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Cold Rolled Steel Sheets with Ultra High Lankford Value and Excellent Press Formability*



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1 Introduction

Cold rolled steel sheet possessing a high Lankford value (r-value) is widely used in the automotive industry as the most suitable material for deep draw forming. A brief history of the improvement of the r-value of the deep drawable cold rolled steel sheet at Kawasaki Steel is presented in **Fig. 1**[1].

The highest r-value of commercial cold rolled steel sheets at present is about 2.2 in EDDQ steel, which is achieved by adopting an IF (interstitial free) chemistry with the carbon content reduced to about 20 ppm and stabilized by Nb, Ti, and the continuous annealing process. EDDQ steel is widely used in various automotive applications which require improved formability.

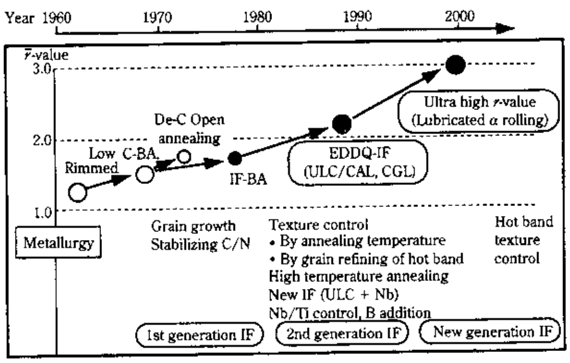

Fig. 1 History of development of deep drawable cold-rolled steel sheet

Recently, however, a higher r-value than that of EDDQ has been required for wider integrated panels and more complicated parts such as oil pans and side panel outers. In response to these needs, Kawasaki Steel developed a new technology called the "lubricated ferrite rolling process", making it possible to obtain r-values higher than 2.9 for the first time in the world[2].

The most difficult technical breakthrough in realizing the "lubricated ferrite rolling process" was how to prevent the slipping of the sheet bar at the threading into the finishing mill, given the heavy lubrication. The layout of the new hot strip mill constructed at Chiba Works of Kawasaki Steel in 1995 is shown in **Fig. 2**. The fully continuous, or "endless" hot-rolling has been accomplished through a welded sheet bar between the rougher and the finisher[3]. This "endless hot strip mill" makes it possible to employ heavily lubricated hot-rolling over the full length of a hot strip with stable condition.

This paper describes an overview of the metallurgical background of the "lubricated ferrite rolling process" and describes the formability of the newly developed

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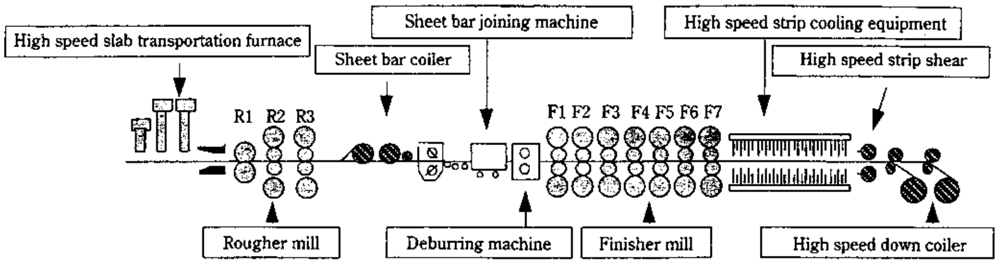


Fig. 2 Layout of new endless hot strip mill at Chiba Works of Kawasaki Steel

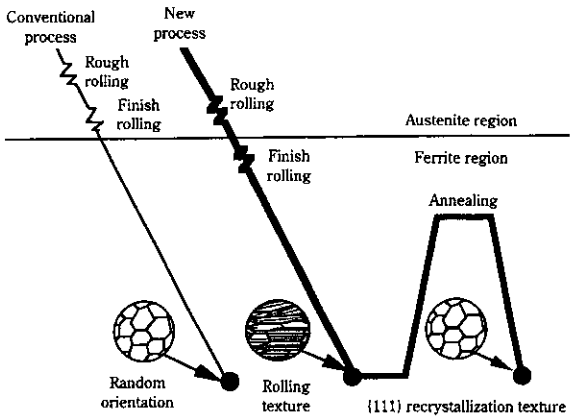


Fig. 3 Comparison of mechanism of {111} texture development in lubricated ferrite rolling process with conventional one

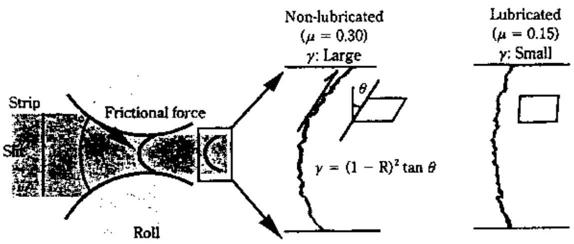


Fig. 4 Effect of lubrication on reduction of shear strain of a hot strip (μ: friction coefficient, γ: additional shear strain, R: reduction ratio)

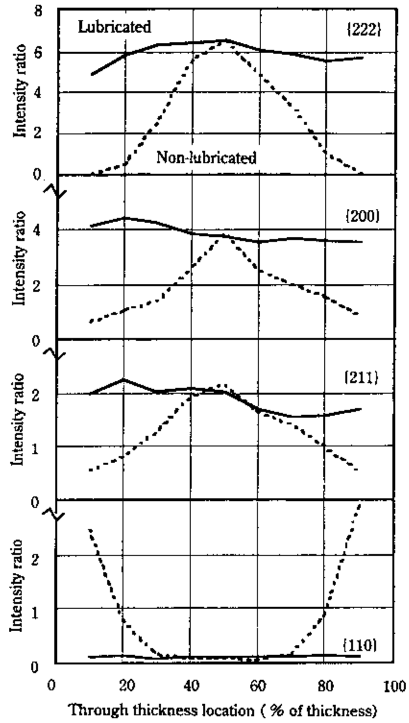


Fig. 5 Effect of lubrication on the texture of hot band (lubricated: $\mu = 0.1$, non-lubricated: $\mu = 0.2$)

cold rolled steel sheets obtained through this technology.

2 Metallurgical Background of Lubricated Ferrite Rolling Process

It is well known that the drawability of steel sheets strongly depends on the polycrystalline orientation, with the {111} texture being most favorable for improving the r-value[4].

Figure 3 shows the mechanism of {111} texture formation by the "lubricated ferrite rolling process" in comparison with the conventional hot-rolling process. In the conventional process, the {111} texture cannot be developed because hot-rolling must be finished above the Ar_3 temperature in order to obtain a fully recrystallized structure, resulting in an almost random crystalline orientation. On the other hand, the newly developed process can realize a strong {111} intensity after hot-rolling over the full thickness of a strip, because the {111} structure generated due to the finishing temperature in the ferrite region is developed by the strong lubrication in the finishing mill, which reduces the strong shear strain in the strip surface. This {111} recrystallization texture can be significantly developed by annealing after hot-rolling. The hot strip obtained in this way exhibits extremely high r-values after cold-rolling and annealing.

The heavy lubrication is required to achieve a uniform texture over the full thickness of the strip. **Figure 4**

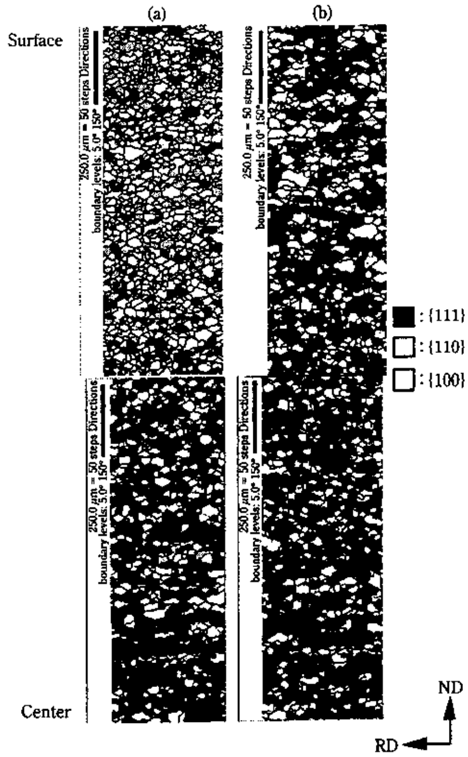


Fig. 6 EBSD map showing effect of lubrication on texture of hot band after 750°C × 5 h annealing: (a) non-lubricated: $\mu = 0.3$, (b) lubricated: $\mu = 0.1$

shows a comparison of the strain distribution with and without lubricated rolling. In a non-lubricated condition ($\mu = 0.3$), a large gradient (tan θ) in the metal flow line means the introduction of significant shear strain[5]. On the other hand, the heavily lubricated rolling ($\mu = 0.15$) results in a nearly straight flow line, with negligibly small shear strain at the same rolling reduction. The additional shear strain introduced without lubricated rolling develops the <110>//ND texture, reducing the preferable {111} texture, as shown in **Fig. 5**.

Figure 6[6] shows a diagram of the crystalline orientation of the grains in a hot strip after annealing with and without lubricated rolling, which is evaluated by EBSD (electron back scattering diffraction). In the surface of the non-lubricated hot strip, the <110>//ND texture introduced in hot-rolling remains predominant after annealing, as reported previously[7], causing poor development of {111} grains. On the other hand, the lubricated hot strip represents strong {111} orientation after annealing.

3 Formability of Newly Developed Cold Rolled Steel Sheets

The typical mechanical properties of the newly developed cold rolled steel sheet, which is produced by lubricated ferrite hot-rolling followed by cold-rolling and annealing, are shown in **Table 1**. The r-values obtained in this way are compared to those in conventional IF steel as shown in **Fig. 7**. It is clear that the lubricated ferrite rolling process can remarkably improve the r-value, resulting in the highest level in the world (Ave: 3.0).

Table 1 Typical mechanical properties of newly developed cold rolled steel sheet (t = 1.2 mm)

YS (MPa)	TS (MPa)	El (%)	$\bar{r}$	Δr
140	280	55	3.0	0.4

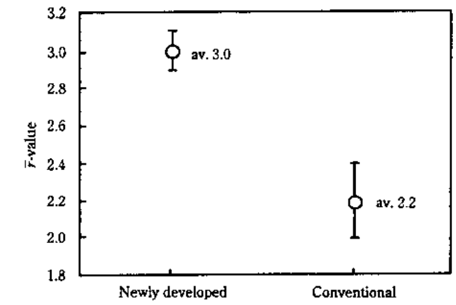


Fig. 7 Comparison of $\bar{r}$-value of steel sheets in newly developed process with conventional one

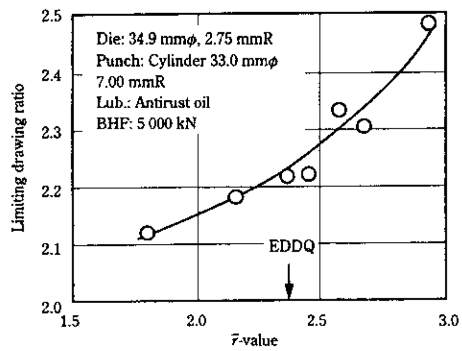
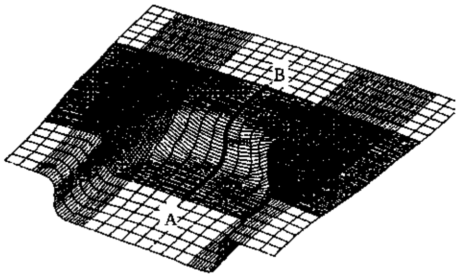


Fig. 8 Effect of $\bar{r}$-value on drawability

Figure 8 shows the effect of the r-value on drawability, as evaluated by the limit drawing ratio obtained by the Swift cup test. The maximum height of cups for the newly developed cold rolled steel sheet (r-value: 2.9) is shown in **Photo 1** and compared with that of a conventional one (r-value: 2.5/best value). It is abvious that the higher r-values mean better drawability, and the newly developed cold rolled steel sheet represents superior drawability over the conventional one.

The newly developed cold rolled steel sheets are expected to be used in automotive parts such as side panels and oil pans, which require better drawability. Since the formability of actual parts is often affected by



Name of FEM code: LS-DYNA version 940
Number of nodes: 2 701 (sheet), 375 (tools)
Number of elements:
2 592 (sheet) Belytschko-Tsay shell element, 300 (too
Hardware: SUNW, Ultra-1
Punch diameter: 600 mm
Radius of punch shoulder: 50 mm
Radius of die shoulder: 40 mm
Sheet thickness: 0.7 mm
Yield strength: 140 MPa

Fig. 9 Model of real floor panel and analysis conditions

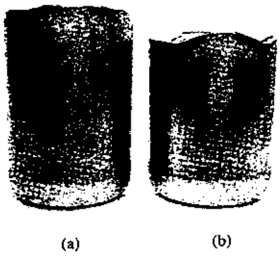


Photo 1 Comparison of maximum height of cup (a) developed ($\bar{r}$ = 2.9), (b) conventional steel sheets ($\bar{r}$ = 2.5) (Deep drawing condition are shown in Fig. 8)

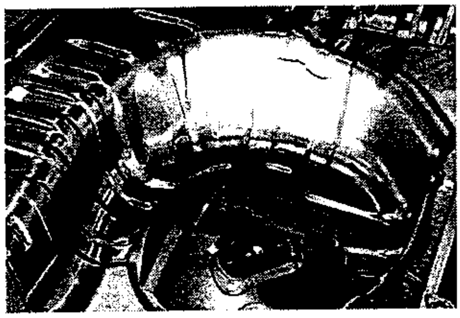


Photo 2 View of real floor panel used for computer simulation, showing breakage in wall

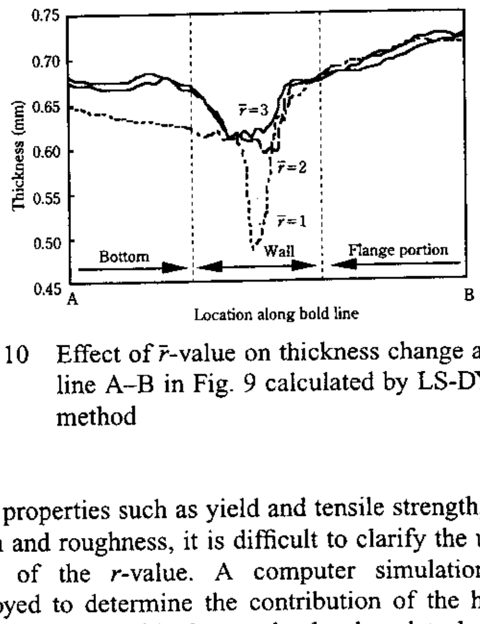


Fig. 10 Effect of $\bar{r}$-value on thickness change along line A–B in Fig. 9 calculated by LS-DYNA method

many properties such as yield and tensile strength, elongation and roughness, it is difficult to clarify the unique effect of the r-value. A computer simulation was employed to determine the contribution of the high r-values obtained with the newly developed technology. As an example, the rear floor panel shown in **Fig. 9** was used in a calculation. The computer simulation was completed by LS-DYNA, which is an explicit nonlinear finite element program. **Figure 10** shows the change in thickness along line A–B in Fig. 9 when the r-value of the steel sheet was varied. At the wall, where breakage tended to occur as shown in **Photo 2**, thickness reduction could be substantially avoided by using material with a high r-value of 3.0. Therefore, we concluded that a high r-value can improve the formability of actual parts.

4 Conclusion

Kawasaki Steel has established the "endless" hot-rolling technology for the first time in the world, and succeeded in applying heavy lubrication over the full length of a hot strip at ferrite finishing temperature with consistent results. A new cold rolled steel sheet with a higher r-value than that of the conventional EDDQ grade has been successfully developed with the application of the hot strip obtained in this new "lubricated ferrite rolling" technology, and has been applied to automotive parts, which are subject to complex and heavy press deformation. This technology can be applied not only to cold rolled but also to various coated, high tensile steel sheets.

References

1) T. Obara and K. Sakata: Proc. of 39th Mechanical Working and Steel Processing Congress, Indianapolis, (1997), 307
2) K. Sakata, S. Matsuoka, T. Obara, K. Tsunoyama, and Shiraishi: *Materia Japan*, **36**(1997), 376
3) Y. Ogawa, T. Nakamura, and N. Kitao: *Kawasaki Steel Giho*, **27**(1995)3, 131
4) S. Nagashima: "Shugososhiki", (1984), 268, [Maruzen]
5) K. Kato: *Nihon Kinzoku Gakkai Ho*, **23**(1984), 996
6) K. Okuda, Y. Kawabata, K. Sakata, and T. Obara: Proc. of 39th Mechanical Working and Steel Processing Congress, Indianapolis, (1997), 297
7) S. Matsuoka, T. Obara, K. Tsunoyama, T. Sakai, Y. Saito, and K. Kato: Proc. of the 1986 Autumn Meeting of JIM, (1986), 136