COMPARISON OF MECHANICAL PROPERTIES AND FRACTURE BEHAVIOUR OF Co-BASE AND Ni-BASE ALLOYS

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Abstract
The specific desired properties for structures and components capable of operating under critical loading conditions require the development and use of special materials. Especially in the field of jet aircraft and marine engines, power generation plants and chemical industry is the urgent need of high-strength materials which have to resist high temperatures, special corrosion environments and considerable mechanical loadings. One of the perspective approaches to satisfying these specific requirements is an application of heat resistant Ni-base and/or Co-base alloys. Presented paper is concerned with an experimental study of mechanical properties and fracture behaviour of the Ni-alloy 141I and Co-alloy Stellit. The both alloys were received in the state after casting with no following heat treatment. Wide experimental programme of tensile and Charpy tests in temperature range from 20°C to 1000°C, and constant-load tensile creep tests was done. Fractographic analyses were performed for all specimens failed during these tests. Obtained results were completed with microstructure analysis.

Key words:
Ni-base alloy, Co-base alloy, mechanical properties, creep, fracture behaviour,

1. INTRODUCTION
The current technical practice demands new perspective heat-resistant materials. This reality puts great emphasis on the continual development of new alloys with specific properties and high utility value. Materials that can fulfil the demanding requirements for mechanical properties at high temperatures are namely nickel and cobalt based alloys. Cobalt alloys can be melted and cast on the air, which is a great advantage in comparison with the majority of nickel alloys. Experimental cobalt alloy was cast in the PBS Velká Bíteš, a.s. This alloy could expand the range of materials used for castings working in the liquid glass environment. In this work the properties of the cobalt based alloy Stellit are investigated and compared with 141I nickel alloy, which is the most common for the given application. Presented paper deals with an experimental study of mechanical properties and fracture behaviour of the Ni-alloy 141I and Co-alloy Stellit in the state after casting (i.e., with no following heat treatment). The wide experimental programme containing microstructure analysis, tests of mechanical properties, and fractographic analyses was realised for the both alloys.

2. EXPERIMENTAL MATERIALS
Experimental cobalt alloy Stellit was cast on the melting furnace with the shell mould temperature of 1050°C and the liquid metal temperature of 1580°C. This cobalt alloy can be classified as heat-resistant and refractory alloy. Heat treatment for this type of alloy is not expected. The nickel alloy 141I was prepared under the similar conditions (liquid metal temperature of 1600°C). Heat treatment of this alloy is supposed for some special use, but in the presented investigation it was use also in as-cast state. The chemical composition of the both investigated alloys Co-base Stellit and Ni-base 141I is compared in Tab 1 and 2.
Table 1: Chemical composition of Co-alloy, wt. %.

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Cr</th>
<th>Ni</th>
<th>W</th>
<th>Fe</th>
<th>Mn</th>
<th>Nb</th>
<th>Si</th>
<th>Co</th>
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<td>31.10</td>
<td>10.30</td>
<td>8.53</td>
<td>0.50</td>
<td>0.33</td>
<td>2.29</td>
<td>0.45</td>
<td>bal</td>
</tr>
</tbody>
</table>

Table 2: Chemical composition of Ni-alloy 141I, wt. %.

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Cr</th>
<th>Co</th>
<th>W</th>
<th>Fe</th>
<th>Mn</th>
<th>Nb</th>
<th>Ta</th>
<th>Si</th>
<th>Ni</th>
</tr>
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<tbody>
<tr>
<td></td>
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<td>26.90</td>
<td>3.07</td>
<td>4.94</td>
<td>7.97</td>
<td>0.58</td>
<td>0.99</td>
<td>0.93</td>
<td>0.55</td>
<td>bal</td>
</tr>
</tbody>
</table>

3. RESULTS

3.1 Microstructure of alloys

Microstructure of both alloys in the as-cast state consists of austenitic solid solution and primary carbides. Primary carbides form casting cells boundaries, and sometimes precipitate in the form of carbide eutectics. Morphology of precipitated carbides is mostly tabular. Chromium rich carbides correspond to the $M_7C_3$ or $M_{23}C_6$ type, niobium carbides are of MX type (Figs 1-4). [1, 2, 3]

![Microstructure of as-cast Ni-alloy 141I](image1)

**Fig. 1:** Microstructure of as-cast Ni-alloy 141I

![Microstructure of as-cast Ni-alloy 141I (detail)](image2)

**Fig. 2:** Microstructure of as-cast Ni-alloy 141I (detail)

![Microstructure of as-cast Co-alloy](image3)

**Fig. 3:** Microstructure of as-cast Co-alloy

![Microstructure of as-cast Co-alloy (detail)](image4)

**Fig. 4:** Microstructure of as-cast Co-alloy (detail)
3.2 Mechanical properties of alloys in as-cast state

Mechanical properties of the cobalt based alloy in the as-cast state were measured. Comparison of the mechanical properties of both alloys is shown in Fig. 5.

Tensile strength tests have been carried out in the temperature range 20°C ± 1100°C. The measured values were compared with the characteristics of alloy 141I. Strength properties of cobalt alloy are higher than that of Ni-base 141I alloy (Figs. 5a and 5b). From the point of view of expected working temperature of about 1000°C, the differences in yield strength and rupture strength of these alloys is no longer significant. Better strength properties of the cobalt based alloy are, however, at the expense of plastic properties. The elongation of cobalt alloy is around 10% lower values than the elongation of the alloy 141I at the temperature of 1000°C (Fig. 5c).

Charpy impact toughness tests (U-notch 2mm) were carried out in the temperature range 20°C ± 1100°C. Measured impact toughness values of Stellite alloy are very low, namely in comparison with values for Ni 141I alloy (Fig. 5d). The KCU values at high temperatures (>800°C) are even lower than required value 30 J·cm⁻², which is the limit for the anticipated applications of cobalt alloys in technical practice.

![Graphs of mechanical properties](image)

**Fig. 5:** Comparison of mechanical properties of the both investigated alloys, [1]

In the frame of mechanical tests the creep behaviour of the Co alloy was investigated, see [4]. The constant-load tensile creep tests were realised at two levels of load (160 MPa and 200 MPa) and temperature 800°C, see [4]. In Fig. 6 the obtained creep results are compared with the results of analogical creep tests for Ni-alloy 141I. This graph unambiguously proves that creep resistance of Co-alloy is markedly higher than creep resistance of Ni-alloy 141I.
3.3 Fractographic analysis

Fractographic analyses of specimens failed during the mechanical properties were realised in following step. The main goal of these analyses was description of the characteristic micromorphological features and based on them description of failure processes corresponding to the different type of loading (tensile, Charpy and creep tests).

Five basic type of micromorphological features were found during the detailed microscopic observation of fracture surfaces (see Figs. 7 - 9):

a) ductile dimples and/or serpentine glide corresponding to the ductile failure of matrix (Figs. 7b and 8b);
b) secondary cracks following casting cells boundaries (boundary of dendrite structure);
c) particles of different phases either broken or separated from matrix (Figs. 7a and 8a),
d) areas corresponding to the failure of carbide eutectics,
e) micromorphology of oxide layer covering fracture surface (namely for creep fractures – Fig. 9).

Failure processes for all studied type of loading are strongly influenced by casting dendrite structure and its orientation to the load direction and crack propagation. On the other hand the failure mechanisms are not influenced by the rate of the loading. Proportion of individual failure processes described above depends not only on loading conditions but namely on microstructural characteristics, i.e. on the chemical composition and heat treatment of appropriate alloy.

![Fractographic analysis](image)

**Fig. 7:** Typical micromorphology of fracture after tensile test.

\[ R_m = 809 \text{ MPa}, \quad R_{p0.2} = 614 \text{ MPa}, \quad A_5 = 1.0 \% \]

\[ R_m = 521 \text{ MPa}, \quad R_{p0.2} = 317 \text{ MPa}, \quad A_5 = 15.3 \% \]
4. DISCUSSION

Microstructural characteristics and fractographic description of failure processes taking place in the investigated alloys offered information for explanation of differences in mechanical properties.

From qualitative point of view failure processes of the investigated Co-alloy and Ni-alloy are not influenced by the loading rate (tensile tests & impact test) and by the test temperature (from 20°C to 800°C). On the other hand changes of loading conditions can more or less influence the proportion of individual basic failure processes described in previous section.

Failure processes of the both investigated alloys are strongly dependent on the number, size, and distribution of primary carbides and/or secondary precipitated carbide eutectics (i.e., on chemical composition and heat treatment). Also number and size of shrinkages can influence the failure processes and of course resulting mechanical properties – in investigated alloys these defects were found only exceptionally and their effect was negligible.

Higher strength properties of Co-alloy correspond namely to higher content of carbides and carbide eutectics in structure of this alloy. Spatial distribution of carbide eutectics and shape of individual carbide particles (i.e.,
form of carbide particles network) can significantly increase the cohesion of carbides with matrix. Moreover, it is very probable that strength of cobalt matrix will be higher than nickel matrix of 141I alloy. Fractographic findings confirm lower ability of plastic deformation of Co-alloy – practically no ductile dimple fracture was found on the corresponding fracture surfaces. On the contrary all fractures of Ni-alloy specimen showed areas of ductile fracture.

5. CONCLUSIONS

Presented paper summarises the results obtained in the experimental observation of two different cast alloys Co-alloy Stellite and Ni-alloy 141I. Experimental study included microstructural analysis, tests of mechanical properties and fractographic analyses. Microstructural characteristics and fractographic findings were used for explanation of differences in mechanical properties of investigated alloys. Obtained results can be use as an input for development of the new heat resistant and refractory alloys with specific properties (tailored material).

ACKNOWLEDGEMENT

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LITERATURE


