STRUCTURAL AND FRACTURE CHARACTERISTICS OF NICKEL-BASED ALLOYS

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Abstract
Selected nickel alloys were melted by vacuum induction melting (VIM). Samples were melted and cast under vacuum into the shape of rods with diameter of 10 mm. Thus prepared castings were directionally solidified at the rate of 100 mm/h in order to eliminate casting defects. Flaw detection tests were performed on the samples in the directionally oriented condition. Thus prepared samples did not contain any casting defects and they were used for determination of the basic mechanical properties and fracture characteristics at room temperature. It is evident after comparison of the tensile diagrams of experimental alloys that the alloys based on IC396, IC221M and IC438 and have similar character of failures. The sample based on the alloy IC50 exhibits with comparison with other alloys lower yield strength, the value of which is almost half. The alloy exhibits very high ductility and higher strength than the other alloys, but its low yield strength limits the possibilities of its practical use. The alloy IC396 has, however, significantly improved ductility compared to the alloys IC221M and IC438. Porosity and micro-hardness was also determined in these samples. Porosity and micro-hardness results do not show significant differences at measurements in transverse and longitudinal direction. Evaluation of the phase composition was performed on an analytical scanning microscope. Matrix composition corresponds approximately to the nominal composition of the alloys. The alloys contain furthermore phases with variable content of basic and alloying elements. The obtained results will be used as input information for further laboratory and pilot testing.

Keywords: Nickel alloys, directional solidification, fracture characteristics, structure

1. INTRODUCTION
Nickel and nickel alloys have useful resistance to a wide variety of corrosive environments, typically encountered in various industrial processes such as in chemical processing petrochemical processing, aerospace engineering, power generation and energy conversion, thermal processing and heat treatment industry, oil and gas production, pollution control and waste processing, marine engineering, pulp and paper industry, agrichemicals, industrial and domestic heating, the electronics and telecommunication industries, and other [1]. Nickel alloys containing an intermetallic phase Ni₃Al are very interesting thanks to their properties. The Ni₃Al-based alloy has been modified with chromium, molybdenum, zirconium, and boron additions for obtaining a combination of improved strength and ductility properties [2]. These alloys have boron as the key trace addition since it improves the grain boundary cohesive strength and room temperature ductility. The other alloying additions include chromium (6±9%) for reducing environmental embrittlement and oxidation at higher temperatures, Zr (0.2±2.0%) for improving high temperature strength via solid solution strengthening, and Mo (1±3%) for increasing the strength at ambient and elevated temperatures. Although these alloys are developed for commercial applications essentially as castings, their ductility is sufficiently high for hot working at temperatures above 1100°C [3].
2. EXPERIMENTAL PART

Nickel based alloys, which were used for high-temperature applications, were chosen for an analysis. Chemical composition of the alloys was modified and it is given in table 1. The experimental alloys were based on IC50, IC396, IC221M and IC438. Selected nickel alloys were melted by vacuum induction melting. Samples were melted and cast under vacuum into the shape of rods with diameter of 10 mm. Chemical composition was verified by method of optical emission spectrometry. Thus prepared castings were directionally solidified at the rate of 100 mm/h in order to eliminate casting defects. The rods were directionally solidified (DS) by Bridgman’s method in corundum tubes with a specific angle. Directional solidification was realised in a two-zone solidification furnace. Flaw detection tests were performed on the samples in the directionally oriented condition. Thus prepared samples did not contain any casting defects and they were used for determination of the basic mechanical properties and fracture characteristics at room temperature.

### Table 1 Content of modified Ni based alloys

<table>
<thead>
<tr>
<th>Type of alloy</th>
<th>Modified alloy</th>
<th>Al</th>
<th>Cr</th>
<th>Mo</th>
<th>Zr</th>
<th>B</th>
<th>Ni</th>
</tr>
</thead>
<tbody>
<tr>
<td>IC 50</td>
<td>A1</td>
<td>11.30</td>
<td>-</td>
<td>-</td>
<td>0.60</td>
<td>0.01</td>
<td>88.08</td>
</tr>
<tr>
<td>IC 396</td>
<td>A2</td>
<td>7.98</td>
<td>7.72</td>
<td>3.02</td>
<td>0.85</td>
<td>0.01</td>
<td>80.42</td>
</tr>
<tr>
<td>IC 221M</td>
<td>A3</td>
<td>8.00</td>
<td>7.70</td>
<td>1.43</td>
<td>1.70</td>
<td>0.01</td>
<td>81.10</td>
</tr>
<tr>
<td>IC 438</td>
<td>A4</td>
<td>8.10</td>
<td>5.23</td>
<td>7.02</td>
<td>0.13</td>
<td>0.01</td>
<td>79.52</td>
</tr>
</tbody>
</table>

2.1 Evaluation of mechanical characteristics, fracture

Tensile tests were performed at room temperature. The strain rate used for the sample A250.2 was $1.2 \cdot 10^{-4}$ $s^{-1}$. Due to slow progress of testing the strain rate was increased to $7 \cdot 10^{-4}$ $s^{-1}$. The obtained values of yield strength, strength, ductility and contraction are given in table 2. It is evident from comparison of the tensile diagrams of experimental alloys that the alloys based on IC396, IC221M and IC438 have similar character of failures. The sample based on the alloy IC50 exhibits in comparison with other alloys lower yield strength, the value of which is almost half. The alloy exhibits very high ductility and higher strength than the other alloys, but its low yield strength limits the possibilities of its practical use. The alloy IC396 has, however, significantly improved ductility compared to the alloys IC221M and IC438.

### Table 2 Mechanical characteristics of the Ni based alloys

<table>
<thead>
<tr>
<th>Sample</th>
<th>Alloy</th>
<th>Rp0.2 [MPa]</th>
<th>Rm [MPa]</th>
<th>A [%]</th>
<th>Z [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>IC 50</td>
<td>239</td>
<td>880</td>
<td>48.8</td>
<td>44.4</td>
</tr>
<tr>
<td>A2</td>
<td>IC 396</td>
<td>551</td>
<td>658</td>
<td>41.2</td>
<td>40.7</td>
</tr>
<tr>
<td>A3</td>
<td>IC 221M</td>
<td>530</td>
<td>633</td>
<td>22.0</td>
<td>20.5</td>
</tr>
<tr>
<td>A4</td>
<td>IC 438</td>
<td>414</td>
<td>688</td>
<td>23.2</td>
<td>23.0</td>
</tr>
</tbody>
</table>
Figure 1 shows a tensile diagram of the Ni based alloys. Figures 2 to 9 shows fracture surfaces. The fracture area in the sample 1 is of a mixed character with share of trans-crystalline fracture of dimple-like shape and trans-crystalline plastic fracture of cascade type. On the fracture area of the samples 2, 3 and 4 only trans-crystalline cleavage fracture of cascade character was observed.

Fig. 1 Tensile diagram of the Ni based alloys

Fig. 2 Sample No. A250.2, fracture

Fig. 3 Sample No. A252.2, fracture
2.2 Evaluation of structural characteristics

Structural analysis was made on longitudinal and transverse sections of the samples. Figures 6 to 9 show micro-structures of the samples in directed state. Porosity results do not show significant differences at measurements in transverse and longitudinal direction. Porosity in all the samples in transverse and longitudinal direction makes approximately 0.05 %. Evaluation of the phase composition was performed with an analytical scanning microscope. Matrix composition corresponds approximately to the nominal composition of the alloys. The alloys contain furthermore phases with variable content of basic and alloying elements. The alloys contain usually identified phases [4]. These alloys contain γ phase, carbides of various types, phases containing sulphur and zirconium (ZrSₓ) and other phases.
Micro-hardness HV0.05 was determined in all the samples in directed state both in transverse and longitudinal direction. Differences between the values measured in transverse and longitudinal direction are no too distinct. The alloy of the type IC50 has micro-hardness of approx. 230 HV0.05, which is the smallest values of all experimental alloys. The alloys of the types IC396, IC221M and IC438 have micro-hardness around 300 HV0.05.

3. CONCLUSIONS

The prepared samples did not contain any casting defects and they were used for determination of the basic mechanical properties and fracture characteristics at room temperature. The alloys based on IC396, IC221M and IC438 and have similar deformation behaviour. The sample based on the alloy IC50 exhibits in comparison with other alloys lower yield strength, the value of which is almost half. The alloy exhibits very high ductility and higher strength than the other alloys, but its low yield strength limits the possibilities of its practical use. The alloy IC396 has, however, significantly improved ductility compared to the alloys IC221M and IC438. Porosity and micro-hardness was also determined in these samples. Porosity and micro-hardness results do not show significant differences at measurements in transverse and longitudinal direction. Evaluation of the phase composition was performed on an analytical scanning microscope. Matrix composition corresponds approximately to the nominal composition of the alloys. The alloys contain furthermore phases with variable content of basic and alloying elements. The obtained results will be used as input information for further laboratory and pilot testing.

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LITERATURE

