# STRUCTURAL CHARACTERISTICS OF Ni-Al-Mo BASED ALLOYS

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**Abstract**

The paper deals with the characterisation of the structure and phase composition of selected types of nickel alloys. Castings were prepared by vacuum induction melting and centrifugal casting. Samples of Ni-Al-Mo based alloys with various contents of molybdenum were directionally solidified by Bridgman method in corundum tubes with specified apex angle. Rate of solidification was 50 and 20 mm/h. The samples were used for structural analysis in longitudinal and transverse direction. The structure is significantly influenced by the process of directional solidification. Microstructural characterisation of materials was performed with use of scanning electron microscope. Distribution of individual elements in phases was captured on linear analysis. These alloys do not exhibit significant chemical heterogeneity. The samples are composed of a phases $Ni_3Al$ and (Ni) with various contents of molybdenum. The existence of a separate phase (Mo) was not confirmed. Determined values of microhardness show the dependence on molybdenum content and rate of directional solidification.

**Keywords:** Ni-Al based alloys, molybdenum, directional solidification, Bridgman method, structural characteristics

## 1. INTRODUCTION

The evolution of nickel based alloys is focused on Ni-Al-Mo base single crystal alloys too. These alloys can be use in high temperature applications, for example as materials for usage of turbine blades and vanes. Content of alloying elements reduction in alloys proves financially and technologically more favorable. Very interesting is $Ni_3Al$ base single crystal superalloy IC6SX [1,2]. In the study of non-alloyed $Ni_3Al$ based alloys were achieved interesting results [3], their high temperature characteristics can be still improve. Possible way is alloying with one alloying element only, such as molybdenum, tungsten or chromium. For many years already molybdenum is used as an alloying element in single crystal superalloys and also in classical Ni-based superalloys in smaller and larger contents. Increased amounts of cobalt, chromium, tungsten, molybdenum and iron in nickel alloys decreases the solubility of aluminium in the γ matrix, which leads to an increase of the volume fraction of γ' phase. The presence of tungsten, molybdenum and cobalt results in an increase of coherence of γ and γ'-phases due to increase of the lattice parameter caused by formation of substitution solid solutions [4-7]. It may be assumes that the microhardness will depend on the resulting crystal orientation similarly as in the case of single crystal molybdenum [8]. The experiments focus on two directionally solidified systems of Ni-Al-Mo alloys, in which it is possible to expect occurrence of a multiphase structure formed by a matrix of NiAl or $Ni_3Al$ and by Mo fibres. In this case these are composites "in-situ", which have excellent characteristics [1-2,9-10].

## 2. EXPERIMENTAL PART

Castings were prepared by vacuum induction melting and centrifugal casting on the equipment Supercast 13. Samples of Ni-Al-Mo based alloys with various contents of molybdenum were directionally solidified by

Bridgman's method in corundum tubes with specified apex angle. Samples were solidified under argon atmosphere. Rate of solidification was 50 and 20 mm/h. **Table 1** includes the content of alloys and rates of directional solidification $r_{DS}$. **Fig. 1** shows rod made Ni-Al-Mo alloy before and after directional solidification carried out with equipment Clasic CZ and Linn FRV-5-40/550/1900.

**Table 1** Content of alloys and rates of directional solidification

| Alloy | Sample No. | Chemical content [at. %] | Chemical content [wt. %] | Rate of directional solidification [mm/h] |
|---|---|---|---|---|
| A | A1-50 | Ni-16.7Al-7.3Mo | Ni-8Al-12.5Mo | 50 |
| | A2-20 | | | 20 |
| B | B1-50 | Ni-16.7Al-6.5Mo | Ni-8Al-11Mo | 50 |
| | B2-20 | | | 20 |
| C | C1-50 | Ni-16.5Al-5.5Mo | Ni-8Al-9.5Mo | 50 |
| | C2-20 | | | 20 |

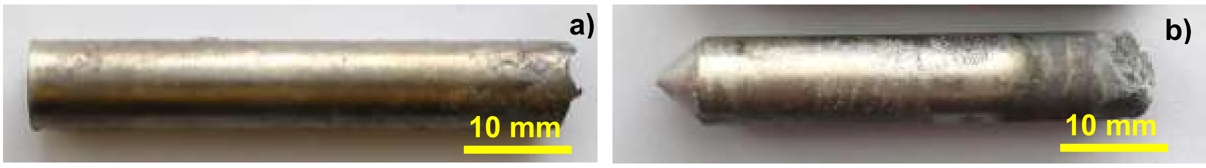


**Fig. 1** The rod of Ni-Al-Mo alloy: a) in cast state, b) after directional solidification

### 2.1 Evaluation of structural characteristics

The samples were used for structural analysis in longitudinal and transverse direction. The structure is significantly influenced by the process of directional solidification, while the grains have various orientation in the structure. The samples are composed of a phases $Ni_3Al$ (γ') and Ni solid solution (γ) with various contents of molybdenum. With detailed observation, small particles of NiMo phase were detected in the structure. **Figures 2 to 7** show structures of the samples in directed state.


**Fig. 2** Alloy Ni-8Al-12.5Mo, directed state: 50 mm/h

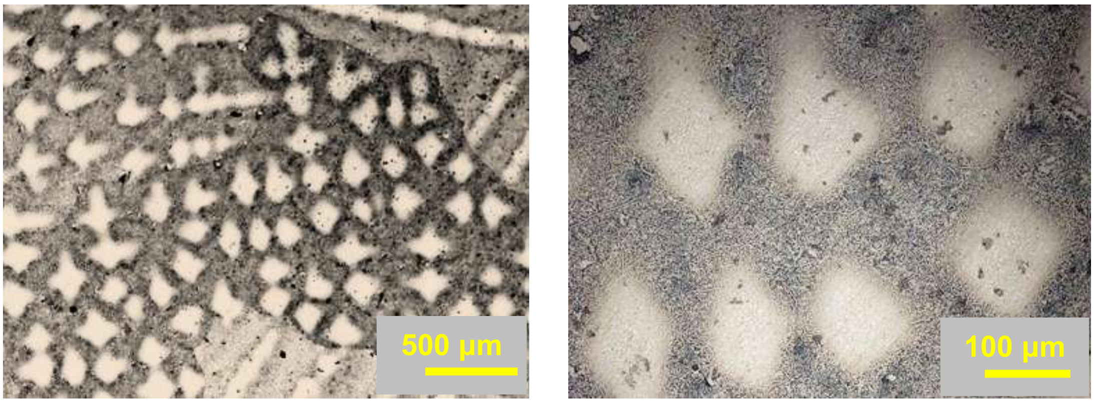


**Fig. 3** Alloy Ni-8Al-12.5Mo, directed state: 20 mm/h

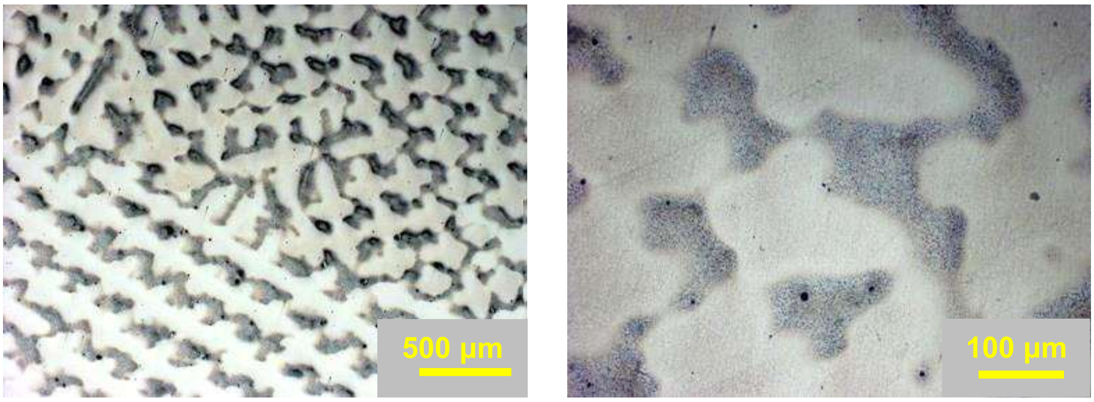


**Fig. 4** Alloy Ni-8Al-11Mo, directed state: 50 mm/h

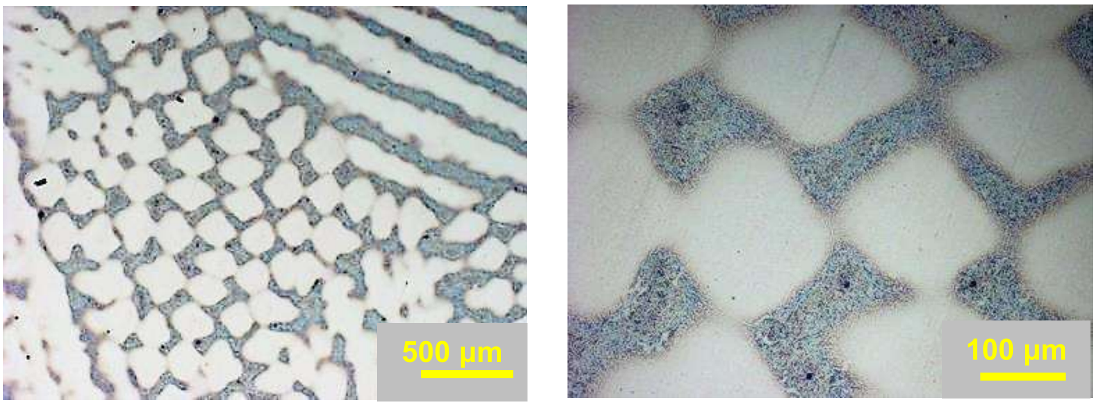


**Fig. 5** Alloy Ni-8Al-11Mo, directed state: 20 mm/h

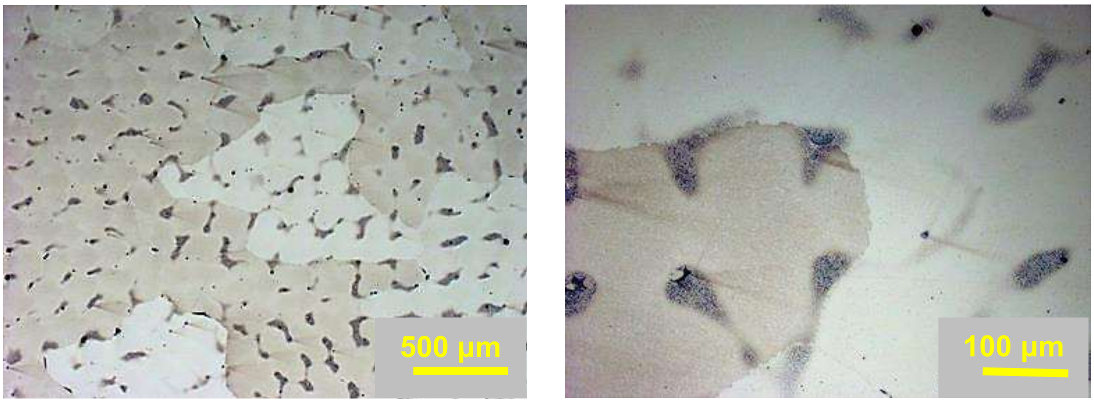


**Fig. 6** Alloy Ni-8Al-9.5Mo, directed state: 50 mm/h

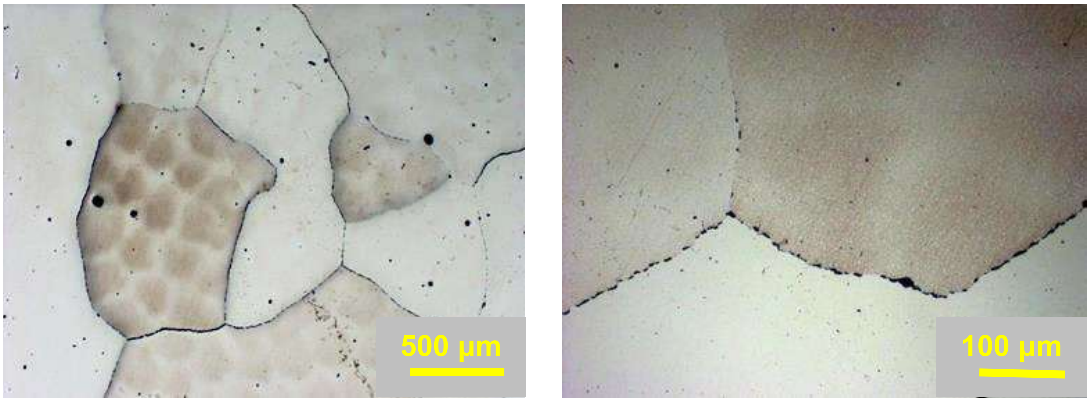


**Fig. 7** Alloy Ni-8Al-9.5Mo, directed state: 20 mm/h

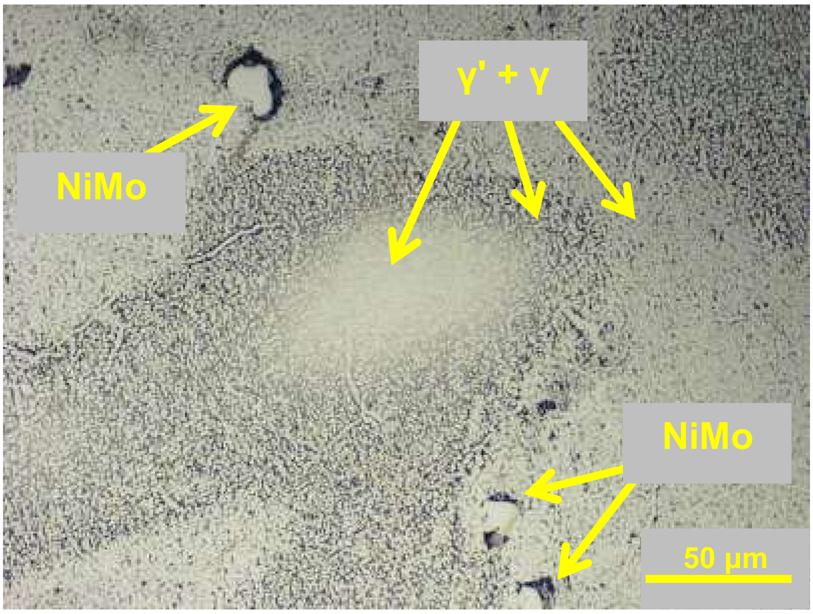


**Fig. 8** Sample A1-50, Mo rich alloy – detail of structure

The structure is significantly influenced by the process of directional solidification. Microstructural characterisation of materials was performed with use of scanning electron microscope. Distribution of individual elements in phases was captured on linear analysis. These alloys do not exhibit significant chemical heterogeneity. **Figure 8** illustrates in detail the multiphase structure. It is evident that the structure is composed predominantly by the $Ni_3(Al,Mo)$ phases and by solid solution of aluminium and molybdenum in nickel (Ni). NiMo phase is seen in the structure in limited quantity only. The existence of a separate phase (Mo) in the samples in directed state was not confirmed. Bright and dark regions in the structure were formed as a result of the etching effect (**Figures 2-8**). It is not a presence of different phases. The measured characteristics are in accordance with the literature [2].

## 2.2 Evaluation of microhardness

The average values of microhardness were measured in transverse and longitudinal section of samples. **Table 2** includes measured values of microhardness in transverse and longitudinal sections. Determined values of microhardness show the dependence on molybdenum content and rate of directional solidification.

**Figure 9** shows the dependence of the microhardness on the molybdenum content. The microhardness values are approximately within the range from 300 to 350 HV0.05. The microhardness values in directional state depend not only on the molybdenum content, but also on the rate of directional solidification. The average values of microhardness in the cross section are higher than the in longitudinal section. The difference between these values is evident particularly in the alloys with higher content of Mo, in the alloys with a lower content of Mo this difference is not significant (**Figure 9**). The alloys solidified at higher rate of directional solidification DS ($r_{DS}$ 50 mm/h) show higher values of microhardness than the alloys solidified lower DS rate ($r_{DS}$ 20 mm/h). Rate of directional solidification influences the volume fractions of γ' phase and primary dendrite arm spacing too [11].

**Table 2** Microhardness in transverse and longitudinal sections

| Alloy [wt. %] | Sample No. | $r_{DS}$ [mm/h] | Section | HV0.05 |
|---|---|---|---|---|
| Ni-8Al-12.5Mo | A1-50 | 50 | longitudinal | 341±14 |
| | | | transverse | 354±17 |
| | A2-20 | 20 | longitudinal | 320±10 |
| | | | transverse | 334±9 |
| Ni-8Al-11Mo | B1-50 | 50 | longitudinal | 316±10 |
| | | | transverse | 320±10 |
| | B2-20 | 20 | longitudinal | 305±8 |
| | | | transverse | 304±8 |
| Ni-8Al-9.5Mo | C1-50 | 50 | longitudinal | 305±8 |
| | | | transverse | 299±9 |
| | C2-20 | 20 | longitudinal | 304±5 |
| | | | transverse | 295±7 |

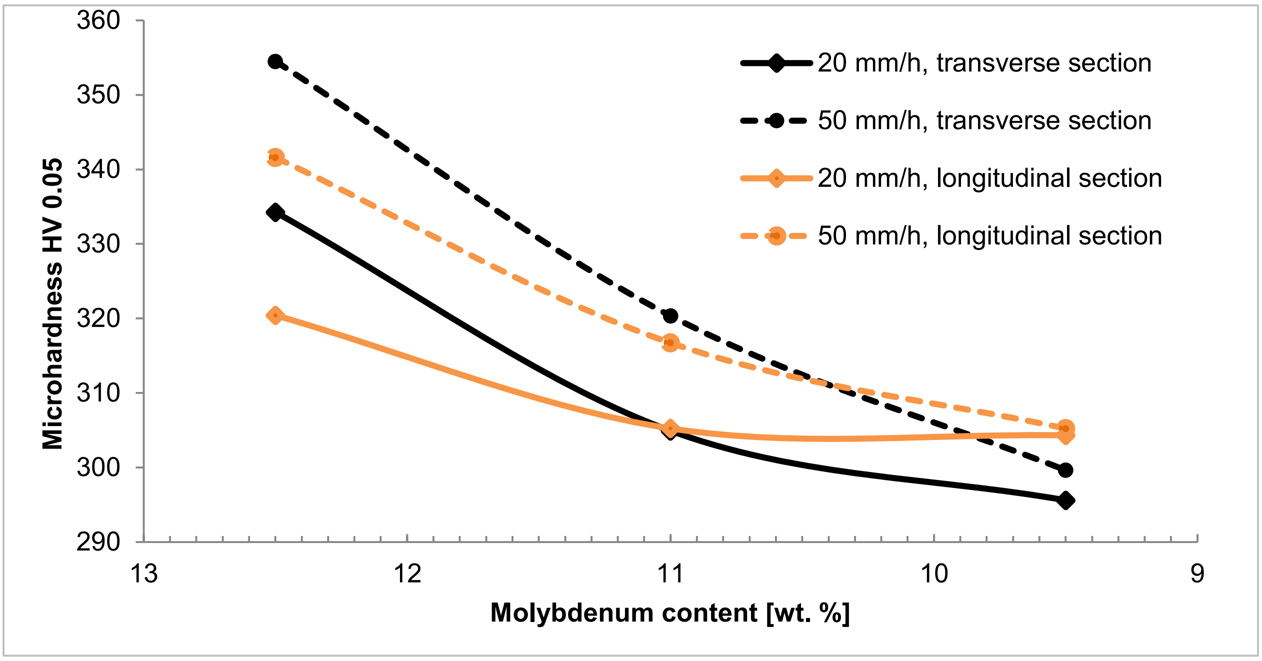


**Fig. 9** Dependence of the microhardness on the molybdenum content

## CONCLUSION

The structure is significantly influenced by the process of directional solidification. Microstructural characterisation of materials was performed with use of scanning electron microscope. Distribution of individual elements in phases was captured on linear analysis. These alloys do not exhibit significant chemical heterogeneity. The samples are composed of a phases $Ni_3Al$ and (Ni) with various contents of molybdenum. The existence of a separate phase (Mo) was not confirmed. Determined values of microhardness show the dependence on molybdenum content and rate of directional solidification. The alloys solidified at higher rate of directional solidification show higher values of microhardness than the alloys solidified lower rate.

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