Development of SP4 rail with high wear resistance for heavy haul railways

Kazuya Tokunaga
JFE Steel Corporation
Contents

1. History of JFE’s rail

2. Basic study on improved rail endurance

3. Manufacture and basic performance of developed rail
【Comparison of wear loss in passenger and heavy haul trains】

● Improvement in durability of rail for heavy haul railways is required.
History of JFE’s rail

- **1978** THH 370HB
- **1992** SP1,2 390HB
- **2000** SP3 430HB
- **2008** SP4 450HB
- **2015**

- **Online heat-treatment (air cooling)**

- We have been developing **SP4** rail with an excellent wear resistance and rolling contact fatigue (RCF) resistance.
1. History of JFE’s rail

2. Basic study on improved rail endurance

3. Manufacture and basic performance of developed rail
Effect of hardness on wear resistance

The wear resistance was improved by increasing hardness.
Increase of hardness in pearlitic rail

Bright phase: Ferrite
Dark phase: Cementite

HB340 class rail
HB370 class rail

● Hardness of rail was increased by refining pearlite lamellar structure.
Relation between pearlite lamellar spacing and hardness

\[ HV = 58 + 86 \times (LPS)^{-1/2} \pm 18 \]

- Refining lamellar spacing \( \Rightarrow \) High hardness

Lamellar spacing, \( \lambda^{-1/2} (\mu m^{-1/2}) \)

Rough \( \xrightarrow{\Leftarrow} \) Fine

Refinement of pearlite lamellar spacing

$T_e$: Equilibrium transformation temp. (depend on the chemical composition)

$P_s$: Pearlite transformation temp. (depend on the cooling condition)

$\Delta T$: Supercooling

1. $T_e$ (SP4)
2. $T_e$ (HB370 class rail)

Refinement of pearlite lamellar spacing:

1. Chemical composition: optimization
2. Cooling condition: rapid

Increase $\Delta T$ (SP4)
Influence of alloy element on equilibrium transformation temperature (Te)

【Effects of Si, Cr and Mn content on Te】

- Addition of Si and Cr
- Decrease of Mn

Base steel: Fe-0.8%C (Calculated by Thermo-Calc)

Equilibrium Transformation Temperature (℃)

Alloy content (mass %)

Increase of Te
Decrease of Te
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### Chemical composition of SP4 (mass%)

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>others</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP4</td>
<td>0.8</td>
<td>add.</td>
<td>decrease</td>
<td>≦0.02</td>
<td>≦0.005</td>
<td>Cr and V</td>
</tr>
<tr>
<td>Conventional rail (HB370 class rail)</td>
<td>0.8</td>
<td>0.31</td>
<td>1.14</td>
<td>≦0.02</td>
<td>≦0.005</td>
<td>Cr</td>
</tr>
</tbody>
</table>

### Manufacturing process

1. **Addition of Si and Cr / decrease of Mn**
2. **Optimized Cooling condition**

   ![Manufacturing process diagram](chart)

   - Continuous casting
   - Hot rolling
   - Slack quenching

- Refine lamellar spacing
<table>
<thead>
<tr>
<th></th>
<th>SP4</th>
<th>Conventional rail (HB 370 Class rail)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Surface</strong></td>
<td>68nm</td>
<td>90nm</td>
</tr>
<tr>
<td><strong>25.4mm</strong></td>
<td>81nm</td>
<td>130nm</td>
</tr>
</tbody>
</table>

- Lamellar structure of SP4 becomes **finer** compared with Conventional rail.

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Hardness distribution

【Hardness distributions of SP4 and Conventional rail (HB370 class rail)】

- Hardness of SP4 was approximately HB450 at the railhead surface and HB400 the depth of 20mm.
- Hardness of SP4 was increased HB50 or more by refining the pearlite lamellar spacing.

![Graph showing hardness distribution](image-url)
**Tensile test**

- Diameter: 12.7mm
- Gauge length: 50mm

<table>
<thead>
<tr>
<th>Tensile Properties</th>
<th>SP4</th>
<th>Conventional rail (HB370 class rail)</th>
<th>AREMA spec.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2% YS (MPa)</td>
<td>1,002</td>
<td>860</td>
<td>Min 827</td>
</tr>
<tr>
<td>TS (MPa)</td>
<td>1,457</td>
<td>1,300</td>
<td>Min1179</td>
</tr>
<tr>
<td>El (%)</td>
<td>13</td>
<td>12</td>
<td>Min 10</td>
</tr>
</tbody>
</table>

- **0.2% yield and tensile strengths of SP4 were 1002MPa and 1457 MPa, respectively, which were higher than those in Conventional rail.**
- **Elongation of SP4 was the same level to that of Conventional rail.**
Wear test

2mm

Test conditions
- Load: 2.45kN
- Contact stress: 1210MPa
- Lubrication: dry
- Slip ratio: -10%
- Hardness of tire sample: 370HB

● Wear resistance of SP4
⇒ 43% higher than that of Conventional rail
Rolling contact fatigue (RCF) resistance

【RCF test】

Test conditions
- Load: 0.98kN
- Contact stress: 2760MPa
- Lubrication: oil
- Slip ratio: -20%
- Hardness of tire sample: 370HB

● RCF resistance of SP4
⇒ 2.6 times higher than that of Conventional rail

2.6 times improvement

SP4 Conventional rail (HB370 class rail)
● JFE steel successfully developed the new high performance steel rail (SP4), having high hardness over 400HB at 20mm below the rail head surface.

● SP4 rail is eutectoid carbon rail (0.8%C level) and the rail has an extremely fine lamellar spacing.

● SP4 has high strength compared with Conventional rail. (HB370 class rail)
  (SP4 : 0.2% yield strength =1,002MPa, Tensile strength=1,457MPa)
  Elongation of SP4 is the same level as that of Conventional rail. (HB370 class rail)

● SP4 showed much better wear resistance and RCF resistance than Conventional rail in the laboratory test. (HB370 class rail)
Appendix
Image of electron microscope

<table>
<thead>
<tr>
<th></th>
<th>SP4</th>
<th>Conventional rail (HB 370 Class rail)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface</td>
<td><img src="image" alt="Image of electron microscope" /></td>
<td><img src="image" alt="Image of electron microscope" /></td>
</tr>
<tr>
<td>1inch (25.4mm)</td>
<td><img src="image" alt="Image of electron microscope" /></td>
<td><img src="image" alt="Image of electron microscope" /></td>
</tr>
</tbody>
</table>

● **SP4** as well as **Conventional rail** has pearlitic microstructure.