

# Progress and Prospect of Rail for Railway

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## Abstract

*Since its establishment in 1901, the Kyushu Works of Nippon Steel Corporation have been producing railway tracks at its rail and structural steel plant. Over the past approximately 120 years, it has adapted to the “sophistication” and “speed enhancement” of railway transportation in response to Japan’s economic development. Meanwhile, overseas markets have primarily focused on freight transport, leading to advancements in “heavy load capacity” for improved transport efficiency. There is also a high demand for enhanced wear resistance and resistance to rolling contact fatigue damage, aligning with the goal of extending the lifespan of rails. To meet these customer needs, the rail and structural steel plant has continuously improved its manufacturing processes, established a shipping system for 150-meter rails, and promoted product sophistication. This report outlines these efforts and provides insights into future prospects.*

## 1. Introduction

In 1901, Nippon Steel Corporation started the production of domestic rails at the rail and structural steel plant of its Kyushu Works (hereafter referred to as the rail plant). Since then, railways in Japan and abroad have increased their needs for higher track safety and comfort and lower maintenance cost with the improvement in train speed and the increase in vehicle loads. They have also come to demand better rail quality.

In response to such needs and demands, the rail plant has developed technologies concerning the production of various rails, the improvement of rail quality, and the development of new rails. In this way, we have significantly contributed to the advancement of rail transport not only in Japan, but also abroad. We have also worked to meet rail quality requirements, improve the productivity of rail production, and fill the demand for rails in Japan and overseas. **Table 1** shows the main topics in Japanese railways and Nippon Steel’s rail development history.

## 2. Initiatives Up to Now

### 2.1 History of railways and changes in rail manufacturing in Japan

The first railway line in Japan was laid between Shimbashi and Yokohama in 1872, followed by the 600 km Tokaido Main Line between Shimbashi and Kobe in July 1889. Moreover, private railways were opened all over the country, and a rapid increase in demand for

**Table 1** Brief history of Japan Railway and development of rail at Nippon Steel

Year:	
1872	Railway service started between Shimbashi and Yokohama
1889	Tokaido Line in full distance between Shimbashi and Kobe opened
1901	Production of rails started in Yawata
1933	Production of 25-m-long rails started
1954	Production of head-hardened (HH) rails started
1964	Tokaido Shinkansen opened
1968	Production of EH rails started
1970	Operation with universal rolling technology started
1972	Production of 50-m-long rails for Shinkansen started
1975	Sanyo Shinkansen in full distance opened
1977	Production of new head-hardened rails (NHH) rails started
1982	Tohoku Shinkansen and Joetsu Shinkansen opened
1987	DHH rails developed (inline heat treatment)
1994	Bainitic steel rails developed
1999	Production of hyper-eutectoid steel rails for heavy-haul railway started
2003	Production of rails meeting waviness specification started
2014	Shipment of 150-m-long rails started
2019	Production of intermediate strength rail for passenger railway started

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rails was expected. Accordingly, the then government-run Yawata Steel Works started the construction of a rail plant as the first phase in June 1897 and started the operation of the rail plant in November 1901. The first product was a 60 pound 30 feet rail (weight of 30 kg/m and length 9.144 m), which was the first rail rolled in Japan. Rolling engineers were hired from Germany, and plant personnel who had no knowledge of rolling at the time operated the rail plant under their guidance. This marked the beginning of domestic rail production in Japan. Later in the early Showa period, the rail designations changed from 60 pound rails to 30 kg rails and from 75 pound rails to 37 kg rails. By August 1945 (the end of the war), the Yawata rail plant expanded manufacturing variety to 13 sizes, increased the cross sections of rails, and started the production of crane rails and point rails as well.

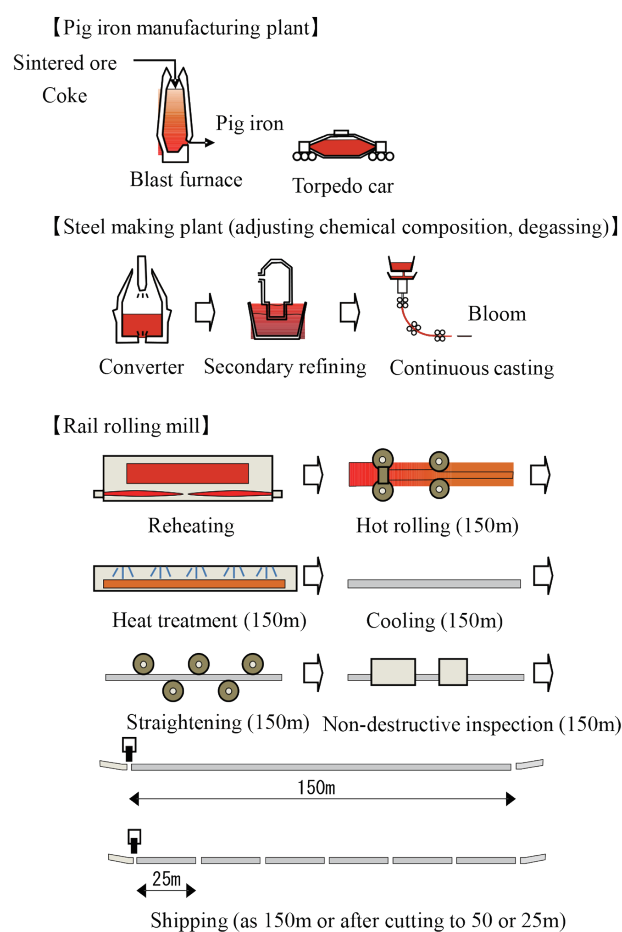
The Yawata rail plant resumed its production in November 1948 after the end of World War II. Its facilities were expanded to increase production capacity and meet the increasing demand with rapid economic growth.

Over the next 20 years since 1945, the Yawata rail plant had been remodeled four times and steadily expanded its production capacity. In 1956, the then rail manufacturing Yawata Iron & Steel Co., Ltd. and Fuji Iron & Steel Co., Ltd. organized a study committee on rail specifications with the then Japan National Railways to improve the rail shapes. The study committee discussed the shape improvement of 50 kg and 37 kg rails, among other topics. In 1958, the committee started the discussion of the shape of rails to be applied to the Tokaido Shinkansen. The Yawata rail plant started the production of 50 T rails and 60 kg rails improved for the Sanyo Shinkansen. Also, the longest and standard length of rails was 25 m then. Because the 25 m long rails posed noise problems and were feared to increase the maintenance cost of bolt fastening, the method of welding 25 m long rails at both ends into 1.5 km long rails was promoted to reduce the maintenance labor. In 1970, the Yawata rail plant was asked to produce 50 m long rails and commenced their production in September 1972.

Since then, we have made innovative capital investments in rail production. In 1970, we introduced universal rolling to improve the forging effect and dimensional accuracy of the rail heads. In 1987, we installed a new in-line heat treatment facility to meet the needs for harder and longer lasting rails, and we developed DHH rails that can keep high hardness deep into the head. Using this in-line heat treatment facility, we developed and commercialized bainite rails in 1994, hypereutectoid rails in 1999, and medium-strength rails in 2019. In 2014, we also established a shipping system for long 150 m rails. This increase in rail length improved train riding comfort and contributed to improvement in track reliability and reduction in welding work. The increases in the dimensional accuracy, service life, and length of manufactured rails are described in detail in the following sections.

## 2.2 Rail manufacturing process

**Figure 1** shows today's integrated rail manufacturing process. The main raw materials for iron are iron ore and coal. The sintered ore and coke produced by processing the iron ore and coal are charged into the blast furnace. High-temperature hot air is blown into the blast furnace, where the iron ore is reduced into high-temperature molten pig iron. The molten pig iron is transported by a special vehicle called a torpedo car to the next steelmaking plant. In the steelmaking plant, the pig iron is first transferred into a converter. High-pressure oxygen is blown into the converter to cause an ox-



**Fig. 1 Integrated rail manufacturing process**

idation reaction, remove the excess carbon and other substances, and turn the pig iron into stronger steel. In the secondary refining process, the final chemical composition of the steel is adjusted, and hydrogen and other gas constituents are removed from the steel. The refined molten steel is then cooled and solidified into rectangular pieces called blooms in the continuous caster. The bloom is sent to the rail plant, where it is charged into the heating furnace, reheated, and then sent to the hot rolling process. The hot rolling mill has two rolls, a top roll and a bottom roll, or four rolls, one top, one bottom, one left, and one right. Grooves called calibers are machined in the rolls. As the bloom is rolled through the calibers, it is gradually stretched into the shape of a rail, finally becoming a rail up to 150 m in length. Heat treated rails such as DHH rails are head treated in a heat treatment device. Then, the rail cooled to near room temperature is made straight through a roller-type straightener, and non-destructively inspected for dimensions, shape, surface properties, and internal properties. Finally, the rail is cut to a length of 150 m, or the length specified by the customer, and is shipped to the customer.

## 2.3 Innovation in rail manufacturing technology

### 2.3.1 Improvement in dimensional and shape accuracies of rails

As the train speed increased, the need increased to improve the dimensional and shape accuracies of rails. European mills introduced the new universal rolling process in place of the conventional caliber rolling process. The Yawata rail plant worked on the development of a universal rolling process on the basis of the technology

of Wendel of France and with its own technology. The universal rolling process uses two vertical rolls, or left and right rolls, in addition to two horizontal rolls, or top and bottom rolls. The universal rolling process is schematically illustrated together with the conventional caliber rolling process in Fig. 2. Since the position of the four rolls can be finely adjusted, the dimensions of the rails to be rolled can be adjusted more finely compared to the caliber rolling process. In addition, the universal rolling process has the following main features: 1) the head and base of the rail can be directly reduced in the thickness direction with such a large forging effect that the head and base, which are important parts for use, are provided with excellent material properties; 2) uniform reduction can be applied throughout the rolling process so that excellent dimensional accuracy is obtained; and 3) the incidence of harmful surface defects is minimal.

In June 1970, the Yawata rail plant was reborn as the world's first rail rolling plant using the full-scale universal rolling process, and its production capacity was increased to 70000 tons/month. In 1997, a high-accuracy universal finishing rolling mill was added to dramatically improve the dimensional accuracy of rails to cope with increasing railway speed. Since then, we have expanded the application scope of the universal rolling process to 60 rails and 50 N rails for the domestic market, rails for exports (according to US standards, European standards, etc.), and rails for switches and crossings. We have also worked to improve the dimensional accuracy of rails.

**2.3.2 Development of rails suited to laying environments**

**(1) Production of in-line heat treated rails**

Since the 1950s, the Yawata rail plant has worked to develop heat treated rails to meet the need for higher strength rails. Initially, an off-line heat treatment process was employed where the head of rails was heated by induction heating, and the rails were then water quenched and tempered. In 1987, the Yawata rail plant started the manufacture of heat treated rails by a new in-line heat treatment process in which the rails are heat treated in air without reheating the rails and by utilizing the heat of the rails immediately after rolling. In-line heat treated rails are called deep heat hardened (DHH) because high hardness can be maintained deep into the heads of the rails.<sup>1,2)</sup> The as-rolled rails were 150 m long. At that time, the 150 m long rails were hot sawed to the product length plus a cutting allowance and heat treated in 25 m lengths. In 2002, the Yawata steel

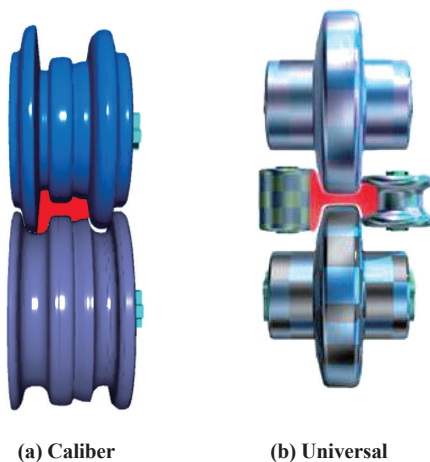


Fig. 2 Method of rail rolling

plant was modified to allow the heat treatment of the 150 long rails without hot sawing.

**(2) Development of wear-resistant rails (HE rails™)**

To further improve the wear resistance of rails in response to the needs of heavy-haul railways, we worked on the development of rail materials in addition to the above-mentioned heat treatment technology. We eventually developed HE rails™<sup>3-5)</sup> and began the mass production of HE rails™ in 1999. HE is an abbreviation for Hyper-Eutectoid (hypereutectoid steel; carbon steel with a carbon content of 0.85% or more). The HE rails™ are made of carbon steel with a carbon content of 0.9% compared to a carbon content of about 0.8% of HH340 rails, which are mainstream heat treated rails for domestic railways. Figure 3 shows the relationship between hardness, wear loss, and carbon content. The harder the rail, the smaller the wear loss. Also, even with the same hardness, the higher the carbon content, the smaller the wear loss and the higher the wear resistance. In addition, the higher the hardness, the better the damage resistance of the rolling contact surface with the wheel. Thanks to their improved wear resistance and surface damage resistance, the HE rails™ are highly rated by freight railways overseas. HE rails™, which contain about 1.0% carbon, are used on freight railways with particularly high axle loads. For improvement in wear resistance with increasing carbon content and hardness and the mechanism whereby rolling contact fatigue damage occurs, refer to the No. 12 report “Property of Wear and Rolling Contact Fatigue Damage in High-hardness Pearlitic Steels”<sup>6)</sup> in this No. 133 issue of the Nippon Steel Technical Report (NSTR).

**(3) Development of bainite steels and intermediate-strength steels for passenger railways**

Repeated contact between wheels and rails may cause fatigue damage (shelling) on the surface of the rails. Shelling occurs on rails in straight sections during high-speed operation and can lead to dents or peeling on the head of rails. Rail grinding was used as an effective measure against shelling. In 1994, bainite rails were developed and commercialized with the concept of suppressing shelling by promoting rail wear by an amount equivalent to the amount of rail grinding. Bainite rails satisfy the strength and other basic properties of flat bottom rails (JIS E 1101), remove by themselves the head top surface metal fatigue layer that initiates shelling damage by promoting moderate wear, and have resistance to shelling damage of the white layer origin type. The bainite rails are increasingly laid in straight sections.<sup>7)</sup>

In recent years, it has been reported that damage called “gauge corner crack” has occurred in outer HH340 rails laid in curved sections with a curve radius of 500 to 800 m and has necessitated the

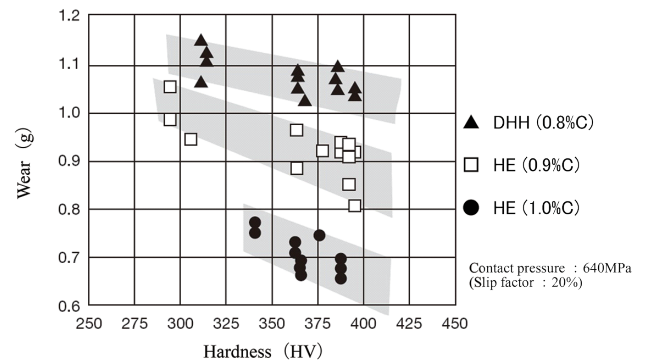


Fig. 3 Relation between hardness, wear, and carbon content

replacement of the rails before they reach their time of replacement due to wear or their passing tonnage standard. The cause of gauge corner cracks is repeated rolling contact between the rails and wheels, just like shelling. We developed intermediate-strength rails by considering the balance between fatigue accumulation and wear, test laid them, and confirmed the reduction of gauge corner cracks in them.<sup>8)</sup> The shipment of intermediate-strength rails began in 2019.

### 2.3.3 Establishment of 150 m long rail shipping system

Rail joints are one of the factors that cause riding discomfort, noise, and vibration, and they are also weaknesses for track maintenance. Railway operators weld rail joints to make the rails longer and make other improvements with respect to rail joints. However, improper welding can cause harmful weld defects and damage the rail welds. In April 2014, we executed equipment measures such as a finishing yard and cranes to enable the handling of 150 m long rails or the longest railway rails in the world (Fig. 4).<sup>9)</sup> We think that our 150 m long rail shipping system will contribute to improving track reliability by reducing the number of rail welds and to reducing welding and maintenance.

To realize the 150 m long rail shipping system, we implemented measures to transport the 150 m long rails to the rail storage yard and to improve the efficiency of storing the 150 m long rails. The 25-m-long rails are generally transported on carrier pallets or carts, but it is difficult to prepare carrier pallets or carts that can accommodate 150 m long rails. In addition, since the rail storage yard had to be located away from the rail production plant, it became necessary to transport the rails along a curved transport path. A curved transport mechanism was thus introduced to push the transport rollers and the sides of the rails to guide the rails along the curved transport path. Also, the rails are stored stacked vertically. If the rails are directly stacked on top of each other, they may be damaged or may



Fig. 4 Handling situation of long rail

be difficult to stack depending on their type and shape. Accordingly, cushions called steel spacers are placed between the rails. The steel spacers are placed by workers at appropriate intervals along the length of the rails. We devised a system that allows one worker to stack the rails and place the steel spacers between them, thereby reducing work time and labor.<sup>10, 11)</sup>

## 3. Future Initiatives

### 3.1 Improvement of weld quality

Railway operators have persistent needs to prevent damage and breakage in track welds. The Yawata rail plant has worked to improve the reliability of rail welds. Flash butt welding, which is a main rail welding method for heavy haul-railways overseas, has caused rail head surface damage resulting from the softened region of the heat affected zone, web cracks originating from the residual stress of welds, breaks, and derailment in the worst case. To deal with these situations, Nippon Steel has developed and patented technologies to reduce the heat-affected zone and to reduce the residual stress using induction heating. We have decided to expand the application of these technologies to railway operators. For details, refer to the No. 13 report “Development of Technologies to Improve the Reliability of Rail Flash Butt Welds” in this No. 133 issue of the Nippon Steel Technical Report (NSTR).

### 3.2 Responses to carbon neutral

Carbon neutral initiatives have been increasing in importance in the steel industry yearly. Nippon Steel thinks that in addition to the high quality and high performance required of rails, the new “carbon neutral” value will be added to the rails’ menu in the future. To achieve carbon neutrality by 2050, Nippon Steel has decided to develop and implement three ultra-innovative technologies: blast furnace hydrogen reduction, hydrogen-reduced iron production, and high-grade steel production in large-size electric arc furnaces. As part of these initiatives, Kyushu Works has begun its study of producing high-grade steel in a large electric arc furnace. In addition, we have been steadily working toward carbon neutrality, such as pioneering the launch of the “NSCarbolex™ Neutral” green steel by applying the mass balance approach and acquiring the EcoLeaf declaration (EPD certification) for our rails.

## 4. Conclusions

We have promoted the initiatives to develop rails suited to specific laying environments and improve rail application technologies. We think that the direction of increasing the strength and dimensional accuracy of rails will not change in the future. This direction is based on our close relationships with the Japan Railway (JR) companies and other railway operators. We firmly believe that rails will progress further with our tireless efforts as a rail manufacturer to launch innovative manufacturing technologies and new products in combination with the supply of needs from railway operators.

We will improve the safety and comfort of railways in cooperation with railway operators and other stakeholders. We will contribute to the carbon neutral activities of manufacturing and railway industries through maintenance cost reduction and modal shift.

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