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The analysis of the microstructure of steel S460NL1 in the conditions of thermo-mechanical treatment

J. Markowski*, M. Knapiński, B. Koczurkiewicz, H. Dyja, A. Kawałek
Institute for the Modelling and Automation of Plastic Working Processes,
Faculty of Process & Material Engineering and Applied Physics,
Czestochowa University of Technology, Al. Armii Krajowej 19, 42-200 Czestochowa, Poland
* Corresponding author: E-mail address: jarekm@mim.pcz.czest.pl

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Analysis and modelling

ABSTRACT

Purpose: The application of new technologies requires, however, modern rolling mills. Indeed, in manufacturing plants of older types, strict compliance with the developed rolling regimes is not always feasible. Improving the mechanical properties in such cases in only possible by means of cooling.

Design/methodology/approach: The testes carried out in this work was performed using the dilatometer DIL 805 A/D with the internal adapter for the plastic deformation of specimen.

Findings: Diagrams of austenite decomposition during continuous cooling of steel have been developed, which are essential for the modernization of the technology of cooling plates of steel S460NL1. Dilatometric tests have been complemented with the results of metallographic examinations.

Practical implications: The results of the researches carried out have allowed to project new technology of thermo-mechanical treatment for this steel grade. These results was used for the physical simulation of normalizing rolling process.

Originality/value: By controlling cooling conditions, structures differing in mechanical properties can be obtained for the same material. Accurate understanding of a structure forming when different cooling conditions are applied enables the control of the process that assures intended structures and mechanical properties to be achieved.

Keywords: Materials cesign; Thermo-mechanical treatment; Physical simulation; Phase transformation

1. Introduction

Technological progress entails the development of many branches of industry. Increased demand for steel and tough competition in the steel product market compel manufacturers to constantly improve their products by enhancing the mechanical properties of finished products and reducing the costs of their manufacture. Technologies for the manufacture of hot rolled products have been developed in recent years, which combine the features of both heat treatment and plastic working, enabling the enhancement of the level of properties [1-2,4,6,8-11,13]. One of them, which is the most often applied, is the normalizing rolling technology that assures a structure of fine pearlite to be obtained, which exhibits very good mechanical properties [3,5,7,12,14-15].

2. Material and methodology of the work

In the investigation carried out within the present study, steel S460NL1 of chemical composition, as shown in Table 1, was used.

To determine tentatively the cooling rates that would enable austenite decomposition diagrams to be plotted accurately, preliminary simulation studies were carried out. The commercial program TTSteel was used for this purpose. The results of the model studies made it possible to select proper cooling rates that were used in physical simulations of cooling using a DIL 805A/D dilatometer. During these simulations, variations in specimen length as a function of temperature were recorded.

To develop CTPc diagrams for the steels under consideration, dilatometric tests were performed on 10 mm-long, 5 mm-diameter cylindrical specimens. During the experimental tests, the specimens were heated up to a temperature of 900°C, soaked at this temperature for 3 minutes, and then cooled down to ambient temperature at different cooling rates. On the basis of the numerical simulations, the following cooling rates were adopted: Cr_1=80°C/s, Cr_2=30°C/s, Cr_3=10°C/s, Cr_4=5°C/s, Cr_5=1°C/s, Cr_6=0.5°C/s and Cr_7=0.1°C/s. As a result of the above procedure, dilatograms were obtained, in which the temperatures of phase transitions were determined following the applicable standard.

Table 1.
Chemical composition of steel S460NL1

C	Mn	Si	P	S	Cr
0,14	1,55	0,42	0,019	0,004	0,08
Ni	Mo	Cu	Al	N_2	V
0,077	0,02	0,18	0,031	0,016	0,115
Nb	B	Ti	Sn	Ca	B
0,015	0,0001	0,003	0,014	0,0013	0,0001

As a result of the test, a series of dilatograms were obtained for the steel tested, as cooled at different rates. The temperatures of phase transitions were determined in accordance with the applicable standard. The obtained dilatograms and the performed metallographic examinations have enabled a CTPc diagram to be plotted, which is shown in Figure 1.

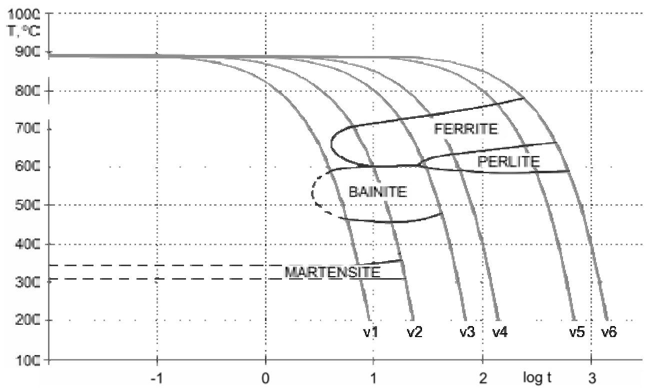

Fig. 1. Developed CTPc diagram for steel S460NL1; V_1- V_7 – steel cooling rates; V_1=80°C/s, V_2=30°C/s, V_3=10°C/s, V_4=5°C/s, V_5=1°C/s, V_6=0.5°C/s

Figure 2 presents photograph of an example structure obtained from the metallographic examination of dilatometric samples of steel S460NL1 cooled at different rates.

Figure 2 presents the structure of steel S460NL1 obtained during cooling at a cooling rate of 5.0°C/s. fine-grained ferritic-pearlitic structure is visible, a banding of structure is not visible.

The lower cooling rate - 0.5°C/s allows to obtain a fine-grained ferritic-pearlitic structure with a grain size of 8 and 9 and a structure banding. Whereas the higher cooling rate - 80°C/s allows to obtain a martensitic-bainitic structure.

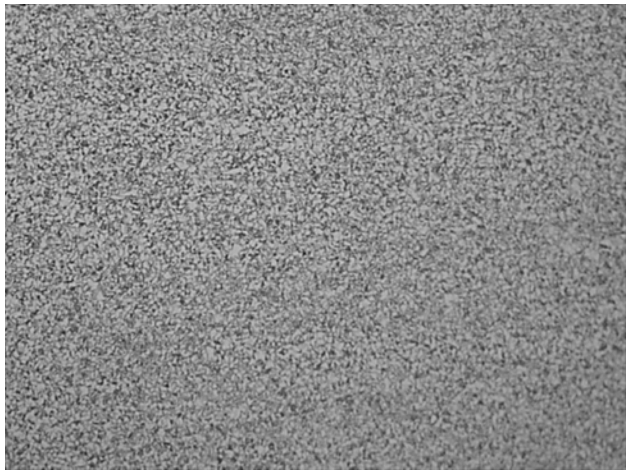

Fig. 2. Structure of steel S460NL1 obtained during cooling at a rate of 5.0°C/s, magn. 100x

The developed CTPc diagrams, as presented above, can be used for developing technologies for the heat treatment of steel S460NL1. During normalizing rolling, due to a mechanical influence on the material, the CTPc diagram does accurately reflect the phenomena occurring in the material. Therefore, in order to determine the actual properties of a material subjected to heat treatment and plastic working, an OCTPc diagram has been developed for the steel investigated.

Table 2.
Deformation parameters

Pass	Temperature T, °C	Strain, ε	Deformation speed, 1/s
1	930	0,10	10,0
2	900	0,05	10,0

To develop an OCTPc diagram (Fig. 3) that would account for deformation for the steel under consideration, plastometric tests were performed on 10 mm-long, 5 mm-diameter cylindrical specimens. During the experimental tests, the test specimens were heated up to a temperature of 930°C, soaked at this temperature for 3 minutes and then cooled down to ambient temperature after a cycle of deformations from the temperature of 900°C at cooling rates of Cr_1=80°C/s, Cr_2=30°C/s, Cr_3=10°C/s, Cr_4=5°C/s, Cr_5=1°C/s, Cr_6=0.5°C/s and Cr_7=0.1°C/s, respectively. Two passes were taken into account in the tests. The average values of strain parameters was determined, which are given in Table 2. As a result of the above procedure, dilatograms were obtained, and metallographic examinations were carried out on the specimens that had been subjected to heat treatment and plastic working, revealing the structure formed.

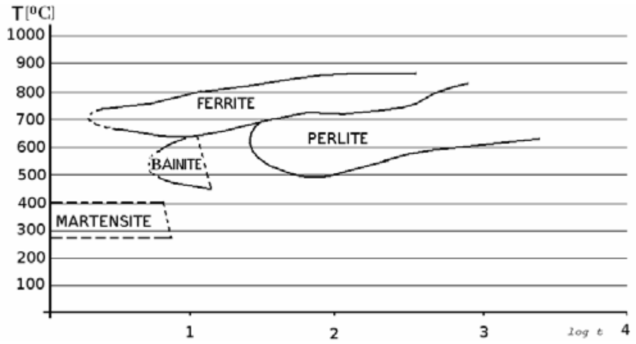

Fig. 3. An OCTPc diagram for steel S460NL1

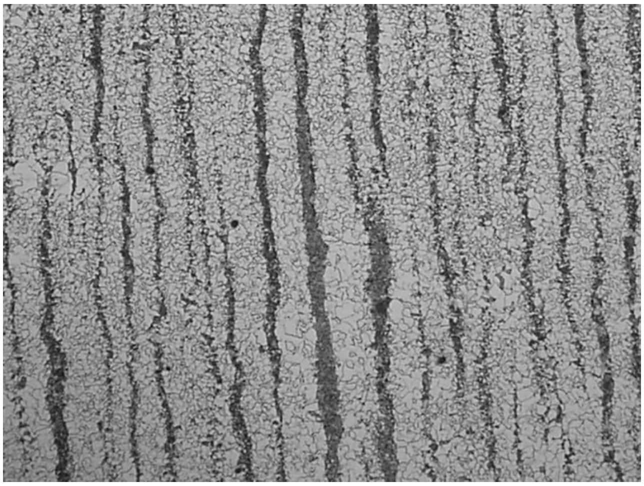

Fig. 4. Microstructure of a specimen obtained after a cycle of deformations followed by cooling at a rate of 0.5°C/s, magn. 100x

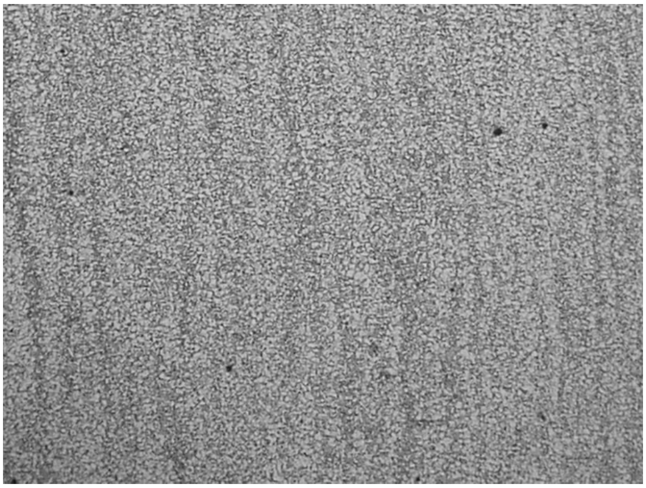

Fig. 5. Microstructure of a specimen obtained after a cycle of deformations followed by cooling at a rate of 5.0°C/s, magn. 100x

Figures 4 to 6 show photographs of structures obtained from different heat treatment and plastic working operations performed on steel S460NL1.

Figure 4 shows the structure of steel S460NL1 obtained after a cycle of deformations followed by cooling at a cooling rate of 0.5°C/s. ferritic-pearlitic structure is visible; a ferrite grain size of 8 to 10; fine pearlite with a grain size of 10. A high structure banding.

Figure 5 shows the structure of steel S460NL1 obtained after a cycle of deformations followed by cooling at a cooling rate of 5.0°C/s. A fine-grained ferritic-pearlitic structure is visible; a grain size is 10. A low structure banding.

Figure 6 illustrates the structure of steel S460NL1 obtained after a cycle of deformations followed by cooling at a cooling rate of 80°C/s. A martensitic-bainitic structure can be seen, a structure banding is visible.

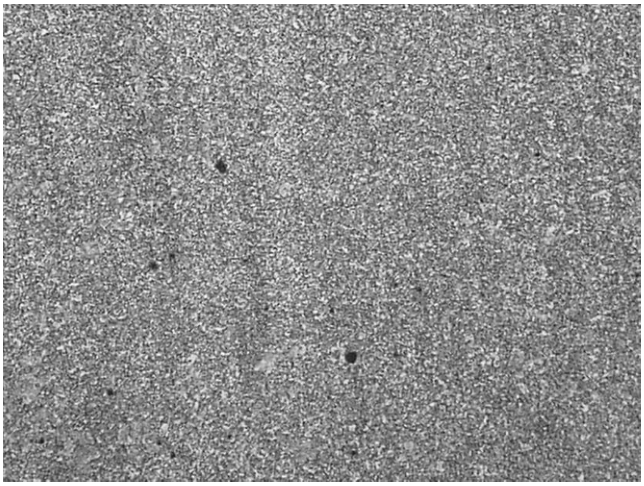

Fig. 6. Microstructure of a specimen obtained after a cycle of deformations followed by cooling at a rate of 80.0˚C/s, magn. 100x

3. Summary

The characteristics of the hot rolled products obtained are determined by the structure formed by way of plastic working and cooling. The technological progress and the growing demands of customers force manufactures to constantly improve their products. To this end, steel working technologies are being developed, which employ a combination of plastic working and heat treatment with the aim of the enhancing strength properties of steel. Accurate understanding of a structure forming when different cooling conditions are applied after deformation enables the control of the process that assures intended structures and mechanical properties to be achieved.

When analyzing the data in Figures 1 and 2 it can be found that the cooling of steel S460NL1 at a cooling rates of 0.5°C/s to 5°C/s has resulted in a ferritic-pearlitic structure of a slight banding. The ferrite grain size is in the range from 8 to 10, while the pearlite grain size ranges from 9 to 10. Cooling at a rate of 10°C/s has resulted in the appearance of structures of pro-bainitic. Increased steel cooling rate, i.e. 30°C/s and 80°C/s, respectively, has yielded bainitic and martensitic-bainitic structures.

When analyzing the data in Figures 3 to 6 it can be found that the deformation has decreased the range of occurring bainite. The cooling rate ranges from 0.5°C/s to 30°C/s (after deformation) enable ferritic-pearlitic structures to be obtained. Higher cooling rates provide bainitic-martensitic structures. The investigation results presented in the paper will enable an optimal technology for the deformation and cooling of steel S460NL1 to be developed in order to obtain intended mechanical properties.

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