Diffusion Bonding of H230 Ni-superalloy for application in microchannel heat exchangers

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The sCO$_2$ cycle offers several advantages:

- **High efficiency due to no phase change during operation and high heat recuperation**
- **Compact turbo machinery reduces capital cost**
- **Ability for higher heat recuperation makes heat exchangers an integral part of the sCO$_2$ cycles**

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*S. A. Wright, “Overview of supercritical co2 power cycle development at Sandia National Laboratories,” in 2011 University Turbine Systems Research Workshop, Columbus, Ohio, 2011.*
Heat Exchangers

- Micro channel heat exchangers have much higher heat transfer efficiency

- Pattern microscale flow paths
- Join these using laser welding, diffusion bonding or brazing

- Dimensional Tolerances
- Uniform microstructure
- Imperative 700°C-800°C, 20-30 MPa
Materials – H230 Ni-base superalloy

- Solid-solution strengthened Ni-Cr-W-Mo superalloy
- Excellent high temperature strength, Oxidation, grain growth and carburization resistance
- $sCO_2$ exposure for 500 h - Lowest mass gain at 700°C, 20 MPa, compared to 282 and 740°

Heat treatment fixture operating at 850°C
Heat treatment basket for 1200°C
Gas turbine engine combustor

Haynes.com; *Pint et al., The effect of temperature on $sCO_2$ compatibility of conventional structural alloys, 4th International Symposium - sCO2 Power Cycles, 2014
Diffusion Bonding Model

Temperature, Pressure and Time for DB??

550 µm H230 shims

**Surface assumptions**-
- Parallel, elliptical voids, contact between ridge tops
- Negligible effect of surface impurities or oxides

**Void Closure due to** -
- Initial plastic deformation of ridges
- Surface & volume diffusion from surface source to the neck
- Evaporation from surface source to condensation at the neck
- Grain boundary and volume diffusion from interfacial source to the neck
- Power-law creep

![Modelled surface—long parallel ridges.](image)

**Area Bonded**

Input Parameters

• Fixed input parameters-
  - Surface roughness height,
  - Temperature, Material properties

• Variable input parameters-
  - Pressure & Time

• Outputs-
  - % area bonded vs. time
  - % strain vs. time

• Diffusion Bonding Parameters – 1150°C for 8 hrs at 12.7 MPa pressure
• Area Bonded - > 85 %
Output of Diffusion Bonding - stacks

Cold rolled and 1232 °C solution annealed - 550 µm H230 shims

→ 1150°C, 12.7MPa, 8 hrs

H230 DB stacks

Tensile samples from H230 DB stacks
Microstructure – Non-plated H230
Grain growth across the bond

- Etched microstructure to observe grain growth through the bond line
- No voids resolved
Microstructure near the bondline

- Primary – Primary carbides which form at higher temperature

- > 90% Area Bonded
W- & Mo-based Primary Carbides

- Primary Carbides – W- and Mo-based carbides which form at higher temperature
Is the DB stack different?

- 3X higher precipitates/unit area in DB stack
Microstructure – Ni-plated H230
Ni-Plated H230

Large voids at bondline

Grain growth at the bondline
Microstructure near the bond

- Primary Carbides
- Increase in Ni, dip in Cr at the bond
Mechanical Properties
At 750°C, the yield strength of both Ni-plated and Non-Ni-plated H230 is 76% and 82%.

- At RT, the yield strength of both Ni-plated and Non-Ni-plated H230 is ~ 90%
Fracture surfaces - Ni-plated H230 DB stack

- Hardly any elongation, fracture at the bond, cup-and-cone fracture at the microscale

RT

- Fracture through the sheet and the bond

750°C
Fracture surfaces - Non-plated H230 DB stack

- Fracture through the sheet
- Fracture through the bond at 750°C
Side view of fracture surfaces – Non-plated H230 DB stack

- RT – microcracks along primary carbide bands
- 750°C – cracking along DB lines
Summary

1) Uniform bond with grain growth across the bondline
2) Ni increase, Cr dip through the bond
3) 750°C - 76% and 82% of H230
   RT - 82.5% and 89% of H230
4) Micro cracking along precipitate bands
5) Cracks along DB
Thank You