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ISSN 0543-5846
METABK 52(2) 239-242 (2013)
UDC – UDK 621.771:621.41:621.78=111

ANALYSIS OF THE MICROSTRUCTURE EVOLUTION DURING THERMO-MECHANICAL TREATMENT OF THE STEEL PLATES IN GRADE X80-X100

Received – Prispjelo: 2012-07-04
Accepted – Prihvaćeno: 2012-10-31
Preliminary Note – Prethodno priopćenje

In the work the results of the physical modeling of plate rolling process of HSLA steel were presented. The simulations were carried out using the Gleeble 3800 device and the anvils set for plane strain compression study. The aim of the simulation were a determination of a influence of changes in chemical composition of steel on obtained final structure and tensile strength of specimens after controlled deformation and accelerated cooling to room temperature. During investigation three grades of steels with a little different chemical composition were examined.

Key words: rolling, plates, thermo-mechanical treatment, HSLA steels

INTRODUCTION

The construction of such pipelines requires the use of certain steel materials characterized by high strength and certain plasticity values. At the same time these materials enable production of the pipelines in which the increased operating pressure is not required using the pipes with reduced wall thickness. These activities are strongly motivated by the economic factors. Development of these materials started about 40 years ago thanks to introduction of the thermo-mechanical rolling technology and has been continued up to the present. The stimulus to the progress in this branch is a constant demand for large diameter pipes [1-3], and the thermo-mechanical process can be effectively used mainly during plate steel production. Nowadays grade X100 plates are produced at the industrial level and the works aimed at starting the production of grade X120 plates are being carried out [4].

It follows from the research results presented in work [4] that the use of steel with the increased strength to build gas pipelines may lead to significant economic results achieved mainly by the cost effectiveness of the used materials. The preliminary calculations showed that the use of X100 high pressure pipelines instead of X80 leads to costs reduction by about 7 %, however when comparing grades X70 and X100 the cost effectiveness may reach even 30 %. The summary cost reduction of the investment does not follow directly from the use of higher strength steel. It is mainly connected with the possibility of the use of the pipes with the smaller wall thickness. The manufacturers of large diameter supply pipes are not eager to decrease the wall thickness, although due to the use of higher strength steel it is possible to use the pipes with a smaller diameter and increase the operating pressure in the pipeline. This solution according to the authors of work [4] seems to be the most effective from the economic point of view. The production of the sheet metal of grade X80 is known in the world, however, its production has not been launched in Poland so far. Thanks to introduction of accelerated cooling after rolling in one of the rolling mills the topic seems to be very interesting again for the rolling mill which is situated in Poland and employs Polish workers [5].

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MATERIAL AND EXPERIMENTAL RESEARCH

In 2011 at the Institute of Modelling and Automation of the Plastic Working Processes of Czestochowa University of Technology the work was carried out with the aim to design the basis for the technology of controlled rolling of plates meeting the requirements of grades X80-X100 using the rolling plant line of one of the plate rolling plant in Poland.

On the basis of the data presented in technical literature at the beginning of the research three chemical compositions were selected which are currently being tested regarding their suitability for rolling in order to obtain the strength parameters required by grades X80-X100. These steels were conventionally numbered: 225, 227 and 228 and their chemical compositions are presented in Table 1.

The aim of the carried out research was to determine the influence of the end of rolling temperature and the rate of cooling after rolling on the structure and the mechanical properties of the steels with little different chemical composition. The experiments were carried out with the help of GLEEBLE 3800 using the perpen-

Table 1 **Chemical compositions of selected steels / mas. %**

Steel no. 225				
C	Mn	Si	Mo	Ni
0,06	1,81	0,22	0,22	0,19
Cu	Nb	Ti	N	CE_{IIW}
0,25	0,02	0,012	0,002	0,435
Steel no. 227				
C	Mn	Si	Mo	Ni
0,09	1,92	0,35	0,20	0,11
Cu	Nb	Ti	N	CE_{IIW}
0,12	0,05	0,023	0,003	0,465
Steel no. 228				
C	Mn	Si	Mo	Ni
0,06	1,93	0,27	0,30	0,23
Cu	Nb	Ti	N	CE_{IIW}
0,02	0,04	0,03	0,005	0,458

dicular specimens and the anvils which enable obtaining the plate state of deformation during compression [6, 7]. Simulation of rolling was carried out to take into account deformation of the metal in the phase of the rough rolling and the finishing rolling. The examined specimens were heated to the temperature of 1 180 °C, then soaked for 300 s and then cooled to the temperature of 1050 °C with the rate of 0,5 °C/s. At this temperature two deformations took place, the temperature gradually decreased. The end of the second deformation took place at 1 000 °C, after that the specimens were cooled with the rate of 0,5 °C/s to the temperatures determined as the beginning of the simulation of the finishing rolling. The temperatures were selected so that after six deformations with the gradual decrease of the temperature to obtain the following temperature values of the end of deformation: 800 and 780 °C. Table 2 shows the scheme of deformation, interpass times and temperatures used during simulation of the rolling process. After the end of deformation the specimens were cooled to the temperature of 300 °C with the controlled rates which were: 1, 10 and 30 °C/s.

Table 2 **Scheme of deformations and temperatures applied in the simulation of rolling**

Operation	Strain	Strain rate	Time of operation / between operations	Temperature var. I / II
	-	1/s	s	°C
Reheating	-	-	118 / -	1 180
Soaking	-	-	300 / -	1 180
Cooling	-	-	260 / -	1 050
Reduction 1	0,16	1,75	- / 40	1 030
Reduction 2	0,16	1,75	- / 60	1 000
Cooling	-	-	185 / -	838 / 818
Reduction 3	0,1	5	- / 7	838 / 18
Reduction 4	0,1	5	- / 9	834 / 814
Reduction 5	0,1	5	- / 11	829 / 809
Reduction 6	0,1	5	- / 14	821 / 801
Reduction 7	0,1	5	- / 17	811 / 791
Reduction 8	0,1	5	- / -	800 / 780

MICROGRAPHIC ANALYSIS

The specimens after the simulating process with accelerated cooling were cut in the plane indicated by the deformation direction and the direction of their height, and on the obtained cross sections the metallographic polished sections were made which were itched with nital. Due to this the microstructures which appeared in the steels were revealed. They are presented in Figures 1-6.

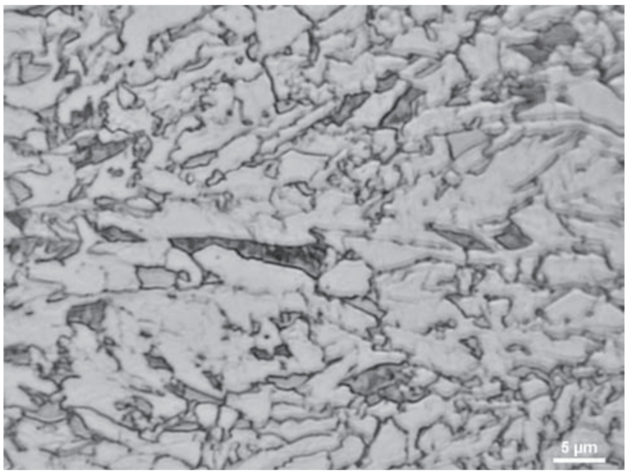

Figure 1 Microstructure of the steel no. 225 – the end of rolling at temperature 800 °C, cooling rate is 1 °C/s; mag. x1000

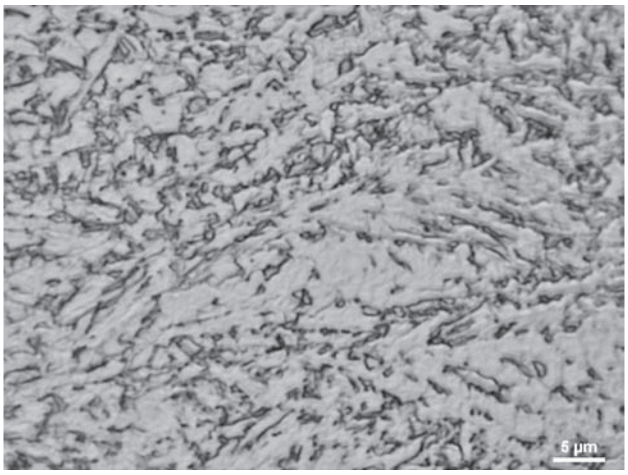

Figure 2 Microstructure of the steel no. 225 – the end of rolling at temperature 780 °C, cooling rate is 30 °C/s; mag. x1000

Observing obtained microstructures can be state, that irrespective of chemical composition of steels and irrespective of the temperature of the end of rolling, cooling at the rate of 1 °C/s leads to obtaining ferritic structures with different morphology and a little pearlite content (Figures 1, 3). A lower temperature of the end of deformation causes an increase in the acicular ferrite in its structure.

An increase in the cooling rate to 10 °C/s causes appearance of the ferritic structure of different morphology – fine-grain ferrite and acicular ferrite (Figure 5),

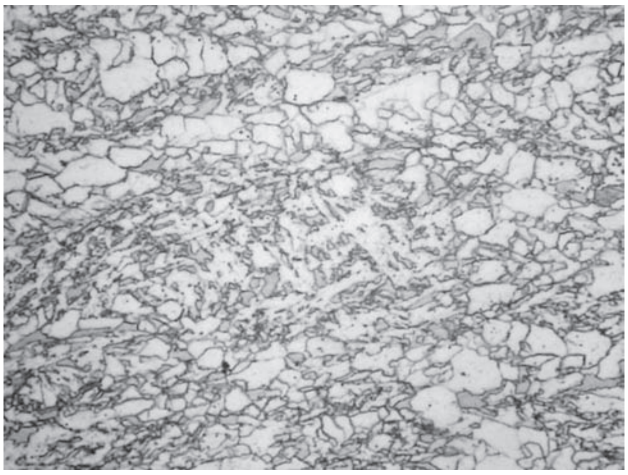

Figure 3 Microstructure of the steel no. 227 – the end of rolling at temperature 780 °C, cooling rate is 1 °C/s; mag. x1000

Figure 4 Microstructure of the steel no. 227 – the end of rolling at temperature 780 °C, cooling rate is 30 °C/s; mag. x1000

more than that, a small number of carbides precipitated in the base or on the borders of the ferrite plate in the case of a lower temperature of the end of rolling. The use of the maximum of the examined cooling rates, that is 30 °C/s resulted in obtaining of the bainitic structures

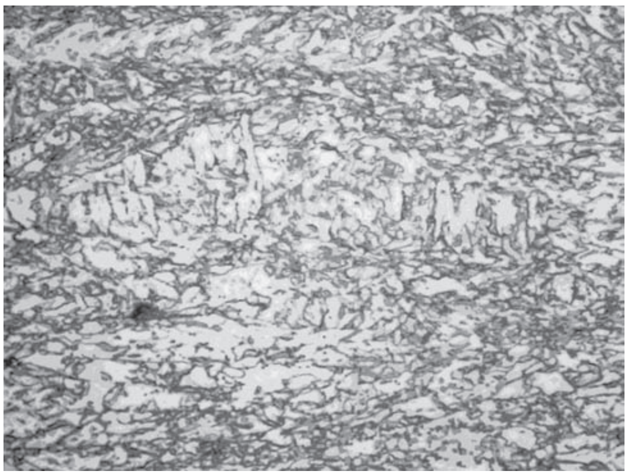

Figure 5 Microstructure of the steel no. 228 – the end of rolling at temperature 800 °C, cooling rate is 10 °C/s; mag. x1000

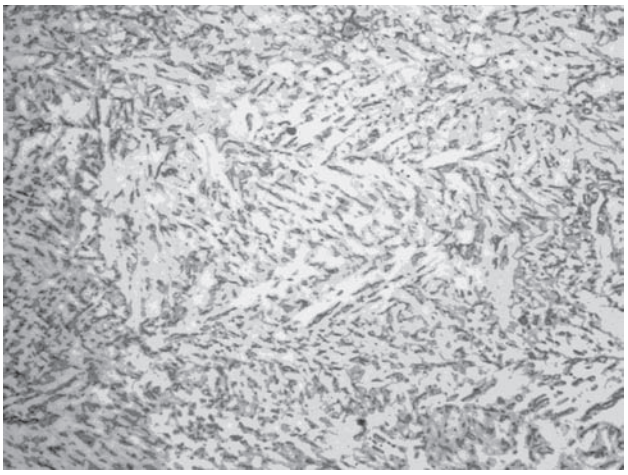

Figure 6 Microstructure of the steel no. 228 – the end of rolling at temperature 780 °C, cooling rate is 30 °C/s; mag. x1000

of different ferrite plate size (Figures 2, 4, 6). On the borders of the ferrite plates precipitations of the carbides is observed.

TENSILE STRENGTH EXAMINATION

From the specimens after the rolling simulation the "micro-specimens" were taken to carry out the strength tests. Unfortunately, the small volume of the tested material disabled carrying out the standard proportional specimens for the static tension tests. It was possible to make specimens of 4 mm of height and the cross section of 12 mm² from the tested steels. The specimens were tension with the machine Zwick Z100 for strength tests, and from the obtained research results it was possible to determine the tensile strength R_m. The determined values of R_m of the steel in all tested cycles of the deformation and cooling are presented in Table 3.

Table 3 **Tensile strength of examined steel for diÃerent finish rolling temperatures (T_{fr}) and cooling rates (CR)**

T_{fr} / CR / °C / °C/s	St. no. 225 R_m / MPa	St. no. 227 R_m / MPa	St. no. 228 R_m / MPa
800 / 1	417	682	645
800 / 10	509	695	656
800 / 30	554	752	702
780 / 1	422	715	654
780 / 10	608	723	654
780 / 30	677	878	707

SUMMARY

The carried out experiments showed that using proper thermo-plastic treatment and controlled cooling after deformation it is possible to control the steel structure and thus the mechanical properties of the final item. It was proved that thanks to the described schemes of deformation it is possible to obtain the steels whose strength exceeds 760 MPa if accelerated cooling with the rate of 30 ^{o}C/s is used – for chemical composition no. 227. The results of tensile strength examination show that tensile strength values are strongly depend on chemical composition of the steel. The highest values of R_m parameter were obtained for the steel with the highest content of carbon and the highest carbon equivalent. The optimal steel structure which guarantees achievement of the intended strength properties is the mixture of the upper and lower bainite with a small number of acicular ferrite. The static tension tests of the specimen showed significant plasticity. Thanks to the measures of its entire length made after the tensile test it was possible to estimate the elongation of the material which relating to the length of a base "micro-specimen" was within the range of 17-25 %. The reason for such a large elongation is probably the presence of the significant number of the polygonal ferrite in the structure which enables the deformation of the steel. Thus, its presence may have a disadvantageous influence on the limit of plasticity value which could not be clearly determined in the tests and which is probably too small regarding the API 5L norm requirement for grade X100. It is essential to modify the temperature and deformation schemes in the thermo-plastic treatment phase which will lead to the end of rolling at a higher temperature and will prevent grained ferrite precipitations. The tests connected with the choice of the optimal conditions of controlled rolling and cooling after the final deformation for the selected steels and some corrections of the chemical composition are still carried out and their results will be published in further works.

Acknowledgement: The work was done within the research project # NR07 0047 10 under the title: "Designing of asymmetric rolling plate technology and controlled rolling with accelerated cooling of the plates after the process of rolling from the new steel grades"

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Note: The responsible translator for English language is Elina Szago-Lalak, ONJO SAS, Czestochowa, Poland