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ANALYSIS OF THE TECHNOLOGY OF ROLLING 5,5 MM-DIAMETER WIRE ROD OF COLD UPSETTING STEEL IN THE MORGAN BLOCK MILL

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Preliminary Note – Prethodno priopćenje

The commercial technology of rolling 5,5 mm-diameter wire rod in Poland's most modern rolling line has been examined within the study. The material used for the investigation was the 20MnB4 steel intended for subsequent cold working. From the performed analysis of the investigation results it has been found that the technology of rolling wire rod of cold upsetting steel, which is used currently in the Rolling Mill under examination, allows the production of finished products that can be deformed with a relative reduction of about 33 %. At larger plastic deformations, cracks occur in the material, which disqualifies it from further cold working.

Keywords: wire rod rolling, cold upsetting steel, mechanical properties, numerical modelling, thermovision examination

INTRODUCTION

Maintaining the leading position in the market by wire rod manufacturers is only possible by continuous broadening of their product range offer and enhancing the product quality in respect of mechanical and plastic properties and dimensional accuracy [1, 2].

In the opinion of the authors of study [3], the examined technological lines and the production technology employed in them do not currently allow the production of wire rod meeting the continually increasing demands of purchasers for the level and stability of its mechanical properties, i.e. the wire rod of quality achieved by the world's leading manufacturers.

Wire rod of cold upsetting steel is used for making fasteners, such as screws, nuts, bolts, etc. Rolled products of these steels should be characterized by a uniform microstructure and stable mechanical properties, as well as high surface quality, tight dimensional tolerances and good formability in subsequent cold plastic working. These steels should be easily weldable and should assure cheap manufacturing of products of complex shapes [3].

The cold deformability of metallurgical products is determined in the upsetting test. Manufactured wire rod should cold deform with a strain not less than 0,5 and a relative specimen height reduction ratio after upsetting of 50 % [4]. In view of the constantly growing requirements of purchasers, efforts should be made to improve the properties of produced wire rod.

TEST PURPOSE AND SCOPE OF THE STUDY

The paper examines the industrial technology of rolling 5,5 mm-diameter wire rod in one of the most modern wire rod rolling lines enabling rolling at high speeds, which, for 5,5 mm-diameter wire rod, is 110 m/s.

The material used for the investigations discussed in this paper was 14 m-long 160 mm-square side 20MnB4 [5] steel stock (concast slab), which was heated up to a temperature of 1 150 °C ± 20 °C in a stepper furnace.

The band temperature distribution during the rolling process, as determined numerically and measured in industrial conditions, was examined. For numerical modelling of the rolling process, which determined the band temperature values at individual rolling process stages, among other things, FORGE® [6], a software program relying on the finite-element method, was employed. The following initial and boundary conditions were assumed in the examination: the coefficient of heat exchange between the band and the rolls α_{roll} = 3 000 W/m^{2}K; the coefficient of heat exchange between the band and the air, α_{air} = 100 W/m^{2}K; the coefficient of heat exchange between the band and the water box water, α_{water} = 5 000 W/m^{2}K; the friction coefficient, $\mu = 0,4$; and the friction factor, $m = 0,8$.

For the measurement of the rolled band temperature under industrial conditions, a ThermaCAM SC640 thermovision camera supplied by FLIR Systems was used. For the processing of obtained results, the ThermaCAM Reporter™ software was employed. The following object parameters were assumed for thermovision examinations: emissivity, 0,82; the distance of the camera from the object, 3 m; ambient temperature, 20 °C; and relative humidity, 50 %.

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In addition, metallographic examinations were carried out within the study, which determined the average ferrite grain value.

At the next stage of the study, selected mechanical properties of the finished product were determined using the static tensile test.

In addition, to establish the possibility of further cold working of the investigated material, cold upsetting tests were carried out.

INVESTIGATION RESULTS

The exact values of the average band temperature and surface temperature before and after individual rolling passes and the values of error between the values computed numerically and measured with the thermovision camera are shown in Table 1.

Table 1 **Computed and measured band temperatures in particular rolling stands**

Stand No.		Average band temperature computed numerically, $t_{avg.}$ / °C		Lateral band surface temperature computed numerically, $T_{lat.}$ / °C		Lateral band surface temperature measured in actual rolling process, $T_{lat.}$ / °C		Error δ / %	
		before stand	after stand	before stand	after stand	before stand	after stand	before stand	after stand
1	Cont. medium-section mill	1 131	1 120	1 086	1 028	1 083	-	-	-
2		1 089	1 108	1 063	1 064	-	-	-	-
3		1 090	1 097	1 050	988	-	-	-	-
4		1 080	1 081	1 033	1 038	-	-	-	-
5		1 076	1 078	1 022	979	-	-	-	-
6		1 075	1 076	1 010	1 015	-	-	-	-
7		1 074	1 075	1 009	984	965	-	4,55	-
8		1 068	1 069	1 014	1 019	-	-	-	-
9		1 069	1 072	1 015	1 007	-	-	-	-
10		1 071	1 076	1 022	1 029	-	-	-	-
11		1 080	1 080	1 028	1 028	-	-	-	-
12		1 082	1 084	1 042	1 048	-	-	-	-
13		1 086	1 088	1 044	1 051	-	-	-	-
14		1 084	1 086	1 056	1 062	-	-	-	-
15		1 088	1 089	1 057	1 061	1 046	-	1,05	-
16		1 092	1 093	1 066	1 072	-	-	-	-
17		1 092	1 093	1 068	1 074	-	1 040	-	3,27
19	No-twist mill	921	925	872	890	840	-	3,81	-
28		1 010	1 015	990	995	-	950	-	4,74
29	Reducing sizing mill	770	782	734	754	780	-	5,9	-
32		810	799	781	781	-	-	-	-

Figures 1-2 show example band temperature distribution examination results, respectively, numerically computed and measured in the actual rolling process.

The analysis of the band temperature distribution in the 5,5 mm-diameter 20MnB4 steel wire rod rolling process has found that the numerically computed temperature values correspond to the industrially measured values with high accuracy. Considering the fact that (NTM and RSM) rolling stands in the Morgan block mill are encased, Table 1 only shows the data at the inlet and outlet of individual (NTM and RSM) rolling units. It is found from the analysis of the data in Figure 2 that the average surface temperature of the wire rod as it moved through the STELMOR cooling line was about 750 °C.

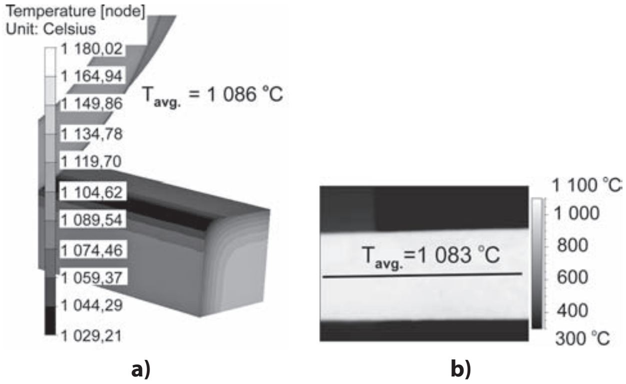


Figure 1 Distribution of band temperature upstream the rolling stand: a) numerically computed, b) measured using a thermovision camera

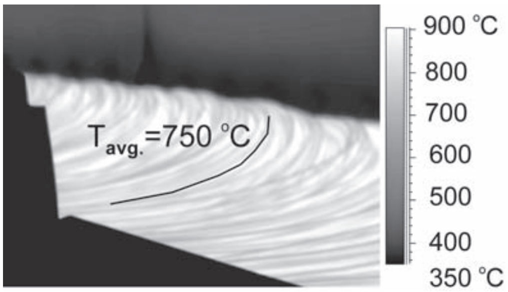


Figure 2 Thermogram of temperature distribution in the STELMOR cooling line

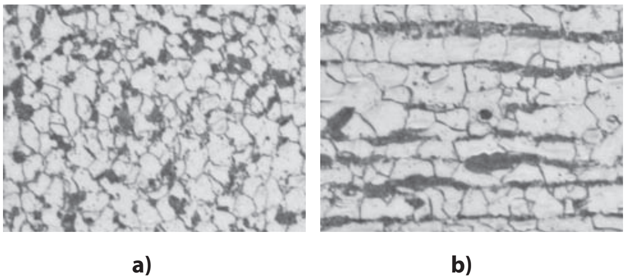


Figure 3 Microstructure of the 20MnB4 steel wire rod: a) cross-section, b) longitudinal section (banding)

The least error between the numerically computed band temperature and the band temperature measured during the real rolling process was obtained in rolling stand no. 1, which amounted to 1,05 %. The largest error between the numerically computed and the measured band temperatures was obtained for the band upstream the first stand of the RSM unit (stand no. 29) of the Morgan rolling line, which was 5,9 %. The difference between the computed and the measured band temperature values might be caused by the occurrence of a large amount of water vapour in the measurement locations.

Figure 3 shows example photographs of the microstructure of finished wire rod.

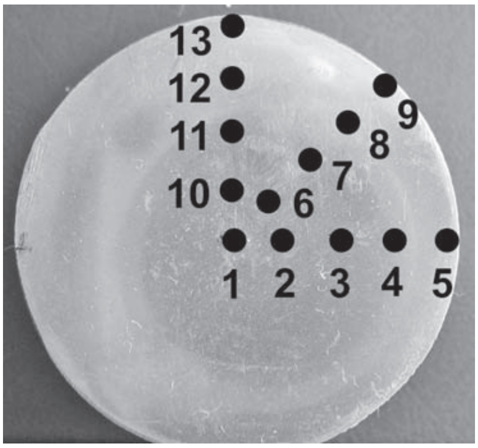


Figure 4 Cross-section of the 5,5 mm-diameter round wire rod with measurement points indicated

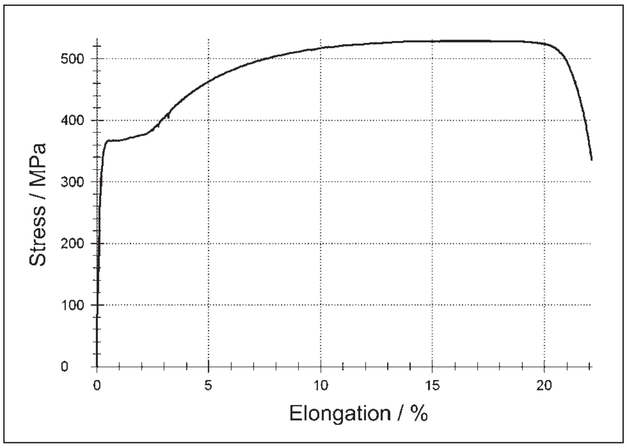


Figure 5 Example tensile test curve for steel 20MnB4

The average ferrite grain size values, calculated based on the microstructure photos taken at particular points on the cross-section of the 5,5 mm-diameter round wire rod (Figure 4), are given in Table 2.

Table 2 **Ferrite grain size distribution in the 5,5 mm-diameter round wire rod**

Meas. location	Average ferrite grain size in the analyzed area D_α / μm
1	20,2
2	19,1
3	19,6
4	19,1
5	17,9
6	19,8
7	22,5
8	22,9
9	17,0
10	19,8
11	21,6
12	23,8
13	19,7
Average value	20,2

The metallographic examinations have shown that the obtained wire rod has a pearlitic-ferritic structure, and the mean ferrite grain size on the finished product cross-section is about 20 μm.

The manufactured 20MnB4 steel wire rod has a banded microstructure that is characterized by the ferrite and pearlite occurring in the form of alternately lying bands. The formation of the banding might be caused by too low a rate of wire rod cooling, creating the possibility for the carbon to diffuse to a greater distance, which is necessary for the formation of wide ferrite bands. To reduce the banding, the band cooling rate should be increased, thus shortening the time in which the carbon diffusion can occur. Steels with a banded structure exhibit a large anisotropy of plastic properties, which are poorer in the direction transverse to the rolling direction.

At the next stage of the study, tests for the mechanical properties of the 20MnB4 steel wire rod manufactured following the rolling technology being currently in use. An example tensile test graph for the steel under examination is shown in Figure 5, while the average values of selected mechanical properties are summarized in Table 3.

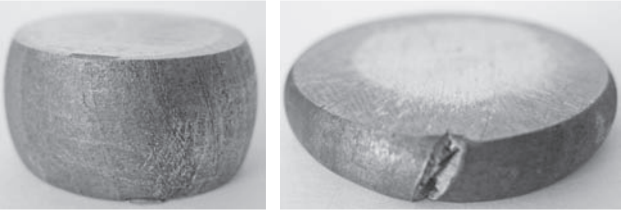
Table 3 **Average values of selected mechanical properties of steel 20MnB4**

Yield point, R_e / MPa	Tensile strength R_m / MPa	Elongation, A / %	Reduction of area, Z / MPa
358,21	527,02	20,1	72,53

At the subsequent stage of the study, the ability of the examined steel grade to be further plastically worked was determined. To this end, a cold upsetting test was carried out. In accordance with the applicable standards, cold upsetting wire rod should be characterized by a plastic strain of 0,5 and a relative specimen height reduction ratio after upsetting of 50 %.

A general view low-carbon steel specimens after cold upsetting up to the 2/3 of the initial height (a plastic strain of about 33 %) is shown in Figure 6a, while after upsetting up to the 1/3 of the initial height (a plastic strain of about 66 %), in Figure 6b.

From the cold upsetting test it has been found that the currently used technology of rolling cold upsetting steel wire rod assures the finished product properties in the plastic strain range up to 33 %. At larger plastic strains, cracks occur in the material, which disqualifies it from further cold working. So, the 20MnB4 steel wire



a) **b)**

Figure 6 View of the specimens after the cold upsetting process: a) upsetting up to the 2/3 of the initial height; b) upsetting up to the 1/3 of the initial height rod does not meet the currently applicable standards for the ability to being further cold worked.

At the final stage of the study, the examination of the dimensional accuracy of the obtained wire rod in respect of the currently applicable standards was carried out. The diameter of the wire rod manufactured according to the currently applicable technology was 5,6 mm. The achieved dimension conforms to the applicable standards, although it lies in the positive range of the permissible dimensional deviation.

In line with the world's industrial practice, efforts should be made to manufacture rolled products within the negative range of dimensional tolerance, which will make it possible to achieve considerable savings in metal and a reduction in the mass of finished product [7].

SUMMARY

From the investigation carried out it can be found that:

- the band temperature values obtained from numerical modelling correspond with high accuracy to the band temperature values measured during the actual rolling process. This confirms that the initial parameters assumed for numerical modelling were determined and selected correctly;
- the presently manufactured 20MnB4 steel wire rod has a bandy pearlitic-ferritic microstructure, which adversely affects the properties of the finished product;
- the average ferrite grain size in the wire rod produced according to the currently applicable rolling technology was about 20 μm;
- the yield point of the wire rod produced according to the currently applicable rolling technology was about 358 MPa, the tensile strength about 527 MPa, while the elongation about 20 % and the reduction of area about 73 %;
- the currently used technology of rolling the 20MnB4 steel wire rod assures the plastic working of finished products at a strain of up to 33 %. At a larger plastic strain, cracks occur in the material, which disqualifies it from further working.

The available technical literature lacks detailed studies on technologies for rolling cold upsetting steel wire rod. Therefore, it becomes justifiable to develop new technologies for rolling these steel grades, which will assure finished product of the required microstructure and mechanical properties, i.e. wire rod of the quality achieved by the world's leading manufacturers, to be obtained.

Acknowledgements

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Note: The professional translator for the English language is Czeslaw Grochowina, Studio Tekst, Poland