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Structure, Phase Composition of Supercooled Austenite, and Kinetics of Its Decomposition in Perlite Temperature Range of Chromium–Manganese Cast Iron

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The current paper studies the kinetics features of supercooled austenite decomposition in the pearlite temperature range (600–500°C) in chromium–manganese cast iron with the content of 2.2% carbon, 12.63% chromium, 5.7% manganese. The structure formation, phase composition, hardness as well as the distribution of elements between the phases and the structural constituents of the above-mentioned cast iron after isothermal soaking are investigated. The average size of secondary carbides after isothermal soaking is determined using JMicroVision v.1.2.7 free software.

Key words: kinetics of decomposition, supercooled austenite, perlite, phase transformations, dilatometric curves.

У роботі розглянуто особливості кінетики розпаду переохолодженого аустеніту в перлітній області температур (600–500°C) у хромоманґановому чавуні, що містить 2,2% вуглецю, 12,63% хрому та 5,7% манґану. Вивчено структуроутворення, фазовий склад, твердість, а також розподіл елементів між фазами та структурними складовими чавуну, який досліджувався після ізотермічних витримок. За допомогою безкоштовного програмного забезпечення JMicroVision v.1.2.7. визначено середній діяметер вторинних карбідів після ізотермічних витримок.

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Ключові слова: кінетика розпаду, переохолоджений аустеніт, перліт, фазові перетворення, дилатометричні криві.

В работе рассмотрены особенности кинетики распада переохлаждённого аустенита в перлитной области температур (600–500°C) в хромомарганцевом чугуне с содержанием 2,2% углерода, 12,63% хрома и 5,7% марганца. Изучено структурообразование, фазовый состав, твёрдость, а также распределение элементов между фазами и структурными составляющими исследуемого чугуна после изотермических выдержек. С помощью бесплатного программного обеспечения JMicroVision v.1.2.7. определён средний диаметр вторичных карбидов после изотермических выдержек.

Ключевые слова: кинетика распада, переохлаждённый аустенит, перлит, фазовые превращения, дилатометрические кривые.

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1. INTRODUCTION

Nowadays, the problem of enhancing wear resistance of components working under friction condition and the problem of improving the quality of materials along with reducing their production costs are important and they make up one of the most urgent tasks of modern materials science. For the production of the components to be operated under conditions of impact abrasive wear, abrasive wear, increased friction, and aggressive environments, the metallurgists widely apply the alloys with high contents of chromium, manganese and expensive and scare alloying elements of molybdenum, nickel and vanadium [1, 2]. As the sufficient reserves and stocks of these expensive elements are not available in Ukraine, it makes us search the alternative solutions able to improve the wear resistance and the quality of the components without relying mainly on the mentioned. The studies reported in the latest publication claim that chromium–manganese cast iron can be used for this purpose [3, 4]. This alloy finds its applications both as the cast material and as heat-treated one when regarded as tribological materials: production of blades for shot-blasting machines to grind the bodies for hard materials processing, plates to protect mills, rolling rolls, rolling tools, *etc*. As commonly known, the properties of cast iron products working under conditions of intense impact abrasive wear, abrasive wear, or frictional forces can be improved by heat treatment [5]. In order to develop the thermal hardening regimes capable to increase the product service life, it is necessary to carry out the profound studies on the patterns of structure formation, kinetics of supercooled austenite decomposition as well as liquation processes in the chromium–manganese cast iron during heat treatment.

Therefore, we consider that one of the important problems of the

modern materials science is the study on supercooled austenite decomposition kinetics, the structure formation features, the phase composition, and the properties of economically alloyed chromium–manganese cast irons.

2. MATERIAL AND METHODS

The research material is the chromium–manganese cast iron samples (cylindrical shape 5 mm in diameter and 10 mm in length) obtained industrially for the study purposes. Their chemical composition is given in Table 1.

In the current paper, the kinetics of supercooled austenite decomposition has been studied by a dilatometric method within the temperature range of 650–500°C. The thermal analysis was performed at NETZSCH DIL 402C dilatometer. During the tests, the samples were subjected to austenization at 950°C for 1 hour, followed by isothermal soaking at 650, 600, 550, and 500°C for 30 hours.

The microstructure of the samples was revealed with 10% alcoholic nitric acid solution and studied with JEOL JSM 7600F scanning electron microscope and NEOPHOT 32 optical microscope. The hardness was measured at Zwick 3112 hardness tester: the load applied was 10 kg of force, test for 10 s and standard method of testing. The phase composition was studied at PHILIPS diffractometer in CoK_α x-ray.

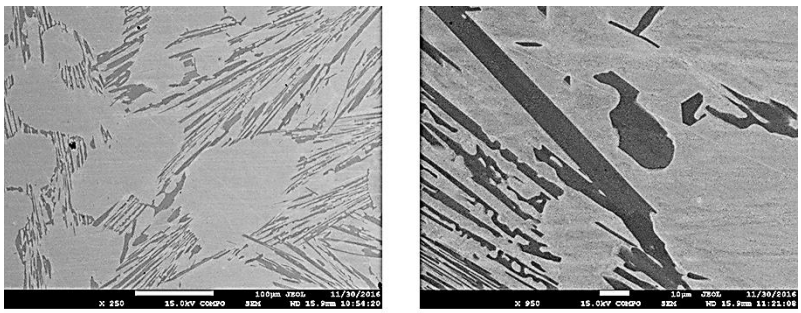
3. RESULTS OF THE STUDY

The structure of the chromium–manganese a cast iron in cast state consisted of the austenite primary dendrites and carbide eutectic of M7C3 + austenite (Fig. 1). The eutectic colonies grew both in the longitudinal and transverse directions. Due to the high content of manganese (5.7%), the retained austenite present in the structure did not undergo transformation when cooled in air to room temperature.

The samples of the chromium–manganese cast iron were subjected to thermal treatment according to the regime as follows: austenization at 950°C for 1 hour was followed by isothermal soaking at temperatures of 650, 600, 550, and 500°C for 30 hours. The dedicated dilatometric curves are shown in Fig. 2.

TABLE 1. Chemical composition of chromium–manganese cast iron samples.

Alloying elements content, % mass									
C	Cr	Ni	V	Mn	Si	Cu	S	P	Fe
2.20	12.63	0.83	0.25	5.70	1.00	0.10	0.009	0.013	retained



a *b*

Fig. 1. Microstructure of the chromium–manganese cast iron in a cast state (SEM): *a*—longitudinal section of the eutectic colonies of $A+M_7C_3$, *b*—transversal section of the eutectic colonies of $A+M_7C_3$.

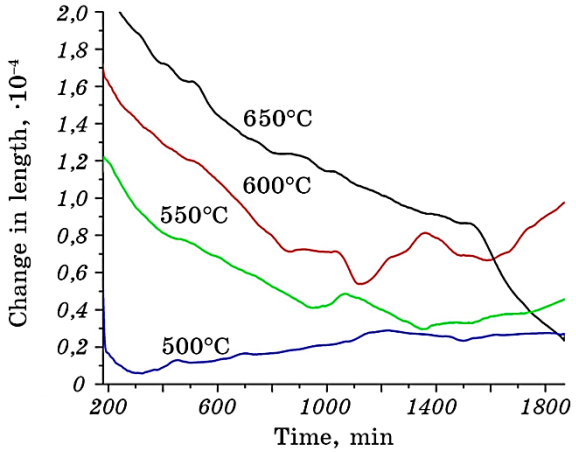
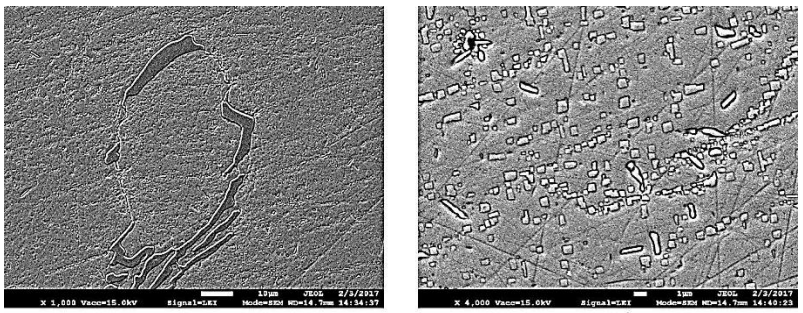


Fig. 2. Dilatometric curves of the white cast iron to describe the process of isothermal soaking at the temperature range of 650–500°C.

The pearlite transformation region at the temperature range of 600–500°C for the cast iron under study was determined after the analysis of the dilatometric curves.

The monotonic decrease in the length of the sample at the temperature of 650°C was probably related with the precipitation of the secondary carbides during the process of the isothermal soaking (Fig. 3). Moreover, the kinks in the curves at 600°C and at 550°C have indicated the presence of austenite ≥ ferrite phase transformation. On the dilatometric curve written during the isothermal soaking at the temperature of 600°C, the elongation of the sample was clearly observed in the time intervals of 1100–1300 min and 1600–1850 min. The dilatometric curve to correspond to the isothermal soaking at temperature of



a *b*

Fig. 3. Chromium–manganese cast iron microstructure after isothermal soaking for 30 hours at 650°C (SEM): *a*—×1000, *b*—×4000.

550°C has showed the bends in the interval of 1050–1300 min, further the sample size remained almost unchanged as long as up to 1850 min of the isothermal soaking.

Based on the comparison of the obtained data of the phase and microstructural analysis, it can be stated that the effect recorded in these intervals corresponds to the temperature and time interval for pearlite structure formation. The dilatometric curve recorded during the isothermal soaking at the temperature of 500°C within the interval of 1150–1450 min has evidenced the slight increase in the length of the sample, which indicates a very weak development of the phase and structural transformations at the given temperature and correlates with the results of the microstructural analysis.

Figure 3 shows the microstructure of the chromium–manganese cast iron formed during the isothermal soaking at 650°C.

The significant amount of secondary carbides of various shapes was observed within the structure formed. The presence of the pearlite transformation region at the temperature range of 600–500°C has been confirmed by the dilatometric curves and the metallographic analyses. The x-ray phase analysis has determined the fact that the structure of the cast iron after the isothermal soaking at the pearlite temperature range was the composition of eutectic carbides (M_7C_3), perlite, secondary carbides (M_7C_3 and M_3C) and retained austenite (Fig. 4). The most intensive decomposition of the austenite occurred at the temperate of 550°C, which was confirmed by the microphotographs (refer to Fig. 4, *c* and Fig. 4, *d*) and also by the x-ray diffraction analysis to evidence 20% of the retained austenite in the structure (refer to Table 2).

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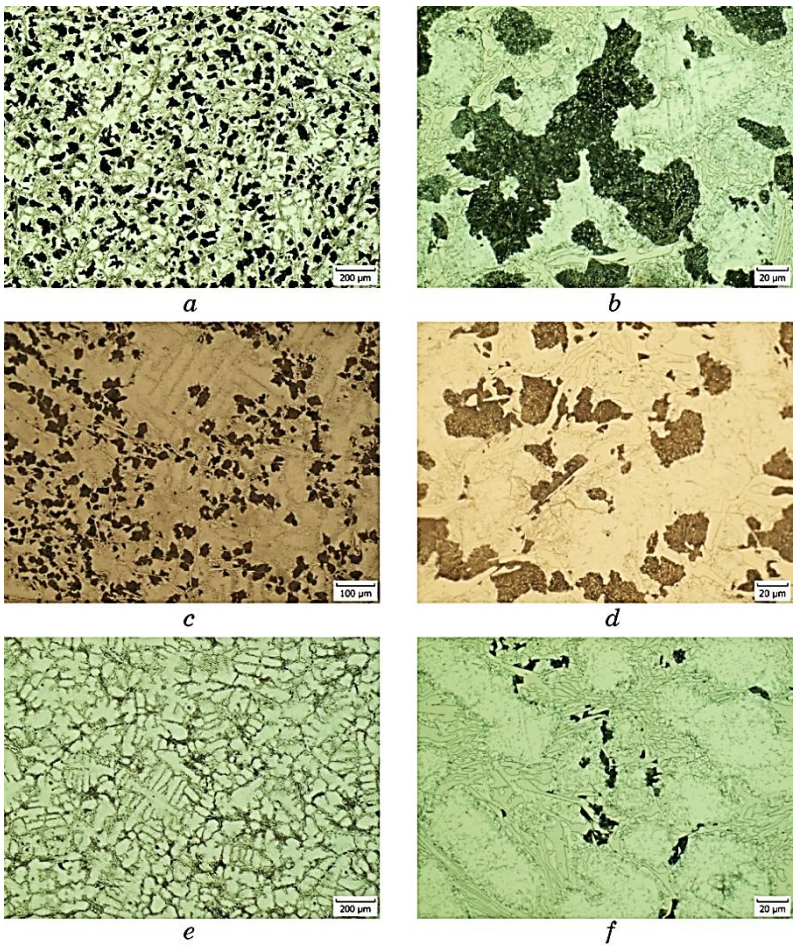

Fig. 4. Microstructure of the cast iron sample after the isothermal soaking of 30 hours at the temperature range of 600–500°C: *a*, *b*—600°C; *c*, *d*—550°C; *e*, *f*—500°C (*a*, *c*, *e*—×50; *b*, *d*, *f*—×400).

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The analysis of the elements distribution between the phases and the structural components after the isothermal soaking at 600°C has showed that the eutectic carbides of M_7C_3 contained chromium, manganese, iron, and carbon (Fig. 5).

TABLE 2. The hardness of the chromium–manganese cast iron and the amount of the retained austenite within the structure of cast iron after isothermal soaking.

Sample state	Hardness, HV_{10}	Retained austenite, %
Cast state	388	87
$T_{aust.}$ = 950°C, τ = 1 hour; $T_{isot.}$ = 650°C, τ = 30 hours	625	29
$T_{aust.}$ = 950°C, τ = 1 hour; $T_{isot.}$ = 600°C, τ = 30 hours	550	37
$T_{aust.}$ = 950°C, τ = 1 hour; $T_{isot.}$ = 550°C, τ = 30 hours	566	20
$T_{aust.}$ = 950°C, τ = 1 hour; $T_{isot.}$ = 500°C, τ = 30 hours	463	35

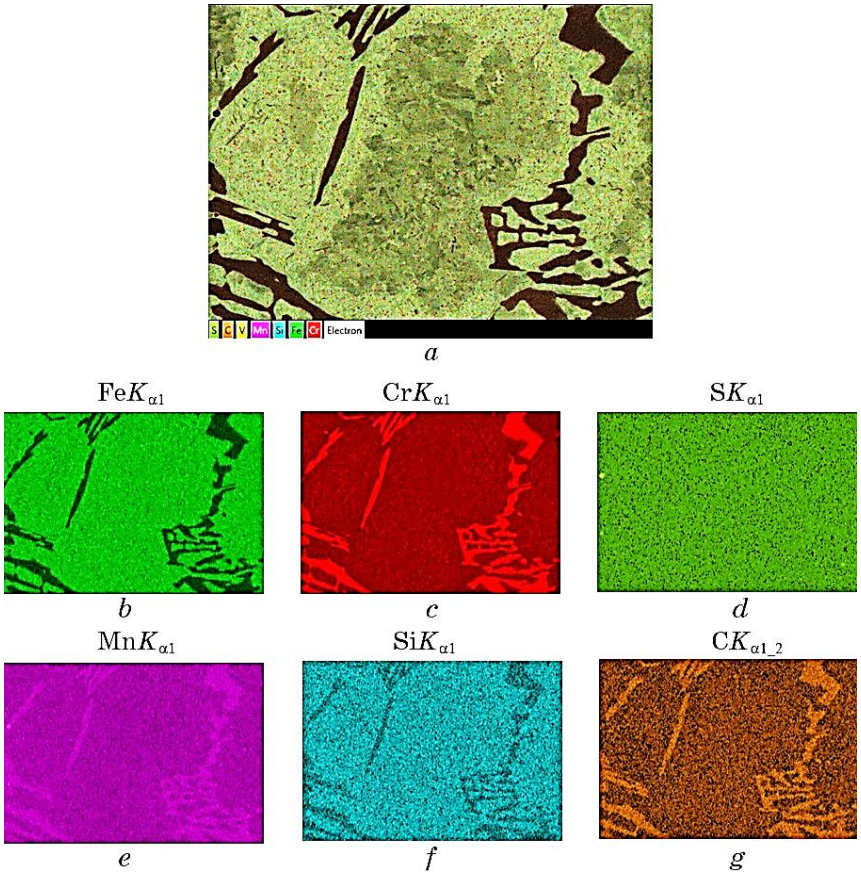
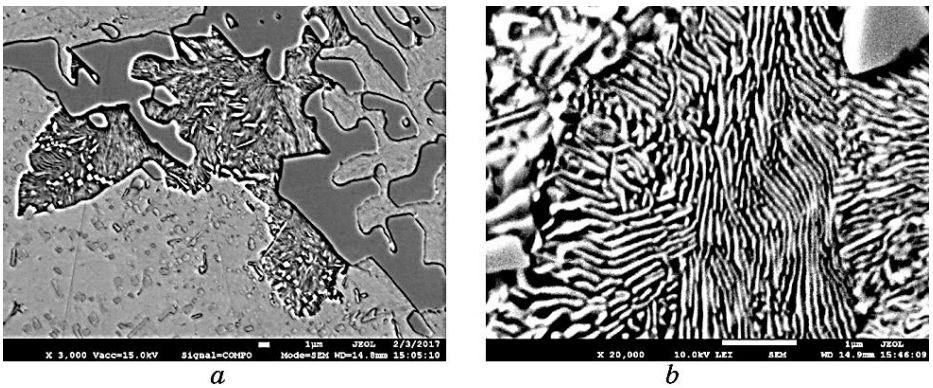


Fig. 5. Distribution of the elements between the phases and the structural components of the cast iron sample after the isothermal soaking at the temperature 600°C (EDX analysis): *a*—microstructure of the cast iron; *b*–g—microstructure of the cast iron in reflected electrons.



a *b*

Fig. 6. Microstructure of the cast iron under studies after the isothermal soaking of 30 hours at the pearlite temperature range of 600–500°C(SEM): *a*—600°C (×3000), *b*—550°C (×20000).

The separate inclusions of the MnS compound were observed within the structure.

The matrix was mainly iron and the alloying elements of manganese, chromium and silicon.

The first pearlite colonies were spawned and they grew at the boundary of the primary austenite dendrites/M_7C_3 eutectic carbides and developed into the depths of the dendritic austenite branches (Fig. 6, *a*). Figure 6, *b* shows the lamellar structure of the pearlite colonies in the cast iron.

The data on the hardness of chromium–manganese cast iron in the cast state as well as the heat-treated state, and the data on the amount of the retained austenite within the structure are given in Table 2. The maximum hardness (625 *HV*) was determined in that cast iron, which was subjected to the isothermal soaking at 650°C during 30 hours. In the pearlite region, the maximum hardness (566 *HV*) was achieved by soaking at 550°C for 30 hours.

A large number of secondary carbides appeared after the isothermal soaking within the structure of the chromium–manganese cast iron. The cross-section of the sample was polished section having different shapes: rods (bars) and hexagons (Fig. 7), depending on their orientation to the surface of the polished section.

Carbide M_7C_3 had a hexagonal lattice and the main growth direction was $\langle 0001 \rangle$ [6].

The average size of secondary carbides after isothermal soaking was determined from microphotographs at temperatures of 600, 550, and 500°C by using the free software JMicroVision v.1.2.7. The average size of secondary carbides as it has been determined varies within 100 nm to 2 μm.

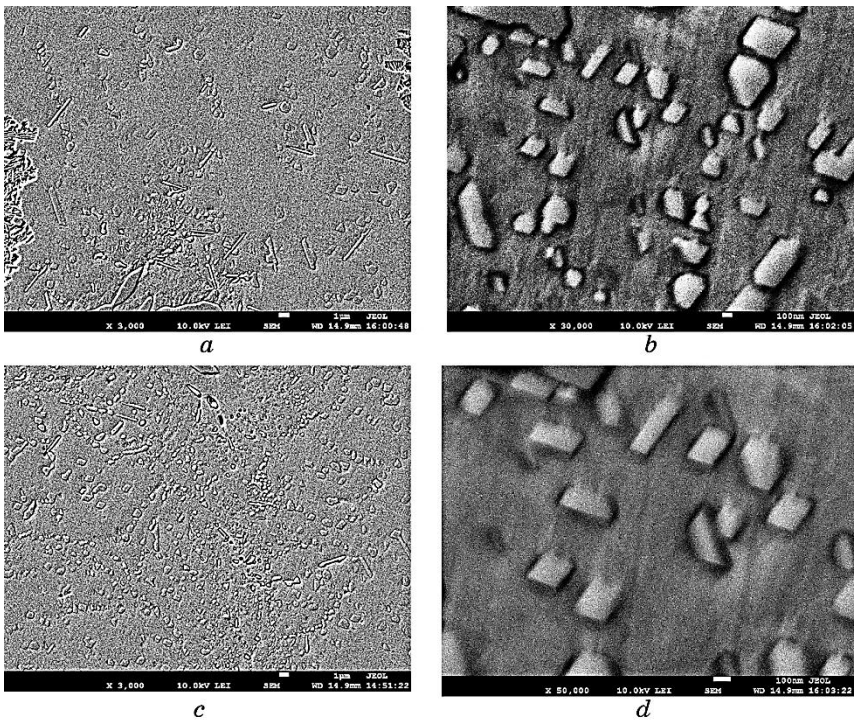


Fig. 7. Microstructure of the chromium–manganese cast iron after the isothermal soaking for 30 hours at 600°C (SEM): *a*, *c*—×3000, *b*—×30000, *d*—×50000.

4. CONCLUSIONS

1. The kinetics of supercooled austenite decomposition in the pearlite temperature range in the chromium–manganese cast iron with a content of 2.2% carbon, 12.63% chromium, and 5.7% manganese is studied. The temperature intervals of the pearlite transformation for the chromium–manganese cast iron are determined after isothermal treatment. As shown, the perlite transformation is revealed in the temperature range of 600–500°C.
2. The phase composition of the chromium–manganese cast iron is determined after isothermal soaking at 650, 600, 550, and 500°C for 30 hours.
3. The features of the pearlite transformation kinetics in the cast iron under the research are shown. The first pearlite colonies are spawned and grow on the boundary of the primary austenite dendrites/M_7C_3 eutectic carbides and develop into the depths of the dendritic branches of austenite.
4. In the pearlite region, the maximum hardness (566 *HV*) is achieved

with an isothermal soaking at 550°C for 30 hours.
5. The average size of secondary carbides is within 100 nm to 2 μm.

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