Environmentally Friendly Bar and Wire Rod Steels*

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Synopsis:

A complicated secondary machining process is usually applied to a steel for machine components, which is supplied in the form of either bar or wire rod. From the environmental point of view, steel makers should develop the steel according to a philosophy such as that of considering not only the simplification of manufacturing processes of bars and wire rods at the steel makers but also the simplification in the final use and disposal at the end users. Kawasaki Steel has developed many environmentally friendly steels based on the above-mentioned philosophy, and the typical products include (1) an as rolled 900 MPa class high tensile strength steel manufactured without a quenching and tempering process, (2) an 800 MPa class TPCP type steel with high tensile strength and excellent toughness also manufactured without a quenching and tempering process, (3) a steel manufactured without softening and drawing processes, and (4) a cold forgeable graphitized steel with excellent free cutting properties without a Pb addition.

1 Introduction

Special steels supplied in the form of bars and wire rods become final products after a complex secondary processing at the user side, which includes forging, machining and heat treatment. For this reason, to reducte the environmental loads of bars and wire rods, it is necessary to consider not only the manufacturing processes of bars and wire rods, but also secondary processing and the use and disposal of final products by end users.

On the basis of LCA (life cycle assessment)[1], Kawasaki Steel has been developing various steels. This report presents examples of typical bars and wire rods that should make a great contribute to the reduction of environmental load.

2 Energy-Saving Bar Products

2.1 Applications and Secondary Processing of Bars and Wire Rods

Applications of special steels supplied as bars and wire rods and examples of secondary processing for them are shown in **Table 1**. As mentioned above, bars and wire rods are processed into final products after machining, forging and heat treatment at the customer side. Therefore, omitting heat treatments, such as annealing, quenching and tempering, in the secondary working process is effective in saving energy. This also helps to reduce manufacturing costs and shorten a processing time.

2.2 Steels Manufactured without Quench-Tempering

The company has developed various non heat treated steels which do not require quenching and tempering, thereby contributing greatly to energy savings and a reduction in manufacturing cost for users. This subsection describes a 900 MPa class high-tensile-strength steel manufactured without heat treatments, called NH48MV, and an 800 MPa class TPCP type high-tensile-strength, high-toughness steel manufactured without quenching and tempering.

2.2.1 900 MPa class high-tensile-strength steel manufactured without quench-tempering

NH48MV, which is a high-tensile-strength ferritic-pearlitic steel that is used after cutting, has been developed to eliminate the heat treatments of quench-tem-

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Table 1 Typical secondary working processed for special steels

Steel	Secondary working	Final products
Carbon and low-alloy steels for machinery structural use	Bar → Shearing → Machining → Quenching and tempering	Machine component for automobile
	Bar → Shearing → Hot-forging → Machining → Quenching and tempering	
	Bar → Shearing → Spheroidizing annealing → Cold forging → Quenching and tempering	
	Rod → Annealing → Drawing → Spherodizing annealing → Drawing → Cold forging → Quenching and tempering	High tension bolts
Bearing steel	Bar → Annealing → Shearing → Hot-forging → Spheroidizing annealing → Machining → Quenching and tempering → Grinding	Ball bearing
	Rod → Spheroidizing annealing → Drawing → Cold-forging → Quenching and tempering → Grinding	
High carbon steel	Rod → Patenting → Drawing → Stranding → Bluing	PC wire
	Rod → Drawing → Patenting → Drawing → Electroplating → Drawing → Stranding	Tire cord

pered alloy steels used in structural members of large machines. In order to obtain uniform mechanical properties as large members, the C, M, Cr and V content is optimized and low-temperature heating and low-temperature, high-reduction rolling are conducted, to ensure that a uniform microstructure of ferrite plus pearlite is obtained from surface to center.

Figure 1 shows a comparison of the radical distribution of mechanical properties between cross sections of a large ϕ190 mm bar of NH48MV and a quench-tempered SCM435. In the quench-tempered SCM435, the tensile strength at the center of the bar is 800 MPa, whereas the tensile strength value near the surface is about 880 MPa, showing a great variation due to the mass effect. In NH48MV, on the other hand, the tensile strength is not less than 900 MPa in every position of the cross section, higher than that of quench-tempered SCM435, and non-quench-tempered NH48MV also has excellent uniformity of strength.

Figure 2 shows the effect of bar size on the strength and fatigue limit in a 1/4-diameter portion of NH48MV bar. Even when the bar size increases from 70 to 190 mm in diameter, the yield point and tensile strength are, not less than 600 MPa and not less than 900 MPa, respectively. Thus consistently high strength is obtained irrespective of bar size. Furthermore, the fatigue strength determined by the rotating bending fatigue test is not less than 460 MPa, higher than that of quench-tempered SCM435.

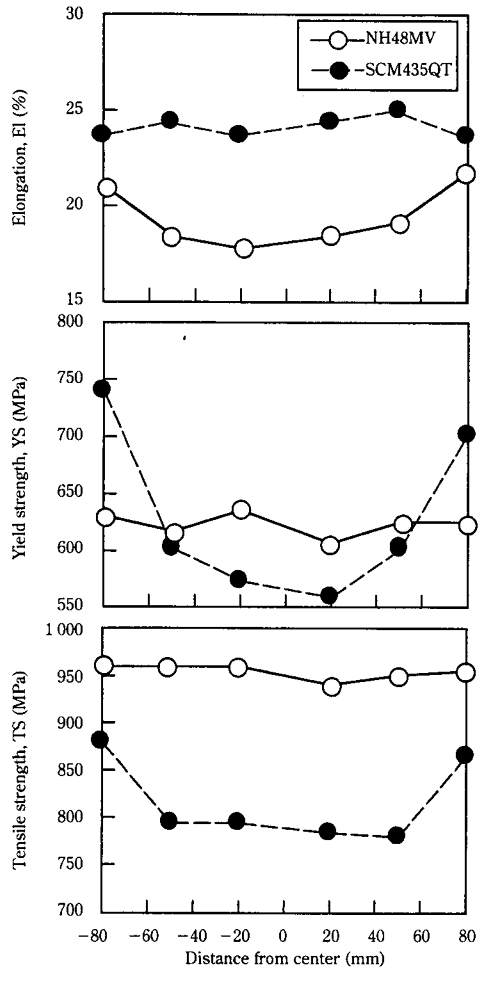

Fig. 1 Radial distribution of mechanical properties for NH48MV and quench-tempered SCM435 steels with a diameter of 190 mm

2.2.2 800 MPa class TPCP type high-tensile strength, high-toughness steel manufactured without quench-tempering

In general, non-quench-tempered ferritic-pearlitic steels have lower toughness than quench-tempered alloy steels for machine structural use, so their applications are limited. To solve this problem, the company has developed a TPCP type non-quench-tempered steel as one of its steels manufactured without heat treatment, to which higher toughness than in quench-tempered alloy steels for machine structural use can be imparted.

Although non-quench-tempered bainitic steels can be given higher toughness than conventional ferritic-pearlitic steels, they have the problems of low yield

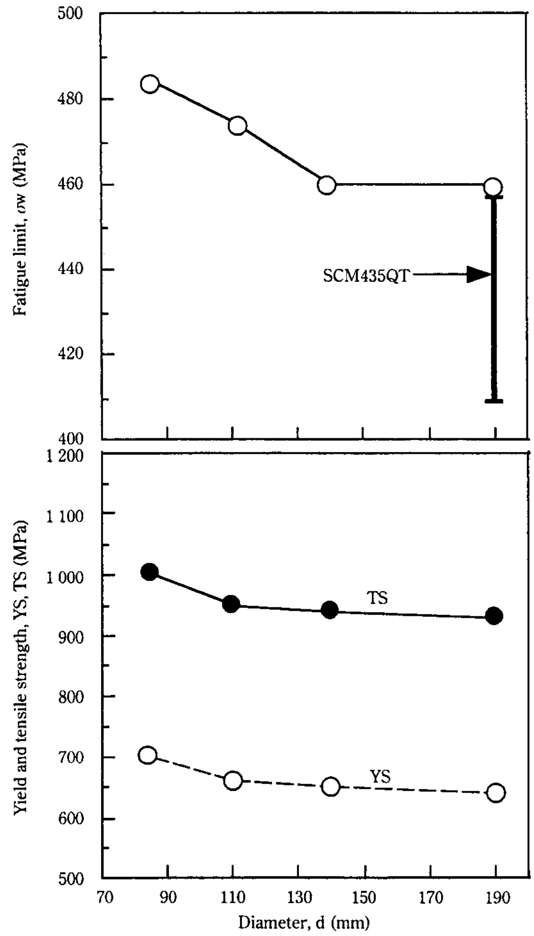

Fig. 2 Effect of steel bar diameter on strength and fatigue limit of NH48MV steel, of which properties were measured by the specimen collected from the position of a quarter diameter in each steel

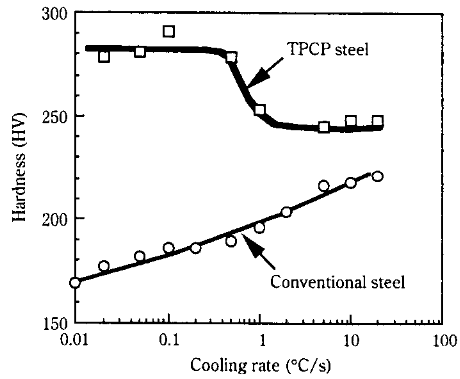

Fig. 3 Relation between cooling rate and hardness for newly developed ultra-low carbon bainitic steel and conventional one

Table 2 Mechanical properties of TPCP and quench-tempered SCM435 steels of 170 mm in diameter

Steel	YS (MPa)	TS (MPa)	El (%)	uE + 20 (J/cm²)
TPCP	717	847	25	320
SCM435-QT*	605	788	22	146

*Quenching: 870°C × 1 h → Oil-quenching
Tempering: 600°C × 1 h

point and great mass effect, and their range of application to large members is limited. In order to overcome these problems, the company used information on extremely-low-carbon steels[2)] to develop a technique for controlling microstructures called the thermomechanical precipitation control process (TPCP)[3)] and applied it to the development of non-quench-tempered steels.

The basic concept of TPCP is to select a chemical composition of steel in which the microstructure has very small cooling rate dependence and to control strength by controlling precipitation instead of the cooling rate. It is appropriate to apply TPCP to extremely-low-carbon bainitic steels, which provide a uniform microstructure in a wide cooling rate range. In the application of TPCP, consistent strength can be ensured in a wide cooling rate range by selecting types and added amounts of precipitation hardening elements according to a strength level while also by selecting appropriate hot rolling conditions.

The relationship between cooling rate and strength of a TPCP-applied steel as compared to a conventional steel is shown in **Fig. 3**. In the conventional steel, hardness decreases linearly with decreasing cooling rate. By applying TPCP, however, hardness can be controlled to an almost constant level in a very wide cooling rate range of 0.01 to 0.5 °C/s.

TPCP can be applied both to steels for machine structural use to be used after cutting, and to steels for machine structural use for hot forging. An example of the former one is described below. **Table 2** compares the mechanical properties of a TPCP steel with those of quench-tempered SCM435 in ϕ170 mm bars. The yield point and tensile strength of the TPCP steel are higher than those of quench-tempered SCM435, particularly the increase in yield point, which is as large as about 100 MPa. Furthermore, the impact value of the TPCP steel is better than that of quench-tempered SCM435 in spite of its high strength exceeding 800 MPa. Thus, thanks to the use of TPCP, this bar steel has high toughness in spite of being made without the quenching and tempering processes, thereby exceeding quench-tempered SCM435 in this respect.

2.3 Steel Manufactured without Softening and Drawing

After softening and drawing in the secondary working process, low-alloy wire rods are subjected to final working, such as forging and cutting, for the manufacture of final products. The company has developed a high-

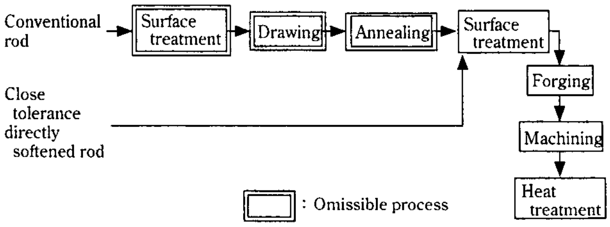

Fig. 4 Example of process applying close tolerance directly softened rod

dimensional-accuracy, direct-annealed wire rod steel that eliminates the need for the annealing and drawing processes. A typical example is shown in **Fig. 4**.

The wire rods of high dimensional accuracy and of arbitrary size, which do not require the drawing process, are manufactured by the size-free 4-roll rolling technology[4] developed by the company. An arrangement of 4-roll mills is shown in **Fig. 5** and the main specifications of the 4-roll mills are shown in **Table 3**. The 4-roll rolling equipment is comprised of high-rigidity rolling mills, each provided with an adjustment mechanism which is capable of fine adjustments of roll gaps in 0.01 mm increments, and offline equipment which is used to assemble and disassemble the rolling mills with high accuracy.

Rolling results are shown in **Fig. 6**. Superhigh dimensional accuracies within ±0.07 mm in a size-free range of 7.2 to 8.0 mm in diameter were achieved and the drawing process could be omitted.

Direct annealing in which softening is omitted can be performed by controlled rolling and controlled cooling. The manufacturing method by direct annealing and applied steel grades and sizes are shown in **Table 4**. **Photo 1** shows a comparison of microstructure between a direct-annealed steel and a conventional rolled steel. The direct-annealed steel has a ferrite plus pearlite structure, that is softer than the bainite of the conventional rolled steel.

As examples of application, **Photo 2** shows a low-alloy hexagon socket bolt and a low-alloy flange bolt made by this steel without the softening process. The products have been brought to the commercial stage by quenching and tempering without posing a problem to cold forgeability or product accuracy.

Table 3 Main specifications of 4 roll mills for bar and wire rod rolling

Items	Specifications of 4 roll mill	
	For bar rolling	For wire rod rolling
Organization of mill	2 stands par unit Roll arrangement: + → ×	3 stands par unit Roll arrangement: + → × → +
Product size	16~85 mmΦ	4.0~19.0 mmΦ
Rolling speed	0.8~16 m/s	15~110 m/s
Rolling load	Max. 49 000 N	Max. 9 800 N
Rolling torque	Max. 47 000 N-m	Max. 1 200 N-m
Mill constant	980 MN/mm	20 MN/mm
Roll drive	2 rolls driven by motor and 2 rolls rotated by water spray	4 rolls driven by motor
Roll diameter	400 mmΦ	220 mmΦ
Roll gaps adjustment	Remote control from operation room Control accuracy = ±0.01 mm	Remote control from operation room Control accuracy = ±0.01 mm
Stand change	Automatic change system Changing time = 3.5 min/unit	Automatic change system Changing time = 3 min/unit
Maker	Sumitomo Heavy Industries, Ltd.	Sumitomo Heavy Industries, Ltd.

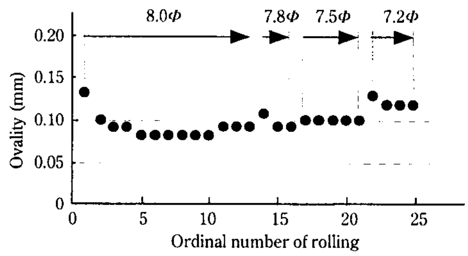

Fig. 6 Size-free rolling results of wire rod by the 4 roll mill

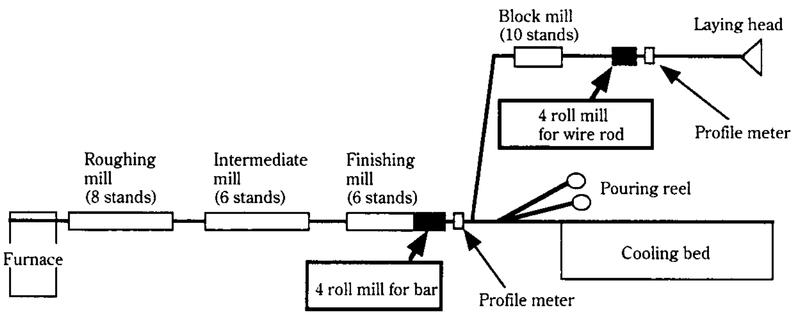

Fig. 5 Mill layout of bar and wire rod mills at Mizushima Works

Table 4 Production method for directly softened rod

Steel / Diameter	SCr420 ~440	SCN420 ~435	SCM440
5.5~10 mmφ			Slow-cooling
11~19 mmφ	Retarded stelmor		

Photo 1 Microstruture of 14 mmφ SCM440 steel

(a) Hexagon socket bolt (b) Flange bolt

Photo 2 Example of products from directly softened rods

3 Newly Developed Product Contributing to the Elimination of Toxic Substances

In the manufacture of automotive parts and industrial machine parts using steels for machine structural use, machinability is very important. For this reason, free-cutting elements such as Pb, S and Ca are usually added. Pb has a particularly small effect on mechanical properties and improves machinability in various methods of cutting, so it is widely used as a free-cutting additive. However, since Pb is harmful to the human body[4], Pb-added free-cutting steels have many problems in their manufacture, use and recycling. For this reason, free-

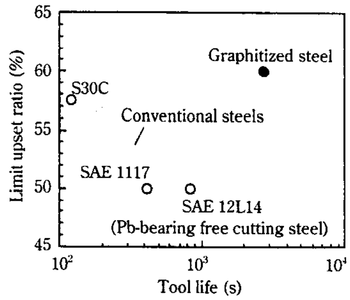

Fig. 7 Relation between tool life in turning test and limit upset ratio in cold forging test

machining steels that do not contain Pb are required to control toxic-substance emissions.

Moreover, although a combination of hot forging and machining has been widely used as a manufacturing process for parts, a combination of cold forging and machining is increasing in terms of energy and resource savings and demand is rising for steels that combine cold forgeability with machinability.

To meet these demands, the company has developed a graphitized steel for machine structural use. In this graphitized steel, cold forgeability is improved by changing hard cementite into soft graphite, whose lubrication action improves machinability. Although there are examples[5,6] in which cast iron is used by graphitizing the carbon contained, it is difficult to use cast iron in machine structures.

Graphite is finely dispersed in the newly developed steel by optimizing its chemical composition and hot rolling conditions, enabling this steel to be applied to machine structures. **Figure 7** shows the relationship between tool life during turning and cold forgeability of a 0.53%C graphitized steel as compared to S30C (S: 0.010%), which is a spheroidizing-annealed steel; and SAE1117 (S: 0.12%, P: 0.028%) and SAE12L14 (S: 0.32%, P: 0.006 3%), which are free-cutting steels for general structural use. Cold forgeability was evaluated by the limit upset ratio obtained from a compression test using columnar specimens of 15 mm in diameter × 22.5 mm in thickness. Machinability was evaluated by the tool life obtained in a turning test using a cemented carbide tool P10. Tool life was defined as the cutting time that it takes for the flank wear of the tool to reach 0.2 mm.

The graphitized steel is excellent in both machinability and cold forgeability. Furthermore, it is promising as a free-cutting machine steel that does not contain Pb, because its machinability is equal to or better than that of Pb-added free-cutting steels.

4 Concluding Remarks

In order to reduce the loads of steel products on the environment, it is necessary to tackle this problem in the total process from steelmakers to end users. From this point of view, Kawasaki Steel intends to keep developing and manufacturing environmentally friendly products by keeping in close contact with its customers.

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