INVESTIGATION OF STRUCTURE AND CRACK FORMATION IN WELDED JOINTS OF SINGLE CRYSTAL NI-BASE ALLOYS

V.S. Savchenko¹  K.A. Yushchenko¹  A. Zvjagintseva¹  S. A. David²  J. M. Vitek²

¹ E.O. Paton Electric Welding Institute (Ukraine)
² Oak Ridge National Laboratory (United States)

ABSTRACT

Conditions of initiation of hot cracks in welding of single crystal heat-resistant alloys with a 56 % content of the γ'-phase were studied. Conditions for providing a polycrystalline structure in HAZ and part of the weld metal were artificially created in one region of a welded joint with the single crystal structure. Welding of the single crystal alloy was performed by the electron beam method in vacuum. Cracks in a low-temperature ductility dip range (ductility dip cracking) were found to form in HAZ and weld of a welded joint with the polycrystalline structure. The nature of cracking of the single crystal weld is related to formation of low-melting point eutectoid interlayers, as well as to exhausting of the safety factor for ductility. Cracks in the single crystal weld along the strain grain boundaries are formed by a similar mechanism.

IIW-Thesaurus keywords: Cracking; Crystal structure; Defects; EB welding; Heat resisting materials; Hot cracking; Nickel alloys; Radiation welding.

Alloy JS-26 is a heat-resistant nickel alloy with good short- and long-time properties at high temperatures, which is provided by an up to 65 % content of fine precipitates of the γ'-phase.

This γ'-phase content is achieved by complex alloying of metal with aluminium, titanium and niobium (Table 1).

Nickel alloys of this alloying system, having an equilibrium structure, are very sensitive to hot cracking during welding. So, studies were conducted to investigate the characteristics of welded joints in single crystal (SC) samples of alloy JS-26, as well as comparative data obtained on JS-26 metals with directionally solidified (DS) crystal and equiaxed grain structures.

Investigations were carried out on cast sample-plates of 5 × 50 × 100 mm, having a single crystal structure in the initial state.

The middle part of a sample along its length was subjected to cold plastic deformation using a hard ball under a load of 30 kN. The locally deformed sample was subjected to austenising at a temperature of 1100 °C in vacuum to produce recrystallisation. As a result, the sample before welding had a single crystal structure with a narrow zone containing equiaxed grains. The sample was electron beam welded with complete penetration at a speed of 10 m/h. A schematic diagram and metallographic view of the sample surface after welding are shown in Figure 1 a), b). According to the welding technique that was used, the heat-affected zone with an equiaxed structure is located to the right of the weld in the figure, and the zone with a single crystal structure is located to the left of the weld.

Examination of the microstructure of the welded joint on the single-crystal side showed that the structure of the
weld is inherited by the direction of growth of dendrites in the base metal (Figure 2), and retains, as shown by X-ray examination, the crystallographic orientation and structure of the base metal.

Zones located in the weld centre contain isolated grains with crystallographic orientation other than that of the bulk of the weld metal (Figure 3). These grains, so-called stray grains, are formed during the solidification process, and are separated from the bulk of the weld metal by high-angle boundaries [1].

Examination of the structure of the deformed HAZ [Figure 4 a) b)] revealed the presence of grains that favoured formation of stray grains in the weld [Figure 4 b)]. As proved by the experiments, transverse cracks initiated in the HAZ subjected to deformation +

<table>
<thead>
<tr>
<th>Table 1 – Chemical composition of nickel alloy JS-26</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Content of elements, wt. %</strong></td>
</tr>
<tr>
<td>C</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>0.15</td>
</tr>
</tbody>
</table>

Figure 1 – Scheme specimen for welding by EB process

Figure 2 – Coincidence of the direction of growth of primary solidification forms of the weld with the direction of crystallographic orientation of cast single crystal nickel alloy

Figure 3 – Appearance of the weld surface resulting from controlled oxidation of the surface of a section

Figure 4 – Microstructure of the weld on alloy JS-26