CORUS PREMIUM GRADES TO ADDRESS WEAR
AND ROLLING CONTACT FATIGUE

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ABSTRACT

In order to improve the wear and rolling contact fatigue (RCF) resistance of rails, Corus has developed 3 different chemistry compositions:

1. MHH low alloyed pearlitic heat treated rails, to delay wear and RCF
2. B320 and B360 bainitic rails to eliminate RCF defects, and
3. A novel micro structurally engineered hypereutectoid steel (HPRail) in both as-rolled and heat treated conditions for step change resistance against the key degradation mechanisms of wear and rolling contact fatigue.

Revenue track tests have demonstrated that MHH rails offer outstanding wear resistance. This grade is used worldwide in heavy haul tracks and mixed traffic railways in Europe.

The carbide-free bainitic grades (B320 and B360) have excellent resistance to RCF that has been demonstrated in several high profile European track such as the heavily used Eurotunnel route. These grades are recommended for both switches and plain line tracks where grinding needs to be minimised/avoided.

HPRail is the latest development from Corus and is undergoing track trials including in the TTCI FAST loop.
INTRODUCTION

There are increasing demands for the industry to move towards heavier axle loads, increased train speed, mixed traffic operations. The need to accommodate these demands with reduced track maintenance time and costs has been a key driver for the railway companies and rail manufacturers to jointly develop new rail steels. These new grades display lower wear rates and a higher resistance to the initiation and propagation of rolling contact fatigue (RCF) defects (i.e. head checks and spalling).

The traditional approach for the development of new grades to address wear and RCF has been to increase steel hardness. This increase has been achieved during the last 40 years through microalloying using alloying elements such as chromium and/or through the use of heat treatment/accelerated cooling of eutectoid and, more recently, hypereutectoid steels.

Gauge side lubrication is also now widely used to reduce side wear in curves.

There is a strong belief that the lower wear rates of these new steels has lead to rolling contact fatigue becoming a major cause of rail degradation and replacement. Hence, preventive grinding is implemented in majority of heavy haul and mixed traffic railways to remove the fatigued layer.

Therefore, use of premium rails combined with a preventive grinding policy and appropriate rail lubrication enables rail life to be maximised.

Unfortunately, the rate of improvement in the desired rail properties has decreased in recent years and striving for the highest level of hardness does not appear to be the best strategy for
an effective solution. Consequently, rail steel grade development at Corus has been focussed on engineering the metallurgical microstructure. These grades, despite not being the hardest, combat wear and RCF defects more efficiently. These grades are:

- MHH and MHH+ heat treated low alloyed pearlitic steel
- B320 and B360 bainitic steels
- A novel hypereutectoid steel (HPRail) in both as rolled and heat treated conditions.

This paper describes the characteristics of these grades and gives a summary of the most recent track results.

**MHH AND MHH+ HEAT TREATED LOW ALLOYED PEARLITIC STEELS**

The chemical composition of the MHH and MHH+ grades is given in table 1.

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>Cr</th>
</tr>
</thead>
<tbody>
<tr>
<td>MHH / MHH+</td>
<td>0.72/0.82</td>
<td>0.40/0.80</td>
<td>0.80/1.10</td>
<td>0.40/0.60</td>
</tr>
</tbody>
</table>

Table 1 : chemical composition (% mass)

These pearlitic grades comply with the AREMA requirements for low alloy chemistry premium rails and will be included in the next issue of the European rail standard. The MHH+ grade is manufactured to slightly higher levels of hardness. The main mechanical properties are given in table 2.

<table>
<thead>
<tr>
<th></th>
<th>Yield strength ksi / MPa</th>
<th>Tensile strength ksi / MPa</th>
<th>Elongation %</th>
<th>Brinell hardness surface</th>
<th>Brinell hardness 20 mm below rail surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>MHH</td>
<td>120 / 830</td>
<td>185 / 1280</td>
<td>12</td>
<td>381</td>
<td>346</td>
</tr>
<tr>
<td>MHH+</td>
<td>123 / 850</td>
<td>188 / 1300</td>
<td>12</td>
<td>388</td>
<td>363</td>
</tr>
</tbody>
</table>

Table 2 : minimum values
MHH rails have been laid in the UP Tehachapi test site and compared with other rail grades, including hypereutectoid grades [1]. The transportation Technology Center, Inc (TTCI) performed the tests and their results are given in figure 1 (area loss).

![Figure 1: high rail wear rate](image1)

The hardness of the rails is given in figure 2.

![Figure 2: hardness of the rails](image2)

At the end of the test no significant rail surface deterioration was noted.
MHH rails displayed the best wear resistance, compared to the other tested grades, including harder hypereutectoid rails.

The excellent resistance to RCF defects initiation and propagation of MHH rails has already been proven in conventional and heavy haul tracks [2]. Although not the hardest rail steel, the excellent resistance to both wear and RCF of MHH rails can be explained by optimised chemical composition and cooling conditions achieved in the off line heat treatment facility of Corus Hayange. Furthermore, the avoidance of roller straightening following heat treatment imparts the unique attribute of slightly compressive residual stresses on the rail head and foot compared to the higher tensile residual stresses associated with other in-line heat treatment processes.

**Corus HPRail - HIGH PERFORMANCE HYPEREUTECTOID STEEL**

Corus wanted to develop an as rolled (not heat treated) rail steel that had equivalent or better resistance to both wear and RCF than currently available heat treated grades.

The two key elements of the microstructural design philosophy were:

- Increase strength of pearlitic ferrite through solid solution and precipitation strengthening
- Increase volume fraction of fine pearlitic cementite lamella using a hypereutectoid composition.

Laboratory tests have been carried out and the results have been compared to other conventional pearlitic rail grades (figures 3 4 5).

The resistance to wear and RCF (number of cycles to RCF initiation) was determined using a conventional twin disk equipment, using 2 counter-rotating disc-shaped specimens, one obtained from the rail steel, and the other from a standard wheel steel.
Figure 3: Proof stress and ultimate tensile strength of HPRail and conventional pearlitic rails.

Figure 4: Wear rate of HPRail and conventional pearlitic rails.

Figure 5: Fatigue initiation speed of HPRail and conventional pearlitic rails.
These laboratory results show that the wear resistance and the fatigue resistance of Corus HPRail (as rolled and heat treated) are significantly better than those of conventional pearlitic rails with equivalent or even higher hardness levels. The microstructural deformation in the tested samples was also measured using Electron Back Scattered Diffraction techniques developed at Corus that confirmed that the depth of microstructural deformation was significantly lower in HPRail compared to conventional heat treated grades.

Corus HPRail steel, in both as rolled and heat treated conditions, have been laid in February 2010 in the TTCI FAST loop, for evaluation in heavy haul conditions. As rolled HPRail have also been laid in April 2010 on the Sheffield Supertram network in UK on a very tight radius curve.

B320 AND B360 BAINITIC STEELS

Although heat treated pearlitic grades (eutectoid or hypereutectoid) have been shown to delay the initiation of RCF cracks, the need for preventive grinding has not been eliminated and is generally undertaken at intervals of between 15 and 100 MGT depending on track and traffic characteristics. Grinding of rails consumes rail life (enforced wear) and requires careful management of operational logistics, both of which add to the life cycle costs of the rail. Grinding of switches and in tunnels add to the complexity and costs.

Therefore Corus, in technical partnership with SNCF, SBB and Eurotunnel, has developed two new carbide free bainitic grades (B320 and slightly harder B360 grades) that do not initiate RCF defects [2].

The chemical compositions and key mechanical properties are given in tables 3 and 4.
<table>
<thead>
<tr>
<th>Grade</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>Cr</th>
<th>V</th>
<th>Mo</th>
</tr>
</thead>
<tbody>
<tr>
<td>B320</td>
<td>0.15/0.25</td>
<td>1.00/1.50</td>
<td>1.40/1.70</td>
<td>0.30/0.70</td>
<td>0.10/0.20</td>
<td>0.10/0.20</td>
</tr>
<tr>
<td>B360</td>
<td>0.25/0.35</td>
<td>1.00/1.50</td>
<td>1.40/1.70</td>
<td>0.30/0.70</td>
<td>0.03 max</td>
<td>0.10/0.20</td>
</tr>
</tbody>
</table>

Table 3: chemical composition (% mass)

<table>
<thead>
<tr>
<th>Grade</th>
<th>Yield strength</th>
<th>Tensile strength</th>
<th>Elongation</th>
<th>Brinell hardness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ksi / MPa</td>
<td>ksi / MPa</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>B320</td>
<td>116/800</td>
<td>159/1100</td>
<td>14</td>
<td>320</td>
</tr>
<tr>
<td>B360</td>
<td>123/850</td>
<td>174/1200</td>
<td>13</td>
<td>360</td>
</tr>
</tbody>
</table>

Table 4: minimum values

The resistance of bainitic rail steels to crack initiation is exceptionally high. One can give the following explanations:

- The bainitic microstructure is a combination of ferrite, cementite and retained austenite as characterised by the micrograph below (figure 6). Due to the inherent complexity of the bainitic microstructure, both the initiation and propagation of cracks is more difficult than in pearlitic structures (figure 7), where ferrite and cementite form parallel lamellae.

Figure 6: bainitic structure

Figure 7: pearlitic structure
- the lower wear resistance of the bainitic steels (compared with pearlitic steels of the same hardness) increases the elimination of the fatigued layer by wear.

**Switch and crossings**

The B360 grade is now homologated by SNCF for movable points of high speed lines because of its exceptional resistance to head checking (figure 8).

![Figure 8: SNCF high speed movable points](image)

Following the excellent results of bainitic steel on movable points, SNCF decided to test bainitic B360 switch blades on the Paris suburb line, where R260 rails are affected by severe head checking (figures 9 and 10).
After 32 MGT and no grinding, the rail surface is perfectly smooth, with no evidence of RCF defect (figure 11).
Plain track

B320 rails have been tested in the tunnel between France and England since March 2007, in large curves previously affected by head checks (figure 12).
After 286 MGT and no grinding, the bainitic rails surface is smooth, without any head check, while the standard R260 rails are affected by heavy head checking (figures 13 and 14).

Figure 13 : standard R260 rail with head checking

Figure 14 : bainitic B320 rail without any head checking
B360 bainitic rails have also been tested in Switzerland (SBB) tracks, on curves affected by head checking. Based on their excellent resistance to RCF defects, 600 tons of B360 rails have been laid in Switzerland in 2009 - 2010 for curves with radii between 450 and 1500 m.

**Narrow flash butt welds and aluminothermic welding post treatment**

Bainitic steels are susceptible to tempering so that, during flash butt welding or aluminothermic welding, the softened heat affected zone (HAZ) is wider than with pearlitic steels; it leads to differential wear causing "cupping". In order to combat this drawback, two improvements have been developed:

- a novel narrow HAZ flash butt process
- a post treatment of the aluminothermic welds.

**Narrow flash butt welds**

In this novel process the aims were to reduce heat input, to reduce time available for conduction, to obtain a balanced heat input with conduction cooling. The aims were achieved through a slightly longer initial flash duration, a significant reduction in the number of preheats, shorter preheat “on” and “off” times and shorter final flash duration. This gives a significantly narrower HAZ than those produced using standard welding practices. Figure 15 shows the hardness profile across a narrow B360 weld, on the top of the head, 5 mm below the running surface.
The recovery in hardness to that of the parent B360 rail is achieved at a distance of only 50 mm from the fusion line, compared with 100 mm in the standard welds.

**Post treatment of aluminothermic welds**

In order to eliminate the softened zones of aluminothermic welds, a post treatment with gas burners has been developed (figure 16).

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**Figure 15:** Bainitic B360 narrow weld

**Figure 16:** Post treatment of aluminothermic welds
This post weld treatment results in a more uniform hardness profile across the weld (figure 17).

CONCLUSION

Corus has successfully developed 3 different rail chemistries to combat wear and RCF. These grades have been designed to solve maintenance issues on different types of tracks:

- MHH rails for wear and RCF on heavy haul and mixed traffic railways
- B320 and B360 rails for tracks where RCF is the main issue (switches and plain track) and where grinding needs to be avoided/minimised.
- as rolled hypereutectoid HPRail with significantly improved wear and RCF resistance as demonstrated through laboratory tests.
REFERENCES


[2] D. Boulanger, World Congress on Railway Research, 2003, “rail metallurgical developments to address the changing needs of the railways”