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Increasing the strength class of rolled steel made of high-carbon steel in the stream of continuous wire mill

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Abstract
The technology of deformation-thermal treatment of rolled steel that will ensure uniformity of distribution of the pearlite structure over the cross section, reduce the depth of decarbonized layer, increase the initial strength of the metal while improving ductility characteristics has been developed. The complete absence of water cooling stage of rolled steel after its output from the finishing wire

rolling mills was the main peculiarity of the currently used cooling modes of rolled steel on Stelmor line. Cooling mode includes the following technological operations: the temperature of the end of rolling and output of rolled product from the wire block – at the level of 1050 ºC; cooling with water prior laying head is not performed; metal temperature at the laying head is 1030…1020 °C; accelerated air cooling of the wire rod turns up to temperatures of 560…540 °C when the heat-insulating caps are open; further cooling is when closed insulating caps to a temperature of ~150 °C. As a result of the industrial implementation of a fundamentally new approach to cooling of high-carbon rolled steel in a stream of high-speed continuous wire mill using the rolling heat heating, the best quality indicators of rolled steel with diameter of 10.0 mm were comprehensively achieved, which were previously considered unattainable.

Key words: ROLLED STEEL, HIGH-CARBON STEEL, DEFORMATION-THERMAL TREATMENT, PEARLITE, STRENGTH, DECARBONIZED LAYER

Introduction

The modern world tendencies of the construction industry determine this branch as primary consumer of metal products of critical applications, a significant share in the volume of which is high-tensile reinforcement and fittings manufactured in the form of high-strength cold deformed wire and ropes. Requirements for strength class of wire elements (1670; 1770; 1860 and 2000 MPa) necessitate the use in their manufacture of high-carbon rolled steel with diameter of 8.0 ... 16.0 mm with ultimate tensile strength more than 1150 MPa and a high level of initial plasticity [1 -5]. European metallurgical plants (ArcelorMittal Hamburg, Ovako, FNSteel) provide the required grade of rolled product by alloying steel with expansive chemical elements (V, Cr, or by their combined addition to the steel). Production of high-strength wire at national metalware enterprises is characterized by the need for performing in the technological cycle of environmentally harmful and energy-intensive operation on patenting in molten salts, lead or fluidized bed. Therefore, the production of high-strength cold deformed wire from rolled steel of high-carbon steels with diameter of 8.0 ... 16.0 mm by direct drawing is virtually impossible without the use of heat treatment.

Current status of the problem

In terms of prime cost reduction and improvement of economic indicators as raw materials for the production of high-strength wire rolled steel made of high carbon steel should be used, which does not contain additional alloying elements, and improving the deformation-thermal me- tal treatment modes should be implemented without expansive upgrading of existing technological equipment stock.

Work objective is an identification of new patterns of structure formation in high-carbon steel at changing the basic technological parameters of deformation and heat treatment.

Materials for research are industrial batches of rolled steel of the following grades C78D, C80D, C82D (EN 10016-1) and C86D (EN 16120-1). Used equipment: light microscopes «Neophot 32» and «Axiovert 200 M MAT», automatic image analyzer «IA-3001», electron microscopes «EF-2» and «VEGA TS5130MM».

The results of research

In the course of investigations, it was established that the main process parameters responsible for the formation of the required quality indicators of rolled steel products were metal output temperature from the finishing block of roll stands, laying head temperature, movement speed (stacking density) of rolled product turns on the roller conveyor, the number and power of the involved blower fans at the stage of rapid air cooling of metal on the conveyor line Stelmor. Complex variation of technological parameters of deformation-thermal treatment in the production of rolled steel with diameter of 8.0 ... 12.0 mm of steel grades C78D, C80D, C82D (additionally alloyed with vanadium and/or chromium) showed its effectiveness. Achieved values of ultimate tensile strength were in the range of 1200 ... 1280 MPa depending on the finished dimension of rolled section. However, for steels that do not contain addition of alloying elements required values of ultimate strength have not been achieved ($\sigma_u \leq 1130$ MPa), which indicates the inefficiency of applied deformation-thermal modes that do not provide formation of the required microstructure.

The steel C86D micro-alloyed with boron was used for the development and introduction of innovative technology of rolled steel sorbitizing. To increase the stability of the metastable austenite [6-8] during continuous cooling of rolled steel, the microalloying of steel with boron was applied in regulated amount and temperature of metal destacking on turns maintained in the range of 1030…1020 °C that is by 180…130 °C higher than standard adopted temperatures in industrial practice of rolled steel manufacturing made of high-carbon steel. Cooling mode included the following technological operations: the temperature of the end of rolling and output of rolled product from the wire block ~ 1050 ºC; complete elimination of water cooling stage; metal temperature at the laying head – 1030…1020 °C ; accelerated air cooling of the wire rod turns up to temperatures of 560…540 °C when the heat-insulating caps were open (during the work of 8 ventilation systems: 6× 1480 min^{-1} and 2× 750 min^{-1}); further cooling to temperatures of ~ 180…150 °C.

Metallographic studies have shown a significant difference in the formation of structures of rolled steel manufactured according to base (1) and experimental (2) technologies. The microstructure of rolled product cooled on a mode 1 includes areas of coarsely lamellar pearlite which corresponds to 10 point according to GOST 8233-56 10, and rolled structure cooled by mode 2, the maximum point of observed lamellar pearlite is not more than 2 ... 3. The results of the comparative analysis of quality indicators of rolled steel cooled by the modes 1 and 2 at different temperatures of turns forming are shown in the Table 1.

Table 1. The results of metallographic studies of samples. Mechanical properties of rolled steel with diameter of 10.0 mm made of steel C86D

Mode number[1)]	Depth of decarburized layer, %				Amount of perlite 1 point[2)], %	Amount of perlite 1 point[3)], %	σ_u [4)], MPa	ψ [4)], %	δ_{10} [4)], %
	According to GOST 1763-68		According to EN ISO 16120-1:2011						
	Average value	Maximum value	Average value	Maximum value					
1	1.20	1.50	1.12	1.40	62	59	1122…1145 / 1138	19…24 / 23	7…9 / 8,5
2	0.65	1.03	0.62	0.96	87	84	1193…1215 / 1205	28…32 / 31	10…12 / 11,5

Note: 1) 1 - basic mode: turns formation temperature of 930…950 °C , average speed of the air cooling ~ 8 °C/s , 2 – experimental mode: turns formation temperature of 1030…1020 °C , speed of the air cooling ~ 18 °C /s; 2) point method by A. A. Glagolev; 3) method of EN ISO 16120-1:2011 (D); 4) in the numerator the specified minimum and maximum values are shown, in the denominator - the average values

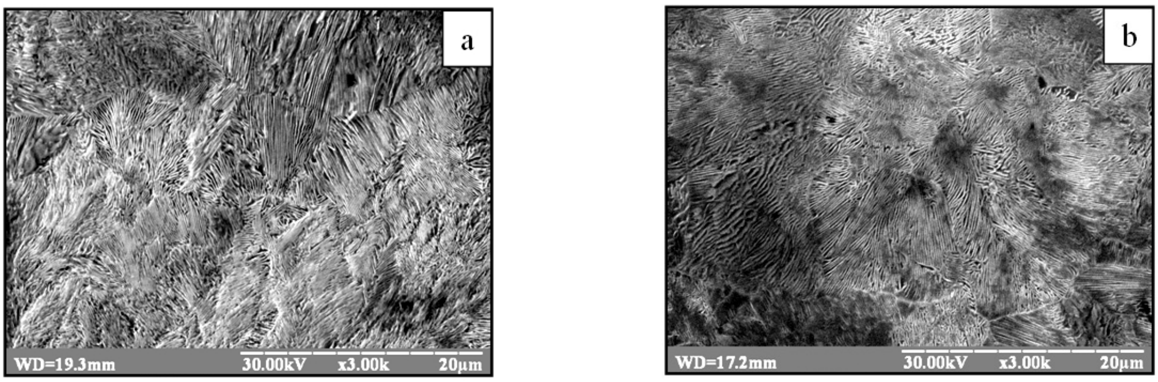

Figure 1. The microstructure of perlite in rolled steel with diameter of 10.0 mm of steel C86D cooled using different technological modes: a – technological mode No 1; b – technological mode No 2

Analysis of the data shows that increasing the turns formation temperature by 180…130 °C while increasing the speed of accelerated air cooling to 18 °C/s reduces the depth of decarburized layer in average by 1.4 ... 1.8 times and increases the amount of sorbitizing pearlite of 1 point by 1.4 times, eliminates occurrence of lamellar pearlite areas of more than 3…4 points, which is a very important criterion for rolling product subjected to direct cold drawing. Experimental mode of rolled product cooling increases its tensile strength by 5%, constriction and elongation ratio by 34 and 35%, respectively. Electron microscopy metallographic analysis has shown that the pearlite structure in the samples of rolled steel cooled on a mode 2 has a higher dispersibility compared with mode 1 and the value of interlamellar distance decreases by ~ 23 % and reaches values of 0.142 micron, which is typical for metal subjected to patenting (Fig. 1).

Conclusion

1. It has been established that increasing the turns formation temperature of rolled steel made of steel C86D up to 1030…1020 °C and air-cooling speed up to ~ 18 °C /s reduces the depth of decarbonized layer in average by 1.4…1.8 times, increases the amount of sorbitizing perlite by ~ 23 %, eliminates areas of coarsely dispersed lamellar pearlite of more than 2 ... 3 points. Proposed cooling mode increases tensile strength of hot-rolled product by 5%, constriction and elongation ratio by 34 and 35% respectively.

2. The industrial implementation of a fundamentally new approach to cooling of high-carbon rolled steel in a stream of high-speed continuous wire mill using the rolling heat heating allowed to achieve the best quality indicators of metal, which were previously considered unattainable.

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