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FROM MIXED TRAFFIC TO URBAN TRANSPORT: ACHIEVING LONGEST SERVICE LIVES AND LOWEST MAINTENANCE NEEDS BY CUSTOMIZED RAIL SOLUTIONS WITH SMART MICROSTRUCTURES

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Abstract

The high demands of the modern railway system require – either in urban tramway transport systems, or in mixed traffic transport – the use of track components with correspondingly high resistance against rail degradation to cope with higher loads, more passengers and shorter train intervals. Based on the knowledge about the positive effect of fully pearlitic material concepts with C › 0.9% on the performance of rails, a new class of rail steels was introduced in tracks more than 20 years ago; the so-called Super Premium Rail Steels. Based on this great deal of theoretical and practical experience, the success story of rail steels with higher carbon content has been transferred from heavy-haul application into mixed traffic and urban railways. The very positive behaviour of these Super Premium Rails does not only involve rail wear minimization, but also the behaviour of the rails with respect to the formation of corrugation and the development of rolling contact fatigue (RCF) is extraordinarily improved. The paper deals with track experiences and the most economic rail grade strategy for mixed traffic as well as urban transport. However, a holistic system approach requires consideration and optimization of both sides of the wheel/rail contact. It is a common perception that reducing the wear rate of the material on one side of the wheel/rail interface will result in an increase in wear on the other side of the interface. Within the paper a review of research and published papers has been undertaken and it has been found that increasing the hardness of one material has little or no effect on the wear rate of the other material, and many researcher have actually observed a reduction in the wear rate in both materials when the hardness of one of them is increased. Highly resistant materials can therefore be beneficial for rail as well as the wheel and provide a benefit in reducing whole system maintenance costs.

Keywords: rail, maintenance, wear, rolling contact fatigue (RCF)

1 Introduction

Offering solutions to the railway undertakings is the key driving factor for innovative enterprises in the railway business. Therefore, the elongation of service lives, the reduction of maintenance needs and the provision of highest safety is the goal to be pursued. All this is the direct result of a high resistance of the rail material against all kinds of deterioration and damage. In this context, the constant further development of existing rail steels or the development of new rail steels is much more than just courtesy to railways; it is an absolute must in order to cope with the constantly increasing demands of railway operation that all sectors of railroading are facing. The dynamics within the railway business might be an accurate characteristic to describe railroading properly - although this is not visible to the public.

New rail steels needed at the respective time for sustainable operation have been introduced: As rolled rail steels (alloyed, naturally cooled) at the very first beginning, then premium rail steels (heat treated, sometimes also alloyed) finally culminating in the most modern and most resistant rail steel class, the so called Super Premium hypereutectoid and heat treated rail steel R400HT (see Table 1).

Table 1 Vignole Rail grades according to EN13674-1 [1]

Steel grade		Chemical composition [mass %]				Mechanical properties		
		C	Si	Mn	Cr	Rm [MPa]	A5 [%]	Hardness [HB]
"As rolled" rail grades	**R200**	0.40-0.60	0.15-0.58	0.70-1.20	≤0.15	≥680	≥14	200-240
	R220	0.50-0.60	0.20-0.60	1.00-1.25	≤0.15	≥770	≥12	220-260
	R260	0.62-0.80	0.15-0.58	0.70-1.20	≤0.15	≥880	≥10	260-300
	R260 Mn	0.55-0.75	0.15-0.60	1.30-1.70	≤0.15	≥880	≥10	260-300
	R320 Cr	0.60-0.80	0.50-1.10	0.80-1.20	0.80-1.20	≥1,080	≥9	320-360
Heat treated rail grades	**R350HT**	0.72-0.80	0.15-0.58	0.70-1.20	≤0.15	≥1,175	≥9	350-390
	R350LHT	0.72-0.80	0.15-0.58	0.70-1.20	≤0.30	≥1,175	≥9	350-390
	R370CrHT	0.70-0.82	0.40-1.00	0.70.1.10	0.40-0.60	≥1,280	≥9	370-410
	R400HT	0.90-1.05	0.20-0.60	1.00-1.30	≤0.30	≥1,280	≥8	400-440

What is already anchored in the standard for Vignole rails is also evident in the area of grooved rails: Towards the end of the 20th century, voestalpine Rail Technology developed the heat treated grooved rail steel grades R290GHT and R340GHT with improved wear properties. These grades feature a minimum hardness of 290 [HB] and 340 [HB] respectively, they exhibit a long-standing history of successful use. In addition to these well-established and standardized heat treated grooved rail grades a further optimization and development was achieved, which makes maintenance, in form of gauge corner repair welding, as easy as possible with 290GHT-CL or in best case, avoids it at all with the hypereutectic grooved rail grade 400GHT® (see Table 2).

Table 2 Rail grades according to EN14811 [2] and 290GHT-CL and 400GHT

Steel grade		Chemical composition [mass %]				Mechanical properties		
		C	Si	Mn	Cr	Rm [MPa]	A5 [%]	Hardness [HB]
"As rolled" rail grades	**R200**	0.40-0.60	0.15-0.58	0.70-1.20	≤0.15	≥680	≥14	200-240
	R220G1	0.50-0.65	0.15-0.58	1.00-1.25	≤0.15	≥780	≥12	220-260
	R260	0.62-0.80	0.15-0.58	0.70-1.20	≤0.15	≥880	≥10	260-300
Heat treated rail grades	**R290GHT** (HSH® GM)	0.50-0.65	0.15-0.58	1.00-1.25	≤0.15	≥960	≥10	290-330
	R340GHT (HSH® GM)	0.62-0.80	0.15-0.58	0.70-1.20	≤0.15	≥1,175	≥9	340-390

Steel grade		Chemical composition [mass %]				Mechanical properties		
		C	Si	Mn	Cr	Rm [MPa]	A5 [%]	Hardness [HB]
Heat treated rail grades	290GHT-CL (Low Carbon for easy Gauge Corner Repair Welding)	0.40-0.50	0.15-0.58	0.70-1.10	max 0.15	≥960	≥11	≥280
	400GHT (Maximised service life)	0.90-1.05	0.20-0.60	1.00-1.30	Max 0.30	≥1,280	≥8	400±20

2 Hypereutectoid rail steels in track

Hypereutectoid (Super Premium) rail steels from voestalpine nowadays have been in use in tracks with high operational demands for almost 20 years. First test installations were established in tracks of heavy haul railways with axle loads of up to 42 tons, which were soon followed by standard installations no longer for testing purposes, as the tests immediately showed the great potential of this type of rail steels. The very positive behaviour of Super Premium Rails does not only involve rail wear, but also the formation of corrugation as well as rolling contact fatigue. Since their first successful installations in tracks, VOESTALPINE RAIL TECHNOLOGY has been producing rails of the Super Premium Class under the brand 400 UHC® HSH® and 400GHT®, where HSH® stands for the world famous heat treatment process of voestalpine Rail Technology in Austria.

2.1 Track performance of 400UHC® HSH® under mixed traffic conditions

Besides various track experiences in other mixed traffic lines, the rail steel 400 UHC® HSH® has been tested in a R = 300 m Radius curve in Hungary since Oct. 2015. The performance of the rails has been compared to the rail steel R260 that was implemented in this curve before and has been implemented in the opposite track of this double track section.
The service life of the rail steel R260 has been only 2.3 years (~ 56 Million Brutto Gross Tons (MBGT)) due to severe side wear on the high rail – see Figure 1 [3].
For the 400 UHC® HSH® rails, wear was measured continuously, leading to less than 2 mm of side wear after the same experienced traffic load – see Figure 2.

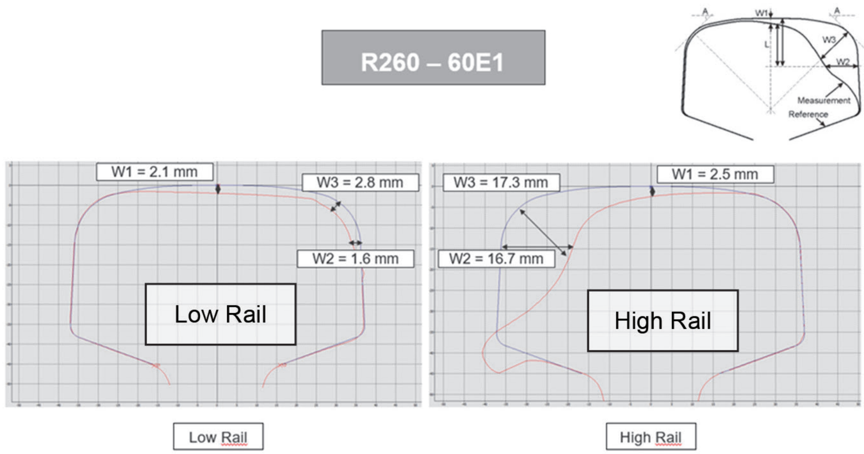

Figure 1 Wear of R260 rail steel in R = 300 m curve after 2.3 years (56 MBGT), 40mm superelevation

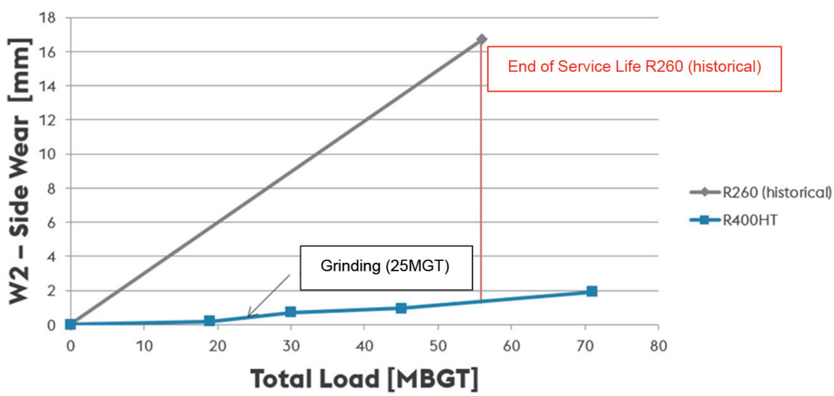

Figure 2 Comparison of rail side wear of 400 UHC® HSH® (R400HT) and R260 rails

Furthermore, a significant reduction of corrugation development was observed when comparing 400 UHC® HSH® rails with R260 rails of the opposite track – see Figure 3, where measurements of the rail surface at different positions are displayed. R260 already shows significant corrugation of 0.4 mm while corrugation is just beginning after 63 MBGT. For R260 rails, the corrugation has already lead to a degradation of ballast, indicating the necessity of damping.

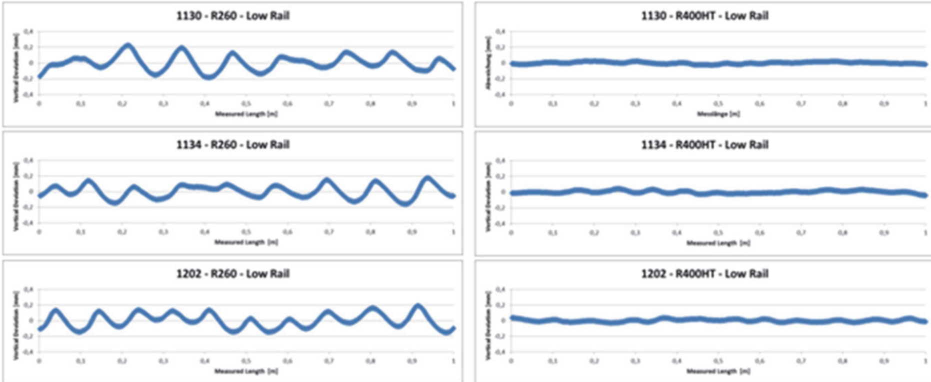

Figure 3 Depth of corrugation of R260 and 400 UHC® HSH® in comparison – reduction by factor 8

The depth of Head Checks was measured with eddy current handheld devices in several positions, demonstrating a reduction of the Head Check depth from max. 2.7 mm for R260 to max. 0.6 mm for 400UHC® HSH®. Continuous measurement with Eddy current by measuring train showed a reduction HC depth of approximately 300 % in this tight curve.
Based on the measurements a prognosis for the service life and ideal maintenance cycle of 400 UHC® HSH® rails can be deducted by using usual maintenance intervention limits – see Figure 4. As can be seen, no rail grinding was conducted for R260 as service life was limited and so short that grinding for corrugation or Head Checks would have been uneconomic.

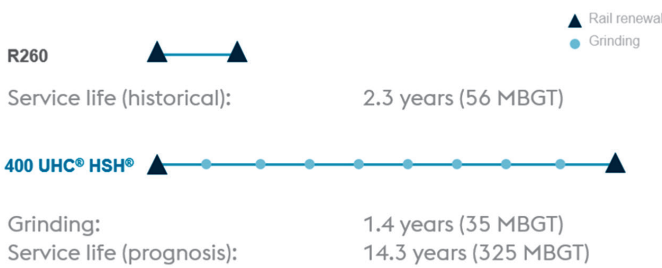

Figure 4 Modelling of service life cycles of R260 and 400 UHC® HSH®

Based on the findings several installations in mixed traffic lines in Europe have been realized. The expected good results have been obtained in all installations. E.g. in Austria die 400 UHC® HSH® is used in curves below 600 m radius.

2.2 Track performance of 400GHT® grooved rail in urban transport

Many tramways prolong rail service life time by build-up or repair welding (strategy “build-up welding” or “easy-to-maintain”) of the worn rail profile and re-profiling by grinding. With the rail grade R290GHT, which was developed especially for that strategy, two requirements can be fulfilled at the same time: highest resistance against wear (horizontal and vertical) and corrugation and good build-up weldability [4].
Another strategy of application is called “put-in and forget”, where the rail is not maintained during its life cycle by repair welding and remains as it was installed in track until the wear limit is reached. Therefore highest hardness and wear resistance are required. In that case the worldwide hardest grooved rail grade 400GHT® is the best solution. Based on track experiences from Vienna, Berlin and Warsaw the material behaviour of 400GHT® grooved rail steel is demonstrated in comparison to other state of the art rail steels.

Prognoses based on yearlong wear measurements suggest that the service lives of R200 and R290GHT rail steel will be exceeded in all cases, without the need for Gauge Corner Repair welding. The slower development of corrugation is a further performance attribute of 400GHT® leading ultimately to a durable silent track with lowest demands on rail maintenance. Figure 5 shows a schematic illustration of possible maintenance strategies in urban tramway systems (3). The differences are based on track tests in various tramways, but the real number of possible build-up welding cycles depends on many boundary conditions and may differ in detail [5].

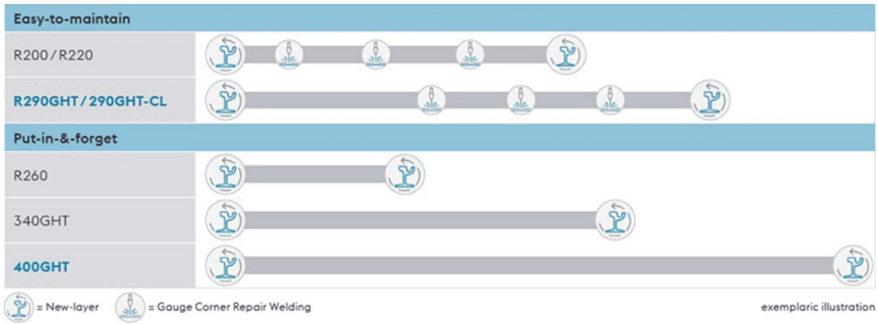

Figure 5 Exemplary illustration of expected track service lives and maintenance cycles in curves

3 Interactions in the rail-wheel system

Contrary to the rail steel developments, already in the past, the question of the influence of changes in rail hardness to wheel wear was often subject to investigations and still is today. A review of research and published papers has been undertaken to determine if this view is supported by experimental or experiential evidence.

First tests regarding rail hardness and wheel wear were carried out at the Transportation Technology Center Inc. (TTCI) of the American Association of Railroads (AAR). There, wheel wear was monitored over a longer period of time on test installations in the High Tonnage Loop (HTL) of the Facility for Accelerated Service Testing (FAST) [6].

Essential background for this research, which was conducted in a practical as well as in a theoretical way, is a basic principle of Rabinowicz [7], dealing with the contact between two bodies with different harnesses: While wear of the harder contact partner depends on the hardness of both contact partners, wear of the softer one depends on its own hardness only. This is demonstrated in Figure 6, where as long as the rail is the softer partner in the contact system, by increasing the rail hardness, the wheel wear is increasing as well, i.e. the wear of the constant parameter is growing. The wear of both contact partners is defined by the softer parameter – in this case the rail. Hence, the changing parameter – the rail – defines the contact conditions during the force transmission and therefore the wear. Consequently, the rail wear is decreasing with increasing hardness. Since the beginning of modern railroading up to now, the wheels have always been softer than the rails (see EN13262 [8]: wheel hardness between 225 [HB] and 255 [HB] and EN13674-1: rail hardness between 260 [HB] for the standard rail steel and 400 [HB]).

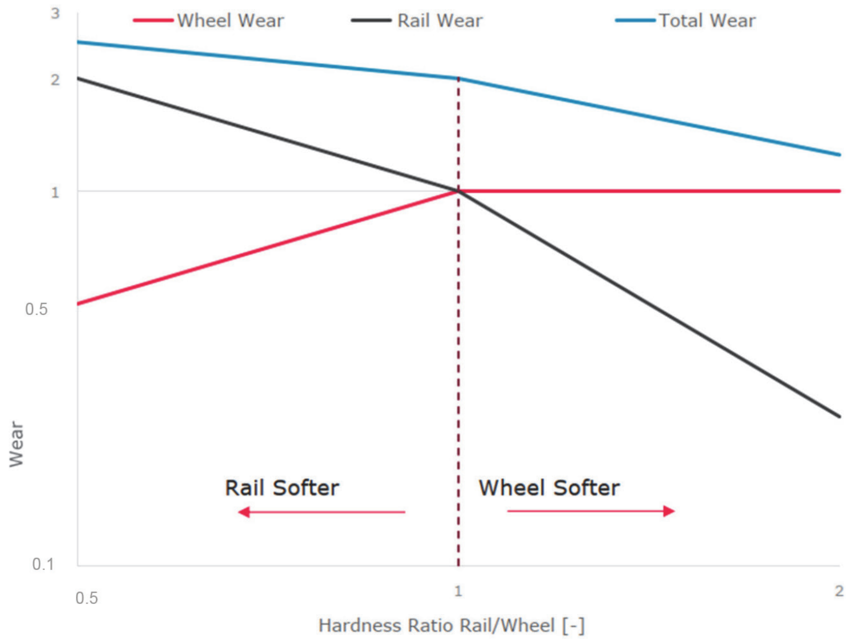

Figure 6 Rail – It´s behaviour and relationship to total system wear [7]

As soon as the rail is harder than the wheel, increasing the rail hardness does not result in an increase of the wheel wear. As already shown, the wear of the softer parameters is defined by its own hardness only and does not depend on the hardness of the harder contact partner – the rail. Since the hardness of the wheel (softer contact partner) is kept constant, the contact characteristics are not changing. The wheel has always the same hardness but is softer than the rail. Consequently, the wear of the wheel remains constant, even when the rail hardness is increased.

Various laboratory investigations on this topic were also carried out on wheel / rail test rigs and twin disc setups. A work by Knabl [9], which aimed to evaluate all the literature and studies on the topic, showed that including the applied loadings in the tests, the following conclusions can be derived:

Under high contact pressures with twin-disc tests or high forces on the wheel-rail test rigs, wheel wear tend to stay constant while increasing the hardness ratio between rail/wheel. At low loads however, there is a decrease in wheel wear when the hardness ratio increases (compare Figure 7 and 8). From these findings it can be deduced that the connection between real wheel wear and rail quality are described by two effects:

A) On the one hand, the material behaviour in contact influences the wear behaviour.

- This shows a dependence on the contact pressure and for contact pressures that are equal to or lower than those of European mixed traffic (≤ 22.5 t axle load), wheel wear decreases with increasing rail hardness
- Wear models, such as those by Jendel or Krause & Poll [10,11], describe this behaviour through the effect of different wear regimes.

B) On the other hand, wear behaves due to the geometric configuration of the system.

- This is dependent on the contact geometry at the contact point.
- The precondition is that the target geometry is maintained with regard to track gauge, rail inclination, track clearance, etc.

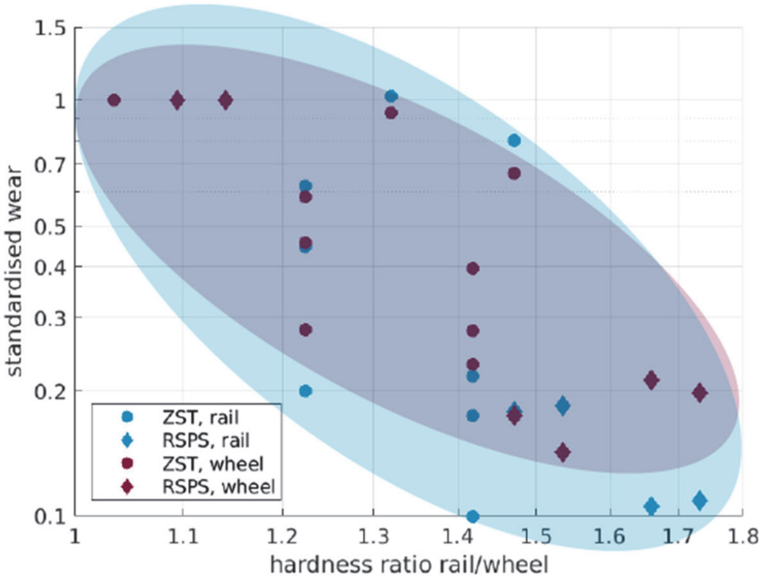

Figure 7 Standardized wear as a function of the hardness ration for workload corresponding to an axle load ‹ = 22,5to [9] ZST: Twin-Disc Testing, RSPS: Rail-Wheel-Test-Rig

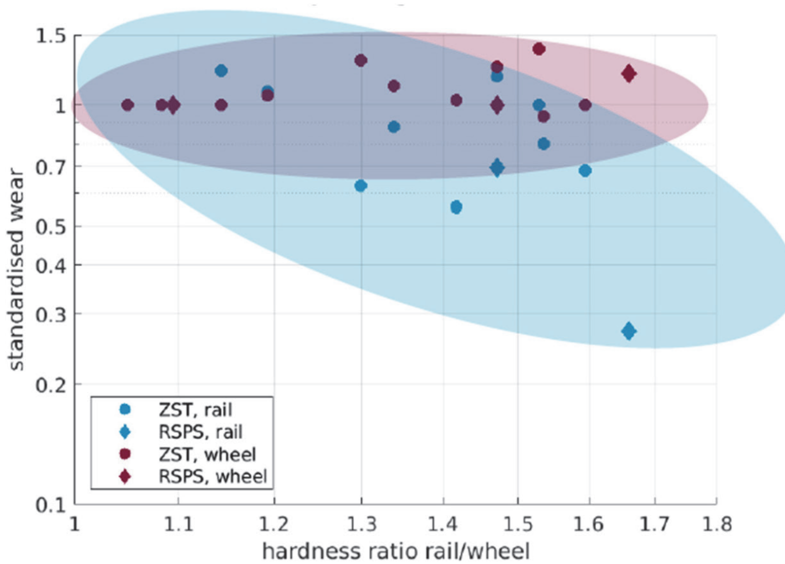

Figure 8 Standardized wear asa function of the hardness ratio for workload corresponding to an axle load ››22,5 t [9] ZST: Twin-Disc Testing, RSPS: Rail-Wheel-Test-Rig

4 Summary

The high-strength 400 UHC® HSH® rail grade has been very successfully used in tracks with high loads for years. The use of this grade in tighter curves of mixed traffic lines (22.5 t) has been identified as being highly beneficial, leading to a technical and economic optimization of the whole superstructure. Due to the high resistance against wear and RCF the use of 400 UHC® HSH® rail steel reveals huge economic potential in curves up to 1500m.
In urban tracks the service life and the low maintenance concept of 400GHT® eliminates the risk of potential failures from Gauge Corner Repair welding in track. As RCF (Head Checks) plays no role in tramway networks the recommended areas of HSH® grooved rails are tight curves below 150m and station areas, when these are prone to corrugation.
Also when considering the entire wheel/rail system, a review of a wide range of research and published papers and test results has shown that there is no basis to conclude that an increase in material hardness on one side of the interface will result in an increase in wear rate on the opposite side of the interface. On the contrary, depending on the contact pressure and thus the acting wear regime, the following relationships arise:

- For contact pressures that are equal to or lower than those of European mixed traffic (≤ 22.5 t axle load), wheel wear decreases with increasing rail hardness
- At higher contact pressures (and thus axle loads of heavy haul applications), wheel wear remains constant as rail hardness increases.

No increase in wheel wear, thus disproving statements for higher wheel wear could be found. Also the German Railway Federal Office came to these conclusions in a study [12], in which it was able to disprove that higher-strength materials in wheels or rails generally come at the expense of the wear or rolling contact fatigue resistance of the respective contact partner.

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