Ni_3Al-B ALLOYS AND THEIR MECHANICAL PROPERTIES AT HIGH TEMPERATURES

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Abstract

The Ni-22Al-0.5B and Ni-24Al-0.5B alloys (at.%) were prepared by a vacuum induction melting process followed by a gravity casting process. The castings were directionally solidified in a resistance furnace at a temperature of 1550 °C and rate of directional solidification of 50 $mm \cdot h^{-1}$. The castings and ingots after directional solidification were used for preparation of samples for a compression test. These tests were carried out at a temperature of 800 °C and deformation rate of $5 \cdot 10^{-2}$ s^{-1}. The samples were shaped as a short cylinder (8×12 mm). The results of the compression tests have confirmed that the directionally solidified Ni_3Al alloys alloyed with boron have a higher yield strength than the castings of these alloys and the Ni_3Al alloys unalloyed with boron.

Keywords: Nickel aluminides, directional solidification, compression test

1. INTRODUCTION

Alloys of the Ni_3Al intermetallic compound are commonly used at high-temperature applications up to a temperature of approximately 800 °C. It is caused by its structure ($L1_2$ type) which exhibits an anomalous behaviour - an increase of the yield strength with an increasing temperature up to 800 °C [1]. Unfortunately, the Ni_3Al intermetallic compound is very brittle at a room temperature [2]. The brittleness is caused by atomic hydrogen which diffuses along grain boundaries and weakens their strength. The problem can be solved by using the intermetallic with a hypo-stoichiometric concentration of aluminum alloyed with a small addition of boron [3]. Boron preferably precipitates along grain boundaries and improves their cohesive strength. Mathematics models [3] confirmed that the most suitable amount of boron added to the Ni-24Al alloy is 0.45 at.%. Nevertheless, experimental tests [4] demonstrated that the Ni-24Al-0.24B alloy exhibits the best ductility. When a boron concentration is greater than 0.24 at.%, ductility strongly decreases and transgranular fracture becomes intergranular.

The aim of this paper was prepared the Ni-22Al-0.5B and Ni-24Al-0.5B alloys (at.%) by methods of vacuum induction melting and directional solidification. Experimental alloys were examined in not only a structurally phase analysis but also a compression test at a temperature of 800 °C. Results are concluded at the end of this paper.

2. EXPERIMENT

The Ni-22Al-0.5B and Ni-24Al-0.5B alloys (at.%) were prepared by vacuum induction melting under an argon atmosphere in the LEYBOLD furnace IS3/1 type and cast into a graphite mould. Chemical composition of the alloys was confirmed by an optic emission spectrometry method (**Table 1**). The castings were directionally solidified in the CLASIC resistance furnace at a rate of 50 $mm \cdot h^{-1}$ and temperature of 1550 °C. The castings and ingots after directional solidification were used for a preparation of samples for a compression test. The samples were shaped as a short cylinder (8×12 mm). The compression tests were carried out in the HDS-20 deformation simulator at a high temperature of 800 °C and deformation rate of $5 \cdot 10^{-2}$ s^{-1}. In addition to a compression test, the alloys were examined in a structurally phase analysis.

Table 1 Chemical composition of the castings determined by an OES method

	Ni-22Al-0.5B			Ni-24Al-0.5B		
	Ni	**Al**	**B**	**Ni**	**Al**	**B**
x (at.%)	78.38 ± 0.11	21.19 ± 0.11	0.43 ± 0.01	76.30 ± 0.02	23.34 ± 0.02	0.36 ± 0.01
w (wt.%)	88.86 ± 0.11	11.05 ± 0.11	0.09 ± 0.01	87.60 ± 0.02	12.32 ± 0.02	0.08 ± 0.01

3. RESULTS AND DISCUSSION

3.1. Structure

The aluminum concentration in the nickel matrix has a significant effect on a microstructure of the Ni_3Al intermetallic compound [5, 6]. The lower aluminum concentration is, the higher volume fraction of disordered phase of the solid solution of aluminum in nickel (γ phase) is. In the case of castings, an alloy solidifies under uncontrolled conditions and its structure consists of fine grains oriented perpendicularly to the mould walls. During a directional solidification process, an alloy solidifies under controlled conditions and a structure is formed with coarse grains oriented in the solidification direction. There are dendrites passing through the coarse grains. The dendrites are consisted of alternating bands of the Ni_3Al phase (γ' phase) and γ phase. This two-phase structure is characteristic for the alloy with 22 at.% of aluminum (**Figure 1**). A volume fraction of the γ phase in the Ni-24Al-0.5B alloy is zero (**Figure 2**).

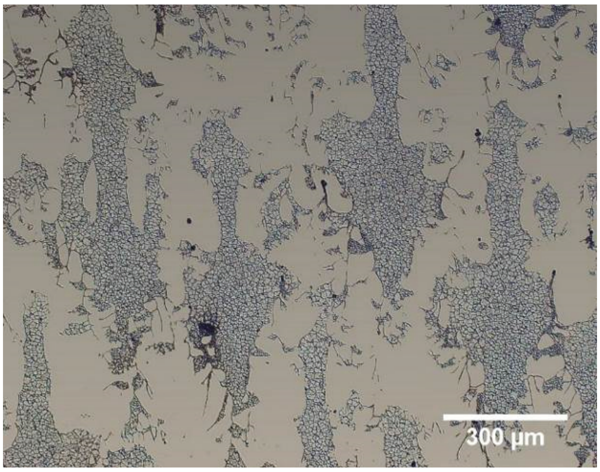

Figure 1 A detail of the directionally solidified structure of the Ni-22Al-0.5B alloy

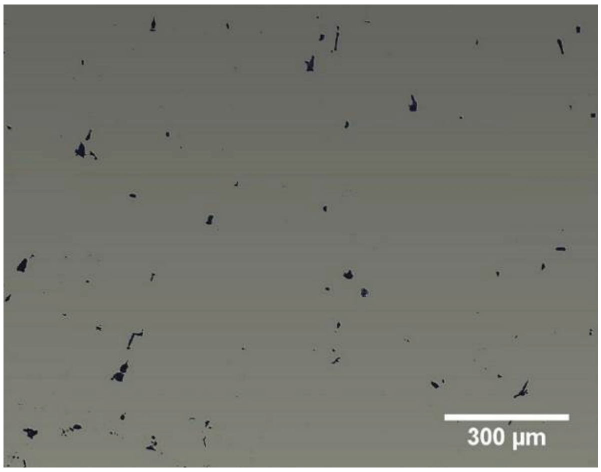

Figure 2 A detail of the directionally solidified structure of the Ni-24Al-0.5B alloy

There are values of the volume fraction of the γ' + γ phase area in the **Table 2**. They were determined for the castings and directionally solidified ingots of the Ni-22Al-0.5B and Ni-24Al-0.5B alloys. A decrease of the volume fraction of the γ' + γ phase area in the matrix of the Ni-24Al-0.5B alloy is caused by a change of an aluminum concentration and solidification conditions [7, 8]. Uncontrolled conditions of a solid-liquid interface growth during solidification of melting in the mould lead to breaking of chemical balance and formation of small amount of the γ' + γ phase area. A controlled process of solidification reduces the breaking of chemical balance. Therefore, the structure of the Ni-24Al-0.5B alloy after directional solidification matches the composition expected from the Ni-Al binary phase diagram, i.e. it only consists of the γ' phase.

Table 2 Volume fraction of the $\gamma' + \gamma$ phase area in the Ni-22Al-0.5B and Ni-24Al-0.5B alloys

Alloy (at.%)	Ni-22Al-0.5B		Ni-24Al-0.5B	
State	cast	directionally solidified	cast	directionally solidified
***V* (%)**	51.86 ± 0.52	52.36 ± 0.76	6.83± 0.37	0.00 ± 0.00

3.2. Compression test

Transversal sections of the samples after a compression test carried out at a temperature of 800 °C are shown in the **Figures 3**, **4**, **5** and **6.** There is a difference between failure modes of the castings and directionally solidified ingots. During a compression process, the castings of the Ni-22Al-0.5B and Ni-24Al-0.5B alloys were fractured along the wall of the compression sample (**Figures 3** and **4**), while the samples after directional solidification were deformed diagonally across the whole sample (**Figures 5** and **6**). These different manners in a deformation of the samples during the compression tests were caused by different conditions of an alloy preparation and different grain orientation.

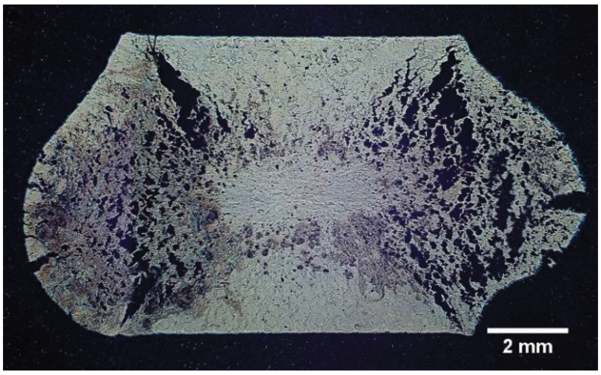

Figure 3 The sample of the Ni-22Al-0.5B alloy in cast state after compression test

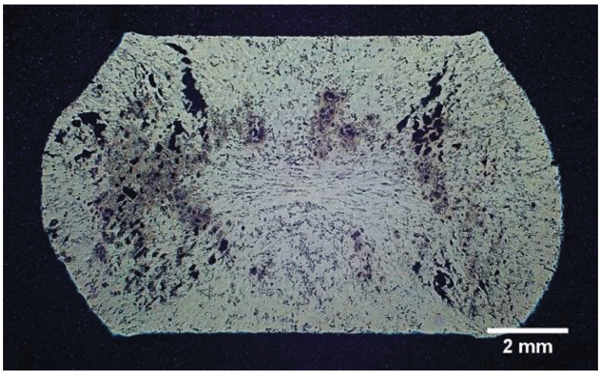

Figure 4 The sample of the Ni-24Al-0.5B alloy in cast state after compression test

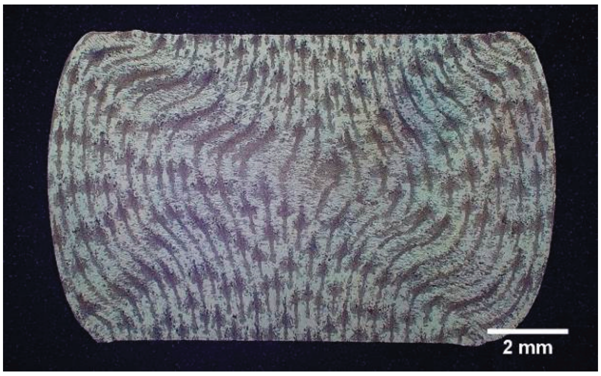

Figure 5 The sample of the Ni-22Al-0.5B alloy in directionally solidified state after compression test

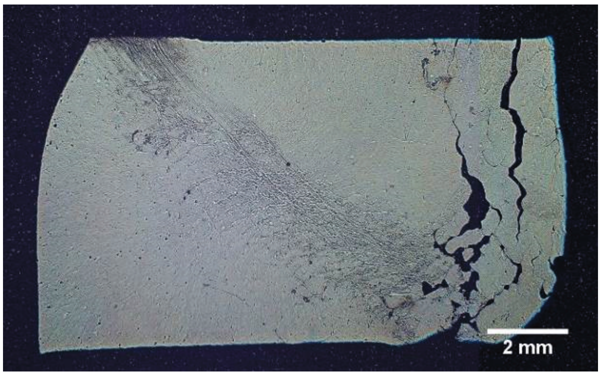

Figure 6 The sample of the Ni-24Al-0.5B alloy in directionally solidified state after compression test

Figure 7 shows a plot of the compression test processes carried out on the castings and directionally solidified samples of the Ni-22Al-0.5B and Ni24Al-0.5B alloys at the temperature of 800 °C. The tests were stopped before reaching of the ultimate compression strength. There was a potential danger of the heating element damage in the inner space of the furnace. In the cases of the both samples of the Ni-22Al-0.5B alloy and the cast sample of the Ni-24Al-0.5B alloy, offset yield strengths $R_{p0.2}$ had to be determined. The directionally solidified sample of the Ni-24Al-0.5B alloy exhibited a yield point phenomenon, so an upper yield point R_{eH} and lower yield point R_{eL} were determined. All the values of the mechanical properties are given in the **Table 3**.

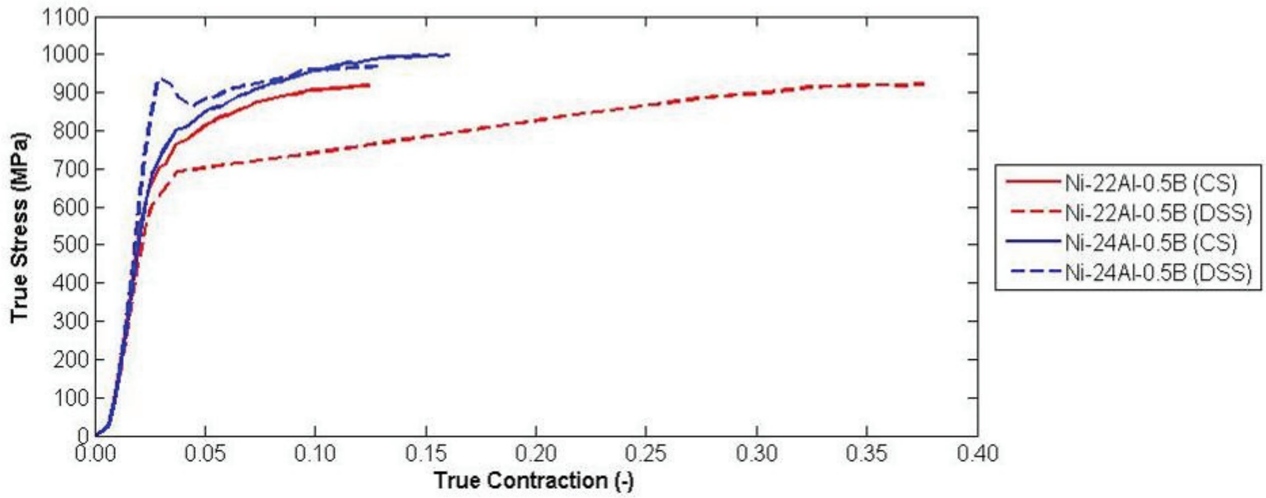

Figure 7 A plot of the compression test processes carried out on the castings and directionally solidified samples of the Ni-22Al-0.5B and Ni24Al-0.5B alloys at the temperature of 800 °C

A reason why a yield point phenomenon occurred relates to the directionally solidified structure of the Ni-24Al-0.5B alloy. The yield point phenomenon is characteristic for polycrystalline materials containing a small amount of interstitially dissolved impurity [9]. In this case, the matrix is consisted of directionally orientated grains of the γ' phase and of boron atoms which precipitates in the interstitial positions of the $L1_2$ type lattice [2].

Table 3 Values of the mechanical properties of the Ni-22Al-0.5B and Ni-24Al-0.5B alloys after compression tests carried out at a temperature of 800 °C

Alloy (at.%)	**State ***	$\varepsilon_{Rp0.2}$ (-)	$R_{p0.2}$ (MPa)	ε_{ReH} (-)	R_{eH} (MPa)	ε_{ReL} (-)	R_{eL} (MPa)
Ni-22Al-0.5B	CS	0.025	640				
	DSS	0.026	583				
Ni-24Al-0.5B	CS	0.026	668				
	DSS			0.030	912	0.046	827

* CS - cast state, DSS - directionally solidified state

There are counter plots in the **Figures 8** and **9** showing a dependence of the yield strength on a changing concentration of aluminum and boron in the Ni-Al-B matrix. The values of the yield strength for the Ni-22Al and Ni-24Al unalloyed with boron were obtained from the paper [10]. The yield strengths of the experimental alloys increase in two sequences - it is Ni-22Al < Ni-24Al < Ni-22Al-0.5B < Ni-24Al-0.5B for the castings and Ni-22Al < Ni-22Al-0.5B < Ni-24Al < Ni-24Al-0.5B for the directionally solidified ingots. In the both cases, the conclusion published in the papers [3, 6] has been confirmed - using boron as an alloying element and a direction solidification process improve mechanical properties of the Ni_3Al intermetallic compound.

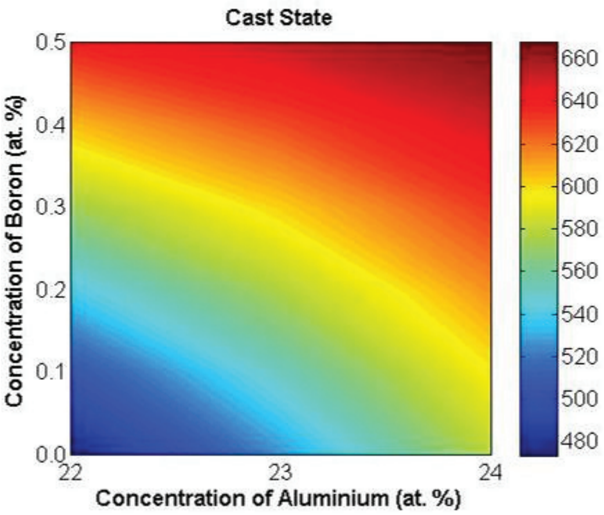

Figure 8 A comparison of values of the yield strengths for the castings of the Ni-22Al, Ni-24Al, Ni-22Al-0.5B and Ni-24Al-0.5B alloys determined by compression tests at a temperature of 800 °C

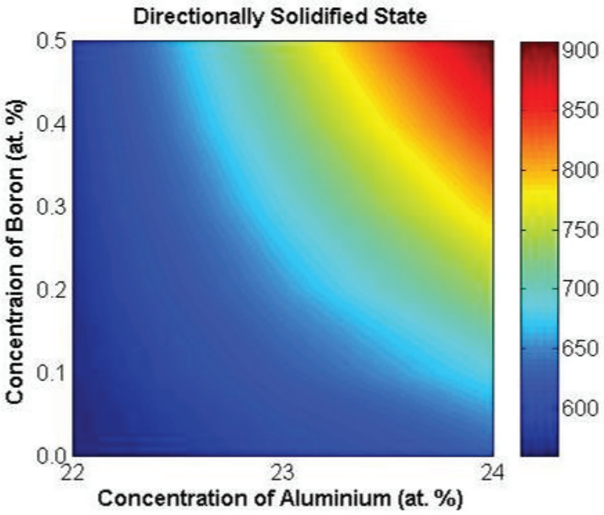

Figure 9 A comparison of values of the yield strengths for the Ni-22Al, Ni-24Al, Ni-22Al-0.5B and Ni-24Al-0.5B alloys after directional solidification determined by compression tests at a temperature of 800 °C

4 CONCLUSION

The aim of this paper was the preparation of the Ni_3Al intermetallic compound. The strength of this intermetallic was improved by two manners - alloying and preparation. An alloying process of the Ni-22Al and Ni-24Al alloys with 0.5 at.% of boron led to cohesive strengthening of grain boundaries. The directionally solidified Ni-24Al-0.5B alloy contained coarse grains of the γ'-phase oriented in direction of the solidification. In the case of the Ni-22Al-0.5B alloy, the structure was formed by two-phase area of alternating bands of the γ' + γ phases. A compression test carried out at a temperature of 800 °C has confirmed better mechanical properties of directionally solidified alloys than the castings and the alloys unalloyed with boron.

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