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High Carbon Hot-rolled Steel Sheet with Excellent Formability "SUPERHOT™-F" †

1. Introduction

High carbon steel sheets, represented by carbon steels for machine structural use (SC materials: Japanese Industrial Standard (JIS) G 4051: 2009), are widely used as materials for various types of structural parts, beginning with automotive powertrain components. Many of these structural parts have a complex shape with a partly large difference in thickness, and numerous processes from forming to heat treatment are required in their manufacture.

On the other hand, unrelenting efforts are being made to downsize and lighten such parts and to reduce cost of manufacturing them. Likewise, in automotive powertrain components, active study is being given to integration and minimization of parts and shortening the manufacturing process by a changeover from parts by hot-forging with steel bars to those by cold-forming with steel sheets[1]. In recent years, remarkable progress has been achieved in cold-working technology and processing equipment, and practical application of sheet metal forming accompanied by local fattening in thickness, which is termed sheet metal forging, is also progressing rapidly[2].

In response to the conditions outlined above, JFE Steel developed high carbon hot-rolled steel sheets with excellent formability, which are suitable for the application to modular sheet metal forming of structural parts, and commercialized those as "SUPERHOT™-F" series. The following introduces the details of development and product features of "SUPERHOT™-F."

2. Product Design

2.1 Required Properties and Development Scheme

A well-balanced quality is required in steel sheets for machine structural parts with hard-to-form shapes, which consists of excellent formability (press-formability, softness, punchability) chiefly, and also good hardenability, gauge accuracy, surface properties, etc. Therefore, JFE Steel developed new steel sheets targeting further improvement in formability, based on the "SUPERHOT™" high functionality high carbon hot-rolled steel sheets, which are already in mass production.

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Table 1 Chemical composition of "SUPERHOT™-F" steels

(mass%)

Designation	C	Si	Mn	P	S
S35C	0.35	0.17	0.72	0.017	0.004
S45C	0.46	0.20	0.75	0.010	0.002

2.2 Steel Grades and Alloy Design

In order to satisfy both excellent formability and enough hardness after heat treatment for most machine structural parts, S35C and S45C grades were selected for the objects, as SC materials with C contents of 0.3–0.5mass%. Examples of the chemical composition of "SUPERHOT™-F" are shown in **Table 1**. The contents of alloying elements were held within the range regulated in JIS G 4051 and the addition of special elements which would intensify the anisotropy in steel sheet properties was avoided for extensive application of the developed steels.

2.3 Microstructure Control for Improved Formability

Appropriate control of the microstructure (components, morphology, distribution) of the steel after spheroidizing is necessary in order to impart excellent formability to high carbon steel sheet. A matrix of equiaxed and well-ordered ferrite grains with fine spheroidal cementite uniformly dispersed at the grain boundaries is favorable composition from the viewpoint of press-formability[3]. To obtain a high carbon hot-rolled steel sheet with this kind of microstructure, controlled cooling after hot-rolling is indispensable in addition to proper spheriodizing.

A schematic diagram of the controlled cooling adopted in the manufacture of "SUPERHOT™-F" is shown in **Fig. 1**. The hot-rolled steel sheet by normal cooling develops a coarse mixed microstructure of pre-eutectoid ferrite and pearlite because the cooling rate after finishing rolling is not so large, which leads to an undesirable microstructure with unevenly dispersed

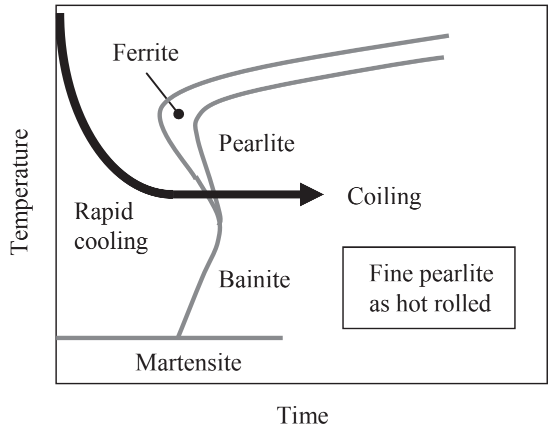

Fig. 1 Schematic diagram of controlled cooling after hot rolling

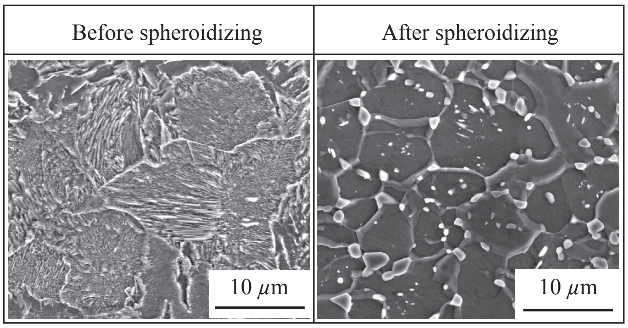

Photo 1 Microstructure of S35C hot rolled steel sheets

coarse cementite after spheroidizing. To avoid this, the microstructure of the hot-rolled steel sheet is wholly adjusted to fine pearlite by rapid cooling, suppressing a formation of pre-eutectoid ferrite. The microstructure of the “SUPERHOT™-F” obtained by controlled cooling in this manner is shown in **Photo 1**. The single component structure of fine pearlite after hot-rolling brings uniformly dispersed fine spheroidal cementite after spheroidizing.

3. Material Properties

The mechanical properties of “SUPERHOT™-F” with a sheet thickness of 4.0 mm are shown in **Table 2**. Besides high carbon steel, both steel sheets have enough values comparable to those of conventional plain carbon steel sheets, and would withstand severe cold-forming.

4. Application

The main target parts for “SUPERHOT™-F” application are automotive powertrain components, particularly the rotating parts comprising transmissions such as the clutch hub/drum of automatic transmission (AT) and the piston/cylinder of continuously variable transmission (CVT). Application trials have been carried out by many manufacturer of automobile or transmission, and an informal decision has been made on the first adoption of “SUPERHOT™-F” in actual automobiles released in several months.

Table 2 Mechanical properties of “SUPERHOT™-F” steel sheets

Designation	YP (MPa)	TS (MPa)	El (%)	HV
S35C	312	472	38	147
S45C	339	499	34	157

Test piece: JIS No. 5 Thickness: 4.0 mm
YP: Yield point TS: Tensile strength El: Elongation
HV: Vickers hardness

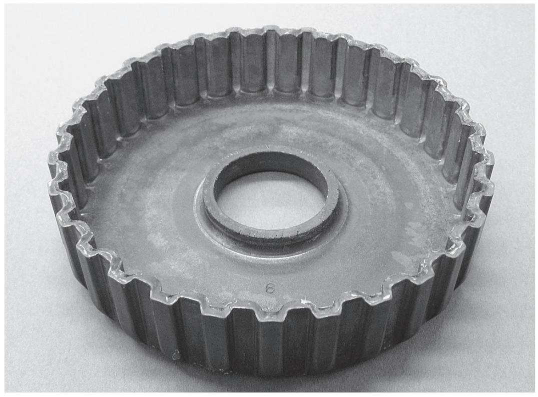

Photo 2 Clutch drum model formed with S35C hot rolled steel sheet (by Toyo Advanced Technologies Co., Ltd.)

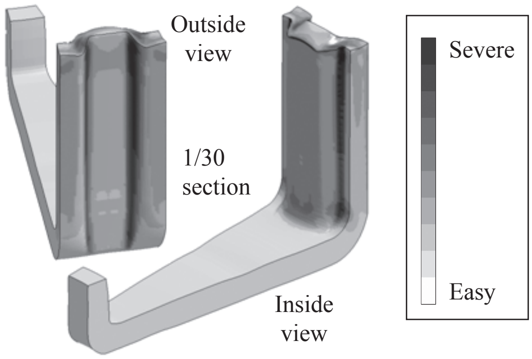

Fig. 2 Finite element method (FEM) simulation for tooth forming

The appearance of a model part imitating a clutch drum is shown in **Photo 2**. This model has a cylindrical shape (outer diameter: 124.5 mm) with teeth on the outer circumference, and was formed by press-forming in 6 steps with S35C “SUPERHOT™-F” hot-rolled steel sheet. The teeth were also cold-formed by ironing. This is an example in which cold-forming with steel sheet was achieved and also shape accuracy were improved by incorporating the mechanical properties of the steel sheet in the multi-stage forming analysis method established by JFE Steel, as shown in **Fig. 2**.

5. Conclusion

“SUPERHOT™-F” is the optimal steel sheet material for machine structural parts which are formed by severe cold-forming. Many customers are under evaluation of this product for application to various types of parts, and expanded application is expected in the future.

References

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3) Nakamura, Nobuyuki et al. Jour. Jpn. Soc. Tech. Plasticity. 2010, vol. 51, no. 594, p. 628–632.

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