Design of a Braze Alloy for Fast Epitaxial Brazing of Superalloys

Sebastian Piegert – Siemens AG
Britta Laux – MTU Maintenace GmbH
Joachim Rösler – IfW TU Braunschweig

MCWASP XIII  2012-06-19
Schladming/Austria
Outline

- Introduction
- Boundary Conditions for Fast Epitaxial Brazing
- Simulation of Process Window
- Validation
  - Experimental Process Window
  - Experiment vs. Calculation
- Summary
## Technological Environment

### Environment
- $T_{\text{TIT}}$ up to 1400 °C
- $v_{\text{gas}}$ up to 400 m/s
- $\omega$ up to 12,000 min$^{-1}$
- $t_{\text{serv}}$ up to 25,000 h
- contamination of hot gas

### Degradation
- oxidation
- corrosion
- erosion
- creep
- fatigue

### Materials
- nickel-based superalloys
- high temperature strength
- corrosion and oxidation resistant
- costs per part up to 20,000 €
High Temperature Brazing

- Ni-based braze alloys with B and/or Si as melting point depressant
- brazing above 900 °C under shielding gas or vacuum

Conventional Brazing
- temperature driven solidification
- microstructure: polycrystalline, multiphase
- semistructural repair
- fast repair process

Diffusion Brazing
- isothermal solidification
- microstructure as substrate, no brittle phases
- structural repair and joining
- extended solidification times

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Siemens Energy Sector F PR GT EN MT 2 4
Choice of Melting Point Depressant

Boundary Conditions

- Temperature driven epitaxial solidification w/o formation of a final eutectic
- High solubility of MPD in Ni
- Partition coefficient $k_0 \rightarrow 1$
- Repair of single crystals
- Economical brazing times for technical relevant gap widths ($w_0 \geq 300 \mu m$)
- Compatibility with Ni-based superalloys
  - Ni-based
  - Good wetting and flow
- Sustains service conditions
  - Narrow melting interval
- $T_{liq} \leq 1250 \degree C$ and $T_{sol} \geq 1100 \degree C$
Calculation of Process Window

Calculation
- thermodynamics: TCC ver. S with TTNi7
- kinetics: DICTRA 25 with MobNi1

Limit for Single Phase solidification
- cooling with 0.6 K/min
- joint width $w_0 = 100 \, \mu m$
- eutectic reaction $L \rightarrow \gamma + \text{Mn}_6\text{Si}_7\text{Ni}_{16}$ (G-phase) must not occur

Liquidus surface of ternary Ni-Mn-Si system
Calculation of Process Window

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Experimental Validation – Composition Space

Liquidus surface of ternary Ni-Mn-Si system

DSC analysis

<table>
<thead>
<tr>
<th>Braze</th>
<th>$T_{\text{sol}}$</th>
<th>$T_{\text{liq}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lot 1</td>
<td>1114</td>
<td>1150</td>
</tr>
<tr>
<td>Lot 2</td>
<td>1022</td>
<td>1022</td>
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<td>Lot 3</td>
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<td>Lot 4</td>
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<td>Lot 5</td>
<td>1124</td>
<td>1238</td>
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<tr>
<td>Lot 11</td>
<td>1173</td>
<td>1248</td>
</tr>
<tr>
<td>Lot 12</td>
<td>1139</td>
<td>1197</td>
</tr>
</tbody>
</table>

Boundary conditions for brazing

- substrate: René N-5 SX
- $T_B \approx T_{\text{liq}} + 10$ K
- $-14.4$ K/min $\leq dT/dt \leq -0.84$ K/min
- $T_F = 1000$ °C
Experimental Results – Composition Space

Lot 1

γ + Mn₆Si₇Ni₁₆

Lot 4

Lot 12

Lot 2

Lot 5

Lot 3

Lot 11

EBSD analysis of Lot 3

SX

SX but unstable

formation of eutectics

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Experimental Results vs. Calculations

**DICTRA model**

- moving boundary problem
- grid: linear in liquid and geometric in solid
- initial state: 150 µm liquid at $T_B$
- $dT/dt = -6.4$ K/min down to $1000\, ^\circ C$
- G-phase and $\gamma'$ as inactive markers for onset of eutectic reaction

**Result**
- reasonable prediction of widening
- good fit of element distributions
- at $z < 75$ µm strong Mn pileup in simulation
- solidification terminates in eutectic reaction
Solidification Sequence

Boundary conditions
- substrate: René N-5 SX
- braze alloy Lot 3
- \( T_B = 1210 \, ^\circ C \)
- \( t_B = 30 \) min
- \( \frac{dT}{dt} = -6.4 \, K/min \)
- \( w_0 = 200 \, \mu m \)

Result
- single phase solidification
- all typical features of brazing occur
  - widening
  - isothermal solidification
  - anisothermal solidification
  - homogenisation of solid
Summary

Comparison of calculated and experimental process window

- a new brazing process was identified and developed
- initial process window calculated
- successful experimental validation
  - braze alloy composition
  - parameters for stable process identified and evaluated
- process simulation by means of DICTRA helps to understand mechanisms of solidification
- experimental and theoretical process windows overlap ➞ calculation gives starting point for development
Problems and Wishes

- Stability of calculations extremely dependent on
  - Mesh,
  - boundary conditions (temperature, amount of species, joint widths), and
  - allowed time steps

- Name of macro file should be displayed in the head of the editor used
Problems and Wishes

- Joining of dissimilar materials, i.e. Fe-based and Ni-based alloys

High temperature brazed joint 16Mo3/Nimonic 75
100 % sound joints, however, poor mechanical properties

Linescann across the joint
Experimental Results – $dT/\text{dt}$ and $w_0$ Dependence

$dT/\text{dt}$

-0.84 K/min

-4.32 K/min

-26.0 K/min

$w_0$

200 µm

600 µm

1000 µm