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ABOUT EFFECTIVE WAYS OF IMPROVING REGULATED MODES OF WIRE ROD AIR-COOLING IN INDUSTRIAL CONDITIONS

The paper considers design features and composition of the main equipment of Stelmor line used at the most metallurgical enterprises for cooling wire rod in coils. Perspective directions of improving coiled wire rod quality indicators by controlled regulation of structure formation during hot-deformed steel cooling process are determined. Industrial implementation of such rational modes for high-quality wire rod air-cooling makes it possible to achieve significant economic effect at the metalware production stage.

Keywords: *wire rod in coils, deformation-thermal treatment, Stelmor line, cooling modes.*

Introduction

Theoretical foundations of wire rod deformation-thermal treatment (DTT) are based on the regularities of phase and structural transformations in the metal, which is subjected to hot plastic deformation with further cooling [1 – 5]. Based on experimental data and their theoretical analysis, new technological approaches to the parameters of metal DTT modes in the stream of continuous small-section wire mills are being developed. For designing a certain DTT mode a number of indicators should be taken into account: the temperature of a workpiece heating in the furnace, deformational heating of metal in the stands of rolling mill and wire unit, deformation division and rate, hot-rolling finishing temperature, post-deformation pause duration as well as cross-section of the manufactured profile sizes [3, 6, 7].

According to the studies [4, 8, 9], at the initial stage of DTT development the designers were trying to achieve the highest indicators during tensile strength tests and to reduce metal scale losses. For this main attention was focused on two basic DTT schemes: low-temperature and high temperature ones, which include martensite hardening after warm or hot deformation of austenite respectively. Subsequently, other wire rod DTT types, conventionally termed isothermal, started to appear. This made it possible to provide formation of a ferrite-perlite, perlite or bainitic structures of the metal from rolling heat.

It should be noted that steel recrystallization processes, occurring during DTT, play a particularly important role as their favorable effect is neutralized with the intensive development of collective recrystallization, while hot plastic deformation parameters in such case correspond to the notion of DTT only formally. It is believed that if collective recrystallization stage is not reached, the metal hardens upon subsequent cooling, and when the latter is reached metal softening occurs [4, 10].

During hot deformation recrystallization (dynamic, metadynamic, static) differs significantly from recrystallization caused by heating of the cold-deformed metal. By changing main parameters of hot deformation during DTT, namely, deformation degree and rate, temperature and post-deformation pause duration, a set of various structures and properties of the metal can be obtained depending on the purpose of its subsequent application.

Book [12] presents classification of the different types of high-temperature DTT, which exclude formation of final structures of steels by martensitic mechanism, and the decomposition of austenite occurs with the formation of structures consisting of ferrite and perlite, perlite, perlite and cementite, sorbitol, troostite or bainite.

Implementation of the said DTT modes does not require cooling of the rolled stock with the rates exceeding the upper critical hardening rate, and manufacturing technology could be implemented using the existing equipment of the metallurgical enterprises.

The research aim is to determine perspective directions of improving wire rod quality indicators through providing the possibility of controlled regulation of structure formation processes during hot-rolled steel cooling process.

The material used for the research is coiled wire rod of a wide-range of grade compositions (0.05 – 0.90 % C), subjected to further plastic deformation at the metalware production stage.

Research results. An effective method has been developed, which enables obtaining different sets of properties through providing the possibility of controlled regulation of the metal air-cooling rate after it is laid in coils on the conveyor.

At present, despite the existence of numerous ways for cooling wire rod in the stream of continuous small-section wire mills [13], one of the most common in metallurgical practice is the so called Stelmor process and the metal cooling technological section is termed a two-stage water-air cooling line (Fig. 1). On such a line, after leaving the finishing stand of the wire unit, the rolled stock is cooled with water by special nozzle devices, and after it is laid in coils – by air flows, pumped by blowers from the bottom up on the conveyor [13 – 15].

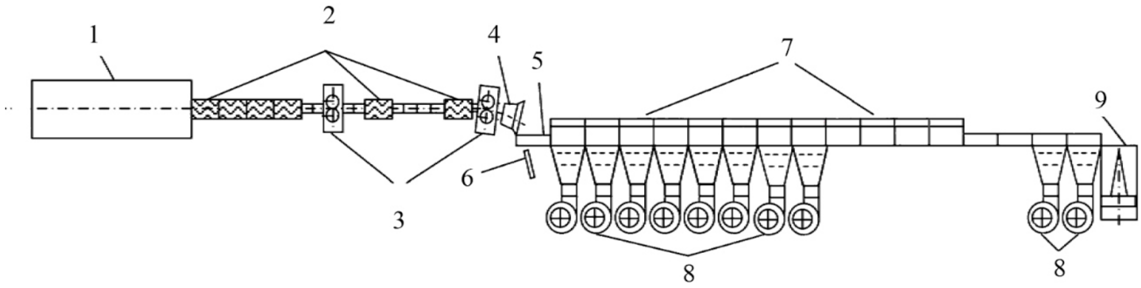

Fig. 1. The scheme of the main equipment location at the wire rod water-air cooling stage: 1 – wire-rolling unit; 2 – water cooling section; 3 – pinch roll unit; 4 – laying coiler; 5 – rolled stock coils receiving table; 6 – pyrometer; 7 – regulated air-cooling section with a roller conveyor and heat insulation covers; 8 – air blower systems; 9 – coil receiver pit

In order to create effective metal cooling conditions, design features of the Stelmor line equipment are being constantly improved. For example, in the production of rolled stock from medium- and high-carbon steel grades, a standard "short" Stelmor line is used, and for low-carbon alloyed steels, including complex-alloyed steels intended for welding purposes, a slow cooling mode is required, which predetermined creation of a "long" Stelmore line that is more effective and universal. Design features of such a line enable implementation of various modes for cooling rolled stock. Accelerated metal cooling occurs due to air supply to the conveyor by blowers. If cooling rates are at least 15 C° / s, rolled stock structure will consist mostly of the sorbitol-like perlite and is practically identical with the structure of metal subjected to the additional thermal treatment – patenting. Uniform distribution of the structural components over cross-section of steels of the perlite class is particularly important in the case when metal is subsequently subjected to the high-degree cold plastic deformation [16].

Sorbitol-like perlite is the most favorable structure for manufacturing high-strength cold-deformed products with a high degree of deformation. Due to continuous modernization of drawing equipment and improvement of metalware production process flowcharts, the possibility of obtaining steel of such structure is becoming an increasingly relevant problem, the solution of which is aimed at increasing the productivity and reducing material costs associated with pre- or intermediate heat treatment of rolled products before or during the drawing process.

Along with improved strength indicators, hot-rolled steel with a structure of a sorbitol-like perlite also possesses considerable plasticity resource, which allows not to use patenting during the drawing process and not to subject metal to the high-degree plastic deformation [17, 18].

We believe that one of the most efficient directions of the existing Stelmor cooling line modernization could be not only satisfying the metalware industry demands but also orientation of the metallurgical enterprises towards creation of their own metalware production. This will ensure processing of the effective types of wire rod into highly cost-effective metalware products, which have an increased surplus value due to lower energy costs. Vivid examples of successful implementation of such a technological solution are JSC "BMZ" (Zhlobin) and JSC "BMK" (Beloretsk) metallurgical enterprises.

Welding wire, high-strength reinforcement ropes, steel ropes, cold-formed reinforcement, spring wire, metal cord and high-strength fasteners are traditionally considered the most cost-effective metalware products. As to hot-rolled reinforcing bars in coils, demand for them at the construction market is seasonal. Besides, products of this kind can hardly be attributed to the exclusive and highly cost-effective ones, taking into account current trend towards the production of middle-strength highly ductile reinforcement facilities, made by the method of cold deformation combined with reverse bending (using the Bauschinger effect) [19].

Production of high-quality types of wire rod in coils for the assortment of metal products under consideration requires innovative approaches to DTT modes in the stream of continuous small-section wire mills, including metal air cooling modes on Stelmore line [20 – 22].

One of the main tasks of the "short" Stelmore line modernization should be provision of the possibility to implement a regulated metal air cooling rate in order to obtain a given set of the coiled wire rod quality indicators. To obtain a rational combination of the structure and properties of metal from high-carbon non-alloyed steel, average metal air-cooling rate should be no less than 15 °C / s, and that for low-carbon alloyed steel for welding purposes should not exceed 0.3 °C / s . In the latter case, this effects the reduction of bainitic-martensitic structures and, accordingly, increases technological plasticity of the metal during the drawing process.

According to the data of the world-known manufacturers of metallurgical equipment ("Danieli", "SchloemanZimag", "MorganConstruction"), the length of conveyor section at the "short" Stelmor line from the coiler to the pit does not exceed 70 meters and the size of section, where metal coils move under heat-insulating covers, does not exceed 62 meter.

The ideology of creating Stelmor line up to 150 m long with the possibility of regulated control of airflows during metal cooling process promoted by Danieli (DSC process) has not been widely implemented. Metallurgical enterprises have not realized the indisputable importance of such equipment and especially the role it plays in the formation of a wide range of structures and properties of rolled metal intended for various purposes [23].

Regarding design features of Stelmor lines used at the metallurgical enterprises of Ukraine, it should be noted that they correspond to the standard specification and their length does not exceed 70 m. Air cooling sections are equipped with low-power blowers, while nozzle channels of the air flow distribution across the roller conveyor width do not provide the required result, which leads to significant temperature gradient along the metal coil length and respective structure inhomogeneity as well as essential spread of the parameters of hot-rolled metal mechanical properties [24] .

As the rolled metal diameter increases from 5.5 mm to 10.0 – 14.0 mm, cooling rate of metal coils made of high-carbon steel becomes slower and less effective due to the influence of scaling factor – reduction of the actual cooling rate. In the production of rolled metal for welding purposes a negative factor could be insufficient sealing of the conveyor sections under heat-insulation covers, which causes suction of the in-shop ("cool") air into the thermostatic tunnels and increases actual metal cooling rate [13].

For modernization of Stelmore line air-cooling sections world-known producers of metallurgical equipment propose to replace outdated low-power blowing fans (15 – 110 kW) with modern highly efficient air-cooling systems with the power of at least 200 KW and differential distribution of air flows across the conveyor width. Today there are also propositions of the home producers, the so-called high-pressure jet cooling units (HJCU), which are in the lower price segment. By means of individual channels, located in the pressure box, such HJCU systems can supply air to the conveyor sections at a speed of up to 100 m / s. While cooling the coils of rolled steel, air flows are distributed differentially across the conveyor width in accordance with a certain calculation algorithm so that a minimum temperature gradient along the length of the metal coil is achieved (Fig. 2).

HJCU systems power is identical to that of foreign analogs (200 – 220 kW) (Fig. 3), although their cost is about 2.5 – 3 times higher. Total number of HJCU on Stelmore line could vary from 6 to 10 units depending on the assortment of rolled stock produced. Their efficiency is less than 90 %, which is explained by the fact that HJCU has no double conversion of kinetic energy into potential energy of the air, sucked into the guide box, and then into kinetic energy at its output.

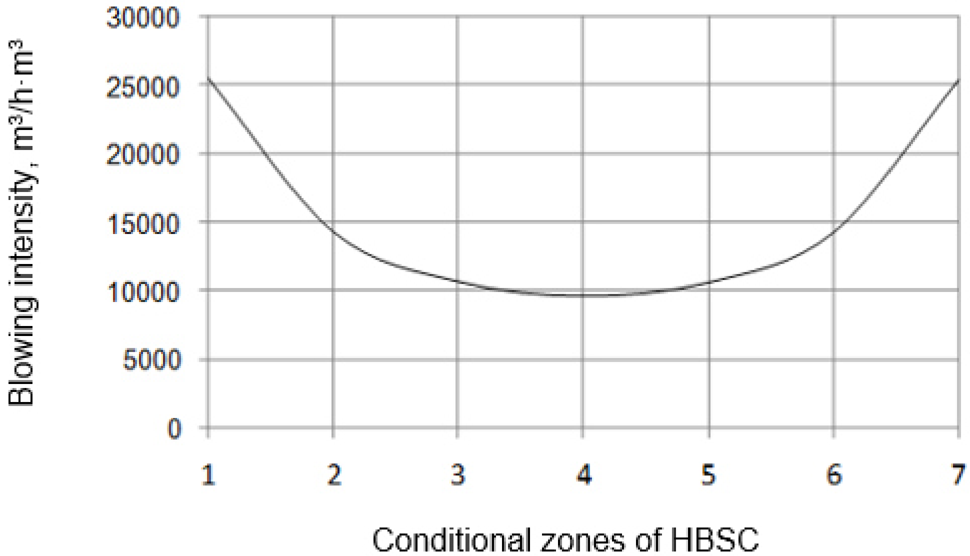

Fig. 2. Distribution of the intensity of blasting the rolled metal coils through HJCU nozzle panel: 1, 2, 6, 7 – side zones of the conveyor; 3, 4, 5 – central zone of the conveyor

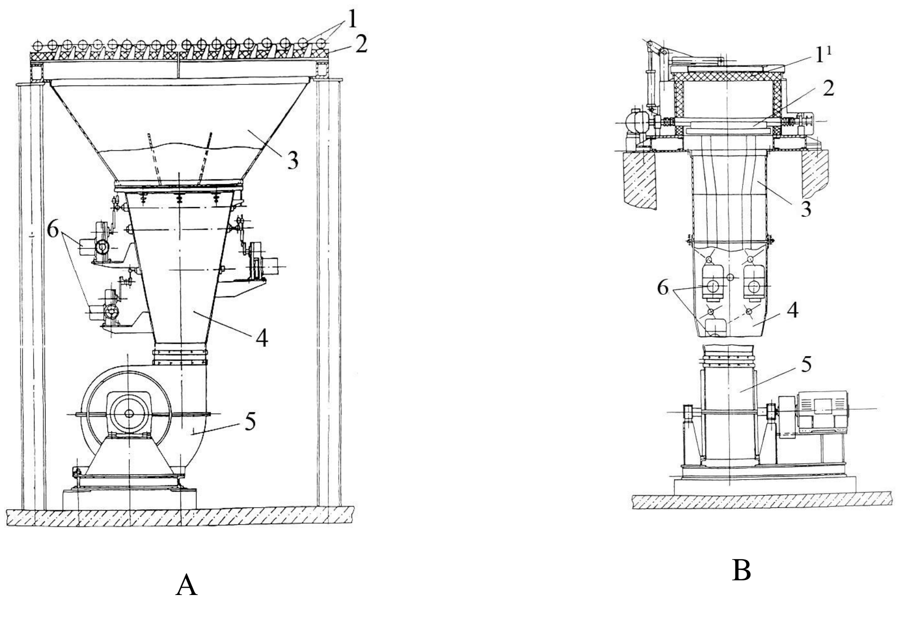

Fig. 3. Schematic presentation of HJCU in the conditions of JSC “MMZ” with air supply to the roller conveyor of Stelmor line by means of adjustable device: A – longitudinal section; B – cross-section; 1 – roller conveyor; 1^1– heat insulation cover; 2 – nozzle channels; 3 – pressure box; 4 – output control device; 5 – blowing fan; 6 – actuator

The achieved effect is realized due to the presence of individual channels, which supply air directly to the conveyor without conversion of energies and significant losses of the initial kinetic energy. HJCU systems have been installed and successfully implemented at JSC “BMK” and JSC “MMZ” (Rybnytsia).

The modernized two-stage cooling Stemor line with the length of 147 m in combination with HJCU system has made it possible to implement adjustable modes of cooling rolled metal in the speed range of 0.30 – 25° C / s depending on the chemical composition of steel and profile size. The results, obtained at JSE “MMZ” in regard to metal cooling process at Stelmor line, are as follows:

– for wire rod in coils, made of high-carbon steel with the diameter of 5.5…14.0 mm: average cooling rate in the range of 27 - 15° C/s; the amount of sorbitol-like perlite in the metal structure – not less than 80%; possible degree of cold plastic deformation by drawing according to the direct drawing scheme with a relative reduction – not less than 90%;

– for rolled products, made of low-carbon welding steel: the minimum possible cooling rate – 0.30° C / s; the amount of bainitic-martensitic areas in the metal structure has been reduced from 45 – 50 % to 5 ... 3 % and the total relative reduction according to the direct drawing scheme – < 98%.

In addition, at JSC 'MMZ' the water cooling sections, located in front of and behind the wire rolling unit, were modernized, which made it possible to increase the accuracy of reinforcing bar cooling rate control and, as a result, to improve the quality indicators of the finished rolled metal.

Preliminary calculations have shown, that for differential air cooling of rolled high-carbon steel with a diameter of 8.0 – 16.0 mm on Stelmor line with the rates of at least 15 ° C / s a sufficient condition is installation of 8 – 10 HJCU units with the power of at least 220 kW, which will ensure structural homogeneity in both transverse and longitudinal sections of the metal.

Laboratory modeling of the conditions for cooling rolled products made of low-carbon alloy steel intended for welding purposes as well as of the rolled metal for the production of high-strength fasteners by the method of cold volumetric stamping was conducted. The studies have shown that the maximum duration of austenite decomposition under isothermal conditions is no more than 1000 ... 1200 s, which corresponds to the movement of metal coils on the conveyor in the speed range of 0.09 ... 0.12 m / s (air-cooling rate does not exceed 0.3 ° C / s). The mode of decomposition of austenitic steel in isothermal conditions under heat-insulating covers of the “long” Stelmore line is possible to be implemented only in case of additional installation of electric heaters and circulation fans.

If isothermal exposure of rolled products made of high-carbon steel is used under industrial conditions in the given temperature-time intervals, it will be possible to implement the air patenting mode for a metal with the structure consisting entirely of sorbitol-like perlite. This will make it possible to improve technical and economic indices in manufacturing cold-deformed products (high-strength ropes, fittings, springs, metal cord). Said finished products are in great demand at the market and the proposed solutions could provide significant competitive advantage, primarily, due to the reduced material expenses for wire rod processing.

In order to achieve economic effectiveness and improve ecological cleanliness of rolled metal at the metalware production stage, a modernized Stellmore line should provide fulfillment of the following conditions: 1) the possibility of cooling rolled metal in a wide range of cooling rates; 2) formation of scale on the metal surface consisting predominantly of wustite, which can be completely removed mechanically [25].

According to the data of metalware enterprises of Ukraine, when processing 1 ton of wire rods made of high- and low-carbon steels, including welding steel, the cost of heat treatment (patenting, annealing) is ~ 700.00 UAH / ton. The cost of preparing the metal surface for drawing using a chemical method (etching in solutions of sulfuric or hydrochloric acids) is much higher - ~ 614.32 UAH / ton, while for mechanical method it is 89.16 UAH / ton.

Economic effect from implementation of the required technological solutions can be calculated for minimal annual wire rod consumption by large metalware enterprises – 45 000 ton, which is a rather well-grounded indicator according to the data of the raw-material market of Ukraine.

If to assume that hot-deformed wire rod is processed according to the direct cold drawing scheme and removal of the surface scale is performed mechanically, annual economic effect may be calculated by the expression:

$$E_f = V \cdot P + V \cdot (X - M),$$

where E_f – the expected economic efficiency, UAH; V – average annual wire rod consumption, tons; P – the cost of annealing or patenting, UAH; X, M – the cost of chemical and mechanical methods for preparing the rolled metal surface for drawing, respectively, UAH.

$$E_f = 45\,000 \cdot 700{,}00 + 45\,000 \cdot (614{,}32 - 89{,}16) = 55\,132\,200{,}00\ UAH.$$

The expected economic effect could be divided in approximately equal proportions between metallurgical and metalware enterprises due to reduction of material expenses for the technological process of the latter. In this case payback of the required capital investments could be achieved in shortest terms possible due to the use of the modernized Stelmor line.

It should be noted that recoupment from the introduced new industrial technologies determines minimal period required for payback of the spent funds and is one of the key indicators in evaluating investment attractiveness of the business projects to be implemented.

The economic effect determination is based on the idea of resource-saving in processing wire rod with improved quality indicators, and the calculation procedure is not influenced by depreciation charges and possible sharp price changes at the commodity markets. The obtained data show that the proposed technical solutions for modernizing Stelmore lines of obsolete design are expedient, economically viable and quickly recoupable.

Many years' experience of the authors of this work, connected with the industrial implementation of new and improvement of the existing DTT modes for different-purpose wire rod, has shown that for achieving the best combination of metal structure and properties effective management of the technological processes is required at all stages of steel production, starting from the steelmaking process [20 – 22].

Overcoming the design and technological shortcomings (modernization) in the operation of equipment involved in hot-rolled metal production will enable controlled regulation of different-purpose wire rod structure formation processes.

Conclusions

Brief analysis of the development of hot-deformed wire rod cooling methods in industrial conditions is presented. Design features and composition of the main equipment of Stellmor line, used at most metallurgical enterprises for cooling wire rods, are considered. Effective means for improving the regulated metal air-cooling modes are determined, depending on the metal brand and purpose of its further application. Industrial implementation of the rational modes for cooling high-quality wire rod has made it possible to receive significant economic effect at metalware production stage. The possibility of controlled regulation of structure formation processes in steels in various cooling rate intervals along with the use of modern high-power HJES system are shown to be the main advantages of cooling the rolled metal coils on the "long" Stelmor line.

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