INFLUENCE OF ROLLING TEMPERATURE AND COOLING CONDITIONS ON THE PROPERTIES AND MICROSTRUCTURE OF STEEL 23MnB4 FOR COLD-HEADING

KUC Dariusz, NIEWIELSKI Grzegorz, SCHINDLER Ivo, BEDNARCZYK Iwona

Silesian University of Technology, Katowice, Poland, grzegorz.niewielski@polsl.pl

Abstract

The article presents the results of tests of influence of the thermo-mechanical treatment parameters (such as temperature, cooling conditions) on the mechanical properties and microstructure of steel 23MnB4 indicated for cold-heading. The process of rolling was conducted in simulation in continuous finishing train arrangement of four rolling stands in a laboratory of Faculty of Metallurgy and Materials Engineering VSB Ostrava. Results of presented tests will be applied for optimization of the rolling process on rolling mill type MORGAN equipped with a system of regulated cooling Stelmor. Achieved results for steel 23MnB4 will be useful for optimization of heat-plastic treatment in order to achieve products with good mechanical properties.

Keywords: Hot rolling, 23MnB4 steel, wire rods, mechanical properties, microstructure

1. INTRODUCTION

Low-carbon steel types intended for cold-heading are rolled in modern continuous systems [1-3]. Linear velocity of rolling wire rod in such systems equals up to 120 m / s. In such dynamic conditions the parameters of rolling process and later cooling process play an important role in shaping the microstructure and mechanical properties. Constant growth in requirements concerning properties of the products needs improvement of manufacturing technology. Conduction of experiments in order to choose the optimal parameters of the process on industrial production lines is very difficult due to the need f application of a big amount of material in a singular process. That is why laboratory rolling mills are constructed to illustrate the conditions of the real rolling process in a more detailed way. An example of the above mentioned test can be the semi-production line for rolling in Bergakademie in Freiberg for [4] semi-industrial simulation of manufacturing processes of alloys and metal products (LPS) in IMŻ Gliwice (Institute for Ferrous Metallurgy) [5]. Another modern device for physical modeling of hot-rolling processed is the semi-continuous laboratory mill for rolling bars in VSB - Technical University of Ostrava, Faculty of Metallurgy and Materials Engineering, Czech Republic [6]. Initial rolling is conducted on reversing rougher, whereas the finish rolling was done on four-rolling stands of continuous finishing mill. Potential applications of semi-continuous laboratory are simulations of industrial rolling conditions, choice of optimal process parameters and regulated cooling of steel and alloys non-ferrous alloys. Cooling rate on industrial production line for rolling wire rod can be regulated on Stelmor line where in the final part the loops of the wire rod are arranged [7]. The change of cooling rate is possible through closed or open heat-insulating lids, forced airflow through ventilators and change of rate of roll conveyor movement. Cooling steel intended for cold-heading on Stelmor line is conducted very slowly which results in achievement of very coarse-grained ferritic-pearlitic microstructure with relatively low resistance to tension but beneficial plasticity. Increase of cooling rate may cause the increase of resistance in steel with satisfactory plasticity because the fine-grained ferritic-pearlitic microstructure without the presence of bainite. The aim of the paper was the analysis of the influence of rolling process parameters - temperature and cooling rate on microstructure and mechanical properties of investigated steel 23MnB4. Conditions of physical simulation were close to the real conditions present of industrial production line for rolling wire rod. Achieved results will be used to improve the process of rolling on industrial production lines.

2. METHODOLOGY

Materials for tests were rods made of steel 23MnB4 meant for wire rods for cold-heading. The content of particular chemical elements is defined in the norm PN EN 10263-4 (**Table 1**).

Table 1 Chemical composition of steel 23MnB4 according to norm PN EN 10263-4.

Content of chemical elements, [mass %]								
C	Mn	Si	S	Si	Cr	Cu	B	C
0.20÷0.25	0.90÷1.2	max. 0.3	max. 0.025	max. 0.025	max.0.3	max. 0.25	0.0008÷0.005	0.20÷0.25

Rods from steel 23MnB4 were gathered after continuous casting rolling in breakdown passes in 17 cage block. Further rolling was conducted on semi-continuous laboratory mill for rolling bars in VSB - Technical University of Ostrava, Faculty of Metallurgy and Materials Engineering. Czech Republic [5] Initial rolling of rods was conducted on 6 breakdown passes from diameter of ø 30 mm to ø 15.8 mm on a reversing rougher (**Figure 1a**). Before rolling the rods were heated to a temperature of 1100°C and held for 30 minutes. Finish rolling was performed on four-rolling stands of continuous finishing mill (**Figure 1b**) from diameter of ø 15.6mm to ø 9.8 mm. Finish rolling was conducted in three different temperature options: 750 °C, 900 °C and 1020 °C. There were two different types of cooling after rolling applied:

- cooling in air to a temperature of 550 °C (about 5 °C per second), and next with furnace with a rate of 0.4 °C / s to 400 °C and next in air to a temperature of surrounding.
- slow cooling with furnace with a rate of 0.4 °C / s to 400 °C and next in air to a room temperature.

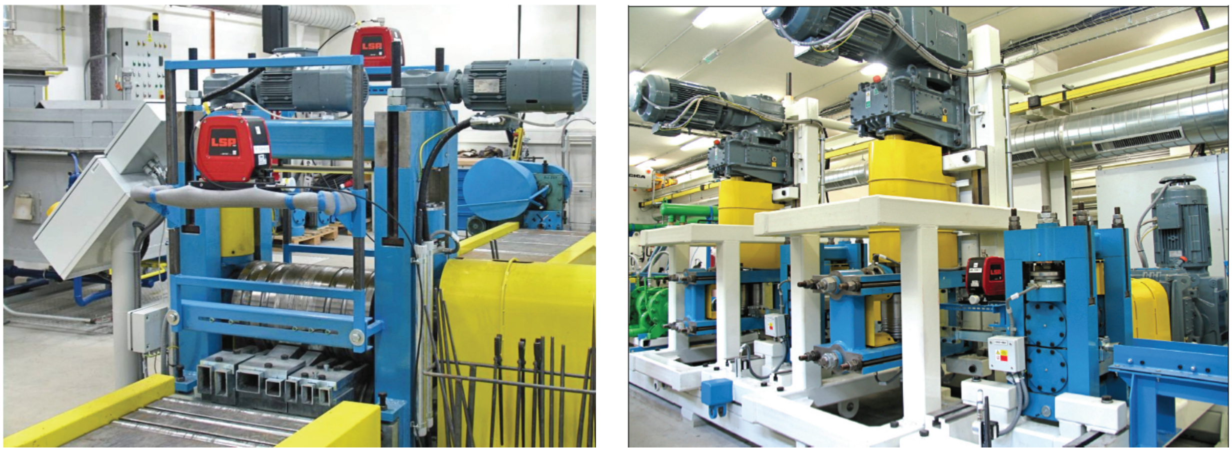


Figure 1 Semi-continuous laboratory mill for rolling bars. Reversing rougher (a), Horizontal and vertical rolling stands of continuous finishing mill (b).

After rolling the rods, there were tests of mechanical properties conducted - a static tests of tension and compression, hardness measurement and metallographic tests.

Samples with round cross-section were prepared from the rods with mechanical properties in accordance with norm PN-EN ISO 6892-1. Test of mechanical properties was conducted on testing machine Zwick/Roell Z100. On the basis of the test the following aspects were marked: Ultimate Tensile Strength (UTS), Yield point ($R_{p0.2}$), elongation (A_5) and reduction in area (Z). Tests were conducted on hardness tester Zwick type 3212002/00. Metallographic tests were conducted on light microscope type Olympus GX51 with magnification range from 200÷1000 x. With the use of specialised software of computer program METILO [8] to the quantitative assessment of microstructure the content of pearlite and the size of grains of pearlite and ferrite in microstructure were determined after rolling with varied parameters.

3. RESULTS OF TESTS

Cooling after rolling in laboratory roller can be conducted in air, slow in furnace or with water spray. Cooling with water spray causes too big overcooling and bainite can appear in microstructure of steel 23MnB4. That is why cooling is conducted in furnace or in air. Temperature changes in time function were registered after rolling and cooling in air. Rods cooled in air reached a cooling rate of average 5 °C / s (**Figure 2a**) and with such cooling rate it is possible to achieve ferritic-pearlitic structure which can be proved by observed changes on registered cooling curve (**Figure 2b**) and microstructure tests.

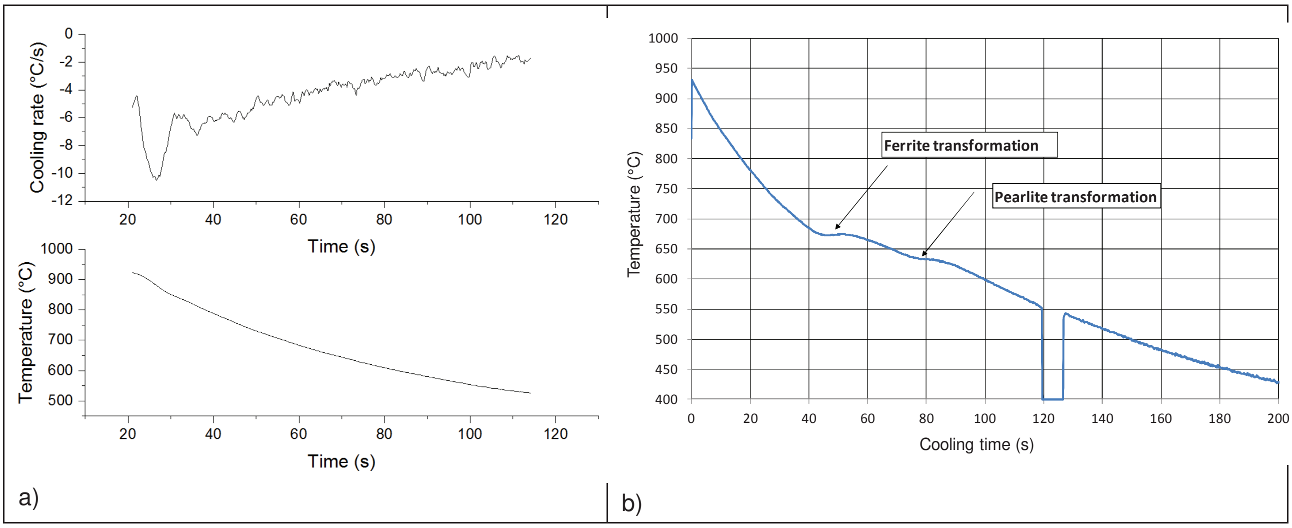
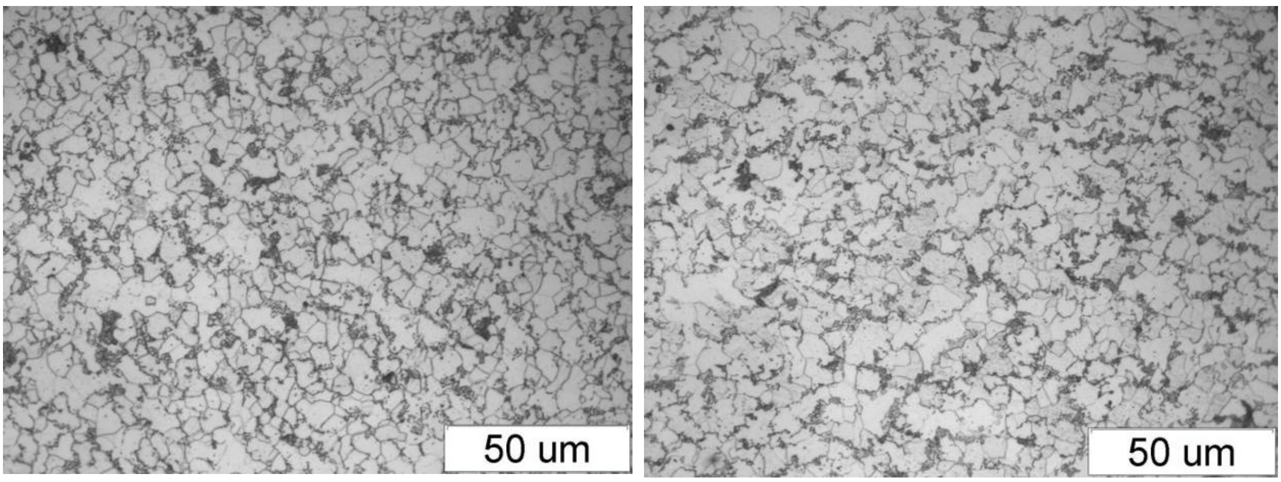
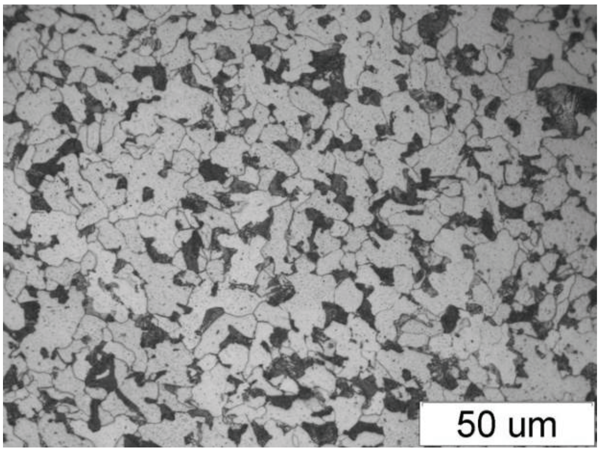


Figure 2 Registered cooling curve with the use of thermal-imaging scanners (a) [5], cooling rate of tested steel (b) for rod ø 9.8mm from steel 23MnB4 after rolling

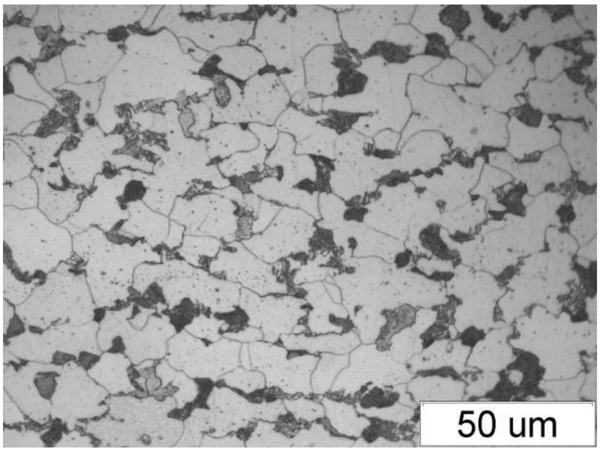
After rolling and cooling for the assumed parameters of temperature and the rate of cooling a ferritic-pearlitic microstructure was achieved in the rods (**Figure 3**). The microstructure of steel 23MnB4 for cold-heading significantly depends on the parameters of rolling and cooling (**Table 2**). Together with the elevation of rolling temperature from 750 °C to 1020 °C the grain size of ferrite and the colony of pearlite increase.



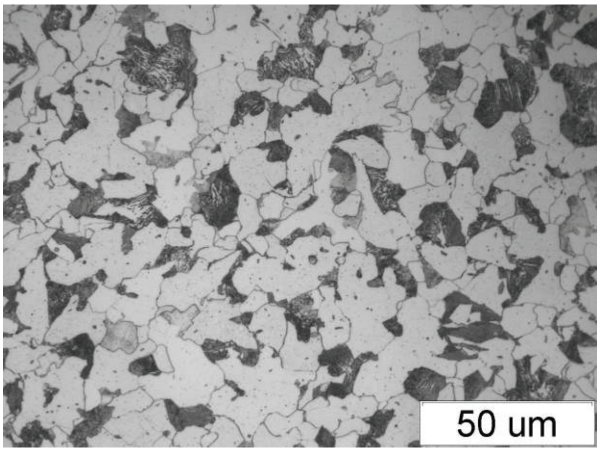
a) 750 °C (5°C/s) b) 750 °C (0.4°C/s)



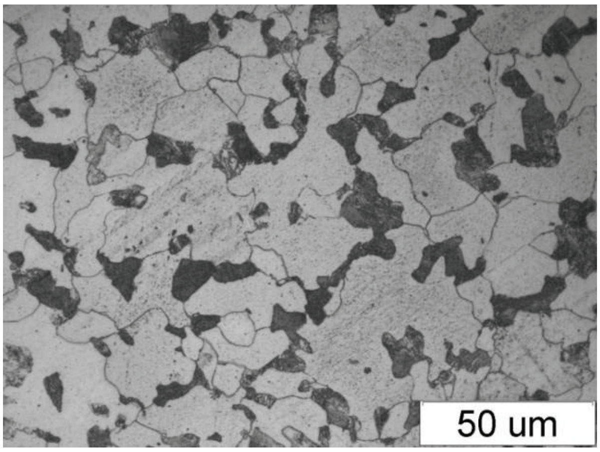
c) 900 °C (5°C/s)



d) 900 °C (0.4°C/s)



e) 1020 °C (5°C/s)



f) 1020 °C (0.4°C/s)

Figure 3 Microstructure of steel 23MnB4 samples after rolling in temperature of 750 °C (a), 900 °C (c) and 1020 °C (e) and cooling in air (5 °C / s) and after rolling in temperature of 750 °C (b), 900 °C (d) and 1020 °C (f) and next cooled in furnace (0.4 °C / s) (transverse section)

Samples after rolling which were slowly cooled in furnace are characterised with bigger size of ferrite grains and colonies of pearlite. It was found that the slight increase of the amount of pearlite occurs with the elevation of temperature of the end of rolling and the increase of cooling rate.

Table 2 Results of quantitative assessment of microstructure

Temperature of rolling + cooling	Volume of pearlite (%)	Pearlite grain size (μm)	Ferrite grain size (μm)
750 °C + 5 °C / s	20.4	3.22	5.01
900 °C + 5 °C / s	22.2	7.56	12.38
1020 °C + 5 °C / s	25.7	10.16	16.81
750 °C + 0.4 °C / s	18.2	4.25	7.76
900 °C + 0.4 °C / s	21.1	9.09	12.99
1020 °C + 0.4 °C / s	23.2	14.27	21.22

Flow curves of tested steel types 23MnB4, achieved in static tension tests, show a visible yield point (**Figure 4**).

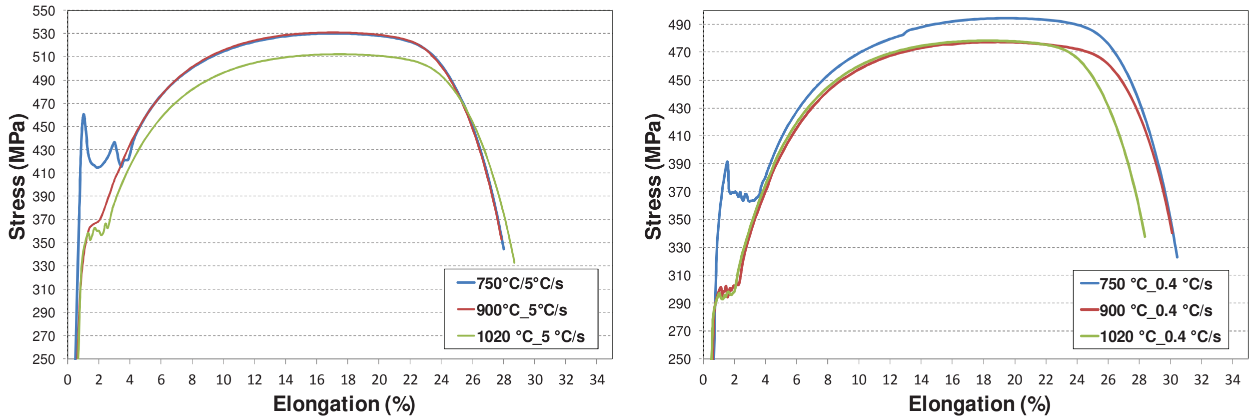


Figure 4 Stress elongation curves for samples of steel 23MnB4 after rolling in temperatures of 750, 900 and 1020 °C and cooling at a rate of average - 5 °C / s (a) and 0.4 °C / s (b)

Results of tests of mechanical properties of steel samples 23MnB4 are presented in **Table 3**. In samples cooled in air after rolling the course of changes in properties in monotonic. The biggest yield stress can be found in samples rolled in temperature of 750 °C and resistance achieved after rolling in 750 °C and 900 °C is comparably similar. The values of elongation and contraction in area are comparable. Samples cooled slowly with furnace show lower values of resistance and yield stress in comparison with the previously described samples. Elongation of samples, however, is slightly bigger for rolling temperature of 750 and 900 °C. In this option the biggest resistance to tension and yield stress can be found in samples rolled in temperature of 750 °C. Those values significantly decrease with the increase of temperature.

Table 3 Results of static tension test and hardness (HV1) of the rolled samples in temperature of 750, 900 and 1020 °C with cooling, first in air and then with furnace

Temperature of rolling + cooling	$R_{p0.2}$ (MPa)	UTS (MPa)	A_5 (%)	Z (%)
750 °C + 5 °C / s	445.2	529.8	28.0	45.0
900 °C + 5 °C / s	366.3	531.2	27.1	40.8
1020 °C + 5 °C / s	356.2	512.3	27.8	44.2
750 °C + 0.4 °C / s	380.0	494.3	29.5	48.0
900 °C + 0.4 °C / s	322.0	477.5	29.2	37.0
1020 °C + 0.4 °C / s	297.0	478.6	27.6	39.8

Samples for cold-heading with sizes ø 8 × 12 mm were taken from rods made of steel 23MnB4. Tests were performed on press ZDJT 30 with maximum pressure of 30 tonnes. Heading was conducted to 1/3 of the height (deformation of 33 %) and to 2/3 of height (deformation of 66 %). For all conducted options of rolling there were no surface defects found which can positively classify the rolled rods from steel 23MnB4 in accordance with the applied criterion of acceptance.

4. CONCLUSION

The conducted tests have shown a significant influence of rolling temperature and cooling rate on the microstructure and mechanical properties of steel 23MnB4 meant for cold-heading. At present, the temperature of the end of rolling equals between 850÷900 °C, and cooling temperature on Stelmor line is very small and equals about 0.4 °C / s. In the presented paper it was stated that if a lower temperature of rolling and a bigger rate of cooling is applied products with better yield stress and resistance to tension without the loss in plasticity can be achieved. Significantly meaningful increase can be achieved after lowering the rolling temperature to 750 °C. Correctly conducted process of production wire rod meant for cold-heading from steel 23MnB4 should allow for the achievement of material which, after being put into heading test, should provide properties of the ready product in the range of relative plastic strain of about 33 % (2/3 of the initial height). However, due to the constantly growing requirements of the recipients the properties of the manufactured wire rod need to be constantly improved even to heading to 1/3 of the initial height of 66 %. Achieved results of tests will be used to determine the mathematical dependencies between parameters of rolling process, mechanical properties and quantitative qualities of the ferritic-pearlitic microstructure such as presented in article [9, 10]. It will make the process of designing the modified technology of producing wire rod with elevated mechanical properties.

ACKNOWLEDGEMENTS

This work was supported by Research Project of The National Centre for Research and Development of Poland No PBS2/A5/32/2012

REFERENCES

[1] GROSMAN, F., WOŹNIAK, D. The modern wire rod mill. *Hutnik - Wiadomości Hutniczne*, 2001, no 3, pp. 97-104.

[2] CAMPBELL, P. C., HAWBOLT, E. B., BRIMACOMBE, J. K. Microstructural engineering applied to the controlled cooling of steel wire rod. *Metallurgical Transactions A*, 1991, vol. 22A, pp. 2791-2805.

[3] LABER, K. DYJA, H., KOCZURKIEWICZ, B. Analysis of industrial conditions during multi-stage cooling of C70D high-carbon steel wire rod. *Materials Testing*, 2015 vol 57, Issue 4, pp. 301-305.

[4] KAWALLA, R., GOLDHAHN, G., JUNGNICKEL, W. Laboratory rolling conditions and its effects on rolling parameters on material properties of hot rolled products. *In 2nd International Conference on Thermomechanical Processing of Steels.* Belgium - Liege, 2004, pp. 17-24.

[5] WOŹNIAK D., GARBARZ A. *Technological and constructional foredesign of LPS module for semi-industrial simulation of hot rolling and thermo-mechanical treatment of strip and bars*, Prace Instytutu Metalurgii Żelaza, 2012, No. 1, pp. 154-160.

[6] KAWULOK, P., KAWULOK, R., SCHINDLER, I., RUSZ, S., KLIBER, J., UNUCKA, P., ČMIEL, K. M. Credibility of various plastometric methods in simulation of hot rolling of the steel round bar. *Metalurgija - Metallurgy,* 2014, vol. 53, no. 3, pp. 299-302.

[7] GROSMAN, F., WOŹNIAK, D.: Technological aspects of wire rod rolling from modern steels, *Hutnik - Wiadomosci Hutnicze,* 2002, no. 11, pp. 408-414.

[8] SZALA, J. Application of computer image analysis method in the quantitative assessment of material structure. *Scientific Journal of Silesian University of Technology - Series Metallurgy*, Gliwice, 2000, vol. 61.

[9] KUC, D., NIEWIELSKI, G., CWAJNA, J. Influence of deformation parameters and initial grain size on the microstructure of austenitic steels after hot-working processes. *Materials Characterization*, 2006, no. 56, pp. 318-324.

[10] CIEŚLA, M., FINDZINSKI, R., JUNAK, G., KAWAŁA, T. The effect of heat treatment parameters on mechanical characteristics of 10CrMo9-10 steel tube bends. *Archives of Metallurgy and Materials*, 2015, vol. 60. pp. 2961-2965.