Development of High Strength Pearlitic Steel Rail (SP Rail) with Excellent Wear and Damage Resistance

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NKK has developed a high-strength pearlitic rail named the SP (Super Pearlite) rail, which has superior wear and damage resistance and is most suitable for heavy haul railroads. Comprehensive research on the relation between microstructural factors and wear and RCF (Rolling Contact Fatigue) behaviors revealed that refining the pearlite colonies greatly improves wear and damage resistance. In the SP rail, the pearlite colonies are refined through microalloying design and TMCP (Thermo-Mechanical Controlled Processing). This paper introduces the basic properties of the SP rail including its wear and RCF behaviors as well as the concept of microstructural control.

1. Introduction

In North America, the railroads are mainly used for transporting cargoes such as grain and ore. Transportation efficiency has been improved mainly by mass transportation through increasing the load capacity of freight cars. Long trains hauling more than 100 freight cars full of cargoes, called mile trains, run across the North American continent. A fully loaded freight car weighs close to 160 tons, nearly 2.5 times as heavy as Japan's passenger coaches. The requirements for rails used for such heavy haul railroads are very strict, because the performance of rails is one of the most important factors for improving the efficiency of railroad cargo transportation.

The establishment of technologies for producing clean steel and the development of on-line heat treatment technologies of rails in Japan since the 1970s have greatly improved the ability of rails to withstand wear and RCF (Rolling Contact Fatigue) damage[1-4]. **Fig.1** shows recent changes of railroad car weight in North America. Increasing car weight, which has been made possible by improving the wear and damage resistance of rails, has greatly improved transportation efficiency, but this has encouraged the use of even heavier cars, making the requirements for rails even more stringent. The wear resistance and RCF damage resistance of rails need to be improved even further.

NKK has developed a high-strength SP (Super Pearlite) rail, which has significantly higher wear resistance and RCF damage resistance over the conventional heat-treated rail, through microstructural control by means of microalloying design and TMCP (Thermo-Mechanical Controlled Processing). This paper outlines the basic concept of the is refined, and the hardness and wear resistance are improved. The lamellar spacing in the state-of-the-art heat-treated rail is as fine as about 0.1 μ m, which is nearly the limit that is industrially achievable[5].

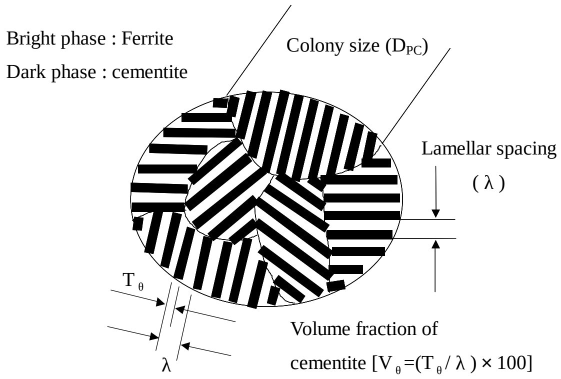

Fig.2 Schematic drawing of pearlitic structure

Recently, a new highly wear resistant rail was developed, in which the carbon content is increased from the eutectoid composition (0.8%) to the hyper-eutectoid level (0.9%)[6]. The increase in the volume fraction of cementite (V_θ), stemming from the increased carbon content, affects the structural changes at the micro to nano level when plastic deformation occurs under rolling contact with the wheel. As a result the surface hardness of the rail increases the longer it is used, thus helping to improve the wear resistance of this type of rail[7].

As noted above, it is known that the wear resistance is improved by controlling the lamellar spacing (λ) and the volume fraction of cementite (V_θ). However, the effects of changes in the microstructure of pearlitic steel on its wear resistance and RCF damage resistance have not been systematically identified.

We therefore prepared a large number of pearlitic steel specimens having a wide variety of microstructures, in order to clarify what type of microstructural control can improve wear resistance and RCF damage resistance. Firstly, microstructural features of each specimen were quantified, then the characteristics of each specimen were evaluated by the newly developed RCF test machine (**Photo 1**)[8]. Thus, the correlation between the microstructure and wear and damage resistance was systematically clarified.

In the newly developed RCF test machine, a wheel sample and rail sample, both in the form of a disc 130 mm diameter and 30 mm thick, are contacted and rotated. The wheel sample is made of pearlitic steel with Vickers hardness (HV) of about 370. The contact angle between the wheel sample and rail sample (angle of attack) can be var-

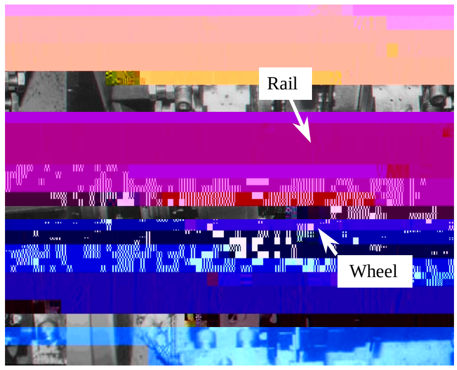

Photo 1 Appearance of the RCF test machine

ied to more accurately simulate wear and RCF behaviors on curved railroad sections with various curvatures. The details of the change in wear and RCF behaviors with varying angle of attack are given elsewhere[8,9].

Photo 2 shows some of the microstructures of the steel specimens used for this test. **Table 1** shows the results of quantitative microstructural analysis and hardness measurement for each specimen. Note that the hardness varies in the range of HV 270 to 395 with varying values of D_{PC}, λ and V_θ.

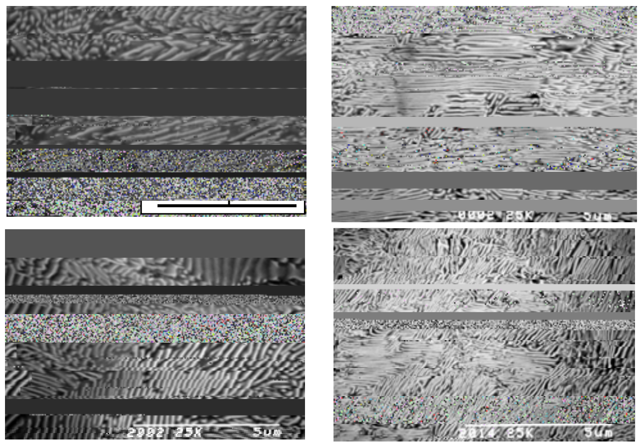

Photo 2 Microstructure of the steel specimens

Table 1 Quantitative microstructural analysis results

The wear resistance and RCF damage resistance of pearlitic steel specimens of various microstructures were evaluated including those specimens shown in **Photo 2** and

Table 1. The wear resistance was evaluated in terms of

3. Basic performance of the SP rail

3.1 Microstructure and mechanical properties

The SP rail is a steel rail of 0.82% carbon in which the colony size is refined by microalloy addition and TMCP. **Photo 4** shows a typical microstructure at 5 mm below the head surface. The results of quantitative microstructural analysis are D_{PC}=50 μm, λ=0.11 μm, and V_θ=48%. This microstructure is similar to that of specimen P4 shown in **Photo 2**.

Photo 4 Microstructure of the SP rail

Table 2 compares representative tensile properties of the SP rail with those of the conventional heat-treated rail, both measured following the standard of AREMA (American Railway Engineering and Maintenance Association). The strength of the SP rail is almost the same as that of the conventional heat-treated rail, but its elongation is superior.

Table 2 Tensile properties of the SP rail

Fig.5 shows the performance (tensile strength and elongation) of the SP rail actually produced. It is clear that the strength and elongation performance of the rail are excellent and stable.

Fig.5 Production results of the SP rail: (a) EL, (b) TS

Fig.6 compares the hardness distribution in the SP rail with that in the conventional heat-treated rail along the depth from the head surface. The surface hardness of the SP rail is almost the same as, or slightly higher than, that of the conventional heat-treated rail; however, the SP rail maintains the hardness deeper into the rail body.

Fig.6 Hardness distribution from the rail surface

Fig.7 shows the relationship between weight loss (abrasion lwnu-14.3smbr-14.3ser s r.wIf th-14.3seb lws th conve8.14(nt4.41i)3.41i

Presumably, refining the colony size disperses these stress concentrations, suppressing crack generation and propagation, and also suppressing separation as abrasion dust, thereby improving wear resistance.

3.3 RCF damage resistance

Likewise, disc-shaped specimens of 30 mm diameter and 8 mm thick with curved contact faces were taken from 3 mm below the head surface. These specimens were rotated in contact with wheel specimens under oil lubricated conditions with contact pressure of 2.2 GPa, rotating speed of 800 rpm, and slip ratio of –20%. **Fig.9** compares the time to RCF damage (flaking) in the conventional heat-treated rail with that in the SP rail, indicating that the RCF damage resistance of the SP rail is improved by about 40% over the conventional heat-treated rail.

Fig.9 Initiation time for flaking

3.4 Welded joint performance

Fig.10 shows a longitudinal hardness distribution at 5 mm below the head surface of a flush-butt welded joint of the SP rail, welded under the same conditions as those for welding the conventional heat-treated rails. An excellent hardness distribution was obtained. Further, the static bending performance was evaluated by the 4-point bend test following the standard of AREMA (**Fig.11**). As **Table 4** indicates, the bend test confirmed that both the modulus of rupture and the deflection conform to the specifications.

Fig.10 Hardness distribution near the weld joint

Fig.11 Test method (4-point bend test)

Table 4 Results of the bend test

4. Conclusion

improves the wear and damage resistance. On the basis of such findings, NKK developed the SP rail that has small colony sizes realized by applying microalloying design that includes microalloy addition, and TMCP. The evaluated properties of the SP rail closely reproduced the laboratory study results. It was confirmed that the welded joints of the SP rail, welded under the same conditions as those for welding conventional heat-treated rails, exhibit an excellent hardness distribution and static bending properties.

The superb performances of the SP rail are now being verified by field tests in North America. The outstanding wear and damage resistance of the SP rail will no doubt contribute to a significant reduction in the cost of railroad maintenance.

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