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Kinetics of phase transformations in chromium-manganese cast iron

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Abstract
Kinetics of supercooled austenite decomposition in chromium-manganese cast iron, the principle of structure formation, phase composition and properties was studied at present work. Isothermal diagram decomposition of austenite in cast iron with content 2.7% of C, 15.9% of Cr, 10.5% of Mn, which has area of austenite decomposition by diffusion and shear-diffusion mechanisms was built. Temperature intervals of austenite decomposition on pearlite (550-400°C) and bainite (350-250°C) area were installed. Phase composition of chromium-manganese cast iron after isothermal soaking was determinated. The maximum hardness of cast iron is formed during isothermal soaking in the pearlite area at 500°C temperature and in the bainite area at 250°C.
Key words: KINETICS, CHROMIUM-MANGANESE CAST IRON, ISOTHERMAL SOAKING, PEARLITE, BAINITE

Introduction

White cast irons are widely used for the manufacture of parts working under intensive abrasive and abrasive-corrosive and erosive wear: groundwater pumps, slurry pipelines, blades for shot blasting machines, plate armor mills and grinding bodies for grinding solid materials as well as mill rolls and rolling tool [1-4].

A large proportion of these parts are made of C-Fe-Cr-Mn-Ni white cast iron in various combinations. Chromium is the major alloying element of wear-resistant cast irons. Its content in the metal determines the wear resistance and corrosion properties of these alloys. Chromium interacts with carbon to form various carbides. The number, type, size and shape of carbide determine the wear-resistance properties of cast irons. Depending on the chromium and carbon in white cast irons such carbides are formed: $(Cr,Fe)_3C$, $(Cr, Fe)_7C_3$ and $(Cr, Fe)_{23}C_6$. Chromium bonded in carbides, is not involved in the alloying of the steel substrate and does not influence on its anticorrosive properties. According to A. Gierek, L. Bajka and [5], 1% carbon can bind 6 to 16% chromium. In the system Fe-Cr chromium forms continuous series of solid solutions with α-iron, the maximum solubility of chromium in γ-iron is about 12% [6]. To ensure the corrosion resistance of alloys with austenitic metal base requires the adding of alloying elements (Mn, Ni), that extending the area of γ-iron existence and correspondingly increase the solubility of chromium in it. Manganese, having a great affinity for carbon, replaces the iron in cementite and carbides of chromium, with the formation of chromium carbides, alloyed iron and manganese [7, 8]. Manganese forms a continuous series of solid solutions with γ-iron in the Fe-Mn system [6]. Joint alloying chromium white iron, manganese, nickel and other elements provide the necessary operational properties.

The properties of cast iron products, working in conditions of intensive shock-abrasive wear, can be significantly improved by heat treatment. For the development of modes of thermal hardening, which allows to increase service life of products is necessary to study the regularities of structure formation and kinetics properties of transformations in the pearlite and intermediate temperature area in white wear-resistant cast iron. However, information about structure formation and the kinetics of supercooled austenite decomposition in white chromium-manganese cast iron is almost absent.

That is why, study kinetics of the austenite decomposition, structure formation, phase composition and properties of economically alloyed chromium-manganese cast irons is an actual problem of modern materials science.

Materials and methods of study

The object of investigation in this work, were the samples of experimental-industrial melting of chromium-manganese cast iron, the chemical composition of which is given in table 1.

Table 1. The chemical composition of the investigated cast iron

Chemical composition, %									
C	Cr	Ni	V	Mn	Si	Cu	S	P	Fe
2.7	15.91	0.95	0.25	10.5	0.9	0.9	0.009	0.027	67.9

At present work investigated kinetics of the supercooled austenite decomposition by dilatometric method in the temperature range 550-250°C. Thermal analysis was carried out on the dilatometer DIL805A/D, used cylindrical samples with 5 mm diameter and length 10 mm. In the research process, the cast iron was subjected to austenitization at 950°C for 1 hour, and then isothermal soaking at temperatures of 550°C, 500°C, 400°C, 350°C, 300°C, 250°C, 200°C during 24-40 hours.

The microstructure of the samples was identified in 10% nitric acid solution. Research of microstructure was carried out by using the optical microscope Nikon Eclipse MA-200. Microhardness of phases and structural components was defined by using microhardness measuring instrument PMT-3 on a standard procedure. Phase composition of samples was studied on the diffractometer DRON–3M in FeK_{α} - radiation. Hardness (HRC) of the investigated cast iron in the cast stay was determined by the Rockwell's standard method.

The results of the study

Based on these data, constructed the isothermal transformation diagram of supercooled austenite for the investigated cast iron (Fig.1). Critical points are respectively equal to: AC_3 – 795°C, Ar_3 – 825°C.

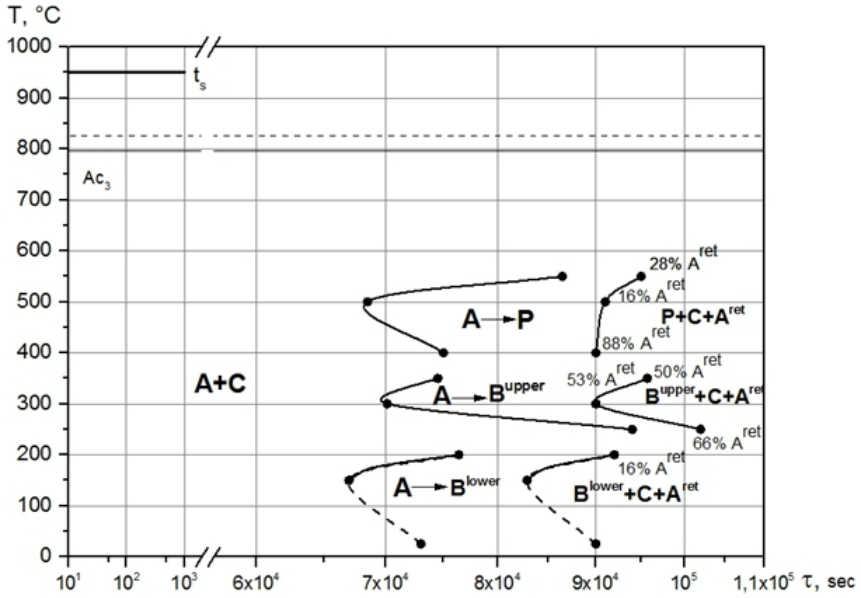

Figure 1. Isothermal transformation diagram of supercooled austenite for the investigated chromium-manganese cast iron

The diagram is characterized by the splitting temperature intervals of transformation and high stability of the austenitic area due to the higher content of manganese.

The stability of supercooled austenite below the A_{C3} temperature depends on the isothermal soaking temperature. Minimum stability of austenite in the pearlite transformation area observed at a temperature of 500°C. Decomposition of austenite begins after soaking during 19h and ends only after 24h. In this case, the structure is preserved a small contain of the retained austenite (15%). Isothermal soaking at 550°C leads to significant stability increase of austenite. In this case, decomposition of austenite on pearlite starts after 23.5 hours, while after fixation structure following 24h, the amount of retained austenite was 28%.

In the temperature interval 400-350°C, there was high austenite stability, the so-called "time window". However, only a small contain of the austenite is transformed after soaking for 35h proportion of retained austenite is ≈88%.

In the intermediate temperature interval 350-250°C minimum stability of austenite is observed at temperature of 300°C. Decomposition of austenite starts during 19.5h, and ends only after 27h. In this case the transformation is not complete in the structure saves a large amount of retained austenite about ≈53%.

The rise of isothermal soaking temperature up to 350°C leads to higher stability of austenite. In this case, austenite decomposition with the formation of bainite begins after 20.5h and ends in 28 hours. The absence of inflections on dilatometric curves in the further soaking up to 30 hours shows the absence of further transformations, thus the amount of retained austenite is maintained at ≈50%. The stability of supercooled austenite increases with decreasing temperature of isothermal soaking up to 250°C. In this case, the first bainite colonies begin to appear only after 26 hours. In the process of further soaking up to 40 hours only 23-26% of supercooled austenite may destruct. If structure maintains a large amount of austenite (≈66%), it can be assumed that in the temperature area of 250-210°C there was another area of austenite of high stability.

Due to the fact, that at high content of manganese in cast iron the martensite transformation start temperature lies in the field of negative temperatures that is why, after cooling to room temperature there saved retained austenite in the structure. It should be noted that in isothermal transformation diagram of supercooled austenite of investigated chromium-manganese cast iron separation line of the secondary carbides is absent. For its construction it is necessary to conduct an additional experiment with the use of the quenching-microstructural method.

Fig. 2 shows diffractogram of cast iron after isothermal soaking in the temperature interval of 550-250°C. Diffraction analysis of investigated chromium-manganese cast iron samples, after isothermal treatment indicates about the present of ferrite, eutectic carbides Me $(Cr, Mn, Fe)_7C_3$, and the secondary carbides Me $(Cr, Mn, Fe)_2C$, $Me(Cr, Mn, Fe)_5C_2$, alloyed cementite and retained austenite in the structure.

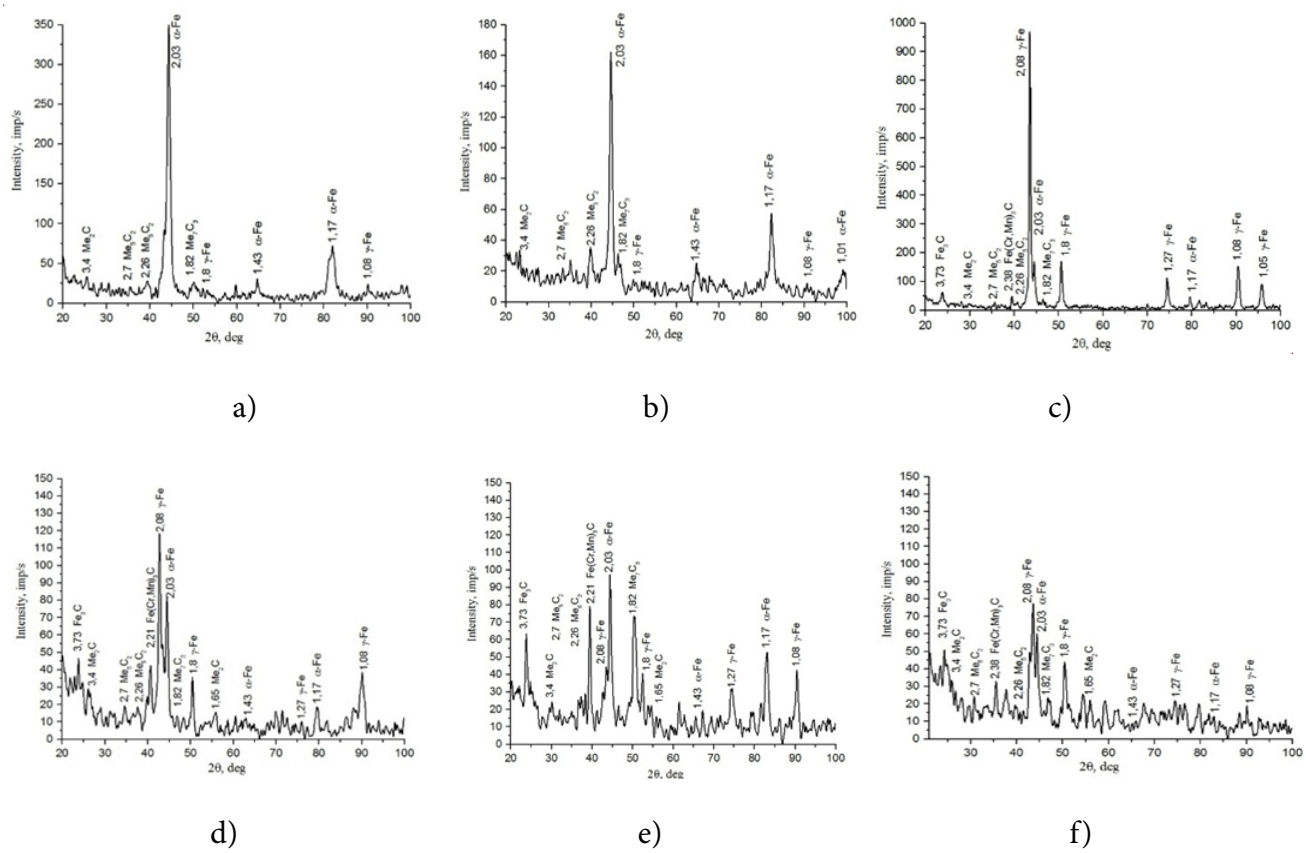

Figure 2. Schemes of chromium-manganese cast iron diffractogram after isothermal soaking: **a** – T=550°C, τ=24h; **b** – T=500°C, τ=24h; **c** – T=400°C t=35h; **d** – T=350°C, τ= 30h; **e** – T=300°C, τ= 40 h; **f**– T=250°C, τ=40h

In table 2 there compared the data of x-ray analysis of cast iron samples in as-cast condition and after isothermal treatment: $\beta_{0.5}$ values of the line (011) α, which characterize the imperfection of α – phase present in the alloy as eutectoid ferrite and bainite ferrite; amount of retained austenite (%γ); parameter of retained austenite (a_γ) and parameter α – phase (a_α).

It is shown that isothermal soaking at T=550°C leads to that there is an α -phase in the structure of cast iron, the lattice imperfection degree ($\beta_{0,5}$) which is small – 0.29 deg. the lattice parameter of α -phase

(a_α) – 0,287 nm. The amount of retained austenite is ≈28%.

At the temperature of 500°C which corresponds to the minimum stability of austenite in the pearlite area (19h) there is a decrease of the lattice imperfection degree ($\beta_{0,5}$) and 0.19, and the amount of retained austenite is ≈16%. After soaking at 400°C in the structure there preserved an ample quantity of retained austenite of ≈ 88%, which indicates a "time window" at this temperature.

Table 2. Data of x-ray structure analysis of the investigated cast iron in the cast state and after isothermal treatment

Condition	a on (011)α	aγ	The degree of α – phase imperfection ($\beta_{0,5}$)	% γ
cast	0.288	0.362	0.59	92
T_{isot}=550°C, τ	0.287	0.361	0.29	28
T_{isot}=500°C, τ	0.287	0.375	0.19	16
T_{isot}=400°C, τ	0.288	0.376	0.16	88
T_{isot}=350°C, τ	0.289	0.377	0.2	50
T_{isot}=300°C, τ	0.288	0.377	0.21	53
T_{isot}=250°C, τ	0.288	0.377	0.2	66
T_{isot}=200°C, τ	0.287	0.360	0.23	16

Isothermal soaking at 350°C leads to the fact that in the structure of investigated cast iron α -phase is present, the lattice imperfection degree ($\beta_{0,5}$) which is small – 0.2 deg. the lattice parameter of α -phase (a_α) – 0.288 nm. The quantity of retained austenite remains at high level ≈50%. At temperature of 300°C which corresponds to the minimum stability of austenite in the bainite area (19,5h) the lattice imperfection degree ($\beta_{0,5}$) – 0,21 deg. the lattice parameter of α -phase does not change (a_α) – 0.288 nm, and the amount of retained austenite is maintained at a level of ≈53% even when soaking was 40h. After soaking at temperature of 250°C in the structure there preserved an ample quantity of retained austenite ≈ 66%. Table 2 shows that the ferrite component of banite undergoes in the course of long soakings tempering, causing the value of the lattice parameter of α -phase close to the equilibrium value.

Data of microhardness measuring of austenite decomposition products, eutectic carbides and hardness of investigated cast iron in cast state and after isothermal soaking was resulted in table 3.

Table 3. Microhardness of austenite decomposition products, eutectic carbides and hardness of investigated cast iron in the cast state and after isothermal soakings

Condition	Microhardness of phases and structural components, MPa		Hardness, HRC
	A-K eutectic	Matrix	
cast	5610	3520	42
T_{isot}=550°C, τ	4953	4226	46.2
T_{isot}=500°C, τ	4729	4213	46.7
T_{isot}=400°C, τ	4685	4366	45.1
T_{isot}=350°C, τ	4631	4451	45
T_{isot}=300°C, τ	4642	4140	45.5
T_{isot}=250°C, τ	6438	4290	49
T_{isot}=200°C, τ	4805	4154	45.6
T_{isot}=150°C, τ	5840	4869	43

Analysis of hardness values of chromium-manganese cast iron indicates that there was satisfactory correlation between the data of metallographic, x-ray diffraction analysis and the change in hardness during heat treatment of investigated cast iron. The maximum hardness was characterized by cast iron after

isothermal soaking in pearlite temperature area after treatment T_{isot}=500°C, τ = 24h (46.7 HRC), and in the intermediate area of temperatures after treatment T_{isot}=250°C, τ= 40h (49 HRC).

The maximum microhardness of austenite decomposition products and eutectic colonies provide isothermal soaking of cast iron at temperature of 500°C and 250°C.

Conclusions

1. Isothermal transformation diagram of supercooled austenite in chromium-manganese cast iron with content 2.7% of C, 15.9% of Cr, 10.5% of Mn, which has area of austenite decomposition by diffusion and shear-diffusion mechanisms was built. Temperature intervals of austenite decomposition on pearlite (550-400°C) and bainite (350-250°C) area were spesified.

2. Phase composition of chromium-manganese cast iron after isothermal soaking was determined.

3. The maximum hardness of chromium-manganese cast iron was formed during isothermal soaking in the pearlite area at 500°C temperature and in the bainite area at 250°C.

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