UDC 669.187.56
DOI: 10.30838/J.PMHTM.2413.280323.73.947

REGULATIONS OF THE FORMATION OF BAINETIC COMPONENT MATRIX IN ECONOMY ALLOYED CHROMO-MANGANESE ALLOYS

POHREBNA N.E.[1], *Ph. D., Prof.,*
NOSKO O.A. [2], *Ph. D., Assoc.Prof.,*
AIUPOVA T.A.[3*], *Ph. D., Assoc.Prof.,*
HREBENIEVA A.V.[4], *Ph. D., Assoc. Prof.,*
AIUPOV O.A.[5], *Stud.*

[1] Department of Materials Science and Heat Treatment of Metals, Ukrainian State University of Science and Technology, 2, Academicain Lazarian St., Dnipro, 49010, Ukraine, e-mail: nataliapogrebnaa3@gmail.com, ORCID ID: 0000-0002-3956-9590
[2] Department of Coatings, Composite Materials and Metal Protection, Dean of Faculty of Quality and Material Engineering, Ukrainian State University of Science and Technology, 2, Academician Lazarian St., Dnipro, 49010, Ukraine, e-mail: olganosko30@gmail.com, ORCID ID: 0000-0002-5749-7578
[3*] Department of Materials Science and Heat Treatment of Metals, Ukrainian State University of Science and Technology, 2, Academician Lazarian St., Dnipro, 49010, Ukraine, tel. +38 (050) 101-52-03, e-mail: tanyaayupova@ukr.net, ORCID ID: 0000-0002-5706-4211
[4] Department of Materials Science and Heat Treatment of Metals, Ukrainian State University of Science and Technology, Dnipro, Ukraine, e-mail: zhivotovich.anna@gmail.com, ORCID ID: 0000-0003-3594-9497
[5] Department of Quality Systems, Standardization and Metrology, Ukrainian State University of Science and Technology, 2, Academician Lazarian St., Dnipro, 49010, Ukraine, e-mail: tk136@ua.fm, ORCID ID: 0000-0002-1414-0835

Abstract. ***Purpose****.* The purpose of the investigation is to establish the regularities of the kinetics of supercooled austenite decomposition in the bainite temperature range (400−200 °C) in chromium-manganese cast iron for the development of thermal hardening regimes that increase the service life of products. ***Methodology.*** The object of the study are samples of research and industrial smelting of chrome-manganese cast iron containing 3,1 % carbon, 13,1 % chromium, and 15,75 % manganese. The study of the supercooled austenite decomposition kinetics was carried out by the dilatometric method in the temperature range of 400−200 °C, the study of the microstructure, phase composition, as well as the measurement of microhardness and hardness was carried out according to standard methods. ***Scientific novelty.*** The peculiarities of the supercooled austenite decomposition kinetics in the bainite temperature range (400−200 °C) in chromium-manganese cast iron were determined, the structure of the cast iron after aging consists of eutectic carbides Me (Cr, Mn, $Fe)_7C_3$, products of austenite decomposition, secondary carbides Me (Cr, Mn, $Fe)_7C_3$, Me (Cr, Mn, $Fe)_3C$, as well as untransformed austenite in the amount of 70...75 %. The maximum hardness of the experimental cast iron was established during isothermal exposure at 350 °C for 35 hours. ***Practical value.*** The established regularities of the chromium-manganese cast iron structure formation and the determined and optimized temperature-time intervals of the supercooled austenite isothermal decomposition in cast iron are the basis for the development of heat treatment regimes to increase the strength, wear resistance of the material and the service life of its products.

Keywords*: chromium-manganese cast iron; isothermal soaking; microhardness; hardness*

ЗАКОНОМІРНОСТІ ФОРМУВАННЯ БЕЙНІТНОЇ СКЛАДОВОЇ МАТРИЦІ В ЕКОНОМЛЕГОВАНИХ ХРОМОМАРГАНЦЕВИХ СПЛАВАХ

ПОГРЕБНА Н. Е.[1], *канд. техн. наук, проф.,*
НОСКО О. А.[2], *канд. техн. наук, доц.,*
АЮПОВА Т. А.[3*], *канд. техн. наук, доц.,*
ГРЕБЕНЄВА А. В.[4], *канд. техн. наук, доц.,*
АЮПОВ О. А.[5], *студ.*

[1] Кафедра матеріалознавства та термічної обробки металів, Український державний університет науки і технологій, вул. Академіка Лазаряна, 2, 49010, Дніпро, Україна, e-mail: nataliapogrebnaa3@gmail.com, ORCID ID: 0000-0002-3956-9590

[2] Кафедра покриттів, композиційних матеріалів і захисту металів, Український державний університет науки і технологій, вул. Академіка Лазаряна, 2, 49010, Дніпро, Україна, e-mail: olganosko30@gmail.com, ORCID ID: 0000-0002-5749-7578
[3*] Кафедра матеріалознавства та термічної обробки металів, Український державний університет науки і технологій, вул. Академіка Лазаряна, 2, 49010, Дніпро, Україна, тел. +38 (050) 101-52-03, e-mail: tanyaayupova@ukr.net, ORCID ID: 0000-0002-5706-4211
[4] Кафедра матеріалознавства та термічної обробки металів, Український державний університет науки і технологій, вул. Академіка Лазаряна, 2, 49010, Дніпро, Україна, e-mail: zhivotovich.anna@gmail.com, ORCID ID: 0000-0003-3594-9497
[5] Кафедра систем якості, стандартизації та метрології, Український державний університет науки і технологій, вул. Академіка Лазаряна, 2, 49010, Дніпро, Україна, e-mail: tk136@ua.fm, ORCID ID: 0000-0002-1414-0835

Анотація. ***Мета*** роботи − встановлення закономірностей кінетики розпаду переохолодженого аустеніту в бейнітній області температур (400−200 °C) у хромомарганцевому чавуні для розроблення режимів термічного зміцнення, що підвищують термін служби виробів. ***Методика.*** Об'єктом дослідження служили зразки дослідно-промислової плавки хромомарганцевого чавуну із вмістом вуглецю 3,1 %, хрому 13,1 %, марганцю 15,75 %. Дослідження кінетики розпаду переохолодженого аустеніту проводили дилатометричним методом в інтервалі температур 400−200 °C, дослідження мікроструктури, фазового складу, а також вимірювання мікротвердості і твердості виконували за стандартними методиками. ***Наукова новизна.*** Визначено особливості кінетики розпаду переохолодженого аустеніту в бейнітній області температур (400−200 °C) у хромомарганцевому чавуні, структура чавуну після витримки складається з евтектичних карбідів Me (Cr, Mn, $Fe)_7C_3$, продуктів розпаду аустеніту, вторинних карбідів Me (Cr, Mn, $Fe)_7C_3$, Me (Cr, Mn, $Fe)_3C$, а також неперетвореного аустеніту в кількості 70…75 %. Установлено максимум твердості дослідного чавуну за ізотермічної витримки за температури 350 ºС протягом 35 годин. ***Практична значимість***. Установлені закономірності структуроутворення хромомарганцевого чавуну та визначені й оптимізовані температурно-часові інтервали ізотермічного розпаду переохолодженого аустеніту в чавуні є підставою для розроблення режимів термічної обробки для підвищення міцності, зносостійкості матеріалу та терміну служби виробів із нього.

Ключові слова: *хромомарганцевий чавун; бейніт; ізотермічна витримка; мікротвердість; твердість*

Introduction

Currently, the problem of improving the materials quality and the wear resistance of parts operating in friction conditions, while simultaneously reducing the costs of their production, is an important and one of the most urgent tasks of modern materials science. Materials characterized by a high content of chromium, manganese and deficient alloying elements - molybdenum, nickel and vanadium are widely used for parts that work in shock-abrasive and abrasive wear conditions, increased friction and in aggressive corrosive environments [1; 2]. Modern studies show that chromium-manganese cast irons can be prospective alloys for work in such conditions [3−6]. It is known that the properties of cast iron products operating under conditions of intensive abrasive and shock-abrasive wear, as well as friction, can be significantly improved due to heat treatment [7−9]. In order to develop modes of thermal strengthening increasing products service life, a detailed study of the patterns of structure formation and the kinetics of the disintegration of supercooled austenite in chromium-manganese cast irons is necessary.

Research material and methodology

The object of investigation are samples of research and industrial smelting of chromium-manganese cast iron. The chemical composition of investigated cast iron is given in Table 1.

Table 1

Chemical composition of the chromium-manganese cast iron

Alloying elements, %mass									
C	Cr	Ni	V	Mn	Si	Cu	S	P	Fe
3.1	13.1	1.15	0.25	15.75	0.9	0.15	0.003	0.025	65.57

The supercooled austenite decomposition kinetics was studied by the dilatometric method in the temperature range of 400−200 °C. Thermal analysis was carried out on a DIL805A/D dilatometer, using cylindrical 5 mm diameter and 10 mm length samples. Cast iron was austenized at a temperature of 950 °C for 1 hour, then isothermal soaking at temperatures of 400 °C, 350 °C, 300 °C, 250 °C, 200 °C for 35−40 hours was carried out.

The microstructure of the samples was detected in a 10 % Nital. The microstructure was studied using a Nikon Eclipse MA-200 light microscope. Microhardness was determined on the FM-700 microhardness tester under a load of 5 kgf for 5s, and hardness was determined on the FV-700 hardness tester under a load of 5 kgf for 10s according to the standard method, the phase composition was studied by X-Ray on the diffractometer DRON-3M in FeK-α radiation.

Results

In the cast state, the cast iron structure consists of austenite primary dendrites and carbide eutectic «M_7C_3 – austenite» (Fig. 1). Both longitudinal and transverse sections of eutectic colonies are observed. Austenite does not decompose during air cooling to room temperature due to the high content of manganese (15.75 %).

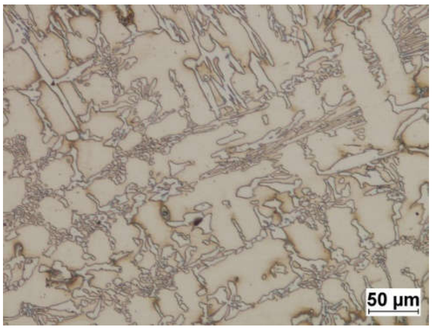


Fig. 1. Structure of researched cast iron in the cast state

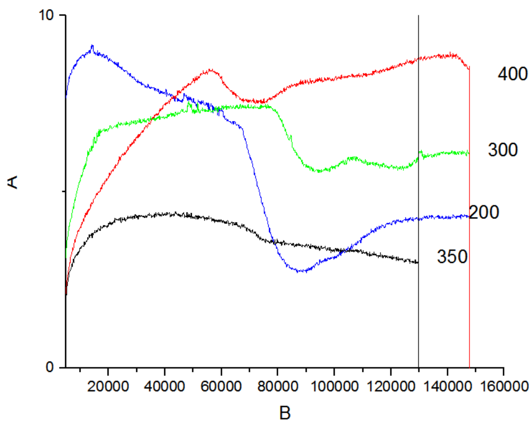


Fig. 2. Dilatometric curves of the investigated cast iron at the isothermal soaking in temperature range of 400−200 °C

The investigated cast iron was subjected to dilatometric tests in the temperature range of 400−200 °C. Dilatometric curves are presented in Figure 2.

In the process of isothermal soaking (Fig. 2) at 400 °C, bends in the dilatometric curves indicate the presence of austenite → ferrite phase transformation. The transformation begins after 15.5 hours, the fraction of retained austenite, according to X-ray structural analysis, is ~ 71 %.

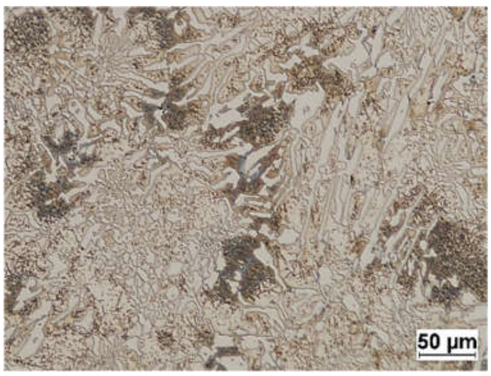
On the dilatograms obtained during isothermal exposures at 300 °C and 200 °C, a similar course of the curves is preserved, only with a slight shift of the beginning of the transformation at 300 °C to the region of high stability of supercooled austenite.

After isothermal soaking at 300 °C and 200 °C, the untransformed austenite fraction in the structure is 75 % and 70 %, correspondingly. The dilatometric curve corresponding to soaking at the temperature of 350 °C indicates a minimal change in samples length. After isothermal soaking at a temperature of 350 °C, the untransformed austenite fraction in the structure is 70 %.

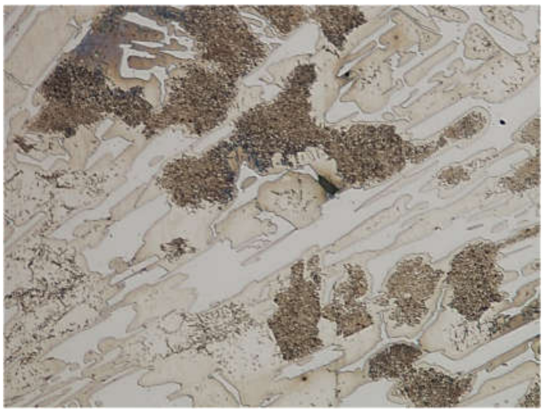
The microstructure of the investigated cast iron after isothermal soaking the temperature range of 400−300 °C is shown in Fig. 3.

After the isothermal soaking at 400 °C the supercooled austenite decomposition in structure of researched cast iron is observed.

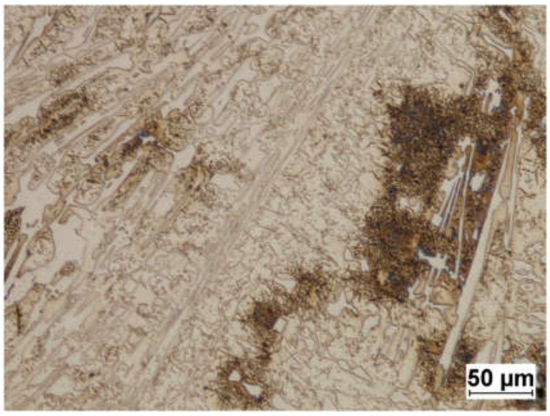
Probably, the first bainite aggregates appear at the dendrites boundaries and grow deep within them, the accumulation of secondary carbides on the boundaries [10; 11] also indicate the beginning of the formation of bainite aggregates in primary austenite dendrites.



a



b



c

Fig. 3. Microstructure of the investigated cast iron after isothermal soaking in the temperature range 400–300 °C, ×200: a – T = 400 °C, τ = 40 hrs; b – T = 350 °C, τ = 35 hrs; c – T = 300 °C τ = 40 hrs

After isothermal soaking at 300 °C, the minimum stability of austenite in the bainite range of temperatures is observed. Austenite decomposition begins after 13 hours of exposure and finishes after 21 hours. The supercooled austenite decomposition occurs with the formation of bainite aggregates growing deep into the dendrites centers. The fraction of disintegrated austenite is 25 %.

After soaking at 200 °C, the supercooled austenite decomposition begins within 17.5 hours and finishes within 24 hours. The amount of residual austenite in the structure is 70 %. By the X-Ray it is determined that the cast iron structure after soaking in the bainite range of temperatures consists of eutectic carbides Me $(Cr, Mn, Fe)_7C_3$, austenite decomposition products, secondary carbides Me $(Cr, Mn, Fe)_7C_3$, Me $(Cr, Mn, Fe)_3C$, as well as untransformed austenite in the amount of 70...75 %.

The austenite decomposition products, structural components, eutectic carbides microhardness measurement results and the hardness of the investigated chromium-manganese cast iron after isothermal soaking are presented in Table 2.

Table 2

Microhardness of structural components and hardness of the investigated chromium-manganese cast iron after isothermal soaking in bainite temperature range

Treatment	Microhardness, HV		Hardness, HRC
	Matrix	Austenite-carbide eutectic	
Cast state	465	636	47,5
950 ˚C_1hour_ 400 ˚C_40 hours	401	472,1	41,5
950 ˚C_1 hour _ 350 ˚C_35 hours	402,6	588,7	45
950 ˚C_1 hour _ 300 ˚C_40 hours	421	468,8	44
950 ˚C_1 hour _ 250 ˚C_35 hours	418,5	503,3	42,3
950 ˚C_1 hour _ 200 ˚C_40 hours	375,8	601,7	43

At the table 2 the direct relationship between the data of metallographic and X-Ray structural analysis and the change in hardness after heat treatment of cast iron is shown. The maximum hardness (close to the hardness in the cast state) is observed after isothermal soaking of cast iron at T = 350 °C, τ = 35 hours (45 HRC), corresponding to the region of maximum supercooled austenite stability (Fig. 2).

Conclusions

1. The regularities of the supercooled austenite decay kinetics in the bainite range of temperatures (400–200 °C) in chromium-manganese cast iron containing 3.1 % C, 13.1 % Cr, 15.75 % Mn have been established. A bend in the dilatometric curve corresponding to the austenite − ferrite transformation was revealed; under conditions of isothermal exposure at 400 °C, the austenite − ferrite transformation begins after 15.5 hours. Under the conditions of decreasing the isothermal soaking temperature to 300...200 °C, the course of the curves is preserved, there is a slight shift

in the beginning of the transformation to the region of high stability of supercooled austenite.

2. The structure of cast iron after aging at 400 °C, 350 °C, 300 °C, 250 °C, 200 °C for 35−40 hours consists of eutectic carbides Me (Cr, Mn, Fe)$_7$C$_3$, austenite decomposition products, secondary carbides Me (Cr, Mn, Fe)$_7$C$_3$, Me (Cr, Mn, Fe)$_3$C, as well as untransformed austenite in the amount of 70...75 %; the first bainite aggregates appear on the dendrites boundaries and grow deep within them, the accumulation of secondary carbides on the boundaries also indicate the beginning of the formation of bainite aggregates in primary austenite dendrites.

3. The maximum hardness (45 HRC) of the experimental cast iron is established during isothermal exposure at 350 °C for 35 hours.

REFERENCES

1. Vdovyn K.N., Synytskyi E.V., Volkov S.Iu. and Abenova M.B. *Vybor bazovoho sostava chuhuna dlia yzghotovlenyia lytykh meliushchykh tel* [The choice of the basic composition of cast iron for the manufacture of cast grinding media]. *Teoryia y tekhnolohyia metallurhycheskoho proyzvodstva* [Theory and Technology of Metallurgical Production]. 2013, no. 1, pp. 42–45. (in Russian).

2. Mohylatenko V.H., Yamshynskyi M.M., Fedorov H.Ie., Platonov E.A. and Kuzmenko A.Iu. *Povyshenye yznosostoikosty khromomarhantsevykh chuhunov* [Improving the wear resistance of chromium-manganese cast irons]. *Metalloobrabotka. Oborudovaniye i instrument* [Metalworking. Equipment and Tools]. 2008, no. 1 (97), pp. 38–41. (in Russian).

3. Kutsova V.Z., Kovzel M.A., Grebeneva A.V., Ratnikova I.V. and Velichko O.A. The influence of alloying elements on structure formation, phase composition and properties of chromium-manganese iron in the cast state. Metallurgical and Mining Industry. 2015, no. 9, pp. 1084–1088.

4. Kutsova V.Z., Kindrachuk M.V., Kovzel M.A., Tisov O.V., Hrebenieva A.V. and Shvets P.Iu. *Vplyv struktury, fazovoho skladu ta vlastyvostei na abrazyvnu znosostiikist khromomarhantsevykh chavuniv u lytomu stani* [The influence of the structure, phase composition and properties on the abrasive wear resistance of chromium-manganese cast irons in the cast state]. *Problemy tertia ta znoshuvannia* [Friction and Wear Problems]. 2016, no. 2 (71), pp. 78–85. (in Ukrainian).

5. Kutsova V.Z., Kovzel M.A., Hrebeneva A.V., Shvets P.Iu., Zyska A. and Konopka Z. *Vlyianye struktury, fazovoho sostava i svoistv na yznosostoikost khromomarhantsevykh chuhunov v lytom sostoianyy v uslovyiakh trenyia pry povyshennoi temperature* [Influence of structure, phase composition and properties on the wear resistance of chromium-manganese cast irons in the cast state under friction conditions at elevated temperature : coll. monogr.]. New Technologies and Achievements in Metallurgy, Material Engineering, Production Engineering and Physics. Czestochowa, 2017, no. 68, pp. 53–59. (in Russian).

6. Kutsova V.Z., Kovzel M.A., Hrebeneva A.V., Shvets P.Iu., Zyska A. and Koczurkiewicz B. *Struktura y mekhanycheskye svoistva khromomarhantsevykh chuhunov v lytom sostoianyy* [Structure and mechanical properties of cast chromium-manganese cast irons : coll. monogr.]. New Technologies and Achievements in Metallurgy, Material Engineering and Production Engineering. Czestochowa, 2016, no. 56, pp. 147–153. (in Russian).

7. Kindrachuk M.V., Kutsova V.Z., Kovzel M.A. and Velychko O.O. *Vplyv izotermichnoho hartuvannia na znosostiikist vysokokhromystykh splaviv v umovakh tertia pry pidvyshchenykh temperaturakh* [The effect of isothermal quenching on the wear resistance of high chromium alloys under friction conditions at elevated temperatures]. *Mashynoznavstvo* [Mechanical Science]. Lviv, 2013, no. 7−8 (193−194), pp. 59–63. (in Ukrainian).

8. Kutsova V.Z., Kovzel M.A., Hrebenieva A.V. and Velychko O.O. *Trybotekhnycheskye svoistva vysokokhromystykh splavov v lytom y termoobrabotannom sostoianyy pry komnatnoi y povyshennoi temperature ispytanyi* [Tribological properties of high-chromium alloys in the cast and heat-treated state at room and elevated test temperatures]. *Metallurhycheskaia y hornorudnaia promyshlennost* [Metallurgical and Mining Industry]. 2014, no. 3, pp. 69–74. (in Russian).

9. Kindrachuk M.V., Kutsova V.Z., Kovzel M.A. and Tisov O.V. *Suchasni funktsionalni materialy z beinitnoiu nanostrukturnoiu matrytseiu ta pidvyshchenymy trybolohichnymy vlastyvostiamy* [Modern functional materials with a bainite nanostructured matrix and increased tribological properties]. *Problemy tertia ta znoshuvannia* [Friction and Wear Problems]. 2016, no. 1 (70), pp. 112–130. (in Ukrainian).

10. Kutsova Valentina, Kovzel Maksim, Shvets Pavlo and Grebeneva Anna. Kinetics of phase transformations in chromium-manganese cast iron. Metallurgical and Mining Industry. 2016, no. 9, pp. 47–52.

11. Kutsova V.Z., Kovzel M.A., Shvets P.Iu., Hrebeneva A.V. and Ratnykova Y.V. *Zakonomernosty formyrovanyia strukturы, fazovыi sostav, svoistva y kynetyka raspada pereokhlazhdennoho austenyta v khromomarhantsevom chuhune* [Patterns of structure formation, phase composition, properties and kinetics of decomposition of supercooled austenite in chromium-manganese cast iron]. *Metaloznavstvo ta termichna obrobka metaliv* [Metal Science and Heat Treatment of Metals]. 2017, no. 1, pp. 48–57. (in Russian).

СПИСОК ВИКОРИСТАНИХ ДЖЕРЕЛ

1. Вдовин К. Н., Синицкий Е. В., Волков С. Ю., Абенова М. Б. Выбор базового состава чугуна для изготовления литых мелющих тел. *Теория и технология металлургического производства*. 2013. № 1. С. 42–45.

2. Могилатенко В. Г., Ямшинський М. М., Федоров Г. Є., Платонов Э. А., Кузьменко А. Ю. Повышение износостойкости хромомарганцевых чугунов. *Металлообработка. Оборудование и инструмент*. 2008. № 1 (97). С. 38–41.

3. Kutsova V. Z., Kovzel M. A., Grebeneva A. V., Ratnikova I. V., Velichko O. A. The influence of alloying elements on structure formation, phase composition and properties of chromium-manganese iron in the cast state. *Metallurgical and Mining Industry*. 2015. № 9. Pp. 1084–1088.

4. Куцова В. З., Кіндрачук М. В., Ковзель М. А., Тісов О. В., Гребенєва А. В., Швець П. Ю. Вплив структури, фазового складу та властивостей на абразивну зносостійкість хромомарганцевих чавунів у литому стані. *Проблеми тертя та зношування*. 2016. № 2 (71). С. 78–85.

5. Куцова В. З., Ковзель М. А., Гребенева А. В., Швец П. Ю., Зиска А., Конопка З. Влияние структуры, фазового состава и свойств на износостойкость хромомарганцевых чугунов в литом состоянии в условиях трения при повышенной температуре : коллективная монография. *New Technologies and Achievements in Metallurgy, Material Engineering, Production Engineering and Physics*. Честощево, 2017. № 68. С. 53–59.

6. Куцова В. З., Ковзель М. А., Гребенева А. В., Швец П. Ю., Зиска А., Кожуркевич В. Структура и механические свойства хромомарганцевых чугунов в литом состоянии : коллективная монография. *New Technologies and Achievements in Metallurgy, Material Engineering and Production Engineering*. Честощево, 2016. № 56. С. 147–153.

7. Кіндрачук М. В., Куцова В. З., Ковзель М. А., Величко О. О. Вплив ізотермічного гартування на зносостійкість висококхромистих сплавів в умовах тертя при підвищених температурах. *Машинознавство*. Львів, 2013. № 7−8 (193−194). С. 59–63.

8. Куцова В. З., Ковзель М. А., Гребенєва А. В., Величко О. О. Триботехнические свойства высокохромистых сплавов в литом и термообработанном состоянии при комнатной и повышенной температуре испытаний. *Металлургическая и горнорудная промышленность*. 2014. № 3. С. 69–74.

9. Кіндрачук М. В., Куцова В. З., Ковзель М. А., Тісов О. В. Сучасні функціональні матеріали з бейнітною наноструктурною матрицею та підвищеними трибологічними властивостями. *Проблеми тертя та зношування.* 2016. № 1 (70). С. 112–130.

10. Kutsova Valentina, Kovzel Maksim, Shvets Pavlo, Grebeneva Anna. Kinetics of phase transformations in chromium-manganese cast iron. *Metallurgical and Mining Industry*. 2016. № 9. Pp. 47–52.

11. Куцова В. З., Ковзель М. А., Швец П. Ю., Гребенева А. В., Ратникова И. В. Закономерности формирования структуры, фазовый состав, свойства и кинетика распада переохлажденного аустенита в хромомарганцевом чугуне. *Металознавство та термічна обробка металів.* 2017. № 1. С. 48–57.

Надійшла до редакції: 22.02.2023.