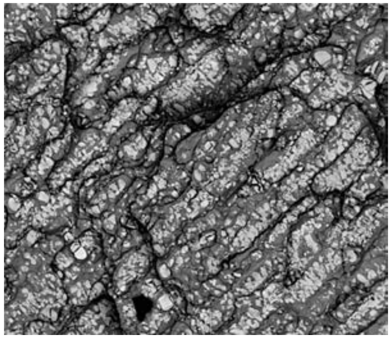
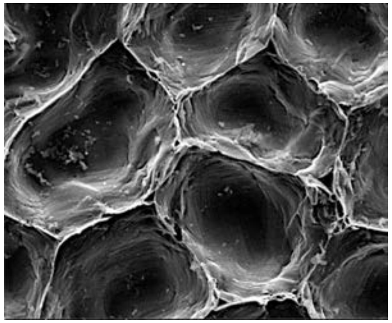
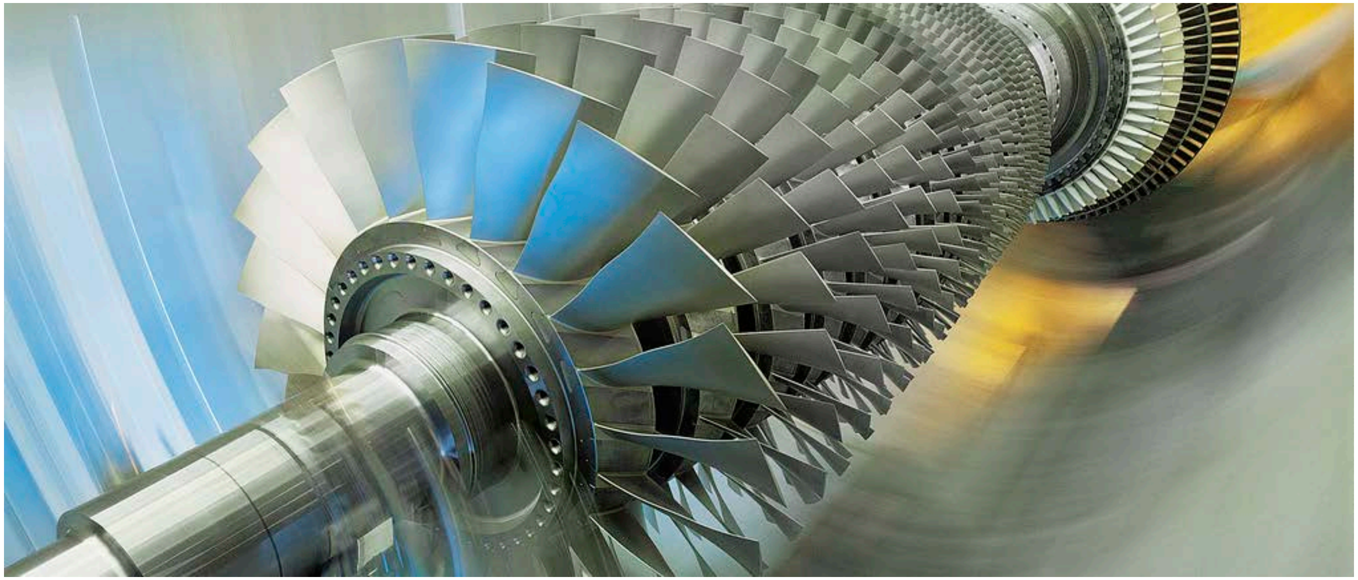
Driving Innovation ♦ Delivering Results







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

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The 5th International Symposium - Supercritical CO_2 Power Cycles

March 28-31, 2016, San Antonio, Texas

U.S. DEPARTMENT OF ENERGY | National Energy Technology Laboratory

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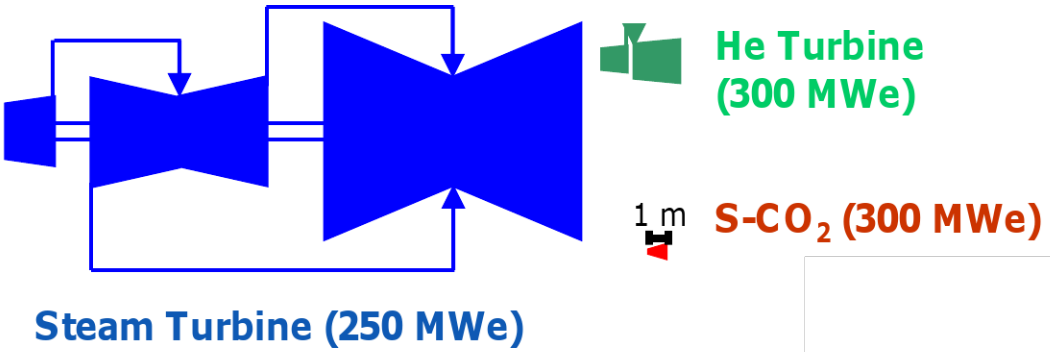
sCO_2 cycle

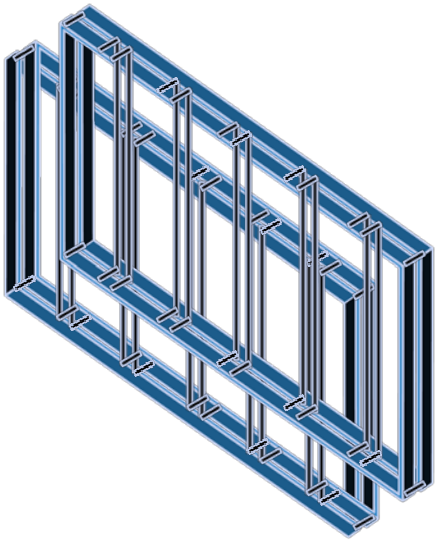
- **High efficiency due to no phase change during operation and high heat recuperation**
- **Compact turbo machinery reduces capital cost**
- **Ability for higher heat recuperation makes heat exchangers an integral part of the sCO2 cycles**

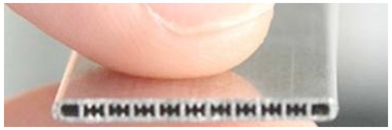


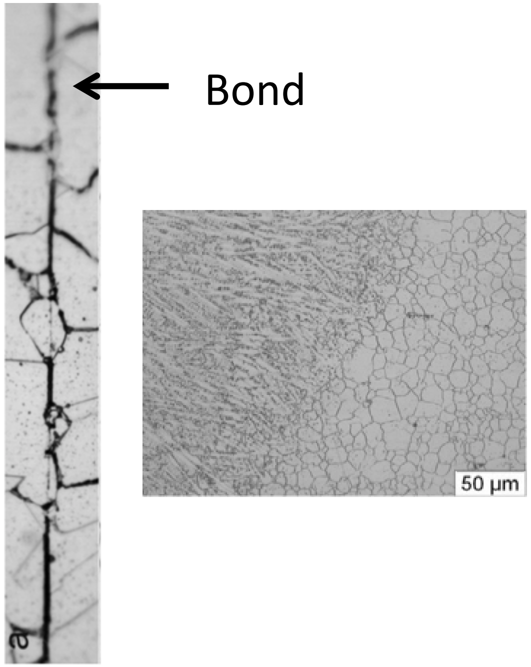
S. A. Wright, "Overview of supercritical co2 power cycle development at Sandia National Laboratories," in 2011 University Turbine Systems Research Workshop, Columbus, Ohio, 2011.

Heat Exchangers

- **Micro channel heat exchangers have much higher heat transfer efficiency**





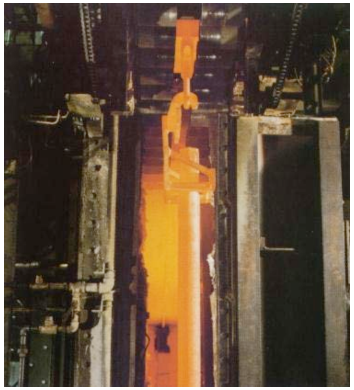


- Pattern microscale flow paths
- Join these using laser welding, diffusion bonding or brazing

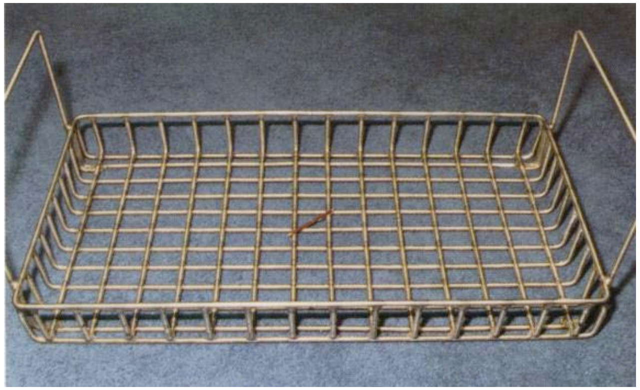
- Dimensional Tolerances
- Uniform microstructure
- Imperative700°C-800°C, 20-30 MPa

Microfluidics.com, Basuki et al., MSEA, 538 (2012) 340-348; Zapirain et al. Physics Procedia, 12 (2011) 105-112

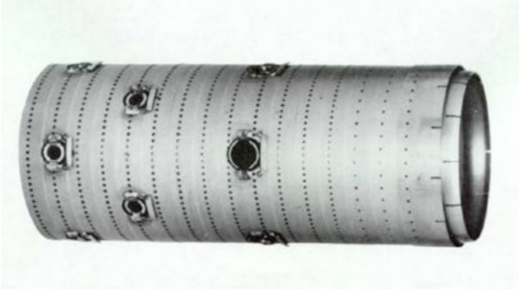
Materials – H230 Ni-base superalloy



Heat treatment fixture operating at 850°C



Heat treatment basket for 1200°C



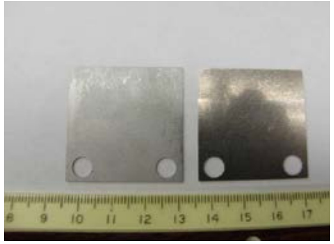
Gas turbine engine combustor

- 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*

.

*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



550 µm H230 shims

→ Temperature, Pressure and Time for DB??

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

Surface assumptions-

•Parallel, elliptical voids, contact between ridge tops

•Negligible effect of surface impurities or oxides

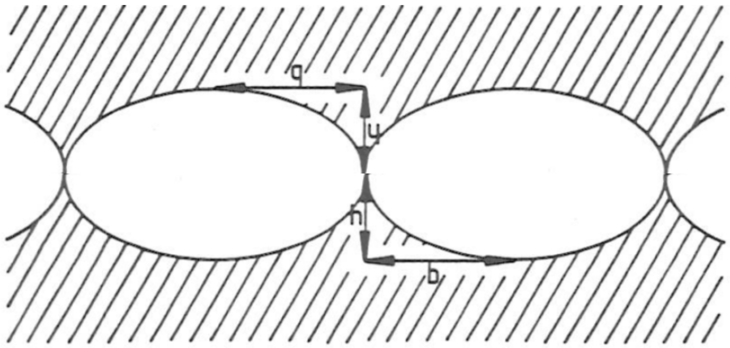
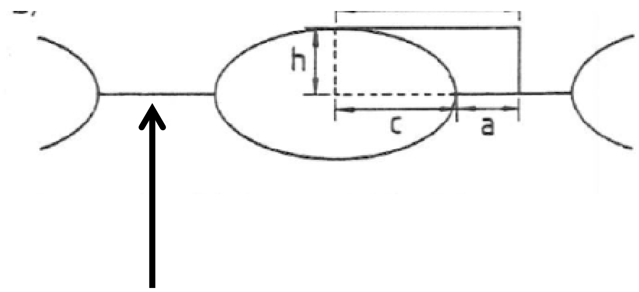


Fig. 1. Modelled surface—long parallel ridges.

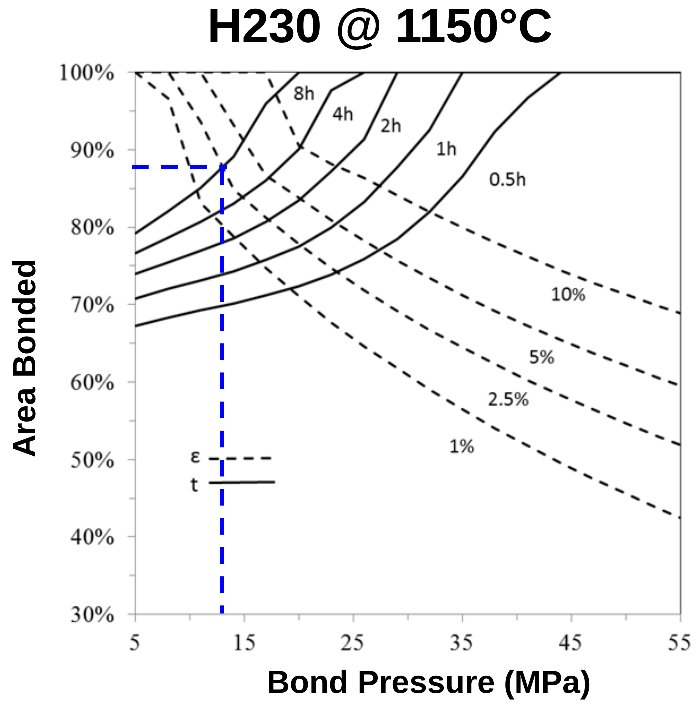


Area Bonded

A. Hill, E. Wallach. Modeling solid-state diffusion bonding, Acta Metallurgica 37 (1989) 2425-2437.

Input Parameters

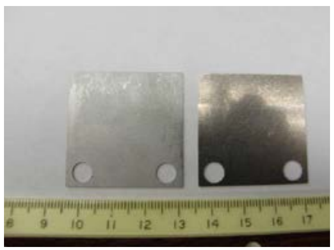
- Fixed input parameters-
  - Surface roughness height, Temperature, Material properties
- Variable input parameters-
  - Pressure & Time
- Outputs-
  - % area bonded vs. time
  - % strain vs. time



Balance creep, time, pressure and bonded area

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

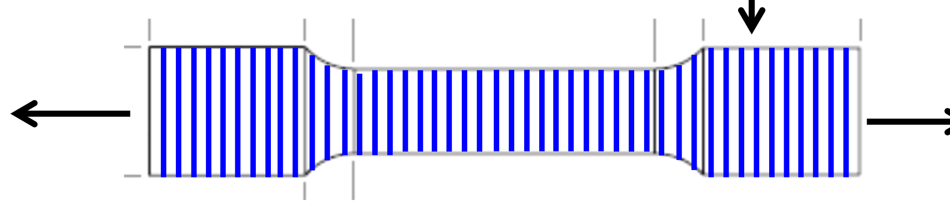
Output of Diffusion Bonding - stacks



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

1150°C, 12.7MPa, 8 hrs

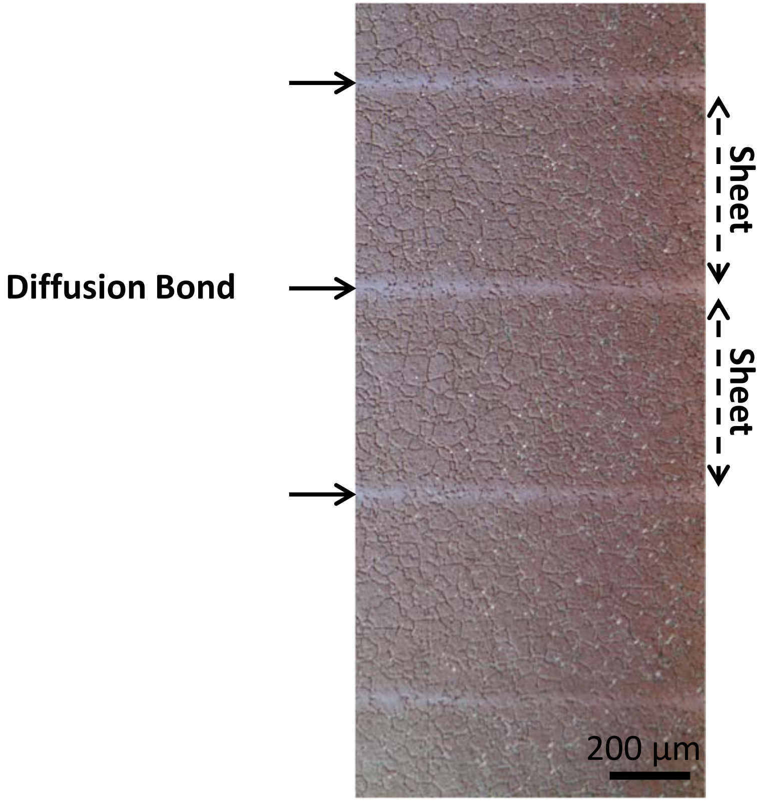
H230 DB stacks

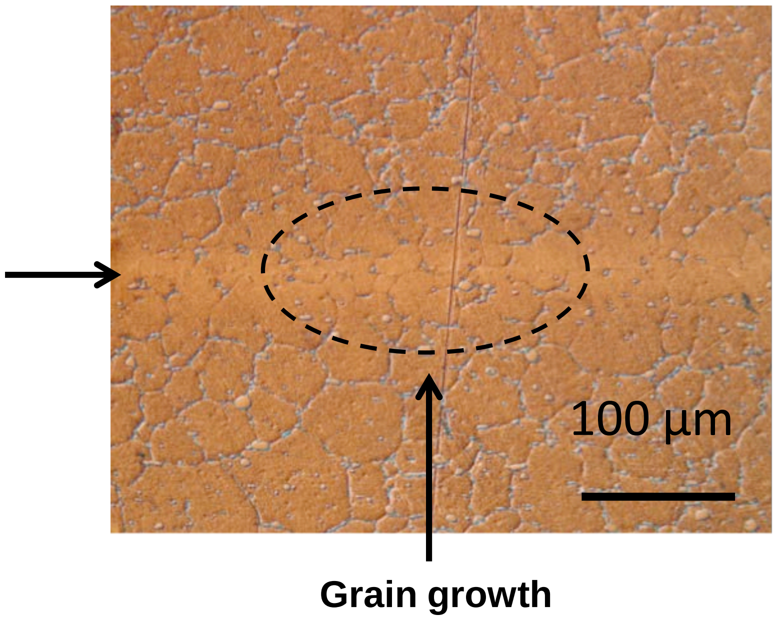


Tensile samples from H230 DB stacks

Microstructure – Non-plated H230

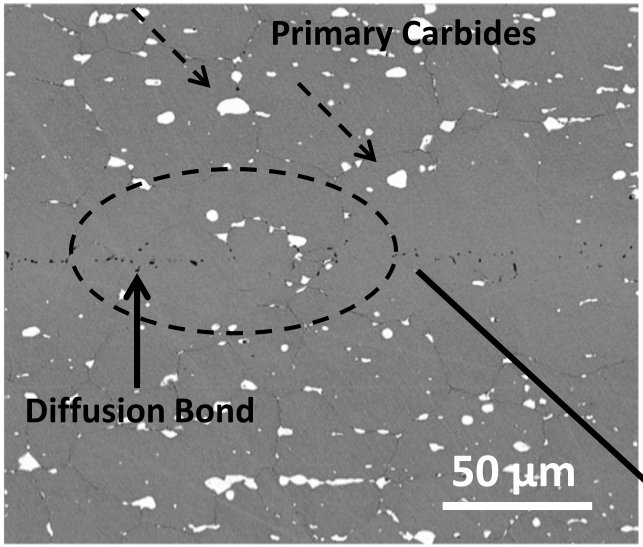
Grain growth across the bond





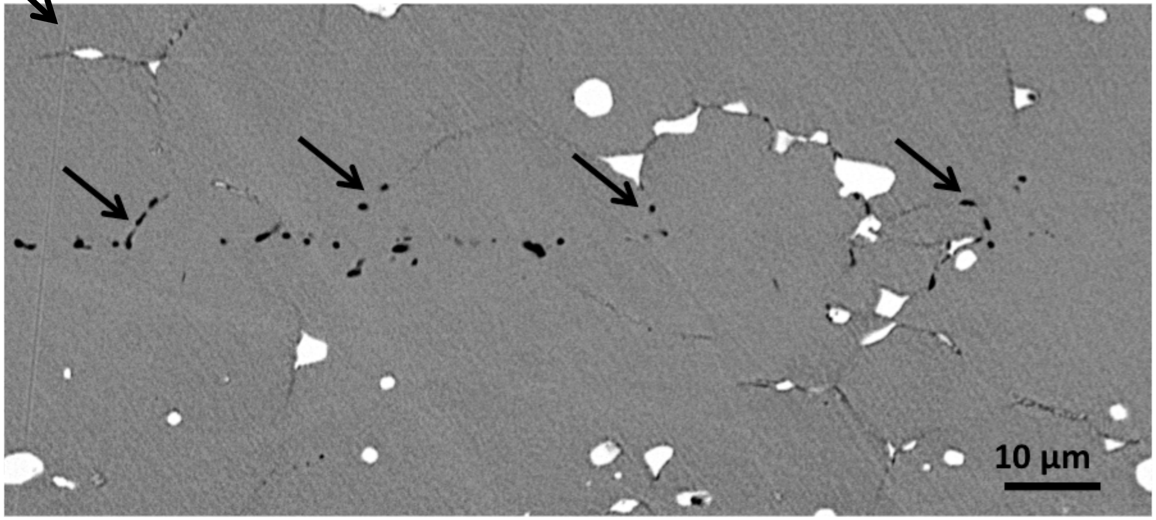
- **Etched microstructure to observe grain growth through the bond line**
- **No voids resolved**

Microstructure near the bondline

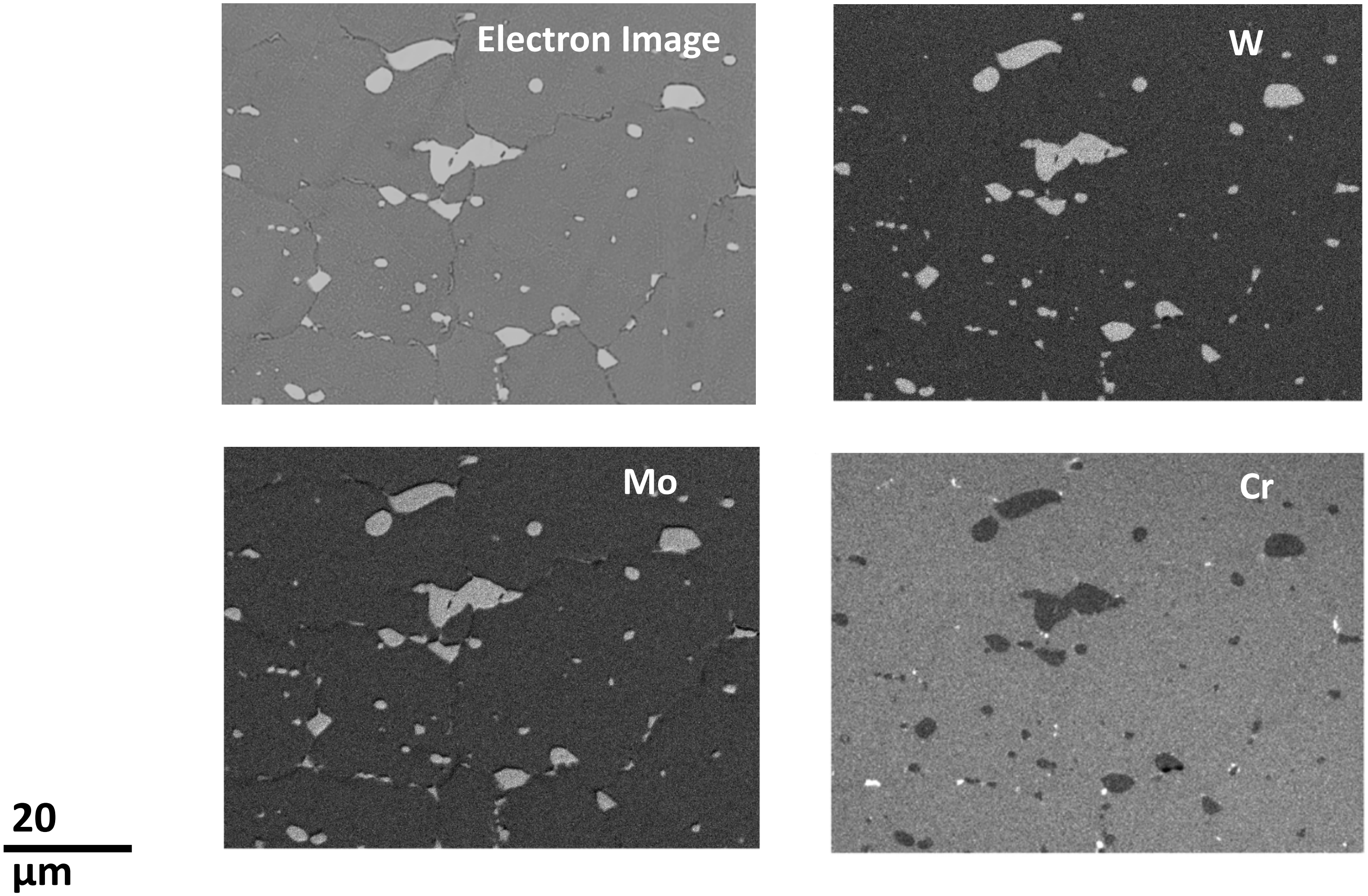


- Primary – Primary carbides which form at higher temperature

- > 90 % Area Bonded



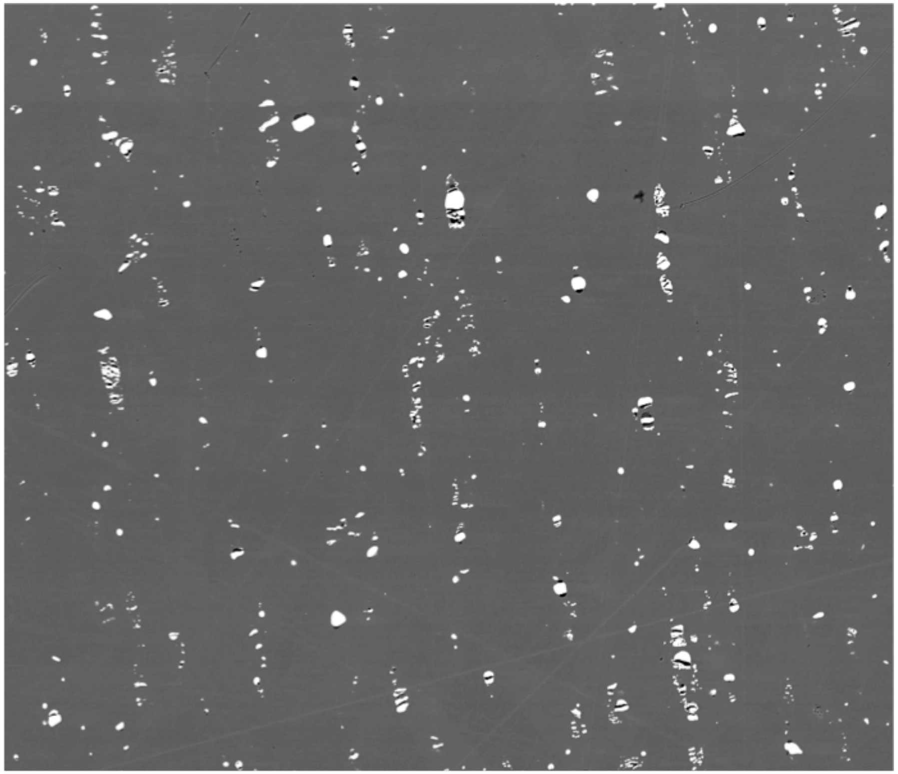
W- & Mo-based Primary Carbides



- **Primary Carbides – W- and Mo-based carbides which form at higher temperature**

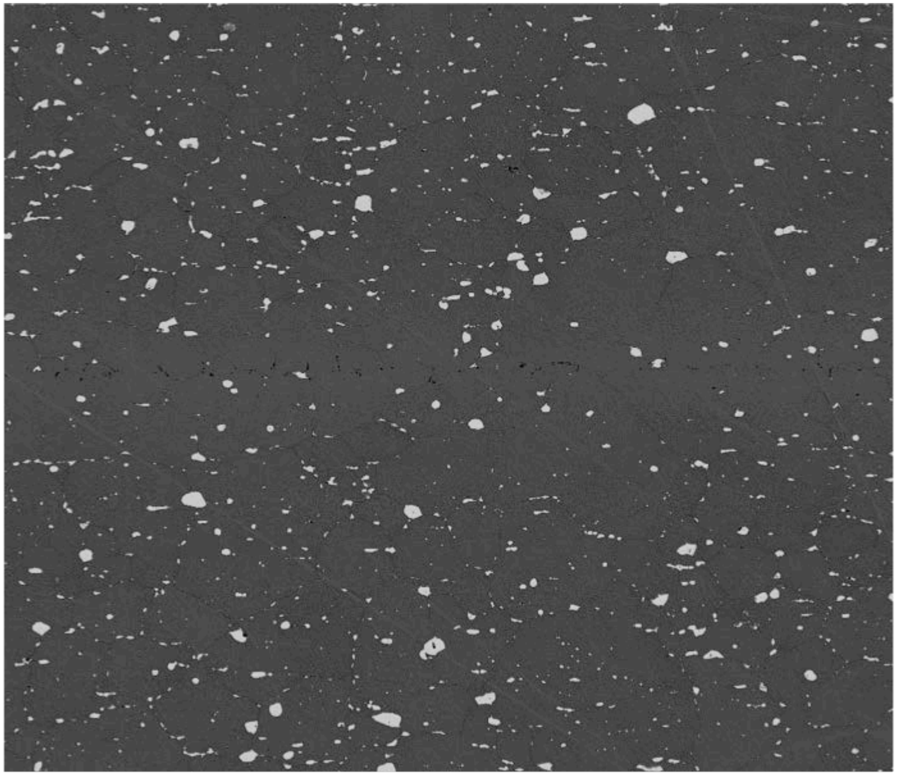
Is the DB stack different?

H230 Sheet



100 µm

H230 DB stack

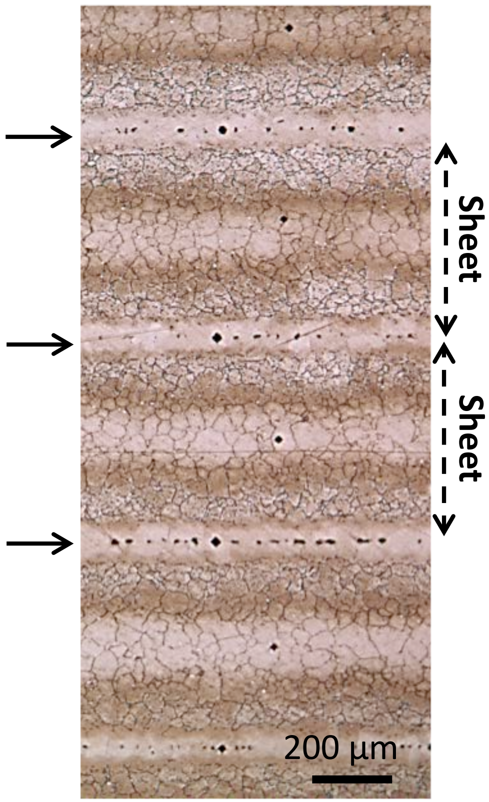


- **3X higher precipitates/unit area in DB stack**

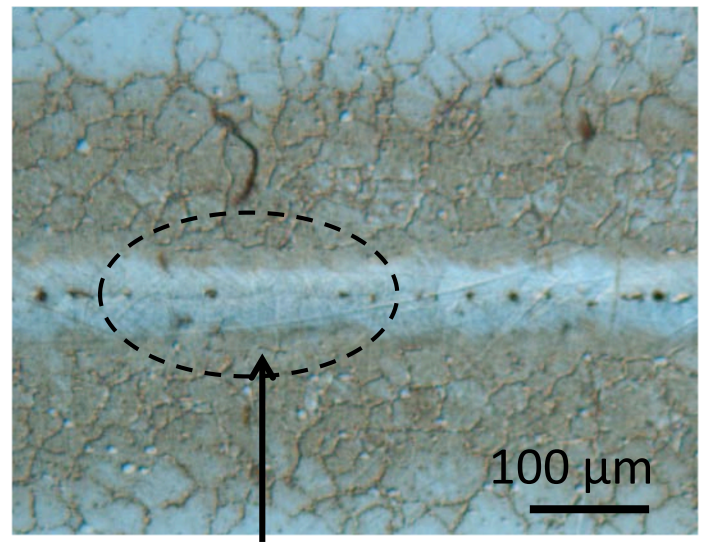
Microstructure – Ni-plated H230

Ni-Plated H230

Diffusion Bond

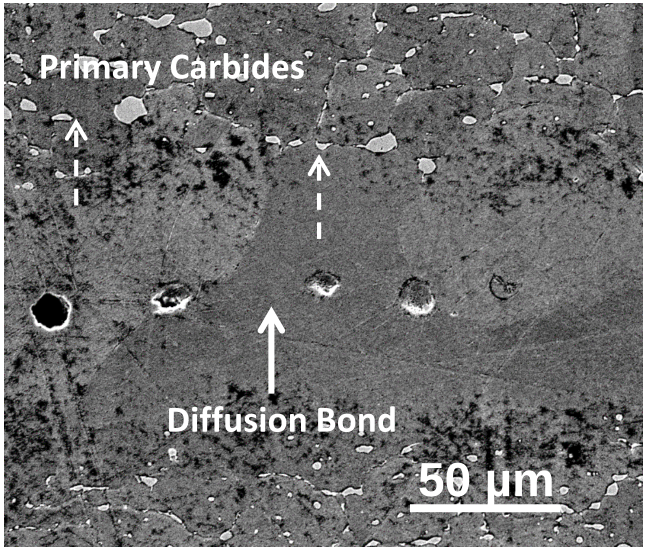


Large voids at bondline

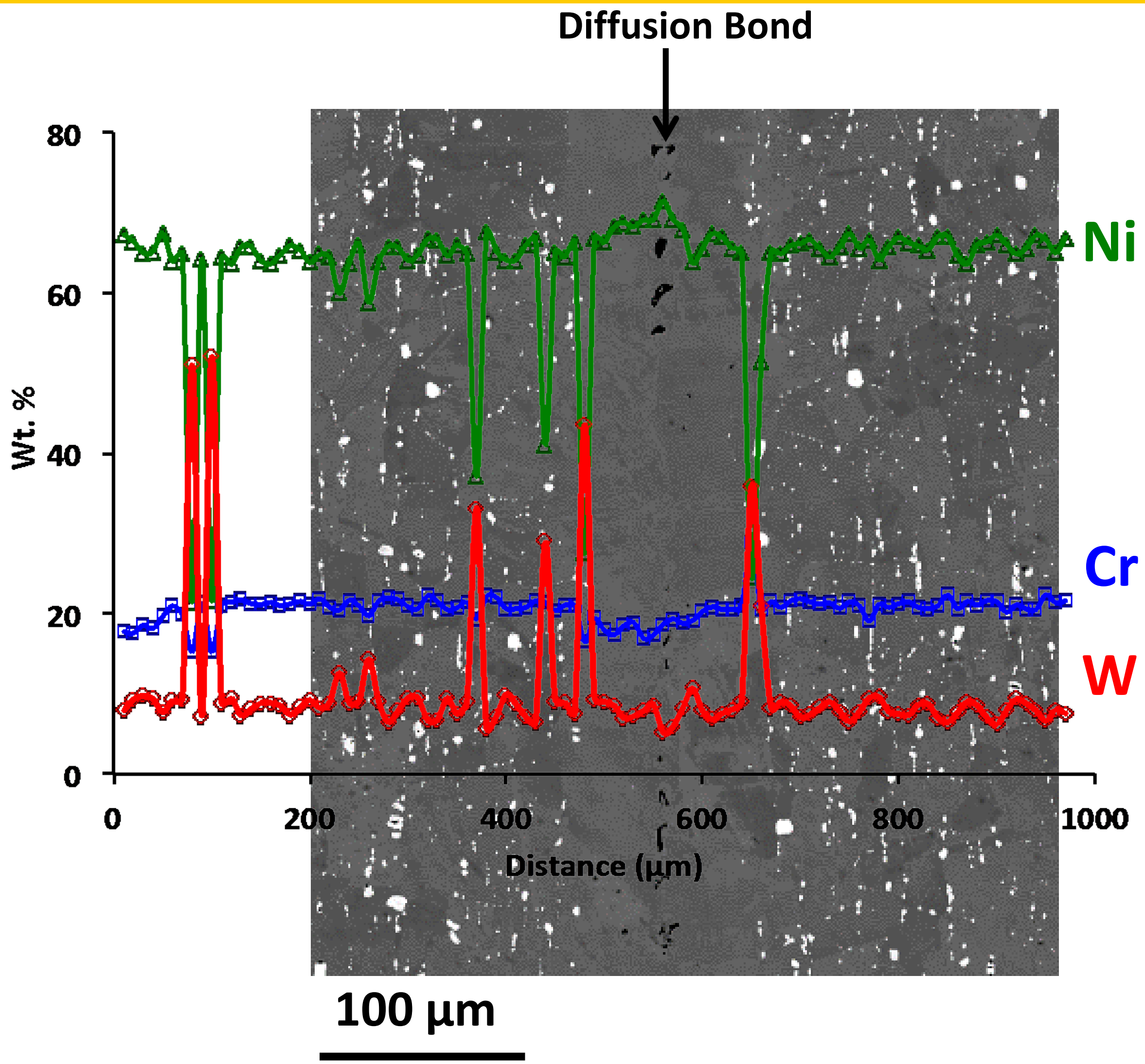


Grain growth at the bondline

Microstructure near the bond

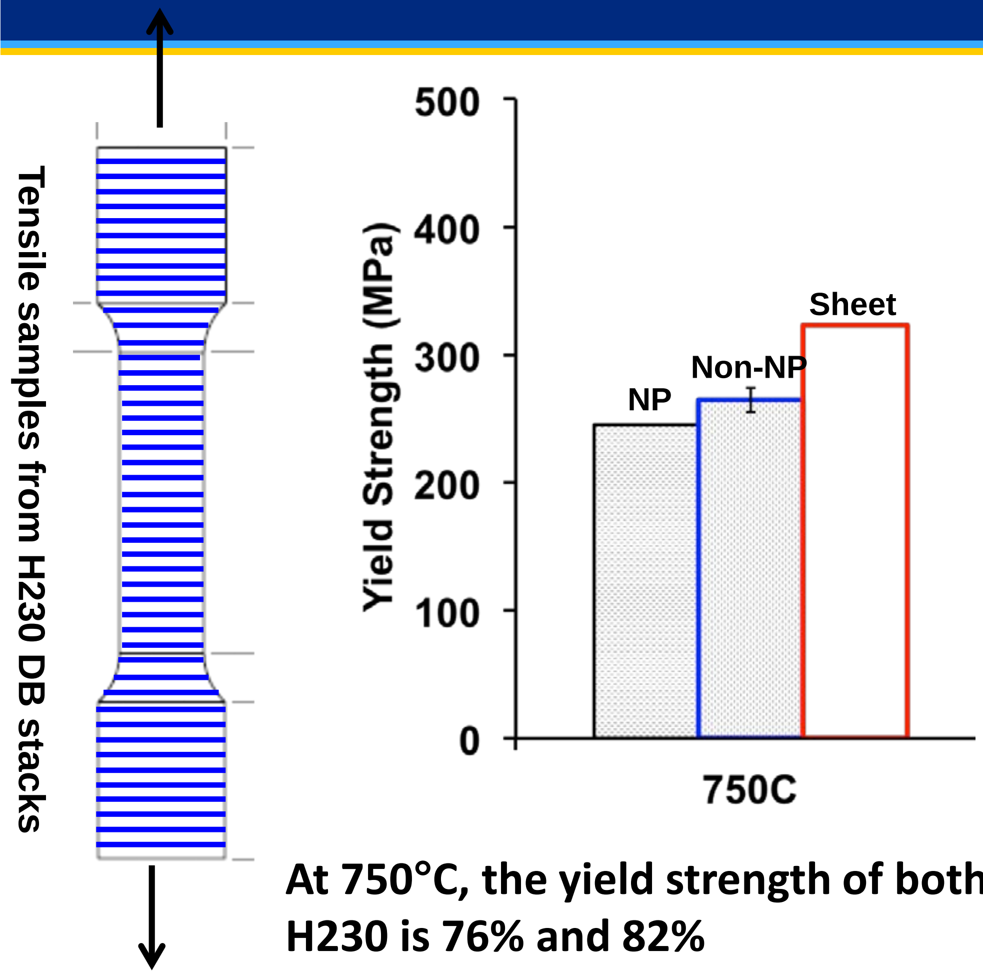


- Primary Carbides
- Increase in Ni, dip in Cr at the bond



Mechanical Properties

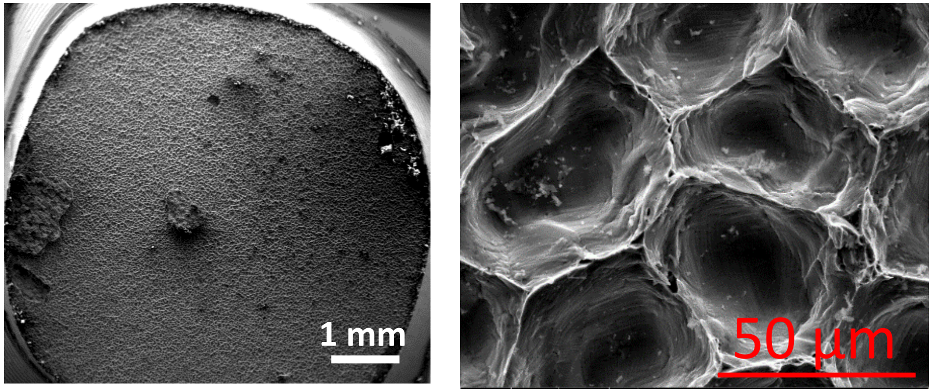
Summary of yield strength



At 750°C, the yield strength of both Ni-plated and Non-Ni-plated H230 is 76% and 82%

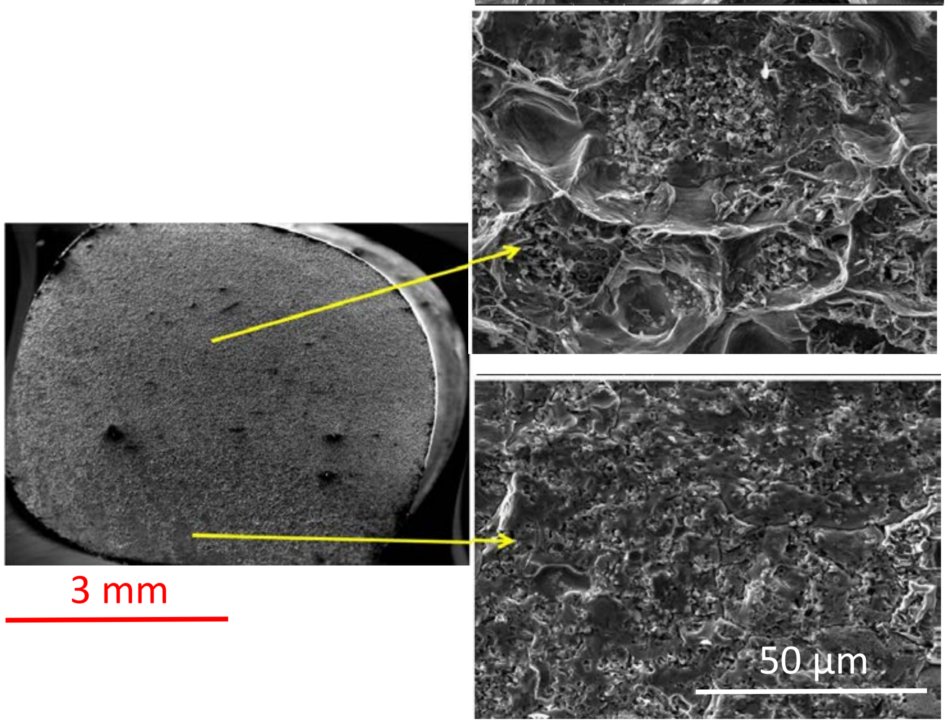
- At RT, the yield strength of both Ni-plated and Non-Ni-plated H230 is ~ 90%

Fracture surfaces - Ni-plated H230 DB stack



RT

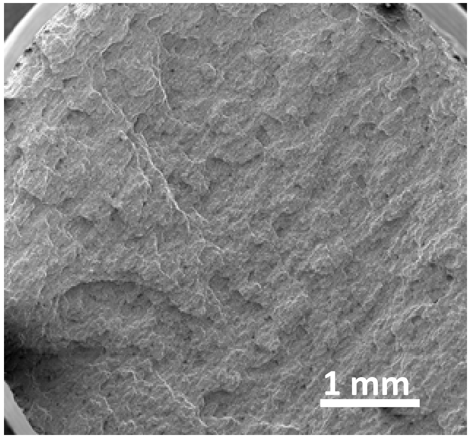
- Hardly any elongation, fracture at the bond, cup-and-cone fracture at the microscale

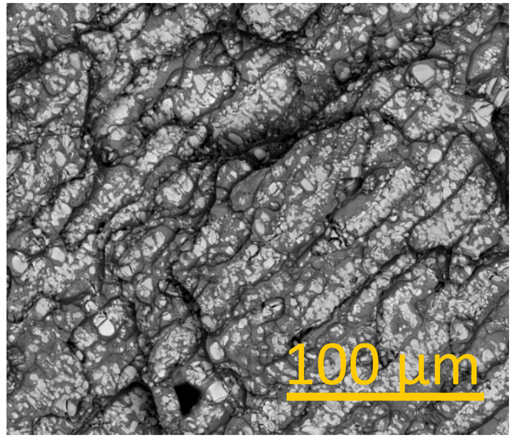


750°C

- Fracture through the sheet and the bond

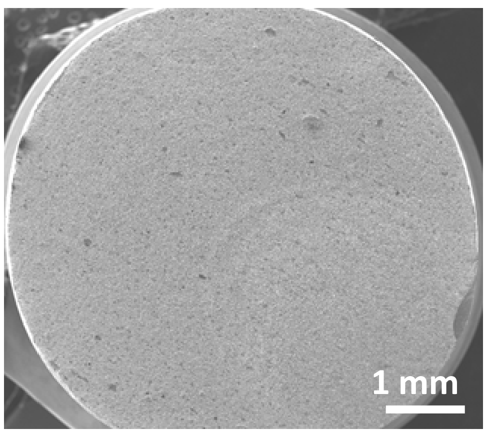
Fracture surfaces - Non-plated H230 DB stack

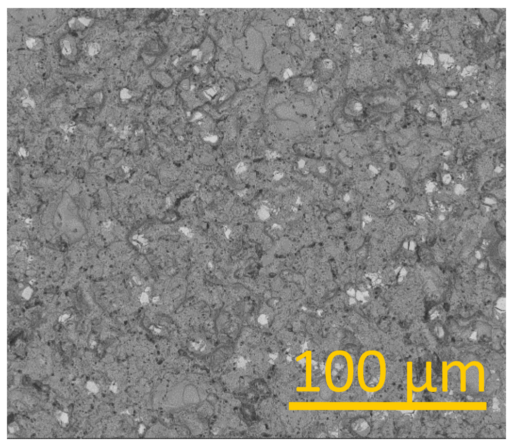




RT

- **Fracture through the sheet**

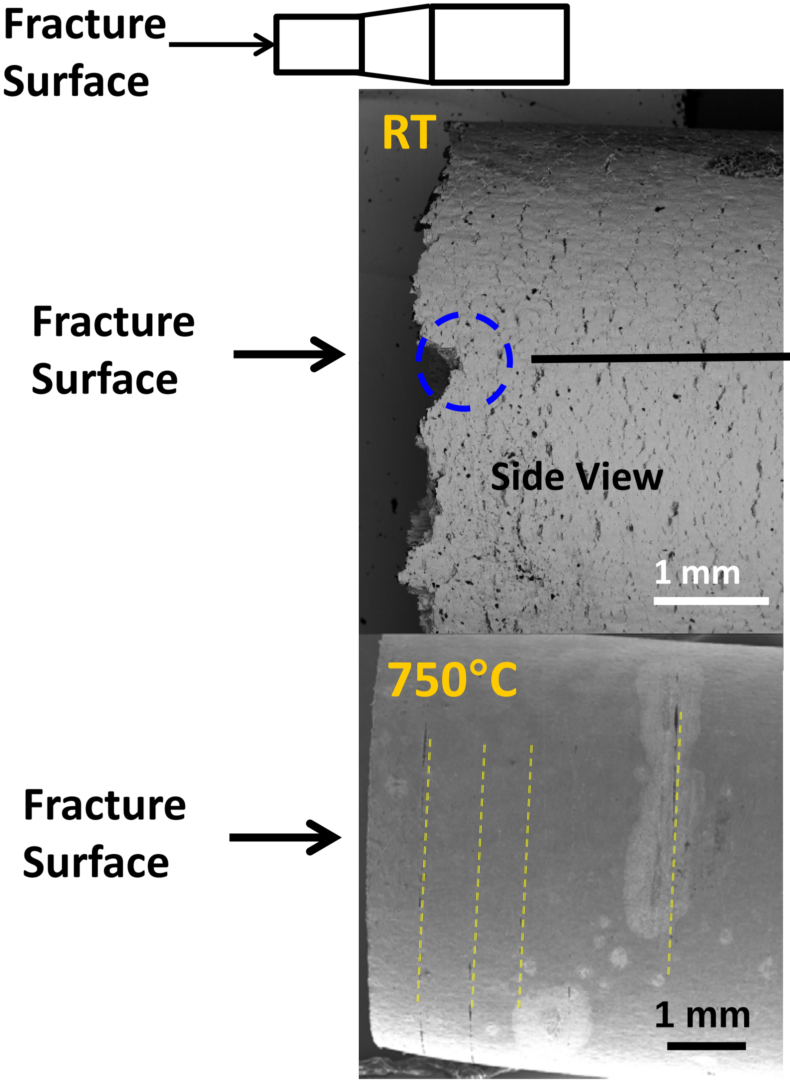


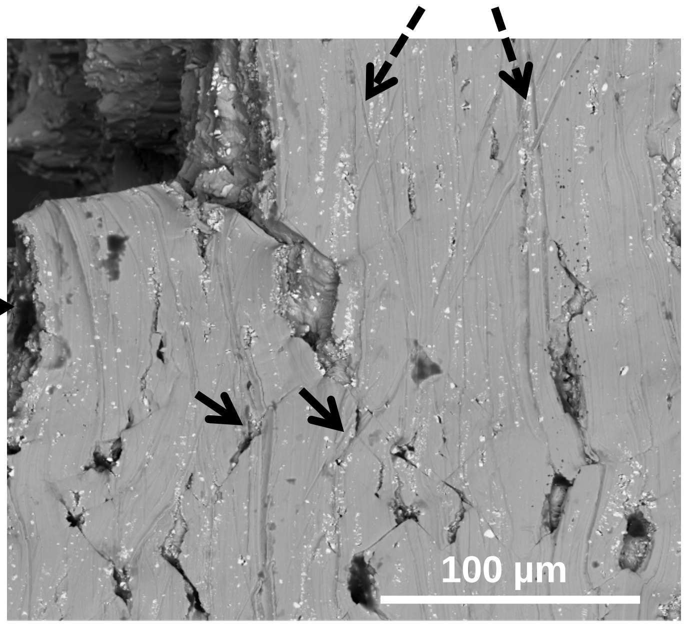


750°C

- **Fracture through the bond**

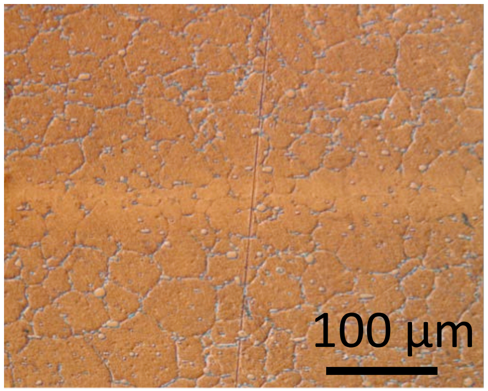
Side view of fracture surfaces – Non-plated H230 DB stack



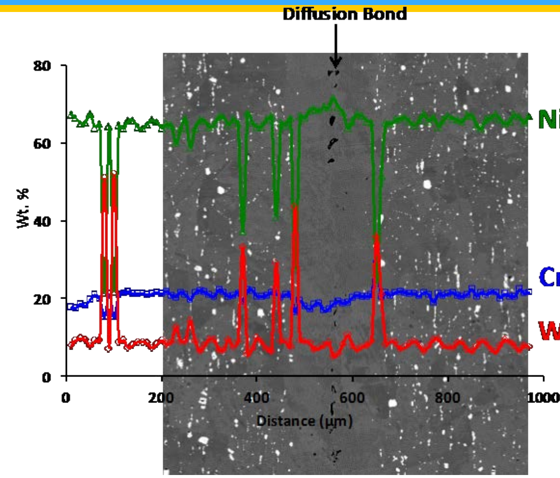


- RT – microcracks along primary carbide bands
- 750°C – cracking along DB lines

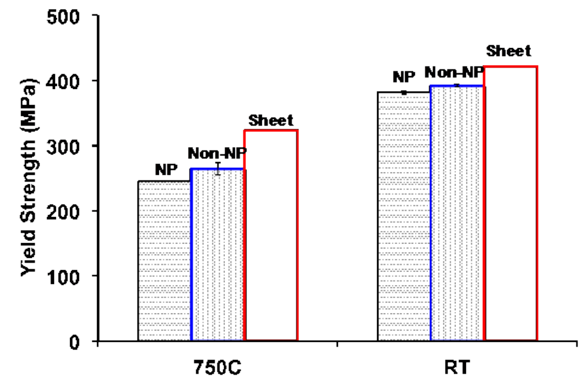
Summary



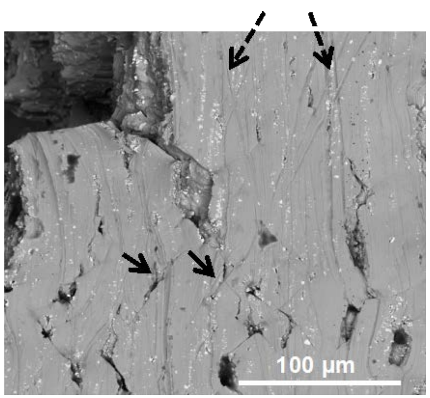
1) Uniform bond with grain growth across the bondline



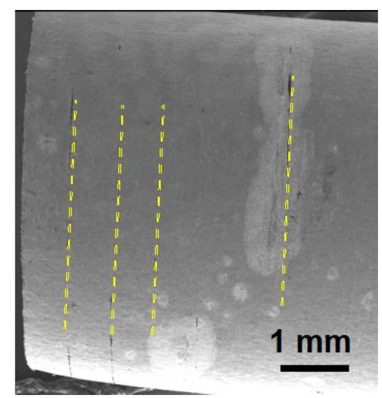
2) Ni increase, Cr dip through the bond



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

Questions?

Thank You