MECHANICAL PROPERTIES AND MICROSTRUCTURE OF IN713LC NICKEL SUPERALLOY CASTINGS

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Abstract

IN713LC is a nickel-base casting alloy developed for applications requiring high strength at elevated temperatures. Its balanced composition provides a good combination of tensile and creep-rupture properties as a result of gamma-prime strengthening enhanced by solid solution and grain-boundary strengthening. IN713LC alloy performs a good castability. Castings are used in as-cast state, without heat treatment. Currently, this alloy is used widely, for example, for manufacturing of turbine wheels in turbochargers. Recently, customers demand the production of increasingly larger parts of impellers than before. This requirement has resulted in a greater weight of castings and thus different conditions during solidifying and cooling of the castings. Therefore modified castings microstructure arises.

When approving the castings, mechanical values are measured by tensile test on test bodies made from the centres of the castings. These test bodies often exhibit lower values than required, in particular the rupture strength and elongation at room temperature. The presence of fragile niobium carbides in the structure of the alloy was identified as the main cause of this situation, which originated as a result of the slow speed cooling. Test bodies made from quickly chilled castings show significantly higher mechanical properties at room temperature.

Keywords: superalloys, microstructure, mechanical properties, carbides

1. INTRODUCTION

IN713LC is a nickel-base casting alloy developed for applications requiring high strength at elevated temperatures. Its balanced composition provides a good combination of tensile and creep-rupture properties as a result of gamma-prime strengthening enhanced by solid solution and grain-boundary strengthening. IN713LC alloy performs a good castability. Castings are used in as-cast state, without heat treatment. Currently, this alloy is used widely, for example, for manufacturing of turbine wheels in turbochargers. Recently, customers demand the production of increasingly larger parts of impellers than before. This requirement has resulted in a greater weight of castings and thus different conditions during solidifying and cooling of the castings. Therefore modified castings microstructure arises.

When approving the castings, mechanical values are measured by tensile test on test bodies made from the centres of the castings. These test bodies often exhibit lower values than required, in particular the rupture strength and elongation at room temperature. Our aim is to find the origin of low mechanical properties of the casting.

2. EXPERIMENTAL

The chemical composition of the IN713LC alloy melt used is given in Table 1.
Table 1 Chemical composition (in wt. %) of the IN713LC alloy

<table>
<thead>
<tr>
<th></th>
<th>Cr</th>
<th>Ti</th>
<th>Al</th>
<th>Mo</th>
<th>Ta</th>
<th>Nb</th>
<th>Fe</th>
<th>Si</th>
<th>Mn</th>
<th>C</th>
<th>Cu</th>
<th>Zr</th>
<th>B</th>
<th>Ni</th>
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<tbody>
<tr>
<td>Min.</td>
<td>11,0</td>
<td>0,4</td>
<td>5,5</td>
<td>3,8</td>
<td>0,75</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0,03</td>
<td>0</td>
<td>0,05</td>
<td>0</td>
<td>0,005</td>
<td>Bal.</td>
</tr>
<tr>
<td>Max.</td>
<td>13,0</td>
<td>1,0</td>
<td>6,5</td>
<td>5,2</td>
<td>1,10</td>
<td>0,5</td>
<td>0,5</td>
<td>0,5</td>
<td>0,25</td>
<td>0,07</td>
<td>0,1</td>
<td>0,25</td>
<td>0,15</td>
<td>Bal.</td>
</tr>
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</table>

Castings were vacuum investment cast in PBS Velká Bítěš foundry. Two types of castings were examined. First one from the centre of heavy turbocharger rotor, second one from small light and rapidly cooled casting. Experimental work consisted of tensile test at room temperature and consequent metallographic (light metallography – LM) and fractographic analysis (scanning electron microscopy – SEM). Grain size, gamma prime phase size, amount of casting defects and carbides were determined.

3. RESULTS

Experimental results of two different castings are given in Table 2. Interesting and important structural features are documented on following figures, see Fig. 1 - 6.

Table 2 Mechanical and structural properties of different casting of the IN713LC alloy

<table>
<thead>
<tr>
<th>Cast</th>
<th>Rp0,2 [MPa]</th>
<th>Rm [MPa]</th>
<th>A [%]</th>
<th>Grain size [mm]</th>
<th>Void fraction on fracture [%]</th>
<th>Void fraction on section [%]</th>
<th>Carbides fraction on section [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>heavy average</td>
<td>718,5</td>
<td>762,8</td>
<td>1,60</td>
<td>1,78</td>
<td>0,00</td>
<td>0,0125</td>
<td>0,80</td>
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<tr>
<td>dev.</td>
<td>9,88</td>
<td>10,81</td>
<td>0,41</td>
<td>0,24</td>
<td>0,0077</td>
<td>0,05</td>
<td></td>
</tr>
<tr>
<td>light average</td>
<td>885,0</td>
<td>952,0</td>
<td>4,47</td>
<td>1,91</td>
<td>4,10</td>
<td>0,27</td>
<td>0,47</td>
</tr>
<tr>
<td>dev.</td>
<td>6,00</td>
<td>30,59</td>
<td>1,75</td>
<td>0,12</td>
<td>1,07</td>
<td>0,12</td>
<td>0,07</td>
</tr>
</tbody>
</table>

Heavy castings exhibit rather low mechanical properties, especially elongation. Investigation of metallographic sections and fractures shows very low void fraction, but large amount of carbides, see Fig. 1 - 3. Intergranular cracks are found, which were caused by long needle-like particles (2 – 3 μm thin, 50 – 100 μm long), identified by EDS as niobium carbides. Rather small grains are result of intentional mold shaking during casting.

Light castings exhibit rather high mechanical properties, included elongation. Metallographic and fractographic analysis shows quite large casting voids and small carbide fraction, see Fig. 4 - 5. Most of the fracture surface is covered by marks of ductile fracture.

Fig. 1 Etched (left) and nonetched (right) longitudinal metallographic section of tensile test specimen made of heavy casting’s central part
**Fig. 2** Needle-like grain boundary carbides. Light metallography, etched (left), SEM - Back scattered electrons Compo (right)

**Fig. 3** Broken needle-like grain boundary carbides on fracture surface, SEM. Secondary electrons (left), Back scattered electrons Compo (right)

**Fig. 4** Etched longitudinal metallographic section of tensile test specimen made of light casting (left). Casting voids found preferentially on grain boundaries, (right)
Stereographic analysis of gamma prime phase particles was also performed. Mean volume fraction was found around 69% in both castings. Gamma prime phase particles found in light castings are apparently smaller, see Fig. 6, mean particle size is 0.5μm, than in large castings where gamma prime phase particles mean size was found 0.9 μm.

4. DISCUSSION

Results show that low mechanical properties of large castings are caused by large gamma prime phase particles and presence of long needle-like intergranular carbides, where fracture begins [1].

Light castings contain smaller particles with mean particle size 0.5 μm. This value is considered as optimum for cast nickel superalloys [2]. Absence of needle-like carbides results in higher value of elongation (A) and rupture strength (Rm). Correlation of these properties arises from given stress-strain curve, see Fig. 7. There is a linear stress strain correlation in plastic deformation region in case of cast nickel superalloys almost until fracture. Thus Rm and A values are closely connected. When alloy tends to deform easily values are higher, when fragile obstacle for dislocation movement occur, Rm and A values are rather lower.

Interesting feature is presence of large casting voids in light castings caused probably by shrinkage during rapid cooling. The microstructure without carbides performs higher fracture toughness [1], thus mechanical properties are higher than in case of large castings even in presence of such casting voids.
Similar differences in mechanical properties of castings with different solidifying and cooling conditions were observed in literature [3].

![Stress-strain curve of IN713LC light castings](image)

**Fig. 7 Stress-strain curve of IN713LC light castings**

5. **CONCLUSION**

Heavy IN713LC nickel superalloy castings were investigated. It was shown, that room temperature tensile properties are directly influenced by castings microstructure and thus solidifying and cooling conditions. Most important microstructure features are presence of long needle-like niobium carbides and gamma prime phase mean particle size.

**ACKNOWLEDGMENT**

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**LITERATURE**

