LABORATORY SIMULATION OF HEAT TREATMENT OF RAILS

Fabík R.[1], *Kurek V.*[2], *Kocich R.* [1], *Macháčková A.* [3]
[1] *VŠB – TU Ostrava, Faculty of Metallurgy and Materials Engineering, Department of Materials Forming, 17. listopadu 15, Ostrava – Poruba, 708 33, Czech Republic, e-mail: richard.fabik@vsb.cz, radim.kocich@vsb.cz*
[2] *Třinecké železárny, a.s. – Technology and Research, Průmyslová 100, Třinec 739 70, Czech Republic. Vaclav.Kurek@trz.cz*
[3] *VŠB – TU Ostrava, FMMI, Department of Thermal Engineering, 17. listopadu 15, Ostrava – Poruba, 708 33, Czech Republic, e-mail: adela.machackova@vsb.cz*

LABORATORNÍ SIMULACE TEPELNÉHO ZPRACOVÁNÍ KOLEJNIC

Fabík R.[1], *Kurek V.*[2], *Kocich R.* [1], *Macháčková A.* [3]
[1] *VŠB – TU Ostrava, Fakulta metalurgie a materiálového inženýrství, Katedra tváření materiálu, 17. listopadu 15, Ostrava – Poruba, 708 33, e-mail: richard.fabik@vsb.cz, radim.kocich@vsb.cz*
[2] *Třinecké železárny, a.s. – Technologie a výzkum, Průmyslová 100, Třinec 739 70. e-mail: Vaclav.Kurek@trz.cz*
[3] *VŠB – TU Ostrava, Fakulta metalurgie a materiálového inženýrství, Katedra tepelné techniky, 17. listopadu 15, Ostrava – Poruba, 708 33, e-mail: adela.machackova@vsb.cz*

Abstrakt

Tento příspěvek je věnován problematice tepelného zpracování kolejnic. V současných podmínkách je zvyšovaní axiální síly na kolejnice realitou a proto je nezbytné se tomu u výrobce přizpůsobit. Základní parametry životnosti kolejnicové oceli (otěruvzdornost, odolnost proti kontaktním vadám a křehkým lomům za nízkých teplot) souvisí se základními pevnostními a plastickými vlastnostmi (mez kluzu, pevnost, tvrdost, tažnost, kontrakce). Tyto vlastnosti jsou ovlivňovány mikrostrukturními faktory perlitu, především velikostí perlitické kolonie, mezilamelární vzdáleností a objemovým podílem cementitu. Tyto faktory lze ovlivnit buď změnou chemického složení oceli nebo tepelným zpracováním hlavy kolejnice. V článku je představena jak metalurgická tak technologická stránka tohoto problému. Praktická část příspěvku popisuje laboratorní experiment měření ochlazovacích křivek pro dvě konfigurace kalícího zařízení. K měření teplot po průřezu kolejnice bylo použito 11 zavrtaných termočlánků, povrchová teplota byla měřena pyrometrem. K vyvrtání děr pro termočlánky byl použit vodní paprsek. Měření bylo doplněno snímky pořízenými termovizní kamerou. Naměřené ochlazovací křivky byly přidány do ARA diagramu. Aby mohla být tato superpozice provedena, musela být stanovena teplota počátku perlitické transformace (*Tps*) pro každou ochlazovací křivku. Kritériem pro nalezení teploty *Tps* byl odklon ochlazovací křivky od předpokládaného exponenciálního trendu o více než 0,5 %. Na základě předchozích experimentů byla odhadnuta výsledná tvrdost takto zpracované kolejnice. Za použití tangenciálního ventilátoru se podařilo zvýšit tvrdost na povrchu hlavy kolejnice o min 30 HV, zároveň však došlo k nežádoucímu zvýšení tvrdosti paty kolejnice.

Abstract

This paper is concerned with heat treatment of rails. Increasing axial forces acting on rails have become a fact, to which the rail manufacturers have to adapt. Fundamental parameters of rail steel life (wear resistance, resistance to contact failures and low-temperature brittle fracture) are related to basic strength and plasticity properties (yield strength, ultimate strength, elongation, reduction of area). These properties are influenced by microstructural parameters of pearlite: namely the pearlite colony size, interlamellar spacing and cementite volume fraction. It is possible to modify these either by changing the chemical composition of the steel or by heat treatment of the rail head. Both the metallurgical and technological aspects of the issue are discussed here. The practically-focused section of the paper provides description of a laboratory experiment involving measurements of cooling curves for two cooling equipment configurations. 11 thermocouples inserted in drilled holes were used for measuring temperatures across the rail cross section. The holes were cut with a water jet. A thermal imaging camera was used for collecting images accompanying the measurements. The measured cooling curves were incorporated into the CCT diagram. For this superposition to be done, the temperature of the onset of transformation to pearlite (*Tps*) had to be established for each cooling curve. The criterion for finding the *Tps* temperature was a deviation of the cooling curve from the expected exponential trend of more than 0.5%. Results of previous experiments were used for estimating the resulting hardness of a rail upon such treatment. Using a tangential fan made it possible to increase the hardness of the rail head by 30 HV at the least. However, this was accompanied by an undesired increase in the hardness of the rail flange.

Keywords: cooling curves, thermocouples, rails, TT diagram, hardness

1. Introduction

This paper describes experience related to and results of the second-to-last stage of a project, which was aimed at incorporation of pilot heat treatment into rail production at the Třinecké železárny, a.s. steelworks. The following issues had to be resolved before starting the pilot experiments:

Constructing CCT diagrams of selected rail steels using a BAHR dilatometer. The impacts of chemical composition and austenitising temperature on the offset of transformation curves were reviewed as part of this issue.

The data on positions of individual transformation areas was loaded into the TTSteel program. It will be used for computer simulation of the effect of the heat treatment (HT) on the resulting mechanical properties. For this purpose, the TTSteel program's calculation of mechanical properties upon quenching was adapted to better fit the conditions of the reversing mill in Třinecké železárny company.

Two comprehensive computer simulations of the actual accelerated cooling of rail were run. Their goal was to examine the parameters of the cooling equipment and find the limits of the HT cycle. The limits should help avoiding formation of undesired types of microstructures (bainite, tempered bainite) [1].

Experimental heat treatment cycles (performed on the dilatometer) were designed and conducted on the basis of results of the dilatometric experiment. With the results obtained, it is possible to evaluate comprehensively the impact of heat treatment on mechanical properties of the material and its hardness in particular. Steel samples processed in dilatometric experiments will be used for studying the effects of the cooling-start temperature and the cooling rate in the area of phase transformation upon the pearlite microstructure parameters.

2. Materials and experimental methods

UIC60, 900A-type rail was selected for the measurements. The rail steel had the following chemical composition: 0.762 wt % C, 0.89 wt % Mn, 0.371 wt % Si, and

0.05 wt % Cr. Eleven OMEGA TJ36-CAXL-116E-12 thermocouples were used for measuring the temperature across the rail cross-section. These are K-type thermocouples with the probe diameter of 1.6 mm and length of 300 mm. The measuring end of the probe is bare [2]. Thermocouples were inserted to the depth of 150 mm according to fig. 1 (left). The holes for thermocouples were drilled with water jet in cooperation with the Dept. of High Speed Water Jet of the Institute of Physics of VŠB-TU Ostrava. This technique allowed cutting holes with greater depth and smaller diameter than in those that could be made by drilling [3]. A special jig was designed and built in order to simplify insertion of the thermocouples into the rail. Its additional role was to insulate the rail surface against heat upon mounting the thermocouples (fig. 2). The purpose of the insulation is to minimise the heat flow in the rail axis direction. The surface temperature of the piece was measured with an OMEGA HH506R infrared radiation thermometer. A thermal imaging camera was used for collecting images accompanying the measurements.

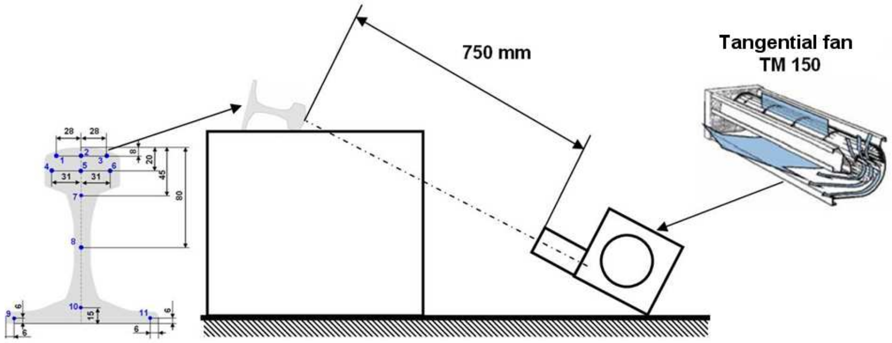

Fig.1 Layout of the measuring station.

Fig.2 Insulating the rail ends and mounting the thermocouples

Cooling curves were measured at the Třinecké železárny, a.s. hardening shop. The first experiment served as a simulation of conditions, which can actually be achieved on the cooling bed of the Třinecké železárny reversing mill. The distance between the top of the rail head and the opening of the special extension of the TM 150 tangential fan (the working section length is 1,064 mm [3]) was 750 mm (see figure 1). For the second experiment, the distance between the fan and the rail was decreased to a minimum (90 mm). Before the fan was started, the rail had cooled in air for 5 minutes.

Recorded cooling curves from the moment of starting the fan are shown in figure 3. The thermocouple no. 3 was damaged in the process of setting up the measuring operation. The data measured by this thermocouple is not shown below (unfortunately, the location of this thermocouple is very important).

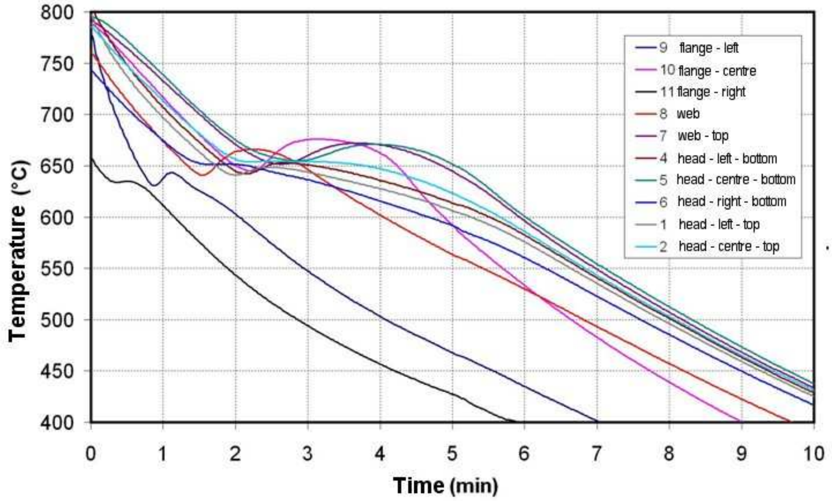

Fig.3 Measured cooling curves

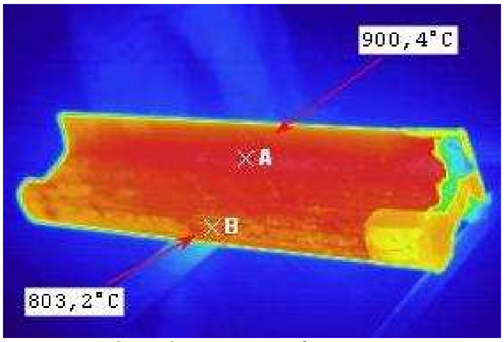

Fig.4 Thermal imaging – surface temperatures

As evident from measured cooling curves, highest rate of cooling is found in both sides of the rail flange under the direct current of air driven by the fan. Second highest cooling rate was found in the rail web (measured by thermocouple no. 8). Surprisingly, the next closely following one is the location measured by thermocouple no. 6 in the right bottom part of the rail head. This is the reason why the lack of data of the thermocouple no. 3 is rather a nuisance. As the thermal image (fig. 4) shows, the bottom edge (marked as the right one in our case) of the rail head is colder than the rest of the rail head. The thermal image on the left shows the insulation of the rail end. Lowest cooling rates were measured by thermocouples no. 7 and 5, which had been inserted to greatest depth below surface. The cooling rate in these locations does not significantly differ from that ordinarily seen in the cooling bed at Třinecké železárny during air-cooling of rails.

3. Discussion

The cooling rates alone do not give much indication as to what mechanical properties might be expected in a rail treated in this fashion. It is only the superposition on the CCT diagram of the steel (fig. 5), which can give a clear idea of the situation. For this superposition to be done, the temperature of the onset of transformation to pearlite (Tps) had to be established for each cooling curve. The criterion for finding the Tps temperature was a deviation of the cooling curve from the exponential trend of more than 0.5%. The time was then calculated using the equation (1), which was derived by means of dilatometer data regression processing:

$$T_{ps} = 485{,}04 \cdot t_{ps}^{0{,}0612} \quad (1)$$

where *tps* is the time of the onset of transformation to pearlite in CCT diagrams starting at 900 °C, *Tps* temperature of the onset of transformation to pearlite.

Using the results of previous laboratory experiments and the cooling curve of the air-cooled rail [5], it is possible to estimate hardness values, which can be expected in individual measured locations of the rail. Table 1 shows the summary of results.

Table 1 Calculated coordinates of the onset of transformation to pearlite and hardness estimate

Location		**Pearlite start**		**Hardness**	**Location**		**Pearlite start**		**Hardness**
		T (°C)	**t (s)**	**HV**			**T (°C)**	**t (s)**	**HV**
Flange	Right	633.9	79.3	359.3	Head	Left top	654,1	132,5	320,8
	Left	638.0	88.1	352.6		Centre top	653,7	131,1	321,7
	Centre	648.2	114.2	333.5		Right top	-	-	-
Web	Bottom	643.2	100.7	343.3		Left bottom	655,4	136,8	317,9
	Top	657.3	143.4	313.5		Centre bottom	664,6	171,7	295,4
						Right bottom	657.4	144.0	313.1

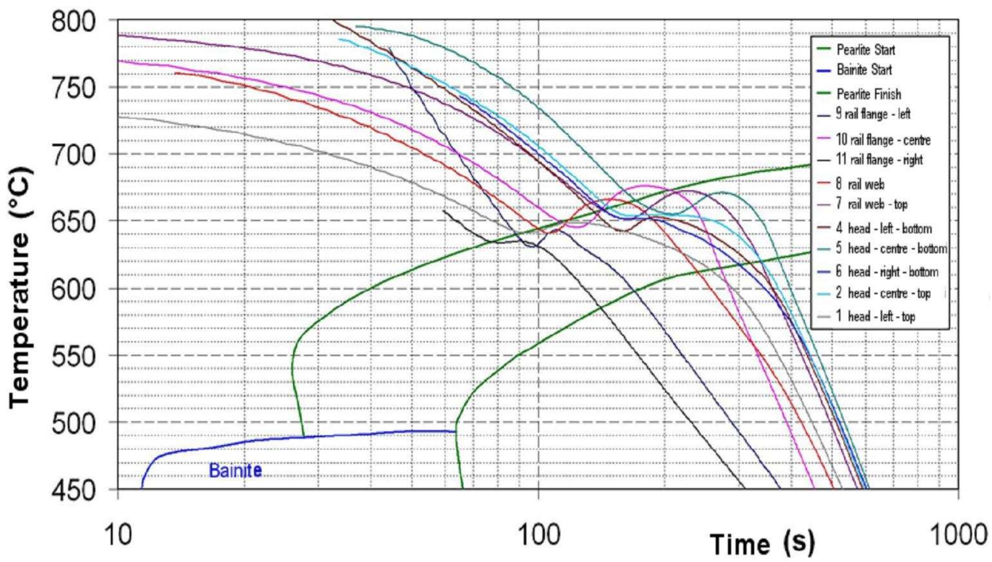

Fig.5 Superposed measured cooling curves and CCT diagram of the examined steel

4. Conclusion

Using a tangential fan made it possible to achieve a higher hardness in the rail head by at least 30 HV. However, this was accompanied by an undesired increase in the hardness of the rail flange. The flange will have to be protected against direct effects of the streaming air. The upcoming stage of processing the measured data will involve determination of the heat transfer coefficient by means of inverse analysis. The purpose of this step will be to obtain base information for further mathematical simulation [6].

Acknowledgements

This investigation was conducted with the support of Ministry of Education, Youth and Sports of the Czech Republic under the research plan MSM 6198910015.

Literature

[1] Fabík R., Kurek V., Bazgierová E, Stanovení technologických…, In: *Forming 2006*, Szczawnica, Politechnika Śląska Katovice, pp. 21 – 26. ISBN 83-910722-8-2

[2] Super OMEGACLAD® XL Thermocouple Probes, [online][cit. 2007-27-05], Available at: WWW: http://www.omega.com/Temperature/pdf/TJ36CAXL_NNXL.pdf

[3] Hlaváč L.M.: JETCUT . In Jetting Technology, Bury StEdmunds/London, BHR Group, Prof. Eng. Pub. Ltd., 1998, p. 25-37. R, ISBN 1-86058-140-4

[4] *LTG - tangential fans,* [online][cit. 2007-20-05] Available at: WWW: http://www.ltg-ag.de /56.0.html?&L=1

[5] Fabík R. Simulace zrychleného ochlazování kolejnic, In *FORMING 2004*. Štrbské Pleso – Vysoké Tatry, Slovakia: STU v Bratislave, 2004, pp. 61-66.

[6] Fabík R., Babinec A. Determination of boundary conditions…. In *STEELSIM 2005*. Brno: Třinecké železárny, a. s., 2005, pp. 473-486. ISBN 80-239-5005-3