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Effect of Chromium and Titanium on Structure and Properties of White Cast Iron

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Joint effect of chromium and titanium on structure and properties of hard castings is investigated in present work. It is determined that titanium neutralizes carbide-forming effect of chromium in the investigated concentration intervals. In the presence of titanium, the effect of chromium on hardness of samples is lower as compared to its individual effect. Therefore, addition of only chromium raised hardness of experiment billets by 2.1 times; together with titanium (0.2%) only by 1.1 times, and at 0.01% Ti increase of chromium content did not affect the hardness.

Keywords: WHITE IRON, CHROMIUM, TITANIUM, STRUCTURE, HARDNESS, ALLOYING

Introduction

Cast iron is one of the constantly popular and progressive materials. It is characterized by high castability, small shrinkage, unique cyclic loading resistance and possibility to be produced by using power- and resource saving technologies.

Selection of alloying elements is very important when making castings with high operation properties. But often alloying elements ensuring these properties make it difficult to manufacture goods from these castings. Therefore, it is necessary to consider the effect of additions and impurities on technological properties. In many cases, macro- and microstructure of casting metal, gas pickup in alloy during melting and dirtiness, liquation macroheterogeneity of casting composition are important [1, 2].

Composition, amount, shape and distribution of graphite are regulated by chromium addition in cast iron makeup. Chromium is also one of the most widespread alloying elements for Fe-C alloys and is among imported high-priced metals, therefore it is important to find the optimum amount of chromium for enhancement of definite functional properties [3, 4].

Titanium enters the melt from charge materials and is always present in cast iron. It has the highest affinity for carbon and gaseous elements (N_2, O_2), and forms high-melting compounds, even in small amount titanium affects the structure and properties of castings [5].

Methodology

Samples of experiment cast irons were melted in high-frequency unit HFI 10-10/0.44 using premelted addition alloy (%, by weight: C 3.13-3.27; Si 1.30-1.74; Mn 0.41-0.56; S 0.02-0.03; P 0.05-0.07; Fe the rest) at 0.01% Ti and 0.2%Ti and at increasing amount of chromium from 1.17 up to 5.63%.

Chemical composition of cast iron was determined by means of optical emission spectrometer with microprocessor control and measure system “Polivak E2000”.

Microstructure of cast iron was studied using an optical microscope MIM-8 (No. 59200) at magnifications x150, x600. Etching was carried out in 5 % alcoholic solution of nitric acid and in Marble reagent. Amount of structural components was determined by A. A. Glagolev's point method [6]. Huygens eyepiece 7^x with orthogonal squaring (289 nodal points), 25 viewing fields at magnification x420. The absolute accuracy was ±1 at confidence coefficient P = 0.5.

Microhardness of cementite and perlite was measured with the use of device PMT-3 (No. 59586) at loading 0.49 N and magnification x485. The value of microhardness was determined by results of 51 measurements, measurement accuracy of diagonal of impression was ±0.07 mkm.

Results and Discussion

Applied alloying complex Cr + Ti enables to obtain the minimum quantity of nonmetallic inclusions in the casting structure. And chromium is in both carbides and solid solution, but not in oxides, which confirms its complete recovery. Even at small titanium contents, there are hardening compounds TiN, TiCN, amount of which increases with increase of titanium concentration.

At 0.01% Ti, the majority of inclusions are inside perlite or cementite grains, which is favorable for mechanical properties, since cluster of inclusions on colony boundaries embrittles them.

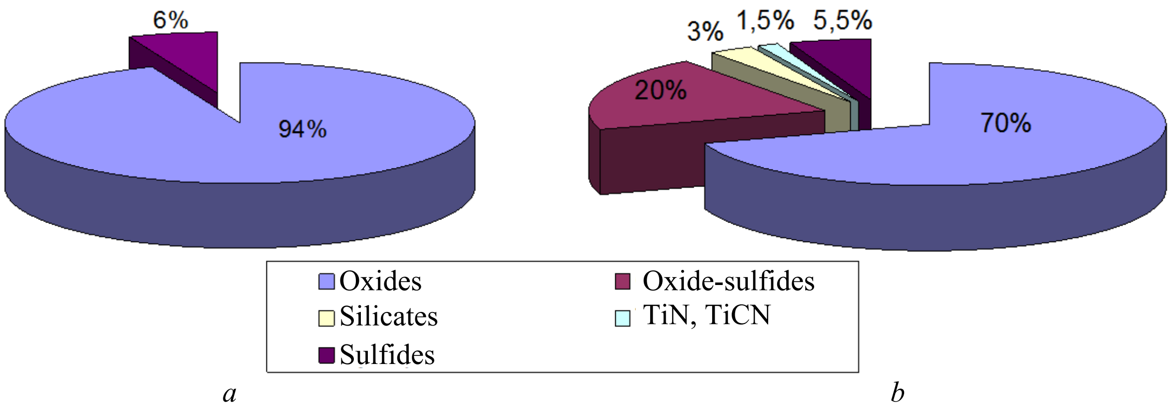


Figure 1. Makeup of nonmetallic inclusions in the experiment castings: *a* – 1.17% Cr, 0.01% Ti; *b* – 2.73% Cr, 0.2% Ti

At 0.2% Ti, there are more nonmetallic inclusions with a great variety of their types (**Figure 1**), but they have compact round shape and are allocated in structural components. Inclusions of carbides and carbonitrides of titanium play a role of hardening phase.

It is determined that Ti and Cr joint alloying in the investigated concentration interval has a many-valued effect on amount of basic structural components of cast irons (**Figure 2**), which considerably differs from the results obtained at their individual application [3, 5]. At 0.01% Ti, the significant amount of cementite is revealed for chromium content 1.26%. Further increase of chromium amount in the range of 1.26-5.63% reduces quantity of cementite down to initial values. Chromium effect varies at higher concentration of titanium (0.2%). At 1.48-2.55% Cr, the quantity of cementite was approximately the same and made ~29.7-31.4%. It is necessary to note that the same amount of cementite was also in cast irons with smaller content of titanium (0.01%) in similar concentration interval of chromium. As chromium content increased up to 5.03%, the amount of cementite in cast iron structure increased as well.

At Cr >2.5% and 0.2% Ti, the total amount of cementite was higher by 7.0-11.0% in average. Comparing the obtained results with the individual effect of chromium, it is possible to emphasize that titanium neutralizes the carbide-forming effect of chromium. So in earlier investigations [2], at 5.3% Cr the amount of cementite was ~45.0 %; for comparison – 29.6% cementite (Cr 5.63%, Ti 0.01%) and 35.0% cementite (Cr 5.03%, Ti 0.2%).

In the identical concentration interval of chromium: in case of its individual effect, the amount of cementite varied from 24.5% up to 45.2% (by ~21%); at 0.01% Ti from 27.9% to 39.0% (by ~11%) and at 0.2% Ti from 29.7 to 35.7% (by ~6%).

More than half cementite was as a part of ledeburite in the structure of experiment cast irons, accordingly its amount is characterized by allocation similar to cementite. And this is an essential difference of cast irons containing Cr+Ti from those alloyed with only chromium, in which amount of eutectic was from 6 up to 9%, whereas in the experiment cast irons ~15-30%.

At 0.01% Ti, as the amount of chromium increased, the thickness of cementite plates reduced and it became thin-differentiated. From the first sample at 1.17% Cr, honeycomb ledeburite was formed in all cast irons of this series. With the rise of chromium content, the amount of honeycomb ledeburite varies: the eutectic colonies occupy the large area in the structure of sample and ledeburite differentiation increases in the process of colony growth.

The overall structure refining of experimental cast iron is revealed with increase of chromium amount (**Figure 3**), but not as obvious as at its individual effect [4].

Amount of perlite in the structure of 0.01% Ti experimental cast irons was the same at higher concentration of chromium, and at 0.2% Ti –

slightly changed. It is of interest since titanium promotes the formation of perlite, and it would be logical that increase of titanium concentration would lead to similar change of perlite quantity. Perlite is nonuniform at both contents of titanium (**Figure 4**).

Inhomogeneity of cast irons revealed earlier at 0.47-1.08% Cr is saved [4], but its concentration interval moved towards higher content of Cr 1.17-1.74% (0.01% Ti) and 1.48-2.02% (0.2% Ti).

Effect of chromium and titanium alloying on microhardness of structural constituents and hardness of experiment ingots is studied in further investigations. The results are illustrated in **Figures 5, 6**.

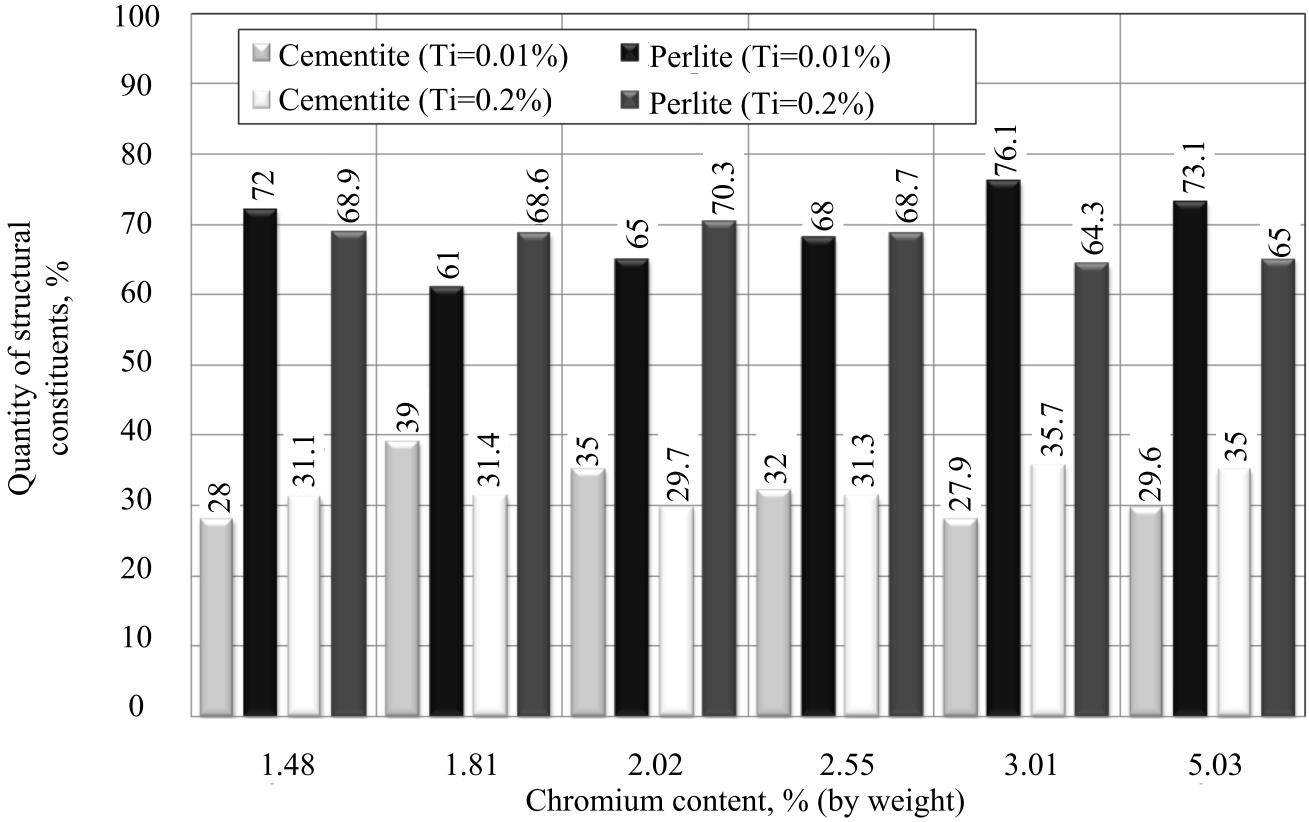
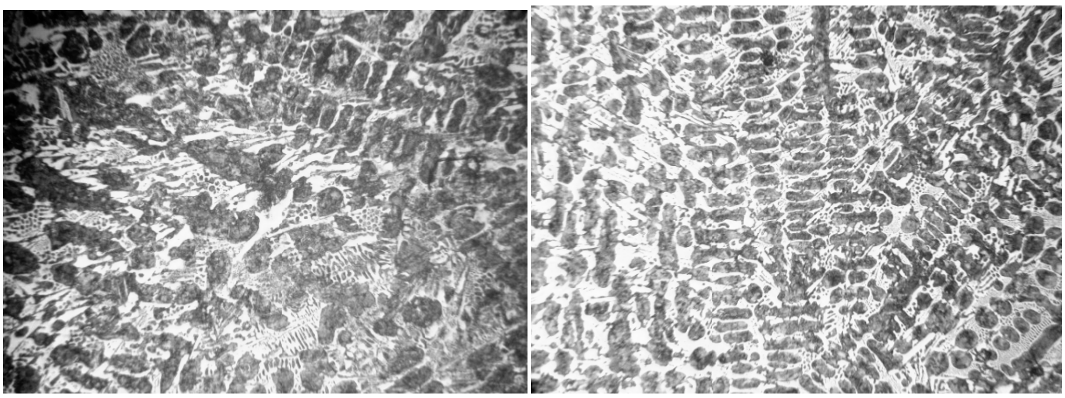


Figure 2. Quantity of structural constituents



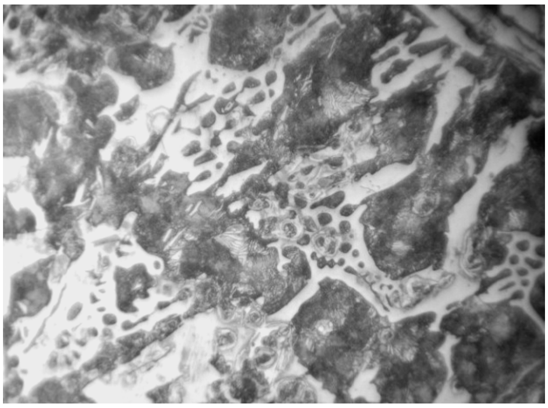
a *b*

Figure 3. Microstructure of samples, x150: *a* – 1.17% Cr, 0.01% Ti; *b* – 5.03% Cr, 0.2% Ti

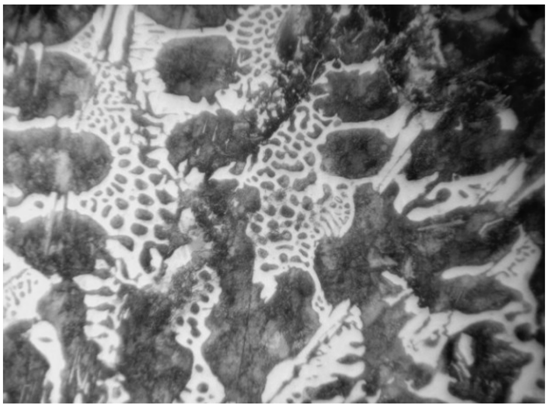
At 0.01% Ti, cementite microhardness varies till 1.74% Cr, further it is stabilized at the level of 9774-10297 MPa; at 0.2% Ti, H_μ of cementite increases and inhomogeneity is less observable at low contents of chromium. Ledeburite microhardness in the experiment ingots changes in the same way. The cementite constituent is dominant in eutectic.

Perlite microhardness changes in a different way as the content of chromium increases. Perlite microhardness is on the level of 3960-4090 MPa (0.01% Ti) without considering insignificant fluctuations in the interval of chromium low concentrations. At 0.2% Ti, H_μ of cementite increases by ~1760 MPa.

In cast irons alloyed with only chromium, microhardness of cementite and perlite raised substantially with increase of chromium quantity, and that of ledeburite dropped. In case of the joint alloying with chromium and 0.01% titanium, as the content of chromium increases, the microhardness of both ledeburite (~14%) and cementite (~12%) reduces for the reason that predominant part of cementite is in eutectic. In the process of ledeburite transformation, there is a complex redistribution of chromium, as a result of which chromium can concentrate on phase boundaries, as a consequence H_μ of cementite and of the whole ledeburite decreases. In 0.2% Ti samples, microhardness of all structural constituents increases with increasing quantity of chromium. Obtained results confirm that titanium in amount of 0.01 and 0.2% affects the formation and properties of structural constituents of cast iron.



a



b

Figure 4. Microstructure of samples, x 600: *a* – 1.17% Cr, 0.01% Ti; *b* – 3.01% Cr, 0.2% Ti

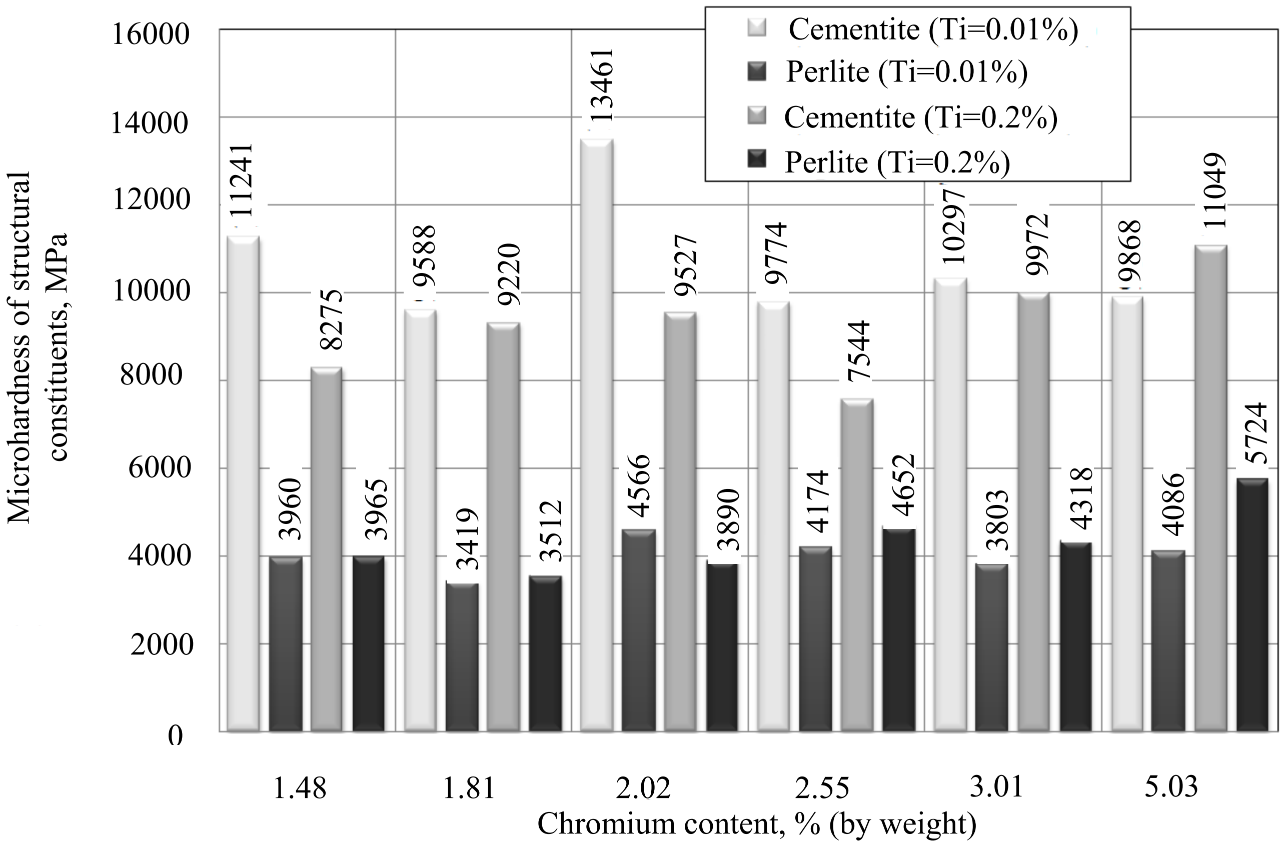


Figure 5. Microhardness of basic structural constituents

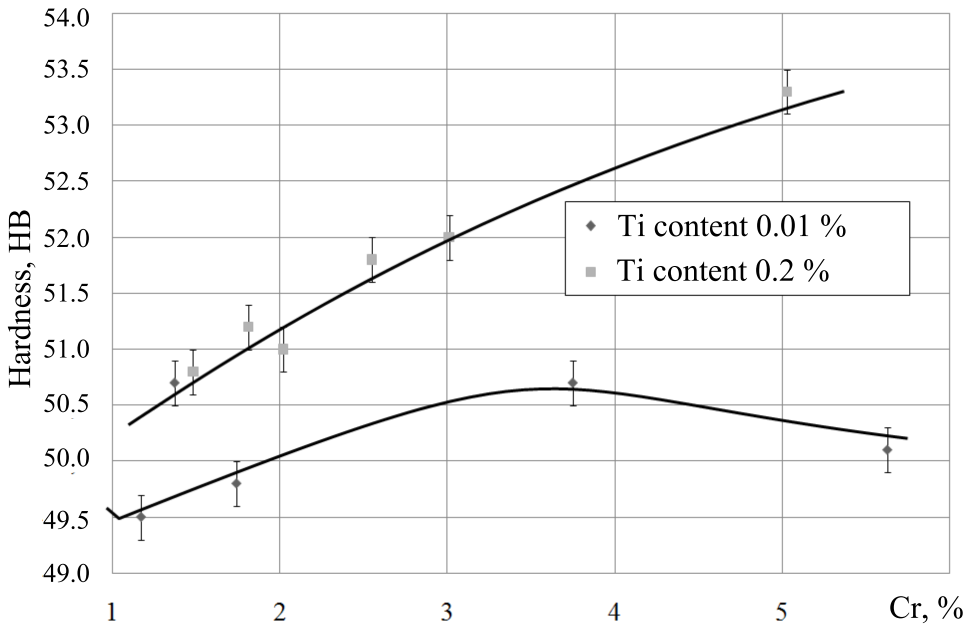


Figure 6. Effect of chromium and titanium on hardness of experiment cast irons

Castings hardness data confirm reliability of obtained results (**Figure 6**). In 0.01% Ti ingots with increasing chromium concentration, the hardness is the same. The tendency to hardness increase is revealed at the corresponding raise of chromium concentration at higher content of titanium. It can be explained by the fact that great number of hardening phases on the basis of titanium were formed primarily in perlite, and amount of cementite increased in this set of samples. In the presence of titanium, the effect of chromium on the hardness of samples is lower as compared to its individual effect.

Conclusions

Alloying complex Cr + Ti allows obtaining the minimum quantity of nonmetallic inclusions in cast structure. At 0.01% Ti, the majority of inclusions are inside perlite or cementite grains, which is favorable for mechanical properties since cluster of inclusions on colony boundaries embrittles them. Inclusions of carbides and carbonitrides of titanium act as hardening phase.

It is determined that titanium neutralizes the carbide-forming effect of chromium. In its identical concentration interval: in case of individual effect the amount of cementite changed by ~21%; at 0.01% Ti – by ~11% and at 0.2% Ti – by ~6%.

The amount of perlite in the structure of experiment 0.01% Ti cast irons was the same with increase of chromium content, and at 0.2% Ti – dropped insignificantly. Titanium did not promote the perlite formation in the investigated concentration interval.

At Cr + 0.01% Ti joint alloying, with increase of chromium content the microhardness of cementite and ledeburite decreases, and that of perlite remains unchanged. Under the same conditions, the microhardness of all structural constituents increases at 0.2% Ti. Obtained results confirm that titanium in amount of 0.01 and 0.2% affects not only the formation of structural constituents of cast irons, but also their properties.

The effect of chromium on the hardness of samples is lower as compared to its individual effect in the presence of titanium. Addition of chromium only in the same amount increased hardness of experiment ingots in 2.1 times; with 0.2% Ti – only in 1.1 times, and at 0.01% Ti the hardness did not change with increase of chromium content.

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Влияние хрома и титана на структуру и свойства белых чугунов

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В настоящей работе проведены исследования совместного влияния хрома и титана на структуру и свойства отливок из белого чугуна. Установлено, что в исследованных концентрационных интервалах титан нивелирует карбидообразующее воздействие хрома. В присутствии титана влияние хрома на твердость образцов ослаблено, по сравнению с его индивидуальным воздействием. Так, ввод только хрома повышал твердость экспериментальных слитков в 2,1 раза; совместно с Ti (0,2%) всего в 1,1 раза и при 0,01% Ti с увеличением содержания Cr твердость не изменялась.