G. SHVACHYCH, I. MAMUZIĆ, V. TSVYKH, M. KHYLKO, H. SASHCHUK,
O. TIMCHENKO, O. IVASCHENKO, D. MOROZ

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SOME COMPLEX INTENSIFICATION FEATURES OF SPHEROIDIZING ANNEALING OF LOW CARBON STEEL

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The paper considers complex intensification features of spheroidizing annealing of low-carbon steels and possible technological realizations of intensive annealing modes in current lines. The research aims to reveal the intensification nature of the steel's spheroidizing due to the non-isothermal holding and an internal coolant for the metal heating. That allows a significant reduction of the spheroidizing annealing process while improving the steel product's technological properties – providing a high dispersion and homogeneity of the structure across the entire plane of its section. The multiprocessor computing system with its mathematical and IT software for modeling the heat treatment modes of metal billets effectively controls the processes.

Keywords: steel wire, spheroidizing annealing, kinetic factor, thermodynamic factor, properties

INTRODUCTION

Over the past few decades, more and more attention focuses on the carbide phase spheroidization with the granular perlite structure, which serves as an alternative to long-term traditional processes of steel billets' spheroidizing annealing. Those include methods and technologies of combinational spheroidizing treatments of various types of metal products [1].

Spheroidizing annealing is often used to prepare a heterophase alloy for cold deformation [2]. Nowadays, there are two classical schemes of spheroidizing annealing: annealing at subcritical temperatures and annealing with incomplete phase recrystallization. The disadvantage of heat treatment according to the first scheme is in its long duration. Metal annealing, according to the second scheme, allows minor reduction of its time intervals. Meanwhile, due to rapid heating and incomplete steel austenitization, partial dissolution of cementite plates occurs. At the subsequent cooling, the formed austenite disintegrates on the abnormal mechanism on ferrite and cementite, and it, in turn, at the further endurance, provides cementite spheroidization. Under such conditions, the scheme is less time-consuming. However, those schemes have significant disadvantages of heating the metal with external carriers [3].

A promising direction of annealing intensification of steel products is the metal's electro contact or induction heating [4]. The indisputable advantages of electrothermal treatment are: giving steel products a high set of properties due to the specific effect of high heating intensity on the mechanism and kinetics of structural changes in steel, limited scale, and decarburization, environmental pollution avoidance, processing time reduction. Most importantly, those electrothermal steel treatment methods allow for heat treatment in automated production lines [2]. In implementing steel spherical annealing mode in the production line [5], a significant contribution to reducing the total annealing duration is an increase in heating rate and an increase in cooling rates at the appropriate stages of the heat treatment mode. Therefore, the practical implementation of spheroidizing annealing in production lines requires, first of all, the solution of new technical problems. However, high-speed heat treatment (HT) processes still require research, primarily to control the basic technological parameters to optimize them.

THE PURPOSE AND OBJECTIVES OF THE RESEARCH

The purpose of the research is to systematically cover the complex intensification processes of steel spheroidizing annealing and consideration of possible technological implementations of intensive annealing modes in current lines.

The research objective is to intensify steel spheroidizing annealing by non-isothermal holding an internal coolant for heating metal with a significant reduction in the annealing spheroidization duration and simultaneous improvement of technological steelware properties. The approach allows application of the proposed installation in modular production lines and automated complexes for preparing steels for cold massive forging.

G. Shvachych, (e-mail: sgg1@ukr.net), O. Ivaschenko, National Metallurgical Academy of Ukraine, Dnipro, Ukraine, I. Mamuzić, University of Zagreb, Zagreb, Croatia, V. Tsvykh, M. Khylko, H. Sachchuk, Taras Shevchenko National University of Kyiv, Kyiv, Ukraine, O. Timchenko, Lviv University of Trade and Economics, Lviv, Ukraine, D. Moroz, University of Technology, Dnipro, Ukraine.

THEORETICAL SUBSTANTIATION OF COMPLEX INTENSIFICATION DIRECTIONS OF STEEL ANNEALING SPHEROIDIZATION

For studies of the steel annealing spheroidization intensification process, we take as a basis the equation of the spheroidization speed process (V_{sp}), which, like most structural transformation processes, is written in the following form:

$$V_{sp}=A\cdot KF\cdot TF, \tag{1}$$

where *A* is the ratio that depends on the structural transformation type, *KF* – kinetic factor, *TF* – thermodynamic factor.

We consider the main features of the metal structural transformations. In the first stage of long product annealing, the spheroidization process is based on the kinetic factor (*KF*). The direct analytical relationship to determine such a factor is described as follows:

$$KF=\gamma\cdot e^{-\frac{\Delta G_a^D}{R\cdot T}} \tag{2}$$

where: γ is the thermal oscillations frequency; ΔG_a^D is the component diffusion activation energy, which determines the change in the morphology of the structural component; *R* is the gas constant; *T* is the temperature.

The spheroidizing annealing intensification process of a long steel product is run due to the thermodynamic factor (*TF*), which is determined from the ratio:

$$TF=(1-e^{-\frac{\Delta G_{TDF}}{R\cdot T}})\cdot grad(\Delta G_{TDF}) \tag{3}$$

where: ΔG_{TDF} is the thermodynamic driving force of this structural transformation (*ST*); $grad(\Delta G_{TDF})$ is the gradient of the ST thermodynamic driving force.

Note that the relations (2) and (3) analysis show that if the *KF* value is a temperature increasing function, then the *TF* value decreases the temperature function.

Directly graphical interpretation of changes in the thermodynamic factor (*TF*) and kinetic factor (*KF*) values in the cementite complex spheroidization process is given in Figure1.

Here, line 1 shows the thermodynamic factor influence on the cementite spheroidization intensification process; line 2 is the kinetic factor influence on the cementite spheroidization intensification process; line 3 shows the general trend of these factors on the cementite spheroidization process.

Definition 1. The influence lines intersection on the thermodynamic and kinetic factors spheroidization process is called the point of thermodynamic equilibrium.

Definition 2. The spheroidization process interval up to the point of thermodynamic equilibrium (when *TF>KF* is called the interval of cementite active spheroidization process.

Definition 3. The spheroidization process interval after the point of thermodynamic equilibrium (when *TF<KF* is called the interval of cementite passive spheroidization process.

Therefore, in the interval of cementite active spheroidization process, the thermodynamic driving force of the spheroidization process can change the processing speed by over three orders of magnitude. On this interval of cementite spheroidization, the procedure of spheroidization intensification by non-isothermal holding is performed. However, as shown in Figure 1 (line 1), such a component is the decreasing temperature function. At the same time, the kinetic factor (Figure 1 line 2) is the temperature increasing function. The feature is used for non-isothermal holding by raising the temperature at a specific rate. The process compensates for the decrease in *TF* due to the increase in *KF.* Against the background of these factors, we can state the general trend of the cementite complex intensive spheroidization due to the main properties of non-isothermal metal holding, which is shown in Figure 1 line 3. Therefore, the evolution study of reducing the steel spheroidizing annealing duration allows noting the main factors of complex intensification of the metal annealing process.

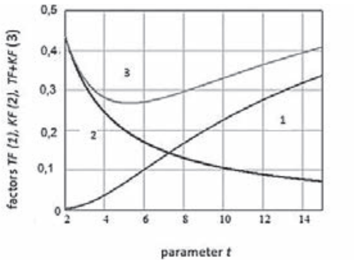


Figure 1 Graphic interpretation of changes in the values of thermodynamic and kinetic factors in the cementite complex spheroidization process

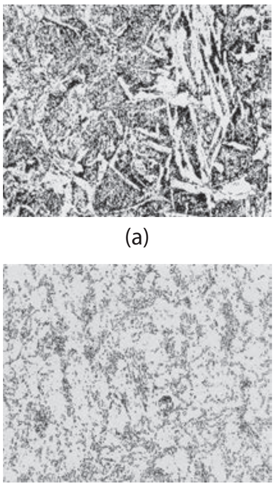
First, it is necessary to prepare the required metal structure by pre-heat treatment, which eliminates the formation of structurally free ferrite, and the austenite to bainite conversion is run by the type of isothermal forging. That ensures a uniform distribution of cementite globules in the ferrite matrix, which does not lead to the possible viscous cracks.

Secondly, those temperature regimes of cementite spheroidization include changes in thermodynamic (*TF*) and kinetic (*KF*) factors during structural transformations. Under such conditions, non-isothermal holding with increasing temperature with a specific heating rate is used for cementite spheroidization. That compensates for the decrease *TF* by *KF* increase.

Third, the heating by the internal coolant at the spheroidization stage to obtain the Heveling effect for heterophase structures. The effect is provided by a local increase in temperature in the microregions in the interfacial zone of ferrite-cementite, i.e., based on existing ideas about the spheroidization mechanism, wherein the diffusion rate of the components is crucial for the required structural transformation.

EXPERIMENTAL STUDIES

For experimental research, the installation was used to intensify the long steel product spheroidizing annealing [6]. In this case, several experiments were performed when the wire of 20 mm diameter of 20G2R and



(b)

Figure 2 Steel 20G2R microstructure:
a) initial ferritic-bainitic (martensitic) structure, x 500;
b) structure after annealing - granular perlite (score 2), x 500

30G1R steel were subjected to heat treatment. The main feature of experimental research was that, on the one hand, according to Figure 1, the process of non-isothermal aging was realized. On the other hand, temperature control was carried out by a multiprocessor computing system with its corresponding mathematical and IT software.

On the other hand, the multiprocessor computing system has blocks that allow obtaining information about the current parameters of controlled processes. Its peculiarity is that at each technological processing stage of the billet, a two-dimensional thermal conductivity problem is solved. The multiprocessor computing system software allows controlling the temperature, both on the entire cross-sectional plane of the billet and its length. The control of such temperature regimes is carried out in the center of the billet's cross-sectional plane.

The metal microstructure study was performed by the »Neophot21« microscope. The metal's mechanical properties were determined by uniaxial stretching by a standard technique on the FU-10000ez device. The metal hardness was determined by Brinell using an TSH-2M instrument.

Consider a typical experiment

The billets' ferritic-bainite (martensitic) structure served as the initial one. The material heat treatment was run by heating the billet within the intercritical zone. The following values of critical points are set for a given material: Ac_1 = 725 °C; Ac_3 = 795 °C. The heating was to the value: Ac_1 + (10 – 30 °C). In the next stage of material processing, the 45 seconds isothermal holding process was implemented. Then the cooling process continued at a speed of 13 – 22 °C/s to the temperature of 620 °C followed by non-isothermal holding when the billet was heated at a rate of 13 – 22 °C/s to subcritical temperatures.

During the experiment, the structure formation in the billet material was analyzed. Figure 2 a shows the initial ferrite-bainite (martensitic) structure of the metal. Figure 2, b demonstrates the final view of the material structure after spheroidization. The structure is granular perlite with a standard score of 1 point; its hardness is 148 − 169 HB.

Therefore, the carbide phase spheroidization in the billet heat treatment corresponding modes provides the material with a granular perlite structure. Moreover, the high-speed spheroidization causes a more uniform distribution of cementite globules in the ferrite matrix (Figure 2, b). Steel billets of almost the same hardness after heat treatment acquired a fine structure, which provides a higher level of metal ductility.

CONCLUSION

The proposed approach for the steel spheroidizing annealing intensification allows:

– Due to non-isothermal holding with increasing temperature to ensure a high level of intensification of the spheroidizing annealing and, as a consequence, to obtain a minimum spheroidizing annealing duration of low-carbon steels with a prepared initial structural state.

– To control the technological parameters of the steel spheroidizing annealing intensification, particularly heating, holding, and cooling temperatures in isothermal and non-isothermal holding modes on the entire cross-sectional plane and along the billet length, using a multiprocessor computing system.

– Significantly reduce the direct steel spheroidizing annealing duration, which allows synchronizing and significantly reducing the technological process of manufacturing of the finished steel product in general.

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Note: The responsible for English language is V. V. Busygin, Dnipro, Ukraine