THE EFFECT OF CARBON ON PHASE COMPOSITION AND PHASE TRANSFORMATIONS IN Fe-B SYSTEM ALLOYS

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The investigations of carbon alloyed Fe-B alloys (0,2-0,6 % (w.)) reveal the eutectics formation, which consists of iron monoboride FeB and iron boride Fe₂B. It is ascertained, that phase transition, which takes place in these alloys for solid state at the temperature of 1425 K depending on carbon content, bears no relation to transformation of iron monoboride\[\beta \rightarrow Fe(B,C) \rightarrow \alpha \rightarrow Fe(B,C)\], but is related to the formation of boron cementite Fe₃(CB).

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INTRODUCTION

Fe-B system alloys is of practical use because of complex of unique properties, such as infusibility, high hardness, chemical resistance in various corrosive media and others. So, for example, borides and boron-bearing alloys are used in nuclear power engineering owing to their special properties [1, 2]. It is known, that bearing alloys are used in nuclear power engineering media and others. So, for example, borides and boron-hardness, chemical resistance in various corrosive complex of unique properties, such as infusibility, high hardness, and strength.

Authors of the paper [4] show, that in alloys under boron content over 8,86% (w.) at the temperature of 1682 K in the process of interaction of liquid and iron monoboride FeB the peritectic transformation \(L + FeB \leftrightarrow Fe_B\) takes place, in consequence of which the formation of boride Fe₃B is the case [3]. In the state diagram of Fe-B system a number of authors points to the phase transformation \(\beta \rightarrow FeB \rightarrow \alpha \rightarrow FeB\) [3, 4, 6, 14], which occurs at the temperature of 1400 K. But investigations of Fe-B system alloys of pure materials reveal the absence of polymorphic transformation [3, 8, 15, 16]. Besides, authors of the paper [8, 15] point out that great impact on the formation of FeB phase is due to carbon, carbon content of 0,05-0,80 % (w.) and boron content of 9,0-12,0 % (w.), the rest is iron. To obtain Fe-B system alloys there is used burden consisting of carbonyl iron (with iron content of 99,95 % (w.)), amorphous boron (with boron content of 97,5,0 % (w.)), electrode graphite (with carbon content of 99,96 % (w.)). To prevent liquation alloys were made of previously mixed thoroughly and pressed powders of burden material. The smelting of specimens was carried out in Taman furnace with graphite hearth, melting of specimens was carried out in alundum sagger under argon atmosphere. The cooling rate for alloys amounted to 10 K/s. To ascertain alloy chemistry the chemical and spectrographic analysis were used [13]. Study of microstructure changes depending on reheat temperature was performed on the plant for microstructure investigation of materials at high temperatures “Kyrgyzstan” in argon medium with heating rate of 24 K/min. To study the physical properties of obtained alloys there was used durametric analysis (by means of microhardness tester PMT-3).

The phase composition of alloys was determined by method of electron-probe test by means of microscope JSM-6490, and by means of light microscope “Neophot-21”. X-ray phase analysis was performed by means of diffractometer DRON-3 in monochromated Fe-Kα radiation under voltage of \(U = 35\) kV and anode current of \(I = 14\) mA.

1. MATERIAL AND RESEARCH TECHNIQUE

The investigation was carried out on specimens with carbon content of 0,05-0,80 % (w.) and boron content of 9,0-12,0 % (w.), the rest is iron. To obtain Fe-B system alloys there is used burden consisting of carbonyl iron (with iron content of 99,95 % (w.)), amorphous boron (with boron content of 97,5,0 % (w.)), electrode graphite (with carbon content of 99,96 % (w.)). To prevent liquation alloys were made of previously mixed thoroughly and pressed powders of burden material. The smelting of specimens was carried out in Taman furnace with graphite hearth, melting of specimens was carried out in alundum sagger under argon atmosphere. The cooling rate for alloys amounted to 10 K/s. To ascertain alloy chemistry the chemical and spectrographic analysis were used [13]. Study of microstructure changes depending on reheat temperature was performed on the plant for microstructure investigation of materials at high temperatures “Kyrgyzstan” in argon medium with heating rate of 24 K/min. To study the physical properties of obtained alloys there was used durametric analysis (by means of microhardness tester PMT-3).

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2. DISCUSSION

In Fe-B system alloys with boron content within interval of 9,0-15 % (w.) there is observed the two-phase structure, which represents primary dendrites of FeB, contained in matrix of Fe₂B phase (Figs. 1, 2.).
The measurements of microhardness of boride phases reveal that microhardness of iron monoboride equals to 20,15 GPa, and for iron boride it equals to 17,46 GPa.

Alloying the Fe-B system alloys with carbon up to 0,1 % (w.) slightly leads to structure change of alloy. With increase of carbon content more than 0,6 % (w.) there is forming the eutectics consisting of graphite and boride Fe₂B. At carbon content within the interval of 0,2-0,5 % (w.) in iron-based alloy with boron content over 9,0 % (w.) there was observed the eutectics FeB + Fe₂B with core morphology (Fig. 3, a, b).

Microhardness of iron monoboride in these alloys decreased to 16,56 GPa, and for iron boride it decreased to 15,23 GPa.

If we compare obtained values of microhardness for boride phases with values of microhardness for these phases for binary Fe-B alloy, which is not alloyed with carbon, we can conclude that in the process of carbon...
alloying the microhardness of iron monoboride and boride is considerably decreased.

Besides, the microspectrum analysis results reveal that in monoboride iron content amounts to 82.5-84.1 % (w.), boron contents amounts to 17.42-15.75 % (w.) and carbon content amounts to 0.08-0.15 % (w.). Iron boride Fe\(_2\)B contains 91.2-92.1 % (w.) of iron, 8.76-7.83 % (w.) of boron and 0.04-0.07 % (w.) of carbon, which coincides with results obtained in the papers [11, 12]. In diffractogram of alloy with boron content of 11.0 % and carbon content of 0.4 % (w.) there are a few curves corresponded to ones specific to boron cementite Fe\(_3\)(CB) (Fig. 3, d).

To reveal phase transformations in Fe-B alloys there was performed differential thermal analysis. According to its results for alloy with boron content of 11.0 % (w.) it is shown that if temperature of monoboride FeB formation is 1843 K [7, 14], then in the process of alloying with carbon this temperature decreases and under carbon content of 0.1 % (w.) amounts to 1733 K, and for carbon content of 0.4 % (w.) equals to 1712 K. In thermogram of alloy with boron content of 11.0 % (w.) and carbon content of 0.4 % (w.) at the temperature of 1596 K thermal effect appears, which probably corresponds to eutectic transformation \( L \rightarrow Fe_2B + FeB \).

Authors of the paper [7] point to possibility of such reaction. The last thermal effect in thermogram at the temperature of 1425 K corresponds to transformation in a solid state. This transformation relates to polymorphic transformation \( \beta \rightarrow Fe(B,C) \rightarrow \alpha \rightarrow Fe(B,C) \) of high-temperature modification \( \beta \)-Fe(B,C) to low-temperature \( \alpha \)-modification [5, 6].

To verify the fact of existence of two modifications \( \alpha \)- and \( \beta \)-Fe(BC) there was performed study of reheating effect on carbon alloyed Fe-B alloy with weight boron content of 11.0 % and carbon effect of 0.4 % up to temperature of 1490 K on the plant “Kyrgyzstan” in argon medium under polarized illumination.

Investigation of alloy microstructure in the process of reheating up to temperature of 723 K shows that there are no notable changes in it.

But further reheating up to temperature of 1425 K leads to occurrence of white in colour finely divided inclusions of the size of 0.8-1.5 µm (Fig. 4). As a result of temperature rise up to 1480 K monoboride surface gains on pure colouring, and there are no finely divided inclusions. So, structure investigation of alloys consisting of FeB and Fe\(_2\)B phases verifies the fact that at the temperature of 1425 K solidphase transformation takes place. Such a phenomenon in the process of structure investigation of iron-based alloys with boron content of 9.1 % (w.) and carbon content of 0.3 % (w.) by means of high-temperature microscope was observed by authors of the paper [19]. They pointed out that at the temperature of 1453 K during sequenced time steps it is intervening phase decomposition of Fe(BC). But authors didn’t ascertain what phases are forming in this case.

Fig. 4. Microstructure of alloy with weight content of boron of 11.0 % and carbon of 0.4 % at the temperature of 1423 K

To fix a phase transition the alloy specimen with boron content of 11.0 % (w.) and carbon content of 0.4 % (w.) was sealed up in a quartz vessel, reheated up to 1425 K, isothermically held for 20 hours and was cooling with a rate of 100 K/s. In carbon alloyed Fe-B alloy instead of iron monoboride FeB after layer-by-layer filing filmy precipitates (Fig. 5, a) 50-100 nm in thickness were observed. The results of microspectrum analysis enable to assume that filmy precipitates contain the boron cementite Fe\(_3\)(CB) (Fig. 5, b). Formation of these precipitates can be explained by decreasing of carbon solubility as a result of temperature decrease.

On the basis of this paper results we can assume that transformations within the temperature interval of 1420-1480 K occur due to carbon effect. Considering the fact that carbon solubility in FeB and Fe\(_2\)B borides is low, presence of carbon in iron borides is determined by availability of odd vacancies [8, 9], which along with carbon atoms set up the stable complexes [17]. Besides,
iron monoboride FeB has homogeneity region, and at high temperatures carbon solubility is higher than one at low temperatures. Probably, within the temperature interval of 1420-1480 K depending on carbon content decomposition of supersaturated with carbon monoboride FeB takes place, at which point boron cementite Fe₃(C) is forming.

CONCLUSIONS

1. It is shown, that in the process of alloying the Fe-B system alloys with carbon of content of 0.2-0.6 % (w.) formation of eutectics Fe₂B + FeB of core morphology takes place.
2. It is ascertained, that phase transformation, occurring at the temperature of 1425 K, is unrelated to transformation of iron monoboride β − Fe(B,C) → α − Fe(B,C), but probably is related to formation of boron cementite Fe₃(CB).

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ВЛИЯНИЕ УГЛЕРОДА НА ФАЗОВЫЙ СОСТАВ И ФАЗОВЫЕ ПРЕВРАЩЕНИЯ В СПЛАВАХ СИСТЕМЫ Fe-V

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Исследования сплавов Fe-B, легированных углеродом (0,2…0,6 мас.%), показали, что происходит образование эвтектики, составляющими которой являются моноборид железа FeB и борид железа Fe2B. Установлено, что фазовое превращение, которое происходит в твердом состоянии в этих сплавах при температуре 1425 К в зависимости от содержания углерода, не связано с преобразованием моноборида железа, а связано с образованием бороцемента Fe3(CB).

ВПЛИВ ВУГЛЕЦЮ НА ФАЗОВИЙ СКЛАД ТА ФАЗОВІ ПЕРЕТОВОРЕННЯ В СПЛАВАХ СИСТЕМИ Fe-V

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Дослідження сплавів Fe-B, легованих вуглецем (0,2…0,6 мас.%), показали, що відбувається утворення евтектики, складовими якої є моноборид заліза FeB та борид заліза Fe2B. Встановлено, що фазове перетворення, яке відбувається в твердому стані в цих сплавах при температурі 1425 К в залежності від вмісту вуглецю, не пов’язане з перетворенням моноборида заліза $\beta - Fe(B,C) \rightarrow \alpha - Fe(B,C)$, а пов’язане з утворенням бороцементу Fe3(CB).