DETERMINATION OF OPTIMUM CONDITIONS FOR THE PROCESS OF CONTROLLED COOLING OF ROLLED PRODUCTS WITH DIAMETER 16.5 MM MADE OF 20MnB4 STEEL

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Abstract

This paper presents results of the examinations aimed at determination of the best controlled cooling conditions for wire rod with diameter 16.5 mm. The examinations were carried out for 20MnB4 steel grade for cold upsetting.

The first stage of the research was analysis of currently used wire rod rolling and cooling technology, with particular focus on controlled cooling process based on Stelmor technology. The effect of rolling technology on microstructure and mechanical properties of wire rod was evaluated. The next stage of the research was to prepare TTT and DTTT diagrams for the steel grade studied. The purpose of this research stage was to determine cooling rate for microstructure formation in the steel grade analysed in the study.

Based on the obtained diagrams and metallographic investigations, some modifications in wire rod controlled cooling process were proposed.

Keywords: 20MnB4 steel grade, wire rod for cold upsetting, controlled cooling, heat treatment, metallographic examinations

1. INTRODUCTION

There are a number of methods to improve quality and mechanical properties of hot-rolled steel products. The desired effect is usually obtained through proper choice of technology, and parameters of deformation and cooling. The most advantageous solution is to find close correlation between the above factors, which however involves the necessity of accurate controlling of rolling process and taking into consideration the important metallurgical phenomena [1÷3]. Complex processes that affect formation of a specific structure characterized by both high strength and plastic properties are occurring in steels after heat treatment [4]. Improving properties of carbon steels and low-alloy steels is also possible through introduction of accelerated cooling during and after the rolling process [5]. In the case of steel for cold upsetting, the accelerated cooling is aimed to help form the ferritic structure with finest grain possible, with its size reducing as the temperature of austenite-ferrite transition decreases. This temperature can be reduced by addition of alloy elements to steel and the application of the process of accelerated cooling [6].

In order to evaluate proper parameters of heat treatment it is necessary to carry out dilatometric examinations and prepare TTT and DTTT diagrams.

2. AIM AND SCOPE OF THE STUDY

The aim of the study was to determine the most beneficial conditions of cooling of rolled products with diameter of 16.5 mm made of steel for cold upsetting which should ensure the improvement in microstructure and properties of the final product. The examinations were carried out for 20MnB4 steel [7]. The first stage of the study was analysis of currently used technology of rolling and its effect on the microstructure and properties of final product. The second stage of the study was development of TTT and DTTT diagrams for the steel analysed in order to determine the effect of cooling rate on formation of the microstructure. Based on the analysis of the results obtained in the study, the authors proposed modifications in rolling technology.

3. ANALYSIS OF THE RESULTS

The examinations presented in the study were carried out in a rolling plant equipped in an extended system of multi-stage controlled cooling of the band. The charge in the rolling plant was a band from an average intermediate continuous rolling mill with temperature of ca. 1050 ºC. The first cooling zone was designed after initial rolling in the intermediate continuous rolling mill. The second cooling zone was located after the first rolling block, whereas the third cooling zone was located between the finishing block and the device for forming coils. The rolling line is finished with STELMOR cooling system.

In the process analysed in the study, the band moved from the intermediate continuous rolling mill was rolled only in four roll passes of the finishing block. Table 1 contains mean values of the parameters of accelerated band cooling for current rolling technology for wire rods with diameter of 16.5 mm made of 20MnB4 steel.

Table 1. Parameters of the process of multi-stage band cooling during rolling of wire rods with diameter of 16.5 mm made of 20MnB4 steel

Cooling zone		1	2	3
Pressure P, [bar]		3.66	4.35	0.14
Flows F, [l/min]		1541	1725	41
Temperature T, [ºC]	Entry	1041	928	858
	Exit	932	865	859

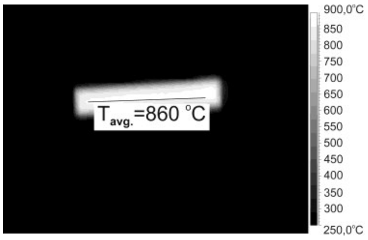

Fig. 1. Thermogram for temperature distribution in rolled wire rod with diameter of 16.5 mm made of 20MnB4 steel between coil former.

Cooling of the steel grade analysed in STELMOR system was performed with covers closed and fans turned off. Mean temperature of the rolled product surface at the entry to the STELMOR transporter was ca. 860 ºC (Fig. 1).

It was found that the rolled products obtained had an inhomogeneous pearlite-ferrite structure, whereas mean ferrite grain size in the cross-section of the final product was ca. 17 µm. The rolled products obtained from 20MnB4 steel have a band microstructure (Fig. 2), characterized by presence of ferrite and pearlite in the form of alternately deposited bands. The occurrence of the band structure might be caused by insufficient cooling rate that promotes carbon diffusion to the greater distance, which is necessary for formation of thick bands of ferrite. In order to reduce band structure, one should increase the speed of band cooling by shortening the time of carbon diffusion. Steels with band structure show high anisotropy of plastic properties, which are worse in the direction transverse to rolling.

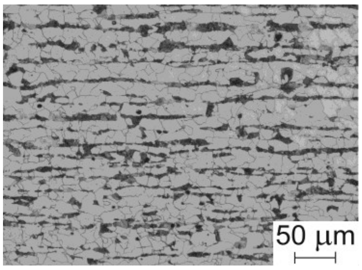

Fig. 2. Microstructure of rolled wire rod with diameter of 16.5 mm made of 20MnB4 steel: cross-section (band microstructure)

Yield point and tensile strength of this rolled product, calculated based on the relationships presented in the study [8] were R_e= 284.2 MPa and R_m=507.3 MPa, respectively.

As demonstrated in the study [9], this rolled product allows for further cold metal forming with relative strain of up to 50%. With greater plastic strain, the material begins to show cracking (Fig. 3)

Fig. 3. Specimen made of 20MnB4 steel after cold upsetting; relative plastic strain: 75%

The rolled product obtained in the study meets the requirements of current standards. However, due to increasing expectations of customers, the attempts are being made to improve the rolled products so that their cold working with relative strain of even 75% is possible.

Therefore, the next stage of the study was aimed at determination of the most favourable cooling conditions (after rolling process) that ensure improvement of mechanical properties and better capability of cold forming, the authors prepared real TTT and DTTT diagrams of the steel grade analysed. Firstly, the values of specific temperatures Ac_3 and Ac_1 were determined during heating. Steel specimens were heated continuously with constant heating rate of 3°C/min. The characteristic temperatures determined according to the standard [10] were: Ac_3 = 827 ºC and Ac_1 = 719 ºC. The value of temperature Ac_3 represented the basis for determination of the value of austenitization temperature of the specimens of the material during dilatometric tests used to determine temperatures of phase transitions that occur during continuous cooling.

During preparation of TTT diagrams for the steel studied, the austenitization temperature was adopted as T_A=880 ºC (T_A=Ac_3+50 ºC), whereas during preparation of DTTT diagrams, the specimens were heated to the temperature of 1050 ºC. Heat treatment diagrams used for preparation of real TTT and DTTT diagrams are presented in Fig. 4. During preparation of DTTT diagrams, specimens were deformed at the temperatures of 880 ºC, 870 ºC and 860 ºC. A cycle of three deformations was employed: $\varepsilon_1=\varepsilon_2=\varepsilon_3=0.2$ with strain rate of 10 s^{-1}, and breaks between deformations of 0.2 s.

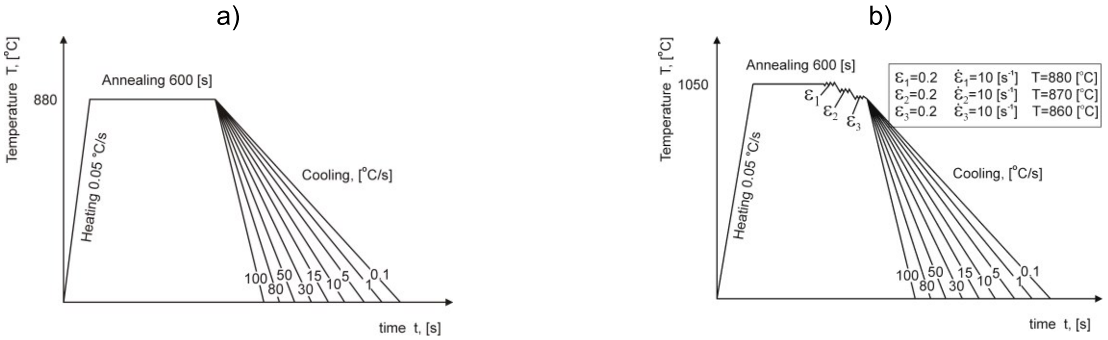

Fig. 4. Heat treatment diagrams used for preparation of TTT and DTTT diagrams for 20MnB4 steel

After annealing of the specimens at the austenitization temperature for 10 minutes (and additionally deformed in the case of DTTT diagrams), the specimens were cooled at varied cooling rates in the range of 0.1÷ 100 ºC/s. Based on the analysis of the dilatograms obtained, the temperatures of phase transitions that occur during continuous cooling (TTT diagrams) and during continuous cooling after deformation (DTTT diagrams) were evaluated. Metallographic analysis was carried out after dilatometric examinations to reveal the microstructure. The measurements of hardness and microhardness were also carried out. The measurements allowed for identification of the structural components. The results allowed for construction of real diagrams of phase transition kinetics under conditions of continuous cooling and continuous cooling after deformation.

Fig. 5 presents example photographs of the microstructure of the specimen made of 20MnB4 steel after heat treatment without deformation, whereas example photograph of the microstructure of the specimen of the steel grade studied after heat treatment with additional deformation is presented in Fig. 6.

Characteristic temperatures of phase transitions of the steel studied obtained based on the analysis of dilatograms during cooling and cooling after additional deformation are presented in Table 2. Table 2 contains also the values of hardness for the specimens studied.

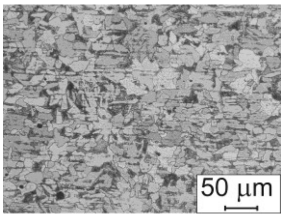

Fig. 5. Ferrite-pearlite microstructure of 20MnB4 steel cooled at the cooling rate of 1 °C/s: longitudinal section

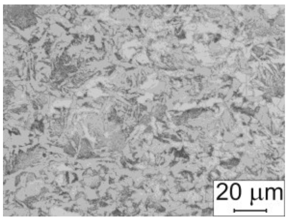

Fig. 6. Microstructure of 20MnB4 steel composed of the mixture of pearlite and ferrite cooled after deformation at the rate of 10 °C/s: longitudinal section.

Table 2. Characteristic temperatures of phase transitions and hardness of 20MnB4 steel

Cooling rates **Cr [ºC/s]**	TTT diagram		DTTT diagram	
	Characteristic temperatures [ºC]	**Hardness HV5**	**Characteristic temperatures [ºC]**	**Hardness HV5**
100	Ms=391 Mf=256	462.5	Ms=406 Mf=248	460.0
80	Ms=399 Mf=208	449.0	Bs=550 Bf=460 Ms=420 Mf=370	450.0
50	Bs=533 Bf=Ms=385 Mf=214	445.0	Bs=560 Bf=450 Ms=430 Mf=324	325.0
30	Fs=751 Ff=684 Bs=566 Bf=Ms=399 Mf=27	405.5	Fs=700 Ff=680 Ps=630 Pf=Bs=550 Bf=485	250.0
15	Fs=729 Ff=Bs=598 Bf=512	216.0	Fs=729 Ff=Ps=650 Pf=560	218.0
10	Fs=754 Ff=Ps=683 Pf=Bs=571 Bf=549	206.0	Fs=757 Ff=Ps=670 Pf=562	190.0
5	Fs=756 Ff=Ps=681 Pf=581	180.5	Fs=743 Ff=Ps=670 Pf=618	183.0
1	Fs=776 Ff=Ps=712 Pf=622	150.0	Fs=760 Ff=Ps=660 Pf=633	164.0
0.1	Fs=750 Ff=Ps=697 Pf=652	135.0	Fs=790 Ff=Ps=692 Pf=632	139.0

Real diagrams of phase transition kinetics occurring during continuous cooling and during cooling after deformation of 20MnB4 steel are presented in Figs. 7 and 8.

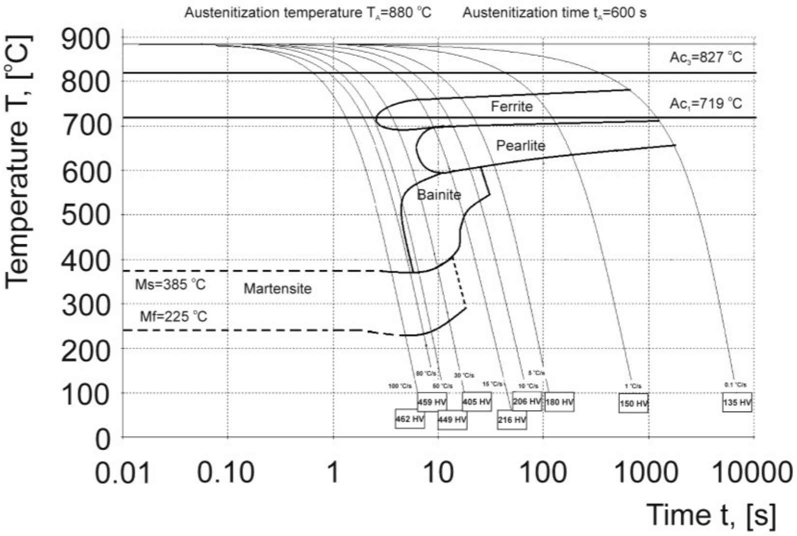

Fig. 7. Real TTT diagram for 20MnB4 steel

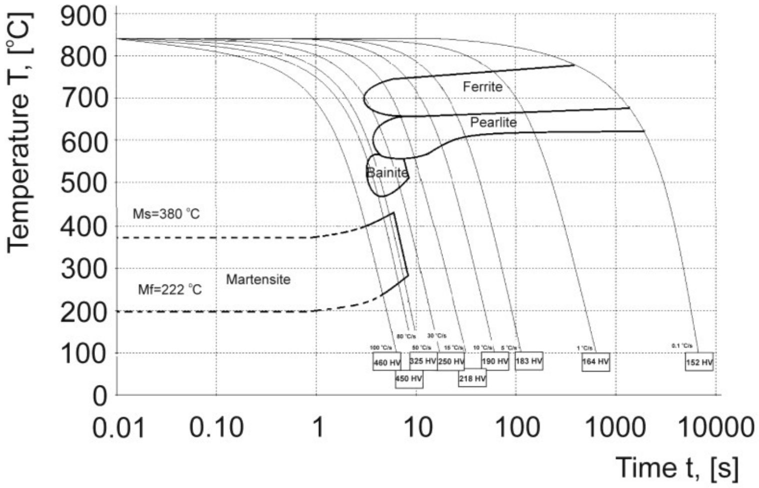

Fig. 8. Real DTTT diagram for 20MnB4 steel

It was found based on the analysis of the results obtained that cooling of the steel grade studied with the cooling rate from 0.1 to 15 ºC/s ensures formation of the ferrite-pearlite microstructure in the steel. Increasing the cooling rate results in formation of the bainite, bainite-martensite and martensite structure, which causes deterioration of the capability of the steel for further cold forming or, in extreme cases, it makes it impossible. It was found that the optimum range of cooling rates for 20MnB4 steel after the rolling process ranges from 5 to 15 ºC/s.

In the last stage of the study, with respect for the results of dilatometric examinations and the real TTT and DTTT diagrams obtained based on these examinations, the physical modelling of rolling process was carried out using Gleeble 3800 simulator, according to the parameters and methodology presented in the study [11]. Table 3 presents example results of the examinations of specimens after physical modelling of the rolling process. Yield point and tensile strength was determined based on the measurements of hardness according to the relationships presented in the study [8].

Table 3. Selected results of examinations of 20MnB4 steel after physical modelling of rolling process.

End rolling temperature, [°C]	Cooling rate after rolling, [°C/s]	Average ferrite grain size, [μm]	Average hardness, [HV]	Yield point R_e, [MPa]	Tensile strength R_m, [MPa]
860	1.75 (V1)	17.37	155.83	289.26	512.71
	2.24 (V2)	12.34	166.81	318.30	543.90
	5 (V3)	12.08	173.68	336.47	563.40
	10 (V4)	6.47	205.10	419.59	652.67
	15 (V5)	6.15	205.40	420.39	653.52
V – process variant					

It was found based on the results of physical modelling of rolling of wire rods with diameter of 16.5 mm made of 20MnB4 steel that mean size of ferrite grain in the specimen after physical modelling that reflected currently used rolling technology under industrial conditions (variant V1) was 17.37 µm. This value corresponds to the size of ferrite grain in the rolled products obtained under industrial conditions. Selected mechanical properties determined based on the measurements of hardness were also similar to the values obtained based on measurements of hardness of the real product. Consequently, this demonstrated that physical modelling of the rolling process was carried out properly. Analysis of the results of the study obtained for higher cooling rates after the process of rolling (variants: V2÷V4) found a favourable effect of increasing the cooling rate after rolling on the size of ferrite grain and selected mechanical properties of 20MnB4. Furthermore, the increase in cooling rate from 10 °C/s to 15 °C/s did not cause any noticeable improvement in mechanical properties of the steel grade studied.

CONCLUSIONS

This study was aimed to determine optimal cooling conditions for rolled wire rods with diameter of 16.5 mm made of 20MnB4 steel and to analyse the results obtained. The study showed that:

- currently obtained rolled products have a band pearlite-ferrite microstructure, which unfavourably affects the properties of final product, whereas current rolling technology ensures plastic cold working of final products with relative deformation of 50 %,
- characteristicc temperatures for the steel grade studied were: Ac_3 = 827 °C and Ac_1 = 719 °C,
- dilatometric examinations allowed for development of real TTT and DTTT diagrams for 20MnB4 steel and determination of optimal conditions for controlled cooling of rolled products during rolling process,
- cooling of specimens made of 20MnB4 steel with cooling rate in the range of 0.1 ÷ 15 °C/s ensures formation of ferrite-pearlite structures. Band ferrite-pearlite structure was observed only in the case of specimens cooled at the rate of from 0.1 to ca. 2 °C/s,
- the optimum ranges of cooling rate after deformation allow for obtaining ferrite-pearlite structures in 20MnB4 steel with equally distributed colonies of pearlite and fine ferrite grain,
- as a result of modifications (variant V2÷V5), favourable fragmentation of the microstructure of the steel grade studied and improvement in mechanical properties was observed: yield point increased by even over 45 % whereas tensile strength rose by even over 27 % with respect to currently used rolling technology.

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