DEFORMATION BEHAVIOUR OF Ni_3Al BASED ALLOYS IN COMPRESSION

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Abstract

Ni_3Al based alloys in the as-cast state and directionally solidified were used for tests in compression at higher temperatures. The alloys were prepared by vacuum induction melting. Directional solidification was performed by Bridgman method with the vertical arrangement. The mechanical characteristics in compression were determined at the temperatures of 1000 °C and 800 °C with use of the equipment Gleeble 3800. Evolution of deformation of the alloys in the directed and as-cast state has a similar course, yet it is still possible to observe some differences. The directionally solidified alloys show more stable evolution of deformation, whereas the phase Ni-24Al alloys achieve better mechanical properties at higher temperatures. It was found that the yield strength increases up to the temperature of 800 °C. Directionally solidified mono-phase and multi-phase alloys exhibited at testing at the temperature of 1000 °C distinct yield strength, which is not typical for these alloys within the temperature range of 20-800 °C. The yield strengths are similar for all the samples, approximately 530 to 600 MPa at 800 °C. The Ni-22Al alloys are less susceptible to a change of the yield strength with the increasing temperature. The yield strength value does not decrease significantly even at the temperature of 1000 °C.

Keywords: Ni_3Al based alloys, directional solidification, Bridgman method, mechanical characteristics, hot compression tests

1. INTRODUCTION

Determination of yield strength in tension and yield strength in compression for Ni_3Al based alloys is already for several years in the centre of interest. The dependence of the yield strength on the aluminum content, on the content of alloying elements, such as B, Hf, Zr, etc., on the grain size and other parameters is being monitored and investigated [1-4]. It was found that the yield strength of the Ni_3Al based alloys with and without boron is dependent on the addition of boron in the alloys with 24 at.% Al. However, this does not show for the alloys with 26 at.% Al [3]. The yield stress increases with the increasing temperature, up to the temperature of 800 to 1000 °C in dependence on the content of alloying elements, which is a significant feature of these alloys [2]. However, in certain alloys, this property is not so distinct and the yield strength varies with the temperature only very slowly. This concerns e.g. the CMSX-4 or TMS-75 alloys, containing a higher content of cobalt [5]. Tensile and compression tests are performed in the temperature range from room temperature up to the temperature of 1250 °C, according to the type of alloy and the possibility of its utilisation [5-7]. In the work [7] the Ni-25Al alloy was tested in the as-cast condition after annealing at different temperatures. The yield strength is in this case dependent on the temperature, its value at the room temperature is approx. 400 MPa and it increases with the increasing temperature. However, in the temperature range from 450 to 750 °C it does not change and its value is approx. 650 MPa.

2. EXPERIMENTAL

The non-alloyed Ni_3Al based alloys with various contents of aluminium were prepared by vacuum induction melting and casting. A part of castings were directionally solidified by Bridgman's method in corundum tubes with specified apex angle. The samples were solidified under an argon atmosphere. The solidification rate was

50 mm/h. **Table 1** presents the content of the alloys and state of the samples (AC - as-cast state, DS - directionally solidified). **Figure 1** shows sample after directional solidification carried out with the use of the equipment Clasic CZ and Linn FRV-5-40/550/1900.

Table 1 Content of alloys and state of the samples

Alloy	Sample No.	Chemical composition (at. %)	Chemical composition (wt. %)	Rate of DS (mm/h)
1	1AC	Ni-22Al	Ni-11.48Al	-
	1DS			50
2	2AC	Ni-24Al	Ni-12.67Al	-
	2DS			50

Figure 1 The alloy after directional solidification

2.1. Mechanical properties in compression under higher temperatures

The samples were prepared from the castings (AC) and bars after a directional solidification (DS) in the form of cylinders with a height of 12 mm and a diameter of 8 mm. The plastometer GLEEBLE 3800 was used for isothermal tests by uniaxial compression. The test temperature was 800, 1000 and 400 °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 $5 \cdot 10^{-2}$ 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	T (°C)	R_p (MPa)	σ_{max} (MPa)	e_p (-)
1AC-1	800	458	870	0.17
1AC-2	1000	445	608	0.08
1AC-3	400	417	-	-
1DS-1	800	531	1043	0.13
1DS-2	1000	534	660	0.16
1DS-3	400	245	-	-
2AC-1	800	527	937	0.15
2AC-2	1000	375	570	0.08
2AC-3	400	385	-	-
2DS-1	800	609	1013	0.23
2DS-2	1000	480	715	0.20
2DS-3	400	356	-	-

Table 2 presents the resulting values of mechanical characteristics for the temperatures of 800, 1000 and 400 °C. The yield strengths R_p are similar for all the samples, approximately of 530 to 600 MPa at 800 °C. Only the sample 1AC-1 exhibits an even lower yield point. The maximum achieved values of stress and corresponding deformation were determined as indicative values. The value σ_{max} for the samples in the as-cast state is approximately 900 MPa, but in a directional state, it is more than 1000 MPa. The process of directional solidification has a positive effect on the material strengthening, whereas no significant reduction of deformation takes place. In contrast, in the sample 2DS-1 its strain e_p increased to the value of 0.23. **Figure 2** shows the flow curves of the samples in the as-cast state and in the directed state, tested at 800 °C. **Figure 3** then shows them at the temperature of 1000 °C. Compressive stress-strain curve at 800 °C of alloy Ni 22Al/DS shows atypical course. This is caused by a very complicated structure after directional solidification probably. The structure corresponds to metal matrix composites and behavior of this material under stress is very complicated. This is further verified.

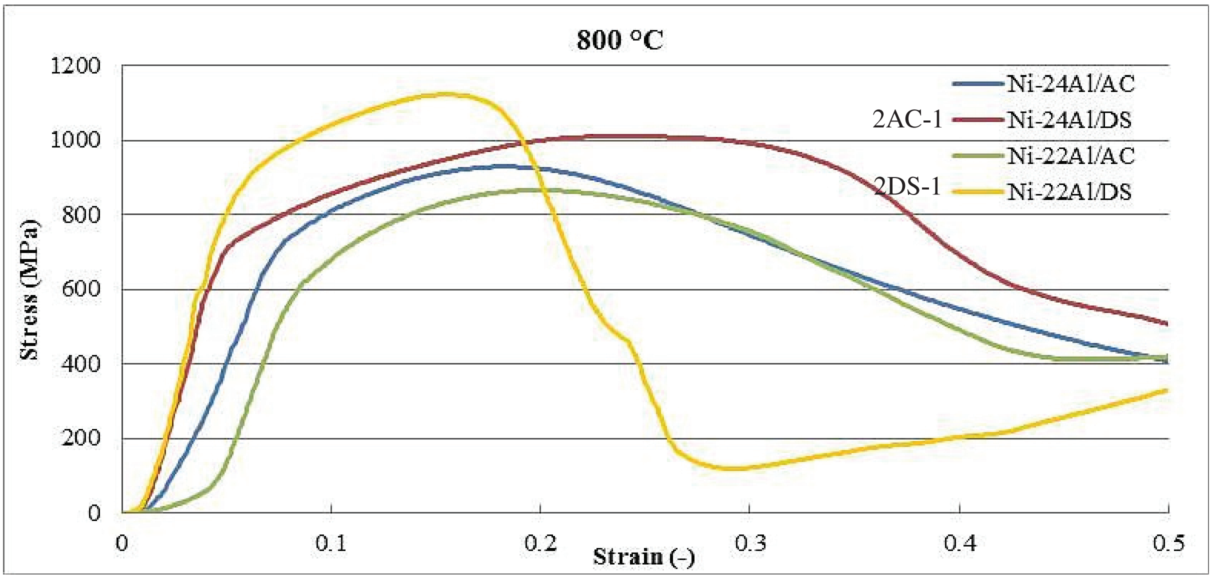

Figure 2 Compressive stress-strain curves at 800 °C

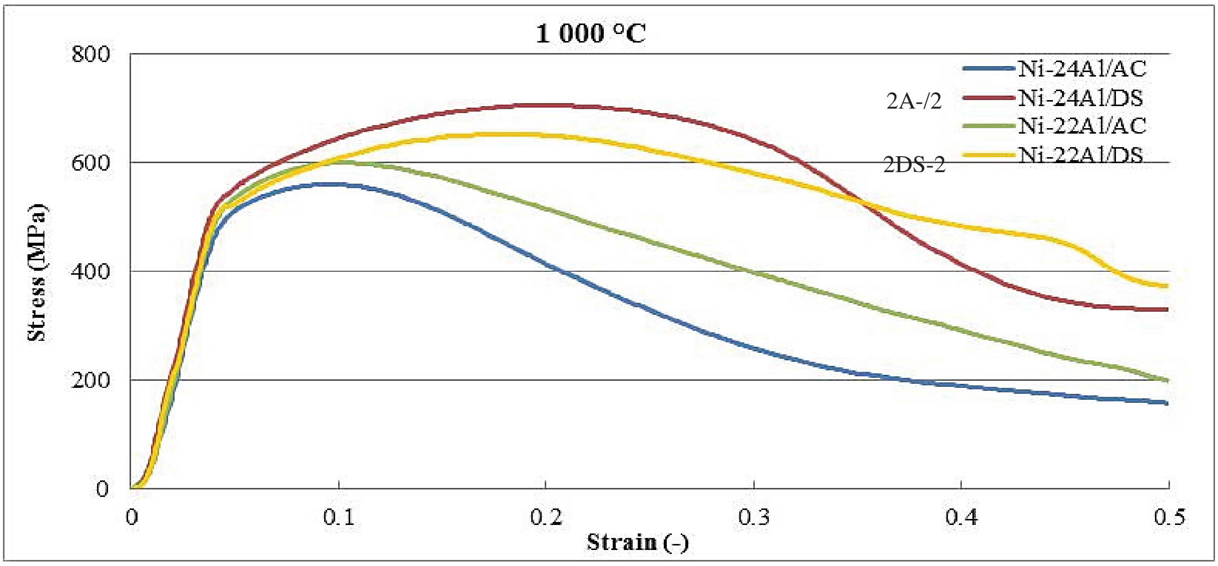

Figure 3 Compressive stress-strain curves at 1000 °C

Figure 4 shows the dependence of the yield stress on the temperature for individual samples. The alloys with 24 at.% Al exhibit a similar evolution of dependence. The maximum yield strength was reached at 800 °C, at the temperature of 1000 °C it decreases. The *Rp* value does not decrease significantly even at the temperature of 1000 °C. Hypostoichiometric alloy after directional solidification exhibits lower yield strength at lower temperatures (400 °C). For this alloy, it is typical to have low yield strength and also the yield strength in tension, when this value is similar [8, 9].

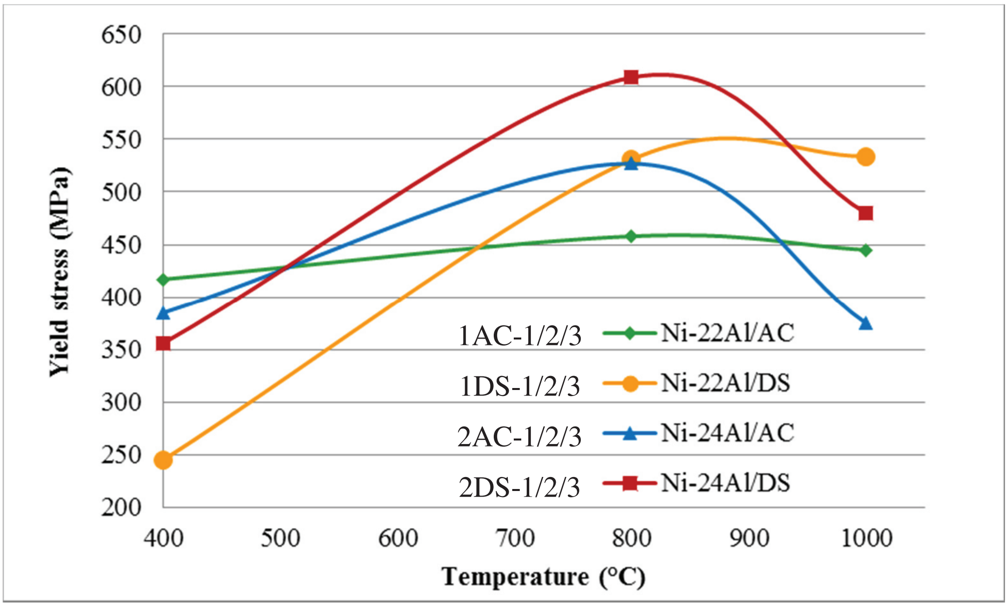

Figure 4 Yield stress at various temperatures

2.2. Evaluation of structural characteristics

Figures 5 - 8 show on the left the microstructures of the samples in their initial state, then in the middle their cross section is shown, and on the right are shown macro-images of the samples after the compression tests at 800 °C. The cast samples presented in **Figures 5** and **7**, have a dendritic structure of the cast samples. **Figures 6** and **8** show a directed structure with distinct columnar grains. The Ni-24Al alloys are formed only by the phase Ni_3Al. The Ni-22Al alloys are formed by the phase Ni_3Al (light areas) and the so-called network, which is formed by channels of the solid solution of Ni and of the smaller grains of Ni_3Al. The macro-images show a clear damage of the samples after compression testing when considerable cracking took place. On the sections are evident deformation bands and according to their shape, it can be concluded that the samples are rather brittle. Only the sample 2AC-1 shows higher plasticity.

2.3. Discussion and summary of results

The Ni-22Al alloys in the as-cast condition are less susceptible to a change of the yield strength with the increasing temperature, which appeared also e.g. for the alloys CMSX-4 and TMS-75 [5]. In this case, however, the values of the yield strength are higher as a result of numerous alloying elements.

The obtained results are similar for example to those obtained for the cast and heat-treated materials based on Ni-25Al [7], but also for materials prepared by rapid solidification on the basis of NiAl-Cr [1]. Even some parameters in comparison with the values reported in [7] are higher. The heat treated castings from the Ni-25Al alloy mentioned in this paper show deformation at 750 °C of approx. 7 % and σ_{max} of approximately 800 MPa, while the alloy Ni-24Al prepared and tested by us shows in the as-cast condition without heat treatment a deformation of 15 % and σ_{max} of 937 MPa at 800 °C.

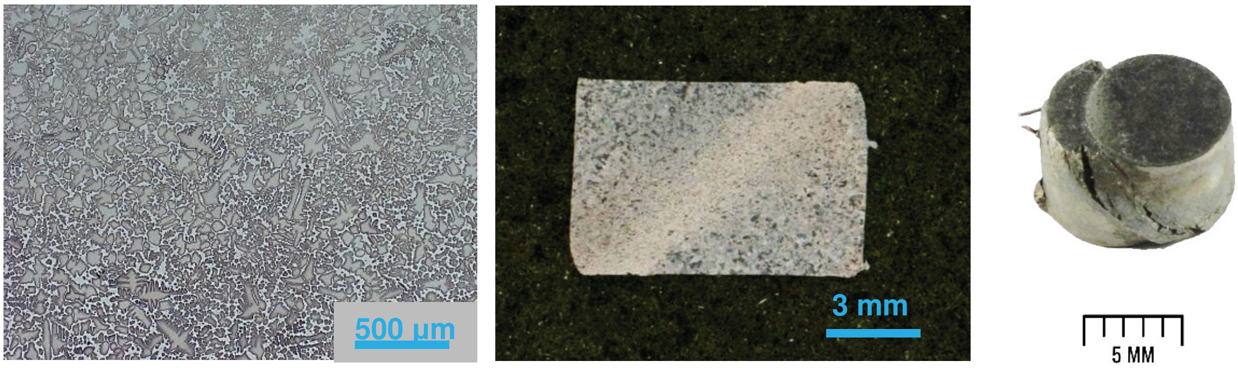

Figure 5 Sample 1AC-1, Ni-22Al, as-cast state - initial state, cross-section and macro after compression test

Figure 6 Sample 1DS-1, Ni-22Al, direct. solidified - initial state, cross-section and macro after compression test

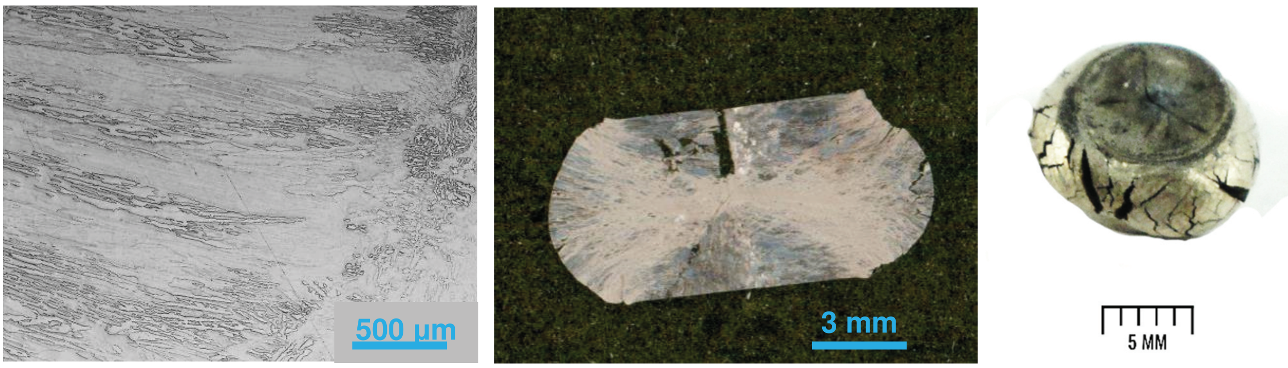

Figure 7 Sample 2AC-1, Ni-24Al, as-cast state - initial state, cross-section and after compression test

Figure 8 Sample 2DS-1, Ni-24Al, direct. solidified - initial state, cross-section and after compression test

3. CONCLUSIONS

The yield strengths are similar for all the samples, approximately 530 to 600 MPa at 800 °C. Only the sample Ni-22Al in as-cast state exhibits an even lower yield point. It was determined indicative maximum values for real stress and corresponding deformations. The value σ_{max} for the samples in the as-cast state is approximately 900 MPa, in a directionally solidified state it is then more than 1000 MPa. The process of directional solidification has a positive effect on the material strengthening, whereas no significant reduction of deformation takes place. The dependence of the yield strength on the temperature exhibit a similar evolution of dependence in the alloys with 24 at.% Al. The maximum yield strength was reached at 800 °C, at the temperature of 1000 °C it decreases. The Ni-22Al alloys are less susceptible to a change of the yield strength with the increasing temperature. The *Rp* value does not decrease significantly even at the temperature of 1000 °C. The samples show visible damage after compression testing when significant cracking took place. On the sections are evident deformation bands and by their shape, it is possible to conclude that the samples are rather brittle. Only the sample of the Ni-24Al alloy in the as-cast state shows a higher plasticity.

ACKNOWLEDGEMENTS

This paper was created at the Faculty of Metallurgy and Materials Engineering within the Project No. LO1203 "Regional Materials Science and Technology Centre - Feasibility Programme" funded by the Ministry of Education, Youth and Sports of the Czech Republic, and the project SP 2016/103 "Specific Research in the Metallurgical, Materials and Process Engineering".

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