TS440MPa Grade Hot-Rolled Sheet Steel with Large Capability of Absorbed Energy at High Strain Rates, Induced by Strain Aging Hardenablity*

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1 Introduction

In recent years, the crashworthiness of automobiles has been required and the use of high-strength sheet steel in car-bodies has been examined. In general, however, formability decreases with increasing strength of sheet steel. Therefore, the development of sheet steels that combine strength and formability is strongly desired.

Through the use of the high-accuracy cooling control technology in the new hot strip mill at its Chiba Works, Kawasaki Steel has developed a 440 MPa grade hot-rolled sheet steel which has low strength and excellent workability during forming and has a great increase in strength after paint baking. The features of this newly developed steel are described.

2 Concept of Development

This steel was developed to increase bake hardenability by making use of nitrogen which has higher solubility in a hot-rolling temperature region than carbon. In the manufacture of this steel, the precipitation of AlN during hot rolling is suppressed in order to ensure the solute nitrogen in steel. Moreover, the grain-boundary area, which provides a stable position for solute nitrogen, increases by refining the grains in order to suppress room-temperature aging. In addition, in order to realize a capability of strain aging hardening which is great and has few variations, the high-accuracy cooling technology is used in the new hot strip mill at the Chiba Works. Five main elements of the developed steel are shown in **Table 1**.

Table 1 Chemical composition of newly developed steel

(mass%)

C	Si	Mn	P	S
0.08	0.10	1.25	0.016	0.003

3 Features of Developed Steel

3.1 Mechanical Properties

Representative mechanical properties of the developed steel are shown in **Table 2**. This steel has good elongation while also providing a high amount of bake hardening (BH) above 80 MPa.

3.2 Formability

Figure 1 compares the forming limit diagram of the developed steel with that of a conventional 440 MPa grade hot-rolled steel. The plate thickness is 1.6 mm and the scribed circle diameter is 6 mm. The developed steel shows excellent formability at all strain ratios.

3.3 Spot Weldability

Figure 2 compares the tensile shear strength of the developed steel obtained by changing a welding current with that of a conventional 440 MPa grade hot-rolled

Table 2 Mechanical properties of newly developed steels

Thickness (mm)	Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)	BH* (MPa)
1.4	370	478	34	95
2.3	361	485	37	99

*2% pre strain → 170°C × 20 min

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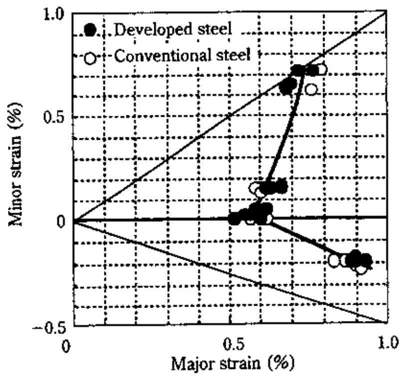

Fig. 1 Forming limit diagram of newly developed steel compared with conventional steel

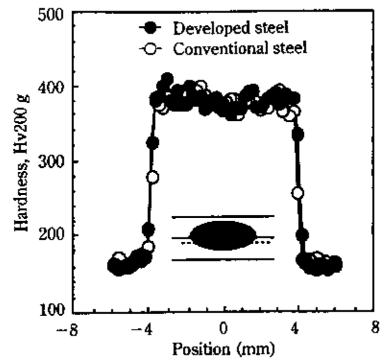

Fig. 3 Distribution of hardness across the spot welded joint parallel to the sheet

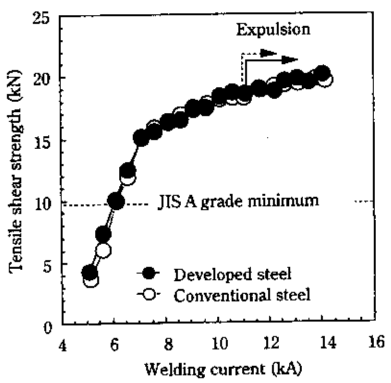

Fig. 2 Effect of welding current on tensile shear strength of newly developed steel

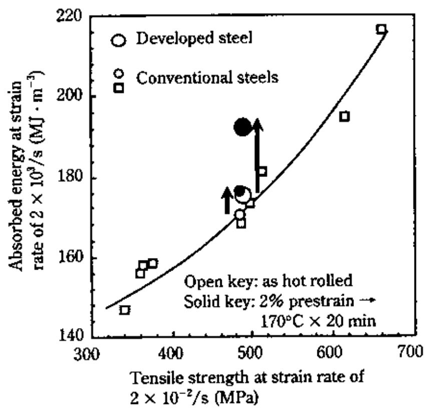

Fig. 4 Influence of strain-aging on absorbed energy at high strain rate of newly developed steel

steel. It meets the JIS A grade standard and the available welding current range in which the tensile shear strength is high enough without occurrence of expulsion is sufficiently wide. Thus, the spot weldability of the developed steel is as good as that of the conventional 440 MPa grade hot-rolled steel. The hardness distribution of spot welds is shown in **Fig. 3**. Normal nuggets are formed.

3.4 High-Strain Rate Deformation Property

After a 2% pre-strain in tension was given, the developed steel was subjected to heat treatment equivalent to paint baking at 170°C for 20 min. In this condition, a high strain rate tensile test was conducted with the aid of a split-Hopkinson pressure bar apparatus. The absorbed energy of this steel compared with that of various steel grades is shown in **Fig. 4**. This figure also shows, for comparison, those of as-hot-rolled steels. As indicated by the arrows in the figure, the absorbed energy of the developed steel increases by the strain aging treatment and, therefore, its anti-crush worthiness increases.

3.5 Room-Temperature Aging Property

The mechanical properties of the developed steel were investigated to examine deterioration in the mechanical properties caused by aging at room temperature. After normal skin-pass rolling, accelerated aging treatment was carried out at 50°C for 200 h. As a result, the decrease in elongation was small by an amount of about 1%.

4 Concluding Remarks

The above-described hot-rolled sheet steel is capable of providing a remarkable increase in strength by paint baking while also providing workability equal to that of a conventional 440 MPa grade hot-rolled sheet steel without the addition of special elements. Because this characteristic is effective in increasing absorbed energy, this steel is suitable for use in crash-resistant parts and under-body parts of automobiles.

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