**E. V. Parusov, Cand. Sc. (Eng.); O. B. Sychkov, Dc. Sc. (Eng.), Prof.;**

**S. I. Gubenko, Dc. Sc. (Eng.), Prof.; I. M. Chuyko, Cand. Sc. (Eng.)**

# ANALYSIS OF TECHNOLOGICAL CHARACTERISICS OF COOLING WIRE RODS ON STELMOR LINE OF OJSC "MMP"

*The paper analyzes technological characteristics of cooling wire rods in the conditions of OJSC "Moldova Metallurgical Plant" ("MMP").*

*Currently, at OJSC "MMP" unique technologies of manufacturing highly efficient types of wire rods, made of boron-microalloyed steel, have been mastered. The development of rational modes of deformation heat treatment enabled production of a new generation of metal products for the hardware industry, particularly, of wire rods made of low-carbon and low-alloy steels, subjected to drawing with deformation degrees of 97.9 ... 98.8% without application of softening heat treatment, as well as wire rods of high-carbon steels, intended for manufacturing steel reinforcing ropes, wire fittings, metal cord, springs, etc., capable of withstanding total deformation degree of up to ~ 95%.*

***Key words:*** *wire rods, manufacturing technology, deformation thermal treatment, microalloying with boron.*

## Introduction

World production of coiled stock (wire rods) constitutes ~ 10 ... 12% of the total volume of rolled products, which is explained by the wide range and purpose of the manufactured metal products, which include springs, metal cord, cables, reinforcing wire, needles, strings, fiber, fasteners, electrodes, etc.

Traditionally, one of the main problems in wire rod production was reduction of metal scale losses during cooling process. At the same time, successful achievement of this task led, in most cases, to deterioration of structure and mechanical properties of the finished metal products.

Processes, occurring during metal cooling after hot deformation, are determined by the peculiarities of structural state of the deformed austenite, which is formed in the processes of multiple high-temperature deformations and makes it possible to control the processes of both hardening and softening of carbon steels [1, 2, 3]. This is connected with the specific nature of the rolled stock controlled cooling modes in the process of deformation thermal treatment and is based on fundamental principles of the phase and structural transformations occurring in steel.

Coiled stock cooling methods, which are currently in use, can be divided into the following groups: water cooling in the supplying pipes; two-stage cooling; cooling in a bath with heated water and surfactants; cooling in water and in a fluidized layer as well as other cooling methods [4 -10].

The rolled stock cooling method, which is the most widely used in metallurgical practice, was developed in 1962 by «Steel companies of Canada» (Canada) and «Morgan Construction Company» (US) [11]. This method was named Stelmor process and wire rod cooling technological section is referred to as Stelmor two-stage water-air cooling line [11].

**Aim of the work** is to analyze technological characteristics of cooling wire rods in the conditions of JSC "Moldova metallurgical plant".

**Research materials and methodology.** Industrial batches of wire rods, made of low-carbon low-alloyed (for welding) and high-carbon steels, were chosen as research material. Research methodology consisted in assessing quality indicators of hot-rolled steel and its adaptability to metalware manufacture.

**Research results and their discussion.** Stelmor process consists in the following (Fig. 1). After leaving the final finishing stand of the wire unit, wire rods are subjected to stepwise cooling with water from the final rolling temperatures to 750…900 °C (to ~ 550 ºC for reinforcing bars in coils).

Between the water-cooling sections temperature alignment across the metal section occurs and thereby the effect of intermittent cooling is provided (the thermal cycling principle). After water cooling, the rolled coils are laid on the conveyor and during the subsequent movement of the coils the second stage of cooling – air-cooling with the application of blast fan systems takes – place. Depending on the rolled steel grades and purpose, speed of the coils motion on the conveyor can vary over a wide range of cooling rates – from 0.1 to 1.3 m / s [12].

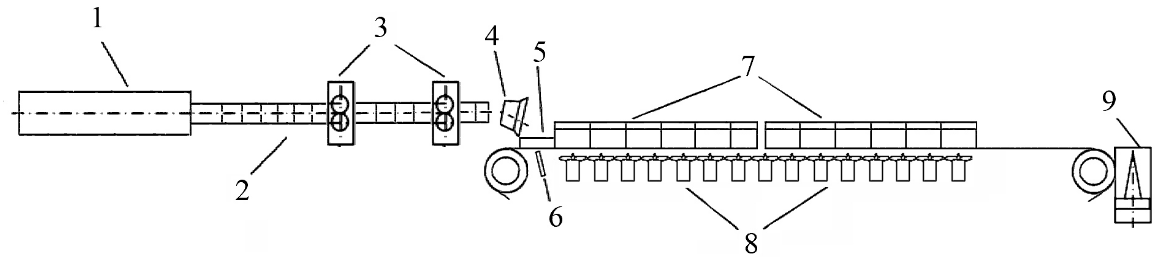



Fig. 1. Principal circuit of the wire rod water-air cooling section at Stelmor line of the wire mill 320/150 of OJSC "MMP" (before modernization)
1 – wire rolling unit; 2 – water-cooling section; 3 – pinch roll unit; 4 – laying head; 5 – rolled coils receiving table; 6 – pyrometer; 7 – controlled water-cooling section with mesh conveyor and heat-insulating covers; 8 – air-blast fans (15 units with the capacity of kW); 9 – coils collection pit

In order to obtain effective microstructure and optimal mechanical properties of the rolled stock, various combinations of the above-mentioned cooling methods are being constantly improved and created, including those used at Stelmor line. Particularly, for manufacturing rolled stock, made of average- and high-carbon steel grades, Stelmor line with the water-cooling section (conveyor) length of ~ 70 m is used, while for low-carbon, alloyed and complex alloyed steels, e.g. for welding wire production, the length of water-cooling section at Stelmor line is ~ 100 m and more [13].

Design features of Stelmor line enable implementation of the following various coiled stock cooling modes:

1. Normalization (cooling in still air) with all heat-insulation covers over the conveyor being opened and blast fans turned off. Such cooling mode contributes to formation of the metal fine-grained structure, which provides obtaining optimal strength and ductility indices for structural steels.

2. Slow cooling of the rolled stock with minimal speed on the conveyor (all heat-insulation covers are closed). This enables obtaining recrystallized coarse-grained structure of ferrite in the metal with reduced strength and increased plasticity characteristics. Such cooling method is used for producing low-carbon steels and steels for welding purposes, which are subjected to significant deformation degrees (≥ 90 %) for hardware formation as well as for producing rolled stock with cold upsetting and springs, made of alloyed steels.

3. Accelerated air-cooling of rolled stock, using blast fans, beginning from the temperatures of the rolled stock laying out into coils (heat-insulation covers are opened). When the required temperature interval is reached, it is cooled with closed covers and then in still air. Typically, this cooling method is used in high-carbon steel production for obtaining a dispersed perlite structure, which makes it possible to exclude patenting during such rolled stock processing.

The above-mentioned modes of cooling wire rods on Stelmor line are based on the cooling rate differentiation and controlled steel structure formation processes.

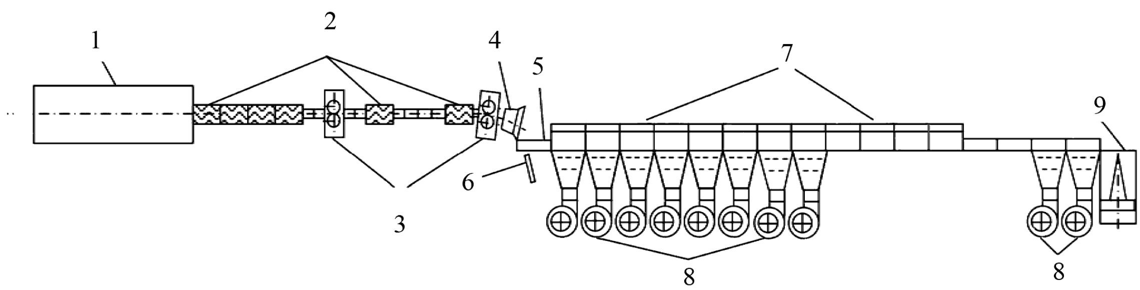
OJSC "Moldova metallurgical plant" (OJSC "MMP"), which was put into operation in January of 1985, is one of the few metallurgical enterprises that has implemented advanced technological processes of producing highly efficient and the most in-demand types of wire rods.

Initially, the enterprise was focused on the production of ordinary-purpose shape-rolled, reinforcing and coiled stock of scrap metal-made steel (basic charge), supplied from Modova and Ukraine. A combined wire-rod mill 320/150 of OJSE "MMP" was designed by "UKRGIPROMEZ" state-owned enterprize (Dniepropetrovsk) according to technical assignment of Nekrasov Iron and Steel Institute of NAS of Ukraine. Manufacture and installation of the equipment as well as starting-up and adjustment operations were performed by SKET company (Magdeburg, Germany) [14].

As the initial semi-finished rolled stock for rolling mill 320/150, a continuous cast blank with cross-section of 125×125 mm, produced with the application of electric arc furnace, was used. The project wire unit was designed for speed of rolling in the finishing mill up to 80 m / s, and for obtaining the required microstructure and mechanical indices we used a regulated two-stage cooling of the rolled products on Stelmor line with the air-cooling section length of ~ 75 м (from the laying head to the coils receiver) and the length of section under heat-insulation covers of 40 m.

In order to master production of a new qualitative range of steel grades and reorientation of the metal products realization to non-CIS foreign markets (European countries, US, South America, Australia, etc.), a number of design flaws of the installed equipment had to be eliminated.

In order to increase productivity of the rolling equipment and to provide the possibility of producing new highly efficient types of wire rods, which are rightfully considered to be the new-generation metal products, within the period from 1997 to 2001 OJSC "MMP" performed a large-scale reconstruction and modernization of the combined rolling mill with its redesigning into a double-strand mill. This has enabled simultaneous rolling processes on the lines for sectional steel and for wire. The length of the air-cooling section at Stelmor line (Fig. 2), which currently has no analogs, was increased to 147 m, including portion located under heat insulating covers that was increased to 147 m. Mesh conveyor of coils was replaced by a multistage roller conveyor. Working speed of rolling was 110 m / s.




1 – wire rolling unit; 2 – water-cooling section; 3 – pinch roll units; 4 – coiler; 5 –rolled coils delivery table; 6 – pyrometer; 7 – regulated water-cooling section with roller conveyor and heat insulation covers; 8 – air-blast fans (6 units with the power of 160 kW and 4 units with the power of 55 kW each); 9 – coils receiver pit

Fig. 2. Principal circuit of the wire rod water-cooling section at Stelmor line of the wire mill 320/150 of OJSC «MMP» after modernization

Stelmor line had to be modernized because production of wire rods, satisfying the contract requirements of consumers as well as the requirements of European and international standards, was not provided at that time. Analysis of the literature, particularly, of the work [15], has made it possible to formulate aims and tasks as to improving the quality of wire rods through improvement of the designed equipment as well as by providing the possibility to control the modes of deformation-thermal treatment of the rolled stock in the flow of continuous wire mill 320 /150.

As a result of measures undertaken at OJSC "MMP", a new line of the two-stage water-air cooling was put into operation, which enabled controlled cooling of the wire rods, made of different steel grades, in the wide range of cooling rates – from 0.1 to 30 °C / s [16 – 23].

Cooling of wire rods on the modernized wire line (Fig. 2) is characterized by the following features:

- spray water-cooling of the rolled stock with temperature-equalization zones along its cross-section;
- the possibility of cooling the rolled coils at different rates;
- instead of the meshed conveyor and the section from the coils layer to the pit with the length of 75 m, a 147 meter-long roller cascade conveyor comprising 14 zones with variable drives was installed, which provides the coiled stock movement at the speed from 0.1 to1.3 m / s;
- the length of the air-cooling section under heat-insulation covers was almost tripled (as compared to the former design) to reach ~ 120 m;
- instead of 15 blast fans (Fig. 1) with the power of 15kW each, 6 jet-cooling units with the power of 160 kW, rotation speed to 1500 $min^{-1}$ and variable frequency were installed as well as four 55 kW-power blast fans, which were formerly located before the pit and two of them were later moved to the beginning of the line in order to increase cooling ability of the metal (see Fig. 2).

A distinctive feature of the fan systems at the modernized Stelmor line is the presence of nozzle panels providing differentiated air supply across the conveyor width, which makes it possible to minimize dispersion of the mechanical properties along the rolled coil length. Imperfectness of fan systems, which do not provide the required cooling of the metal across the conveyor width, causes inhomogeneity of microstructure formation and of the rolled stock mechanical properties. Such effect is rather frequently observed in practice during the coiled stock cooling process at Stelmor line [24].

Development of rational deformational thermal treatment modes has enabled manufacture of the new-generation metal products for the hardware industry [3, 6, 19], particularly, of the wire rods (slow cooling), made of low-carbon and low-alloyed steel grades, subjected to drawing with deformation rates of 97.9 – 98.8% without softening thermal treatment, as well as of the wire rods (high cooling rates) of high-carbon steels intended for manufacturing steel reinforcing ropes, metal cord, springs, reinforcing wire, etc., capable of withstanding total deformation rate of ~ 95% [6, 21, 25, 26].

It should be noted that such metal products are in high demand at the national and world markets as compared to the wire rods of ordinary quality. Production and processing of rolled products of increased deformability enables significant improvement of technical-economic indicators of both metallurgical enterprises themselves (due to the increased realization cost) and metalware enterprises (due to elimination of additional thermal treatment and provision of the possibility to use mechanical method to remove surface scale instead of traditionally used acid etching).

At OJSC “MMP” unique technologies of manufacturing the following highly efficient types of wire rods, made of boron-microalloyed steel, have been mastered [27]:

1. wire rods made of low-carbon, low-alloyed and alloyed steel grades (SAE 1006…1008, Св-08Г2С, Св-08ГНМ, Св-08Г1НМА, Св-08ХГ2СМФ, Св-10ХГ2СМФ, Св-10НМА, etc.) and those intended for producing cold-heading wire. Maximally possible plasticity indicators have been achieved. They provide good manufacturability at the hardware conversion stage without additional thermal treatment (recrystallization annealing) from separate heating;
2. made of high-carbon steel grades 72D…C86D (EN 16120-2:2011) with the diameter of 5.5…14.0 mm, including vanadium-alloyed and / or chromium-alloyed steels, intended, particularly, for conversion into stabilized reinforcing ropes with the diameter of 9.3…18.0 mm of different strength classes (1670…1860 MPa) and cold-deformed reinforcement wire for pre-stressed concrete structures.

Industrial implementation of the developed deformation thermal treatment modes has made it possible to provide direct drawing of the wire rods, made of high-carbon steel grades, at the metalware conversion stage without patenting. In this case perlite dispersion and homogeneity of its distribution over cross-section of the rolled products play the major role. Sorbitic perlite structure (interlamillar spacing less than 0.2 microns) enables achieving high degrees of relative total reduction during wire production. Due to the constant modernization of the drawing equipment and corresponding increase of the drawing rates, the demand in high-quality rolled products has been growing from year to year. Strength classes of the finished products in the range of 1670…1860 MPa can be obtained when rupture strength of the wire rods in the delivery condition is no less than 1150 MPa, which is hard to achieve in practice, especially with increasing nominal diameter of the rolled products. Despite the existing difficulties and due to the complex fundamental approach to the problem solution, based on the rational choice of the chemical composition, liquid steel casting technology and the possibility of controlling the parameters of the deformation thermal treatment, the achieved qualitative parameters of the rolled products correspond to the level of the best world manufacturers (ArcelorMittal Hamburg, FnSteel, Ovako).

In spite of the achieved scientific-technical and practical results, the strategic plan of OJSC "MMP" development includes upgrading of the electric furnace melting shop, which will enable mastering production of new prospective grades and types of rolled products. Main direction of modernization is provision of the possibility to manufacture continuous-cast billets of a larger cross-section (150×150…180×180 mm) and to use the technology of multilevel electromagnetic stirring of the metal with maximal reduction or complete elimination of the columnar dendrite cast structure.

Of no less importance is also further improvement of Stelmor line, which will enable development of new advanced controlled cooling modes with the application of complete isothermal exposure of rolled coils on the roller conveyor. This will facilitate implementation of such types of thermal processing as recrystallization annealing and patenting, which will provide formation of an exclusive complex of the wire rod properties (microstructure, mechanical properties).

## Conclusions

On the basis of the positive practical experience in producing high-quality types of wire rods at OJSC "MMP" and taking into account the composition of technological equipment, it could be stated that for improving quality indicators of wire rods, manufactured at the metallurgical enterprises of Ukraine, the following measures should be carried out:

Installation of the modern electromagnetic stirring units in the section of continuous-cast billet crystallization (in the crystallizer, in the secondary and final cooling zones) in order to reduce the influence of dendrite cast structure on the quality of finished rolled products;

Exclusion, if necessary, of the water cooling stage, which will make it possible to obtain uniform distribution of the structural components over cross-section of the rolled products. This is especially important for the rolled products of large diameter;

Replacement of the air-blast fan systems by more powerful ones with the possibility of differentiated distribution of air flows, supplied via 6…8 individual channels, across the width of Stelmor line conveyor;

Provision of a hermetic air-cooling tunnel over the roller conveyor under the heat-insulating covers in order to prevent air suction;

Installation of additional electrical heaters and circulation fans in the working tunnel under heat insulation covers in order to realize austenite isothermal decomposition mode in the rolled stock continuous cooling process.

Modernization, which does not require significant capital investments and is based on carrying out the above measures, will enable essential improvement of the produced wire rod quality indicators as well as mastering production of the new highly efficient types of metal products at the metallurgical enterprises of Ukraine.

## REFERENCES

1. Разупрочняющая термомеханическая обработка проката из углеродистой стали / В. В. Парусов, А. Б. Сычков, В. А. Луценко, Э. В. Парусов // Металлургическая и горнорудная промышленность. – 2003. – № 6. – С. 54 – 56.

2. Научные и технологические аспекты производства высококачественной катанки / В. В. Парусов, А. Б. Сычков, О. В. Парусов, И. Н. Чуйко // Металлургическая и горнорудная промышленность. – 2010. – № 2. – С. 139 – 145.

3. Освоение технологии производства катанки из стали Св-08ГНМ на Молдавском металлургическом заводе / И. Н. Чуйко, В. В. Парусов, О. В. Парусов [и др.] // Строительство, материаловедение, машиностроение: Сб. научн. трудов. – Дн-вск, ПГАСА, 2007. – Вып. 41, ч. 2. – С. 129 – 134.

4. Потемкин К. Д. Термическая обработка и волочение высокопрочной проволоки / К. Д. Потемкин. – М. : Металлургия, 1963. – 120 с.

5. Лемпицкий В. В. Прогрессивные способы повышения качества стали / В. В. Лемпицкий, И. Н. Голиков, Н. Ф. Склокин. – М. : «Металлургия», 1968. – 340 с.

6. Парусов В. В. Теоретические и технологические основы производства высокоэффективных видов катанки / В. В. Парусов, А. Б. Сычков, Э. В. Парусов. – Дн-ск. : «АРТ-ПРЕСС», 2012. – 376 с.

7. Металлургические и металловедческие аспекты производства высокоуглеродистой катанки / А. Б. Сычков, М. А. Жигарев, А. Ю. Столяров и [др.]. – Магн. гос. техн. универ. им. Г. И. Носова, 2014. – 257 с.

8. Парусов В. В. Развитие научных и технологических основ производства катанки для изготовления канатов и металлокорда / В. В. Парусов, А. М. Нестеренко, Р. В. Старов [и др.] // Метизная промышленность XXI века: проблемы и перспективы: Сб. научн. трудов. – Донецк, 2001. – С. 31 – 33.

9. Структура и технологическая пластичность ускоренно охлажденной углеродистой катанки / В. В. Парусов, В. К. Бабич, А. И. Сивак [и др.] // Сталь. – 1982. – № 9. – С. 78 – 80.

10. Микроструктура канатной катанки, сорбитизированной с прокатного нагрева / Г. П. Борисенко, А. А. Горбанев, В. А. Кулеша [и др.] // Сталь. – 1987. – № 10. – С. 84 – 87.

11. Dull T. The Stelmor process for controlled cooling of roll / T. Dull, A. Dove, I. Hitchcock // Wire and Wire Products. – 1964. – V. 39. – P. 1605.

12. Современные требования к качественным показателям катанки различного назначения / Э. В. Парусов, И. Н. Чуйко, Л. В. Сагура [и др.] // XIX Международная научно-практическая конференция «Металлургия: технологии, инновации, качество», 15-16 декабря 2015 г. Российская Федерация, Новокузнецк // Материалы конференции. – 2015. – С. 90 – 96.

13. Сычков А. Б. Развитие устройств и способов для термической обработки катанки / А. Б. Сычков, С. О. Малашкин, М. А. Жигарев // Сталь. – 2015. – № 10. – С. 50 – 54.

14. Непрерывный мелкосортно-проволочный стан Молдавского металлургического завода / Н. А. Богданов, В. В. Медведев, Б. А. Бирюков [и др.] // Металлург. – 1988. – № 6. – С. 60 – 63.

15. Lestani Massimo. Danieli structure control system / Lestani Massimo. – Danieli. – Morgardshammar. – Butrio: Italy, 1995. – 51 p.

16. Модернизация оборудования и совершенствование технологии для производства качественного проката в условиях Молдавского металлургического завода (ММЗ) / А. Б. Сычков, Н. А. Богданов, В. В. Парусов [и др.] // Металлургическая и горнорудная промышленность. – 2002. – № 8 – 9. – С. 306 – 312.

17. Высокоуглеродистая катанка из стали, микролегированной ванадием / В. В. Парусов, А. Б. Сычков, Э. В. Парусов [и др.] // Металлург. – 2004. – № 12. – С. 63 – 67.

18. Катанка повышенной деформируемости из стали Св-08Г2С / В. В. Парусов, А. Б. Сычков, И. В. Деревянченко [и др.] // Металлург. – 2007. – № 2. – С. 64 – 70.

19. Освоение производства сварочной катанки из легированной стали Св-08ХГСМФА / А. Б. Сычков, В. В. Парусов, М. А. Жигарев [и др.] // Металлург. – 2007. – № 7. – С. 63 – 69.

20. Режим двухстадийного охлаждения катанки из стали 80КРД на линии Стилмор / Э. В. Парусов, В. В. Парусов, М. Ф. Евсюков [и др.] // Металлургическая и горнорудная промышленность. – 2006. – № 3 . – С. 64 – 67.

21. Научно-технологические достижения отдела термической обработки металла для машиностроения за 2009-2014 г.г. / Э. В. Парусов, В. В. Парусов, Л. В. Сагура [и др.] // Фундаментальные и прикладные проблемы черной металлургии: Сб. научн. тр. ИЧМ. Днепропетровск: «Візіон». – 2014. – Вып. 29 – С. 322 – 328.

22. Разработка режима двустадийного охлаждения катанки из стали C80D2, микролегированной бором и ванадием / Э. В. Парусов, В. В. Парусов, Л. В. Сагура [и др.] // Металлургическая и горнорудная промышленность. – 2011. – № 3. – С. 53 – 56.

23. Разработка режима термомеханической обработки катанки из стали 85, микролегированной бором, на основе закономерностей превращений аустенита при непрерывном охлаждении / Э. В. Парусов, В. В. Парусов, Л. В. Сагура [и др.] // Металлургическая и горнорудная промышленность. – 2015. – № 3. – С. 54 – 58.

24. Теоретические и технологические основы высокоскоростной прокатки катанки / А. А. Горбанев, С. М. Жучков, В. В. Филиппов [и др.]. – Мн. : Выш. шк. – 2003. – 287 с.

25. Разработка энерго- и ресурсосберегающей технологии производства высокопрочных прядей / Э. В. Парусов, В. В. Парусов, Л. В. Сагура [и др.] // Металлургическая и горнорудная промышленность. – 2015. – № 1. – С. 157 – 160.

26. Разработка технологии производства высокоуглеродистой катанки для ее энерго- и ресурсосберегающей переработки на метизном переделе / Э. В. Парусов, В. В. Парусов, А. Б. Сычков [и др.] // Строительство, материаловедение, машиностроение: Сб. научн. тр. – Днепропетровск. – 2010. – Вып. 53. – С. 146 – 152.

27. Пат. 103113 Украина, МПК C 22 C 38/32, C 22 C 38/54. Сталь для глибокого волочіння / В. В. Парусов, О. В. Парусов, Е. В. Парусов [та інш.]; заявник та власник Інститут чорної металургії ім. З. І. Некрасова Національної академії наук України. – № a201203164 ; заявл. 19.03.2012 ; опубл. 10.09.2013, Бюл. № 17.

***Parusov Eduard*** – Cand. Sc. (Eng.), senior research worker of the Department of Metal Heat Treatment for Mechanical Engineering, tometal@ukr.net.

Institute of Ferrous Metallurgy of NASU, Dnipropetrovsk.

***Sychkov Oleksandr*** – Dc. Sc. (Eng.), Prof. of the Department of Foundry Production and Material Science, absychkov@mail.ru.

Magnitogorsk State Technical University, Russia.

***Gubenko Svitlana*** – Dr. Sc. (Eng.), Professor with the Department of Materials Science, sigubenko@gmail.com.

State Higher Education Establishment National Academy of Metallurgy of Ukraine.

***Chuiko Igor*** – Cand. Sc. ( Eng.), research worker with the Department of Metal Heat Treatment for Mechanical Engineering, ichuyko@mail.ru.

Institute of Ferrous Metallurgy of NASU, Dnipropetrovsk.