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STUDYING THE EFFECT OF BORON ON HEAT-RESISTANCE PROPERTIES OF Ni-Cr ALLOYS

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Heat-resistant alloys based on Ni-Cr system are widely used as alloys for the manufacture of rings, fasteners, turbine disks and other parts operating at temperatures up to 750 °C. To improve the properties of these alloys, these are additionally doped by Al, Ti, Mo and other elements.

Keywords: Ni-Cr alloy, boron effect, heat treatment, microctryctyra, long-term strength.

INTRODUCTION

In previous studies [1], it have proposed an alloy with a higher chromium content compared with conventional nickel-iron alloys, with chromium content increased to 40 - 45 % with an additional doping by Nb. In the composition of these alloys (e.g. ChN35VTYu) boron is present in an amount of 0,01 – 0,02 %.

Effect of boron on the heat-resistant properties of the alloys, in spite of rather long history of the issue, remains quite controversial. For example, in [2, 3] it was shown that the increase in the boron content above thousandths of one percent leads to embrittlement of the alloy by forming a boride phase.

At the same time, developers of such classical superalloys as S-816, RCC and SAH groups are actively engaged in studying the effect of boron on heat resistance indices [4, 5]. In this study, it studied the effect of boron on heat-resistant properties of the alloys of Cr-Ni-a.e. system.

Alloying with boron in range of 0,4 - 0,7 % increases the strength properties of austenite steels, which have carbide and intermetallic strengthening.

The stress-rupture properties of austenite-boron steels at 650 – 700 °C significantly surpass the properties of similar steels without boron. Furthermore, the steels with boron strengthening are characterized with high stress rupture ductility, which does not decrease with increase of test duration. The high stress rupture ductility of austenite-boron steels is the result of high stability of structure and properties formed during long-term exposure to temperatures at 800 – 700 ^{0}C.

Due to fine grains and coagulation of strengthening phases the austenite-boron steels, unlike similar steels without boron, have a higher plasticity at solidus temperature. These steels owing to presence of duplex austenite-boron structure are not inclined to formation of hot cracks in weld and weld-zone at fusion welding, which is typical for welding high-temperature austenite steels. Therefore, Alloying with boron in range of 0,2 – 0,5 % improves fusibility, allows the elimination of hot cracks without decrease of strength and maintenance of stress rupture strength.

Boron's impact efficiency on high-temperature properties of allows is explained by strengthening the grain boundaries with borides, which are formed on boundary areas. A solubility of boron in solid solution of alloys based on ferrum is minimal. Due to ability of boron to decrease the Gibbs energy along intercrystalline boundaries (horophilicity) and to accumulate on grain boundaries an oversaturation of solid solution, it facilitates to formation of borides on grain boundaries even at really low overall concentration.

At microscopic examination of thin foil in ferrite frame the ferrum borides (Fe_2B and FeB) were found on the boundaries of austenite grain and the concentration of boron in steel was 0,0026 %.

In alloyed steels, the boron forms the compound borides as $(Mo, W, Cr, Ni)_x B_y$ and carboboride phases such $(Cr, Fe)_2 BC$; $(Cr, Fe)_{22} (B, C)_6$ and $(Cr, Fe)_{23}(BC)_6$ on the boundaries of grains.

Thus, the sustainable boride phase, absorbed on grain boundaries, provides the low rates of creep.

It should be noted that influence of boron on change of phase compound of alloyed steels consist mainly of decreasing solubility of alloying agents (for example, chrome and wolfram). Hence, alloying steel with boron is useful only at its low content, as inhibition of plastic deformation, caused by phase precipitation, prevails in steel strengthening. At high content of boron the most part of alloying agents, which strengthen a solid solution, are fixed in carboboride phases and therefore they are not involved into strengthening of solid solution.

EXPERIMENTAL STUDIES
Equipment and tools

The base alloy of our study was alloy with a chromium content of over 40 % (Table 1) wherein the boron content varied from 0,5 % to 2 %.

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Table 1 **Chemical composition of the alloy studied / wt. %**

Content of an element, %	C	Cr	Ni	Fe	Mo	Nb	Ti	Al
	0,065	44,9	35,94	10	0,95	1	4,145	3

Boron used was a ferroboron of FB 20 grade, wherein the impurity content in the alloy was not taken into account in ferroboron alloy composition. The impurities effect on the properties of the final product was taken as permanent, as only one batch was used, and the composition of ferroboron did not change. The chemical composition of the obtained alloy was controlled only in terms of boron, and the content of other elements was not determined.

Samples were smelted in an induction furnace; the melting weigh was 5 kg. After completion of melting the cast was poured into molds which match the form of samples for testing long-term strength. The prepared samples were heat treated under the following procedure: quenching for 2 hours at 1 100 °C, aging for 4 hours at 700 °C.

After the heat treatment, long-term strength tests were carried out using TRMP-50 machine at 700 °C for 100 hours.

The test results are shown in Table 2 and Figure 1.

Table 2 **Value of long-term strength depending on the boron content in the alloy**

Sample no.	Boron content / %	σ^{700}_{100} / MPa
1	0	469
2	0,5	493
3	1	538
4	1,5	252
5	2	246

The estimated regression line is built according to the equation $y = 410{,}2 + 98{,}871\ x - 27{,}939\ x^2$ ith approximation certainty factor $R^2 = 0{,}774$.

As can be seen from Table 2 Boron additives influence the long-term strength. Even when adding 0,5 % of boron, an increase in long-term strength of 5 % occurs. A further increase of boron additive also increases the ultimate long-term strength from 469 MPa to 538 MPa. However, further increase in the boron content to 1.5% leads to a dramatic reduction of long-term stress. This fact is apparently due to the formation of boride phase which was mentioned in studies [2,3].

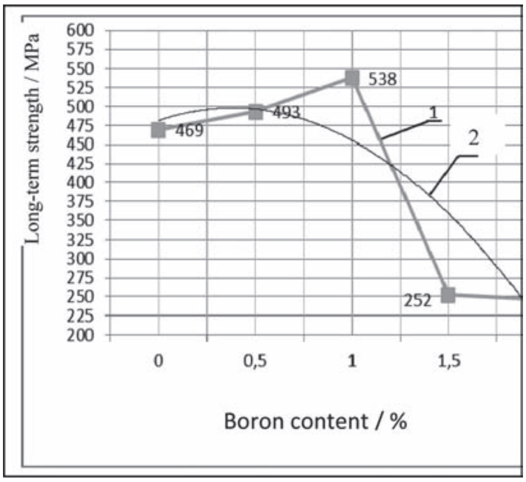

Figure 1 Dependence of the long-term strength on the boron content, 1 - experimental regression line; 2 - the estimated regression line

To clarify the effect of boron content, the microstructure of the samples 3 and 5 were studied (Table 2).

Figure 2 shows the structure of the alloy after etching examined with a scanning electron microscope Tescan Vega. The 92 % HCI 5 % H_2SO_4, 3 %HNO_3 mixture was used as an etchant.

As seen in Figure 2, the increase of boron content contributes to the occurrence of new phases and a clearer structuring of its structure. Figure 3 a and b, shows the unetched structure of the alloy 5 studied by the scanning electron microscope under magnification of x10 000. The structure shows clearly observed hair-like cracks. Obviously these microcracks contribute to a sharp drop in long-term strength. The microcrack formation itself is apparently caused by the formation of a new phase, and therefore we studied the composition of interstitial phases.

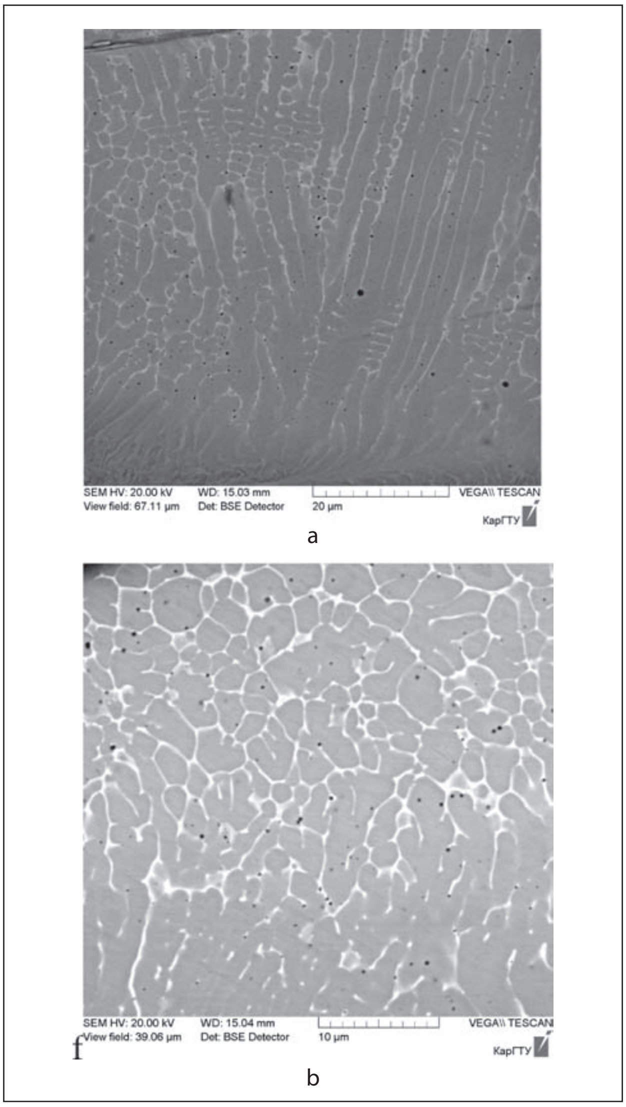

Figure 2 The microstructure of the alloy with boron: a – 1 % B; b – 2 % B (x500)

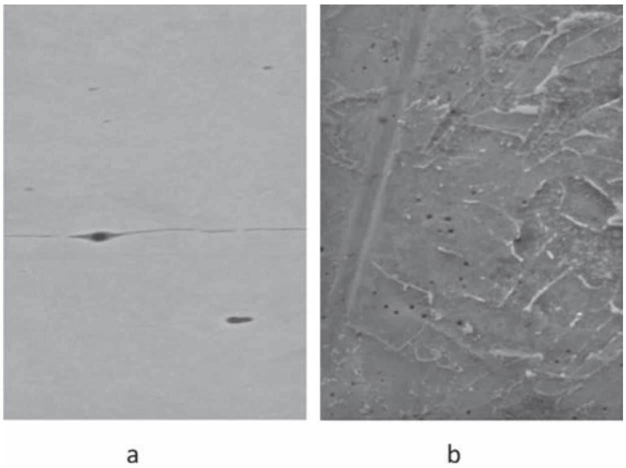

Figure 3 Microstructure of unetched alloy 5 under different magnification: a – presence of trichoid cracks and inclusion form, X1000 b - same, X 10 000

Composition of the interstitial phases (Figure 4) has been studied by the quantitative electron microprobe analysis using electron energy dispersive spectrometer INCA PentaFETx3.

RESULTS AND DISCUSSION

Analysis of the interstitial phases confirmed the presence of intermetallic phase Ti_3Al, carbide phase (Fe, Cr) $_{23}$C6, (Nb, Mo) C and a new interstitial phase which includes boron. The average composition of the interstitial phase can be determined as (Nb, Mo) $_2$B. This composition is confirmed in [5]. Generally speaking, the boride phase is apparently included in the composition of the carbide phase [6], and forms a complex carbide-boride phase. At this point the composition of the boride phase has not been studied in detail.

As it shown by authors [6], the strengthening effect of material, which have difficult-to-form particles, is defined mainly by their distribution shape and pattern (Figures 3, 4).

According to Orovan's theory [7], a motion of dislocation (and consequently the plastic deformation) in alloys, which structure has the interstitial phases, non-deformable with shear, occur by rounding mechanism. When dislocation faces such particles, for example: compound boride phases, it starts to curve between them, and forms so-called "Orovan's loop".

At specific strain, this loop bursts and the motion of dislocation starts, that is plastic deformation and creep. A value of that strain is inversely proportional to a value of distance between particles.

In other words, the more evenly the interstitial phases are distributed, the more difficult to execute the motion of dislocations, the more the creep process develops.

Orovan's theory is fair for fine particles with size of 1 - 0,2 microns. The Figure 4 demonstrates nature of interstitial phases and the inclusions, which sizes are between 0,19 - 0,3 microns.

Besides the distribution pattern of interstitial phases, the morphology of particles has a great influence on strength, including stress rupture strength.

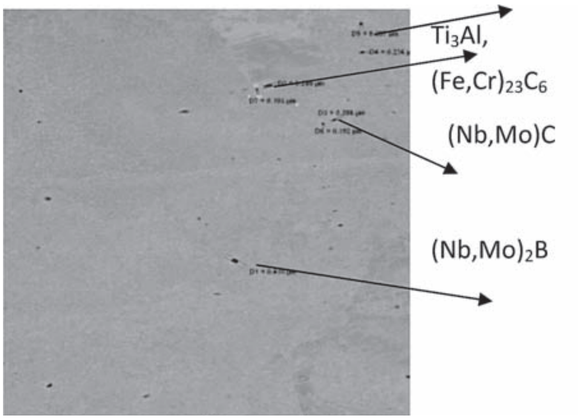

Figure 4 Interstitial phases in alloy 3 (x15 000)

The study [8] shows that the formation of cracks in samples with phase precipitation, such as on Figure 3, occurs faster than in samples with interstitial phases of roundish shape.

The even distributed roundish interstitial phases (Figure 4) force a crack to branch, and the rate of branching of crack decreases in spaces between interstitial phases, it prevents to fracture process.

CONCLUSION

On the basis of the research, data were obtained on the optimal percentage of boron for superalloys of Cr-Ni-a.e. system. Addition of boron improves creep resistance (long-term strength limit). The optimum boron content in the alloys is 1 %. Further increase in the amount of boron results in excessive formation of a complex boride phase which leads to the formation of microcracks and dramatically reduces long-term strength limit.

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Note: The responsible for England language is Nataliya Drag, Karaganda, Kazakhstan