Cold-rolled, 980MPa Grade Steel-sheets with Excellent Elongation and Stretch-flangeability

Masaaki MIURA, Michiharu NAKAYA, Youichi MUKAI; Research and Development Laboratory, Kakogawa Works, Iron and Steel Sector

Ultra-high strength steel-sheets have been used increasingly for automotive body parts to improve crash worthiness while reducing body weight so as to decrease gas emissions for environmental protection. In response to these trends, Kobe Steel has developed several types of 980MPa grade cold-rolled steel-sheets. This article describes the features of two, newly developed, 980MPa grade cold-rolled steels. They are featured by excellent formability due to a superior balance between stretchability and stretch-flangeability. These newly developed steels also exhibit satisfactory performance, such as weldability and phosphatability, required for practical applications.

Introduction

An increasing amount of high-strength steel is used for automotive structures in order to meet requirements for crash-safety, weight-reduction and decreased exhaust-emissions. Kobe Steel has been building a reputation for its 980 MPa grade, cold-rolled steel-sheets optimally formable into various shapes of automotive parts[1). As these steel-sheets are used for an increasing number of applications, the steels are required to have further improved formabilities. In response to such requirements, Kobe Steel has newly developed 980 MPa grade cold-rolled steels, each having an improved balance of elongation and stretch-flangeability (λ-value), two properties which otherwise had been difficult to achieve simultaneously by the conventional technology. This paper summarizes the concept of microstructure control and the main properties of the developed steels.

1. Microstructure control of high-strength steel-sheets for simultaneously achieving high elongation and high stretch-flangeability (λ -value)

Generally, martensite is required in steel's microstructure to achieve a ultra-high strength of 980 MPa grade while reasonably maintaining other properties required for automotive applications, such as press-formability, spot-weldability and phosphatability. The martensite dominant microstructure, however, causes difficulties in securing the elongation required for press-forming the steel-sheet into automotive body shapes. To improve elongation, various microstructure control techniques have been developed which include combining martensite with softer ferrite and introducing residual austenite (γ) that transforms into martensite, dispersing strain during press-forming steps.

1.1 Development of dual-phase type steel-sheets with high elongations and high λ-values

Kobe Steel has been intensively investigating how to improve formabilities of multi-phase steel-sheets, in particular dual-phase (DP) steel-sheets consisting essentially of ferrite and martensite. The company has already established the technologies for manufacturing 980 MPa grade, cold-rolled steel-sheets having well balanced elongations and λ-values. The technologies involve independently controlling the volume fraction and hardness of martensite using a continuous-annealing- furnace of water-quenching type[1)-4)]. These studies have focused mainly on compensating the difference in hardness between the martensite and ferrite, the difference which causes the lack of stretch-flangeability, a major drawback of DP steel-sheets.

Fig. 1 depicts typical techniques employed in improving the elongation and stretch-flangeability of multi-phase, high-strength steel-sheets, including the DP steel-sheets[5), 6)]. Conventionally, those techniques exert opposite effects on elongation and stretch-flangeability (λ-value), making it difficult to simultaneously achieve both the properties at a high level.

In this situation, an attempt has been made to improve the elongation / λ-value balances of high-strength steels by securing significant amounts of ferrite while maintaining finely and homogenously dispersed martensite in steel's matrixes. More particularly, the following techniques, used for the microstructure control of conventional DP steel-sheets[4)], have been applied to the development of new steels:

1) Volume fraction control of martensite by carbon content;
2) Hardness control of ferrite by solid-solution hardening additives;
3) Microstructure control of hot-rolled plates[8)]; and

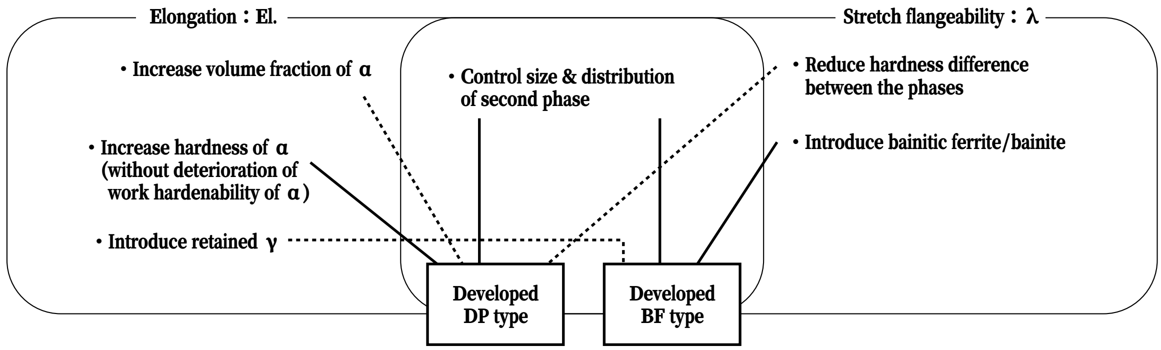

Fig. 1 Metallurgical concepts for improving elongation and λ-value in multi-phase high-strength sheet-steel

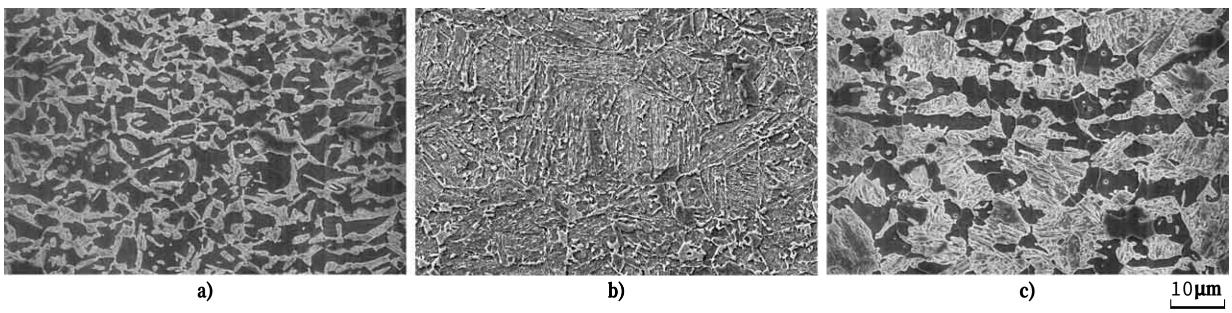

Photo 1 Microstructure of a) DP type developed steel, b) BF type developed steel and c) conventional steel (DP-bending type)

Table 1 Chemical compositions and mechanical properties of 980MPa grade cold rolled sheet-steels

(t : 1.2mm)

			C (mass%)	Si(mass%)	Mn (mass%)	YS (MPa)	TS (MPa)	El.(%)	λ(%)
a)	Developed	DP type	0.09	1.3	2.0	760	1,010	15	60
b)	steel	BF type	0.16	1.3	2.2	770	1,020	15	60
c)	Conventional	Bending type	0.16	1.3	2.0	770	1,010	12	65
d)	DP steel	Moderate type	0.16	1.3	2.0	690	1,030	14	40
e)		Drawing type	0.16	1.3	2.0	610	1,010	17	25

4) Volume fraction control of each phase during the continuous-annealing process step[1].

Based on the above concepts, the volume fraction of the solid-solution hardened ferrite was increased without connections of contiguous ferrite grains. As a result, a new process technology has successfully been implemented which provides a microstructure having martensite finely and homogenously dispersed at ferrite grain boundaries.

Photo 1-a) shows an example of the microstructure of the developed DP type steel. Photo 1-c) shows the microstructure of a conventional DP type steel by way of comparison. The microstructure of the developed steel has finely dispersed martensite with increased volume fraction of ferrite. Although the ferrite volume fraction is increased from about 40% of the conventional DP steel to about 60%, fewer ferrite grains is observed to be connected with others in the developed steel. The morphology, having ferrite surrounded by a network of martensite, is considered to improve elongation. This is because the ferrite, having increased internal stress, retains a high work hardening rate until the later stage of deformation[9]. The network of martensite also serves to prevent propagation of cracks induced at the interface between martensite and ferrite during stretch flange forming and thus improves the λ-value.

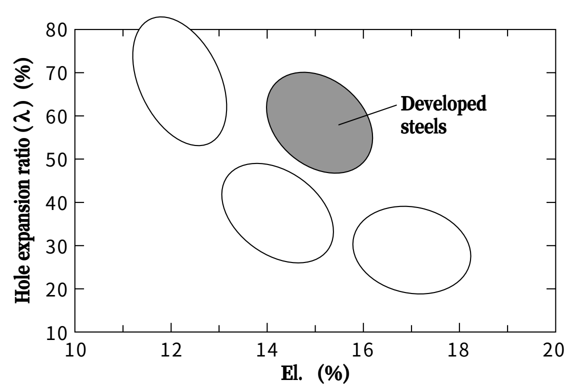

Fig. 2 Elongation and λ-value of 980MPa grade cold rolled sheet-steels

Table 1-a) shows the typical compositions of the developed DP type steel-sheet and the mechanical properties of the steel-sheet of 1.2 mm thick. Also included in the table are the compositions and mechanical properties of three types of conventional DP steel-sheets, i.e., bending-type, moderate-type and drawing-type[3), 4)]. **Fig. 2** depicts the elongation-

λ balance of the developed and conventional steels. The developed DP type steel exhibits well balanced elongation and λ in comparison with the conventional steels, with its elongation and λ consistently falling in the range of ≥ 14% and ≥ 50%, respectively.

1.2 Development of bainitic-ferrite type steel with a high elongation and high λ-value

Steels containing residual austenite (γ) can be elongated well due to transformation induced plasticity (TRIP) effect, however they suffer from the lack of stretch-flangeability as in the case of DP steels[6), 10)]. Kobe Steel has been focusing on bainitic ferrite (BF) as a microstructure for achieving high-strength and excellent stretch-flangeability[11)]. The company developed a high-strength steel-sheet, TRIP-type BF (TBF), which comprise finely dispersed residual γ in between laths in the BF matrix[12)].

Based on this, Kobe Steel has established a process for producing a new BF steel-sheet with a high elongation and high λ-value. To establish the process, the following technologies were developed:

1) The microstructure control of BF involving rapid cooling from an austenite range temperature during the continuous annealing process step; and
2) The volume fraction / morphology control of the residual γ by adjusting the amount of alloying elements and austemper temperature.

Photo 1-b) shows the microstructure of the developed BF steel. The microstructure has a matrix of banitic ferrite (BF) consisting essentially of submicron sized laths. A transmission electron microscopy observation revealed the existence of film-like residual γ in between the laths.

Table 1-b) shows a typical composition and mechanical properties of the BF type steel-sheet developed. The developed BF type steel also exhibits a well balanced elongation and λ-value, as in the case of the new DP steel, with its elongation and λ consistently falling in the range of ≥ 14% and ≥ 50%, respectively.

2. The practical performance of the developed steel

2.1 Formability

The press formability of a steel-sheet is roughly classified into four modes, i.e., stretch-flangeability, bending-formability, stretch-formability, and drawing-formability. Some details have been described above regarding the stretch-flangeability in terms of λ-value. The following describes the test results on the bending-formability, stretch-formability and drawing-formability of the developed steels.

The bending-formability was evaluated on sheet samples (30 x 100 x 1.2 mm) using a die as shown in **Fig. 3.** Several punches, each having a tip radius in the range from 0 to 2.5 mm and a 90˚ tip angle, were used to determine the minimum bending-radius that causes no crack for each sample. The bending direction was set perpendicular to the rolling direction. For comparison, conventional DP steel-sheets of the moderate- and bending-types as shown in Table 1 were also evaluated. **Fig. 4** shows the results. The newly developed DP type steel-sheet exhibited a minimum bending radius of 0.5 mm which is much smaller (better) than the conventional moderate-type DP steel-sheet. Meanwhile, the BF type steel did not crack even when bent with zero tip-radius (R0) and exhibited an excellent bending formability comparable to the conventional DP type steel. It was found that the order of bending formability of DP steel-sheets roughly correlates with their λ-values. This corresponds to the previous results showing that both the bending formability and stretch-flangeability of steel-sheets correlate with their local ductilities[3), 13)]. In contrast, the developed BF type steel has a bending formability superior to that of the DP steel having a similar λ-value. This result may be attributable to the extremely fine distribution of the second phase in the matrix[14)].

The stretch-formability was evaluated using a die having an inner diameter of Φ53.4 mm and a punch having a diameter of Φ50.0 mm with a spherical head (r=25 mm). Each sample sheet of 140 x 140 mm

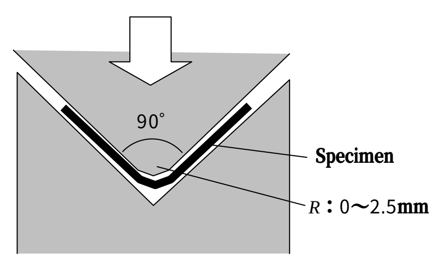

Fig. 3 Schematic illustration of bendability measurement apparatus

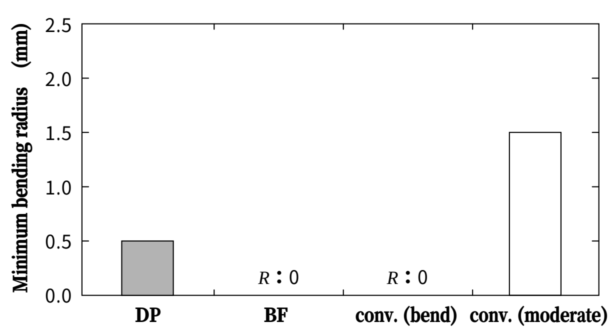

Fig. 4 Bendability of 980MPa grade cold rolled sheet-steels

was held down to the die with a blank holding force of 118 kN to prevent wrinkling. The forming height, to which a sample sheet can be formed without a fracture, was measured for each sample as its index of stretch-formability. The results are shown in **Fig. 5**. Also included in the figure are the results for conventional DP steel-sheets of bending-type and drawing-type. The developed DP steel exhibits a forming height comparable to that of the conventional bending-type steel, while the new BF steel shows a stretch-formability superior to the conventional drawing-type steel. It should be noted that the BF steel demonstrates superior formability despite of its elongation value which is smaller than that of the conventional drawing type DP steel. This is attributable to the plasticity induced by residual γ, which increases work hardening coefficient during the equibiaxial deformation and disperses strain[14].

The drawing-formability was evaluated using a cylindrical die with a inner diameter of Φ53.4 mm. A rod-shaped punch with a diameter of Φ50.0 mm and shoulder radius of 8 mm was pressed against disk shaped samples having Φ80mm to Φ140 mm diameters, each held down to the die with a blank holding force of 9.8 kN to prevent wrinkling. The test results are compared in **Fig. 6**. The developed DP steel is ranked between the conventional bending-type and drawing-type DP steels, while the BF type exhibits a drawing-formability better than the conventional drawing type steel. The excellent drawing-formability of the BF type steel is considered to be attributable to the difference in the transformation of residual γ induced by plasticity. The transformation induced plasticity is dependant on deformation mode, which works to decrease the load for shrink flanging at the center portion compare to the amount of work hardening at the shoulder portion.

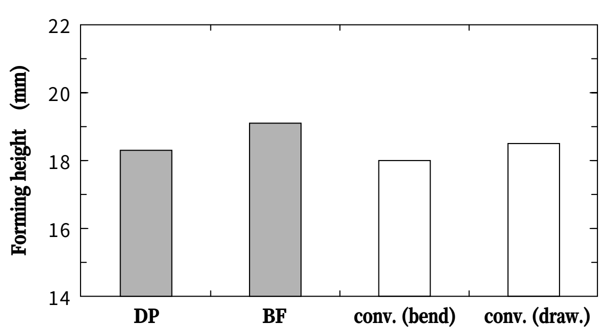

Fig. 5 Stretch-formability of 980MPa grade cold rolled sheet-steels

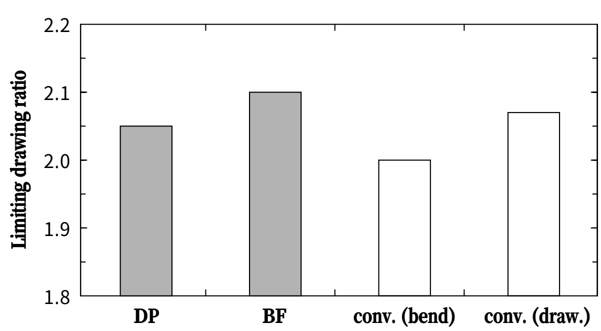

Fig. 6 Deep drawability of 980MPa grade cold rolled sheet-steels

2.2 Spot-weldability

The spot-weldability of the developed steel was evaluated by the joint strength of sample sheets welded in the current range of 5 to 17 kA and under the conditions shown in **Table 2**. **Fig. 7** shows the results of tensile-shear and cross-tension strength measurements. The tensile-shear strengths of the DP type and BF type steels are high enough to satisfy the load specified by JIS-A, or 8.78 kN for a nugget diameter of Φ4.7 mm. A welding current range of 2.5 kA or higher may adequately be applied without causing expulsion. Both the steels have high ductility ratios (cross-tension strength / tensile-shear strength), i.e., 0.45 or higher for the DP steel and 0.40 or higher for the BF steel. Generally, in the case of steel-sheets containing residual austenite (γ), carbon added in a relatively large amount can cause decrease in joint strength. Each of the developed steels, however, retains excellent weldability with an optimized C content, as well as Si content which improves welding joint strength[15].

Table 2 Spot welding conditions

Electrode tip	Dome type Cu-Cr, tip diameter : 6mm
Electrode force	4,000N
Welding time	16cycles (60Hz)
Welding current	5-17kA

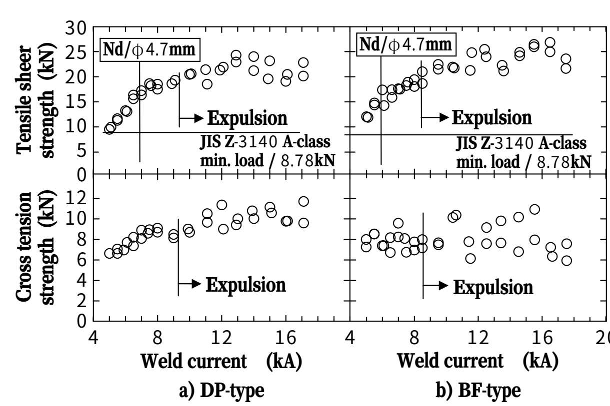

Fig. 7 Relation between tensile-sheer/cross-tension strengths and welding current

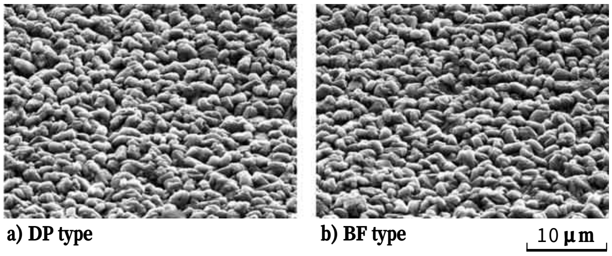

Photo 2 Micrograph of phosphate crystal on developed steels

2.3 Phosphatability

The surfaces of the developed steel-sheets were coated with phosphate by dipping the sheet samples into a commercially available solution (e.g., PALBOND L3020, manufactured by Nihon Parkerizing Co.,Ltd.). **Photo 2** shows the micrographs of the phosphate coatings on DP steel-sheet and BF steel-sheet samples. Each the sample exhibits excellent coating characteristics with optimal crystal grain size and morphology without any coating defect. In general, Si, which improves mechanical properties and spot-weldability, tends to deteriorate phosphatability. Kobe Steel has resolved various issues related to the production of steel having high Si content, after long time research[1] including the structural analyses of surface oxide films[16].

Conclusions

The characteristics have been described of the newly developed, 980 MPa grade, DP and BF steels with high elongations and high λ-values. Both the steels have roughly equivalent elongations and λ-values. The BF steel is suited for applications, in which severe drawing- and / or stretch-formability are required. The DP steel is most suitably used where stable weld strength is essential.

Increasing amount of high-strength steel is expected to be used in more number of automotive body applications. Kobe Steel will keep striving to further improve formability and other practical performance of high-strength steel, based on the newly developed 980 MPa grade, high-elongation, high λ-value steel-sheet.

References

1) Y. Omiya, *R&D Kobe Steel Engineering Reports*, Vol.50, No.3 (2000), p.20.
2) M. Miyahara et al., *R&D Kobe Steel Engineering Reports*, Vol.35, No.4 (1985), p.92.
3) Y. Tanaka et al., *R&D Kobe Steel Engineering Reports*, Vol.42, No.1 (1992), p.20.
4) T. Tamura et al., *R&D Kobe Steel Engineering Reports*, Vol.52, No.3 (2002), p.6.
5) Y. Tomota et al., *Tetsu-to-Hagane*, Vol.68, No.9 (1982), p.1147.
6) K. Makii, *Improvements in the Strength and Reliability of Steels, The Iron and Steel Institute of Japan* (1997).
7) Y. Mukai, *R&D Kobe Steel Engineering Reports*, Vol.55, No.2 (2005), p.30.
8) H. Shirasawa, *Tetsu-to-Hagane*, Vol.73, No.5 (1987), p.124.
9) K. Sugimoto et al., *Tetsu-to-Hagane*, Vol.71, No.8 (1985), p.994.
10) H. Shirasawa et al., *Tetsu-to-Hagane*, Vol.74, No.2 (1988), p.326.
11) T. Kashima et al., *CAMP-ISIJ*, Vol.6, (1993), p.1696.
12) K. Sugimoto et al., *ISIJ-Int*., Vol.40, No.9 (2000), p.920.
13) J. Iwaya et al., *J. Jpn. Soc. Techno. Plast*., Vol.35, No.404 (1994), p.1122.
14) M. Nakaya et al., *CAMP-ISIJ*, Vol.18 (2005), p.1484.
15) Y. Tanaka et al., *Tetsu-to-Hagane*, Vol.68, No.9 (1982), p.1411.
16) M. Nomura et al., *Tetsu-to-Hagane*, Vol.92, No.6 (2006), p.378.