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Trends in Rail Welding Technologies and Our Future Approach

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Abstract

Rail welding technologies are essential for high speed tracks and heavy haul tracks, to achieve safety of their transportation service, and highly reliable rail welds are required for the safety of railways. In this report, we gave an outline of the four welding methods used for rails presently in the world, such as (1) flash-butt welding, (2) gas-pressure welding, (3) thermite welding, and (4) enclosed-arc welding. Further, we described a few quality issues seen in rail welds in overseas heavy-haul freight railways. In the last chapter, we introduced our new flash-butt welder, which we recently installed, in order to discuss the issues.

1. Introduction

Rails are a vital constituent of railways, and their performance is directly linked to the safety of railways. Railway companies are aiming to achieve relatively high transportation efficiency and tackling propositions of relatively high-speed passenger and heavy haul freight railways transportation. In line with these trends, the environmental factors affecting rail usage are becoming harsher than ever, and therefore, rails having relatively high performance are being developed.[1, 2]

A rail joint section with an offset is subjected to mechanical shocks whenever a train passes, influencing the running stability of the train. In order to alleviate such mechanical shocks, long rails produced by welding rails are being installed across the world. Today, the rail welding technology has become an extremely important technology that is partly responsible for the safety of railways.

Further, the quality requirements for a weld section vary depending on the type of railways. A considerable portion of the wheel rolling contact surface at the weld section is required from the viewpoints of running stability and riding comfort. In the case of freight railways, wear and abrasion resistance and surface damage resistance of the heat affected zone (HAZ) developed at a weld section, and fatigue damage resistance of the rail web and the rail base are required in order for the rails to withstand the heavy load exerted by the wheels.

This report introduces four welding methods that have been developed for welding rails, examples of the quality problem at the weld section that has become overt in overseas freight railways, and a new welder introduced to us as a part of the study on the solution of such a problem.

2. Welding Methods of Rails

In this section, the process from the welding of rails to the installation of these rails on a track is described first. Then, the features, welding process, welding time, equipment, weld quality, and the latest technical trends related to the four rail welding methods currently used are described.

2.1 Welding of rails and installation

The steel grades of rails considered in this study are discussed in this subsection. The rails considered are standard carbon rails mainly used in the straight track sections in domestic railways (JIS E1101, carbon content: 0.63-0.75 wt%, HB250-290) and heat-treated rails having a relatively high hardness for use in sharply curved track sections (JIS E 1120, carbon content: 0.72-0.82 wt%, HB321-388). In addition to these, there are heat-treated rails of hyper-eutectoid composition, which have further improved the wear and abrasion resistance for overseas freight railways, realized by increased hardness and a relatively high carbon content (carbon content: 0.9-1.0 wt%, HB370-420).

The process from the delivery of rails from a steel-making company to the installation of these rails on a track by a railway company is shown in **Fig. 1**. Typically, the length of a produced rail is 25 m, and the rails are welded continuously in succession to a length of 200-800 m by plant welding. Then, they are transported to an installation site on specially designed freight cars and further welded to a longer length by field welding. In many cases involving overseas freight railways, field welding is carried out directly on a track.

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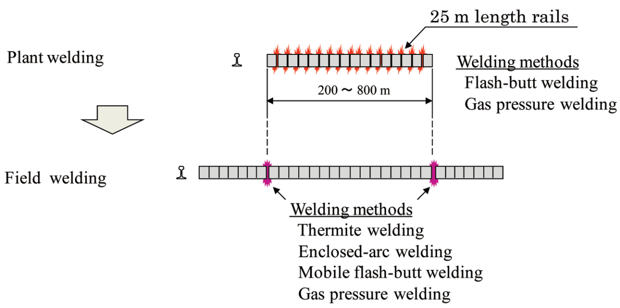

Fig. 1 Long rail construction

However, domestic field welding is carried out at a track side or on a side track at a rail installation site, and the rails are welded to a final length. After the rails are exchanged, final welding for connection to the turnout rails or the like is carried out on the track. Typically, the final length, although varying depending on the railway companies, is 1,000 m or longer.

Overseas, flash-butt welding is used for plant welding (plant flash-butt welding), and thermite welding or miniaturized portable mobile flash-butt welding is employed for field welding. Domestically, flash-butt welding and gas-pressure welding are employed for plant welding and gas-pressure welding; thermite welding and enclosed-arc welding are employed for field welding.

2.2 Methods of welding of rails and their features

2.2.1 Flash-butt welding

(1) Feature

This welding is completely automated and is used worldwide as a welding method that provides high quality and high productivity. A plant flash-butt welder is equipped with a transformer having a large capacity and a large hydraulic system. A mobile flash-butt welder, a miniaturized lightweight type of welder, is also used overseas.

(2) Welding process

This is a welding method wherein a voltage is applied across the end faces of the rails butted to each other so that an electric discharge is produced in succession through local contact, thereby heating and melting the end faces of rails. When the faces are completed converted into a molten state, the rails are pressurized toward each other (upsetting), and both ends are pressure-welded. **Figure 2** shows the welding process. The entire welding process consists of a preheating process, flashing process, upsetting process, and trimming process. In **Photo 1**, the flashing process is shown.

Preheating process: This process is employed in plant flash-butt welder equipped with a transformer of a large capacity, wherein the entire end faces of both the rails are short-circuited with each other, and a very high current is made to flow via electrodes. As the result thereof, the temperature increases at the weld section, and thereby, in the subsequent process of flashing, the time required for both the end faces to transform entirely into a molten state can be reduced.

Flashing process: Rails with a voltage applied across the end faces are made to approach each other at a programmed speed, and local electric arc discharges are repeatedly produced between the rail end faces; these discharges melt and preheat the rail end faces. Drops of molten rails are emitted outward by an electro-magnetic force. The rail end portions in the neighborhood of welding are heated to a high temperature by heat conduction in the longitudinal direction of rails. When the entire end faces are completely melted, upsetting is applied. The rate of approach of the rail end faces is 0.1-2.5 mm/s, and the length of the rail loss at the ends of both the rails

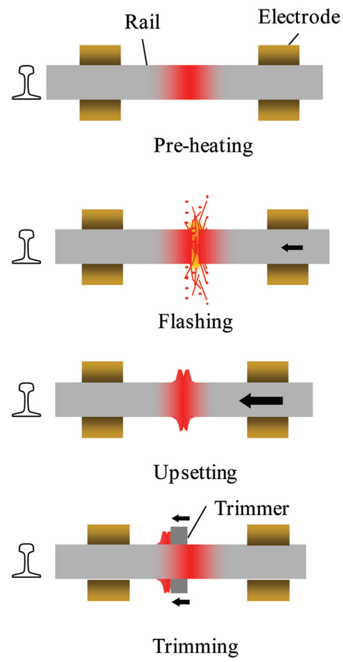

Fig. 2 Principle of flash-butt welding

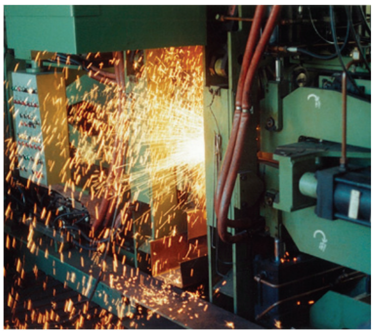

Photo 1 Example of flashing process (plant welding)

is 10-20 mm per rail. In the case of mobile flash-butt welding, since there is no preheating process, the flashing time is set longer in order for the end faces to melt completely. There are two sequences of preheating and flashing. In one, preheating is carried out first, and in the other, flashing is separated into stages and preheating is carried out in-between.

Upsetting process: Rails are pressure-welded by a load applied to the end faces of the rails. Molten steel is discharged outward; the end portions near the end faces, which have been heated to a very high temperature, undergo plastic deformation, and a bulge is formed. The unit pressurizing load is approximately 70 MPa, and the total pressurizing load is 500-600 kN in the case of JIS 60-kg rail (unit weight: 60 kg/m). Upon upsetting, the rail shrinks by 15-25 mm.

Trimming process: The bulge produced at the weld section is removed in the hot state by a hydraulically operated trimmer equipped with a rail-profiled blade.

(3) Welding time

The welding time is 1.5-4 min.

(4) Equipment

The equipment consists of a transformer and electrodes, a pressurizing apparatus, and a hydraulic trimming apparatus. When classified according to the voltage waveform, there are two types of equipment used: one is of the AC type, and the other is of the DC type and is equipped with a rectifying circuit.[3)] Recently, a DC-type flash-butt welder has mainly been employed for plant welding, whereas an AC-type welder has mainly been used as a mobile flash-butt welder. In the case of the AC-type equipment, the electric arc discharge is halted during the periods of voltage changeover from positive to negative and vice versa. In contrast, in the case of the DC-type equipment, continuous discharging is possible; therefore, it is considered that higher stability is obtained in the flashing process by using a DC-type welder. The miniaturization of a welder by using the DC-type equipment is difficult as the welder requires a rectifying circuit; therefore, the application of the DC-type equipment to a mobile flash-butt welder is difficult.

Further, in plant welding that does not have sufficient transformer capacity, and/or in mobile flash-butt welding, in order to obtain efficient heating, certain welders employ an AC pulse flash method where short-circuiting and flashing are repeated between both end faces cyclically in a very short time of one cycle.

(5) Weld quality

Photo 2 shows the longitudinal macro-structure of a section of flush-butt-welded, heat-treated rails. Further, **Fig. 3** shows an example of the longitudinal hardness distribution of flash-butt-welded rails.

Macro-structure: In the weld section, there are two regions. One is the region where the rail material is heated completely up to an austenite temperature region (dark part) by welding, and the other is the region where the rail material is heated to above the A1 point (approximately 720°C) and to a two-phase region (white part) that exists on both sides of the abovementioned region. These two regions are collectively termed as the heat affected zone (HAZ). The width of the HAZ is approximately 30-45 mm.

Hardness distribution: The hardness at the center of the weld section and in its neighborhood is less than the base material hardness of approximately HV390 by approximately HV20. In order to obtain the hardness level equivalent to the base metal level, and depending on the rail steel, some railway companies apply accelerated cooling by means of blowing compressed air to the weld section. Further, at both sides of the HAZ, hardness is reduced; therefore, these zones are called the softened zone.

(6) Latest technical trend

Whenever a train passes over a turnout, a rail is subjected to a strong shock exerted by wheels; therefore, a material having excellent shock resistance is used. At a crossing, which is a vital part of a turnout, high manganese austenite cast steel is often used. The welding of this material and the rail steel is difficult. Therefore, as a countermeasure, the manganese crossing rail is welded to stainless steel by flash-butt welding in the first stage, and then, the stainless steel is welded to the rail steel. This technology is practically employed.[4)]

Further, overseas, the application of flash-butt welding to repairing rails is being attempted. Usually, when a rail or a weld section has a certain kind of damage, several meters of the rail including the damaged portion is replaced with a new rail, and both ends of the new rail are welded to the existing rails. Aimed at shortening of the repair work time, a technology is being developed for repairing the damage on the surface of a rail head without replacing the rail. Flash-butt welding is applied from above to a steel piece that fits a V-shaped groove, removing the damage on a rail head surface.[5)] With this method, the repair work time can be significantly reduced.

2.2.2 Gas-pressure welding

(1) Feature

Gas-pressure welding is a pressure welding method, utilizing gas flame for heating rails, and is widely employed in domestic plant welding and field welding as a highly reliable rail welding method. In this method, the heating work is done by a welding operator, where the operator's skill is needed.

(2) Welding process

This is a welding method in which a joint section and its neighborhood are heated by gas while the butted rail end faces are pressurized toward each other. The welding process consists of a pressurizing and heating process, a forging process, and a trimming process. **Figure 4** shows the welding process, and **Photo 3** shows an example of the heating process. As the closeness of contact of the to-be-welded faces significantly influences the weld quality, the end faces are ground by specially installed grinders prior to welding.

Pressurizing and heating process: Heating is done while rails are

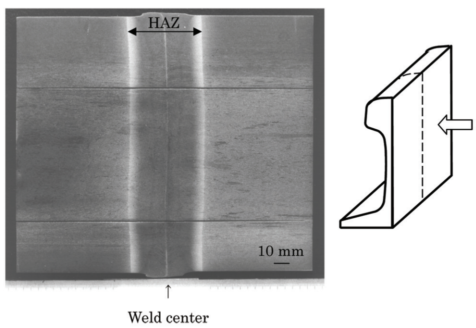

Photo 2 Longitudinal macro-structure of a section of flash-butt welded rail

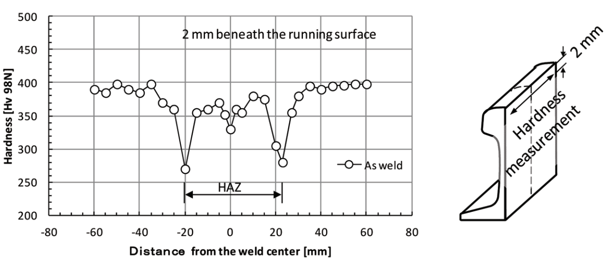

Fig. 3 Longitudinal hardness distribution of flash-butt welded rail

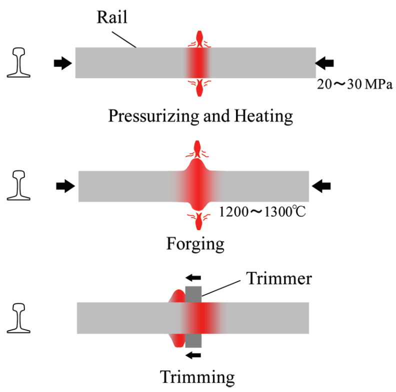

Fig. 4 Principle of gas-pressure welding

Photo 3 Example of pressurizing and heating process in the gas-pressure welding

pressurized toward each other at their end faces. An oxygen–acetylene gas is used for heating, and the heating operation is carried out manually by a welding operator. The end faces as the center of the weld section and their neighborhood are heated to a high temperature, and the surface temperature around the end faces reaches as high as 1,200-1,300°C finally. The pressure at the end faces remains usually constant, 20-30 MPa, throughout the entire processing. The load is approximately 180 kN in the case of JIS60 rail.[6)]

Forging process: The rails undergo plastic deformation around the end faces, and therefore, they shrink in the longitudinal direction. Simultaneously, the rail end faces expand. The rail ends are forged by this processing. The length lost because of the shrinkage by forging is approximately 20-40 mm.

Trimming process: A bulge produced during the forging process is removed in a hot state by a trimmer equipped with a rail-profiled blade and operated by a hydraulic system.

(3) Welding time

The welding time varies, depending on the profile of a rail. In the case of the JIS60 rail, the welding time is 6-7 min.

(4) Equipment

The equipment consists of a gas heating apparatus, a pressurizing apparatus, and a hydraulic trimming apparatus. For the sake of the convenience of transportation to and from a track side site or a side track, miniaturized equipment has been developed.[7)]

(5) Weld quality

Photo 4 shows the longitudinal macro-structure of a section of the gas-pressure-welded rails. Further, the longitudinal hardness distribution of the gas-pressure-welded rails is shown in **Fig. 5**.

Macro-structure: The HAZ width of the gas-pressure-welded rails is approximately 100 mm and is wider than that of a flash-butt-welded rail. In the case of gas-pressure welding, heating takes longer than in the case of flash-butt welding. Used as the heat source, the flaming gas has a lower caloric value than the electric energy that is employed in flash-butt welding. Further, in gas-pressure welding, the amount of heat conducted to the base rail is larger than in flash-butt welding; therefore, the HAZ is widened further.

Hardness distribution: As compared to the base rail hardness of around HV390, the as-weld HAZ hardness is approximately HV330. Further, as the HAZ is wider, the softened zone also becomes relatively wide. Therefore, in the case of the heat-treated rails, in order to obtain the same hardness level as that of the base rail, a method of accelerated cooling by means of compressed air is used after reheating up to the austenite region.

(6) Latest technical trend

Sometimes, weld defects like the inclusion of oxides take place when the closeness of contact in the heating and forging process is poor. A precise study to clarify the process of defect development is under way.[8, 9)] Moreover, with an objective of reducing CO_2 gas, gas-

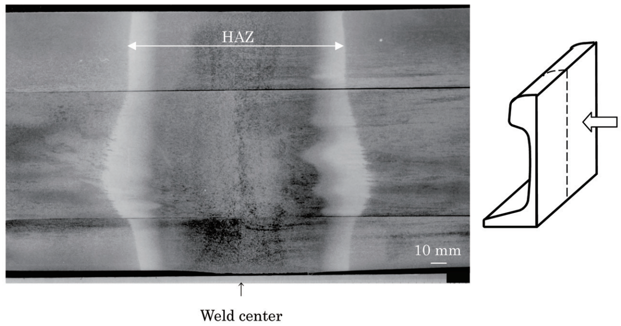

Photo 4 Longitudinal macro-structure of a section of gas-pressure welded rail

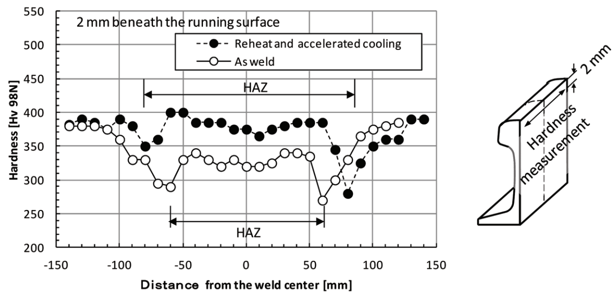

Fig. 5 Longitudinal hardness distribution of gas-pressure welded rail

pressure welding using hydrogen as gas for heating is under study.[10)]

2.2.3 Thermite welding

(1) Feature

The equipment has a simple structure and high mobility and does not need any specialized skill. Further, unlike in the case of pressure welding methods like flash-butt welding and gas-pressure welding, in this welding method, there is no change in the rail length by welding; this welding method is used worldwide as a field welding method for the final stage in rail installation. In flash-butt welding and gas-pressure welding, rails are installed for use after removing the entire bulge produced all around the rail at the weld section. However, in this welding method, only the bulge (weld reinforcement) on the rail head is removed, allowing the rest of the bulge to remain as it is.

(2) Welding process

This is a method of welding rails by pouring into the weld section, molten steel produced through a chemical reaction (thermite reaction) between oxidized iron and metallic aluminum. **Figure 6** shows the welding process. The welding involves the following processes: a thermite reaction process, a tapping and solidification process, and a trimming process. **Photo 5** shows an example of the thermite reaction process.

Prior to welding, an I-shaped groove of approximately 25 mm in width is set between the end faces of the two butted rails, and the groove is enclosed with a mold. A sand mold made of silica sand is used. Further, in order to prevent the occurrence of air bubbles caused by the water/moisture adherent to the mold and/or the rails, and to ensure the melting of the to-be-welded surface, the surfaces are preheated with propane/oxygen gas or the like.

Thermite reaction process: The thermite reaction is promoted by a mixture of powders called the thermite mixture. The thermite mixture consists of oxidized iron and metallic aluminum as the reaction

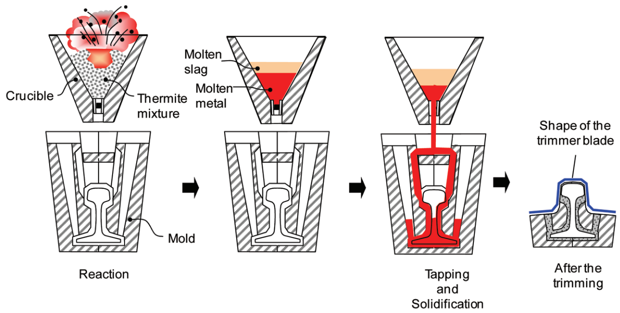

Fig. 6 Principle of thermite welding

Photo 5 Example of thermite reaction process

constituents along with alloy additives like ferromanganese and/or the like, and the composition of this mixture is adjusted so that the composition of the weld metal comes close to that of the rail. The thermite mixture is poured into a crucible set above the mold, and the reaction is started by an ignition agent in the form of a pyrotechnic agent. A reaction lasts for 15-30 s. Molten steel and molten alumina slag are produced as a result of the reaction that reaches 2,000°C or higher in temperature; they remain in the molten state[11] and are separated in the crucible by the difference in specific gravity. This thermite reaction is a reduction reaction where aluminum reduces oxidized iron as shown by equations (1) and (2).

$$Fe_2O_3 + 2Al \rightarrow Al_2O_3 + 2F_e \quad (1)$$

$$3FeO + 2Al \rightarrow Al_2O_3 + 3F_e \quad (2)$$

Tapping and solidification process: The molten steel thus produced is poured into a weld section. Tapping is automatically started as soon as a plug (oxide) at the bottom of the crucible is molten by the heat of the molten steel generated by the reaction. The rail end faces are melted by the poured molten steel. The poured molten steel and the molten rail end faces are solidified together by weld-jointing both the rails. The process from tapping to solidification takes approximately 4 min. Further, in order to avoid the occurrence of weld defects called solidification cracks, it is ensured that the rails are fixed firmly.

Trimming process: The excess weld metal on the top of the head is removed by a hydraulically operated trimmer.

(3) Welding time

The welding time is approximately 30 min.

(4) Equipment

The equipment consists of a preheating burner, a crucible, a mold kit, and a hydraulically operated trimmer. All of these apparatuses are compact in size, enabling convenient transportability to a site on a rail track.

(5) Weld quality

Photo 6 shows the longitudinal macro-structure of a section of the thermite-heat-treated-welded rails, and **Fig. 7** shows an example of the longitudinal hardness distribution of the thermite-welded rails.

Macro-structure: As the chemical compositions of the rail and the weld metal are almost the same, the boundary between the weld metal and the HAZ is not clear. As seen from the boundaries shown in the photo with broken lines, the width of the weld metal is approximately 70 mm at the top and the width of the HAZ is approximately 20 mm on either side.

Hardness distribution: As compared to the hardness of the base material of HV390, the hardness of the HAZ in the as-weld state is as low as HV300. Further, a softened zone exists on either side of the HAZ. In case of the heat-treated high-strength rails, an accelerated cooling method by means of compressed air has been applied where the weld metal is reheated up to the austenite region after welding, and then, the method is applied in order to obtain the same hardness level in domestic railways.

(6) Latest technical trend

In order to eliminate the processes of reheating and accelerated cooling for the heat-treated rails, a thermite mixture composed to achieve a sufficiently high hardness that is equal to that of such rails in practical use is used.[12] The use of this mixture reduces the welding time.

Furthermore, as in the case of the flash-butt welding method, a study is in progress on the possibility of applying the thermite welding method to rail repairing. A welding method for rail repairing called the wide gap method that uses thermite welding is in practical use domestically and overseas. In this method, the rail portion with damage is cut into a 75-mm-long piece and the gap is enclosed with a kit of wide mold; then, thermite welding is applied thereto.[13]

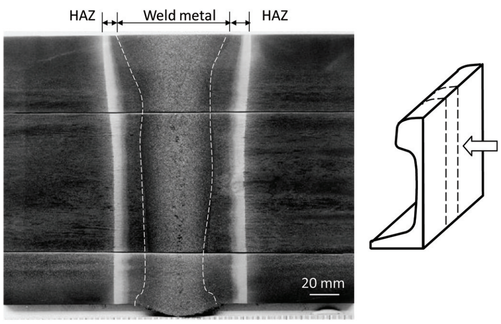

Photo 6 Longitudinal macro-structure of a section of thermite welded rail

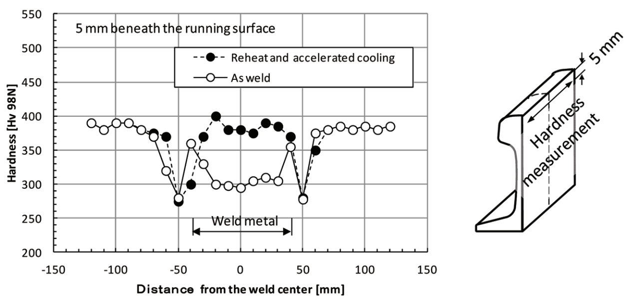

Fig. 7 Longitudinal hardness distribution of thermite welded rail

Moreover, in other countries, a repairing technology is under study wherein the damage is caused on the surface of a rail head; the damage is removed by making U-shaped grooves and pouring the molten steel produced by the thermite reaction into these grooves, thereby repairing the damaged portion.[14)]

2.2.4 Enclosed-arc welding

(1) Feature

Enclosed-arc welding is a field welding method specifically developed in Japan during the construction of the New Tokaido Trunk line. It is a shielded metal arc welding method requiring significant skill. Similar to thermite welding, it is a fusion welding method that does not cause any change in the rail length because of the welding. This equipment is simple and has excellent mobility; it is applied to field welding in new trunk lines and to field welding for turnouts or the like where the working space is insufficient. The narrow space, enclosed by the copper shoes that cover the rail web up to the head and by the rail end faces, is filled in by welding; therefore, this method is called enclosed-arc welding.

(2) Welding process

Figure 8 shows the welding process. The entire welding process consists of penetration bead welding and multi-pass welding at the base, continuous welding at the web and the head, and multi-pass welding at the head. **Photo 7** shows an example of the continuous welding process at the web and the head. The groove is an I-type one having a gap of approximately 17 mm, and prior to welding, the base is preheated to 500°C for the prevention of cold cracks.

Multi-pass welding process for base: Penetration bead welding using a copper shoe is applied to the first layer, followed by multi-pass welding to the entire base. As for the method of build-up, one bead builds up one layer. Further, the slag on each layer is removed.

Continuous welding process from web to head: Water-cooled copper shoes are set on the sides of the groove, and welding is carried out by changing the welding rods without removing the slag.

Multi-pass welding process at head: Multi-pass welding is applied to the rail head portion having a depth of 10-15 mm.

Welding rods of 800-1100-MPa class are used for standard carbon rails. As the carbon content of these rods is low, the weld metal has a bainite structure. In order to improve the wear and abrasion resistance of the weld metal of high-strength rails, a high-carbon welding rod has been developed by Nippon Steel & Sumitomo Metal Corporation in order to produce a weld metal structure of pearlite; this is used in practical applications domestically.[15-17)]

(3) Welding time

The welding time depends on the rail profile. In the case of the JIS60 rail, the required welding time is 60 min or longer. Factors that necessitate a long time are multiple-pass welding, continuous welding, preheating, temperature control between passes, and slag removal between passes in multi-pass welding.

(4) Equipment

A preheating burner, an engine welder, and copper shoes are used in this method.

(5) Weld quality

Photo 8 shows the longitudinal macro-structure of a section of heat-treated rails, enclosed-arc-welded with high-carbon welding rods. **Figure 9** shows an example of the longitudinal hardness distribution of the enclosed-arc-welded rails. Further, in this case, the weld section is reheated up to the austenite region and accelerated cooling is applied to the head, aiming at an improvement of the weld quality.

Macro-structure: The width of the weld metal is approximately

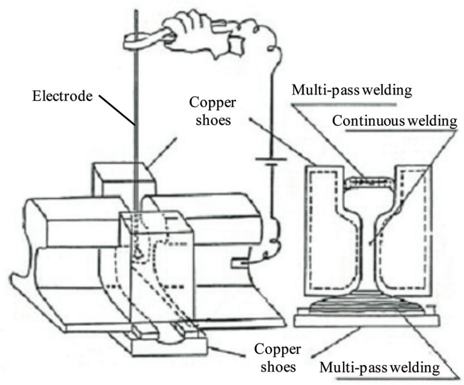

Fig. 8 Principle of enclosed-arc welding

Photo 7 Example of continuous welding process in the enclosed-arc welding

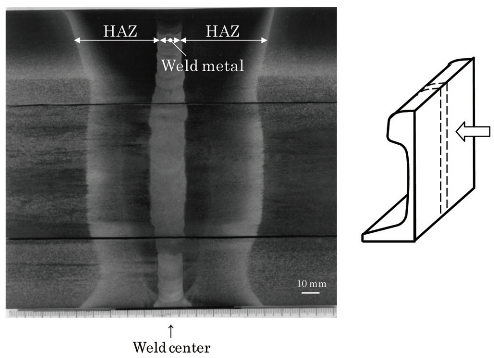

Photo 8 Longitudinal macro-structure of a section of enclosed-arc welded rail

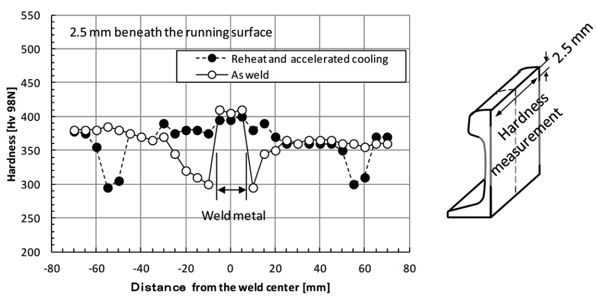

Fig. 9 Longitudinal hardness distribution of enclosed-arc welded rail

20 mm, and the width of HAZ is approximately 50 mm on either side. The HAZ observed here was developed by reheating.

Hardness distribution: The hardness of the weld metal in the as-weld state is close to the base material hardness of HV390. In the case wherein reheating and accelerated cooling are applied, the hardness of the weld metal and the HAZ become more equalized. Further, in the as-weld state, softened zones exist adjacent to the weld metal. On the other hand, when reheating and accelerated cooling are applied, softened zones exist farther away from the center of the weld section.

(6) Latest technical trend

The problem is that the welding by this method needs almost 60 min or longer. A semiautomatic welding method has been developed to reduce the welding time, and there are reports that the welding time is reduced by 30 min.[18, 19]

2.3 Comparison of welding methods

A technical comparison of various rail welding methods and their actual application results is discussed below. The welding time, initial investment of equipment, mobility of equipment, required operators' skill, and the weld quality of the four welding methods are summarized in **Table 1**.

Welding time: The welding time of flash-butt welding is the shortest, and it increases in the order of gas-pressure welding, thermite welding, and enclosed-arc welding. In the vicinity of big cities, a suspension of the train service for track maintenance lasts only 4-5 h; accordingly, at times, it is difficult to carry out repairs by using enclosed-arc welding.

Initial investment of equipment: The initial investment for flash-butt welding, which involves the use of a large-capacity transformer and a large hydraulic unit is the highest among the method considered. In the case of gas-pressure welding where the source of heating energy is changed to gas, the initial investment is less than that in the case of flash-butt welding. The initial investment of thermite welding is low as trimming is applied only to the head portion, and therefore, a small hydraulic unit can be used. Further, in the case of enclosed-arc welding, although an engine welder is necessary, since there is no trimming process and a hydraulic unit is not required, the initial investment is low.

Mobility of equipment: The mobility of flash-butt welding and gas-pressure welding is inferior because each has large pressurizing apparatus. Therefore, as mentioned earlier, an attempt of miniaturization is being made. On the other hand, the equipment used in thermite welding and enclosed-arc welding is simple and has excellent mobility. In particular, enclosed-arc welding is advantageous in that only copper shoes are used around the welding site, and the repairing work is possible even in a narrow space around a turnout where the rail separation is small.

Operators' skill: Any specialized skill is not required for flash-butt welding as the method is completely automated. Likewise, thermite welding is rather simple in its operation; therefore, no specialized skill is required. On the other hand, specialized skill is required for the heating process of gas-pressure welding. Further, highly skilled arc-welding operators are required for enclosed-arc welding.

Weld quality: Since both thermite welding and enclosed-arc welding are fusion welding methods, it is difficult to completely prevent weld defects in the weld metal, such as minute air bubbles and slag. On the other hand, in flash-butt welding and gas-pressure welding, the weld defects tend to be produced less frequently because the base rails are butted and pressure-welded to each other without the intervention of the weld metal. There is a report that the breakage ratios of flash-butt welding and gas-pressure welding are low as compared to the breakage ratios of thermite welding and enclosed-arc welding.[7]

As mentioned above, flash-butt welding is employed worldwide as a welding method for plant welding because in this case, the welding time is short, specialized skill is not required, and high quality is obtained although the equipment is large, the initial investment is high, and mobility is inferior. In case of gas-pressure welding, the weld quality is high and the welding time is short as compared to flash-butt welding. Further, since the initial investment is low as compared to that of flash-butt welding, gas-pressure welding is widely employed domestically. Although the welding time is longer, thermite welding is used worldwide as a field welding method because of its low initial investment, light-weight equipment, high mobility, and easy acquisition of the operating technology. Enclosed-arc welding is employed for field welding around a turnout where the working space is insufficient because specialized skill is required, the equipment is compact and has excellent mobility, and the apparatus used for welding is small in size.

In other countries, gas-pressure welding and enclosed-arc welding are not so widely employed. This can be attributed to the facts that these welding methods require skill that takes time to acquire and that the welding time is longer than that of flash-butt welding and thermite welding.

For the sake of reference, the relatively percentage of the application of these welding methods is given. In other countries, as mentioned earlier, flash-butt welding is mainly used in plant welding, and thermite welding is mainly used in field welding. The percentage of application is basically determined by the entire length of the welded rails constructed by flash-butt welding in plant welding. For instance, in the case of a welded rail length of 200 m, the percentage application of flash-butt welding is 87.5% and that of thermite welding is 12.5%. Further, freight railway companies that are shifting from thermite welding to mobile flash-butt welding that provides higher weld quality are increasing in number.

In **Table 2**, the actual percentage distribution of the domestic applications of the four welding methods is given.[20] Domestically, thermite welding is most widely employed, followed by gas-pressure welding, flash-butt welding, and enclosed-arc welding. The percentage of gas-pressure welding is higher than that of flash-butt welding. This is attributed to the facts that the welding time of gas-pressure welding is short as in the case of flash-butt welding and that a high weld quality is obtained with a relatively low investment.

Table 1 Comparison of four rail welding methods

Welding methods	Welding time (min)	Equipment		Operators's skill	Quality of the weld
		Initial investment	Mobility		
Flash-butt welding	2 - 4	Expensive	Low	Not required	Excellent
Gas pressure welding	5 - 7	Expensive	Medium	Required	Excellent
Enclosed-arc welding	60	Not expensive	High	Required	Good
Thermite welding	30	Not expensive	High	Not required	Good

Table 2 Welding application numbers in JR (FY1988-FY2007)

Welding method	Number	Ratio
Flash-butt welding	140,000	23%
Gas pressure welding	173,000	29%
Thermite welding	242,000	40%
Enclosed-arc welding	49,000	8%
Total	604,000	

3. Problems Related to Weld Section in Overseas Freight Railways and Future Approach

In this section, we have described the examples of damages at a weld section in overseas freight railways that have become overt as a result of a heavy haul. Further, the flash-butt welder recently introduced to Nippon Steel & Sumitomo Metal for the study on the improvement of the reliability of a weld section is discussed.

3.1 Problems related to weld section

In overseas freight railways, a heavy haul is being promoted with an aim to improve the transportation efficiency. As a result thereof, the environmental factors affecting the rail usage have become harsh and cause damage at the weld sections. **Figure 10** shows examples of the surface damage accompanying spalling and fatigue damage developed at the weld sections in the case of flash-butt welding and thermite welding in overseas freight railways.

Surface damage accompanying spalling: In either example of flash-but welding method or thermite welding method (F-1 or T-1), the damage occurs at the locations that are symmetric to each other with respect to the center line of the weld section and coincide with the locations where the hardness is the lowest, as shown in Fig. 3 and Fig. 7. On the basis of this fact, HAZ softening is considered to be caused by the surface damage that accompanies peeling.

Fatigue breakage: The fatigue crack developed at the web of the flash-butt weld section (F-2) is initiated at the edge of a trace of a bulge (edge of a bead), which was already removed by trimming in the welding process, and grows in the horizontal direction. A strong residual tensile stress exists in the perpendicular direction of the web of a rail. This is said to contribute to the occurrence of the crack.[21] Further, the fatigue crack at the base (F-3) is initiated at the edge of a bead. The bending moment is observed at the rail base whenever a train passes over the rail, and this develops a stress concentration at the edge of the bulge that was insufficiently removed in the trimming stage. These are considered to be the causes of fatigue breakage. In the case of thermite welding, a fatigue crack is observed to initiate at the edge of a weld reinforcement (T-2 and T-3). In the case of thermite welding, the sectional shape of the weld reinforcement changes sharply at its edge. Therefore, the stress concentration at the edge is considered to be the cause of the fatigue breakage.

3.2 Introduction of new flash-butt welder and future approach

As mentioned in the previous section, the welding method with the highest percentage share of usage in overseas freight railways is flash-butt welding. The weld metal does not exist at its weld section, and the performance of the base rail material influences the weld quality. Therefore, Nippon Steel & Sumitomo Metal is studying the improvement of the reliability of flash-butt welding as well as the base material. As a part thereof, the company recently introduced a plant-welding flash-butt welder (built by Chemetron Corporation, USA), having the largest equipment capacity among the welders owned by railway companies. **Photo 9** shows its outlook. The new welder has a large-capacity transformer, thereby enabling welding with a very high current applied during preheating. Further, the upsetting load is high; therefore, a study on rails having relatively large cross-sectional areas is possible. In the future, we intend to improve the reliability of weld sections by utilizing this welder.

4. Conclusions

Welding is a very important technology with respect to the installation of rails. There are four widely used welding methods; of these, flash-butt welding and thermite welding are employed overseas. However, domestically, gas-pressure welding and enclosed-arc welding are also employed.

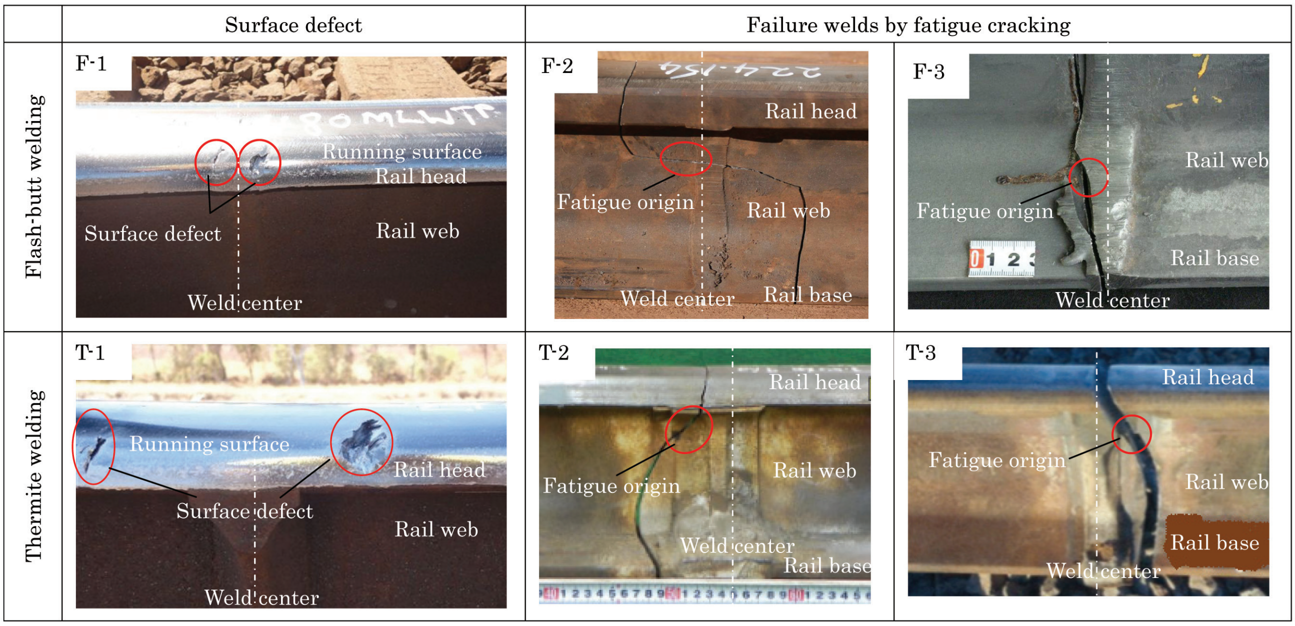

Fig. 10 Defect rails at welds in overseas heavy haul track

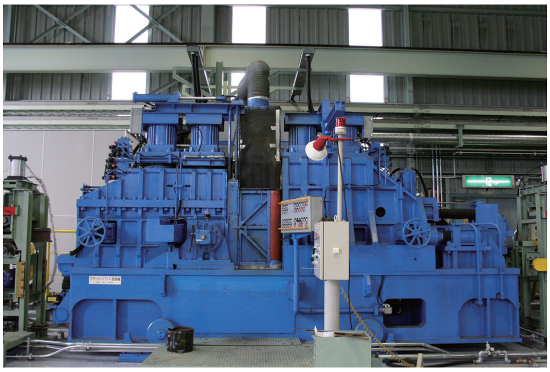

Photo 9 Overview of our new flash-butt welder

In the case of overseas freight railways, in conjunction with a heavy haul, the environmental factors affecting the usage of a weld section are harsh when compared to those in domestic situations. Therefore, sometime, surface damage and/or fatigue breakage is observed. Thus, Nippon Steel & Sumitomo Metal, with the intent of paying attention to the weld quality of flash-butt welding, recently introduced a plant-welding flash-butt welder, having the largest equipment capacity among the various welders owned by railways companies. In the future, we intend to improve the reliability of weld sections by utilizing this welder.

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