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Hot Rolled Steel with Good Deep Drawability and Good Anti-Secondary Working Embrittlement Property, "KFN5"*

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1 Introduction

Hot rolled steel sheets with extremely high elongation are used in heavy gauge parts which are manufactured by deep drawing forming. Examples include automobile clutch covers and compressor shells, which are vessels with a deep cylindrical form. The use of these hot rolled sheets in applications of this type can enable efficient production of parts without supplementary intermediate annealing, etc. in the press forming process. As a matter of course, steel sheets for these applications must have sufficient elongation for deep drawing forming, and from the viewpoint of product reliability, must also have a good anti-secondary working embrittlement property after forming.[1] However, it is difficult to realize both good elongation and a satisfactory anti-secondary working embrittlement property in the same product. For example, coarsening of the crystal grain size is used as a means of improving elongation, but causes a sharp reduction in the anti-secondary working embrittlement property.

By applying a new microstructure control method to ultra low carbon steel, Kawasaki Steel has developed a high elongation hot rolled steel sheet for deep drawing forming, in which both elongation and the anti-secondary working embrittlement property are substantially improved in comparison with conventional hot rolled steel sheets. The features of this new product are described in the following.

2 Development Philosophy

The newly developed steel realizes high elongation and a deep drawing property, together with an excellent anti-secondary working embrittlement property, by practical application of a technology for microstructure control by optimizing both the chemical composition and advanced hot rolling conditions.

The physical property value which has the greatest influence on the deep drawing property is the r value.[2] However, it is generally difficult to improve the r value of hot rolled steel sheets because the formation of a random texture, which accompanies the $\gamma \rightarrow \alpha$ transformation in the hot rolling process, is unavoidable. This means that it is necessary to compensate for the low r value by further increasing elongation to enable forming of hard-to-form parts. In the composition of the material, uniform refining of grains in the microstructure, in order to secure good elongation and deep drawability and improve the anti-secondary working embrittlement property, was achieved by using a base material of ultra low carbon steel with a C content on the order of 20 ppm and Ti and B added in appropriate ranges.

2.1 Formability

The following three metallographic means were used to improve the elongation of the steel.

(1) Refining of the microstructure of the soft ferrite single phase.

(2) Reduction of the content of hard, brittle carbides in the ferrite.[3]

(3) Reduction of the content of solute C in the ferrite.

However, because a trace amount of C is effective in increasing the strength of the grain boundaries[4] and improving the anti-secondary working embrittlement property,[1] the content of solute C was controlled within the optimum range. To control the optimum content of solute C, a steel composition of ultra low carbon steel with trace amounts of added carbo-nitride forming elements is advantageous. Previous research indicated that

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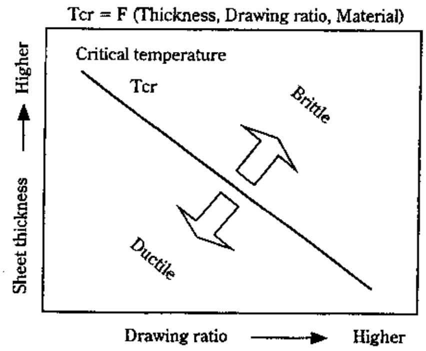

Fig. 1 Schematic illustration showing effect of drawing ratio and thickness on the transition temperature

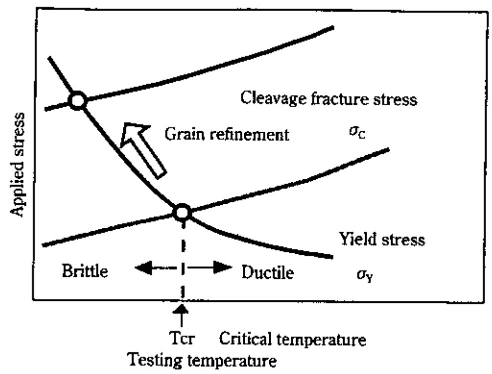

Fig. 2 Schematic illustration showing the transition temperature of secondary working embrittlement

Ti-added steel is the most suitable material for this purpose.[1]

2.2 Secondary Working Embrittlement

Secondary working embrittlement is a brittle fracture phenomenon which occurs when a secondary impact load is given to a material after primary working. Embrittlement becomes remarkable as deep drawing forming becomes more severe and as the secondary working temperature decreases. In cylindrical forming, the material frequently shows a characteristic fracture morphology, called "longitudinal cracking," in which straight cracks occur in the forming direction during cylindrical forming.[2] The brittle fracture which occurs in ordinary low carbon steel shows a cleavage fracture surface, whereas ultra low carbon steel shows a grain boundary fracture surface. (This is particularly true of interstitial atom free, or IF steels, which contain no solute C.) Assuming that embrittlement of the latter type occurs at higher temperatures, it is possible to avoid embrittlement by optimum control of the content of solute C,[1] addition of a trace amount of B, etc. As the mechanism by which the presence of a trace amount of solute C improves the anti-secondary working embrittlement property, two possibilities are conceivable here, these being strengthening of the grain boundary bonding force by C atoms,[4] and reduction of yield stress in the low temperature region by the phenomenon of solution softening of C.[5]

As shown schematically in **Fig. 1**, severe draw forming and increased sheet thicknesses are disadvantageous for the anti-secondary working embrittlement property. Therefore, a steel sheet with an improved anti-secondary working embrittlement property is required.

2.3 Method of Improving Anti-Secondary Working Embrittlement Property

To improve the anti-secondary working embrittlement property, the thermomechanical history and cooling conditions after hot rolling were optimized, using Ti-B added ultra low carbon steel as the basic composition.

A remarkable improvement in the anti-secondary working embrittlement property is possible by refinement of the microstructure. It is assumed that this is because the length of the latent cracks which occur during primary working is reduced, or the progress of cleavage cracks is effectively prevented by grain boundaries. This condition is shown schematically in **Fig. 2**. The critical temperature at which embrittlement occurs is determined by the relationship between yield stress and cleavage fracture stress. The anti-secondary working embrittlement property is improved because grain refinement increases the cleavage fracture stress and reduces the critical temperature.

3 Features of Newly Developed Steel

3.1 Tensile Properties and Anti-Secondary Working Embrittlement Property

Tables 1 and **2** show examples of the chemical composition and representative mechanical properties of the conventional steel (SPHE), a deep drawing quality hot rolled steel sheet (KFN3), and the newly developed steel (KFN5).

Uniform refinement of the microstructure and fine dispersion of precipitated carbides were achieved by

Table 1 Chemical compositions of hot-rolled mild sheet steels

(mass%)

	C	Mn	P	S	Others
SPHE	0.04	0.3	0.01	0.01	Al-killed
KFN3	0.002	0.1	0.01	0.003	Ti, B added
KFN5 (Newly developed)	0.002	0.1	0.01	0.003	Ti, B added

Table 2 Mechanical properties of hot-rolled mild sheet steels

	Thickness (mm)	YS (MPa)	TS (MPa)	El (%)	Average r-value
SPHE	4.5	225	335	48	0.8
KFN3	4.5	185	285	56	0.9
KFN5 (Newly developed)	4.5	203	295	56	0.9

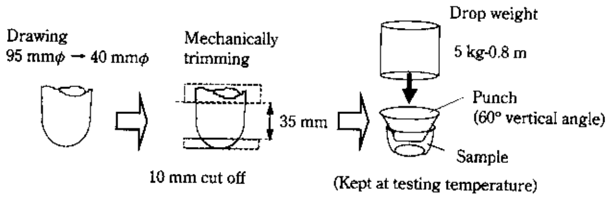

Fig. 3 Experimental procedure for evaluation of secondary working embrittlement

Table 3 Results of secondary embrittlement test

	Testing temperature (°C)						
	−100	−120	−130	−140	−150	−180	−196
SPHE		××					
KFN3		○○	○×	××			
KFN5 (Newly developed)	○○	○○	○○	○○	○○	○○	○○

○ : Ductile × : Brittle

optimizing the thermomechanical technology used in the hot rolling process. The anti-secondary working embrittlement property of the newly developed steel was investigated. An outline of the experimental procedure and the results of secondary embrittlement tests are shown in **Fig. 3** and **Table 3**, respectively. Brittle fracture occurs in SPHE at −120°C. In contrast, brittle fracture does not occur in the newly developed steel even at −196°C. Because the new steel possesses this extremely good anti-secondary working embrittlement property, it is suitable for vessels and parts in which high reliability is required.

3.2 Examples of Applications of Newly Developed Steel

Examples of the applications of this newly developed steel are shown in **Photo 1**. The new steel is suitable for parts which require severe deep drawing and for deep drawing formed parts in which it is necessary to avoid

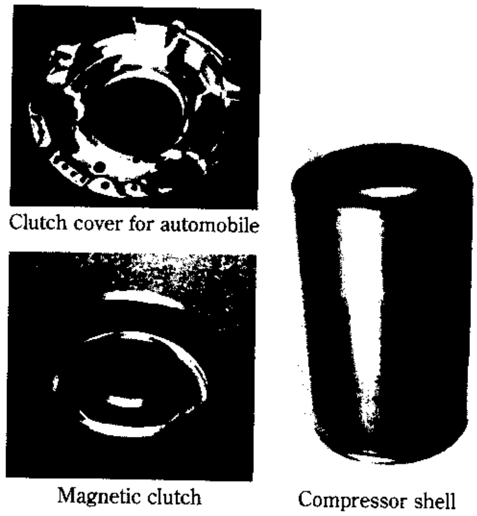

Photo 1 Example of application of developed steel

surface defects. It should be noted that these tests confirmed that both KFN3 and the newly developed steel sheet have excellent resistance to so-called brazing embrittlement, even when brazing and similar processing are applied after forming.

4 Conclusion

The high elongation hot rolled steel sheet for deep drawing forming introduced in this report is a product which was developed to improve formability and the anti-secondary working embrittlement property. An increasing range of applications is expected, beginning with the automobile industry and including various parts for use in electrical equipment and general steel sheet products.

References

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