost equal to that of the conventional material.

Dies for large, actual-size parts simulating a B-pillar and A-pillar were used to evaluate the formability of the developed steel. The results confirm that the developed steel has a formability that substantially exceeds that of conventional type DP steel. The developed steel can reduce costs by enabling the single-piece forming of parts which otherwise had been difficult to form and can increase the degree of freedom in improving collision performance.

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