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The microstructure and properties of the new bainitic rail steels

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Materials

ABSTRACT

Purpose: The aim of this research was presentation of the Continuous Cooling Transformations (CCT) diagrams and mechanical properties of two new bainite rail steels with working names RB370 and RB390.
Design/methodology/approach: The CCT duiagrams was prepared by dilatometric method. The mechanical properities ($R_{p0,2}$, R_m, A, Z, KV, KU2, K_{Ic} and $K_{Ic\,-20}$) was searched according to European Standards.
Findings: It was found, that on the whole cross – section of rails (S49 or UIC60) made of this new steels only bainite (mainly low bainite) will be formed.
Practical implications: Very high mechanical properties of new grades encouraged to implement the first one (nickel – free with hardness of 370 HBW) on commercial scale. Rails (S49) made of it are successfully operating as part of main exit track from ArcelorMittal Steel Plant of Poland in Dąbrowa Górnicza since 2004 year.
Originality/value: Orginal value of the paper is to give an information, that it is possibility to procedure bainite rails S49 or UIC60 types of a very high mechanical properties, directly in rolling mill.
Keywords: Metallic alloys; Rail steels; Mechanical properties; CCT diagrams

1. Introduction

On 23.07.1996 European Parliament and the Council issued a Decision No 1692/96 to upgrade the trans-European conventional rail network to be equipped for speeds up to 200 km/h with axle load not less than 230 kN, and in case of specially built tracks for speeds equal to or higher than 250 km/h. Since that decision there is more interest observed in new materials for rail tracks production including new steels for rail tracks [1-3]. It seems that the highest potential to substitute the traditional rail tracks with perlitic structure have the bainitic steels [4-9], particularly low-carbon ones. Rail tracks made of these steels are easy to weld [10] and can obtain very high strength (R_e, R_m), strain (A, Z) parameters, and are resistant to cracking in dynamic and (KV) static (K_{Ic}) conditions [11].

It is also possible to design their chemical composition making the surface part of the head, on which the wheels roll, subject to self-service [12]. Self-service of head's wheel tread of the rail track consists in that the pits created as a result of operation, micro-cracks and other faults known after their development as squat, head-checking, white layer, corrugated wear etc., are being successively removed by abrasion already during wagon wheels rolling on the tracks. Therefore such rails do not need any special, periodical grinding in order to remove these defects because the surface remains almost unchenged.

This study presents two grades of new bainitic steels, developed and implemented by Rolls – Rolls, Inc. First grade with trade name RB370 is a rail (R) steel of bainitic (B) structure with minimal head hardness of 370HBW. It is a low carbon steel, Mn-Cr-Mo-V. This grade has already been implemented at ArcelorMittal Poland in 2003, and the rails S49 made of it are successfully operating since June 2004 both on straight segments and curved rail track.

The second grade of rail steel with bainitic structure has trade name RB390. It is also a low carbon steel Mn-Cr-Mo-V but with little addition of nickel. Hence, this steel is somewhat more expensive to produce then the first grade (due to nickel addition [13]) causes that it is designed for turnouts and railway frogs in particular, however it can be successfully used for rail production, especially for heavy duty ones. Additions of little amounts of nickel to RB390 steel enable to receive even better properties than in nickel free RB370 steel. Nowadays it is under test to use RB390 grade for cast monoblocks of railway frogs.

2. Kinetics of phase transformations of super-cooled austenite in new bainitic steels for rail tracks

Fig. 1 presents CCT (Continuous Cooling Transformations) diagram of new bainitic steel for rail tracks with trade name RB370. It is low carbon nickel-free steel Mn-Cr-Mo-V. Shaded area on CCT diagram contains experimentally determined [14, 15], range of air cooling curves, realized on a cross section of UIC60 rail. Observing the position of the range, in relation to bainitic transformation, one may be sure that within entire cross section of such rail, air cooled after rolling, bainite (lower bainite) will be formed or developed.

Similar CCT diagram (Fig. 2) has been received for the second steel with trade name RB390, which also is a low carbon steel Mn-Cr-Mo-V but with little addition of Ni. There is also a shaded area containing, experimentally determined [14, 15], air cooling curves, possible to realize on the cross section of UIC60 rail on this figure.

Insignificantly higher stability of super-cooled austenite within bainitic range finding expression in longer for about 200 sec. time to start this transition and lower positioned line of the start of bainitic transition B_s. This indicates that there will be higher content of lower bainite in rail tracks made of this steel. Also their hardness will be higher. It is a result of the presence of little amount of nickel in chemical composition of RB390 steel compared to RB370 steel.

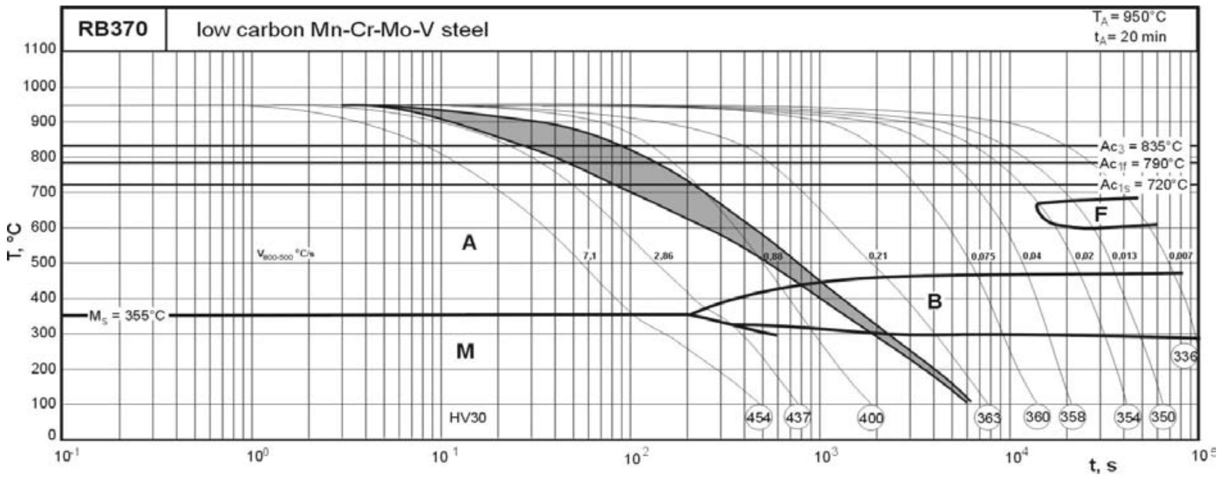

Fig. 1. The CCT diagram of the low carbon Mn-Cr-Mo-V bainitic rail steel. Shaded area contains the range of air cooling curves, realized on a cross section of UIC60 rail

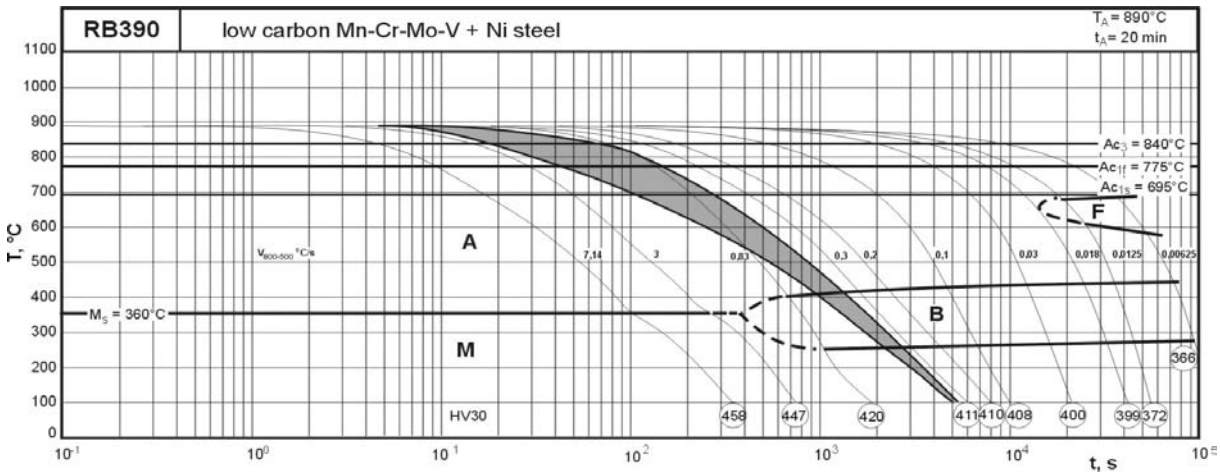

Fig. 2. The CCT diagram of the low carbon Mn-Cr-Mo-V+Ni bainitic rail steel. Shaded area contains the range of air cooling curves, realized on a cross section of UIC60 rail

3. The structure of new bainitic steels for rail tracks

Position of the ranges of cooling rates (determined through experiments) against the background of CCT diagrams (Fig. 1 and 2) indicates that the structure on cross section of heavy rails of UIC60 type should be homogeneous and should contain bainite. Obviously it was confirmed by metallographic inspection conducted on a rail's cross section of S49 type rolled in ArcelorMittal Poland (Fig. 3).

As one may notice, the structure consists of only bainite, mainly lower, and hardness is within a very narrow range of 371 - 378 HBW.

Fig. 4 presents photographs of microstructure of the samples from new bainitic steel RB390, cooled down at the rate corresponding to the center of UIC60 rail head (compare to Fig. 2). In this case there is also a bainite in the structure, however the content of lower bainite seems to be higher than in RB370 steel. Hardness of so cooled samples are within the range of 390 - 398 HBW.

a)

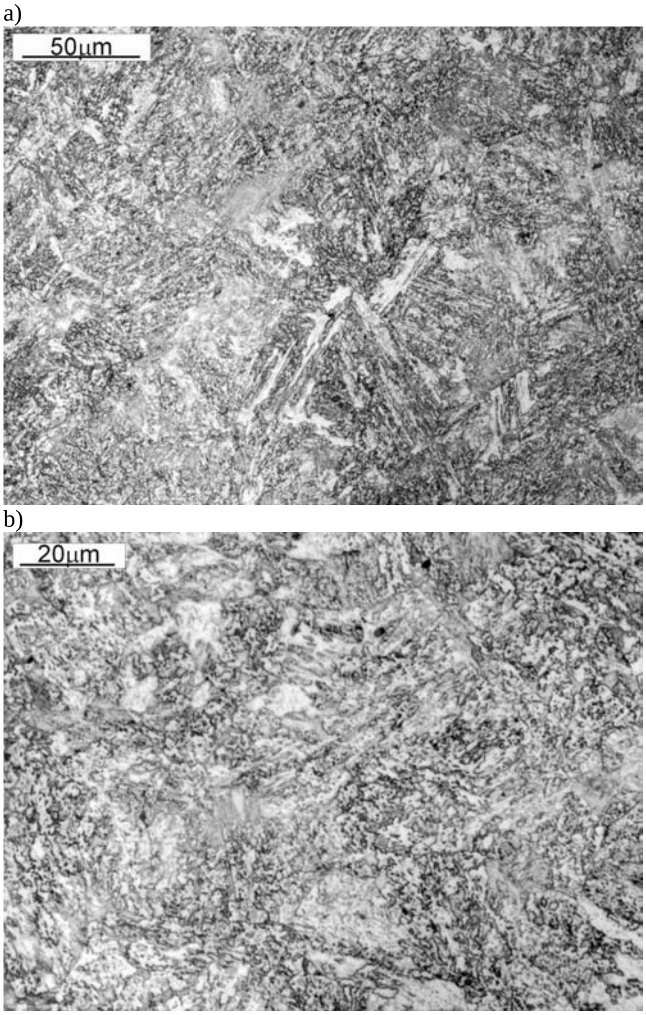

Fig. 3. Structure of S49 rail track made of new bainitic steel RB370. Etched using 3%HNO_3

a)

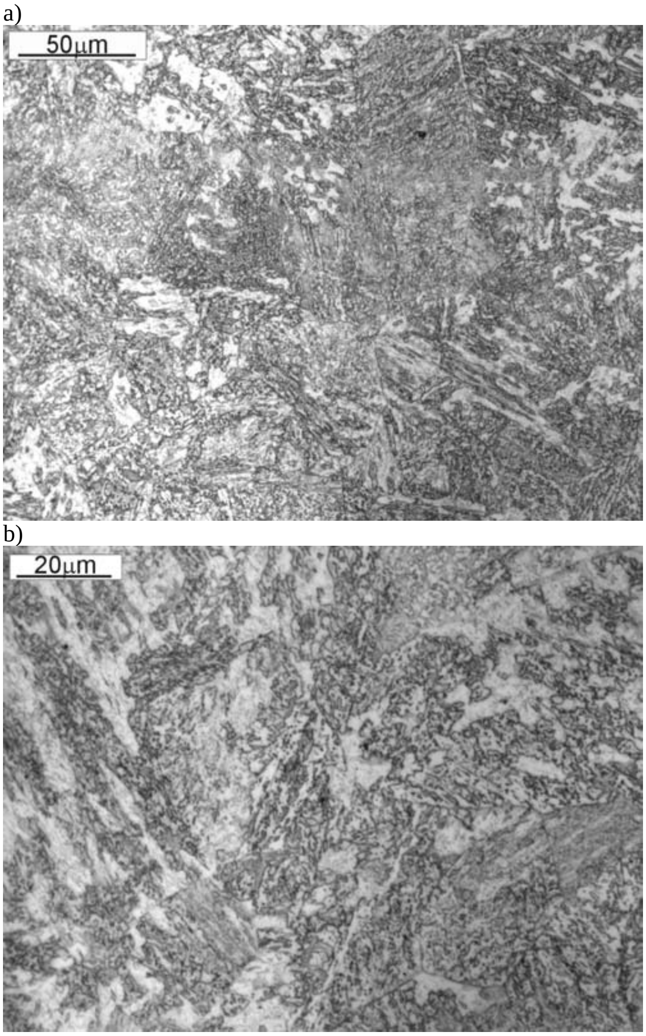

Fig. 4. Structure of the samples from new bainitic steel RB390 cooled down at the rate corresponding to the center of UIC60 rail head. Etched using 3%HNO_3

4. Mechanical properties of new bainitic steels for rail tracks

Table 1 shows mechanical properties of new bainitic steels RB370 and RB390 and also, for comparison, some results of mechanical tests of traditional rail tracks R260 and R350HT from previous author's research.

It must be reported that the results of tests in table 1 were determined using samples collected from S49 rail's head excluding the case of new RB390 steel, which properties were determined using samples collected from rods with cross dimensions of 20x35mm forged from a ø140mm and ca. 50 kg ingot produced in laboratory conditions. However the samples from that steel were cooled down at the rate corresponding to the center of UIC60 rail head (compare to Fig. 2).

Table 1.
Mechanical properties of new bainitic rail steels (RB370 and RB390 as well as traditional steels (R260 and R350HT)

Steel grade	HBW	$R_{p0,2}$ MPa	R_m MPa	A %	Z %	KV J	KU2 J	K_{Ic} $MPa \cdot m^{1/2}$	$K_{Ic\,-20}$ $MPa \cdot m^{1/2}$
RB370	371-378	843-858	1197-1211	12.2-14.1	38.6-43.0	28.3-33.9	31.2-36.2	51.9-54.5	40.3-42.3
RB390	390-398	825-832	1347-1353	13.0-14.9	43.0-49.0	33.2-38.4	73.1-79.5	90.5-92.1	61.2-63.0
R260	262-270	-	880-893	10.0-10.4	-	-	-	min. 29[1)]	-
R350HT	350-390	700-712	1080-1098	10.3-11.1	-	-	23.2-25.6	min. 32[1)]	-

[1)] data acc. to PN-EN 13674-1:2003

5. Summary

Two new bainitic rail steels were investigated. Kinetic of phase transformations of super-cooled austenite of these steels guarantees formation of homogeneous bainitic structure right after rolling, during cooling down in air, within the whole cross section of the rail. Mechanical properties of the tested samples collected from heads of such rails (raw, before heat treatment) are distinctly higher than properties of traditional rails. First of all hardness, which is min. 370 HBW for grade RB370 and min. 390 HBW for grade RB390 respectively, equals to or even exceeds the hardness obtained for heat treated rails (thus considerably more expensive) in grade R350HT. New steels for bainitic rails also demonstrated higher strength R_m along with good strain parameters (A and Z). However it is most important that both cracking resistance in dynamic conditions (KU2) and resistance to crack propagation K_{Ic} are also higher than the same properties and requirements that traditional rails must meet.

In the end, it s necessary to mention that bainitic rails made of RB370 grade are operating as a part of main exit track from ArcelorMittal Poland Steel Plant in Dąbrowa Górnicza and since 2004 are failure-free.

Acknowledgements

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