INFLUENCE OF HOT WORKING AND COOLING CONDITONS ON THE MICROSTRUCTURE AND PROPERTIES OF C70D STEEL FOR WIRE ROD

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Abstract

The article presents the results of tests of influence of the thermo-mechanical treatment parameters on the mechanical properties and microstructure of steel C70D for wire rod. The methodology of quantitative description of pearlite morphology in steels with the use of the method on which a new computer program "PILS" - Pearlite Inter-Lamellar Spacing is based was presented. In order to verify the method, some quantitative tests of microstructure in samples after physical simulation of heat-plastic treatment were conducted on a deformation dilatometer device with diverse cooling rate for steel C70D. The process of rolling was conducted in simulation in continuous finishing train arrangement. Elaborated program and conducted tests will be used during preparations of modified technologies of wire rod rolling to prepare products made of steel, the microstructure of which is characterized with smaller interlamellar spacing.

1. INTRODUCTION

High-carbon steel types for wire rod are rolled in modern continuous systems [1, 2]. 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 of 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 [3, 4]. At present the temperature of rolling finish for high-carbon steel types is 900-920 °C. In practice the achievement of the assumed structure of wire rod from high-carbon steel is possible in Stelmor production line with the use of fans of the first cooling sections working with high efficiency. It enables fast cooling of the band to a temperature of the beginning of pearlitic transition. The amount of mechanical properties in pearlitic steel types depends on the degree to which pearlite is dispersed. 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 C70D [5, 6]. Conditions of physical simulation were close to the real conditions present of industrial production line for rolling wire rod.The main stereological parameter applied to describe this dispersion is the so-called real interlamellar spacing λ_0 defined as the distance between two midpoints of two subsequent lamellae of cementite or ferrite in a given colony of pearlite [7]. Within the verification process there were quantitative tests performed of microstructures of samples after physical simulation of heat-plastic treatment on deformation dilatometer with varied cooling rate and using rolling in continuous finishing train arrangement. Achieved results will be used to improve the process of rolling on industrial production lines.

2. EXPERIMENTAL PROCEDURE

Materials and methodology of hot working. Materials for tests were rods made of steel C70D meant for wire rods. The content of particular chemical elements is defined in the norm EN 10016-2: 1995. Rods from steel C70D 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 [8]. 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. Before rolling the rods were heated to a temperature of 1100 °C and holding time for 30 minutes. Finish rolling was performed on four-rolling stands of continuous finishing mill from diameter of ø 15.6 mm to ø 9.8 mm. Speed of rolling in the first stand equalled 1.0 m/s and in the fourth 2.1 m/s. Finish rolling was conducted in 4 temperature options: 760, 800, 850 and 920 °C. After rolling the rods:

- were cooled in air to temperature of 550 °C,than with furnace at the speed of 0.4 °C/s to the temperature of 200 °C and next in air to temperature of the surrounding.
- were quickly cooled with water shower after rolling to temperature of about 550 °C, and next with furnace at the speed of 0.4 °C/s to temperature of 200 °C and next cooled in air to the temperature of the surrounding.

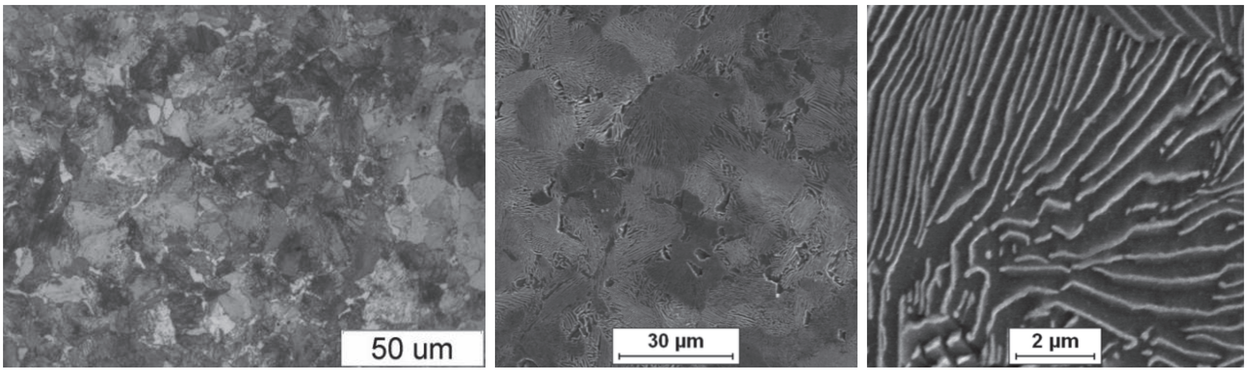
In order to assess the influence of overcooling on the mechanical properties for samples rolled in temperature of 920 °C there was a quick cooling with water shower conducted to temperatures of 665 °C, 655 °C, 625 °C, 420 °C and <400 °C.

There was a static tensile test performed after rolling of the rods. The rods after rolling were used to prepare samples with round cross-section to test the mechanical properties in accordance with norm PN-EN ISO 6892-1. Tests were conducted on testing machine Zwick/Roell Z100. On the basis of test the following parameters were marked: Ultimate tensile strength (UTS), yield point (Rp0.2), elongation (A_5). Hardness measurement was conducted with the use of hardness tester Zwick type 3212002/00. Metallographic test was conducted on light microscope type Olympus GX51 with magnification in range 200÷1000×. In order to conduct quantitative analysis of pearlite areas the images were registered on scanning microscope with magnification up to 15000×. The quantitative tests were conducted with the use of specialised software for quantitative assessment of pearlite microstructure, namely with the computer program "PILS" - Pearlite Inter-Lamellar Spacing [7]. Mean values of distances between cementite lamellae (λ_{av}), thickness of samples (l_{av}) and indicators of variations of those parameters were marked.

3. RESULTS AND DISCUSSION

Conducted tests, in conditions of simulation on experimental semi-continuous roughing stand with cooling of rods in air, at the rate of about 5 °C/s and water shower (cooling of about average 10 °C/s), provide the achievement of pearlitic structure with small amount of ferrite which is proved by the observed changes on the registered cooling curve and tests of microstructure (**Figure 1**). It should be pointed out, however, that the decrease of rolling temperature to 760 °C and next cooling in air causes a significant defragmentation of pearlite lamellae which is disadvantageous from the point of view of steel plasticity.

Rolling in temperature of 900°C - air cooling



a) LM b) SEM

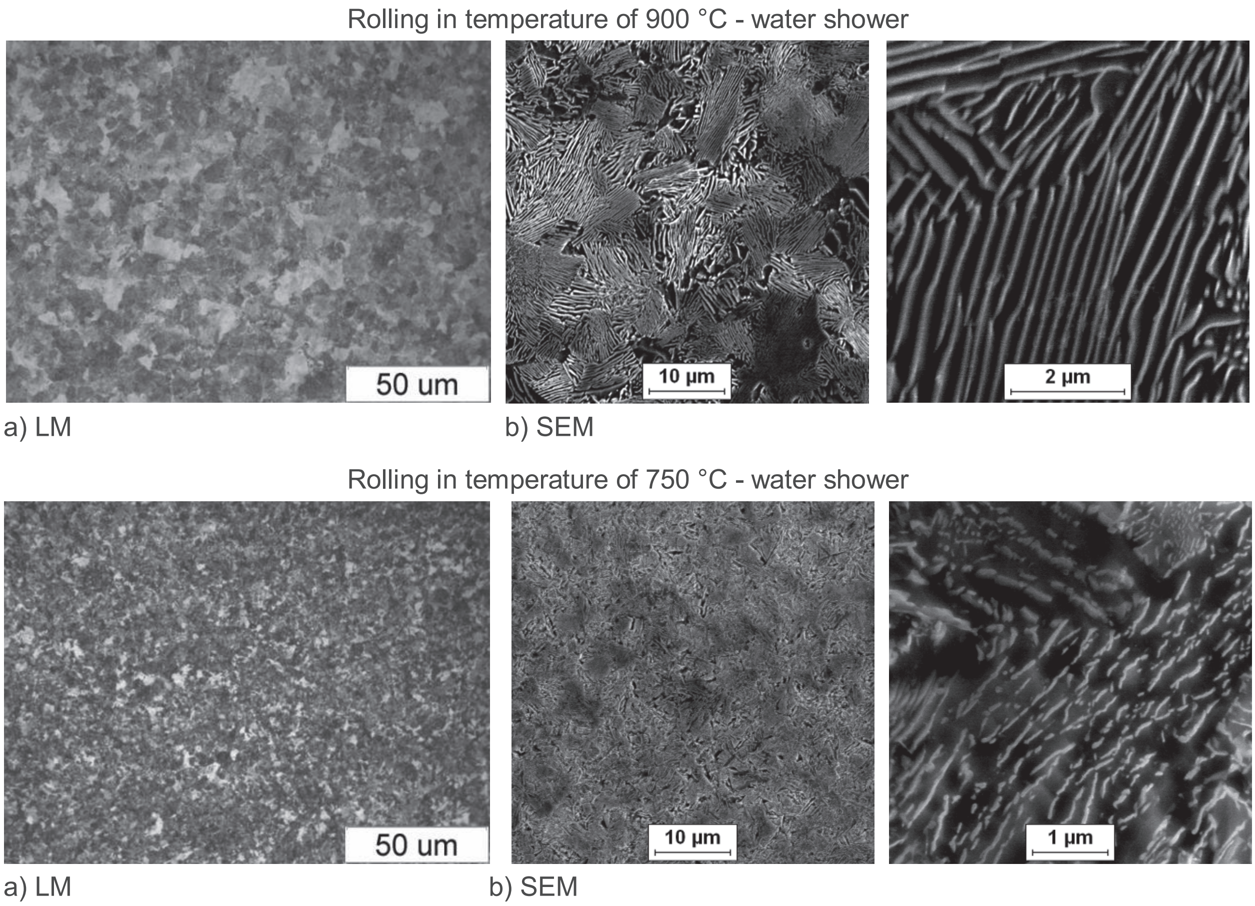


Figure 1 Microstructure of steel C70D after rolling in temperature of 900 °C with air cooling (a), water shower (b) and 760 °C and next cooling with water shower to temperature of about 580 °C (c).

Samples which were initially cooled with water shower have significantly higher resistance properties than the rods cooled in air (**Table 1 and 2**), with slightly smaller elongation value after rolling in temperature range from 800 to 920 °C (Table 14.2.5). It was stated that there is a strong dependency between the Yield stress $R_{p0.2}$, Ulimate tensile strenght (UTS and inter-lamellar distance λ_{av} (**Figure 2**). The highest strength properties are observed in samples which were rolled in temperature of 750 °C but are characterised with limited plasticity (**Figure 3**). Low plasticity results from intense defragmentation of pearlite lamellae occurring in significant overcooling and probable appearance of the bainite areas.

Table 1 Results of static tensile tests and hardness tests (HV1) for samples rolled in temperatures of 750, 800, 850 and 900 °C and next cooling in air

Rolling temperature, [°C]	Average distance of lamellae λ_{av} [µm]	Variation index $\nu(\lambda)$ [%]	Average thickness of lamellae (l_{av}) [µm]	Variation index $\nu(\lambda)$ [%]	$R_{p0.2}$ MPa	UTS MPa	A_5 %
750	0.422	32.4	0.124	36.5	563.2	900.1	16.5
800	0.382	34.5	0.113	33.0	594.5	932.4	13.2
850	0.317	37.6	0.103	32.8	626.0	967.1	15.1
900	0.378	35.3	0.120	35.1	614.5	945.5	14.0

Table 2 Results of static tensile tests and hardness tests (HV1) for samples rolled in temperatures of 750, 800, 850 and 900°C with initial cooling in water shower and next cooling with furnace

Rolling temperature, [°C]	Average distance of lamellae λ_{av} [μm]	Variation index n(λ) [%]	Average thickness of lamellae (l_{av}) [μm]	Variation index ν(λ) [%]	$R_{p0.2}$ MPa	UTS MPa	A_5 %
750	0.171	48.4	0.114	46.5	1050	1200	7.5
800	0.198	34.5	0.082	33.0	950	1130	15.2
850	0.218	37.6	0.080	32.8	820	1080	16.1
920	0.331	35.3	0.130	35.1	815	925	18.0

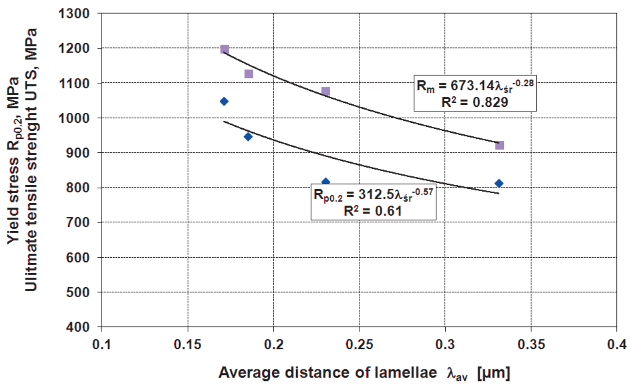


Figure 2 Yield stress $R_{p0.2}$ and Ultimate tensile strenght UTS depending on the distance between the pearlite lamellae distance λ_{av}

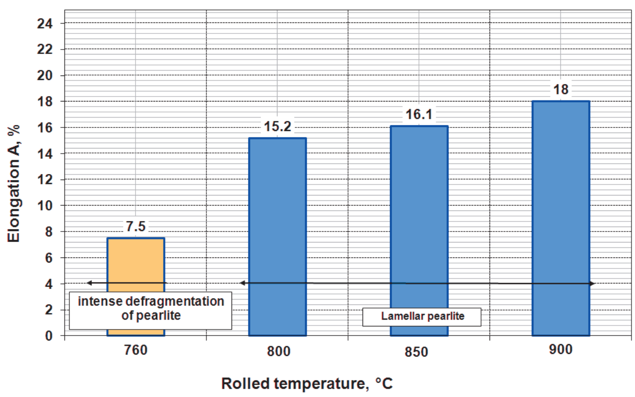


Figure 3 Elongation A_5 (b) depending on rolling temperature with initial cooling with water shower to temperature of 580 °C

Mechanical properties are highly influenced by the overcooling values (**Table 3**). Together with the increase of overcooling from temperature of 920 °C to the range of 665 °C÷550 °C there is an increase of resistance observed in samples with slight decrease in plasticity (**Figures 4**, **5**). Further increase in overcooling from temperature of 920 °C to 420 °C leads to loss of plasticity of tested steel.

Table 3 Results of static tensile test and hardness (HV1) of samples rolled in 920 °C with cooling initially with water shower to temperature of 665 °C, 655 °C 650°C, 625 °C, 580 °C , 420 °C and <400 °C and next with furnace

Overcooling, °C/s	$R_{p0.2}$ MPa	UTS MPa	$R_{p0.2}$/UTS %	A_5 %	HV1
920→665	800	980	0.82	20.5	230
920→655	750	1030	0.73	19.5	245
920→625	790	1085	0.73	18.5	258
920→580	815	1125	0.72	18.0	262
920→420	1027	1200	0.86	9.2	320
920→<400	- failure by 1400 MPa				

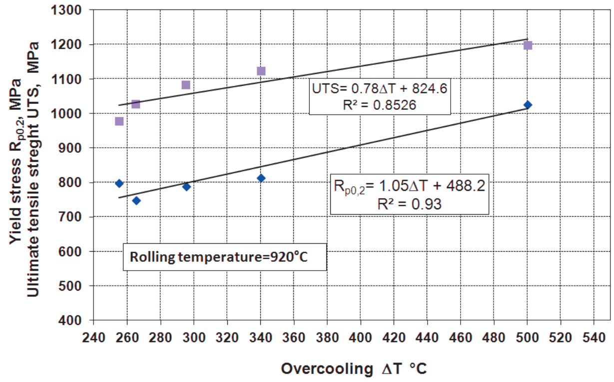


Figure 4 Influence of overcooling from finish-rolling temperature 920 °C on yield stress $R_{p0.2}$ and ulitmate tensile strength UTS of steel type C70D

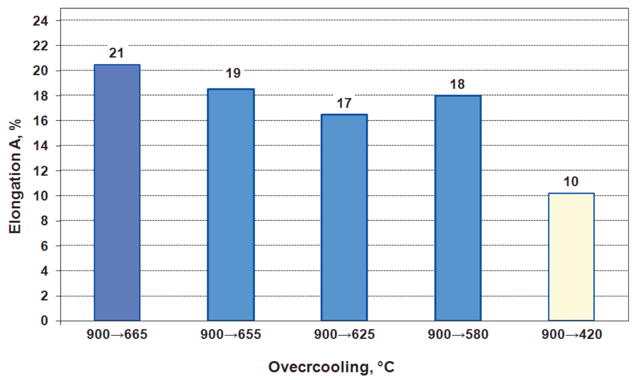


Figure 5 Influence of overcooling from finish-rolling temperature 920 °C on elongation of steel samples type C70D

CONCLUSION

It can be stated, on the basis of data presented in the paper, that there is a significant influence of finish-rolling temperature of the wire rod from steel C70D on its mechanical properties. Together with the decrease of finish-rolling temperature there is an increase of yield point and tensile strength observed. The values of elongation and reduction of area for all samples were similar. The cooling speed in range of occurring phase transitions also has influence on the properties. Samples which were cooled with a bigger speed (with water shower) are characterised with bigger values of resistance properties than the samples which were cooled with furnace. The value of overcooling from temperature of rolling is also important as its value positively influences the resistance properties. Too big overcooling, however, leads to formation of bainite areas and the samples are characterised with limited plasticity.

Conducted tests, in conditions of simulation on the semi-continuous experimental roughing stand, have shown that the decrease of rolling temperature from 900 °C to 800÷850 °C and the increase of cooling speed aids the achievement of wire rod with required microstructure of pearlite with the distances of pearlite lamellae of λ_{av} <0.2 µm with elevated resistance properties and plastic properties which are in accordance with the standard specifications. 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

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