New Products & Technologies

KTM-D Sheet Steel with Superior Deep Drawability and Direct-on Enameling Property*

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1 Introduction

Various types of enameling sheet steels have been developed by the continuous casting-continuous annealing process.[1-3] However, it is difficult to produce sheet steels that combine deep-drawability and enameling properties suitable for direct-on enameling as in decarburization-annealed rimmed steels made from ingots, and it has therefore been impossible to shift the material from ingot-cast steels to continuously cast, continuously annealed steels. Kawasaki Steel recently succeeded in developing KTM-D sheet steel that combines deep drawability and enameling properties using a boron-added medium-oxygen steel[1] already produced by Kawasaki Steel.

2 Composition Design of New Enameling Sheet Steel

The chemical composition of the newly developed enameling sheet steel was designed as shown in **Table 1** to improve the various properties required of enameling sheet steel. The typical mechanical properties are compared with those of the conventional steel in **Table 2**. The new steel is softer than the conventional steel and has higher elongation (El) and a higher Lankford value (r-value), which is a scale for deep-drawability, than the conventional steel. In addition, this steel is characterized by improved resistance to aging deterioration at room temperature because of its low aging index (AI).

The effects of manufacturing conditions on these mechanical properties and other enamel properties are described below.

Table 1 Concept of chemical compositions for newly developed KTM-D sheet steel

Properties \ Steel	Conventional		Developed
Improvement of press formability, anti-sagging and anti-bubbling	0.013%B added extra-low C (C : 0.002%)	→	'0.02%Nb-0.013%B' added extra-low C (C : 0.002%)
Improvement of anti-fishscaling	BN, B_xO_y (MnO)	→	BN, B_xO_y (MnO, NbC, Nb_xO_y)
	0.013%B-0.007%N-0.013%O		0.013%B-0.007%N-0.018%O 0.02%Nb
Improvement of adhesion and weldability	Medium O (0.013%O)	→	Medium O (0.018%O)
Improvement of anti-blister	(0.015%P)	→	Low P (≦0.010%P)

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Table 2 Typical mechanical properties

Steel	YS (MPa)	TS (MPa)	El (%)	YEl (%)	AI (MPa)	$\bar{r}$-value
Newly developed KTM-D	160	310	49	0	20	1.8
Conventional	190	300	46	0	40	1.3

Thickness : 0.8mm, as temper-rolled

3 Effects of Chemical Compositions on Various Properties

3.1 Effect of Nb Addition on Deep Drawability

In the newly developed steel, the properties in the diagonal direction (D) to the rolling direction are greatly improved by adding niobium at an atomic ratio of not less than 1.0 with respect to carbon (**Fig. 1**). High-temperature continuous annealing is conducted to obtain a high average r-value ($\bar{r}$).

3.2 Effect of Oxygen Content on Adherence of Enameling Layer

The effect of the oxygen content on the adhesion of the enameling layer processed by the direct-on enameling treatment is shown in **Fig. 2**. Stable adhesion is obtained when the oxygen content is 130 ppm or more. Good adhesion can also be obtained when 2-coat, 2-bake enameling is conducted and when a ground-coat frit suitable for non-pickling pretreatment is used.

3.3 Effects of Nb Addition and Oxygen Concentration on Anti-Fishscaling Property

To improve the anti-fishscaling property, the oxygen content of the new steel is higher than that of the conventional steel. B_xO_y serves as the trap site for hydrogen. Carbides of niobium are also used for the same purpose.[4] In this newly developed steel, therefore, the diffusion coefficient (D_H) of hydrogen through the steel is small, as shown in **Fig. 3**, and the anti-fishscaling property is superior to that of the conventional steel.

3.4 Effect of Nb Addition on Anti-Sagging Property

Because enameled sheets are fired at high temperatures of above 800°C after temper rolling or press forming, their shape is tends to change due to their dead weight and thermal expansion. In the new steel, since fine NbC particles of about 10 nm in diameter precipitate, grain growth is retarded. At the same time, the amount of critical strain at which abnormal grain growth occurs shifts to the high-strain side. For this reason, the anti-sagging property is good.

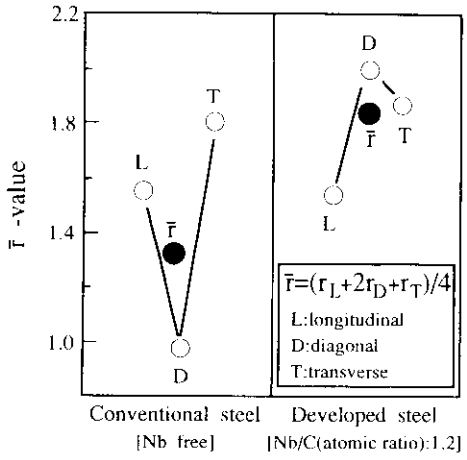

Fig. 1 Comparison of r-value between the developed and conventional enameling steels

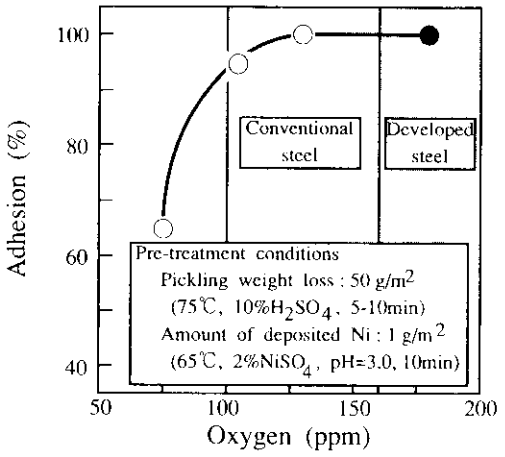

Fig. 2 Effect of oxygen content in the steel on the direct-on enameling adhesion evaluated by the ASTM C313-78 standard (enamel layer thickness: 100–150 μm)

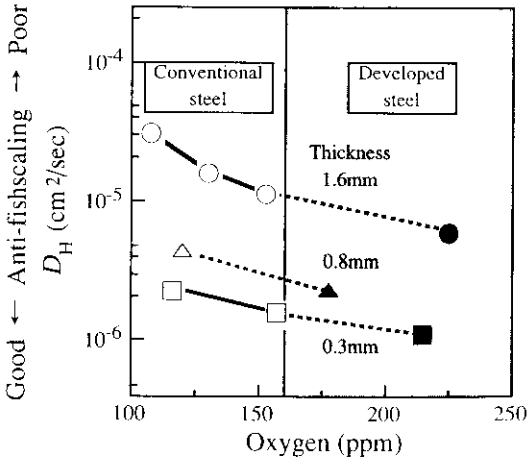

Fig. 3 Effect of oxygen content on the diffusion coefficient of hydrogen (D_H) through steels

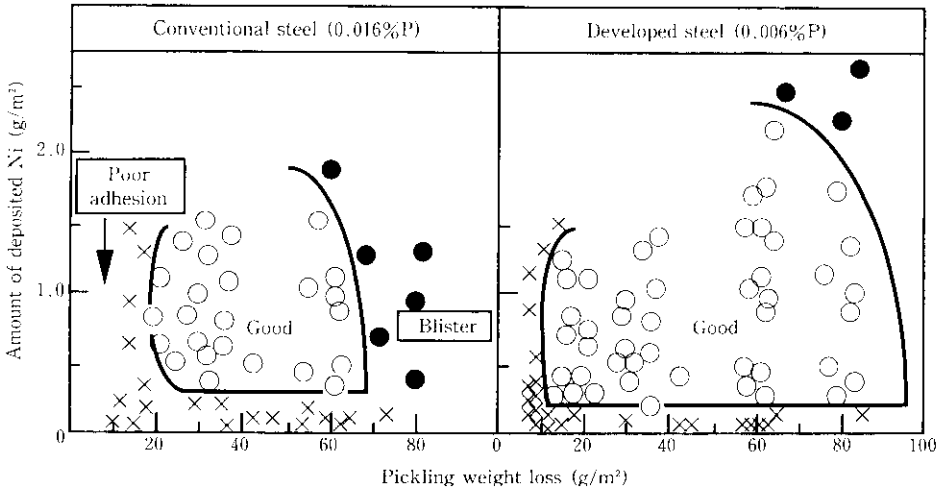

Fig. 4 Effect of pickling weight loss and amount of deposited Ni on direct-on enameling properties of the steel. The specimen is subjected to firstly pickling treatment in 10% H_2SO_4 at 75°C, followed by Ni coating in 2% $NiSO_4$ with pH = 3.0 at 65°C. (enamel layer thickness: 100–150 μm)

3.5 Effect of Decrease in Phosphorus Content on Surface Quality of Enameled Sheets

Direct-on enameling tends to be affected by pretreatment conditions such as sulfuric acid pickling and nickel treatments, and as a result, such defects as pinholes, black spots, and blisters may occur on the surface of an enameled sheet. It is reported that the above defects occur in steels made by continuous casting.[5] In the newly developed steel, since the phosphorus content, which has a great effect on pickling behavior during pretreatment, is lowered, the excessive etching at the grain boundaries during picking is suppressed. Consequently, the surface quality of enameled sheets is improved by reducing the amount of smuts. Products with good adhesion and stable surface quality can be obtained by controlling the pickling weight loss to 10 to 80 g/m^2 and the amount of deposited nickel to 0.3 to 2.0 g/m^2, as shown in **Fig. 4**. Moreover, because the pickling rate decreases due to a decrease in the phosphorus content, it is much easier than with the conventional steel to control the pickling weight loss within the above ranges.

3.6 Effect of Oxygen Content on Weldability

The welding method most frequently employed for enameling sheet steels is butt welding, using a method such as plasma welding. Because the oxygen content of general aluminum-killed steels is lowered to tens of ppm, the surface tension of the molten steel is high. Therefore, uniform welding is impossible at high speeds. In the newly developed steel, the oxygen content is higher than that of the conventional steel. As a result, it has become possible to raise the welding speed by 10%.

4 Concluding Remarks

Kawasaki Steel developed KTM-D enameling sheet steel that combines deep drawability and various substantially-improved enameling properties, in particular, the surface quality obtained from direct-on enameling. This product is manufactured by adding niobium to the conventional type of boron-added medium-oxygen steel and optimizing the elements and manufacturing conditions suitable for each property. Through the development of this steel, the company can now produce all enameling sheet steels by the continuous casting-continuous annealing process and has been able to improve quality and shorten delivery schedules.

References

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