Introduction and Motivation

Despite its excellent combination of strength, toughness, and corrosion resistance, Monel K-500 is susceptible to hydrogen environment-assisted cracking (HEAC) when exposed to cathodic polarizations while stressed in chloride-containing environments. This susceptibility has been shown to vary across five peak-aged lots of Monel K-500, thereby suggesting a role of microstructural variation in determining susceptibility to HEAC.

Critical Question?

For a constant composition, how do variations in heat treatment influence Monel K-500’s susceptibility to hydrogen environment-assisted cracking?

Material and Experimental Approach

Experimental Approach

Select autoclaves and aging temperatures and then conduct systematic aging to determine aging curves

- Select aging times corresponding to non-aged, under-aged, peak-aged, and over-aged
- Conduct slow-rising K testing of each condition to determine the extent to which a specimen known to be inert, mild, aggressive, and extreme to determine differences in HEAC susceptibility

Specimens from each aging condition with hydrogen to facilitate intergranular fracture for AES analysis

Testing Conditions

<table>
<thead>
<tr>
<th>Environment</th>
<th>Potential (mV)</th>
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<tbody>
<tr>
<td>Dry N_2 Gas</td>
<td>N/A</td>
</tr>
<tr>
<td>0.6 M NaCl</td>
<td>-850</td>
</tr>
<tr>
<td>0.6 M NaI</td>
<td>-1000</td>
</tr>
<tr>
<td>0.6 M NaCl</td>
<td>-1200</td>
</tr>
</tbody>
</table>

Testing Setup

Conduct in-depth AES analysis of four aging conditions to determine extent of sulfur segregation to grain boundaries through slow sputter depth profiling on intergranular facets

Results

Small, notched cylindrical specimens were machined for AES analysis. Each specimen was charged with hydrogen for ~60 days using a potentiostatic hold at -1100 mV SCSE in 0.6 M NaCl that was heated to 315 K. Specimens were fractured after immersion in liquid nitrogen for 10 minutes and then placed in the AES system for analysis via slow surface sputtering.

Evaluation of HEAC Kinetics

NA/OA both immune to IG-HEAC up to -1000 mV_{SCSE}, but undergo IG-HEAC at -1200 mV_{SCSE}. OA more susceptible at -1200 mV_{SCSE}. This lack of susceptibility suggests an immunity potential more negative than any previously tested lot of Monel K-500. Previous lots exhibited an immunity potential between -800 to -850 mV_{SCSE}

Grain Boundary Sulfur Characterization

Both OA/NA have IG/TG FCG in all cases and minimal crack growth in dry nitrogen, at -850 mV_{SCSE} and at -1000 mV_{SCSE} At -1200 mV_{SCSE} both OA/NA exhibited IG-HEAC, though extent of IG cracking more extensive in OA specimen.

What Heat Treatment-Sensitive Metallurgical Features Could Influence IG-HEAC?

The over-aged specimens exhibit enhanced susceptibility to IG-HEAC at -1200 mV_{SCSE} as compared to the non-aged specimen. Why? Possible influences could arise from differences in grain size, global slip morphology, yield strength, and grain boundary impurity segregation.

\[ \text{AE5 data suggests minimal differences in grain boundary sulfur concentration for the NA, UA, and PA heat treatments, but a systematically enhanced grain boundary sulfur concentration for the OA heat treatment.} \]

Future Work

1. Conduct fracture mechanics testing on under-aged and peak-aged materials to determine HEAC metrics in dry nitrogen and at -1200 mV_{SCSE}. Conduct testing at -1100 mV_{SCSE} on four aging conditions.
2. Evaluate \( \gamma \) morphology and \( \gamma \)-dislocation interactions as a function of the heat treatment to understand changes in precipitate character/slip interactions.
3. Evaluate the ability of current decohesion-based micromechanical models to capture differences in HEAC susceptibility in the context of the current experimental framework.

Conclusions

1. Systematic heat treatment plus compression testing allowed identification of heat treatments to reach the non-aged, under-aged, peak-aged, and over-aged conditions.
2. Cracking kinetics and fractography show that both NA and OA are highly resistant to IG-HEAC at -1000 mV_{SCSE} but susceptible at -1200 mV_{SCSE}. This suggests that OA is more susceptible than NA at the more negative potential; possible differences in grain boundary impurity segregation, yield strength, grain size, and global slip morphology may facilitate this enhanced susceptibility.
3. AES data collected for each of the four selected heat treatment realized a similar GB sulfur concentration for NA, UA, and PA, but an enhanced GB sulfur concentration for OA.

References


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