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STRUCTURAL CHARACTERISTICS OF Ni_3Al BASED ALLOYS DEPENDING ON THE PREPARATION CONDITIONS

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The paper presents an evaluation of the influence of the composition of alloys based on Ni_3Al on their mechanical characteristics. The structure of the alloy was controlled through directional solidification. The achieved values of mechanical characteristics are in good agreement with the material structure. The alloys with sub-stoichiometric contents of aluminium have a multiphase structure. These alloys contain network with high values of tensile strain. The microstructure of the samples was investigated and behaviour of dislocations in the alloys was analysed by Transmission electron microscopy methods (TEM).

Key words: Ni3Al based alloys, structure, casting, directional solidification, tensile test

INTRODUCTION

Ni_3Al - based alloys are nowadays used commercially, yet numerous alloys are still being developed [1, 2]. For steam power plants that operate at temperatures of 700 °C and higher, nickel-base alloys have been developed [3]. Practical applications of these materials are so far severely limited by their considerable brittleness. Possibilities of influencing this unfavourable feature are still under investigation [4]. Structure of these alloys may be favourably influenced by addition of suitable alloying elements, by heat treatment, hot isostatic pressing and directional solidification [2]. Methods for influencing structure using directional solidification and zone melting are used for different types of materials, including nickel alloys [5]. Nickel alloys are of the main interest, as they can be prepared in the form of single crystals. Mechanical properties of these materials depend on the volume fraction, distribution, size and morphology of the γ' precipitates. Their microstructure consists of a high volume fraction of γ' strengthening precipitates (70 %) coherently merged in a γ matrix [6-8]. At present high alloyed alloys are used, but research is turning also on less alloyed alloys, such as Ni - Al - Mo based alloys [9].

EXPERIMENTAL PART

For experiments we prepared Ni_3Al based samples. The alloys were unalloyed and their aluminium content varied in the range from 22 to 25 at. % (Table 1). Chemical composition of the samples was checked by the optical emission spectroscopy method. The alloy was melted in corundum crucible in a vacuum induction furnace and cast into graphite moulds. The castings were directionally solidified by Bridgman method with vertical arrangement (Figure 1). Solidification was carried out on the equipment Clasic CZ and Linn FRV - 5 - 40/550/1900. The alloys were used for determination of structural, microstructural parameters and mechanical characteristics. Temperature of the melt was 1 550 °C and temperature gradient in liquid at the solid - liquid interface was about 70 °C·cm^{-1}. The 20 mm·hod^{-1} solidification rate was applied. After directional solidification some samples had a multi - phase microstructure formed mainly by Ni_3Al (γ') phase and two phase regions composed of the γ' precipitates embed in the γ matrix. The precipitation of very fine γ' particles was observed in the γ channels separating the γ' particles. The aim of the study is to compare the formed structures with the given aluminium content and their corresponding mechanical characteristics.

Table 1 **Content of Ni_3Al based alloys**

Sample No.	Al content / at. %	Share of network / %
1	25	-
2	24	-
3	23	46
4	22	88

Figure 1 Rod made from Ni_3Al alloy after directional solidification

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STRUCTURAL CHARACTERISTICS

Structural analysis was made on longitudinal and cross sections of the samples. Stoichiometric alloys (near 25 at. %) had a directional structure formed by the phase Ni_3Al (γ‘) (Figures 2 and 3). The samples with stoichiometric composition can contain a small extent the phase Ni_5Al_3 (dark phase in Figure 2). According to the scan of the determined content of aluminium this should be the phase, which occurs in the binary system Ni-Al below the temperature of 700 °C [10]. This phase occurs only at initial part of the samples. After achievement of equilibrium conditions this phase disappears and only Ni_3Al grains with stoichiometric content of aluminium are present here. The grains are directionally orientated in direction of the growth. This fact is reflected in determined values of ductility (Table 2), which are substantially higher than in ordinary poly-crystalline alloys of this type.

The alloys with contents of 23 - 22 at. % Al have a completely different structure (Figures 4 and 5). Typical structure of these samples was formed from Ni_3Al, but which contained also two - phase areas formed by nickel solid solution (γ) and intermetallic phase Ni_3Al (γ‘), so called network structure γ / γ‘. Network structure, is composed of channels of nickel solid solution (γ) and smaller grains of Ni_3Al. The channels γ may contain precipitated particles γ‘ of very small dimensions, which were detectable by the transmission electron microscopy method.

In terms of type these materials correspond to materials MMC (Metal Matrix Composite). The achieved mechanical characteristics, which are excellent, also correspond with this. Share of this two-phase zone (network structure) in the samples is the critical parameter for the achieved results. The share of network should be min. 70% [8]. Share of the network structure was determined with use of image analysis (Table 1).

MECHANICAL CHARACTERISTICS

Short tensile specimens with a length of 55 mm and gauge diameter of 5 mm were prepared by lathe-turning from directionally solidified samples. Table 2 gives the measured values of offset 0.2 % tensile yield stress ($R_{p0.2}$), ultimate tensile strength (R_m) and tensile strain until the fracture A_5^*.

EVALUATION OF MEASUREMENT RESULTS

The achieved values of mechanical characteristics are in good agreement with the material structure. The

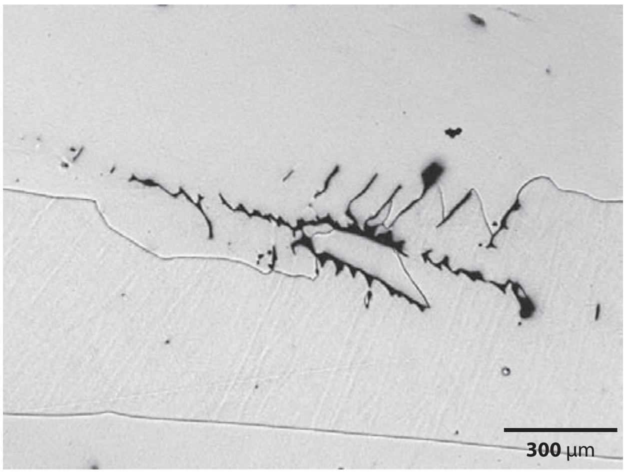

Figure 2 Sample No. 1 - Ni25Al

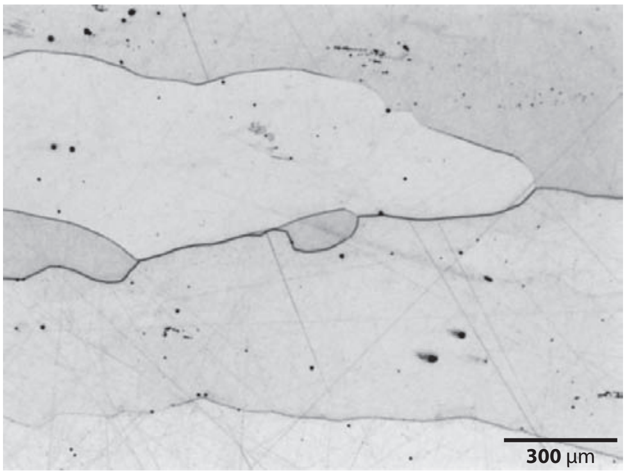

Figure 3 Sample No. 2 - Ni24Al

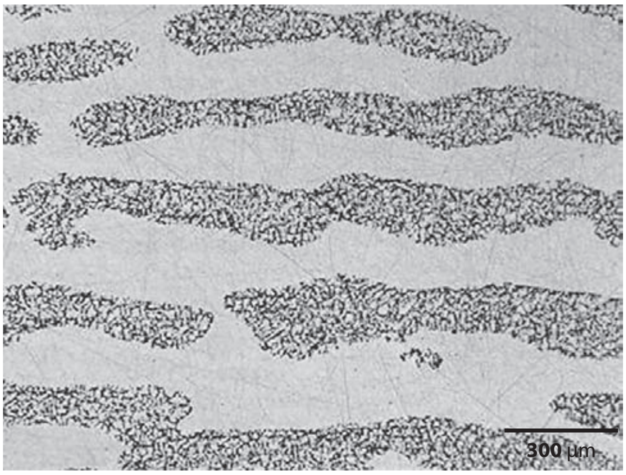

Figure 4 Sample No. 3 - Ni23Al

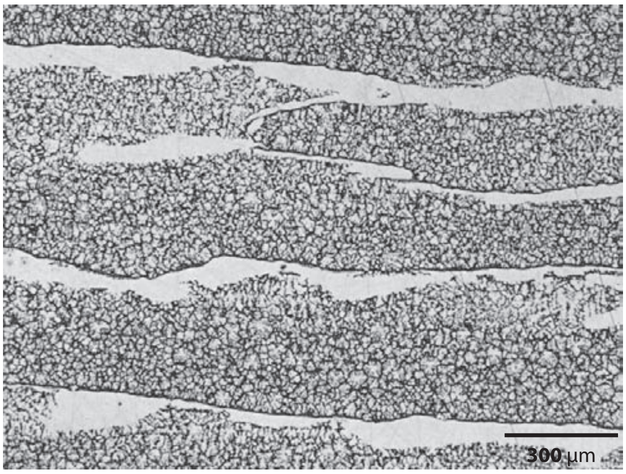

Figure 5 Sample No. 4 - Ni22Al

Table 2 **Mechanical characteristics**

Sample No.	$R_{p0.2}$ / MPa	R_m / MPa	A_5^* / -	Strain rate / s^{-1}
1	220	425	0,14	1,33 x 10^{-3}
2	225	375	0,05	1,20 x 10^{-4}
3	181	511	0,54	1,33 x 10^{-3}
4	164	451	1,41	1,33 x 10^{-3}

alloys containing network show high values of tensile strain until the fracture A_5*. The samples were analysed by TEM methods. Microstructure of the samples was observed and behaviour of dislocations in the alloys was analysed. Dislocation density is the decisive parameter for the achieved mechanical characteristics. The alloys exhibited a high density of dislocations, so it is possible to watch only the consequences of collective behaviour of dislocations. Bending contours and slip planes were observed. In the sample 1 Ni25Al (Figure 6) the density of dislocations is lower, namely 0,6 x 10^{14} m^{-2}. High density of dislocations 2 x 10^{14} m^{-2} of the samples 3 and 4 (Figure 7) corresponds to the obtained value of deformation [11]. Microstructure of the sample 4 is shown in Figure 8. It shows here network in detail and grains of the phase Ni$_3$Al (γ') enclosed in it. Figure 9 shows the dependence of the tensile strain on the Al content. This dependence can be expressed by a regression equation of exponential type. The reliability coefficient is 0,99. For creation of dependence we used the values of tensile strain obtained at the same strain rate. Porosity of the alloys is not big both in directed and as cast state [12].

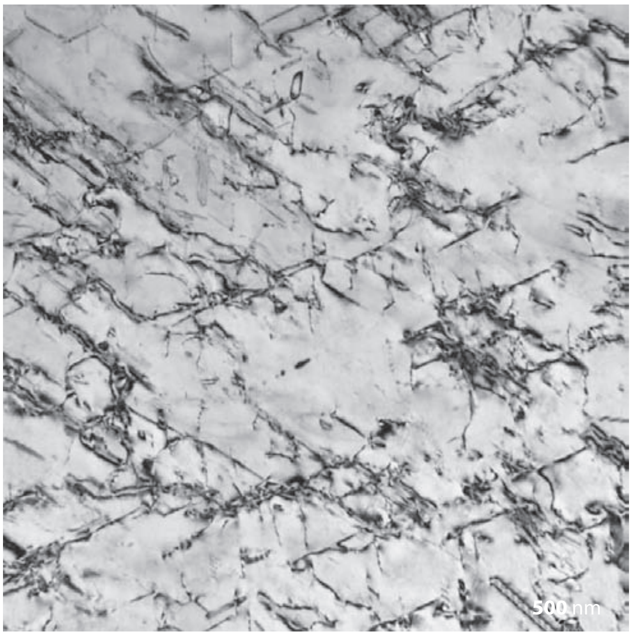

Figure 6 Sample Ni25Al – TEM analysis

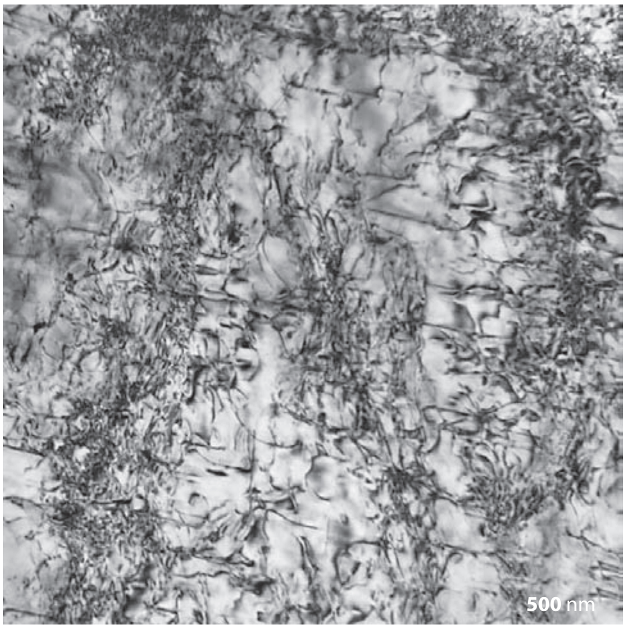

Figure 7 Sample Ni22Al – TEM analysis

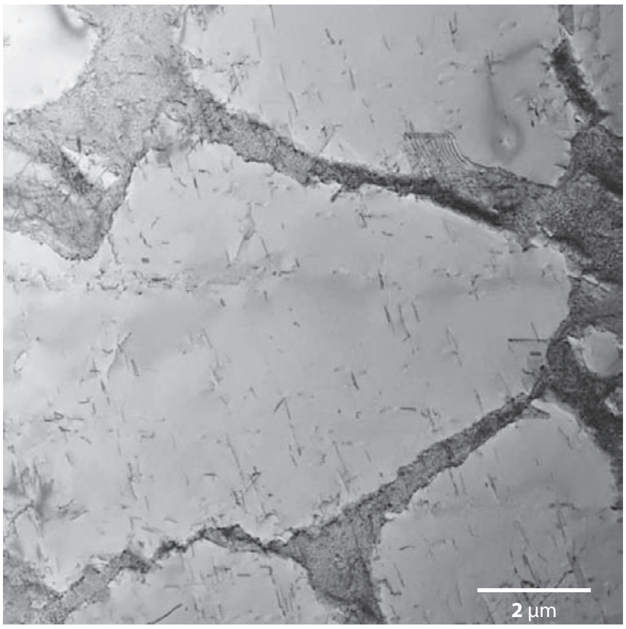

Figure 8 Sample Ni22Al – TEM analysis – network

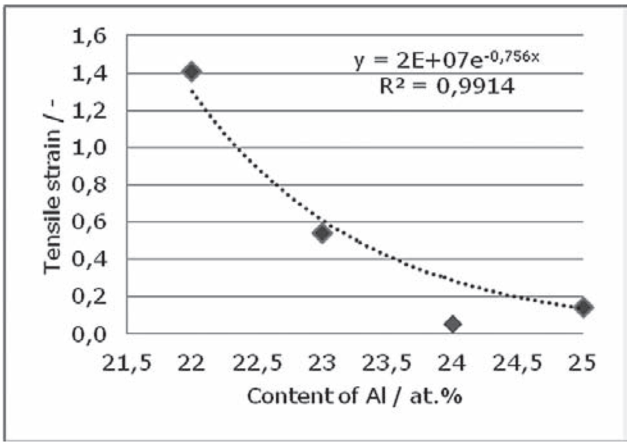

Figure 9 Dependence of the tensile strain on the Al content

CONCLUSIONS

The samples exhibited a multi-phase microstructure formed mainly by single Ni$_3$Al (γ‘) phase and two phase regions containing γ‘ particles embed in the γ matrix.

The achieved values of mechanical characteristics are in good agreement with the material structure. Alloys containing network show high values of tensile strain until the fracture A_5*. Dependence of tensile strain can be expressed using by regression equation of exponential type. The samples were analysed by TEM methods. Microstructure of the samples was observed and behaviour of dislocations in the alloys was analysed.

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