Abrasive wear of railway sections of steel with a different pearlite morphology in railroad switches

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Properties

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. Tests of resistance to abrasive wear were carried out at the Amsler stand.

Findings: The obtained test results confirm that these methods can be effectively used in shaping the pearlitic structure and properties of the steel.

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. The resistance to abrasive wear of steel R260 with a pearlitic structure and different pearlite morphology decreases with the increase of load and slide.

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: Pearlite morphology; Abrasive wear; Railroad switches; Block sections

1. Introduction

Transport systems play an important part in the economic development of a country. Rail transport is one of the systems enabling the long distance transport of people and goods. Modern railway systems built for track vehicles moving with the speed of 300 km/h are an alternative for the air transport. For the above mentioned reasons, high requirements are set to the railroads in the scope of safety issues. Sections composing rail tracks and switches (Fig. 1) must meet high requirements in the scope of the material properties, its shape and continuity. Railroads consist of i.e. rail tracks and switches. The latter create a complex

construction of railroads distances, they fork or join the crossing tracks (Fig. 2).
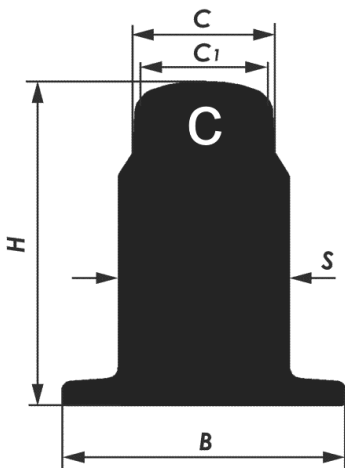
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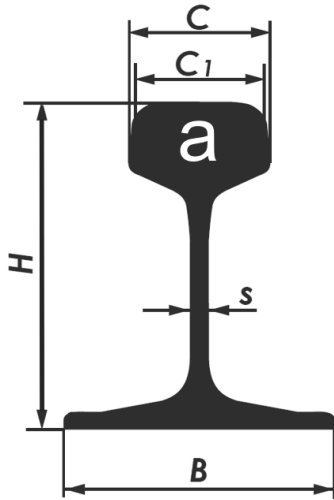
b)
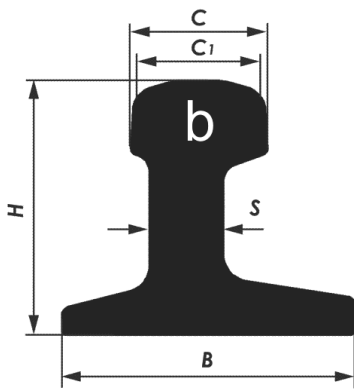
c)

Fig. 1. Sections: a - rail, b - needle, c - block

They are especially exposed to the abrasive or fatigue wear and the changes of shape as a result of dynamic loads action of cyclical nature, occurring when the track vehicles ride through the switch [1-3].The process of a mechanic destruction of the upper layer leads to the undesired change of dimensions and shape of the contacting rolling surfaces of a switch element and a railway wheel.
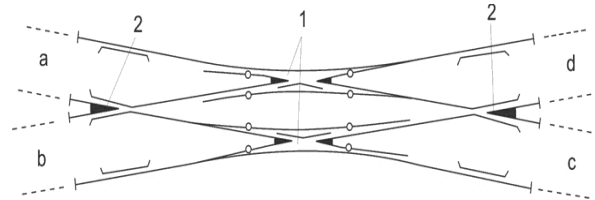

Fig. 2. Scissors crossover: 1 - double frogs, 2 - single frogs

Block sections of KL49 and KL69 type produced with the use of hot rolling method are widely applied in the construction of ordinary and scissors railway switches. The measurements of block sections wear in operational conditions, built in the frog switches have identified certain irregularities in the rolling surface profile wear of the actual frog point (Fig. 3) and its plastic flattening. Measurement methodology was shown in authors' work [3]. The biggest wear occurs on the actual frog point in the place of the biggest load, which decreases as the distance from the frog point increases. Such wear is caused by the momentary increase of the dynamic load acting on a small rolling surface of the frog point. It leads to the intensive wear and flattening as a result of the rail vehicle wheel hits. For the reasons mentioned above, materials used for the production of sections in the rail switches must have specific properties and first of all an increased resistance to abrasive wear and fatigue [11,12,14,15]. High costs of rail switches operation and their exchange are the grounds for the preparation of new materials or technologies for the production of sections of wear increased in relation to the ones currently used.

A basic grade of steel used for the production of rails and sections for railroad switches is carbon-manganese steel with a pearlitic structure. The European Rail Standard (PN-EN 13674) distinguishes seven pearlitic steel grades, the hardness of which varies in a wide range from 200 to 390 HB. The most commonly applied grade of rail steel is R260, which is not only used for the production of rails but also for the production of needle and block sections. This grade of steel is characterised by high levels of endurance and hardness, good resistance to abrasive wear, as well as lower ductility and crack resistance.

High levels of pearlitic steel resistance and hardness at sufficient ductility level may be obtained thanks to the application of appropriate production techniques, controlled rolling and heat treatment - isothermal annealing. The strengthening of the material in the process of rolling may be regulated by means of the deformation parameters and the temperature at the end of rolling or, in the process of isothermal annealing, by means of the initial austenite grain size, transition temperature and rate of cooling from the austenitization temperature to the isothermal

holding temperature, until total disintegration of austenite. The controlled rolling or heat treatment results in size reduction of pearlite colonies and a reduction of the interlamellar distance in cementite. Changing the morphology of the pearlite allows for the regulation, within a wide range, of the steel properties and the durability of rail sections [1,2,4,6-10,13].
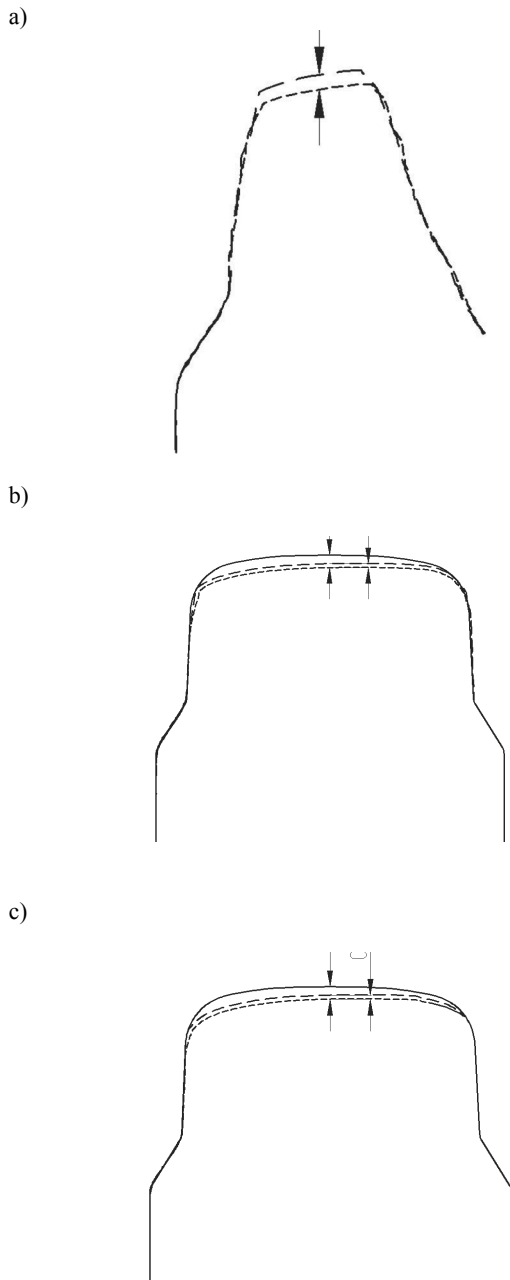
a)

b)

c)

Fig. 3. Vertical wear on the cross-section of the KL60 section in the distance from the actual frog point: a- 10 cm, b- 60 cm, c- 110 cm

2. Research material

Block sections of KL60 type, hot-rolled, made of rail steel of R260 grad e have been chosen for the purposes of the research. The rolling of sections of ingots coming from continuous casting has been conducted in a line unit. The temperature at the end of rolling was about 930°C. Cooling has been performed in a refrigeration plant in smooth air. The control analysis of the chemical composition of steel has been performed using an ARL 3460 multichannel emission spectrometer. The chemical composition and mechanical properties of steel after hot rolling are presented in Table 1.

Table 1.
Chemical composition and properties of R260 steel

Steel grade	Content of chemical elements, %							
	C	Mn	Si	P	S	Cr	Al	V
	0.74	1.08	0.31	0.013	0.018	0.040	0.003	0.004
R260	Mechanical properties							
	R_m, MPa		R_{pe}, MPa		A_5, %		Z, %	
	923		528		11.4		15.9	

Friction couples made of materials used in interacting elements in real conditions were used in the abrasive wear resistance tests at the Amsler stand. P60 steel was used as a counter-specimen. This type of steel is commonly used in rail wheel rings. The chemical composition of P60 steel according to a melt analysis and its mechanical properties are shown in Table 2.

Table 2.
Chemical composition of P60 steel and mechanical properties

Steel grade	Content of chemical elements, %							
	C	Mn	Si	P	S	Cr	Al	V
	0.63	0.82	0.27	0.012	0.009	0.02	0.033	0.001
P60	Mechanical properties							
	R_m, MPa		R_{pe}, MPa		A_5, %		Z, %	
	1001		581		14.9		47	

3. Research methodology

3.1. Heat treatment

The pearlitic structure of R260 steel with a varied pearlite morphology was obtained during physical modelling of isothermal annealing on a Gleeble 3800 simulator in the Institute for Ferrous Metallurgy (Instytut Metalurgii Żelaza) in Gliwice. This simulator ensures maintaining high measurement accuracy and austenitization temperature control, a constant temperature of pearlitic transition in time and a constant cooling rate. Ring-

shaped specimens with the dimensions of φ32x10 mm made of KL60 block section (Fig. 4) were used in modelling of the isothermal annealing process.
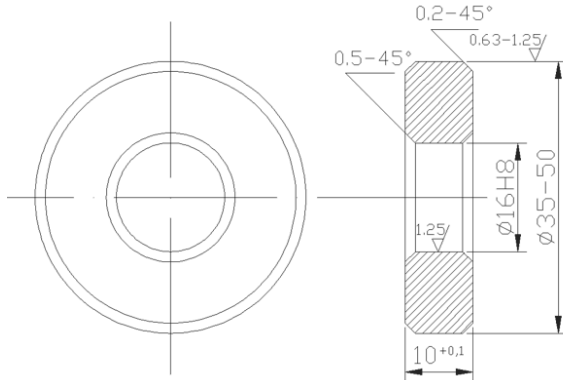

Fig. 4. Specimens for abrasive wear tests at the Amsler stand

The parameters of heat treatment of steel were determined on the basis of dilatometric tests and the results of structural tests of steel after isothermal annealing. The parameters of the heat treatment on the Gleeble simulator were as follows:
- heating of the specimens up to austenitization temperature of 800°C,
- annealing in the temperature of 800°C for 720 s,
- cooling of the specimens at a rate of 15°C/s to the isothermal holding temperature (620, 570, 550 and 520°C),
- isothermal holding for 300s and cooling the specimens to ambient temperature at a rate of 15°C/s.

3.2. Microstructure tests

Microstructure tests were performed with the application of a HITACHI S-3400N scanning electron microscope on specimens that have undergone the process of hot rolling and isothermal annealing. Specimens for the observation of the microstructure were taken from rings used to test the abrasive wear resistance. In order to reveal the pearlite colonies, the specimens, after hot rolling, were etched with 3.5% nital, and after annealing, with an isothermal solution of picric acid. During the observation and measurement of the interlamellar distance, magnifications of 2000 up to 15000x were used.

3.3. Quantitative description of the pearlitic structure

The measurements of interlamellar distance in cementite in R260 steel in the state after hot rolling and isothermal annealing were performed on a HITACHI S-3400N scanning electron microscope at a magnification of 15000x. 32 pearlite colonies were analyzed for the variant from the state after hot rolling, as well as for each variant after isothermal annealing. In each

colony, the number of intersections with cementite lamellae was counted along a section perpendicular to cementite lamellae. During the measurements, various lengths of the section were used, depending on the arrangement of the lamellae and size of a given pearlite colony. The applied measurement methodology is a new one which differs from the methodologies applied so far [5]. The distance between the lamellae [μm] was calculated according to the following dependence:

$$l = \frac{a}{n}$$

(1)

where:
a - length of the section perpendicular to the cementite lamellae [μm],
n - number of intersections of the section with the cementite lamellae.

3.4. Determination of hardness and tensile strength

For the purpose of determining those properties, measurements of hardness were performed, as well as a static tensile test on cylindrical specimens of a special shape. Measurements of the material hardness after hot rolling and isothermal annealing were performed on a KP15002P hardness tester, with the application of the Brinell method, using a ball with a 2.5 mm diameter and a load of 1839N.

Tensile strength of steel with a pearlitic structure and with different morphologies was determined in a static tensile test on specimens with neck in the central part (Fig. 5).
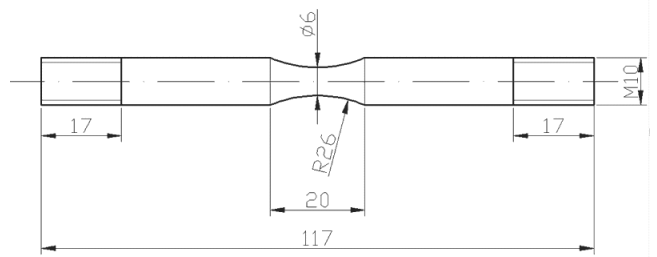

Fig. 5. Dimensions of specimens for strength tests after heat treatment

3.5. Tests of resistance to abrasive wear in the conditions of rolling-sliding friction

Tests of resistance to abrasive wear were carried out at the Amsler stand with a tribological pair of a roller-roller type. The materials tested, in the form of rings, were fastened on two shafts moving in opposite directions. The skid value between the specimen and the counter-specimen was regulated by changing the diameter of the counter-specimen. The load was regulated by

means of a spring mechanism. Two load values were assumed (663 and 903 MPa) and a skid value of 1%. The tests were carried out in a range up to 54.000 cycles in 18 research stages. The applied test parameters corresponded to real operating conditions of railroad switches.

Tribological tests were performed with the application of friction couples interacting in real conditions. The material for the specimens was R260 steel with a diverse pearlite morphologyP60 steel was used as a counter-specimen. This type of steel is commonly used in rail wheel rings so its application increased the credibility of R260 steel wear results.

4. Tests results

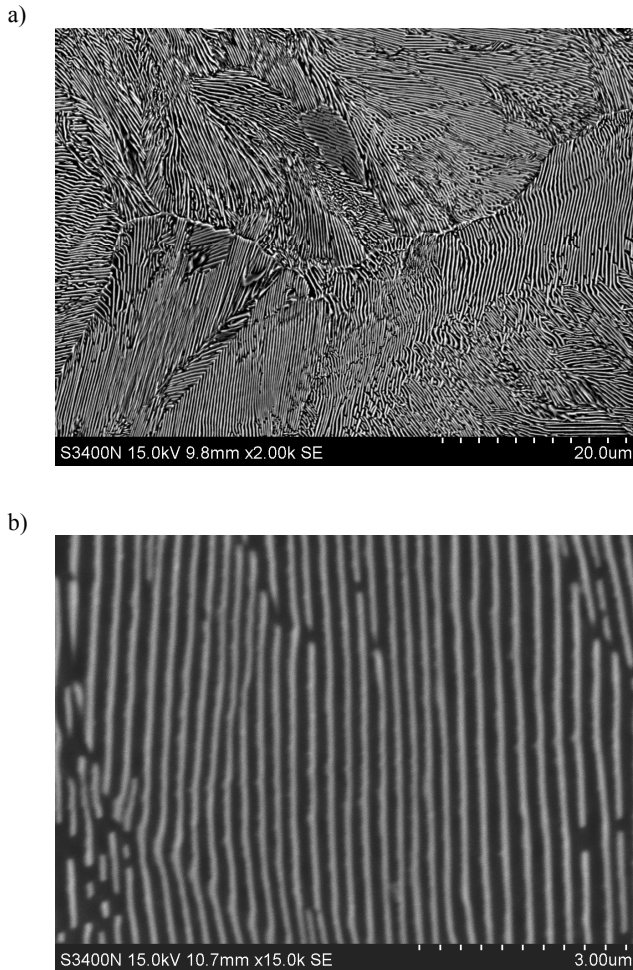## 4.1. Steel microstructure after hot rolling and isothermal annealing

a)

b)

Fig. 6. The microstructure of steel in the state after hot rolling

The identification of the microstructure of the examined steel was performed using a scanning electron microscope. It has been found that in the steel after hot rolling there is a pearlitic microstructure, formed by pearlite colonies of various arrangement directions (Fig. 6).

The material after isothermal annealing demonstrated a pearlitic structure with finer colonies in relation to the colonies after hot rolling. The microstructures after heat treatment were characterized by a smaller interlamellar distance and smaller thickness of cementite lamellae (Fig. 7). On the boundaries of former austenite grains ferrite bands were observed.
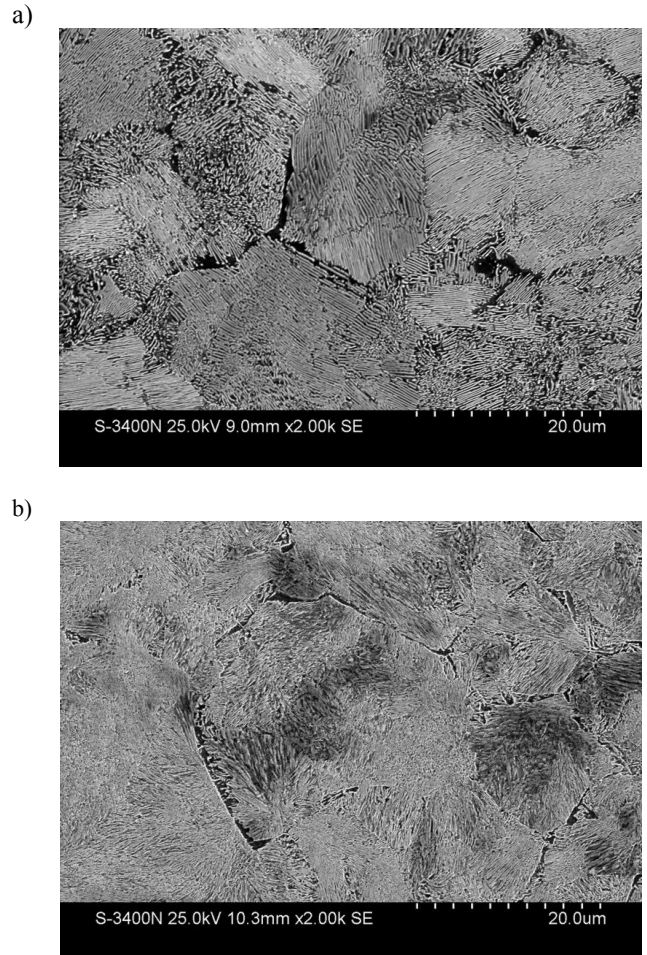
a)

b)

Fig. 7. The microstructure of steel R260 after isothermal annealing at the temperature: a - 620^0C, b - 520^0C

4.2. Quantitative description of the microstructure of pearlitic steel

The measurement results of an interlamellar distance and hardness are demonstrated in Table 3. Depending on adopted parameters for heat treatment, the material contained a pearlitic

microstructure with various interlamellar distances in cementite. The steel after hot rolling contained an average interlamellar distance of 0.28 μm while after isothermal annealing from 0.12 to 0.17 μm (Table 3). The lowering of an isothermal holding temperature caused the reduction of an interlamellar distance. The smallest average cementite interlamellar distance of 0.12 μm was obtained in case of the material annealed isothermally at the temperature of 520^{0}C.The interlamellar distance reduced in this case more than two times in relation to the state after hot rolling.

Table 3.
An interlamellar distance in pearlite colonies

	Interlamellar distance of 1, μm			Standard deviation	Hardness HB
	minimum	maximum	average		
As-rolled condition	0.18	0.35	0.28	0.05	274
^{O}C 620^{0}C	0.14	0.26	0.17	0.02	301
^{O}C 570^{0}C	0.11	0.20	0.14	0.02	325
^{O}C 550^{0}C	0.11	0.17	0.13	0.01	338
^{O}C 520^{0}C	0.10	0.15	0.12	0.01	350

4.3. Mechanical properties

The average results of five hardness measurements depending on an interlamellar distance in cementite are shown in Table 3 and Fig. 8. The reduction of an interlamellar distance results in the increase of material hardness, which is in accordance with the data included in the references. The material after hot rolling is characterized by considerably lower hardness in comparison with the material after isothermal annealing. It is caused by pearlite morphology, a size reduction of colonies and the reduction of an interlamellar distance (Fig. 8).
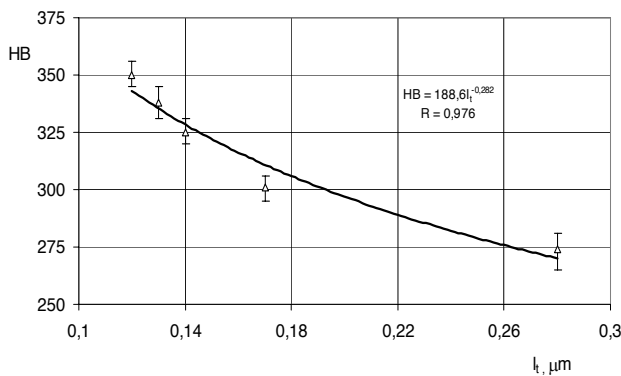

Fig. 8. The changes of HB hardness depending on an interlamellar distance

Tensile strength of the material changes linearly depending on the temperature of isothermal annealing (Fig. 9), which is in accordance with the reference data. A high value of correlation ratio (R) confirms a good matching of an approximate function to the average values of R_m. The lowering of an annealing temperature results in the increase of tensile strength. This increase of tensile strength is caused by a smaller interlamellar distance in cementite (Fig. 10) and smaller thickness of cementite lamellae.
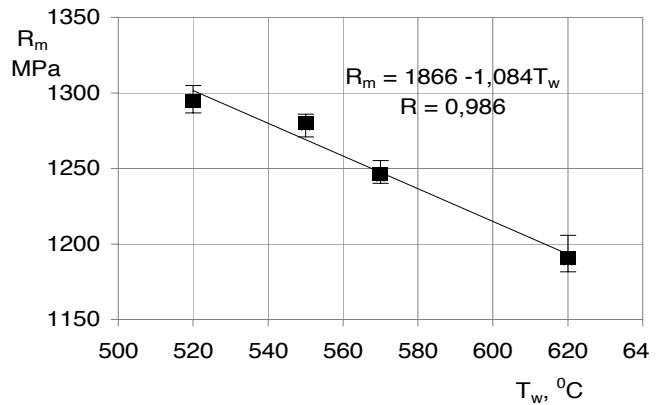

Fig. 9. The dependence of the steel tensile strength on the temperature of isothermal annealing

The comparison of tensile strength for two examined different material states has shown that the material after isothermal annealing was characterized by the tensile strength of 300 to 400 MPa higher in comparison with the material after hot rolling. This fact is reflected by a similar pattern of a thickness change. The increase of strength properties resulting from the reduction of an interlamellar distance caused the change of steel resistance to abrasive wear, which has been proven in own examinations.
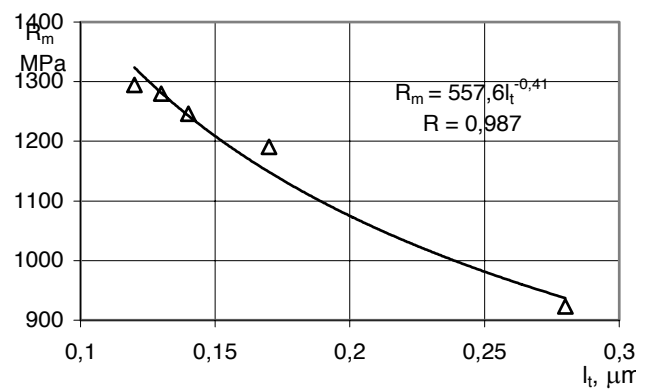

Fig. 10. The influence of an interlamellar distance on steel tensile strength

4.4. Tests of resistance to abrasive wear

In the tests of the resistance to abrasive wear in the conditions of rolling-sliding friction of steel with different pearlite morphology, it has been demonstrated that material wear is dependent on operational parameters and an interlamellar distance in cementite. No abrasive wear was observed in the number of cycles ranging from 8000 to 12000. Above 12000 cycles, the wear assumes the characteristics similar to linear (Figs. 11-14). The steel after hot-rolling (l_t=0.28 μm) was characterized by the lowest resistance to abrasive wear, demonstrating the highest wear for the tested values of pressure. The abrasive wear of rail steel is the more intensive, the larger load at a constant slide is.
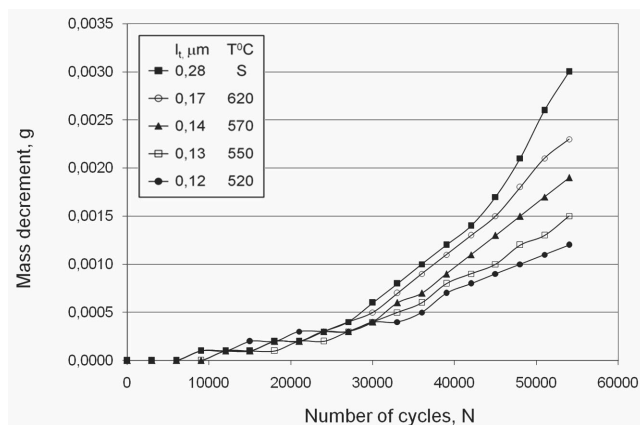

Fig. 11. The course of the abrasive wear of steel R260 with a different interlamellar distance in cementite depending on a number of cycles for the slide of γ=0.1% and the pressure of 663 MPa using steel P60 as a counter specimen

Fig. 12. The course of the abrasive wear of steel R260 with a different interlamellar distance in cementite depending on a number of cycles for the slide of γ=0.1% and the pressure of 903 MPa using steel P60 as a counter specimen
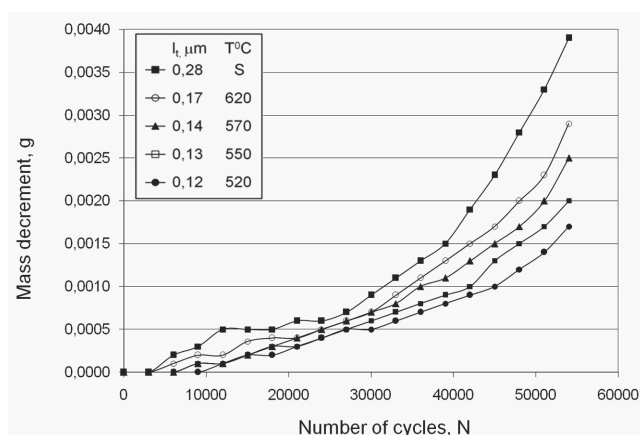

Fig. 13. The course of the abrasive wear of steel R260 with a different interlamellar distance in cementite depending on a number of cycles for the slide of γ=1% and the pressure of 663 MPa using steel P60 as a counter specimen
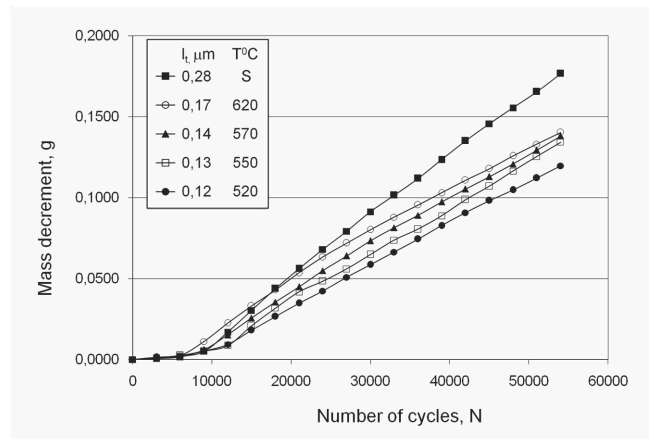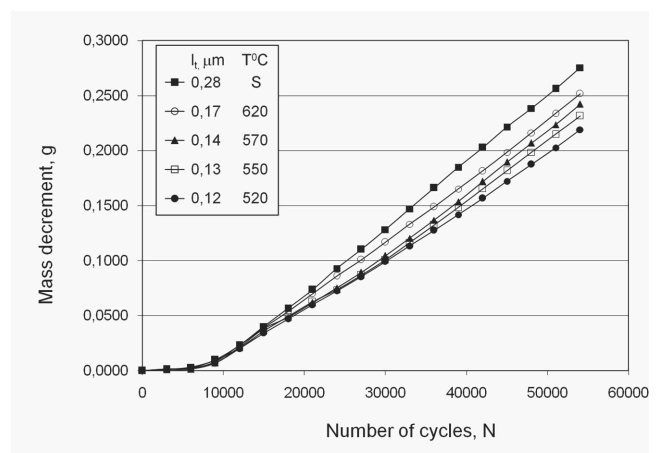

Fig. 14. The course of the abrasive wear of steel R260 with a different interlamellar distance in cementite depending on a number of cycles for the slide of γ=1% and the pressure of 903 MPa using steel P60 as a counter specimen

The material after isothermal annealing characterized by a smaller interlamellar distance in cementite underwent lower abrasive wear, proving that resistance to abrasive wear increases with the decrease of an interlamellar distance in cementite of pearlitic structure.

For instance, the wear of hot rolled material of l_t=0.28 μm was 1.25 times higher than the abrasive wear of material of l_t=0.12 μm after annealing at the temperature of 520^0C (Fig. 13).

Thus, the use of block sections made of steel with pearlitic structure and a small interlamellar distance on switch elements will significantly increase resistance to abrasive wear and, at the same time, prolong their operational period.

5. Conclusions

The increase of ride speed, load and pressure as well as the frequency number of transport should be accompanied with the selection of materials which will ensure lower wear of rail sections and will prolong the durability period of switches and railroads. One of the ways leading to the increase of resistance to abrasive wear of high-carbon steel with pearlitic structure is the modification of its morphology. The morphology of pearlite may be regulated to a large degree by means of isothermal annealing parameters. The properties of rail sections material can be regulated by the change of the size of pearlite colonies and the interlamellar distance in cementite.

On the basis of carried out tests it was found that the microstructure of steel R260 after isothermal annealing at the temperature range of 520~620^{0}C contained reduced in size pearlite colonies, more than two times smaller interlamellar distance in cementite (l_t=0.12-0.17 μm) than the distance in the steel after hot rolling (l_t=0.28 μm). The lowering of annealing temperature causes the reduction of an interlamellar distance, the increase of steel hardness and tensile strength.Resistance to abrasive wear in the conditions of rolling-sliding friction is dependent on an interlamellar distance in cementite. The smaller an interlamellar distance, the higher resistance to abrasive wear. The abrasive wear of rail steel is the more intensive, the larger load at a constant slide is.

On the basis of the tests results, it may be concluded that a combined process of hot rolling and isothermal annealing ensures obtaining perlite morphology with an interlamellar distance of 0.12-0.13 μm in pearlitic steel R260 for rail switches. Such properties of pearlite morphology are obtained in the process of isothermal annealing during austenitization at the temperature of 800^{0}C, with a cooling speed of 20-30^{0}C/s to an isothermal holding temperature of ca. 520-550^{0}C.

1. The abrasive wear of block sections with pearlitic structure made of steel R260, used for rail switches, depends on perlite morphology - an interlamellar distance in cementite and the thickness of lamellae.These quantities may be regulated in the processes of hot rolling and isothermal annealing.
2. The microstructure of steel R260 after isothermal annealing at the temperature range of 520~620^{0}C contained reduced in size pearlite colonies, more than two times smaller interlamellar distance in cementite (l_t=0.12-0.17 μm) than the distance in the steel after hot rolling (l_t=0.28 μm).The lowering of an annealing temperature causes the reduction of an interlamellar distance, the increase of tensile strength and steel hardness as well as higher resistance to abrasive wear.
3. The resistance to abrasive wear of steel R260 with a pearlitic structure and different pearlite morphology decreases with the increase of load and slide.

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