New homogenization cycles for HASTELLOY® X alloy Ni-22Cr-18-Fe-9Mo and HAYNES® 263 alloy Ni-20Co-20Cr-6Mo (wt%) were designed to reduce energy consumption during processing in order to maintain ISO 5001 accreditation. Thermodynamic modeling was used to estimate incipient melting points, which provided a starting point for experimental trials. These experiments yielded optimal temperature and hold steps for the proposed heating cycle. This cycle reduced the hold time by 37.5% while maintaining or exceeding the current homogenization expectation. Degree of homogeneity was determined by measuring area percent of carbides.

Thermodynamic Modeling for Phase Identification and Carbide Morphology

Thermodynamic modeling suggested that the incipient melting temperatures for HAYNES® 263 alloy and HASTELLOY® X alloy are 1210°C and 1220°C, respectively (Figure 5). According to equilibrium data, M23C6 and M6C are the most significant secondary phases (Figure 6).

Results – Incipient Melting

Thermodynamic modeling data was used to design experimental trials in order to experimentally determine the as-cast Scheil temperatures (Table 1).

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Incipient melting?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1200°C, 2 hrs</td>
<td>Yes</td>
</tr>
<tr>
<td>1190°C, 3 hrs; 1220°C, 2 hrs</td>
<td>Yes</td>
</tr>
<tr>
<td>1180°C, 2 hrs; 1220°C, 2 hrs</td>
<td>No</td>
</tr>
</tbody>
</table>

Incipient melting indicated that the alloy got too hot too quickly. Therefore, more time was needed at lower temperatures to homogenize the material and to push up the Scheil temperature. Experimentally, the incipient melting temperature was found to be around 1190°C for both alloys (Table 1).

Results and Discussion

Experimental Results

The proposed cycle for both alloys yielded reductions in area fraction of second phases similar to or exceeding HSP (Figure 9). Additionally, the hold times were reduced by 37.5%. There was a larger compositional difference between the Ti-rich carbides and the HAYNES® 263 alloy matrix compared to that of the Mo-rich carbides and the HASTELLOY® X alloy matrix (Figure 4). Because of this, HAYNES® 263 alloy experienced a steeper compositional gradient, and the solutes experienced a greater diffusional flux, increasing the rate of carbide dissolution (Equation 1). This could explain why the homogenization of HAYNES® 263 alloy exceeded HSP and the homogenization of HASTELLOY® X alloy did not.

Recommendations

- Develop a carbide dissolution curve by varying the final hold time to determine specific recipes for target carbide area fractions (Figure 10).
- Investigate how carbide morphology affects dissolution rate.

References


Project Background

Haynes International is a manufacturer of nickel-based superalloys mainly used in aerospace and chemical processing applications. The processing of these alloys is laid out in Figure 1.

As-cast Structures and Carbide Chemistry

Figure 3: As-cast structures of HASTELLOY® X alloy with 2.3% area of second phases and HAYNES® 263 alloy with 2.0% area of second phase, measured on a 95% confidence interval.

Figure 4: EDS point scans with pie charts indicating compositions for carbides present in HASTELLOY® X alloy and HAYNES® 263 alloy.

Figure 5: Scheil curve for HASTELLOY® X alloy used to determine Scheil solidus (incipient melting temperature), equilibrium solidus temperatures, and to identify phases present.

Figure 6: Equilibrium phase fractions present over relevant heat treatment ranges in HASTELLOY® X alloy.