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The structure and properties of steel with different pearlite morphology and its resistance to abrasive wear

J. Herian [a,*], **K. Aniołek** [b]
[a] Department of Process Modelling and Medical Engineering, Silesian University of Technology, ul. Krasińskiego 8, 40-019 Katowice, Poland
[b] Department of Railway Engineering, Silesian University of Technology, ul. Krasińskiego 8, 40-019 Katowice, Poland
* Corresponding author: E-mail address: jerzy.herian@polsl.pl

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ABSTRACT

Purpose: The analyse of pearlite morphology changes as a result of hot rolling process and isothermal annealing.

Design/methodology/approach: Physical modelling of isothermal annealing for a transition point of 520-620°C was carried out using a Gleeble simulator. A scanning electron microscope was used for a quantitative evaluation of the microstructure.

Findings: The obtained test results confirm that these methods can be effectively used in shaping the pearlitic structure and properties of the steel. During numerical simulation of a ride of a rail-vehicle through a switch, the load acting on a block section being part of the vehicle structure was determined. The load values were used in simulation of the resistance to abrasive wear, which was carried out in physical simulation.

Practical implications: In physical modelling of tests of resistance to abrasive wear for the steel grade R260 after hot rolling and isothermal annealing it has been proved that this feature is a function of the steel structure and properties in the given operation conditions (load and slide magnitude). Abrasive wear of the rail steel is the more intensive, the larger the load at a constant slide is.

Originality/value: An advantageous pearlitic morphology of steel (block sections) with interlamellar distance in the order of 0.12-0.13 µm, ensuring hardness of about 340-350 HB, is facilitated by a hot rolling process combined with isothermal annealing.

Keywords: Abrasive wear; Block sections; Switch; Pearlite morphology; Isothermal annealing

PROPERTIES

1. Introduction

Railroads consist of tracks, railway switches, substructure of the track, engineering structures and railway traffic control devices [1]. Railway switches allow a change of the ride direction. A typical switch is a complex structure composed of points, connecting rails, a frog, switch sleepers and setting devices The frog allows a ride of a rail-vehicle through intersections of rails. [1, 9]. They are constructed using block sections produced via a hot rolling method.

The operation conditions of turnouts, unlike the railway track, are characterized by high dynamic load coming from the rail-vehicle wheels, generated in places of discontinuity of the railway track of the switch and frog. Increased load acting on the block section of the actual frog point accelerates its wear, which in turn reduces the durability of turnouts and increases service costs [5, 10]. Enhanced durability of rail sections made of carbon-manganese steel can be obtained by controlled shaping of the pearlitic microstructure, especially the pearlite morphology during isothermal annealing. Such thermal treatment results in size reduction of pearlite colonies and a reduction of the interlamellar distance in cementite. In consequence, the properties of a pearlitic rail steel and the durability of rail sections change [2-4, 9].

A basic grade of steel used for the production of rails and sections is carbon-manganese steel with a pearlitic structure of the R260 grade. An increased carbon content in the rail steel enhances its strength properties. At the same time, manganese causes a decrease of the pearlitic transition point, thus contributing to the creation of reduced in size pearlite colonies. Such steels are characterized by high stability of the content of main chemical elements and a low level of additive elements, as well as high metallurgical purity and a low content of gases, especially hydrogen (below 2 ppm) and oxygen (below 20 ppm).

High strength and hardness of steel with a pearlitic structure, with simultaneous sufficient ductility, can be obtained by controlled cooling from the austenitization range to the pearlitic transition point of 620-520ºC, and holding at such temperature until total disintegration of austenite [1, 9]. Kinetics of the pearlitic transition determines the pearlitic properties of rail steels. The transition kinetics depends on the chemical composition of the steel, the speed of cooling and the size of austenite grain at the moment of transition initiation [4]. The lower the transition temperature, the faster it proceeds. The higher the degree of cooling, the finer the colonies formed in a lamellar arrangement of alternately, ferrite and cementite. Lowering of the pearlitic transition temperature results in a reduction of the interlamellar distance. The thickness of cementite lamellas reduces, whereas the yield point R_e, tensile strength R_m and hardness increase (Fig. 1) [4, 5, 8].

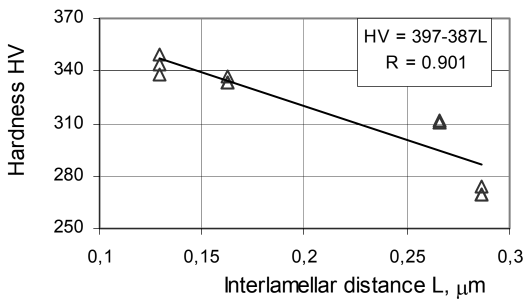


Fig. 1. Hardness HV depending on pearlite interlamellar distance

The latter property correlates well with resistance to abrasive wear. The smaller the interlamellar distance, the lower the rail steel wear intensity [4]. In the case of pearlitic rail steel, resistance to wear is directly proportional to hardness [1-3, 7-9].

2. Steel microstructure after hot rolling and isothermal annealing

Pearlitic structure of steel of grade R260 with a varied pearlite morphology was obtained in a hot rolling process in ”Huta Królewska” steelworks and during physical modelling of isothermal annealing in a Gleeble simulator. The simulator ensures maintaining high measurement accuracy and austenitization temperature control, a constant temperature of pearlitic transition in time and a constant cooling rate. The parameters of thermal treatment were determined on the basis of dilatometric examinations, which enabled determining the R260 steel phase transition temperatures. Ring-shaped specimens, f32x10mm, made of carbon-manganese steel of grade R260 were used in the modelling procedure. Their chemical composition is shown in Table 1. The specimens were made out of slices of block section KL60 taken from the cross-section.

Table 1.
Chemical composition of rail steel

	Chemical composition of steel [%]						
Grade	C	Mn	Si	P	S	Cr	Al
R 260	0.74	1.08	0.30	0.013	0.018	0.040	0.003

The heat treatment consisted of:
- heating of the ring-shaped specimens up to austenitization temperature of 800ºC,
- soaking at a temperature of 800ºC in a period of time allowing for identical temperature distribution,
- cooling of the specimens at a rate of 15ºC/s to the isothermal holding temperature of 620, 570, 550 and 520ºC,
- isothermal holding for 300s and cooling the specimens to ambient temperature.

After hot rolling and isothermal annealing, the structures were observed using a HITACHI S-3400N scanning electron microscope. Investigations of stereological properties of the structure with a varied pearlite morphology were carried out using magnification 15000x During measurement, 32 pearlite colonies were analyzed. In each colony, the number of intersections with cementite lamellae was counted for one secant perpendicular to cementite lamellae. After hot rolling, a pearlitic structure was found (Fig. 2). The average interlamellar distance for steel in as-rolled condition was 0.278 μm.

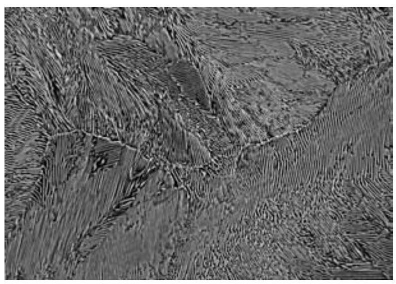


Fig. 2. Steel microstructure after hot rolling. Magn. 2000x

After isothermal annealing, a pearlitic structure with finer colonies was found (Fig. 3) in comparison to the colonies after hot rolling. The structures after heat treatment were characterized by a smaller interlamellar distance and a smaller thickness of cementite lamellae (Table 2). A quantitative evaluation of structures with varied pearlite morphologies and hardness examination have shown that the smaller the interlamellar distance, the higher the rail steel thickness.

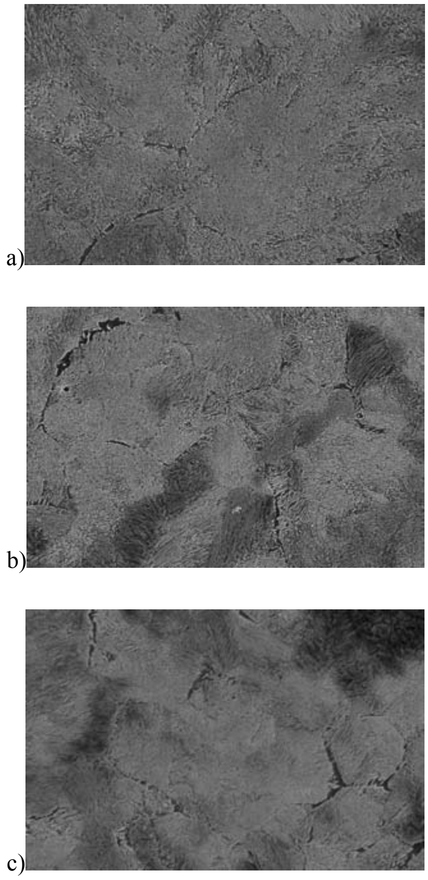


Fig. 3. Steel microstructure after isothermal annealing at a temperature of: a – 620ºC, b – 570ºC and c – 520ºC, Magn. 2000x

Table 2.
Hardness and interlamellar distance in pearlite colonies

	Interlamellar distance 1, µm			Hardness
	min	max	average	
As-rolled condition	0.184	0.349	0.278	274
OC 620ºC	0.136	0.258	0.173	301
OC 570ºC	0.112	0.201	0.141	325
OC 550ºC	0.108	0.167	0.131	338
OC 520ºC	0.100	0.153	0.119	350

3. Steel properties after hot rolling and isothermal annealing

The average mechanical properties of steel after hot rolling, determined in a static tensile test, are presented in Table 3. Specimens used in the tensile test were round specimens f, 10 mm in diameter, with heads. Brinell method was applied to measure the steel hardness after hot rolling and isothermal annealing, using a ball with a 2.5 mm diameter. The results of hardness measurement are juxtaposed in Table 2. Lowering of the isothermal transition temperature caused a reduction of the interlamellar distance and an increase in steel hardness (Table 2). The highest hardness (HB=350) and, at the same time, the smallest interlamellar distance in cementite, was achieved at the transition temperature of 520ºC.

Table 3.
Mechanical properties of rail steel after hot rolling

Rm MPa	A_5 %	Hardness of rolling surface
923	11.4	274

4. Modelling of the load in simulation of a rail-vehicle ride through an ordinary turnout

The Universal Mechanism program was used for modelling the dynamic loads present during a rail-vehicle ride through a turnout. In the developed turnout model, a change of the cross-section contour (profile) along its length was taken into account. The change follows from the turnout construction. The real profile of an element of the switch point and turnout frog was obtained from the measurement of an ordinary turnout. XY profile measurement gauge of GRAW was used when taking the measurements. After transformation of the turnout profiles to a form required for the Universal Mechanism program, the model was subjected to a dynamic analysis. A ready iesel locomotive model was used for the simulation of a ride through the turnout. A speed of 20-80 km/h was applied. The modelling resulted in an estimation of the values of load present on the rolling surface of the turnout elements and its courses as a function of time. An exemplary course for a speed of 80 km/h is presented in (Fig. 4). The determined load values were assumed for modelling of resistance to abrasive wear.

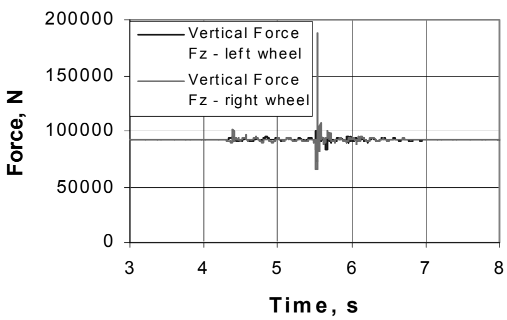
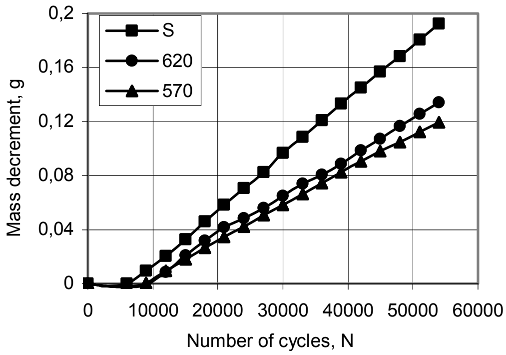


Fig. 4. Graph of load changes as a function of time for a locomotive ride through an ordinary turnout track

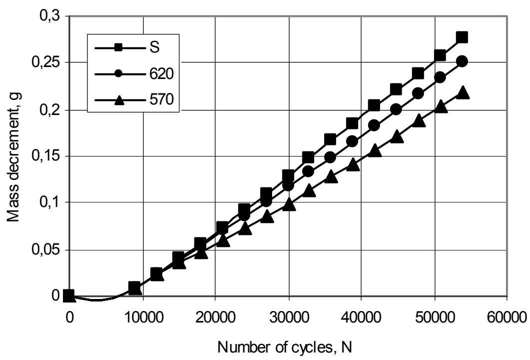
5. Modelling of steel abrasive wear

Model wear tests were carried out at an Amsler stand with a tribological pair of a roller-roller type. As-rolled specimens after isothermal annealing were used for the tests. The tests were carried out in a range from 0 to 54.000 cycles in 18 research cycles. The test were carried out for Hertz pressure of 663 and 903 MPa with a 1% slide between a specimen and counter-specimen. Steel P60 was used as a counter-specimen. This type of steel is used in rail wheel rings. The weight of the ring-shaped specimens was measured using laboratory scales of A&N HM-300 type, to an accuracy of 0.001 g.

Chosen results of the tests of resistance to abrasive wear of specimens with varied pearlite morphologies depending on the number of cycles for different values of Hertz pressure (p_o) and slide (ă) are presented in Fig. 5.



a)



b)

Fig. 5. Degree of wear of pearlitic rail steel R260 for the state after hot rolling (S) and after isothermal annealing, depending on the number of cycles for slide =1%, pressure of 662.7MPa (a) and 903.1 MPa (b).

In the initial stage of tests, a small mass decrement was observed in the specimens. With a growing number of cycles, an increase in the steel wear intensity was recorded. After 12000 cycles, the wear stabilized and was similar to linear. As results from the tests carried out, the resistance to abrasive wear of rail steel is strictly connected with pearlite morphology, which has a decisive influence on mechanical properties. The highest wear was observed for the specimens after hot rolling, irrespective of the pressure level. On the other hand, the steel proves to have higher resistance to abrasive wear after isothermal annealing. The smaller the interlamellar distance in cementite, the higher hardness and wear resistance. For the same tests conditions, a load increased from 662.7 MPa to 903.1 MPa causes an increase of abrasive wear.

6. Conclusions

The obtained test results corroborate that the pearlitic microstructure of steel of grade R260 can be effectively modelled in a hot rolling process and during isothermal annealing. In products after hot rolling and isothermal annealing, a typical pearlitic microstructure with a varied morphology is obtained. The microstructure after isothermal annealing in a temperature range of 520÷620ºC is characterized by reduced in size pearlite colonies, smaller interlamellar distances and smaller thickness of cementite lamellae in relation to the as-rolled condition. Lowering of the isothermal soaking temperature caused a reduction of the interlamellar distance and an increase of the steel hardness. An advantageous pearlitic morphology of steel (block sections) with interlamellar distance in the order of 0.12-0.13 μm, ensuring hardness of about 340-350 HB, is facilitated by a hot rolling process combined with isothermal annealing. Such structure can be obtained during austenitization at a temperature of 800ºC, with a cooling speed of 20-30ºC/s to an isothermal annealing temperature of ca. 520-550ºC.

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