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Shaping the structure during rolling and isothermal annealing, and its influence on the mechanical characteristics of high-carbon steel

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ABSTRACT

Rail sections made of pearlitic steels used in the construction of turnouts and railroads must have appropriate mechanical and fatigue characteristics as well as high resistance to abrasive wear. The paper discusses the influence of temperature at the end of rolling and isothermal annealing on the morphology of pearlite and the mechanical properties of steel R260. Properties of sections were evaluated in a statistic tensile and impact test, while that of the microstructure by using a scanning microscope. For a quantitative analysis of pearlite colonies, the "MET-Ilo v.3.5" computer program was used. The influence of the morphology of pearlite on the impact strength of KCU in the temperature range from −80 °C to 100 °C was also determined. It was demonstrated that in the above-mentioned processes the properties of the steel may be controlled within a wide range by changing the pearlite morphology parameter in the material.

1. Introduction

In operating conditions, rail sections are subject to abrasive and fatigue wear [1]. Railway turnouts are subject to especially intensive wear due to the presence of high cyclically variable loads [2]. They are constructed using hot-rolled railway sections (rails, block and switch point sections).

Rail sections used in the construction of turnouts and railroads must have good mechanical properties and appropriate resistance to abrasive and fatigue wear [1,3–6]. Materials with such characteristics ensure longer service life of railroads and greater safety of rail transport. For these reasons the issue of the durability of rails and turnouts is still the subject of technological research, structural relations and mechanical characteristics [1,3,5–8].

Basic materials used in the production of rails and sections for the construction of roads, including turnouts, are carbon–manganese steels with a pearlitic structure [1,3,7]. The properties of the products made of these steels depend on the microstructure obtained during hot-rolling or after thermal treatment [6,7,9,10].

The required parameters of the processes should be selected based on familiarity with the changes in the microstructure which take place in the material during heating, soaking, plastic working and cooling, or during supercooling from the austenitisation temperature to the pearlitic transition temperature and the time of its completion.

2. Experimental procedures

2.1. Material

In the experimental research, carbon–manganese steel of grade R260 with a pearlitic structure was used. This material is used in the production of rail sections for the construction of railroads, including turnouts. The control analysis of the chemical composition of the steel was performed using an ARL 3460 multichannel emission spectrometer. The chemical composition of the steel is presented in Table 1.

2.2. Elaboration of TTA, CCT and TTT graphs

The elaborated graphs, time–temperature–austenitising (TTA), time–temperature–transition during isothermal holding (TTT) and time–temperature–transition during continuous cooling (CCT), were assumed as a basis for the selection of correct parameters of isothermal annealing and rolling, which allow obtaining a material with a varied morphology. The research involved an analysis of the influence of the heating rate on the position of critical points, and the

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Table 1
Chemical composition of the steel.

Steel grade	Content of chemical elements, %							
	C	Mn	Si	P	S	Cr	Al	V
R260	0.74	1.08	0.30	0.013	0.018	0.040	0.003	0.004

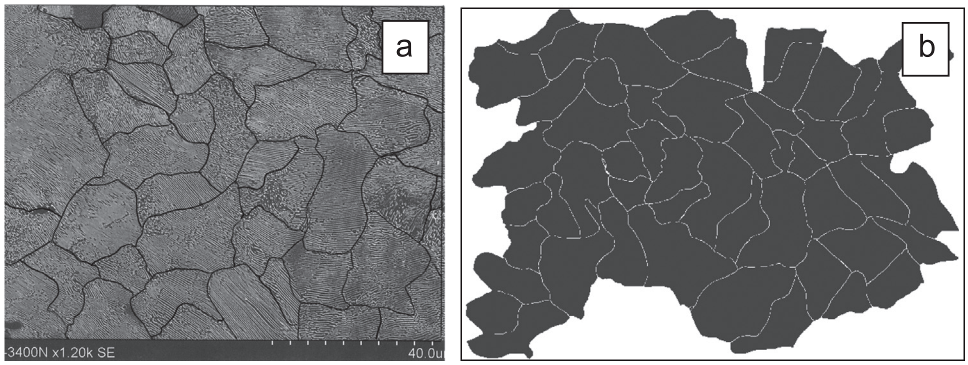

Fig. 1. The recorded images on a scanning electron microscope with borders pearlite colonies (a) and picture, on which measurement was performed (b).

kinetics of the transitions of supercooled austenite in continuous cooling and isothermal conditions.

The TTT graph is necessary to identify the temperatures of isothermal holding of supercooled austenite aimed at diversification of the morphological properties of pearlite, in particular as regards the cementite interlamellar distances and the thickness of lamellae. TTT graphs were documented with the measurements of hardness taken by means of the Vickers method at a load of 5 kG (HV5).

Dilatometric tests were performed on the L78 R.I.T.A. dilatometer made by the Linseis company. Cylindrical specimens with a diameter of 5 mm, prepared from a block section, were used for the tests.

2.3. Shaping the microstructure of R260 steel in a rolling process and during isothermal annealing

The microstructure of steel R260 with a varied pearlite morphology was obtained in hot rolling and isothermal annealing processes.

KL60 block sections and I49 switch point sections were hot-rolled in an Arcelor Mittal Poland S.A. heavy section shape mill. Continuous ingots with a cross-section of 280 × 400 mm and chemical composition shown in Table 1 were rough-rolled using a D1100 cogging mill to slabs of 210 × 270 mm. After reheating and holding in a walking-beam furnace at a temperature of 1160 °C, the slabs were rolled to block sections in a heavy section (three-stand) shape mill. After rolling, the sections were cooled in a cooling bed in calm air. In the case of the standard rolling method the temperature at the end of rolling (T_{fr}) ranged from 930 to 960 °C. The change in pearlite morphology in the hot-rolled steel was achieved by lowering the temperature at the end of rolling to 880 °C.

Thermal treatment was performed in industrial conditions (concern Bohler Uddeholm Polska) in a Rubig VH 669-10-FU hardening vacuum furnace. Screwed cylindrical specimens with a diameter of 10 mm were used for statistic tensile tests and Mesnager specimens – for impact tests. These specimens were used to evaluate the influence of the properties of steel microstructure on basic mechanical characteristics.

2.4. Quantitative evaluation of the microstructure

High-carbon R260 steel in the as-hot-rolled condition for two variants of the temperature at the end of rolling (930 and 880 °C) and after isothermal annealing was observed on a HITACHI S-3400N scanning electron microscope. The specimens were etched with 3.5% nital and pricric acid solution. During observation magnifications of up to 15,000 × were used.

For materials processed according to different technological variants, the following parameters were calculated: the interlamellar distance in cementite (l_t), the average area of the colony's plane section (A) and the average substitute diameter of the colony's plane section (d). For a quantitative analysis of pearlite colonies, the "MET-Ilo v.3.5" computer program was used. In the analyzed colonies the number of intersections with cementite lamellae was counted on one secant perpendicular to cementite lamellae. Due to indistinct boundaries between the colonies and a low contrast inside, as well as impossibility to perform an automatic image analysis, the pearlite colonies were outlined (Fig. 1).

2.5. Examination of mechanical properties

Mechanical properties of R260 steel which are significant from the point of view of operational requirements for two different conditions of the material were determined in a statistic tensile test and in an impact test.

The static tensile test was performed at room temperature on cylindrical specimens with a diameter d_o = 10 mm, using an MTS-810 strength testing machine. Changes in the specimen's length were measured on a length equal fivefold diameter of the specimen. An extension meter with a measuring base of 25 mm was used to precisely measure the elongation.

A bending impact test of specimens of the R260 steel with various pearlite morphologies was performed using the Charpy pendulum machine, manufactured by VEB, with an energy range of 50 J. The studies were conducted on the Mesnager specimens. The range of temperatures was from −80 to 100 °C. The value of fracture work was determined in the test.