Recent Development of Bearing Steel in Japan*

By Toshikazu UESUGI**

Key words: development of bearing steel; bearing steel; oxygen content; rolling contact fatigue life; continuous casting; eccentric bottom tapping; productivity.

I. Introduction

It is indeed a great honor for me to have been awarded this prestigious G. Watanabe Medal. Looking back at my career, I have served in the specialty steel industry all the way through since 1949 exclusively for the research and development, and manufacture of specialty steels, particularly high-carbon chromium bearing steel. High-carbon chromium bearing steel, for which quality requirements are the severest among specialty steels, began to be domestically produced shortly after World War II, but its quality was not on a par with imported steel manufactured overseas, typically represented by SKF Steel (now Ovako Steel) in Sweden. As a manufacture, now leading the world after hosts of developmental works in the manufacturing technology, this past history is quite moving and impressive.

I can not help but be tempted to review developments of quality, as well as manufacturing technology of this steel on this occasion; thus today's topic has been selected.

II. Developmental History of High-carbon Chromium Bearing Steel

I will, in the first place, summarize the history of high-carbon chromium bearing steel in quality and in manufacturing technology as well.

The fact that the basic chemical composition of 1% C-1.5% Cr, which is said to have been developed around the end of the 19th century, has survived with only little variations, testifies that this steel is a fully developed steel. We have, however, witnessed remarkable progress in the last two decades in both quality and productivity.

First, let's look at changes in volume of high-carbon chromium bearing steel produced in Japan.

As seen from Fig. 1, its production gradually increased since the late 1940's owing to recoveries from World War II and the Korean War. Then motorization and high economic growth gave an impetus for an enormous boost from the 1960's through the early 1970's. A steady production hike is still observed since then even with world oil embargoes and Japanese currency's skyrocketing appreciation. Let me add that 600 000 t per annum of the recent high-carbon chromium bearing steel production in Japan shares about 60 % of the total tonnage in the free world, which is naturally the highest in a single country.

Next, let's take a look at quality.

Bearings are used to support rotating axes of every machine represented by automobiles. Axle bearings of Shinkansen (bullet train) are typical examples of components which are not supposed to fail. Bearing materials of high reliability and longevity have, thus, been all the time sought after.

A trend of changes in oxygen contents of high-carbon chromium bearing steel is shown in Fig. 2 for an example demonstrating a change in quality. The reason we take note of oxygen is that oxide inclusions formed by oxygen become stress concentration sources in the matrix of working bearings causing extremely adverse influence on bearing life. Generally speaking, a five-fold increase in life is recognized if oxygen is reduced from 30 to 15 ppm. Introduction of the

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** President, Sanyo Special Steel Co., Ltd., Nakashima, Shikama-ku, Himeji 672.
vacuum degassing system contributed to a steep drop in oxygen reaching levels lower than 10 ppm in the late 1970's to achieve the highest longevity at a time in the world.

It is, accordingly, the reduction in oxygen levels which account for the improvement in bearing life.

Behind such improved quality are technical developments which influenced not only quality, but productivity as well. These are shown in Table 1. While capacity of the electric furnaces has expanded year by year, high power-rapid melting technology applied in the UHP furnaces has realized an outstanding improvement in productivity. Sanyo's rapid melting technology, drawing much attention from the European and American developed continents, has been transferred to such countries as F.R. Germany, France, Sweden and Canada. The vacuum degassing facilities installed since 1964 made contributions not only to increased productivity but also to an epoch making improvement in quality. Based on our philosophy that oxygen or oxide inclusions must be reduced to excel in quality acid open furnace steel that was believed the best at that time, the ladle degassing equipment was introduced first and then, the R-H degassing vessel took its place. Of course the degassing operation is not the single element in lowering oxygen. Others, including ladle metallurgy, the selection of refractories, as well as modern casting process, all contribute to this result.

A series of facilities built in 1982, including the

![Fig. 2. Movements of oxygen content in high-carbon chromium bearing steel produced at Sanyo Special Steel Co., Ltd.](image)

Table 1. Movements of improvements in facilities.

<table>
<thead>
<tr>
<th>Year</th>
<th>Electric steelmaking</th>
<th>Vacuum degassing</th>
<th>Ingot making</th>
<th>Working process</th>
<th>Heat treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1960</td>
<td>15-t EF</td>
<td></td>
<td>Bottom pouring</td>
<td>Hot extruded tube</td>
<td>Bogie</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ladle degassing</td>
<td></td>
<td></td>
<td>Continuous</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(700 t/unit)</td>
</tr>
<tr>
<td>1970</td>
<td>30-t EF</td>
<td>UHP</td>
<td>Towards larger ingots</td>
<td>Hot rolled tube</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Continuous</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(3 000 t/unit)</td>
</tr>
<tr>
<td>1980</td>
<td>60-t EF</td>
<td>Scrap preheating</td>
<td>Continuous casting</td>
<td>Cold rolled tube</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>LF</td>
<td></td>
<td></td>
<td>Continuous</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(10 000 t/unit)</td>
</tr>
</tbody>
</table>
90-t UHP furnace with an eccentric bottom tapping [EBT] system, the ladle furnace, the R-H degassing vessel and the continuous caster, have all contributed to the crystallization of this improved technology. For the first time, extra-low oxygen steel, comparable to vacuum arc remelted steel, was regularly and consistently mass-produced.

Closely related is the fact that the supply of this steel in tubular form contributed to development of the bearing industry and an emergence of the continuous, large capacity heat treatment furnaces is also one of advanced developments which can not be overlooked because it contributed to stable quality product after product.

III. Progress and Development of High-carbon Chromium Bearing Steel

1. Mechanism of Bearing Life

Bearings which operate for an extended time develop flaking on the rolling contact surfaces of rolling elements such as balls and inner or outer races even under normal conditions. This causes irregular rotations and is, in fact, bearing failure. Flaking is a type of fatigue crack phenomenon caused by contact pressure. One example of flaking on the rolling surface is shown in Fig. 3.

Sharp edged foreign material, such as oxide inclusions, located on the maximum shear stress area right below the rolling surface, help develop fatigue cracks. Figure 4 illustrates how voids form around an oxide inclusion. Oxide inclusions are not elongated even by hot working such as rolling, creating voids in the matrix to concentrate stresses which are extremely harmful in developing flaking. So it is most important to reduce oxide inclusions to the lowest level possible in order that early flaking may not occur.

2. Relationship between Oxygen Contents and Bearing Life

The thrust-type life testing machine is used at Sanyo for accelerated results some of which are shown in Fig. 5. Rolling contact fatigue test results, which vary from test to test, are evaluated for $B_{10}$ life as a result of the number of stress repetitions when 10% of specimens tested fail under the same surface stress. $B_{10}$ life, which is a arrow-pointed in Fig. 5, for example, is $4.7 \times 10^7$. The life for over $10^8$ repetitions is not tested because it takes too much time. Life referred to in my presentation is defined as $B_{10}$ life from now on.

Figure 6 shows the relationship between oxygen contents and $B_{10}$ life. 15 ppm oxygen achieved by introducing the vacuum degassing method in 1964 increased life approximately 5 times as compared with the life when oxygen was 30 ppm. As oxygen went further down to below 10 ppm, life improved approximately 15 times. Now with 5 ppm oxygen in the continuous cast steel, approximately 30 times longer life has been obtained in comparison with a non-degassed steel. Recent life testing results, which are equivalent to those of VAR or ESR steel, are rather stable on a high plateau because of inclusions changed in morphology by introduction of the EBT system. The assumption that good life expectancy of ESR material, even for its higher oxygen contents, is due to its finely dispersed inclusions demonstrates that life is affected not only by oxygen levels but also by morphology of inclusions.

As was discussed above, high-carbon chromium

![Fig. 3. Flaking on rolling track.](image)

![Fig. 4. Void formed at both ends of oxide inclusion.](image)

![Fig. 5. Rolling contact fatigue life test results.](image)
bearing steel has been now mass-produced with quality equivalent to VAR or ESR steel.

3. Levels of Oxygen

Histograms of oxygen contents in the recent continuous cast and ingot cast steels are shown in Fig. 7. Oxygen is low in both steels, but it is lower in the continuous cast steel because of minimized contamination through easier shielding from atmosphere and less contacts with refractories, and even the heat to heat variation is smaller. This continuous casting process can be advantageous in responding to today's higher reliability requirement of bearing steel.

4. Levels of Nonmetallic Inclusions

For rating of nonmetallic inclusions in low oxygen high cleanliness high-carbon chromium bearing steel, SAM method focusing on B- and D-type inclusions, which was recently introduced in ASTM A 295, has been increasingly adopted.

As shown in Fig. 8 where domestic and off-shore steels are compared for cleanliness levels, it is understood that Japan's high-carbon chromium bearing steel excels others.

5. Influence of Cold Working on Life

Nonmetallic inclusions are deformed and dispersed in hot and cold working processes. This phenomenon is particularly evident in seamless tubes which have undergone a large reduction in the cold rolling (pilgering) operation. The resulting dispersion of nonmetallic inclusions brought about considerably improved life (Table 2).

The history of developments regarding quality improvements of high-carbon chromium bearing steel has been reviewed; but let me recap it. It is factual to say that high-carbon chromium bearing steel, having the high longevity and good reliability, is produced with low oxygen levels through the proper use of the electric furnace, the ladle furnace and the vacuum degassing vessel followed by continuous casting. Further improvements in the longevity of bearing components is also realized when such steel, in tubular form, is extensively hot worked and cold rolled.
IV. Development and Progress in Melting and Refining

1. Introduction of Vacuum Degassing Process

Vacuum degassed high-carbon chromium bearing steel was first manufactured in 1964 in Japan by the ladle degassing process as shown in Fig. 9 where a ladle is put inside the vacuum tank with steel stirred by an inert gas under 0.5 torr of a final pressure. The R-H process shown in Fig. 10 was later introduced in 1968 to improve cleanliness in the ladle degassed steel which was not satisfactory because of entangled slag of high basicity.

The R-H degassing process has been found the most suited for bearing steel in that it is free of slag contamination and lower in oxygen under 0.1 torr of pressure as compared with the ladle degassing process.

2. Towards Larger Capacity Electric Furnaces and UHP Operation

The concept of UHP rapid melting operation in the electric furnace advocated in the late 1960's was revolutionary and a complete departure from the conventional electric furnace operation. This concept enabled the electric furnace to leap forward in terms of productivity. A major feature of this process was that power put in the furnace was 2 to 3 times higher as compared with the conventional process. UHP operation in the larger furnaces with transformers of higher capacity was progressively accepted for higher productivity in shorter melting time required also of high-carbon chromium bearing steel by high economic growth period of the 1960's. And now a super-UHP era is here to stay.

In line with an increase in the furnace capacity at Sanyo from 30-t to 60-t to 90-t and to 150-t (90-t furnace is overcharged), productivity, that is, good ingot production per melting time, has increased eight-fold as is shown in Fig. 11 from 15 t/h in the 1960's to the present 125 t/h.

Movements in consumption rate of power, electrodes and sidewall refractories are shown in Fig. 12 for your information. We will make further, continued efforts to minimize production costs.

3. Introduction of Ladle Furnace

Use of the larger capacity transformers was found unreasonable in a reduction period controlled by refining rate among melting, oxidizing and reduction periods, as the larger, intensified UHP furnaces came on-stream. The ladle furnace was introduced, then, for the reduction period after tapping of steel from the furnace where the maximum utilization of the large transformer is made during melting and oxidizing periods. Control of aim temperature and casting time has been also made possible by the heating func-
tion incorporated in the ladle furnace. This is a must for synchronization with the continuous caster. As for quality, deoxidization and desulphurization are, furthermore, made easier by an addition of strong basic slag and inert gas stirring, and precision of one point aim in chemistry has improved.

4. Introduction of Eccentric Bottom Tapping System

While steel is, in a conventional method, tapped into the ladle through a spout of the tilted electric furnace, the EBT system shown in Fig. 13 was recently developed. Introduction of the EBT system has achieved higher productivity in a shorter tapping time, but a far-reaching advantage in stable manufacture of higher cleanliness steel is greater because oxidizing slag can be cut for slag-free tapping and also for easier reduction process in the ladle furnace.

A change in oxygen contents as well as in nonmetallic inclusions before and after the EBT installation shown in Table 3 indicates that oxygen has been lowered by 0.4 ppm and a substantial improvement has been made in B-type thin and D-type heavy inclusions as determined by ASTM E45 method A.

V. Progress and Development in Casting

1. Progress in Bottom Casting

Although a change from top casting to bottom casting in the late 1940's is one transition in casting technology, a variety of advancements have been accomplished during a 30-year period until the introduction of the continuous caster. Major research efforts in an earlier stage were centered on development of powder to prevent oxidization of metal in the mold and then, such peripheral technology as atmosphere controlled casting by shrouding metal by an inert gas in place of air was developed in an effort not to re-oxidize the vacuum degassed steel. Also responsible for a great improvement in cleanliness are changes in a line-up of ingot molds and in the quality of the refractories of runners in the bottom plate.

2. Introduction of Continuous Caster

An era of continuous casting was ushered in the late 1970's and the heavy section bloom continuous caster was installed at Sanyo in 1982.

Floating-up of nonmetallic inclusions from steel in the tundish and, the prevention of any re-oxidization of the steel during casting are most important factors in the continuous casting process. As in the schematic figure of the tundish in Fig. 14, oxygen contents in the large capacity, water cooled tundish with dams are maintained almost nil by blowing-in of an inert gas. A gap between the top and the tundish and such openings as a temperature measurement hole are completely closed to hold consumption of an inert gas down to as minimum as possible. Also important is quality of the refractories to prevent contamination of steel. Major elements of the refractories are shown in Table 4.

![Fig. 12. Movements of raw materials consumption.](image)

![Fig. 13. Schematic construction of EBT system.](image)

| Table 3. Oxygen content and nonmetallic inclusion rating as influenced by tapping method. |
|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| Mean oxygen (ppm)               | Mean oxygen (ppm)               | Mean oxygen (ppm)               | Mean oxygen (ppm)               | Mean oxygen (ppm)               | Mean oxygen (ppm)               |
| TST (Tilting spout tapping)     | TST (Tilting spout tapping)     | TST (Tilting spout tapping)     | TST (Tilting spout tapping)     | TST (Tilting spout tapping)     | TST (Tilting spout tapping)     |
| 55                             | 5.8                             | 1.34                           | 0.10                           | 0.72                           | 0.00                           | 0.98                           | 0.37                           |
| EBT (Eccentric bottom tapping)  | EBT (Eccentric bottom tapping)  | EBT (Eccentric bottom tapping)  | EBT (Eccentric bottom tapping)  | EBT (Eccentric bottom tapping)  | EBT (Eccentric bottom tapping)  |
| 70                             | 5.4                             | 1.35                           | 0.12                           | 0.17                           | 0.00                           | 0.90                           | 0.04                           |

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Clogging of the immersion nozzle by build-up of Al₂O₃ is the most concerned problem in the continuous casting of aluminium killed steel. It is necessary for the prevention of such clogging to supply clean steel to the continuous caster by such measures as listed below:

1) Sufficient refining by strong reducing slag in the ladle furnace
2) Prevention of contamination caused by droppings of splashes adhered to the R-H degassing vessel.

The clogging problem has, then, been reduced to zero through casting in the completely non-oxidizing atmosphere for the record production of multiple-heat, continuous cast high-carbon chromium bearing steel ever established in the industry as shown in Table 5.

A wide variety of melting and casting technologies have made possible mass-production of single-ppm oxygen high-carbon chromium bearing steel. Bearing life has improved about thirty-fold in comparison with that of non-degassed steel produced 25 years ago and the production volume has also expanded to lead the world.

VI. Future Tasks

1. High Reliability

In an age where the trend is toward the light, the short, the thin and the small, higher performance of bearings is demanded. Higher reliability such as assurance of 100 % confidence life until flaking occurs in one bearing, not B₁₀ (10 % failure probability), is needed. Further investigation into chemical composition and morphology as well as distribution of nonmetallic inclusions must be pursued in addition to continued work towards stable, lower oxygen levels.

2. Hostile Environments

Bearings are increasingly used in corrosive or high temperature environments as the industrial society progresses. While bearings for these applications are made of such steels as AISI 440C (1% C–17% Cr) and M50 (0.8% C–4% Cr–4% Mo–1% V), research efforts have continued for development of less costly, better workable and longer life material for each particular usage. As is exemplified in ceramics bearings, one of developmental tasks is devoted to bearings of new material.

3. Application of Continuous Cast High-carbon Chromium Bearing Steel to Rolling Elements

Although the amount of high-carbon chromium bearing steel produced by the continuous casting method is increasing, it has not been applied yet to bars or wire rods or wires for such rolling elements as balls and rollers. However, as we succeed in efforts to reduce center segregations, we could expect to find continuous cast steel used for these applications, as well.

Now that the history of development and progress of this steel in Japan has been summarized, please let me finish my presentation by wishing for still greater progress in terms of the development of high-carbon chromium bearing steel.