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THE INFLUENCE OF CHEMICAL COMPOSITION ON STRUCTURE OF PLATE X100 AFTER PHYSICAL SIMULATIONS OF FINISHING ROLLING PROCESS WITH ACCELERATED COOLING

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Preliminary Note – Prethodno priopćenje

The research presented in the current paper was carried out for the experimental steel designed for plate which meets the requirements for grade X100 according to API5L. The tested steel is fine-grained constructional steel for making tubes for gas pipelines with minimal yield point of 690 MPa and tensile strength over 760 MPa. The laboratory tests were obtained that in the structure the polygonal ferrite were observed. That may have a disadvantageous influence on the limit of plasticity value X100 steel. The corrections of the chemical composition were carried out. The temperature and deformation schemes in the thermo-plastic treatment phase were determined.

Key words: HSLA steels, controlled rolling, accelerated cooling, plate rolling, physical modeling

INTRODUCTION

In 2011 at the Institute of Modeling 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. The production of the sheet metal of grade X80 to X100 is known in the world, however, its production has not been launched in Poland so far. This problem is specially important taking into account the state of polish steel industry in terms of membership in the EC [1].

On the basis of the data presented in technical literature [2-4], 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 [5]. These steels were conventionally numbered: 225, 227 and 228 and their chemical compositions are presented in Table 1.

Table 1 **Chemical compositions of selected steels [5] / 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

MATERIAL AND EXPERIMENTAL RESEARCH

The carried out experiments [5, 6] showed that using proper thermo-plastic treatment and regulated 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 ºC/s is used. 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 tear 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 25 - 30 %. 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. For eliminate polygonal ferrite from the structure the higher cooling rates are needed. In industrial condition it isn’t possible. The plates have a large volume and accelerated cooling of them needs a higher consumption of water in cooling device. There is therefore a need to modify the chemical composition, to reduce the amount of ferrite-forming elements, and thus the shift in the

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graphs of ferritic bay on TTT diagrams towards longer cooling times. Based on 227 and 228 steels new chemical composition of experimental steel were developed and presented in Table 2.

Table 2 **Chemical compositions of selected steels / mas. %**

Steel no. 350				
C	Mn	Si	Mo	Ni
0,076	1,91	0,23	0,27	0,20
Cu	Nb	Ti	N	CE_{IIW}
0,08	0,05	0,025	0,004	0,512
Steel no. 355				
C	Mn	Si	Mo	Ni
0,04	1,92	0,35	0,20	0,11
Cu	Nb	Ti	N	CE_{IIW}
0,12	0,05	0,023	0,003	0,437

Ingots of the square 10 000 mm^2 was subjected to preliminary rolling at a thickness of 60 mm. From slab samples 10 mm height 15 mm width and 20 mm length for physical simulation of rolling were cutting. The Gleeble 3800 device with Hdrawedge II module [7, 8] was used. The main aim of study was determinate the influence of deformations during finish rolling process on structure investigated steels. Grade steel samples 350, 355 were heated at a constant rate (10 ºC/s) to the deformation temperature then annealed for 120 seconds, and deformed. A detailed flow diagram of the tests are shown in Figure 1 and parameters of deformation are shown in Table 3.

The examined specimens were heated to the temperature of 900 ºC, then soaked for120 s. After that four

Table 3 **Scheme of deformations in the simulation of rolling**

Operation	Strain	Strain rate
Reduction 1	0,25	5
Reduction 2	0,16	5
Reduction 3	0,12	5
Reduction 4	0,1	5

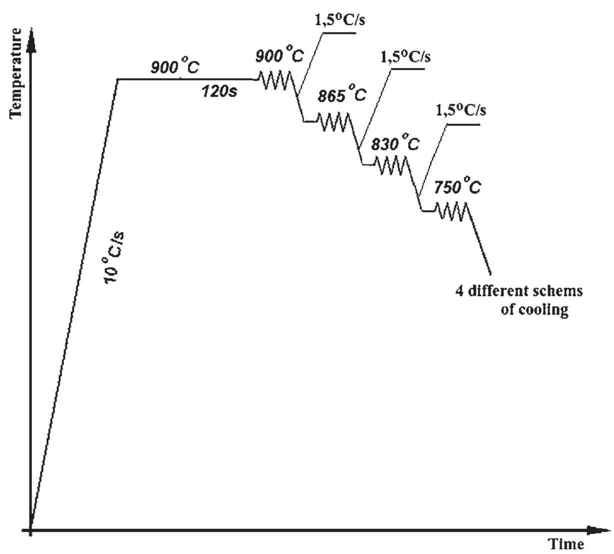

Figure 1 The diagram of experimental research

deformations took place, the temperature gradually decreased. The cooling rate between deformation steps was 1,5 ºC/s. The end of deformation took place at 750 ºC, after that the specimens were cooled with the different cooling conditions. Based on [6] the cooling conditions for obtain mixture of upper bainite and lower bainit microstructure with probainitic ferrite without martensite islands were determined.

After deformation 4 schemes of cooling were done:

1. free cooling of plates (1 ºC /s);
2. accelerated cooling of the mixture of water and air (10 °C / s);
3. accelerated cooling of the mixture of water and air (30 °C / s);
4. regulated cooling simulation: accelerated cooling at a rate of 30 °C / s to 550 °C temperature and subsequent cooling rate 0,7 °C / s to room temperature.

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. Due to this the microstructures which appeared in the steels were revealed. The structure of 350 steel after metallographic research are presented on Figures 2, 3.

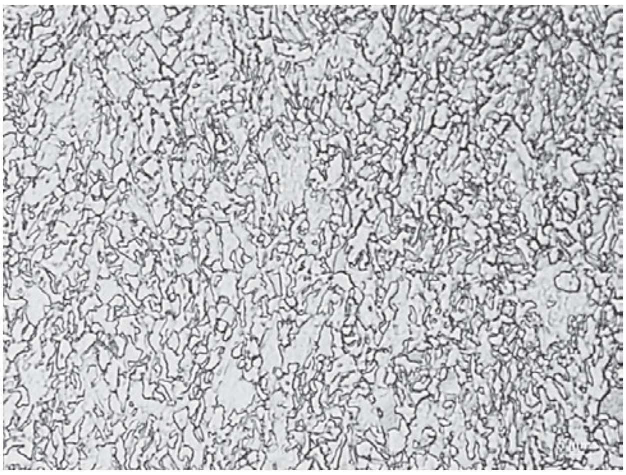

Figure 2 The microtructure of 350 steel cooled to temperature 550 °C with cooling rate 30 °C/s and to 300 °C with cooling rate 07 °C/s to; room temperature, mag. x1000

Observing obtained microstructures it can be concluded that the structure consist with mixture of ferrite with varying morphology and upper bainite with precipitates of cementite Fe_3C between the slats of ferrite and carbide precipitates and carbide - nitride inside the ferrite grains (Figure 2) or mixture of ferrite with varying morphology and upper bainite (Figure 3).

The analysis of results of experiments showed, that structures consist from mixture of upper and lower

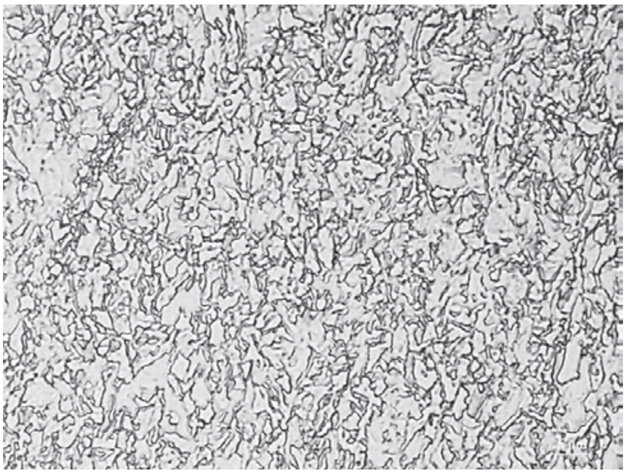

Figure 3 Microstructure of the steel no. 350 – the end of rolling at temperature 780 °C, cooling rate is 30 °C/s; mag. x1000

bainite and polygonal of needle-shaped ferrite were obtained for all of developed cooling schemes after multi-deformation steps of 350 steel. For cooling rate 30 °C/s martensite islands were observed. This kind of structure is undesirable in steel plates for pipelines. In some case of using cooling rate in the range 10 - 30 °C/s high level of hardness can lead to low levels of yield strength. The most preferred option for enables to obtain in finished product a complex structure with the strength and plastic properties is the accelerated cooling to a temperature of 550 °C followed by slow (0,7 °C/s) cooling to a temperature of 300 °C, and cooling to ambient temperature freely. So run the cooling process favors the formation of bainitic structures with needle-shape ferrite. The structure of 355 steel after metallographic research are presented on Figures 4, 5. Observing obtained microstructures it can be concluded that the structure consist with upper bainite and polygonal ferrite with irregular precipitates of cementite Fe_3C and carbide – nitride (Figure 4) and a mixture of upper bainite and polygonal ferrite with carbide precipitates and a small amount of acicular ferrite (Figure 5).

Figure 4 Microstructure of 355 steel cooled to temperature 550°C with cooling rate 30 °C/s and to 300 °C with cooling rate 0,7 °C/s to; room temperature, mag. X1000

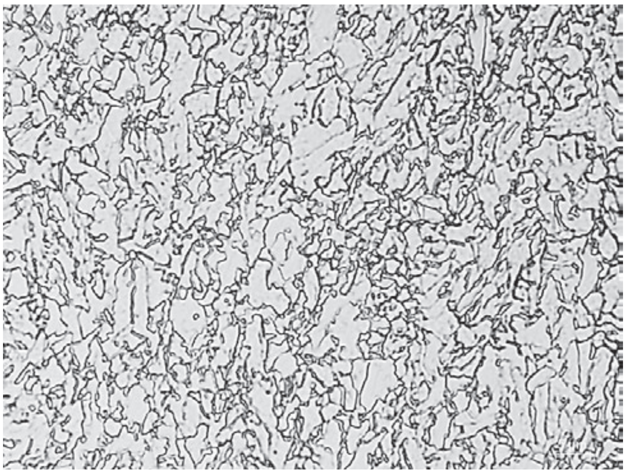

Figure 5 Microstructure of 355 steel cooled to temperature 300 °C with cooling rate 10 °C/s , mag. x1000

Analysis of results of 355 steel showed that the reduced end of the deformation temperature (750 °C) and variants of the cooling do not provide for obtaining requested structures in the sheets for large diameter pipes. The accelerated cooling to a temperature of 550 °C with subsequent slow cooling to a temperature of 300 °C, and accelerated cooling to a temperature of 300 °C caused upper bainite structure and the lower bainite structure were formed. The polygonal ferrite was formed too. His presence in steels of this type is not conducive to achieving a high level of mechanical properties. The most preferred option is this case is end of rolling process in 850 °C an accelerated cooling to a temperature of 550 °C followed by slow cooling (cooling rate 0,7 °C/s) to a temperature of 300 °C and further cooling to freely ambient temperature.

TENSILE STRENGTH EXAMINATION

The Vickers hardness of specements were measured by Future Tech FV-700 hardness testing machine.

Based on equations (1, 2) a yield strength and tensile strength were determined too.

$$R_e = \frac{HV}{0,378} - 123,\ MPa \qquad (1)$$

$$R_m = \frac{HV}{0,352} + 70,\ MPa \qquad (2)$$

Table 4 **Yield strenght and tensile strength of examined steels**

Schem of cooling	St. no. 350 Vickers hardness	St. no. 350 R_e/R_m MPa	St. no. 350 Vickers hardness	St. no. 355 R_e/R_m MPa
1	210	432/666	205	423/705
2	235	498/738	215	498/733
3	260	565/808	229	535/773
4	335	763/1070	230	538/776

SUMMARY

As a result of the physical simulation of rolling sheets of species with a modified chemical composition was determined both conditions-temperature rolling deformation and temperature-time. The structures consist from mixture of upper and lower bainite and polygonal of needle-shaped ferrite were obtained for all of developed cooling schemes after multi-deformation steps. In order to ensure a high level of yield strength for X100 grade steel according to API 5L is required fineness of the austenite structure using a higher total deformation. Next stage of research will be modeling of all rolling process with accelerated cooling to 550 °C with slow cooling to a temperature of 300 °C.

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Note: The responsible translator for English language is Bartosz Koczurkiewicz, Czestochowa University of Technology, Poland