MECHANICAL CHARACTERISTICS OF Ni3Al BASED ALLOYS WITH STOICHIOMETRIC AND HYPO-STOICHIOMETRIC COMPOSITION

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Abstract

Samples of Ni$_3$Al based alloys with stoichiometric and hypo-stoichiometric composition, i.e. 25 and 22 at.% of Al, were used for determination of mechanical characteristics. The samples were non-alloyed. Alloys with directional structure were used for manufacture of short tensile rods. Directional solidification was realised at the Department of non-ferrous metals, refining and recycling at the Faculty of Metallurgy and Materials Engineering, Technical University of Mining and Metallurgy in Ostrava (VŠB-TUO) in a two-zone crystallisation furnace. The samples were placed into corundum tubes with a specified apex angle. Stoichiometric alloys prepared in this manner had a directional structure formed by the phase Ni$_3$Al ($\gamma'$), while hypo-stoichiometric alloys were multi-phase. Mostly two-phase structures formed by solid solution of Nickel ($\gamma$) and Ni$_3$Al ($\gamma'$), by so called network $\gamma$/$\gamma'$, have occurred here and their share formed up to 99 % for lower rates of directional crystallisation. Precipitated $\gamma'$ particles with very small dimensions can be in $\gamma$ channels. Areas of Ni$_3$Al ($\gamma'$) are present here in much smaller extent. Both types of samples with different Aluminium content higher values of ductility till ultimate strength than it is usual in this type of poly-crystalline material. Such high values are given in literature for single crystals. Increasing share of two-phase zones $\gamma$/$\gamma'$ in structure of the alloys with lower aluminium content have very favourable effect on ductility values, and ultimate strength is also sufficient. Unusually high ductility till ultimate strength was measured in the directionally solidified material with higher share of network and cross section of testing part of the rod was considerably narrowed and has elliptic shape.

Keywords: Ni$_3$Al based alloys, mechanical characteristics, directional solidification, multi-phase alloys

1. INTRODUCTION

Favourable properties of inter-metallic compounds enable their use in demanding environments, especially at increased and high temperatures with the influence of oxidation atmosphere. Practical applications of these materials are so far severely limited by their considerable brittleness. Created structure of inter-metallic compounds is greatly dependent on composition and chosen conditions of directional crystallisation. Theoretical calculations and experimental determination of critical parameters for transition of columnar to equiaxed transition can be found in literature [1, 2] for various materials. Main interest is today focused on Ni$_3$Al based inter-metallic compounds with hypo-stoichiometric composition, for which it was established that share of two-phase areas $\gamma$/$\gamma'$ is very significant indicator. These alloys approach by their composition the Ni-based superalloys, where mechanical properties of these materials depend on the volume fraction, distribution, size and
morphology of the $\gamma'$-precipitates. Their microstructure consists of a high volume fraction of $\gamma'$-strengthening precipitates (70\%) coherently merged in a $\gamma$ matrix [3].

2. EXPERIMENTAL PART

Samples of Ni$_3$Al based alloys with stoichiometric and hypo-stoichiometric composition, i.e. 25 and 22 at.% of Al, were used for determination of mechanical characteristics. The samples were non-alloyed. Experiments were made with use of the samples that were first cast into shape of bars and then crystallised by directional solidification (DS) with use of Bridgman’s method. Directional crystallisation was realised at the Department of Non-Ferrous Metals, Refining and Recycling, FMME, VŠB-TU Ostrava in a two-zone crystallisation furnace. The samples were placed into corundum tubes with a specified apex angle. Figure 1 shows the samples after directional crystallisation. The samples prepared in this manner were then used for determination of structural characteristics and for manufacture of tensile rods.

2.1 Evaluation of mechanical characteristics

Short tensile bars were prepared by lathe-turning with length of 55 mm and diameter of central part of the bar 5 mm. Tensile tests were made at the Department of Physics of Materials, Faculty of Mathematics and Physics at Charles University in Prague (UK). The strain rate was approximately $1.33 \times 10^3 \text{s}^{-1}$ for all samples. Share of network $\gamma/\gamma'$ was determined by image analysis. Table 1 gives the measured values of tensile stress at yield, ultimate strength and conventional value of ductility representing the value of tensile strain till the strength limit. Figures 2 and 3 show load diagrams of the samples Nos. 1 – 4. In the sample 2 very high value of ductility to ultimate strength was determined (Fig. 2).
Table 1 Obtained mechanical characteristics and share of network structure

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Al content [at.%]</th>
<th>$r_{DS}$ [mm/h]</th>
<th>$R_{p0.2}$ [MPa]</th>
<th>$R_m$ [MPa]</th>
<th>$A_5^*$ [%]</th>
<th>share of network structure [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>22</td>
<td>20</td>
<td>231</td>
<td>437</td>
<td>69</td>
<td>88</td>
</tr>
<tr>
<td>2</td>
<td>22</td>
<td>10</td>
<td>187</td>
<td>489</td>
<td>91</td>
<td>99</td>
</tr>
<tr>
<td>3</td>
<td>25</td>
<td>20</td>
<td>220</td>
<td>425</td>
<td>14</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>25</td>
<td>10</td>
<td>182</td>
<td>308</td>
<td>20</td>
<td>-</td>
</tr>
</tbody>
</table>

Fig. 2 Load diagrams of the samples Nos. 1 and 2, Ni22Al

Fig. 3 Load diagrams of the samples Nos. 3 and 4, Ni25Al

Figure 3 shows tensile diagrams for the samples 3 and 4. Ductility is again higher in the sample with the lower rate of directional crystallisation. However, the strength value was decreased in this case. Figures 4-7 show fracture areas and parts of tensile rods for each sample. In the sample 1 the cross-section of tested part of the rod was narrowed and the shape of the fracture area of the sample is elliptical (Fig. 4). This phenomenon is more distinct in the sample 2 (Fig. 5), where the value of ductility was determined to reach even 91 %. In the samples 3 and 4 the fractured part of the rod is of a
completely different character corresponding to different structure, as it will be described below (Fig. 6 and 7). The Ni-rich alloy displayed an elongation of 2% at the lowest strain rate and 5-6% at strain rates of $10^1$ s$^{-1}$ and higher [4].

The fracture area in the sample 1 is of a mixed character, and share of trans-crystalline fracture of dimple-like shape that was determined by an estimate to approx. 70 % and 30 % represents trans-crystalline plastic fracture of cascade type. On the fracture area of the sample 2 only trans-crystalline fracture of dimple-like shape was observed, which corresponds to the high share of network (up to 99%) formed by two-phase areas γ/γ'. On the fracture area of the samples 3 and 4 only trans-crystalline cleavage fracture of cascade character was observed.
2.2 Evaluation of structural characteristics

Structural analysis was made on longitudinal sections of the samples. Figures 8-11 show microstructures of the samples Nos. 1-4. Typical structure of samples Nos. 1 and 2 corresponded to it, which was formed from Ni₃Al, but which contained also two-phase areas formed by solid solution of nickel (γ) and Ni₃Al (γ′), so called network structure γ/γ′, as it was already mentioned above. Micrographs show distinct differences in shares of these two-phase areas, and the sample No. 2 has this share of network structure the highest, namely more than 99 %.

Fig. 8 Structure of sample No. 1

Fig. 9 Structure of sample No. 2

Fig. 10 Structure of sample No. 3

Fig. 11 Structure of sample No. 4

Stoichiometric alloys prepared in this manner had a directional structure formed by the phase Ni₃Al (γ′), which has in this case lower aluminium content than 25 at.%. The samples with stoichiometric composition contain to a small extent the phase richer in aluminium (dark phase in Figures 10 and 11). According to the determined content of aluminium this should be the phase Ni₅Al₃, which occurs in the binary system Ni-Al below the temperature of 700°C [5]. In the sample 4 large share of this phase segregated due to different conditions of directional crystallisation and its more homogenous distribution. It is presumed that this fact influenced the final value of ductility.
3. CONCLUSIONS

Both types of samples with different Aluminium content higher values of ductility till ultimate strength than it is usual in this type of poly-crystalline material. Such high values are given in literature for single crystals. Increasing share of two-phase zones $\gamma$/$\gamma'$ in structure of the alloys with lower aluminium content have very favourable effect on ductility values, and ultimate strength is also sufficient. Unusually high ductility till ultimate strength was measured in the directionally solidified material with higher share of network and cross section of testing part of the rod was considerably narrowed and has elliptic shape. The samples with stoichiometric composition do not contain such high values of ductility. In the samples with stoichiometric composition only trans-crystalline cleavage fracture occurs at the fracture areas. In the samples with hypo-stoichiometric composition a mixed trans-crystalline fracture occurs and the share of trans-crystalline fracture of dimple-like type corresponds approximately do the share of network $\gamma$/$\gamma'$ in structure.

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LITERATURE


