Interpretive Article

Research and Development on Prolonging the Service Life of Rails

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A rail is a component that directly supports the weight of trains and in order to ensure the safety and stability of transport, rails need to be replaced at periodic intervals. For this reason, the cost required in replacing rails occupies the largest share among all repair costs. Thus, various research and development initiatives are being undertaken in order to prolong the cycle for replacement of rails. In prior research, a method of prolonging the fatigue life of the welded part of a rail and a method of grinding rails to control shelling that is generated from the surface of rails have reached the practical -application- levels. Based on these results of research, rail grinding work is expected to begin in metropolitan Tokyo from fiscal 2005. This paper reports on the details of this method.

1 Introduction

While a rail may seem to be used endlessly, in reality, it is subject to various stresses as a result of train traffic and eventually becomes damaged or eroded and loses its function as a rail. The period of time from the laying of a rail to the loss of its function is called the "service life of a rail". The rail is a component that directly supports the weight of trains and for the sake of safety and stability, it is necessary to replace a rail with a new rail before the service life of the rail expires. For this reason, the cost involved is approximately 13.5 billion yen including related costs and this occupies the largest share among all repair costs. Assuming that some measure can be taken with respect to rails and that the service life may be prolonged, significant cost reduction will be enabled. If it is possible to elucidate the mechanism leading to the expiration of the service life of a rail for each type of stress involved and to put in place effective measures for dealing with such mechanism, it will be possible to prolong the service life of a rail. This paper reports on the types of service life of a rail and the status of research and development on prolonging such service life.

2 Service Life of a Rail

A rail is made of iron mass and is extremely robust. However, since rails are made from iron mass, with the passage of time, they will rust and the surface will become uneven, but except when laid in extremely poor conditions (such as places that are wet throughout the year due to water seepage, places where salt adheres due to sea wind, etc.) rails are extremely durable. Rails that were manufactured more than 100 years ago are used even today as pillars for the sheds of station platforms and in local lines, the 50PS rail with respect to which manufacturing was discontinued more than 40 years ago or second hand 50T rails that were laid for the Tokaido Shinkansen in the 1960s and since removed in the 1970s when the Tokaido Shinkansen was subjected to construction work for rejuvenation (transition to the use of 60 kg rails from the use of 50T rails) are used in abundance.

On the other hand, since rails are made of metal, failure is generated due to metal fatigue. "Metal fatigue" refers to eventual failure as a result of repeated loading of a force that is so small that a single application exerts no apparent impact. Metal fatigue has been highlighted in the transport industry through the accident involving the crash of a jumbo jet in 1985 and in recent years, the accidents caused by the breakage of a part called the "hub" of a trailer that connects the main tire unit to the axle.

When a train travels, various forces act on the rails. These forces may conceivably be compression, tension, torsion, bending, shear, or any combination of these. Moreover, when a force acts on a rail, elastic deformation or plastic deformation is generated. In this paper, the various forces and deformation will be collectively referred to as "stress." In passing, it is interesting to note that numerous books explain that the derivation of "stress" as used in terms of medicine and health such as in the statement "work related stress is accumulating" or "have a drink and get rid of stress" comes from the term as used in physics. In other words, the term "stress" that is used in this paper is an example of use that is close to the etymological derivation of the term.

The places at which rails are subject to stress that affects the service

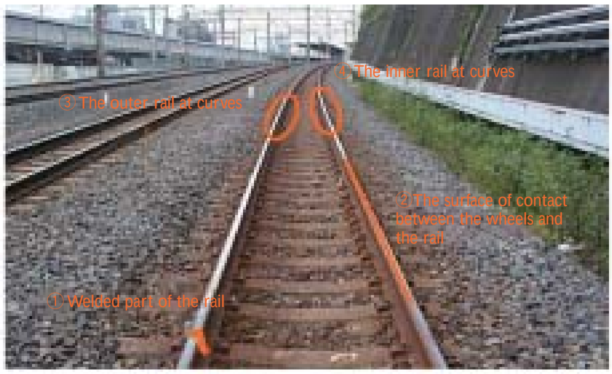

Fig. 1: Places where Rails are Subject to Stress

life of a rail are shown in Figure 1 and consist of the following 4 places: (1) the welded part of the rail; (2) the surface of contact between the wheels and the rail; (3) the outer rail at curves; and (4) inner rail at curves.

The stress in each of these places is small enough that hardly any load is felt in the short term but when the stress acts on the rail over a long period of time, fatigue accumulates and various effects will become manifest. The following section will explain the details of the stress at these places and the phenomena that appear when stress acts on a rail over a long period of time.

2.1 Welded Part of the Rail

In the vicinity of the welded part of a rail, there is a layer that has been affected by heat during the welding work or a difference in the hardness of the rail and the welding metal and for this reason, when a train repeatedly passes over the welded part, unevenness is generated on the surface that is in contact with the wheels. Figure 2 shows the external appearance of a standard welded part of a rail. The unevenness that is generated is in the order of 0.1 millimeters and in most cases, cannot be identified through visual observation. However, when a wheel passes over this unevenness, a "klunk klunk" sound is generated indicating that unevenness has indeed occurred.

Fig. 2: External Appearance of a Welded Part of a Rail (as seen from the side)

Figure 3 is a photograph taken from above the welded part where the unevenness has progressed. Looking carefully at the surface of the rail that is in contact with the wheels, it is possible to identify two points at which the width of the rail is slightly larger than at other points. These points correspond to the place where the rail has become concave. Figure 4 shows the status of the unevenness measured in detail using equipment that is capable of measuring to the order of a thousandth of a millimeter (or in other words 1 micron). While on first viewing the effect may not seem significant, if unevenness of the level shown in Figure 4 has been generated, the force that acts on the rail upon the passing of a train is 30% to 40% larger than in places with no such unevenness.

The stress that is generated by this force is extremely small compared to the acceptable stress on the rail and in the short term, there is absolutely no problem. However, each time wheels pass over such a section, fatigue accumulates though certainly in small increments. If this fatigue accumulates over a long period of time, breakage will occur as a result of metal fatigue. The fatigue that accumulates upon the passing of one wheel is a logarithmic function of the stress generated and for this reason, the welded part of the rail on which a large force acts due to unevenness is a component that determines the service life of a rail due to metal fatigue. Looking at this in another way, if it is possible to reduce the unevenness of the welded part of the rail using some means, it will be possible to prolong the fatigue life of the welded rail.

Fig. 3: External Appearance of a Welded Part of a Rail (as seen from above)

The standard for the replacement of a rail due to the fatigue life of the welded part is, when calculated for existing narrow gauge lines with 60 kg rails and standard vehicles (total weight 40 t), approximately 20 million vehicles. On the Yamanote line that has an extremely large number of vehicles in operation, this translates to fatigue life of about 20 years.

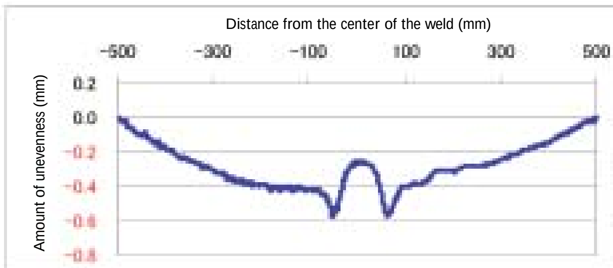

Fig. 4: Unevenness of the Welded Part of a Rail

2.2 Surface of the Contact between the Wheels and the Rail

At the surface of the contact between the wheels and the rail, stress is exerted on the rails as a result of contact as the wheel rolls over the rail. The stress due to rolling contact acts strongly at an extremely shallow depth from the surface of the rail. This force is extremely large when viewed locally and causes deformation in the crystalline structure of the metal subjected to the force. The force acts repeatedly and in the same direction and for this reason, the crystalline structure of the rail is forced to become aligned in a specific direction. If the crystalline structure is aligned in a certain direction, minute cracks form as a result of some triggering mechanism. When such minute cracks are generated, the crack will become progressively larger with the minute crack acting as the point of origin. The crack continues to develop as a result of the complex action of the stress generated by the vehicle load, residual stress within the rail, temperature stress, and other such factors. As a result, even in places that upon first viewing look the same, there are rails in which cracks will be generated and others in which cracks will not be generated. Current technology has yet to elucidate this mechanism for the progressive development of cracks but the development of such cracks can be roughly explained as follows.

For the most part, cracks progress at a depth of several millimeters from the surface of the rail horizontally parallel to the surface. A crack that develops progressively in the horizontal direction is called a "horizontal fissure." Figure 5 is the external appearance of a rail in which a horizontal fissure has progressed to a certain extent. There is a section that has turned blackish in a circular form at the rail head and a section with luster (shining surface) surrounding this. Looking in the longitudinal direction along the rail, the width of this shining surface broadens only at a certain place. The reason for the blackening of the rail head is the denting of the surface of the rail as a result of the horizontal fissure so that this section is not in contact with the wheels. The blackening and denting are visually undesirable but in fact, horizontal fissures have very little impact on the strength of a rail.

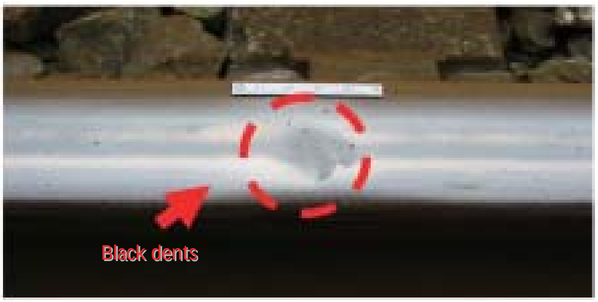

Fig. 5: External Appearance of Flaws

However, with the passage of time, as the horizontal cracks develop further, due to some factor, the crack may develop not horizontally along the rail but branch towards the interior of the rail from the section with the horizontal fissure. Figure 6 is a photograph of a crack that has extended towards the interior of the rail. This crack is called a transverse fissure. If a transverse fissure progresses, since the cross section that supports the weight of a train will decrease, the strength of the rail will be directly affected. If the strength of a rail declines significantly, there is risk of the rail breaking. Since the surface of the crack takes a form that is similar to the pattern seen on a seashell, this type of cracking is called "shelling."

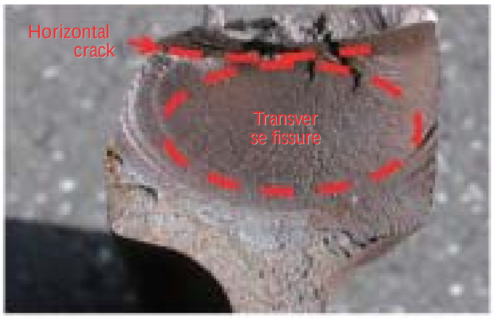

Fig. 6: Crack that has Progressed to the Interior of the Rail

Since shelling may be identified through visual external inspection and the size of horizontal fissures may be measured using a rail defect detector car and other such means thus enabling continuous monitoring, such defects are not left unattended to the point at which breakage of the rail occurs.

However, with the mechanism for the development of cracks not known to date, there is no prospect for the development of methods for stopping or controlling the progress of shelling. For this reason, in the event shelling is generated, the rail will need to be replaced prior to the defect developing into a transverse fissure.

2.3 Outer Rail in a Curve

At the outer rail of a curve, the wheel travels with the flange in contact with the lateral head of the rail. This is because of the centrifugal force that acts on a vehicle as it passes through a curve and the reactive force that acts when the truck is guided by the curve. For this reason, as shown in Figure 7, since the rail and the flange of the wheel grind against each other at the lateral head of the rail (skidding contact) the rail and flange are subjected to wear. As a result, the cross section of the rail is reduced rapidly leading to the end of its service life. The end of the service life of a rail due to wear in extreme curves with a large volume of vehicle traffic may be as short as 1 to 2 years. Figure 8 is a photograph of a rail in which wear has progressed.

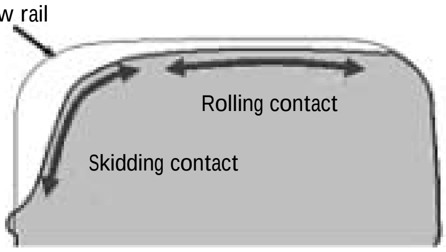

Fig. 7: State of Contact of the Outer Rail

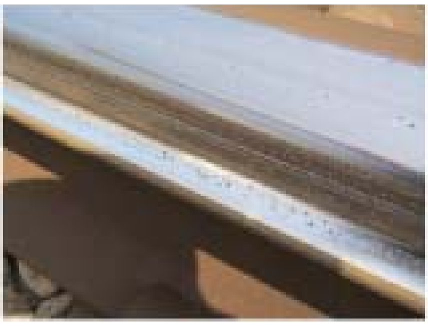

Fig. 8: Rail in which Wear has Progressed

Moreover, when the stress as a result of skidding contact is not large enough to cause wear of the rail, a crack will be generated and progressively develop as a result of this stress. This kind of crack is called "head check." As a head check remains localized to the surface of the rail, it exerts very little impact on the strength of the rail but the rolling noise will increase and if the above mentioned shelling is generated concurrently, there are cases in which the identification of such shelling will be delayed. Figure 9 shows the external appearance of head check.

Fig. 9: External Appearance of a Head Check

2.4 Inner Rail in a Curve

With the inner rail in a curve, there are cases in which periodic unevenness is generated as shown in Figure 10. This is called "undulatory wear." Since a multitude of factors contributes to the mechanism for the generation of undulatory wear and since the phenomenon upon the passing of a single rail is small, follow-up research is difficult and the mechanism has not been elucidated to date. However, since noise increases when undulatory wear progresses, the rail will be replaced.

Fig. 10: Status of the Generation of Undulatory Wear

3 Details of the Research

The Technical Center is undertaking technical development for each of the four elements listed above. In particular, with respect to prolonging the service life of rails in curves, since the balance between the wheels and the rails is important, the research is being undertaken as a joint initiative with the Vehicle Research Group.

In this paper, the details of research on prolonging the service life of the welded parts of rails and on preventing shelling will be introduced.

3.1 Fatigue Life of the Welded Part of a Rail

The fatigue life at a welded part of a rail may be prolonged by reducing the stress generated at such welded part. From research to date conducted by the Railway Technical Research Institute (hereafter referred to as "Railway Research Institute") estimating the fatigue life of the welded part of a rail under various conditions has become possible and upon having estimated fatigue life based on the bending fatigue strength of the welded part of a new rail, it has become possible to prolong fatigue life by making the unevenness of the welded part smooth through rail grinding that is described below.

However, since bending fatigue strength is affected by the minute unevenness of the rail surface, it may be assumed that the bending fatigue strength of the welded part of a rail that has been laid and used on site for many months and that of a new rail will differ. Moreover, the number of samples comprising the data on the amount of unevenness of the welded part of the rail that was used in estimating fatigue life was inadequate and in order to raise the reliability of the data, further investigation was required.

For this reason, in addition to requesting the Railway Research Institute to calculate the fatigue strength of a rail that was laid and used on site for about 30 years as the specified issue for research, detailed investigation was undertaken on the uneven conditions of the welded part of the rail.

The fatigue strength of the rail that was laid on site was, as initially assumed, less than the fatigue strength of the welded part of a new rail. Moreover, it was found that there were some differences from the assumptions to date with respect to the uneven conditions of the rail.

Having calculated the fatigue life from the results of the investigation on the unevenness of the welded part of the rail using the fatigue limit of the rail that was laid on site, it was found that by grinding at the specific frequency explained below, it would be possible to prolong the replacement standard based on fatigue life by about 200 million tons.

3.2 Prevention of Shelling

Since the position of the layer affected by contact that is the point of origin of shelling, a phenomenon that governs the service life of the surface at which the wheels contact the rail is extremely shallow as seen from the surface of the rail, there is the possibility that the layer affected by contact may be removed through rail grinding. To this end, it is necessary to investigate the depth from the surface of the rail to which the layer affected by contact has accumulated. While for the Shinkansen, the effect of periodic removal of the layer affected by contact in controlling shelling has been proven through a study undertaken by the Railway Research Institute in the 1990s, no progress had been made in investigation with respect to existing lines.

For this reason, in addition to investigating the accumulation of the layer affected by contact for new rails or rails with different cumulative service tonnage, rails were grinded on an experimental basis and investigation was undertaken on the status of accumulation of the layer affected by contact beginning immediately after the rail grinding.

As the layer affected by contact accumulates in the interior of the rail, it is not possible to undertake the investigation with the rail laid on the track so, rail specimens were cut out from operating lines and investigated. Moreover, since the phenomenon involves the crystalline structure of metal that is generated at an extremely microscopic level, investigation cannot be conducted through visual observation. Observation is not possible even when a normal microscope is used. For this reason, in collaboration with the Railway Research Institute, investigation is being undertaken using the testing facilities of a specialized company. The investigation involves grinding to a certain surface that is in the depth direction of the rail surface, irradiating this surface with X-rays, and observing the level to which the X-rays are reflected. Since crystals become aligned when stress accumulates, the high level of reflection properties of X-rays irradiated from a specific angle is being utilized.

From research to date, it has been found that, as in the case of the Shinkansen, the layer affected by contact exists in an extremely shallow position from the surface of the rail in the case of existing lines and that this can be removed through rail grinding.

Moreover, the layer affected by contact must be removed before cracks develop with this layer acting as the point of origin. For this reason, the time period to progressive development of a crack was investigated and estimated using the status of the generation of shelling at JR East and the same results as the results of the laboratory tests conducted by the Railway Research Institute were obtained. According to these results, if the layer affected by contact is removed with a frequency of about 50 million tons of cumulative service tonnage, it was found that shelling may be prevented.

3.3 Development of an Effective Method of Rail Grinding

Through progress in the investigation and research described in the preceding section, it was found that the service life of rails may be prolonged by using rail grinding cars to remove the layer affected by contact that is the cause of unevenness in the welded part of rails and the point of origin of shelling.

The term "rail grinding" used here actually means more than the task of polishing or grinding the surface of a rail. However, while the goal of the work of rail grinding is to remove the unevenness at the welded part of a rail and the layer affected by contact, when doing this, the rail head which has complex curves needs to be grinded efficiently and without impairing the condition of contact with the wheels.

For this reason, in order to conduct rail grinding, specialized machinery and work methods are required. Thus, a method of rail grinding is being developed using the rail grinding car of the European company SPENO (Figure 11) that has been adopted for rail grinding for the Shinkansen and is widely used in railways both in Japan and abroad and a rail grinding car of a domestic manufacturer (Figure 12).

Fig. 11: SPENO Rail Grinding Car

Fig. 12: Rail Grinding Car of a Domestic Manufacturer

Rail grinding on which development is currently underway grinds the surface of a rail by causing abrasive grindstones that are directly connected to the drive shaft of a motor to rotate. In order to grind a rail having complex curves, it is necessary to grind the surface to a uniform thickness by adjusting the angle of the abrasive grindstones that contact the rail as shown in Figure 13.

Simply put, this is like rotating a potato slowly when peeling using a peeler. Needless to say, it is not possible to rotate the rails and for this reason the angle of the abrasive grindstone is adjusted slowly to grind the rail. An actual rail grinding car has a number of abrasive

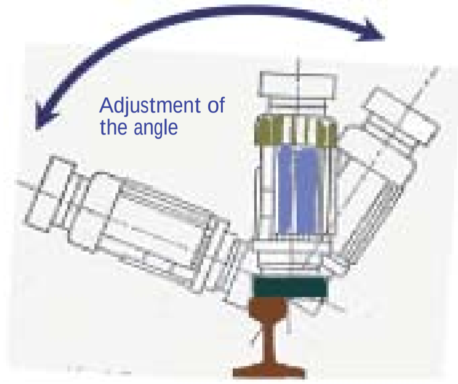

Fig. 13: Angle between a Rail and the Abrasive Grindstone

grindstones as shown in Figure 14 and is capable of grinding multiple angles in one rail grinding session.

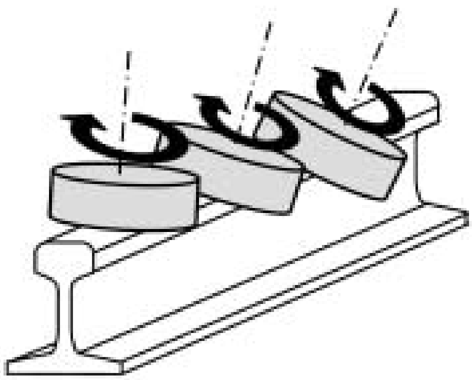

Fig. 14: Deployment of the Abrasive Grindstones on a Rail Grinding Car

Figure 15 is a photograph that shows how the surface of a rail is

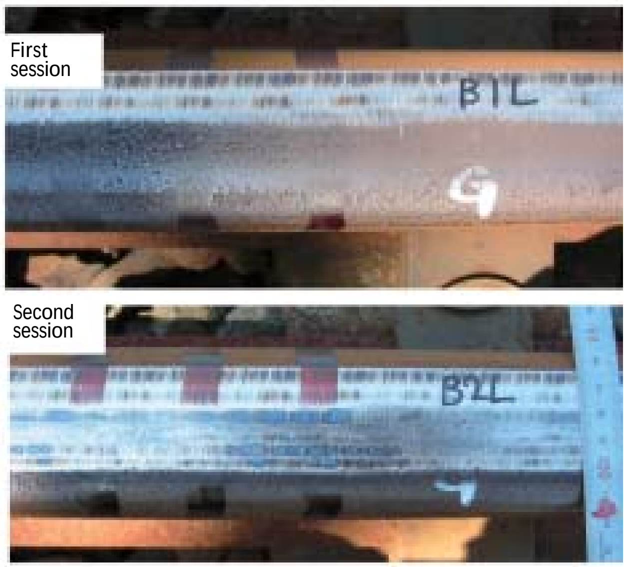

Fig. 15: View of a Rail being Grinded

grinded. In the first rail grinding session, while the abrasive grindstones are in contact with the rail from several angles, only about 1/4 the top surface of the rail can be grinded. In the second rail grinding session, since the abrasive grindstone contacts the rail at a different angle from the first rail grinding session, a different part of the rail is grinded.

In this way, in order to conduct rail grinding in an efficient manner, the angle of the abrasive grindstone and the number of sessions of rail grinding are important. Moreover, it is important to review the significance of the district at which the rail grinding will be undertaken, the work conditions (length of the period between maintenance work, movement and deadheading and loss of machinery, periodicity of work, etc.) and costs such as initial investment (cost of the procurement of machinery, etc.). If the cost of rail grinding were to be higher than the reduction in the cost required for the replacement of rails, there would be no meaning in undertaking such rail grinding.

From the results of on-site rail grinding experiments to date, it has been possible to determine the combination of the angles of the abrasive grindstones when using the 16 head type of grinding car manufactured by SPENO to achieve both the elimination of the layer affected by contact that acts as the point of origin for shelling and the reduction of the amount of unevenness in order to prolong the service life of the welded part of a rail with the minimum number of required sessions (4 sessions). Moreover, with the 6 head type of grinding car manufactured by a domestic manufacturer, while from the perspective of performance, there are issues that need to be addressed regarding the cost of eliminating layers affected by contact that act as the point of origin for shelling, the conclusion that was reached indicating that by grinding only the vicinity of the welded part of the rail, it is possible to prolong the fatigue life of such a component at a low cost.

Prolonging the service life of rails through rail grinding is in the spotlight throughout the world and rail grinding cars using a variety of methods are under development overseas and particularly in Europe and the United States.

For this reason, in August 2004, on-site inspection and exchange of opinions with the technical staff of manufacturers developing rail grinding cars were carried out (Figure 16). As a result, it was found that the new types of rail grinding cars that are under development may be expected to provide striking effects judging from the specifications at the prototype stage, when long term use is taken into consideration, there are numerous aspects that remain unknown. The status of further development in the future is being watched with interest.

Fig. 16: Scene from a Session for the Exchange of Opinions with the Technical Staff of European Manufacturers

4 Initiatives in the Future

From the results of research to date, as the method of rail grinding to prolong the service life of the welded parts of rails and to control shelling has reached a level that allows practical use, from fiscal 2005, rail grinding work is scheduled to begin in the Tokyo Metropolitan area.

Emphasis will continue to be placed on the prolonging of the service life of rails at curves and research will be conducted into head check and undulatory wear.