Technical Review

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Progress and Prospects of Rail for Railroads

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Abstract

From the day of establishment of Nippon Steel & Sumitomo Metal Corporation Yawata Works in 1901, our rail factory had started production of rails for railroads and, for approximately 110 years, we have come in response to economic development of Japan and corresponding sophistication of rail transport "speed-up".On the other hand, "heavy haul" progresses from an aspect of the transportation efficiency improvement, and improvement of abrasion resistance is highly required in foreign countries where freight transport is the main constituent. We have promoted positively the sophistication of manufacturing process and products in order to support such needs from customers. I will report about the contents of above features in this bulletin and give the future prospects.

1. Introduction

In 1901, domestic production of rails was started in the Yawata Works of Nippon Steel & Sumitomo Metal Corporation (hereinafter referred to simply to as "Yawata"). During the period since then, increases in train speed and car load have been achieved both domestically and overseas, and demand for higher rail quality has continued to grow along with the increased needs for higher track safety, improved ride comfort, and reduced maintenance costs. To respond to such needs, the Yawata rail mill has developed various technologies and achieved great improvements in productivity through sophistication of their production process, and has made great contributions to the sophistication of railway transport not only in Japan but also in other countries through its efforts toward the development of new rails and improvement of rail quality. **Table 1** shows the timeline of major events in the Japan railway system and the development of rail at Nippon Steel & Sumitomo Metal.

Table 1 Brief history of the Japan railway system and the development of rail at Nippon Steel & Sumitomo Metal

Year:	
1872 (5th year of Meiji)	Railway service started between Shimbashi and Yokohama
1889 (22nd year of Meiji)	Tokaido Line in full distance between Shimbashi and Kobe opened
1901 (34th year of Meiji)	Production of rails started in Yawata
1927 (2nd year of Showa)	First subway service started between Ueno and Asakusa
1933 (8th year of Showa)	Production of 25-m-long rails started
1942 (17th year of Showa)	Kanmon undersea tunnel opened
1954 (29th year of Showa)	Production of head-hardened (HH) rails started
1964 (39th year of Showa)	Tokaido Shinkansen (with train of 0 system/210 km/h) opened
1968 (43rd year of Showa)	Production of EH rails started
1970 (45th year of Showa)	Operation with universal rolling technology started
1972 (47th year of Showa)	Sanyo Shinkansen between Shin-Osaka and Okayama opened
1972 (47th year of Showa)	Production of 50-m-long rails for Shinkansen started
1975 (50th year of Showa)	Sanyo Shinkansen in full distance opened
1977 (52nd year of Showa)	Production of new head-hardened rails (NHH) rails started
1982 (57th year of Showa)	Tohoku Shinkansen and Joetsu Shinkansen opened
1985 (60th year of Showa)	Commissioning of Shinkansen the 100 system (220 km/h)
1987 (62nd year of Showa)	DHH rails developed (inline heat treatment)
1987 (62nd year of Showa)	Seikan undersea tunnel opened
1992 (4th year of Heisei)	Commissioning of Nozomi 300 system to Shinkansen (270 km/h)
1994 (6th year of Heisei)	Bainitic steel rails developed
1997 (9th year of Heisei)	Commissioning of Nozomi of the 500 system to Shinkansen (300 km/h)
1999 (11th year of Heisei)	Production of hyper-eutectoid steel rails for heavy-haul railroad started
2003 (15th year of Heisei)	Production of rails meeting waviness specification started

2. Achievements to Present

2.1 From start of operation until the end of World War II

The first railroad, which was built between Shinagawa and Yokohama, opened in May 1872; this railroad was followed in July 1889 by the opening of The Tokaido Main Line in a full distance of 605 km between Tokyo and Kobe. In addition to these lines, railway service by private sectors was started in various areas in Japan, and rapid growth of rail demand was expected. Therefore, as the first-stage plan, Yawata Iron and Steel Works, which was then state-owned, started the construction of a rail mill in June 1897 and started operation in November 1901. The first produced rail was 60-lb

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rail of 30-ft length (weight: approximately 30 kg/m; length: 9.144 m). Because these rails were the first rolling rails produced in Japan, Japanese engineers and operators were quite inexperienced in rolling operation; therefore, German engineers were hired, and they guided Japanese workers in operating the mill. However, due to a lack of operating skill and poor equipment condition, production was as low as 1,086 tons in 1901.

With respect to the equipment, steam was used to supply power to the rolling mill during the early stages of operation of the rolling mill; this power supply was replaced by the first domestically built 3,250-HP Ilgner-type electric motor in 1932. Furthermore, at the same time, overseas-constructed equipment of the latest design at the time, such as a roller straightening machine and a Heller-type cold sawing machine, were introduced. With this equipment, mill operation at a higher efficiency and with improved safety was established.

During the early Showa era, the official names of rails were revised: 60-lb rail was renamed to 30-kg rail, and 75-lb rail was renamed to 37-kg rail. In addition, the standard length was revised to 20 m. In parallel with this revision, efforts were made to increase the number of different sizes of product rails, which reached thirteen in August 1945 (at the time of the termination of the War). In addition, records show that the production of rails with enlarged profiles as well as crane rails and switch-point rails was also promoted, and the export of rails to China and Brazil was started during this period.

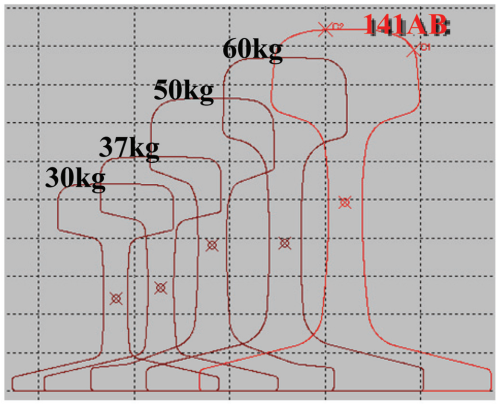
With these achievements, production during the prewar period was as high as 200,000 tons per year, inclusive of steel products other than rails.

2.2 From the postwar reconstruction period to the high economic growth period

Immediately after the termination of World War II, the Yawata rail mill was ordered to be preserved as possible war compensation; therefore, the mill was forced to stop its production operation. However, this order was later lifted, and production resumed in November 1948. One of the background factors that contributed to the lifting of the preservation was the urgency in restoring domestic inland transportation functions for the post-war reconstruction of war-caused devastation. To better cope with further increased demand brought forth by the economy up-surge in the 1950s, the expansion of equipment was focused primarily on expansion of production capacity. The mill underwent four modifications over a period of 20 years after 1945, and the production capacity increased steadily.

With respect to rolling, the mill motor capacity was increased to 4,500 kW. As a result, rolling time was shortened, which prevented a decrease in the rolling temperature of rolled materials, reduced the variation in temperatures during finishing of the material, and further reduced the roll's wear. Furthermore, a rolling mill machine of the then latest design was imported from Germany, which electrified the roll gap setting operation that used to be done manually. With its improved mill accuracy, the new rolling mill machine greatly improved the dimensional accuracy and surface quality of the products and also substantially improved yield and productivity.

The rail profile was also improved during this period. Since 1956, a study group for rail specifications was formed by three parties: two manufactures of rails, then Yawata Iron and Steel Corporation and Fuji Iron and Steel Corporation, and Japan National Railways, a rail customer. These parties discussed revisions of the profiles of 50-kg and 37-kg rails and other topics. Furthermore, discussions were started in 1958 over the rail profile of a rail to be used in Tokaido Shinkansen; as a result of these discussions, the production



1901 : 30kg/m rail
1906 : 37kg/m rail
1925 : 50kg/m rail
1967 : 60kg/m rail
reference : 141AB rail : Maximum size at Yawata

Fig. 1 Trend of size enlargement of rail profile

of 50T rail and 60-kg rail, which was an improved type for Sanyo Shinkansen, was started. **Figure 1** shows the trend in the enlargement of the size of the rail profiles. Among the rails, 141AB rail was the largest produced at the time at the Yawata rail mill.

Furthermore, although the 25-meter length had been the longest and standard length, a method was developed of jointing both ends with a weld to process rails into a single 1.5-km-long rail to counter the noise that occurred at bolt-jointed rail-tying sections and the growing labor cost for the maintenance of such tie sections. However, despite the year-by-year production increases in such rails, production of long rails was requested in 1970 to address rising welding costs. In response to the request, plans were studied, and a new building was constructed for the exclusive production of 50-m rails; production of these rails started in September 1972.

2.3 From the oil crisis period to the Heisei period

During this period, progressive equipment modifications were made with respect to the rolling of rails, and improvements in the quality and production volume of rails were promoted.

2.3.1 Universal rolling method

The universal rolling method was introduced as a replacement for the conventional caliber rolling method (**Figs. 2, 3**). This technology, which was based on the technology of the Wendel Corporation, was developed by incorporating our specific original technology. In the universal rolling process, in addition to two rolls for the upper and lower sides, two other rolls are used: one on the left side and another on the right side. Fine adjustment of the positions of these rolls became possible, which enabled fine dimensional control of rolled rails in a manner different from that used in the conventional caliber rolling process. In addition, the process featured additional advantages: (1) The head and base of a rail are important parts in the function of rails and excellent material quality was obtained in these parts because their thickness could be directly reduced, thereby providing a high forging effect; (2) the dimensional accuracy of such rails was excellent because the entire rolling process could be uniformly reduced; and (3) the occurrence of harmful surface defects was decreased, which resulted in reduced local wear of rolling rolls. Consequently, roll consumption per ton of products was greatly improved.

In June 1970, the mill was upgraded to a rail rolling mill em-

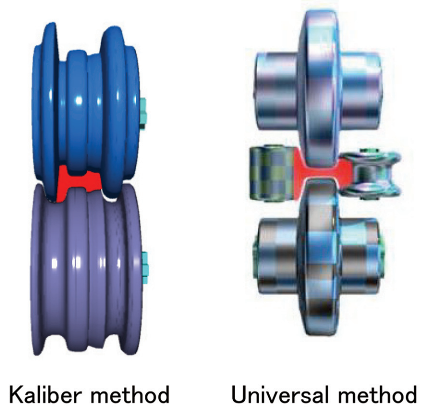


Fig. 2 Method of the rail rolling-1

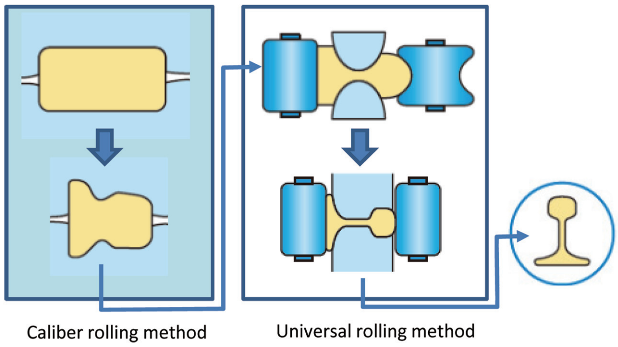


Fig. 3 Method of the rail rolling-2

ploying the full-dress universal rolling process for the first time in the world. The production capacity was expanded to as high as 70,000 tons per month.

In 1997, a universal finishing mill of high accuracy was additionally installed to further improve the dimensional accuracy, which resulted in further dimensional accuracy improvements that contributed to the realization of higher speeds on railways. In addition to the application of the universal rolling process to the production of 60K rail, 50N rail, etc., this process was also extended to the rolling of switch-point rails. Presently, efforts are still underway to improve the dimensional accuracy of rails.

2.3.2 Inline heat treatment

In the Yawata rail mill, a heat-treatment method for rails was developed in the 1950s to address the need for high strength. In the early stage of the development, a quench-and-temper process was used; the head of a conventionally produced rail was heated by induction heating and then water quenched. This process was referred to as the "offline heat treatment process" because the processing was applied on a line separated from the rail production line; the products were referred to as "HH rail."

Afterwards, the process was improved, and a process in which the head was quenched by air after being heated was used in this offline heat treating line in 1976. The rails processed through this new offline system were called "NHH rails" and were standardized as "JIS E 1124 Slack quench Type Heat treated Rails" in 1988. The NHH rails were employed not only in Japan but also in overseas heavy-haul railways and contributed to prolonging rail life because of their excellent wear resistance.

However, with heating by induction, the heated zone depth is limited; therefore, the depth of the hardened zone created by the heat-treating process is also limited. For this reason, the rate of wear after installation of the rail was faster, in accordance with the accumulation of passage tonnage, which caused problems for customers due to the rail change interval becoming shorter than planned or the gradual occurrence of internal fatigue damage due to increased axle load.

Also, the productivity of the offline heat treating line was low because of the process used to reheat rails; consequently, another problem related to the inability to meet the increasing demand for heat-treated rails emerged.

After extensive studies on various cooling methods, a new process—the "inline heat treating process"—was employed that utilized the heat of materials immediately after the completion of rolling for the heat treatment, which circumvented the need for reheating. In 1987, the production of rails heat-treated using this process was started for the first time in the world. Inline heated treated rails are able to maintain high hardness deep at their heads; therefore, they are referred to as DHH (deep head hardened) rails. **Figure 4** shows a comparison of the inline-type and offline-type processes, and **Fig. 5** shows a comparison of the internal hardnesses.

Since 1999, the application of this technology has been extended to the processing of high-carbon steel HE (hyper eutectoid) (carbon content: 0.9%-1.0%). This steel is widely used in railways both in Japan and elsewhere because of its excellent wear resistance, surface damage resistance, and internal fatigue damage resistance.[1, 2]

2.3.3 As-rolled length processing

The length of a rolled material after rolling is 150 m, and the conventional process after rolling involves cutting the rolled material with a hot sawing machine to the ordered length with a marginal length added, cooling the material to an ordinary temperature on a cooling bed, straightening the material with a roller straightening machine, and then precisely cutting it to the ordered length. In the case of rails, because the accuracy in matching mutual rail end profiles strongly influences the welding performance (i.e., the work efficiency of aligning rails for welding and straightness of the weld-jointed section), end straightness allowance is strictly specified (for example, for 60K rails for Shinkansen, the upward end camber is specified to be 0.7 mm or less per 1.5 m and the downward end straightness is specified to be 0 mm). However, in roller straightening, both ends of the products remain un-straightened in principle; consequently, end camber remains, and the products are therefore

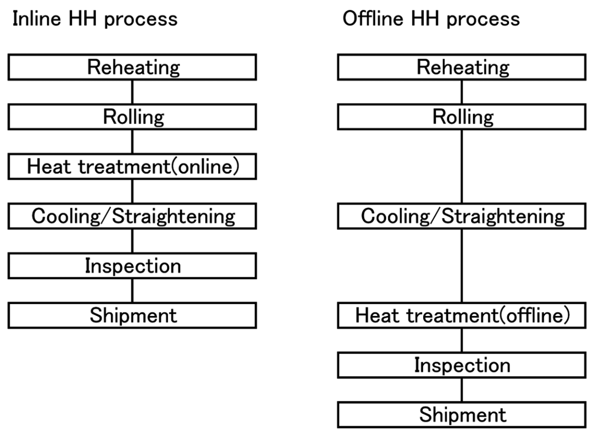


Fig. 4 Comparison of the process in-line vs off line

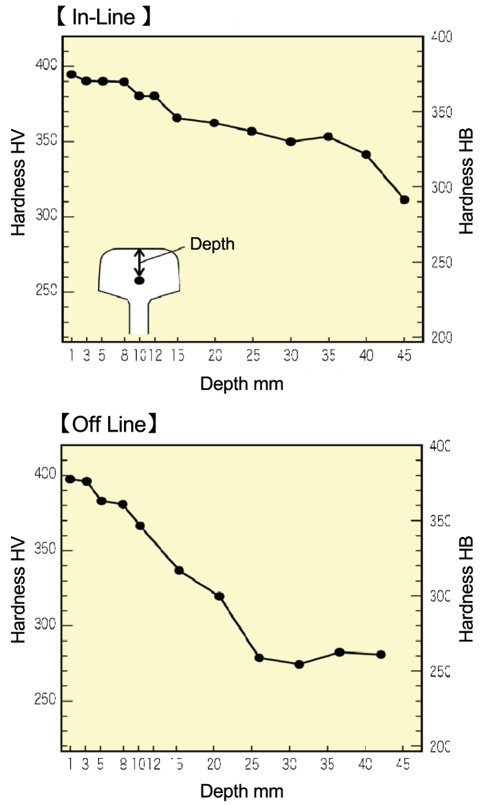


Fig. 5 Comparison of the internal hardness

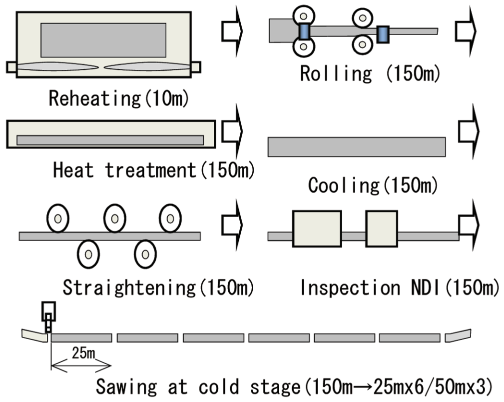


Fig. 6 150m processing

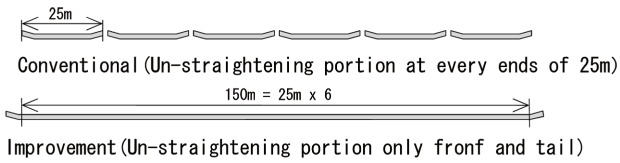


Fig. 7 Improvement of the end straightness

shipped after correction of the end camber by an offline gag press.

To eliminate this process, the entire line from the cooling bed to the cutting process, inclusive of straightening and nondestructive inspection, was redesigned, and the as-rolled length processing for 150-m lengths, i.e., cooling without hot sawing, straightening, the application of nondestructive inspection, and cutting to length, was started in 2002 (**Fig. 6**).

In this as-rolled length processing method, because the 150-m-long rolled material is cooled and roller-straightened as it is, the unstraightened portions at both ends remain within the crop end portions and are cut off during the subsequent process of cutting. This process of straightening 150-m-long rails has contributed to the improvement of long-rail product quality and to the quality assurance level for shipped rails; i.e., quality improvements in terms of improved straightness for welding and for the implementation of welding work with higher efficiency (efficient rail-aligning work, efficient post-welding bend correction work) have been enabled. Furthermore, a problem existed concerning the inability to apply automatic nondestructive inspection equipment because the shapes of the bends in the un-straightened portions of rails varied. However, with this new processing method, automatic inspection over the entire length of a rail was made possible, which contributed to an enhancement of the quality assurance level (**Fig. 7**).

In addition, with the elimination of the hot sawing step, the time between the finishing of rolling and the start of the inline heat treatment could be shortened, which could provide a wider range of advantageous conditions for the development of new products brought forth by the expanded available temperature zone for the start of the heat treatment.

3. Sophistication of Products

The sophistication of railroad transportation means, specifically, the realization of "higher speed" and "heavier hauling." The "higher speed" is the target of high-speed passenger railway service represented by those of Europe and Japan. For the operators entrusted with human life, safety is the supreme mission; to ensure safety and running stability during high-speed operation, straightness of rail bends and flatness of rail heads, which come into contact with wheels, are required. In addition, minimization of the risk of rail breakage is essential (**Fig. 8**).

In contrast, "heavier hauling" is the major target of the cargo railroads in North America and in countries with mining industries. Heavier hauling to enhance transportation efficiency (i.e., increased axle load and enlarged train length) is underway and, along with it, higher wear resistance and higher surface defect resistance of rails are demanded (**Fig. 9**).

This chapter describes how rail shapes and materials have been improved to satisfy the requirements of high-speed rail and how rail life has been extended in the application of heavy hauling.

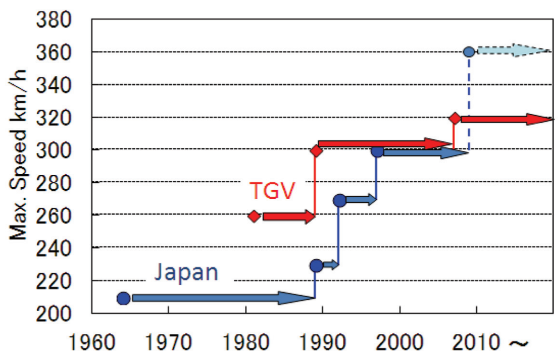


Fig. 8 Trend of train speed

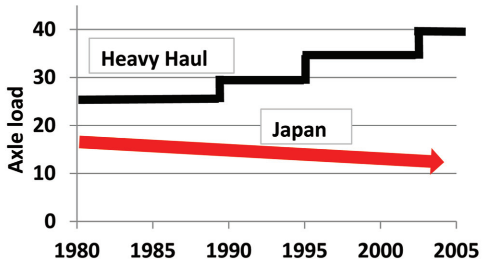


Fig. 9 Trend of the axle road (Japan and USA)

3.1 Rails with flatness for high-speed railways

A roller-type straightening machine corrects the bend of a rolled rail by bending the rail continuously with a number of rollers. Although a rail is straightened by a roller-type straightening machine and the rail becomes straight as a whole, when the straightness in the longitudinal direction of a rail head is strictly examined, very minute downward bends and upward bends are observed. These minute upward and downward bends are collectively called “wavy camber.” This waviness is considered to be caused by the fluctuation in the straightening force within one rotation of a straightening roller that emerges cyclically in the longitudinal direction of a rail. Furthermore, a cycle of the force fluctuation is correlated to straightening of the roller diameter, and the degree of fluctuation in the force is correlated to factors such as the rigidity of the straightening machine and the circularity of the straightening roller.

In the past, no quantitative standard existed for such waviness. (To be correct, the camber was standardized in EN Standard; however, no known published quantitative grounds for the standard exist.) Under this situation, in view of the importance of achieving the higher running stability at high speeds required in Shinkansen, discussions of the establishment of a standard started around 1999. These discussions were prompted by the “Study Team for Rail-related Problems,” which consisted of the JR companies, the Railway Technical Research Institute (RTRI), and rail manufacturers. At the Railway Technical Research Institute, a study on the influence of rail waviness on wheel load fluctuation, as shown in **Fig. 10**, was conducted.[3] This study demonstrated that not only the amplitude of wavy camber but also the wavelength of the wavy camber influence the wheel load.

After a series of similar studies, a standard specifying the waviness.or flatness of rail surfaces was introduced in October 2003. Prior to the implementation of the standard, Nippon Steel & Sumitomo Metal installed new straightening machines and instrumentation and introduced the aforementioned as-rolled long-length processing. With these upgrades, straightness was highly improved and a quality assurance system was established. Two countermeasures were incorporated into the upgraded straightening machine to improve waviness. The first countermeasure was the “enhancement of the rigidity of the straightening machine.” The amplitude of waviness. could be minimized by enhancing the rigidity of the straightening machine and thereby reducing the cyclic force fluctuation within one rotation of a straightening roller. The other countermeasure was the “enlarging of the straightening roller diameter.” With the enlargement of the straightening roller diameter, the wavelength of wavy camber was made longer, and its effect on the fluctuation of axle load could therefore be minimized (**Fig. 11**).

Because of these countermeasures, rails satisfying the standard specifying the maximum waviness have been shipped since 2003.

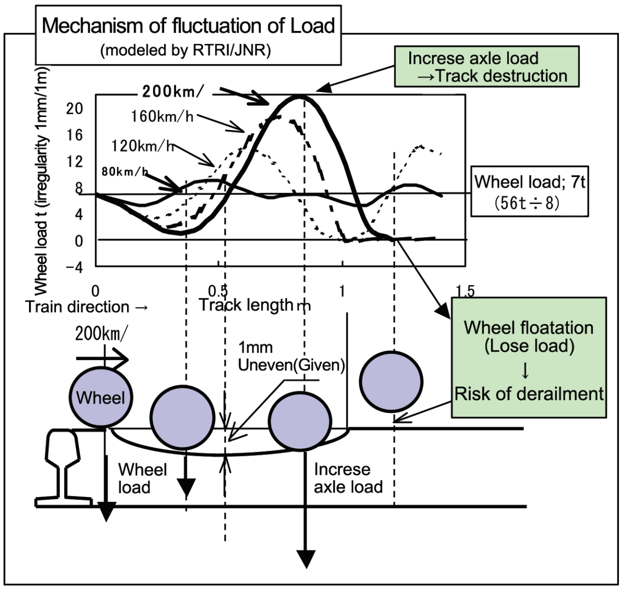


Fig. 10 Mechanism of the fluctuation of axle road[3]

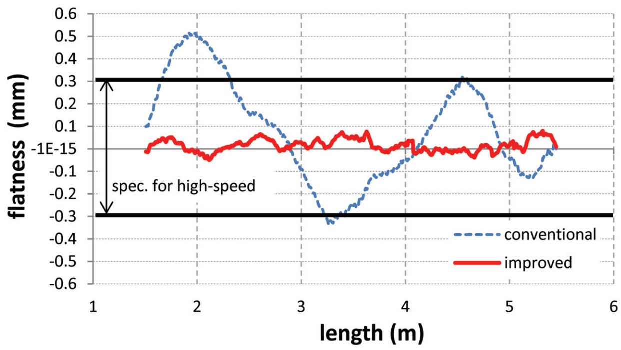


Fig. 11 Improvement of the flatness of rail surface

3.2 Rails for heavy-haul railroads

In the case of transcontinental and mining railroads, an increase in the axle load and an enlargement of train formation length are remarkable from the viewpoint of cost reduction. For example, axle loads of approximately 25 t have increased to 40 t. With respect to train length, trains with 300 cars are practically operated at present, and annual passage tonnage exceeds 400 MGT (million gross tons) on some railways. On such railways, because the prolonging of rail life contributes greatly to decreases in costs and opportunity losses, the Yawata rail mill has responded to such needs by enhancing the strength of rails.

The process of enhancing rail strength is roughly classified into the following four steps:

(1) Heat treatment vs. alloying
(2) Selection of a heat-treating process
(3) Shift to inline heat treatment from offline
(4) Sophistication of the material

An outline of these steps is described hereunder.

(1) Heat treatment vs. alloying

Standards of rails are classified into two categories: standards for high-carbon systems without any alloying elements, such as AREA (American Railway Engineering Association; current AREMA;

American Railway Engineering and Maintenance–of-way Association) in North America or a standard for alloying systems, such as that of UIC (Union des Chemi) of Europe.

In Japan, the JIS Standard is similar to that of AREA and, from the viewpoint of production costs and productivity and due to quality concerns related to weldability, etc., a heat-treatment process was selected.

(2) Selection of heat-treatment process

A slack quench process was finally selected as a result of a series of studies, as described below.

In the early stages of the heat-treatment operation, i.e., during the 1950s, the quench-and-temper process, which involves reheating the head surface layer with induction heating, quenching by continuous water cooling, and then tempering, was employed. Rails produced using this process were termed HH (head hardened) rails and exhibited good performance when used as domestic rails with an axle load of 17 t or less.

For trial applications overseas, HH rails and others were shipped to the CVRD Corporation (currently the VALE Corporation) in 1974. These rails were used for field tests, along with rails from Europe and the USA. As a result of the tests (at the time of an accumulated passage tonnage of 100 million tons), the wear resistance of the HH rails was inferior to that of the European and USA high-strength rails. Subsequent investigation revealed that all high-strength European and USA rails exhibited fine pearlite structures, as opposed to the Yawata-made rails, which exhibited a tempered martensite structure, which resulted in poor wear resistance.

In response to these test results, and as the result of the development of a production process to produce fine-pearlite-structured rails to improve their wear resistance, an offline process that involved reheating the surface layer of the head of a rail followed by quenching in air (slack quench) was employed, as previously discussed.

This new rail, which was heat-treated offline, was named as NHH (new head hardened) rail; since 1976, it has exhibited excellent wear resistance, as proven through trial shipments to the CVRD Corporation and through evaluation by comparison on the FAST test railroad at TTCI in the USA (the Transportation Test Center Institute in Pueblo, Colorado). This rail was used not only in the domestic market but also in overseas heavy-haul railroads and contributed to enhanced rail life because of its excellent wear resistance. In 1988, the NHH rails were standardized as “JIS E 1124 Slack Quench Type Heat Treated Rails.”

(3) Shift to inline heat treatment

As previously described, the development of an inline heat-treatment process was driven by two factors: the shortcomings of the offline heat-treatment process, i.e., demands by customers for higher quality, and the needs from the production side. As a result, DHH (deep head hardened) rail was commercialized as the successor to NHH rail.

DHH rails have been used by various customers, and several derivative rails have been produced depending on the axle load levels and the customers’ infrastructure.

i) Hardness level

Initially, the application to heavy-haul railways was deliberately contemplated; therefore, the rail head surface hardness level was set at HB 370, which was the same level as the NHH rails. Later, because axle load is lower in the domestic market, the domestic application of such rails was studied. As a result, DHH 340 with lower hardness was developed in anticipation that excessive suppression of the progression of wear with DHH 370 might induce surface damage. In 1994, these rails were standardized as “JIS E 1120 Heat Treated Rail, HH340 and HH370,” and this standard is still current.

Table 2 Basic specification of the Nippon Steel & Sumitomo Metal’s HH rail

	Carbon (%)	Hardness HB	Tensile Strength (MPa)	Elongation (%)
DHH	0.80	340 - 370	1,100 - 1,200	≧10
HE	0.90	370 - 400	1,200 - 1,300	≧10
	1.00	420	1,400	≧10

ii) Chemical composition system

In many cases, rails used for railroads are welded together in customers’ welding plants to form a long rail. (See more in detail the article on the study of welding in this Technical Report.)

In welding, because the welded part and its surrounding area are heated to a molten state, the hardness of a rail rendered during the production stage is lower at the welded joint section. Local wear will develop at the welded joint section, which necessitates earlier-than-scheduled replacement of rails if the rails are used without any precautions. One step generally taken to avoid this situation is the application of accelerated cooling to the welded part immediately after the completion of welding to recover hardness. However, in the case of some customers (e.g., Canada), no accelerated cooling device was installed, and the need arose for a method to recover the deterioration in hardness through modification of chemical composition of the rail. Through utilization of the heat transfer from the welded part to the main part of the rail, recovery of deterioration in hardness was achieved with the addition of small amount of an alloying element (e.g., Si or Cr). The identification DHH 370S was given to such rails.

(4) Sophistication of material

Our company started production of DHH rail in 1987, and, coincidentally, overseas railroad companies were simultaneously engaged in increasing axle loads due to their move toward higher transportation efficiency to recover shear in cargo transportation. Consequently, further improvement of the wear resistance of rails was demanded (**Table 2**).

To satisfy the need to improve the wear resistance of rails, HE rail was developed and put into practical use in 1999.[4-7] HE is an acronym for “hyper eutectoid” (i.e., hyper eutectoid steel: carbon steel with a carbon content of 0.85% or more), and these rails contain carbon at a concentration of approximately 0.9%-1.0%. During the development stage, installation tests were conducted with the cooperation of numerous overseas railroad companies. Compared with DHH rails, an improvement in the wear resistance of 10%-30% was achieved. Furthermore, extended monitoring over time proved that the rails also exhibited excellent surface damage resistance and internal damage resistance. These rails have earned a good reputation among overseas heavy-haul railroad companies. Furthermore, in the domestic passenger railway market, expectations for the benefits of HE rail are growing, and a study related to the employment of HE rail is underway.

3.3 Rail with rolling contact fatigue damage resistance

Shelling occurs on straight tracks for high-speed train operation and causes the formation of concave regions, flaking, and rail breakage.

Shelling is categorized into two types in terms of the form of damage: surface fatigue caused by cyclic repetition of rolling con-

Table 3 Chemical compositions of Bainitic rail

C	Si	Mn	Cr	Mo
0.10 - 0.50	0.10 - 0.35	0.30 - 2.00	≦3.00	≦1.00

tact; and damage caused by a white band (a very hard layer with a thickness on the order of microns or millimeters), which is developed by very minute slippage on a rolling contact surface.

As a countermeasure to the occurrence of shelling, periodical rail surface grinding and removal of the shelling was recommended. However, the application of such procedures to existing railroad tracks i limited because of the noise caused by the grinding car and the limited number of working hours.

The Yawata rail mill has developed jointly with the Railway Technical Research Institute a bainitic steel rail that suppresses the occurrence of shelling; such rails have already been put into practical use (**Table 3**). Bainitic rail is defined as a rail that, while satisfying basic characteristics such as strength of a standard rail (JIS E 1101), is capable of removing a fatigued layer on the top of a rail head by promoting the proper amount of wear and thereby endowing resistance to white-band-initiated shelling damage because the fatigued layer is considered to initiate shelling. The application of these rails to domestic railroads' straight tracks is in progress.[8)]

3.4 Improvement of the capability

Because of advances in both processes and products, the capability to allow for customers' choice of rails has been greatly enhanced.

The production of ordinary rails and HH rails that satisfy the flatness standard has become possible due to improvements in the rail straightening process. Furthermore, utilization of the 150-m-length processing, which is the longest in the world, wherein heat treatment, straightening, and nondestructive inspection are conducted, has enabled production of HH rails and bainitic rails with lengths of 50 m. **Table 4** summarizes the latest state of improvements in rail production capability.

4. Conclusion

During the initial stage of operation, the specifications for ordinary as-rolled rail were a weight of 30 kg/m, a length of approximately 9 m (30 ft), a carbon content of 0.45%-0.60%, and a tensile strength (TS) of 637 MPa or greater. The metallic structure was a mixture of ferrite and pearlite.

Today, the specifications are a weight of 70 kg/m, a length of 50 m, a carbon content of 0.7%-1.0%, and a tensile strength of 1,400 MPa, with a metallic structure of fine pearlite. These improved specifications represent a great achievement.

We consider that, in the future, the need to develop rails with greater strength and higher dimensional accuracies will remain, and the close relationship with customers will be the firm base for such development. We also firmly believe that progress in the development of rail products is achieved with the manufacturers' ceaseless efforts to improve all aspects of the development and commercialization of products and to improve productivity and quality assurance, all coupled with the needs specified by customers.

From this time onward, and in cooperation with organizations that represent railroad companies, we wish to further contribute to enhancing the safety and riding comfort and to reducing the maintenance costs of railroads.

Table 4 Improvement of the capability at Nippon Steel & Sumitomo Metal

Rail grade	Flatness	Former Length 25m	Former Length 50m	Today Length 25m	Today Length 50m
Std.	NA	○	○	○	○
	Specify			○	○
HH340, HH370	NA	○		○	○
	Specify			○	○
Bainitic Rail		○		○	○
HE Rail		○		○	

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