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GUIDELINES FOR THE RAIL GRADE SELECTION

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Over the years the rail steel manufacturing process and quality of material produced have improved significantly through alloy design and/or head treatment procedure. The objective of this paper is to give the recommendations for the application of the available rail steel grades in accordance with the accessible investigations. The main source are the results of the Innotrack project in correlation with Euronorm prEN 13674-1. The conclusion for the Serbian Railway is made.

Key words: rail steel grades, criteria for selection, recommendations, wear, rolling contact fatigue

INTRODUCTION

The rail, as the most important component of the track superstructure, means the running surface, carrier and guiding element for the rolling vehicles [1].

To be able to withstand their functions, the rails and rail steel must meet the following requirements [2]:

- High wear resistance;
- High resistance to deformation caused by compression;
- High fatigue strength;
- High yield strength, toughness/tensile strength and hardness;
- High resistance to brittle fracture;
- Good weldability;
- High degree of steel purity and good texture;
- Profile evenness and dimensions accuracy by inspection and acceptance;
- Low residual stresses after manufacturing and straightening.

Some of these requirements are contradicting each other, which makes difficult the choice of rail profile and rail steel grade.

Nowadays, rails are frequently manufactured by continuous casting followed by immediate multi-stage process in the rolling mills. They are usually made of carbon-manganese steel composition with pearlitic or beanitic microstructure.

It can be said that steel is an extremely versatile material. If the suitable alloying additions are made, or the correct heat treatment chosen, then other types of steel structures can be produced. Also, the combinations of alloying and heat treatment are possible and a range of grades can therefore be produced.

In addition to alloyed rails, tensile strength and toughness can be increased by heat treatment. The heat treatment can be applied to either the whole cross-section or to only the rail head providing a very large wear resistance. Head hardening rails (HH) are mainly used in heavy loaded tracks, sharp curves and in turnout elements [3].

In recent years, on railway lines, trains have been running with heavier axle loads, at higher speed and the vehicles have different characteristics. So, there has been a need to develop stronger and more wear and defect resistant rails, in order to minimize rail maintenance costs and maximize asset life.

The railway's choice of rail grade is made in terms of traffic and track conditions, and excellent service life can be achieved with new rail steel grades, particularly if modern rail head lubrication and grinding practice are used. According to those trends, new grades of rail steels have become available and the recommendations and standards for their selection are developed.

The introduction of innovations in the inert conservative system, as the railway is, especially when they don't give the benefits immediately, is a very difficult task. The advantages of the new rail qualities become obvious after a certain time period. During the track lifecycle time these innovations show the increase of track availability and safety.

LITERATURE SURVEY

The use of harder rail steels in terms of the rail degradation behavior have been the objective in many investigations and only a brief review of the publications is given hire.

Already long ago in 1978 Nippon Steel [4] developed a new head hardened rail (NHH) and latter in 1986 a deep head hardened rail (DHH) with high weldability, and uniform quality throughout the entire rail length.

In the tests conducted at FAST facility (Transportation Technology Center, Inc. in Pueblo, Colorado, USA) Nippon Steel proved these rails to have excellent wear

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and fatigue resistance. The results of these comprehensive tests were reported by Steele, 1982 [5]. As a result, they have been widely used in the many countries, contributing to a saving in track maintenance costs. For example, CF&I Oregon Steel Mills from 1993. introduced this technology and made the hardest rail then available DHH390 with a surface hardness of 390 Brinell (McLean, 1997 [6]).

Mutton and Marich, 1989. [7] have shown decreasing wear rate by increasing rail hardness compared with the standard carbon grades under moderate (2,5 times) and extensively (nearly 2 times) lubricated rails.

Schmedders H. et al., 1990. [8] informed that Thyssen Stahl AG for extra heavy loading employed highly wear resistant rails with minimum tensile strength of 1 100 or 1 200 MPa. The results from test track sections after a loading of more than 100 million tonnes indicate an excellent operational behavior.

In order to meet rising demands, in the high-speed segment research at Thyssen Stahl AG has been further focused on the production of bainite rail steels with high toughness properties and on the investigation of fracture mechanics (Kern and Zimmermann, 1998 [9]).

Muster et al., 1996. [10] reported the similar results by the hardened steel grade which showed a 30 % reduction in the depth of head check cracks due to RCF.

There are different opinions regarding the influence of rail grades on rail defects like squats. Deroche et al. 1993 [11] observed that the squats problem could be solved by changing the rail grade from R200 to R260, due to kinematic hardening by the rolling wheels.

Kristan and Sawley, 2002 [12] informed from TTCI tests that work-hardening does not increase the shear yield strength of bainitic as much as pearlitic microstructure. Despite the higher hardness (420HB compared to 370HB pearlitic), the bainitic steel wore appr. 50 % faster in minimally lubricated 350 m curve carrying heavy-axle load vehicles.

Heyder and Girsch, 2005 [13] reported about the tests performed on high-speed tracks of DB where the head checking was the main degradation mechanism. On rails grade UIC800 the depth of head check cracks was twice as much as on grade R260 and six times greater than on grade R350HT.

Yates J. K. [14] from British Steel informed about low carbon carbide-free bainitic steel, which shows a dramatic change in toughness at low temperature, when rails are most vulnerable to fractures.

Tata Steel [15] from India has produced MHH, low alloyed with chromium and silicon, pearlitic heat treated rail in of-line process, incorporating rapid controlled reheating followed by accelerated air cooling. It gives the greater resistance to fracture from foot defects and RCF.

Voestalpine GmbH has reached the 400HSH (head special hardened) rail grade, which is fine-pearlitic heat-treated grade with highest resistance against wear, RCF and formation of corrugation for years. VAE has manufactured the austenic manganese steel with excellent strength and wear resistance mainly used for crossings. The patented flash-butt welding process of VAE permits its connection with common steel by means of intermediate piece, so it can be welded into the CWR tracks [16].

Vitez et al., 2005 [17] elaborated overlook criteria for the use of rail steel grades according to UIC leaflet 721R from 2003 which was based on European standard prEN 13674-1:1999.

RAIL GRADES

The European standard EN 13674-1:2008-01 is the specification accepted by Infrastructure Managers for the supply of rail sections and rail steels. Pearlitic rail steels comprise: standard grade rail steels (naturally cooled), alloyed rail steels (naturally cooled) and heat treated rail steels. In the recent past pr EN 13674-1:2009 [18] includes two additional heat treated rail steels: the R370CrHT and the R400HT. The rail steel reference value used is no longer the tensile strength, but the minimum hardness of the running surface. The current rail steel grades with their hardness range, description and branding lines are given in the Table 1 [13].

Table 1 **Rail grades [13]**

Steel grade		Hardness range (HBW)	Description	Branding lines
Steel name	Steel number			
R200	1.0521	200 to 240	Non-alloy (C-Mn) Non heat treated	No branding lines
R220	1.0524	220 to 260	Non-alloy (C-Mn) Non heat treated	
R260	1.0623	260 to 300	Non-alloy (C-Mn) Non heat treated	
R260Mn	1.0624	260 to 300	Non-alloy (C-Mn) Non heat treated	
R320Cr	1.0915	320 to 360	Alloy (1 % Cr) Non heat treated	
R350HT	1.0631	350 to 390 [b]	Non-alloy (C-Mn) Heat treated	
R350LHT	1.0632	350 to 390 [b]	Non-alloy (C-Mn) Heat treated	
R370CrHT	t.b.a.	370 to 410	Alloy (C-Mn) Heat treated	
R400HT	t.b.a.	400 to 440	Non-alloy (C-Mn) Heat treated	

Present national guidelines for rail grade selection on mixed traffic lines with up to 225 kN axle load and at least 20 MGT annual load is presented in the Table 2 [13].

By the Serbian Railways at least R260 rail grade is recommended in sharp curves, in tunnels, at steep slopes, at sections with breaking and starting the trains, in turnout elements and similar locations, on tracks with at least 10 MGT annual load and speed over 160 km/h. The degree of certain parameter is not defined in details. The alloyed and heat treated rail steels are used only for extremely strengthened turnout elements, like crossing nose is.

Table 2 **Overview over national guidelines [13]**

R [m]	≤ 300	≤ 400	≤ 500	≤ 600	≤ 700	≤ 800	≤ 1 500	≤ 3 000	> 3 000
UIC	R350HT		R350HT/R260			R260			
DB	R350HT (≥ 30 000 t/d)					R260			
DB new	R350HT (≥ 50 000 t/d)							R260	
CH	R350LHT		R350LHT/R320Cr			R320Cr R350LHT	R260		
CH (proposal)	R370CrHT		R350LHT		Bainite up to 1 200 m			R260	
AT	R350HT	R260							
SWE	R350HT	R260							
SWE (HH)	R350HT								R260
NOR	R350HT					R260			
UK	R260								
IT	R260								
BE LUX	R350HT					R260			
NL	R350HT R370CrHT	R370CrHT					R370CrHT		R260
DK	R350HT					R260			
PL	R350HT					R260			
H	R350HT					R260			
RO	R350HT					R260			

THE INNOTRACK PROJECT

The Europe INNOTRACK railway track project [13], with more than 35 participants, was completed at the end of 2009. The objective of its part D4.1.5 was to define the optimum areas of application of the available rail grades. Two rail grade selection methodologies were proposed: "traditional" radii based approach and "innovative" deterioration based approach.

The relationship between curvature and rail degradation is apparent. Wear is dominant in curves with radii of less than 1 000 m, while RCF occurs over a radius range up to about 5 000 m.

The radii based rail grade selection follows experience collected in more than 200 track tests coupled with comparative laboratory simulation, as well as the feedback by European railways. The lower rate of degradation of heat treated pearlitic rail grades led to the general recommendation for their use in curves with radii below 5 000 m for heavily loaded tracks.

In summary, for heavily and moderately loaded tracks the suggested steel grades included in the new European standard EN 13674-1:2011 are [13]:

- For tight curves (R < 300 m) the R400HT (R370CrHT) grade;
- For medium curves (300 m < R < 700 m) the R370CrHT (also R400HT for heavily loaded tracks) grade, followed by R350HT grade with increasing raddii (R > 700 m);
- In case of heavily loaded tracks the R350HT grade is also proposed in wider curves with radii 3 000 m < R < 5 000 m (R260 may be an appropriate solution if RCF is negligible).

For lightly loaded tracks the proposal is:

- Use of the R350HT grade in curves with radii up to 700 m to 1 000 m, depending on the local boundary condition.

The deterioration based rail grade selection gives the steel grade which refer to the dominating rail degradation mechanism under the boundary operational conditions of the specific site. Depending on the actual severity of wear and/or RCF, a rail grade selection recommendation is given (Figure 1 [13]).

Actual installed rail steel **R260**		DETERIORATION BASED RAIL GRADE SELECTION			
WEAR	**SEVERE** $> \frac{15\ \text{mm}}{100\ \text{MT}}$	R400HT	R400HT	R400HT	R400HT
	HEAVY $\leq \frac{15\ \text{mm}}{100\ \text{MT}}$	R370CrHT	R370CrHT	R400HT	R400HT
	MODERATE $\leq \frac{5\ \text{mm}}{100\ \text{MT}}$	R350HT	R350HT	R370CrHT	R400HT
	LIGHT $\leq \frac{2\ \text{mm}}{100\ \text{MT}}$	R260	R350HT	R370CrHT	R370CrHT
		LIGHT $\leq \frac{0{,}5\ \text{mm}}{100\ \text{MT}}$	**MODERATE** $\leq \frac{1\ \text{mm}}{100\ \text{MT}}$	**HEAVY** $\leq \frac{3\ \text{mm}}{100\ \text{MT}}$	**SEVERE** $> \frac{3\ \text{mm}}{100\ \text{MT}}$
		ROLLING CONTACT FATIGUE			

Figure 1 Deterioration based rail grade selection [13]

In the next Tables 3, 4 [13] the classification of deterioration severity, based on the findings of the rail degradation per 100 MT load and the rail service life affected by wear (45 °) and RCF, is given.

The benefits of reduced wear and crack growth rates in terms of elongated rail service life in the track can be noticed. The informations concerning the condition based rail grade selection are presented in Figure 2 [13].

Following the arrows, for example, in the case of the "heavy" wear location site, the replacement of grade R260 with R350HT rails would offer the advantage in terms of LCC. This improvement would be continuously extended through the use of R370CrHT or even R400HT rails for RCF being the dominant degradation mechanism. In that course every change of rail steel can be assessed in the analogous way in order to examine the benefits of using a heat treated rail grades.

The use of heat treated rails defined in the grade recommendations causes the following consequence concerning the maintenance efforts:

– The necessity of grinding is reduced and a replacement of rails within expected track durability is avoided;
– Reduction of track non-availability;
– Increased safety against rail breakage.

All these lead to an improvement in RAMS (Reliability, Availability, Maintainability and Safety) of the entire track.

CONCLUSION

The innovative heat treated rails improve RAMS and reduce the total LCC of the overall track system.

Table 3 **Rail service life under different conditions (wear) [13]**

classification		exam-ple	service life			
verbal	wear rates		MGT	years in track		
-	*mm/ 100 MGT*	*mm/ 100 MGT*		**10** *MGT/year*	**20** *MGT/year*	**30** *MGT/year*
			MGT	*years*	*years*	*years*
light	0 - 2	1	800	80	40	27
medium	2 - 5	3,5	225	23	11	8
heavy	5 - 15	10	75	8	4	3
severe	>15	15	50	5	3	2

Table 4 **Rail service life under different conditions (RCF) [13]**

classification		exam-ple	service life			
verbal	crack growth rates		MGT	years in track		
-	mm/ 100 MGT	mm/ 100 MGT		10 *MGT/ year*	20 *MGT/ year*	30 *MGT/ year*
			MGT	*years*	*years*	*years*
light	0 - 0,5	0,25	>2 500	>100	>100	>100
medium	0,5 - 1	0,75	1 075	>100	53	36
heavy	1 - 3	2	400	40	20	13
severe	>3	3	275	27	13	9

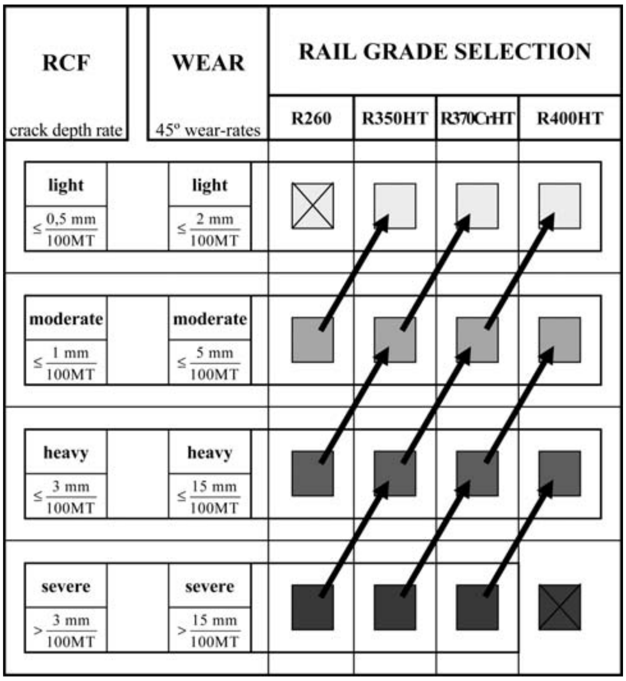

Figure 2 Rail degradation behavior of different rail steel grades [13]

The investigations and guidelines for the use of different rail steel grades are delivered in European INNOTRACK Project, report D 4.1.5. The results of that project show that under the operating conditions examined, only the use of higher grade rail steels can significantly reduce or even eliminate the development of RCF and increase wear resistance.

The cost advantages of heat treated rail steel grades are obvious in all cases that expensive grinding and/or milling operations can be substantially reduced, while unnecessary new capital investment caused by premature rail exchange can be avoided. It is confirmed that cost saving of 35 % and more are achievable in appropriate relation between heat treated premium rails and grinding cycles during the lifespan. This consequently saves up to 50 % the overall life cycle costs of the rails for highly loaded tracks. It is also shown that the amortization of heat treated rails takes place after about two years after installation.

At the end, all these results have to be implemented by Serbian Railways, if it wants to participate equally in other European infrastructure organizations.

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