HIGH TEMPERATURE MECHANICAL PROPERTIES OF Ni_3Al AND Ni_3Al-Mo ALLOYS IN COMPRESSION

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Abstract

High-temperature tests of the alloys Ni_3Al and Ni_3Al-Mo were performed under compression. The alloys were tested in as-cast and directionally solidified state at the temperatures of 800 and 1 000 °C. As-cast samples were prepared by method of vacuum induction melting. Solidified samples were prepared from castings by Bridgman's method. Cylindrical samples with diameter of 8 mm and length of 12 mm were subjected to compression tests under elevated temperatures. The tests were performed on the equipment Gleeble 3800. Obtained values of selected mechanical characteristics of unalloyed and Mo alloyed alloys and also alloys in as-cast and directed state were compared. Alloyed alloys in as-cast state show higher values of yield strength and maximal achieved stress. The alloys in directed state have better values of ductility corresponding to the achieved maximal stress during compression tests. Evolution of stress-strain curves under compression in as-cast samples has very similar character, when a significant decrease of the stress occurs at the achieved deformation of 0.15. In the case of directionally solidified samples this evolution depends on created structure and temperature of testing.

Keywords: Hot compression tests, high temperature characteristics, Ni_3Al-Mo based alloys, directional solidification

1. INTRODUCTION

Some nickel alloys can be used as materials for high temperature applications. On the industrial scale, nickel superalloys are widely used, while Ni_3Al-based alloys are used less frequently. These alloys, such as IC50, IC221M or IC6SX can be used for less demanding applications. Their advantage consists in their lower density and sufficient corrosion resistance. Nickel alloys can also be in the form of a metal matrix composite. An example of this type of material is the IC6SX alloy. These materials can be prepared by zonal melting method or with the use of the Bridgman's method. In this way the alloys based on NiAl or Ni_3Al alloyed with molybdenum are prepared. The structure itself of the composite can be reinforced with molybdenum fibres. The structure of the used alloys is still evolving, and it is nowadays common to use alloys in their single crystal form for specific applications of this type of alloys, while interest less alloyed alloys also exists. An example of such alloy is, for example, a Ni-Al-Mo-based alloy IC6SX, which in the single crystal form has a highly perspective composite structure [1-5].

2. EXPERIMENTAL

The alloyed Ni_3Al based alloys with various contents of molybdenum were prepared by vacuum induction melting in equipment Supercast 13. A part of castings were directionally solidified (DS) by Bridgman's method in tubes with specified apex angle (**Figure 1**). The samples were solidified under an argon atmosphere 5N. The solidification rate was 50 mm/h. Directional solidification carried out with the use of the equipment Clasic CZ and Linn FRV-5-40/550/1900.Alloys were tested in as-cast (C) state and directed state (S). Characterization of Ni-Al-Mo alloys is in **Table 1**.

Table 1 Characterization of Ni-Al-Mo alloys

Alloy	Sample No.	Composition (at.%)	Composition (wt.%)	Rate of DS (mm/h)
1	1C	Ni-16.7Al-7.3Mo	Ni-7Al-14Mo	-
	1S			50
2	2C	Ni-16.7Al-6.5Mo	Ni-7Al-12Mo	-
	2S			50
3	3C	Ni-16.7Al-5.5Mo	Ni-7Al-10Mo	-
	3S			50

Figure 1 Sample after directional solidification by Bridgman's method

2.1. Mechanical properties in compression

The cylinders with a height of 12 mm and a diameter of 8 mm were used for testing of mechanical characteristics in compression. The plastometer GLEEBLE 3800 was used for isothermal tests by uniaxial compression. The test temperature was 800 and 1000 °C with a heating rate of 3 °C/s. The heating to the test temperature was followed by a 15-second dwell. The chosen strain rate was $5\cdot10^{-2}$ s^{-1}. The tests were performed till the height deformation of 0.5. The yield strength R_p was determined from the obtained values of the real stress. Moreover, the following indicative values were also determined σ_{max} (maximum peak value of the real stress) and e_p (true strain corresponding to the σ_{max}).

Table 2 Compressive mechanical characteristics

Sample	Temperature (°C)	C/S	R_p (MPa)	σ_{max} (MPa)	e_p (-)
1C-800	800	C	912	1446	0.20
1S-800		S	661	1021	0.32
2C-800		C	755	1225	0.18
3C-800		C	668	934	0.16
3S-800		S	581	895	0.31
1C-1000	1 000	C	850	999	0.07
1S-1000		S	616	838	0.16
2C-1000		C	672	849	0.09
3C-1000		C	531	655	0.06
3S-1000		S	521	697	0.09

Table 2 summarises the values of mechanical characteristics obtained in uniaxial compression tests at 800 and 1000°C. The samples in the cast state are marked "C", those in the directed state are marked "S". The values of the yield strength and the maximum reached stress show differences both for the samples with different chemical composition and for the samples in different states. The as-cast samples have higher values of R_p and σ_{max}. However, they exhibit lower values of the true deformation corresponding to σ_{max}. If we compare alloys with different molybdenum contents, than the yield strength and strength also increase with the

increasing Mo content in the alloy, as it was assumed. The obtained data were compared with the previously published results [6, 7]. The mechanical characteristics and state of the samples are shown in **Table 3**. The sample marked as 6ZM was prepared by the float zone melting method at a rate of 50 mm/h.

Table 3 Compressive mechanical characteristics - data from earlier sources [6, 7]

Sample	Composition (at.%)	Temperature (°C)	C/S	R_p (MPa)	σ_{max} (MPa)	e_p (-)
6ZM-800	Ni-16Al-8Mo	800	S	820	1199	0.50
4C-800	Ni-24Al		C	527	937	0.15
4S-800			S	609	1013	0.23
5C-800	Ni-22Al		C	458	870	0.17
5S-800			S	440	1132	0.14
4C-1000	Ni-24Al	1 000	C	375	570	0.08
4S-1000			S	480	715	0.20
5C-1000	Ni-22Al		C	445	608	0.08
5S-1000			S	534	660	0.16

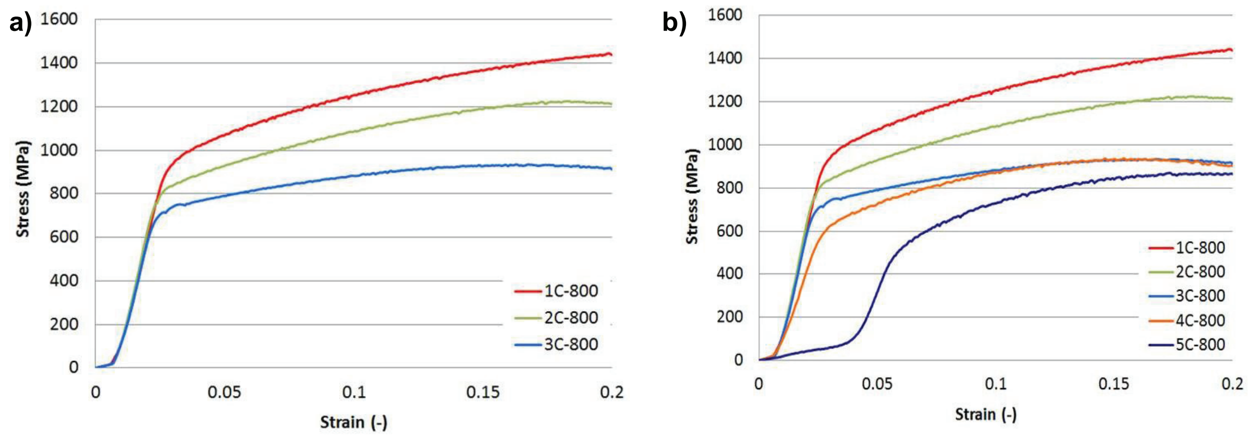

Figure 2 Compressive stress-strain curves at 800 °C, as-cast state: a) curves for the alloys Ni-Al-Mo, b) comparison with the previous results

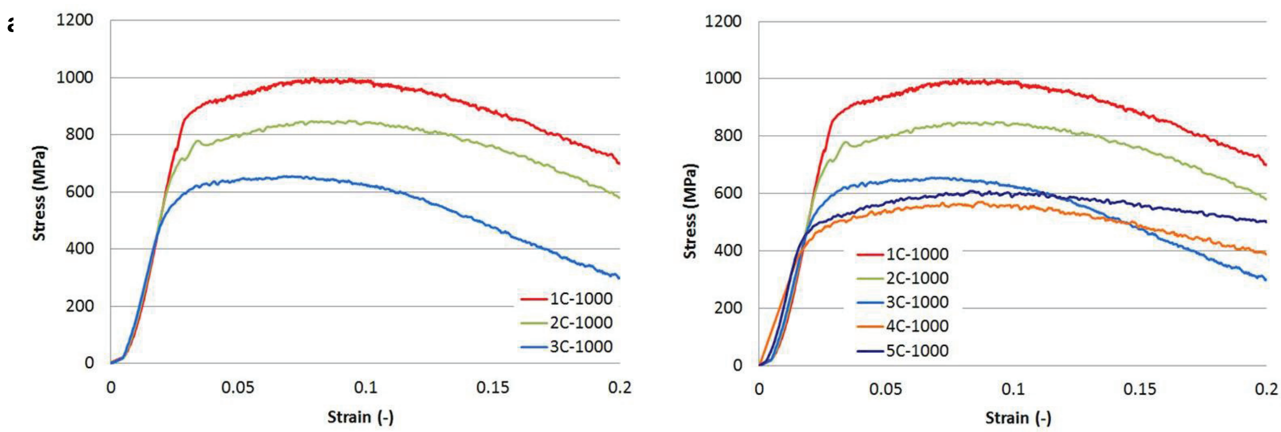

Figure 3 Compressive stress-strain curves at 1000 °C, as-cast state: a) curves for the alloys Ni-Al-Mo, b) comparison with the previous results

Stress-strain curves are presented in **Figures 2 - 5**. Individual diagrams compare the samples in the as-cast or directed state at 800 or 1000 °C. In addition, the diagram is always completed with the previously obtained dependencies. Interestingly, evolution of the strain-stress curve for the alloy in the cast state with the lowest molybdenum content at a temperature of 800 °C is very similar to that of unalloyed 4C and 5C alloys (**Figure 2b**). This is similar also in the case of the load curves at 1000 °C (**Figure 3b**). **Figures 4** and **5** show the load curves for the alloys in the directed state. Here too, the curves for the unalloyed alloys are of similar character as the alloy with the lowest molybdenum content.

Figures 4b and **5b** show comparison of evolution of compression curves are with the previously published data. The comparison shows that the sample 6ZM, which was prepared by float zone melting, has the most favourable evolution. This sample did not reach the maximum deformation at the deformation of 0.5. However, although the alloy with the highest molybdenum content in the directed state 1S also achieves has high values, but has a lower yield strength in comparison with the alloy 6ZM.

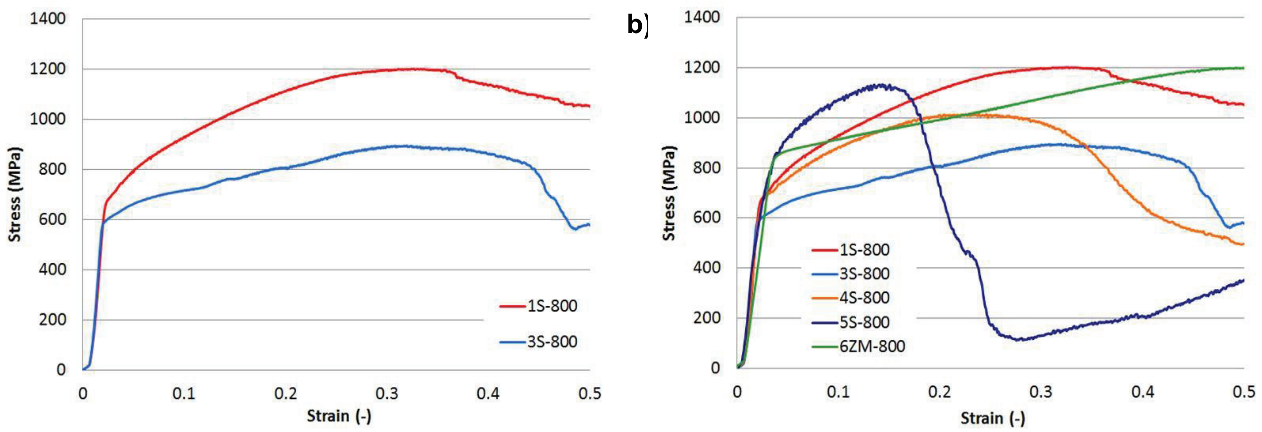

Figure 4 Compressive stress-strain curves at 800 °C, directed state: a) curves for the alloys Ni-Al-Mo, b) comparison with the previous results

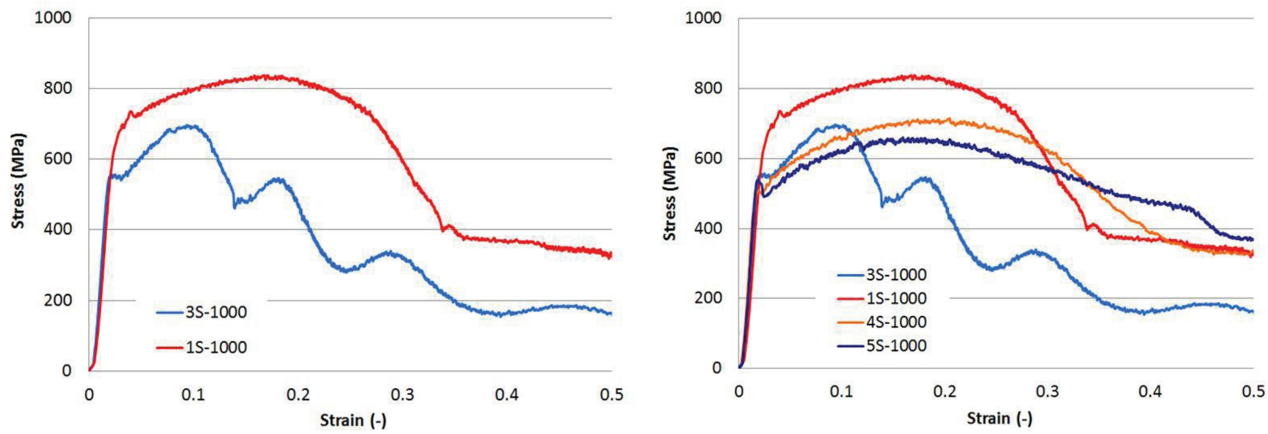

Figure 5 Compressive stress-strain curves at 1000 °C, directed state: a) curves for the alloys Ni-Al-Mo, b) comparison with the previous results

Figure 6 shows dependences of the yield strength and of the maximum stress on the molybdenum content in the alloy in the cast state. Both values show dependence on the molybdenum content for both tested temperatures.

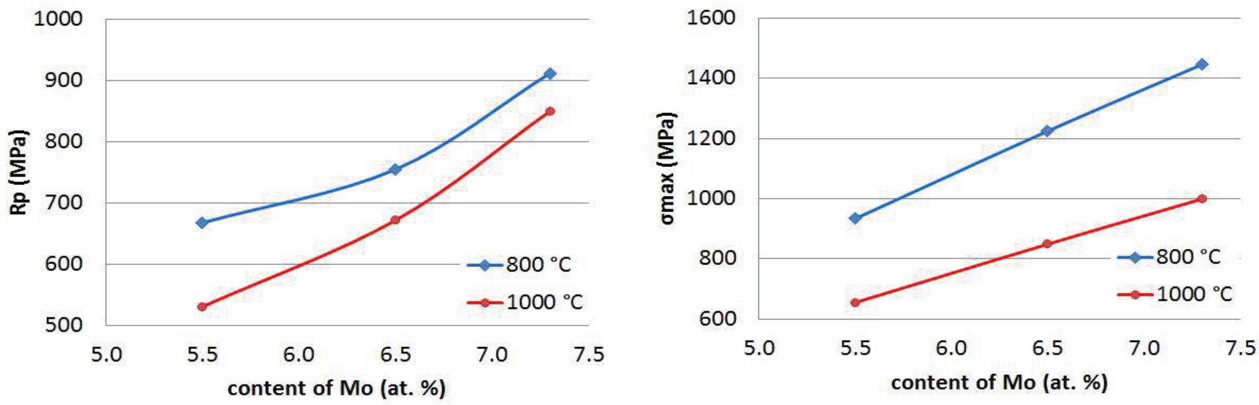

Figure 6 Dependence of the yield strength and the maximum stress on the Mo content, as-cast state

Figure 7 The samples after compression tests - as-cast state

Figure 8 The samples after compression tests - directed state

Figures 7 and **8** show the samples after compression tests performed at a temperature of at 800°C. **Figure 7** shows the samples of the alloy in the as-cast state, **Figure 8** shows them in the directed state. It can be seen from the shape of the samples that the alloys have a fragile character of a fracture, especially in the case of cast alloys.

2.2. Evaluation of structural characteristics

Figures 9 - 12 show microstructures of alloys in the as-cast and directed state in cross sections. The structure of the alloys is dendritic and it consists of the phases of γ´ $Ni_3(Al,Mo)$, γ (Ni) and of particles rich in Mo. The structure of the alloys is very fine, and particularly in the case of the cast samples it is difficult to determine the exact chemical composition of the individual phases. Generally speaking, the light regions are formed by phases γ´ $Ni_3(Al,Mo)$, the dark regions are then formed by the phase γ (Ni). The structure contains moreover

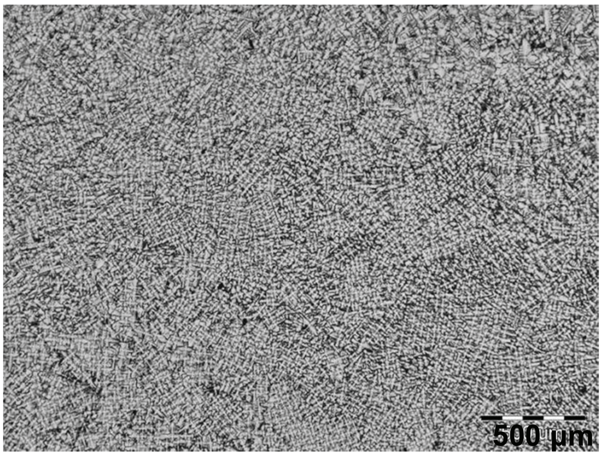

Figure 9 Sample 1C, as-cast state

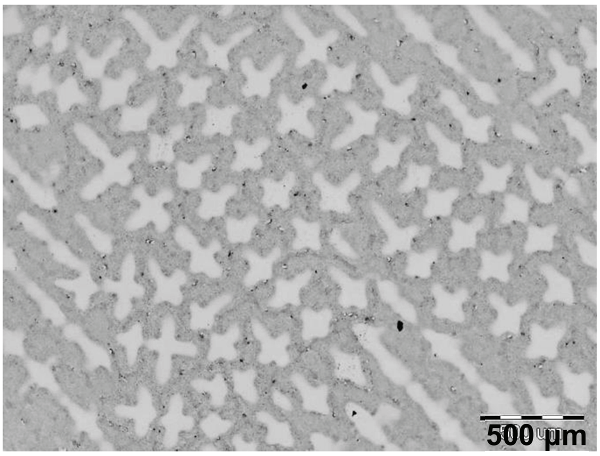

Figure 10 Sample 1S, directed state

lightgray rounded formations that were identified as NiMo or α (Mo) particles. These particles are not visible in **Figures 9-12** due to the used magnification.

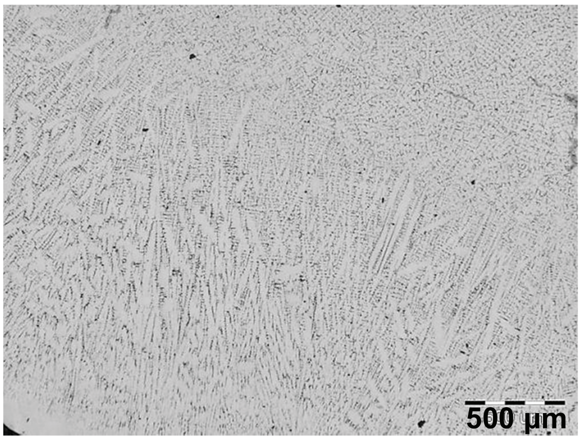

Figure 11 Sample 3C, as-cast state

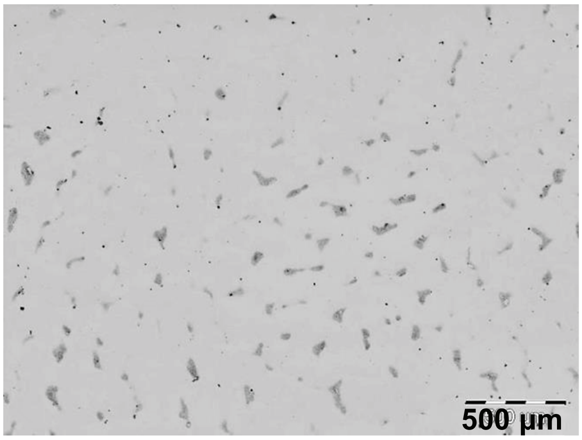

Figure 12 Sample 3S, directed state

3. CONCLUSIONS

High-temperature tests of the alloys Ni_3Al and Ni_3Al-Mo were performed under compression. The alloys were tested in as-cast and directionally solidified state at the temperatures of 800 and 1000 °C. Structure of alloys is dendritic and it is formed by the phases γ´ Ni_3(Al,Mo), γ (Ni) and by particles rich in Mo. Alloyed alloys in as-cast state show higher values of yield strength and maximal achieved stress. The alloys in directed state have better values of ductility corresponding to the achieved maximal stress during compression tests. Evolution of stress-strain curves under compression in as-cast samples has very similar character, when a significant decrease of stress occurs at the achieved deformation of 0.15. In the case of directionally solidified samples this evolution depends on created structure and temperature of testing.

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