Development of Long Life Case-Hardened Bearing Steel with Rust Resistance

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Customers are requiring rolling bearings whose function has been improved through enhanced materials and heat treatment for use in maintenance-free and high-function steelmaking equipment. In response to such demand, a case-hardened steel for bearings with superior rust resistance has been developed.

Key Words: *rolling bearing, rust-resistant, steelmaking application, case-hardened steel*

1. Introduction

The most effective means of extending bearing life is the improvement of raceway ring and rolling element materials and heat treatment methods. To satisfy the need for iron and steelmaking equipment that is maintenance-free and has advanced functional capability, the bearings used therein are required to have high performance, achieved by using improved bearing materials or heat-treatment methods, and, in many applications, also to have high toughness, superior rust and wear resistance, and long rolling fatigue life. Among various types of bearings, roll neck bearings of rolling mills often adopt four-row sealed-type compact tapered roller bearings with high load capacity to satisfy such severe environmental requirements. The sealing performance of these bearings has also been improved[1)], but not yet sufficiently to completely prevent the water in rolling fluids or dust in the surrounding environment from mixing into the bearing lubricants. Therefore, material improvements and general fatigue life improvements to effectively prevent rust and flaking caused by surface damage resulting from contaminants have been desired. Regarding rust in particular, immediate measures are required to resolve problems not only during operation (rotation) but also to prevent the rust and the crevice corrosion at contact between the bearing rings and rolling elements that occurs during stoppage.

Here, the materials and heat-treatment methods best suited to rolling bearings used in iron and steelmaking equipment have been investigated and a case-hardened bearing steel with superior rust resistance and long life has been developed. The results are shown as follows.

2. Required Characteristics for Bearings in Iron and Steelmaking Equipment and its Countermeasures

As a result of investigating various failed bearings that had been used in iron and steelmaking equipment, it became clear that, although certain characteristics are generally required of rolling bearings, the following characteristics are particularly important. Based on these results, the effect of each alloy component in the nickel chromium molybdenum case-hardened steel generally used in the materials of bearings for iron and steelmaking equipment was studied.

1) Rolling fatigue life

Although Si (silicon), Ni (nickel), Cr (chromium), and Mo (molybdenum) all are considered to influence fatigue life, the influence of Cr is thought to be particularly large.

2) Less risk of fracture

Since enhancing internal toughness is most effective in improving crack failure resistance, it is efficient to use case-hardened steel with about 0.2% C (carbon). In addition, it is considered effective to increase the amounts of elements such as Ni or Mo to improve toughness.

3) Load carrying performance

Matrix reinforcement by the addition of Si and Ni is considered to be an effective means of restraining deformation under heavy load conditions.

4) Wear resistance

Although strengthening by Si is effective, the greatest effect is thought to be achieved by carbide deposits resulting from Cr and Mo addition.

5) Rust resistance

The addition of Ni and Cr is considered to be effective. Also, it is expected that surface heat treatment for solid solution of nitrogen will be effective.

The above descriptions[2)] show only what kind of effect each element generally has on steel materials, but the actual effect largely depends on subsequent heat treatment. Therefore, first steel materials were experimentally produced to confirm the effect of each element, and then these characteristics were evaluated after heat treatment to obtain surface strength required for use as rolling bearings.

In this development project, top priority was given to improving the rust resistance described in the above item 5). Accordingly, prototypes were produced based on components of nickel chromium molybdenum case-hardened steel, regarding which good performance of the items 1) - 5) could be expected to a certain extent, and then the effects of Si, Ni, Cr, and Mo on rust resistance were evaluated.

3. Evaluation of Rust Resistance of Prototypes

3. 1 Prototypes

The six steels shown in **Table 1** were experimentally produced to evaluate the influence of each element on rust resistance. These materials were evaluated in comparison with the prototype steel A that was produced based on SAE9310 steel.

Table 1 Elements of trial steels

	C	Si	Ni	Cr	Mo	Remarks
A	0.2	0.25	3.0	1.2	0.3	Base steel: Equivalent to SAE9310 (C → 0.2)
B	0.2	0.25	2.0	1.2	0.3	Ni decreased
C	0.2	0.25	1.5	1.2	0.5	Ni decreased, Mo increased
D	0.2	0.25	2.0	1.5	0.5	Ni decreased, Cr and Mo increased
E	0.2	0.25	1.5	2.0	0.8	Ni decreased, Cr and Mo increased
F	0.2	0.45	2.0	1.5	0.3	Si and Cr increased

Cylindrically shaped ϕ20mm × 36mm test pieces were prepared using the materials shown in **Table 1**. These test pieces were surface-finished by grinding after heat treatment and used in the rust resistance test below. The test pieces were heat-treated with two conditions: the carburizing treatment generally applied to case-hardened steel bearings, and additional carbonitriding treatment after carburizing in order to confirm the effect of nitrogen solid solution.

Figure 1 shows each heat treatment condition.

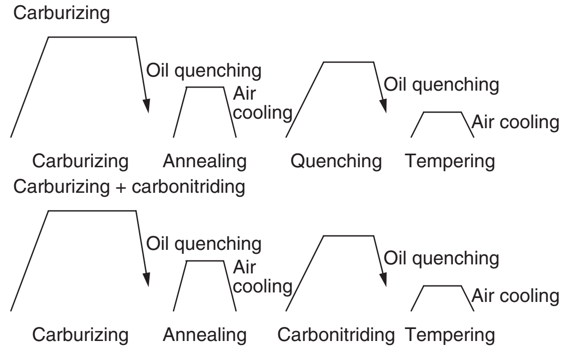


Fig. 1 Heat treatment of specimens

3. 2 Humidity Cabinet Test

The purpose of the rust resistance test was to clarify the effect on rust caused mainly by moisture, and therefore test pieces were examined under humidity cabinet conditions to evaluate both surface rust generation and rust generation in the region of contact with the jig (material: SUJ2) (representing crevice corrosion at contact between the bearing ring and rolling element) under high humidity conditions. The test apparatus and test conditions were based on JIS K 2246.

In a cabinet with the constant temperature and humidity conditions shown in **Table 2**, the cylindrical test pieces were set

1) vertically and
2) horizontally on the jig (V block)

and tested for predetermined hours. After the testing hours, the states of surface rust of the 1) test pieces and the states of crevice corrosion at the contact regions between the jigs and the 2) test pieces were observed and comparatively evaluated.

Table 2 Test conditions of humidity cabinet test

Test temperature	Relative humidity	Test time
49℃ ±1℃	95% or more	96 h

The surface rust and the crevice corrosion were evaluated comparatively among the rating values from 1 to 5 against rating 3 of the carburized test piece of steel A as the standard. The evaluation results are shown in **Table 3**, and examples of rust and crevice corrosion of test pieces after 96 hours of testing are shown in **Figs. 2** and **3**, respectively.

Table 3 Humidity cabinet test results

Heat treatment	Steel	Surface rust	Crevice corrosion
Carburizing	A	3	3
	B	3	2
	C	2	3
	D	4	3
	E	4	4
	F	3	4
Carburizing + carbonitriding	A	5	4
	B	5	5
	C	5	5
	D	5	5
	E	5	5
	F	4	5

Based on a rating of 3 for carburized steel A, 1 = inferior, 2 = slightly inferior, 4 = slightly superior, 5 = superior

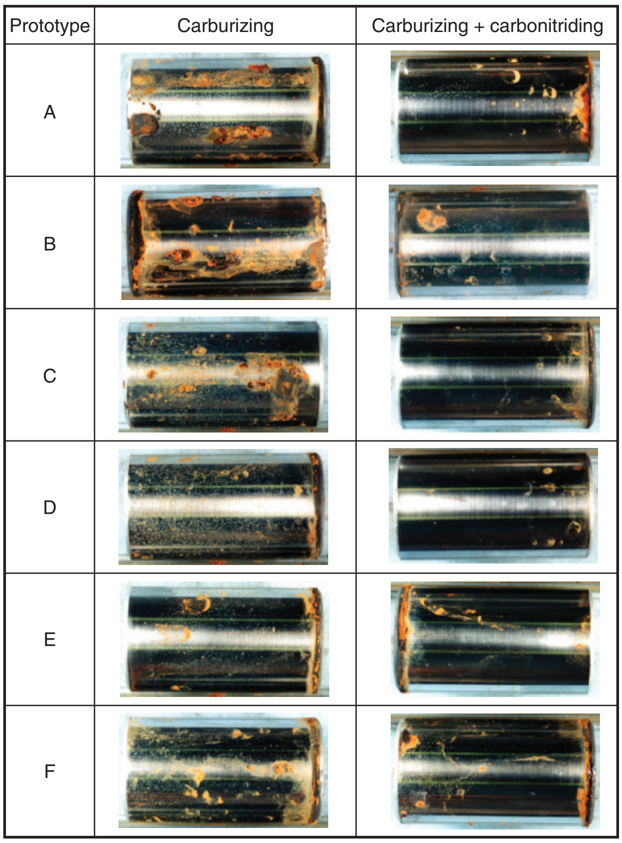


Fig. 2 States of surface rust after humidity cabinet test

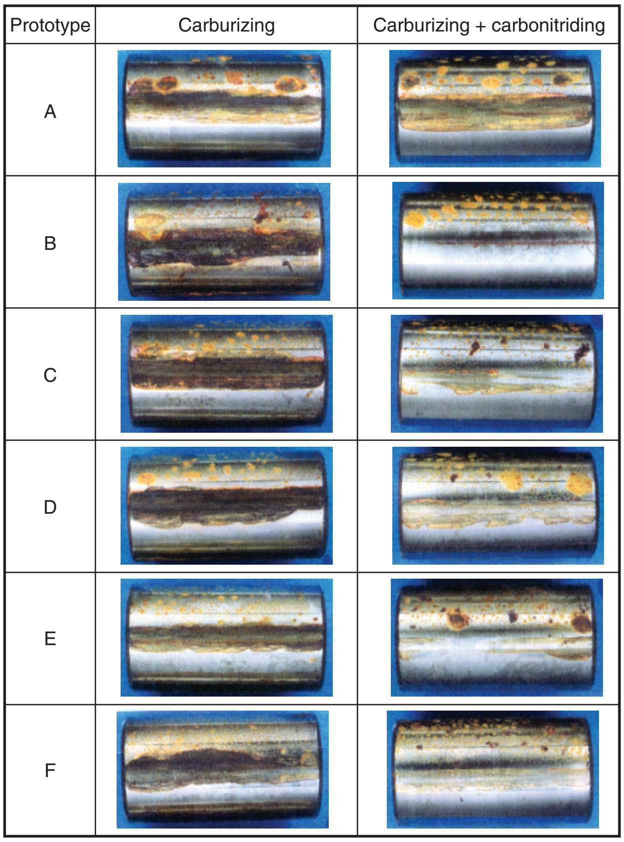


Fig. 3 States of crevice corrosion after humidity cabinet test

As shown in **Table 3**, all prototypes after carbonitriding treatment show superior rust resistance. In other words, it has been found that it is effective to apply nitrogen solutioning to the surface for improvement of rust resistance.

To be noted are the results of specimens after carburizing treatment. Steels D, E and F, regarding which the Ni content is low and the Cr content is high, showed better rust resistance than the standard steel A. Nickel is comparatively expensive compared with chromium, so it is desirable to minimize the Ni content. Therefore, additional trial steels were prepared by changing the Ni and Cr content based on steel E, which achieved the highest rating, and evaluation was carried out under the same conditions to clarify the effects of Ni and Cr content on rust resistance.

The results are shown in **Fig. 4**.

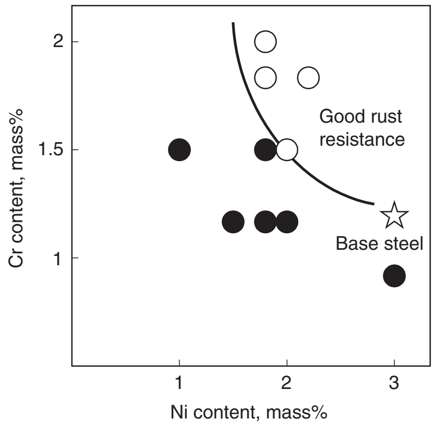


Fig. 4 Effects of nickel and chromium content on rust resistance

The addition of both Cr and Ni is said to be necessary for the improvement of rust resistance for carburized bearings, but from the results, it has been confirmed that similar rust resistance can be achieved by adding increased Cr content even when the addition of more expensive Ni is reduced.

In this development project, taking into account the heat-treatment characteristics in the carburizing and carbonitriding processes, the Ni content was examined based on the results shown in **Fig. 4** on the assumption of setting the of Cr content at 2% or less.

4. Basic Performance of Rust-Resistant Case-Hardened Bearing Steel

Based on the results of the rust resistance examination described in **Sections 1~3**, a nickel-chrome molybdenum steel for rolling bearings has been developed for improvement of fatigue strength and toughness. Basic performance test results of the developed steel are described in comparison with the conventional steel as follows. Although the standard heat treatment for this steel is carburizing, carbonitriding process can be also applied when higher rust resistance or longer fatigue life is strongly required.

(1) Toughness

Toughness was evaluated with the Charpy impact value and the fracture toughness value. Comparative results are shown in **Table 4**.

Table 4 Charpy impact value and fracture toughness

Test material	Charpy impact value J/cm^2	Fracture toughness value MPa・m$^{1/2}$
Developed steel	46～58	98～115
Conventional steel	40～52	85～93
	(JIS 4 type V-notched test piece)	(61×64×12.5 CT test piece)

More Mo was added to the developed steel compared with the conventional steel, and the Ni and Cr content is well-balanced, which is expected to improve toughness.

(2) Rust resistance

Comparison results concerning the rust resistance of rolling elements is shown in **Fig. 5**.

The developed steel showed rust resistance superior to that of the conventional steel, achieved by optimization of the Ni and Cr content as described in **Section 3**. Further superiority by carbonitriding treatment was also confirmed.

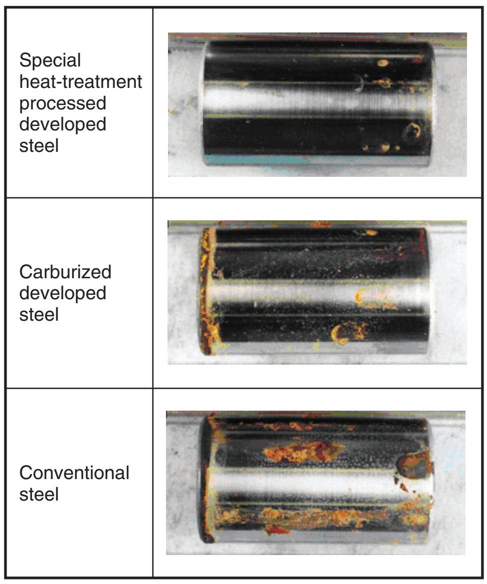
(3) Rolling fatigue life

A comparison of rolling fatigue life is shown in **Fig. 6**.

By reviewing the quantity of alloy components, rolling fatigue life of the developed steel has been also improved in comparison with the conventional steel. Under these evaluation conditions, life improvement of 4 or 7 times is expected by adoption of the developed steel or further carbonitriding treatment, respectively.

Test conditions

Test temperature	Relative humidity	Test time
49℃±1℃	95% or more	96 h



Special heat treatment: Carburizing + carbonitriding

Fig. 5 Rust resistance (humidity cabinet test)

Life test conditions

Test piece	$\phi 20 \times \ell 36$
Max. contact stress	5 800 MPa
Loading cycle frequency	285 Hz
Lubricating oil	Turbine oil (VG68)
Quantity of supply oil	2 ℓ/min (Room temperature)

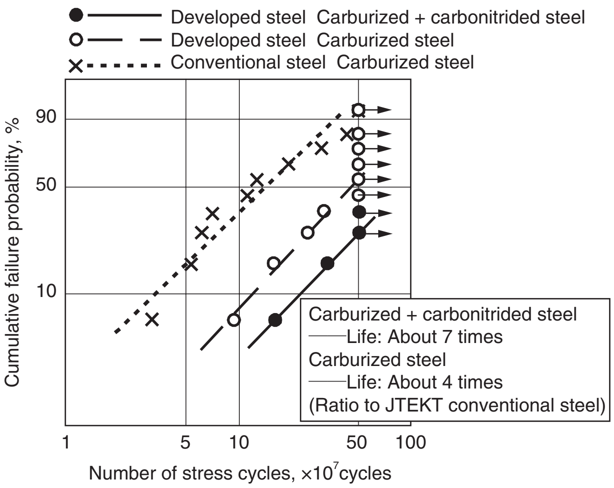


Fig. 6 Results of rolling fatigue life test

5. Conclusions

The developed rust-resistant case-hardened bearing steel has been confirmed to have good performance in the areas of rolling life, toughness and rust resistance, which are particularly important for bearings in iron and steelmaking equipment, superior to that of the conventional steel. Also, further performance improvement is possible by combination of heat-treatment technologies. The developed steel is expected to contribute to longer life and extension of the maintenance interval for bearings used in iron and steelmaking equipment.

References

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