Diffusion bonding of titanium to itself and to aluminium

Amir Shirzadi

Symposium of World Experts in Diffusion Bonding

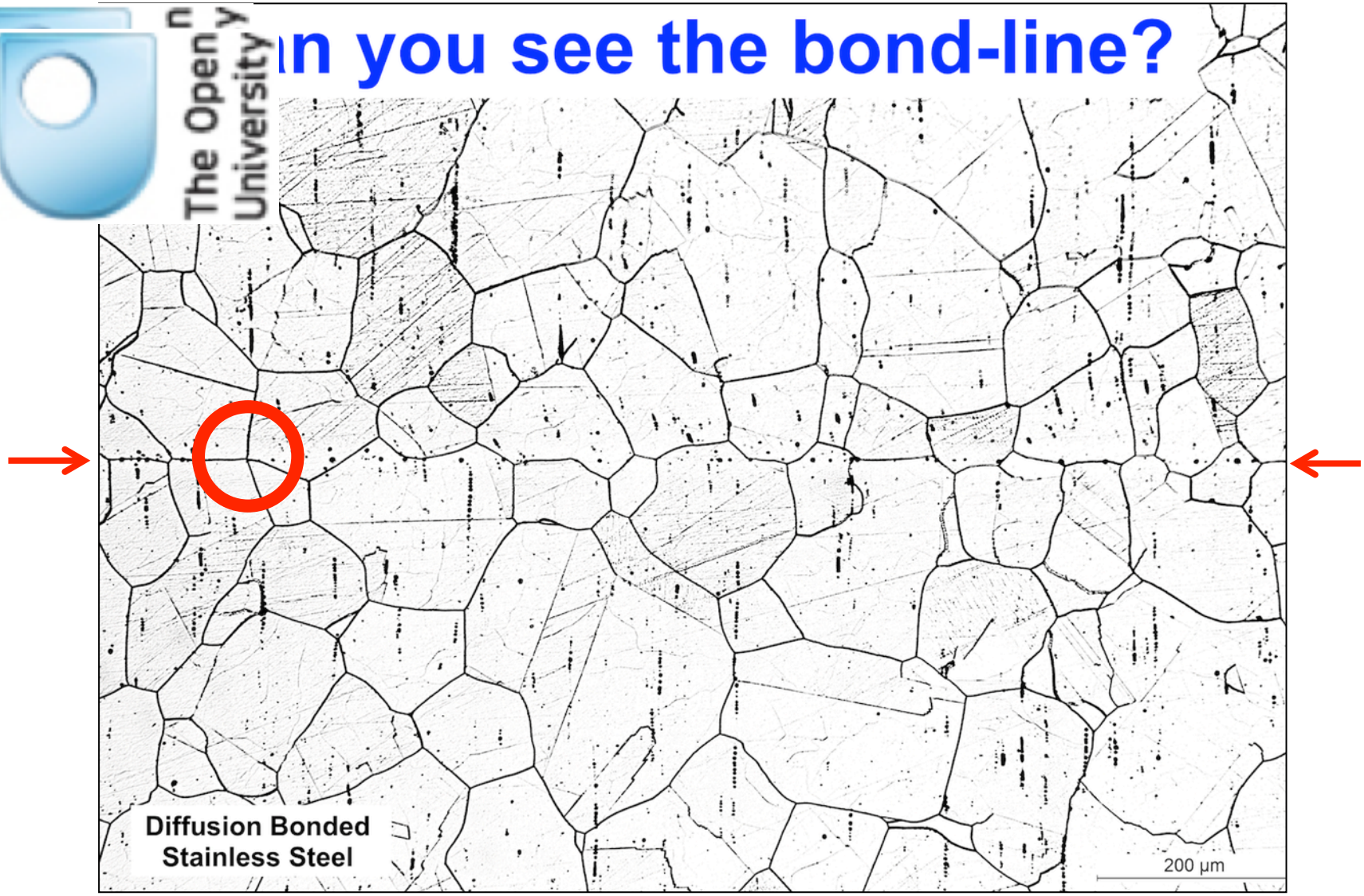
20-21 June 2017

The Open University

The Open University

CJT

n you see the bond-line?



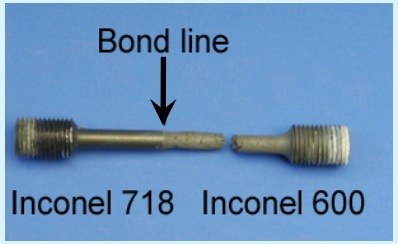
The Open University

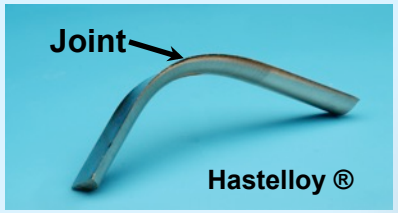
CJT

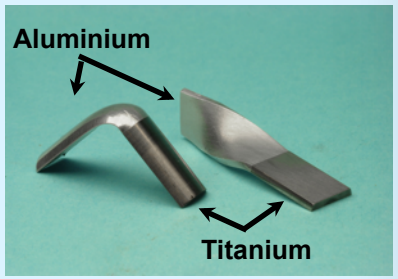
Advanced Joining Methods

Patented in UK and USA

High Strength Joints [Aerospace / Defence]

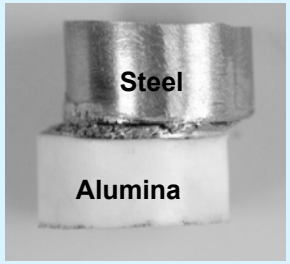


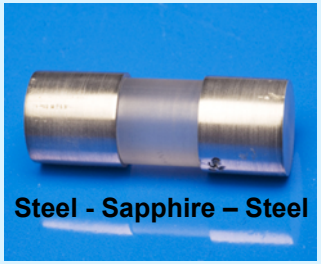




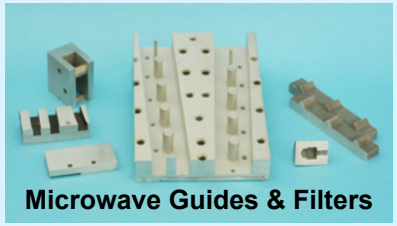
Microjoining [Medical Devices]

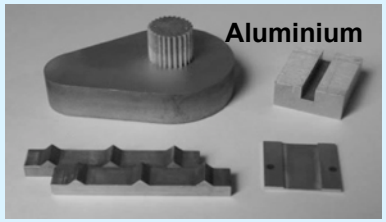
Bonding Ceramics to Metals [Automotive / Optics / Sensors]

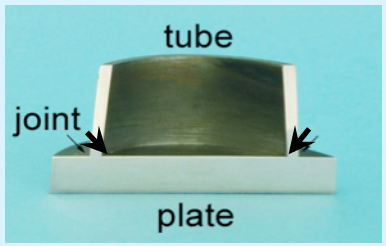




High Precision Bonding [Microelectronics]







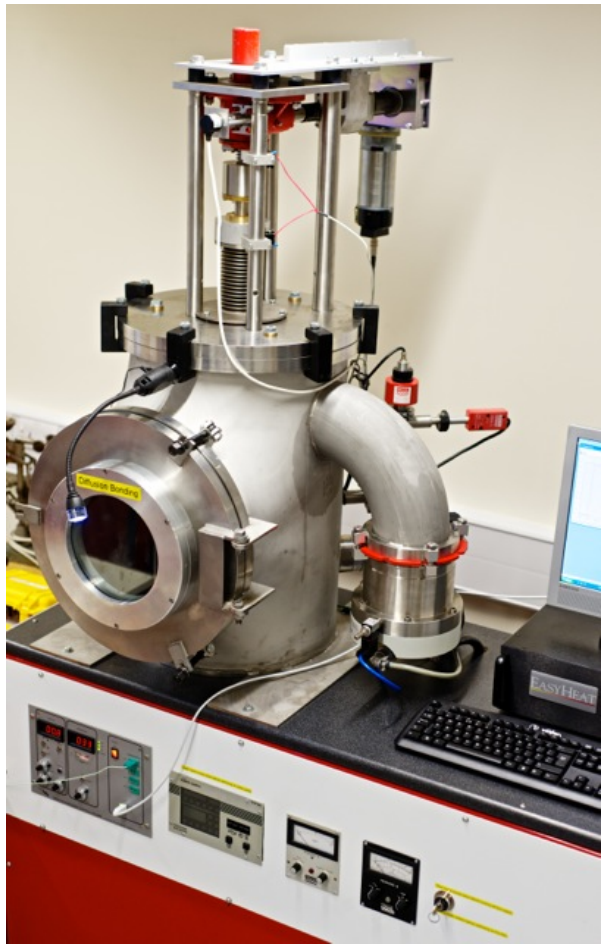
Cambridge diffusion bonding rig

The Open University

CJT

New diffusion bonding rig & specimen setup

(The Open University)

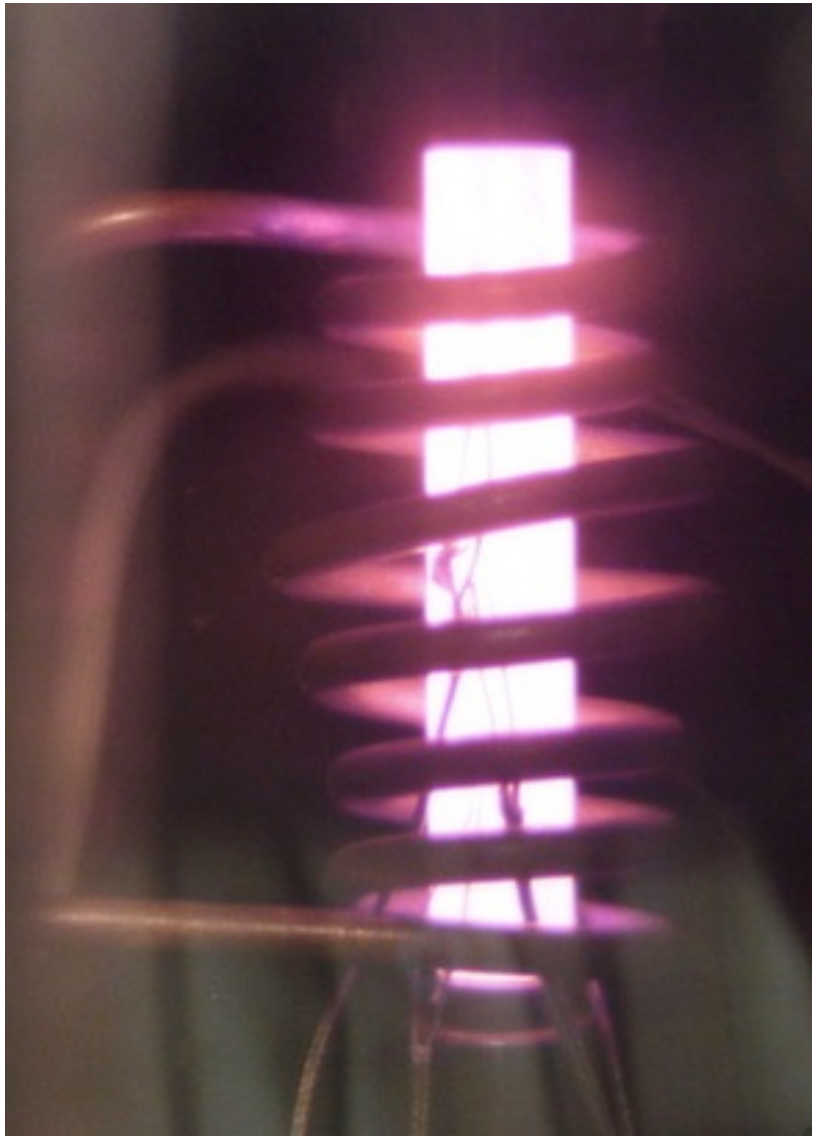


The Open University

CJT

Joining a 60-layer component

Conventional coil



Special coil

The Open University

CJT

…all metals will bond

if

thoroughly cleaned surfaces are brought together within the range of interatomic forces.

Ref: Kazakof's surface oxide hypothesis

The Open University

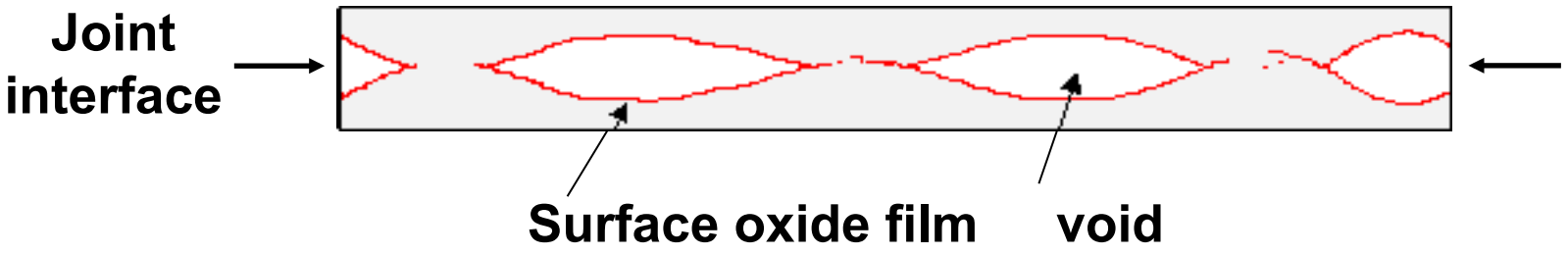
CJT

Classical definition of diffusion bonding:

A process by which faying surfaces are brought into sufficiently close contact using an applied pressure at elevated temperature to allow bond formation by atomic interdiffusion across the joint interface.

But in reality:

surface oxides are brought into close contact not the alloys themselves!

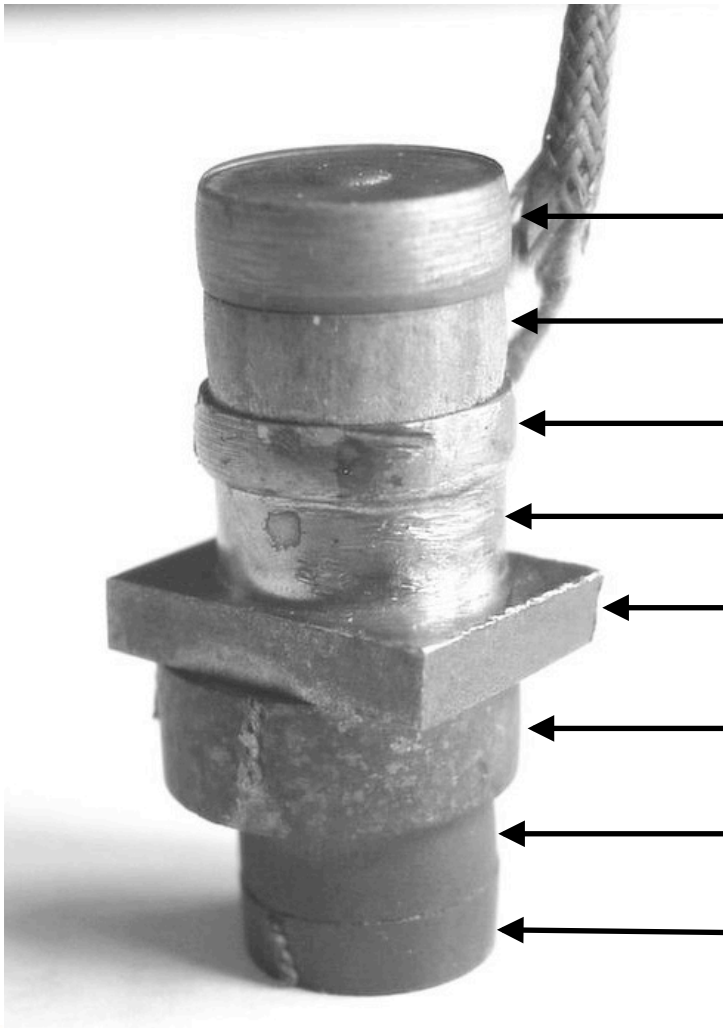


The Open University

CJT

Gallium-assisted solid-state diffusion

(UK and USA Patents)



Al–SiC metal matrix composite

Aluminium (Al6082)

Titanium alloy

Stainless steel (316)

Cobalt base superalloy

Nickel base superalloy (Inconel)

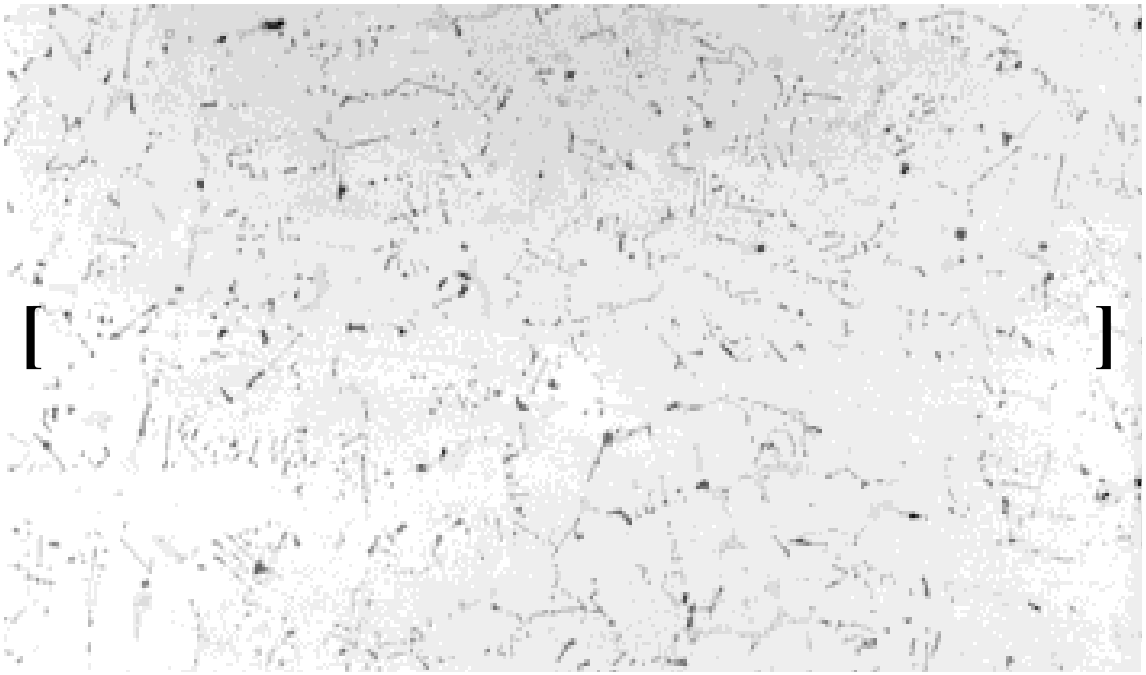
Nickel base single crystal superalloy

Nickel base single crystal superalloy

The Ope
Universit

CJT

Gallium-assisted diffusion bonding of cobalt-base superalloy PWA647



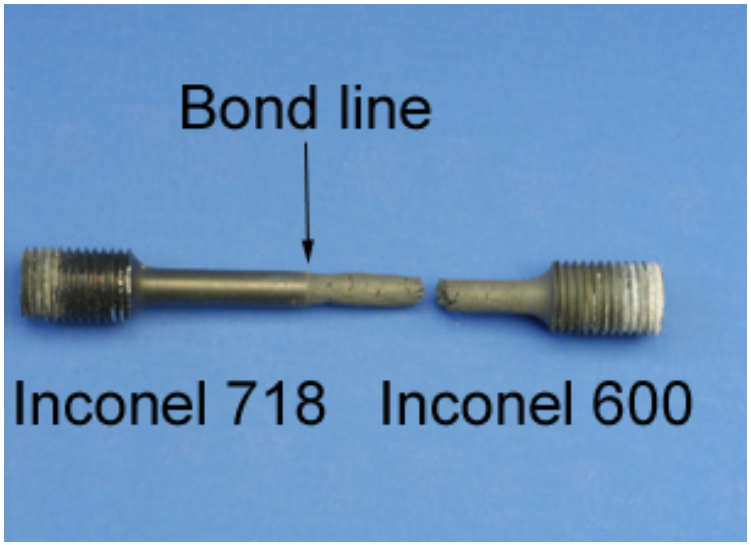
The Open University

CJT

Creep test result
Inconel 600 joined to Inconel 718

Joined sample failed in parent alloy and away from the bond line

- Temperature: 760°C
- Stress: 90 MPa

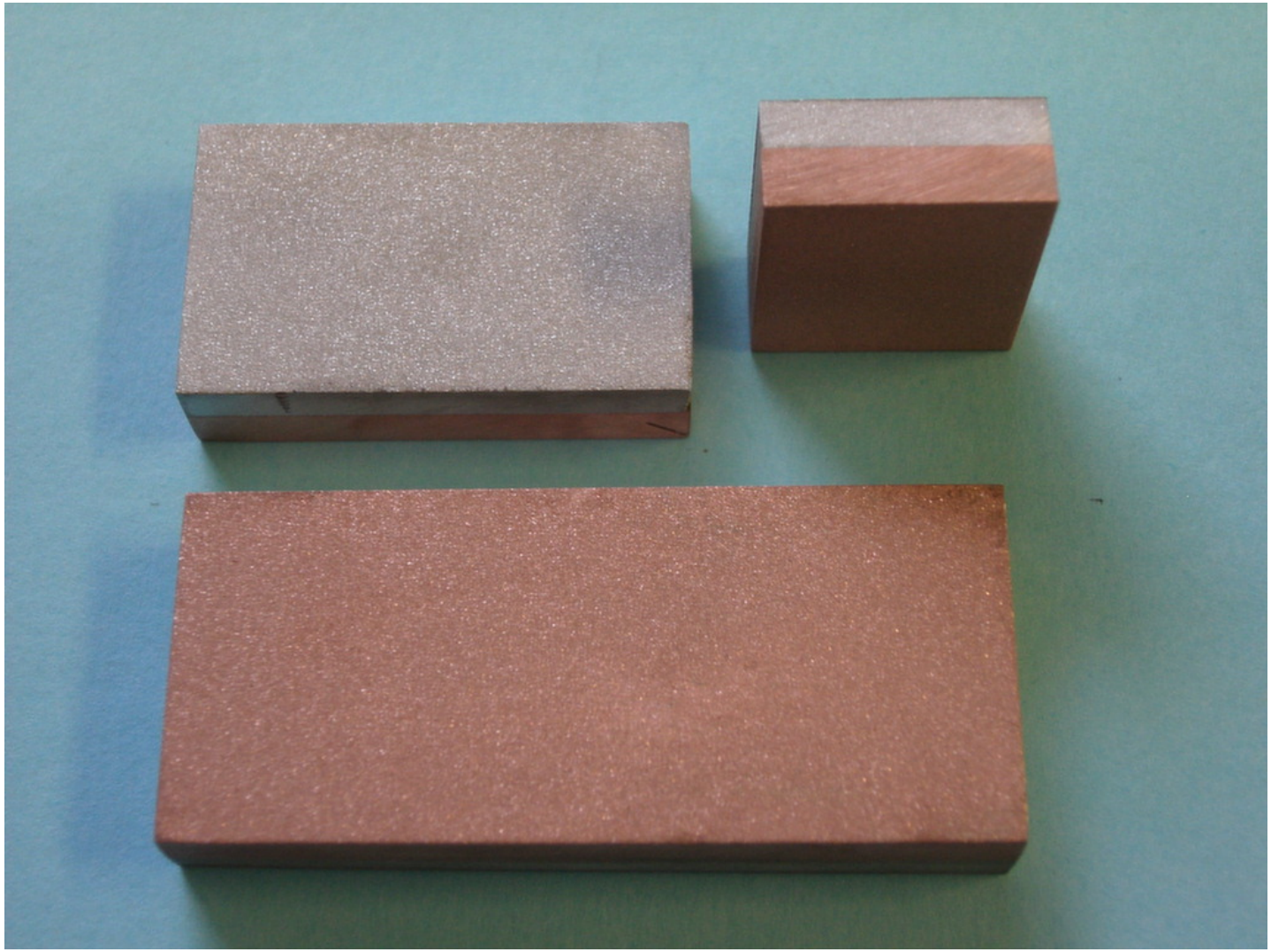


- Lifetime of dissimilar joint: 33 hours
- Lifetime of parent Inconel 600: 31 hours

The Open University

CJT

Diffusion bonding Cu to Al

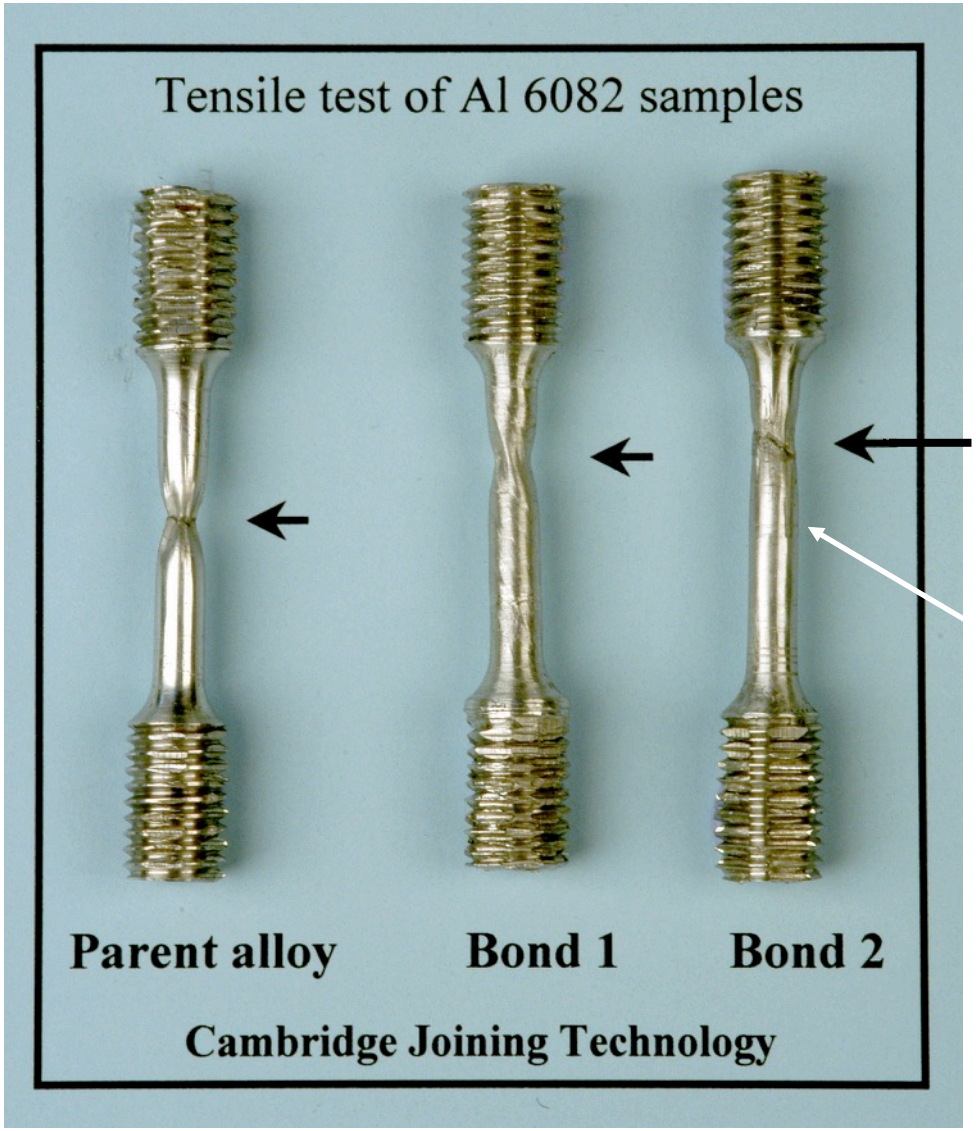


Endured 3000 thermal cycles (Mitsubishi Project)

The Open University

CJT

Room temperature tensile tests of solid-state diffusion bonds



Necking points

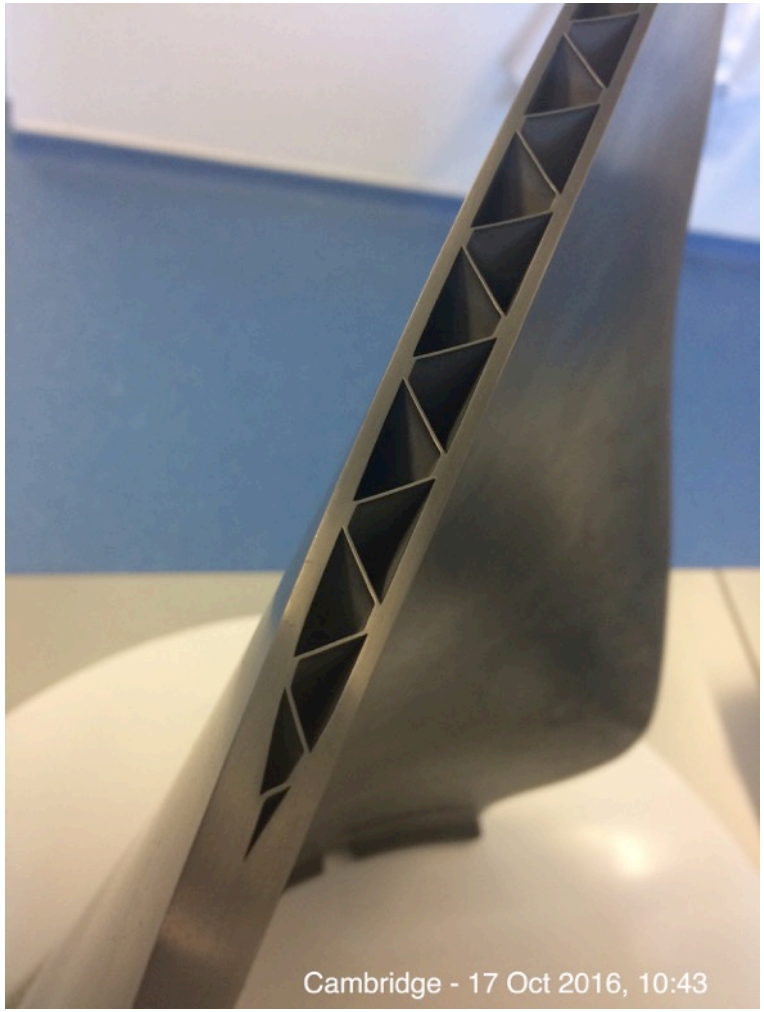
Bond line is in the centre of sample

The Open University

CJT

Rolls Royce Trent 900 Engine

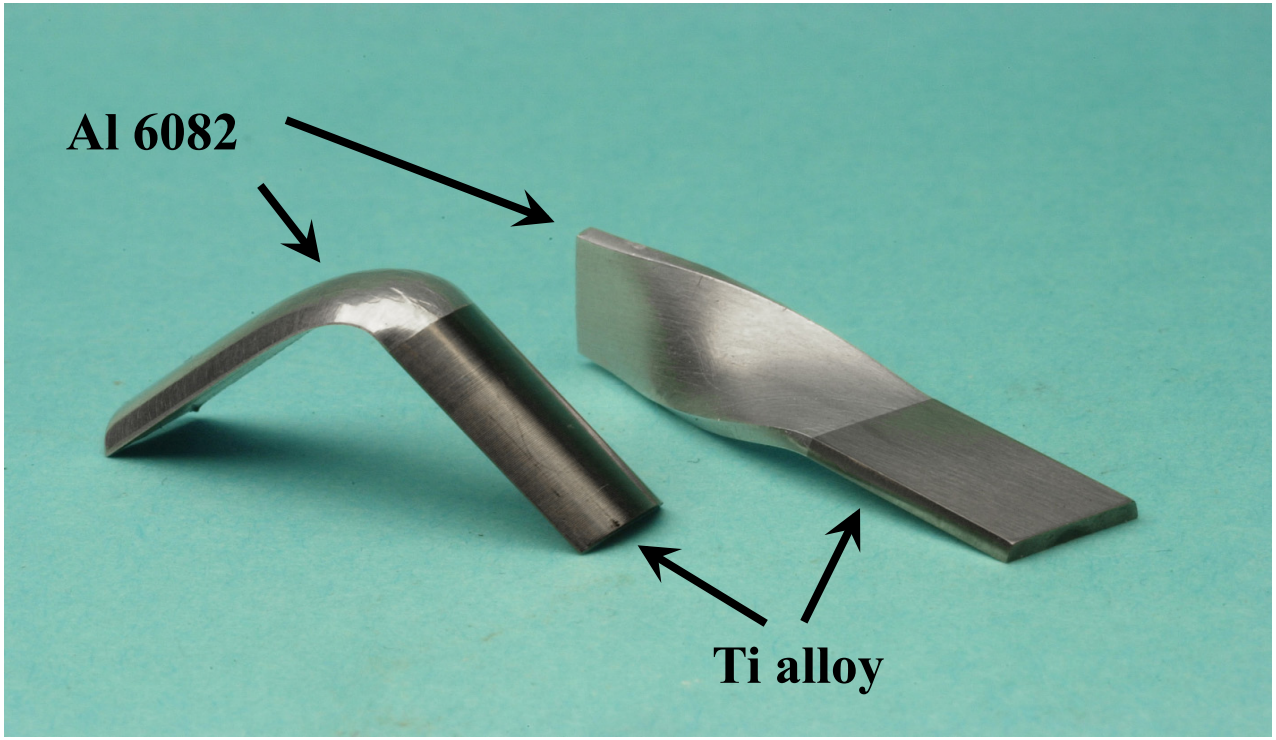
Titanium fan blades made by diffusion bonding



The Open University

CJT

Joining aluminium to titanium

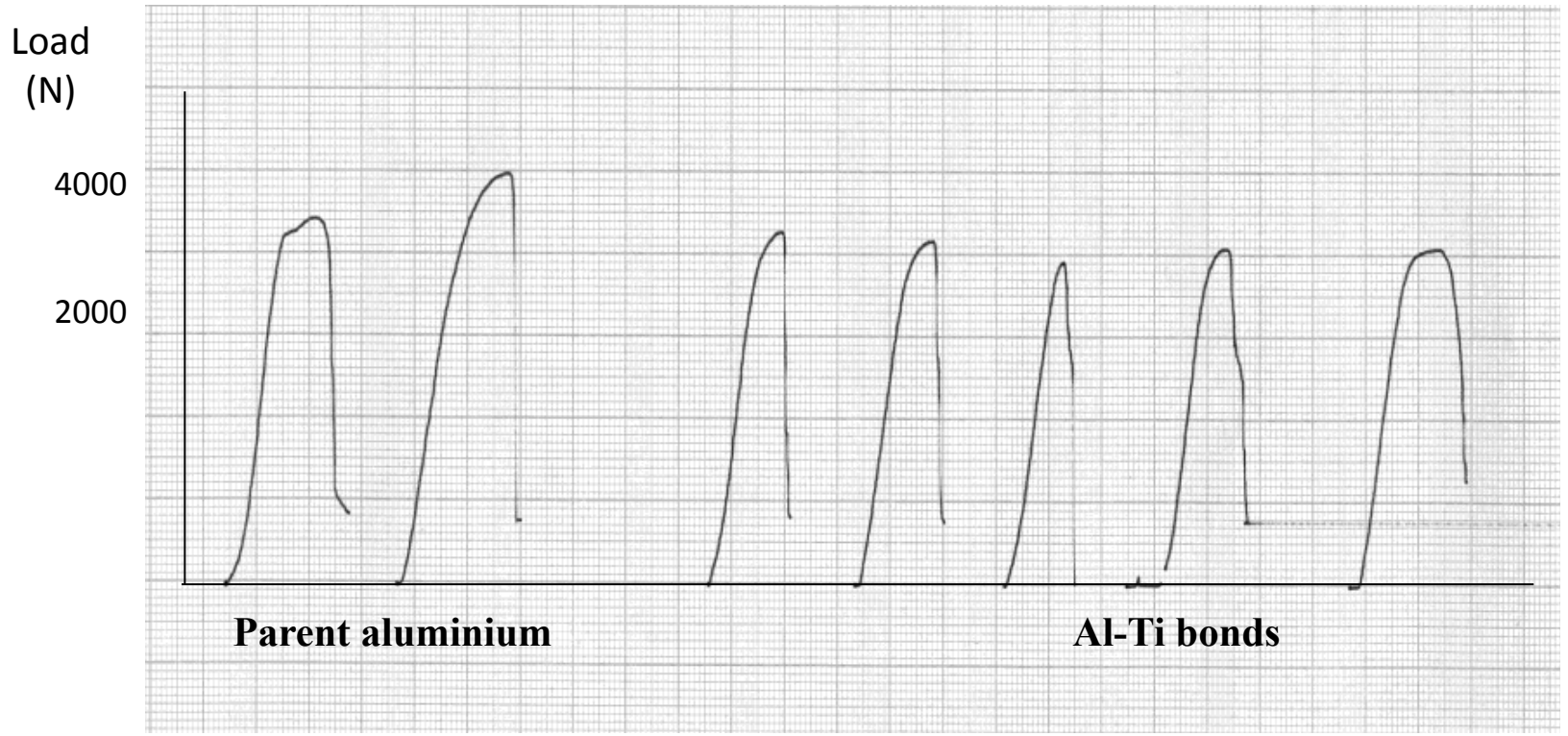


Bonded samples subjected to severe mechanical loads to assess joint integrity

The Open University

CJT

Shear test results for Al-Ti solid-state diffusion bonds

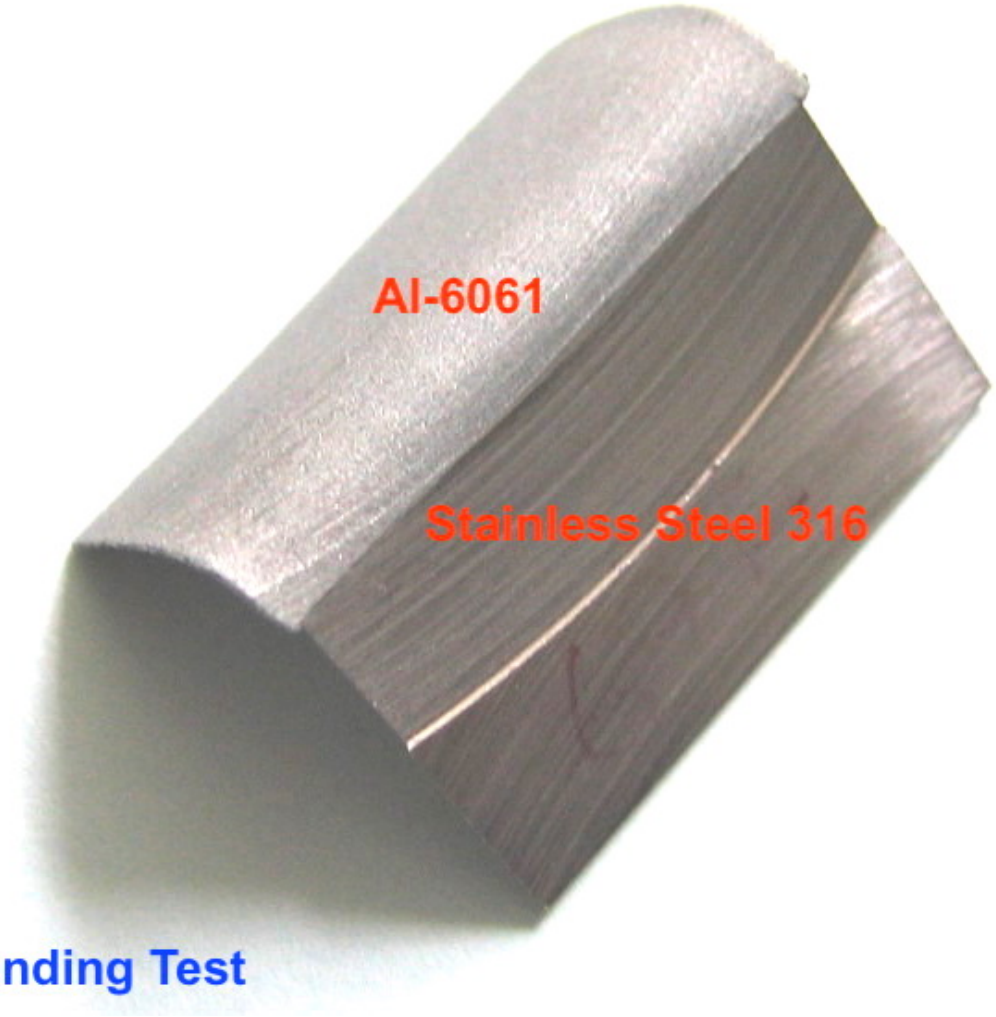


The Open University

CJT

Latest Development:

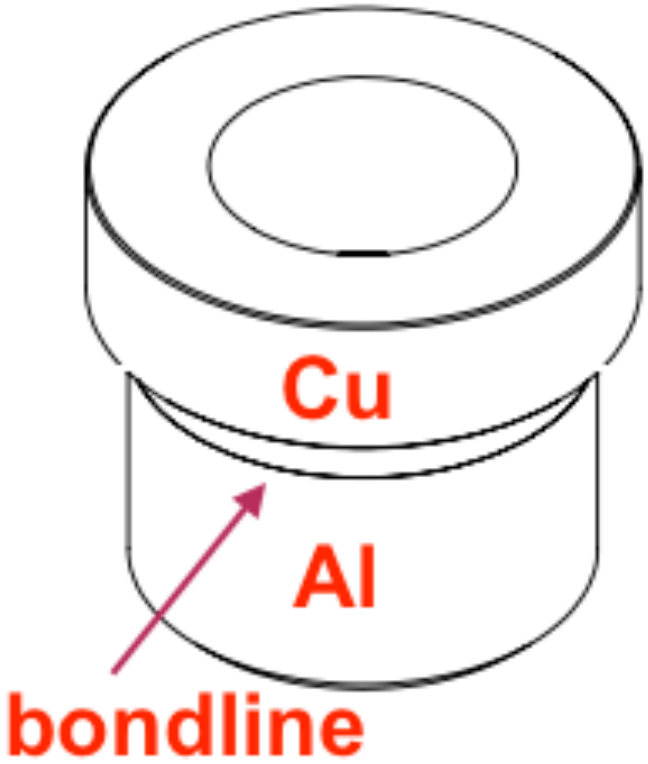
Aluminium to Stainless Steel
Bond Strength 96-102 MPa



The Open University

CJT

Top-hat Tensile Test



The Open University

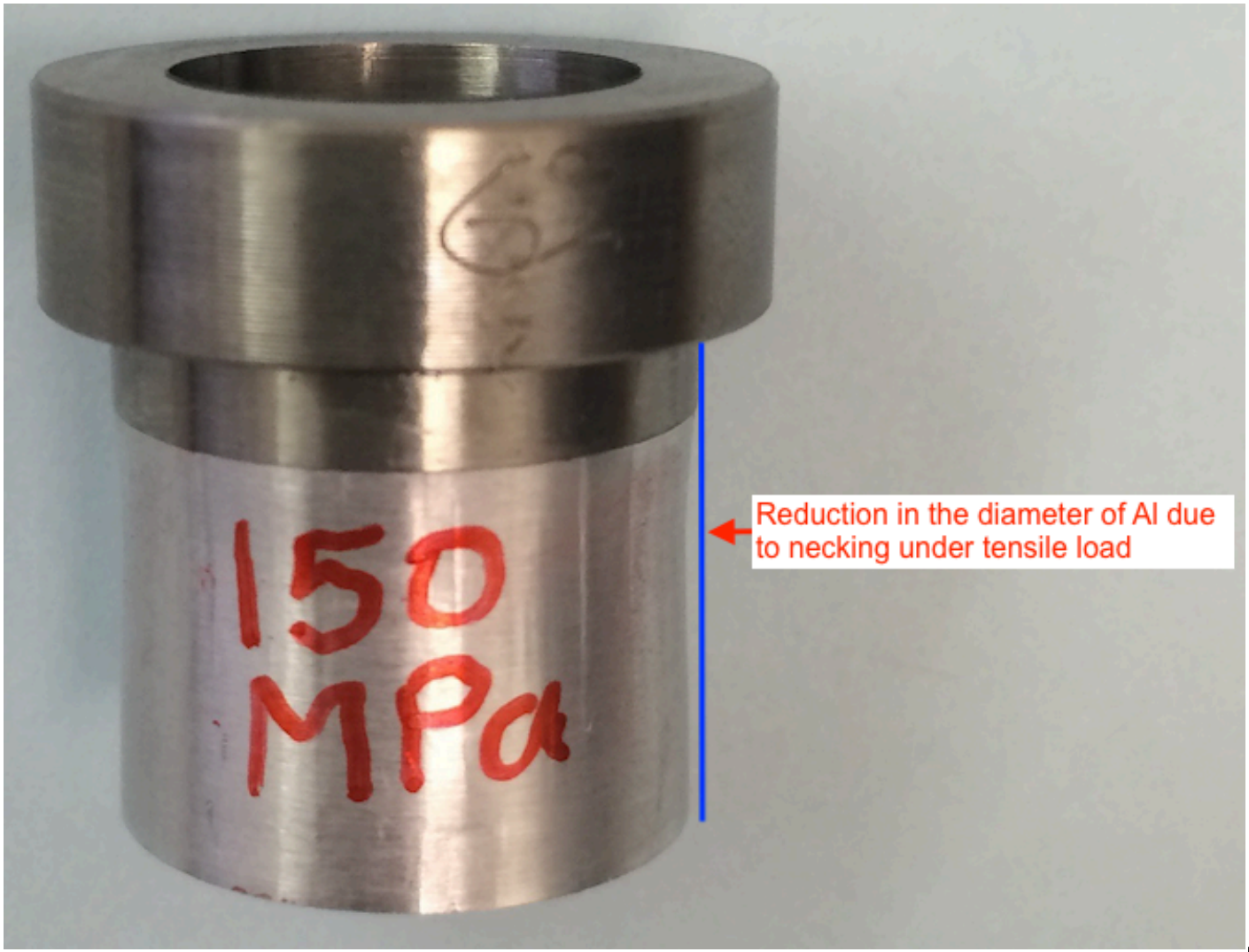
CJT

Top Hat Tensile Testing

The Open University

CJT

Joining aluminium to titanium



The Open University

CJT

Latest Results : 313 MPa

The Open University

CJT

Aluminium – Titanium Adaptors & Flanges

The Open University

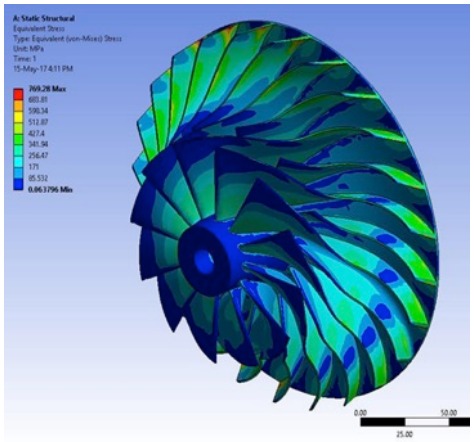
CJT

Oil-free Radial & Centrifugal Compressors and Turbines

Problem Definition

Turbocharger are made in 100,000s per year

- ✓ Air compressors
- ✓ Process gas compressors
- ✓ Natural gas expanders
- ✓ Refrigeration compressors
- ✓ Fuel cell compressors



- Problems:
  - ✧ **High axial load prevents applications where pressure is high or leakage has to be minimised**
  - ✧ **High axial load can result in bearing power loss or failure of compressor**

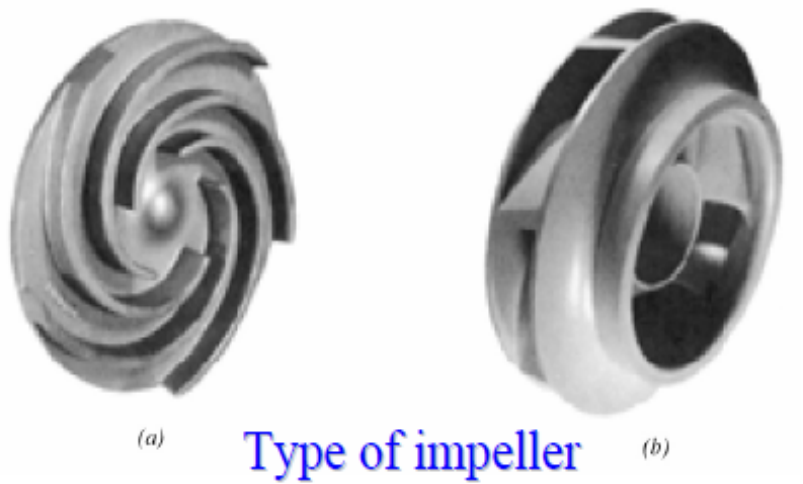
Alex Molyneaux
OFTTech Ltd
UK
www.ofttech.com

The Open University

CJT

Open & Shrouded Wheels

- ✓ **Axial load is substantially reduced using shrouded wheels.**
- ✓ Shrouded wheels are common in centrifugal pumps where pressures are high.
- ✓ Shrouded wheels are manufactured by casting or brazing a front plate.
- ✓ Selective laser sintering is one of the latest methods for manufacturing shrouded wheels



(*a*) Open impeller, (*b*) enclosed or shrouded impeller

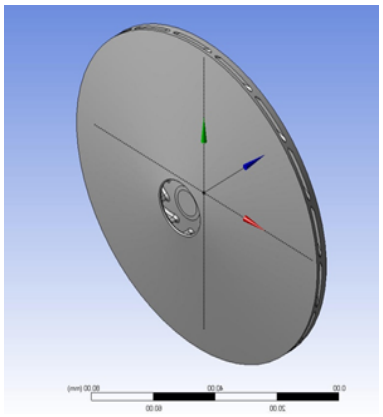
The Open University

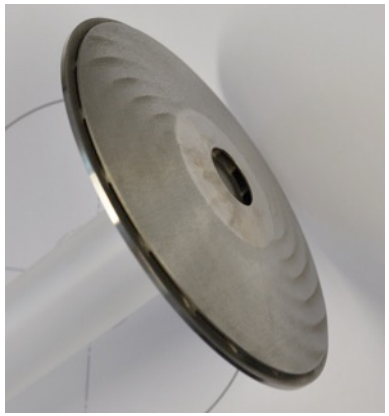
CJT

Gas Bearing Supported Helium Wheel

Application: Helium circulators used in nuclear power plants

Axial load is too high for open wheels





- ✓ Solution was to add a front shroud and
- ✓ Resulting axial load ≈ 0

- ✓ Laser welded <u>successful</u> in 100mm Ø wheel with 2 mm high blades
- ✓ Surface roughness ~ 10-40 microns
- ✓ Max accuracy +/- 25 microns

The Open University

CJT

Gas Bearing Supported Cryo Expander

Application: Cryogenic expander used in satellites

- ✓ 250,000 RPM gas-lubricated bearings
- ✓ 17 mm diameter expander wheel
- ✓ Blade height only 0.5 mm

- X Laser welding is NOT possible,
- X Roughness & accuracy are too poor

- ✓ **Only solution is diffusion bonding**

The Open University

CJT

Gas Bearing Supported Cryo Expander

Application: Cryogenic expander used in satellites

- ✓ 250,000 RPM gas-lubricated bearings
- ✓ 17 mm diameter expander wheel
- ✓ Blade height only 0.5 mm

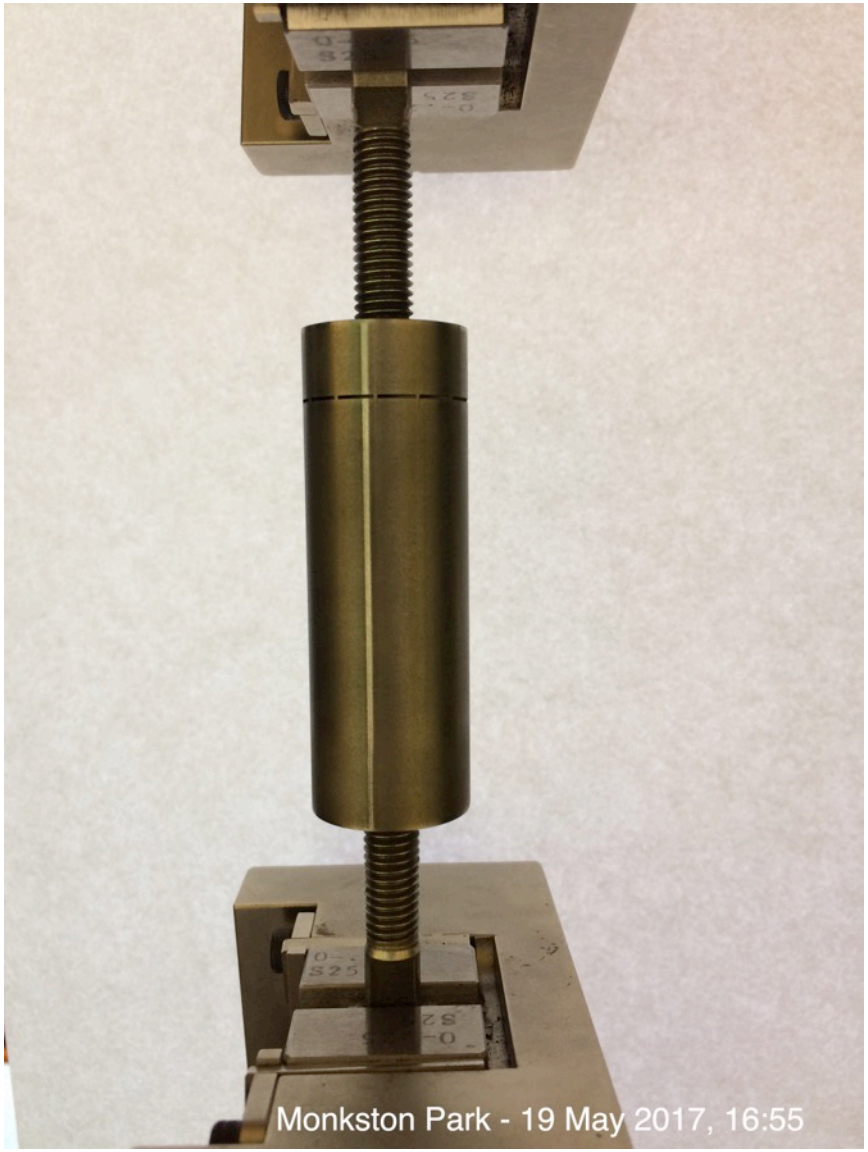
- X Laser welding is NOT possible,
- X Roughness & accuracy are too poor

- ✓ **Only solution is diffusion bonding**

The Open University

CJT

High precision diffusion bonding of Ti-based shrouded turbocharger



The Open University

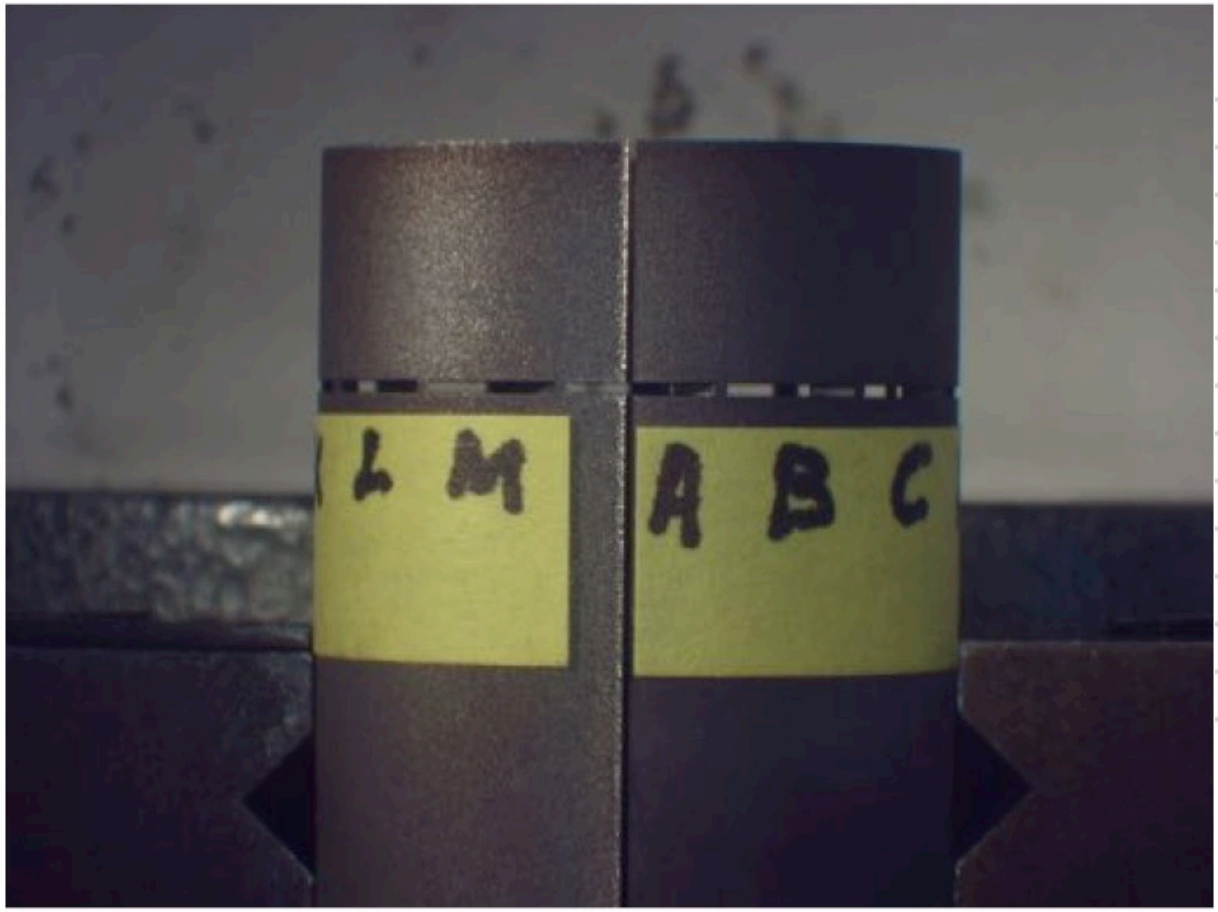
CJT

Tensile strength = 1522 kg (334 MPa)

The Open University

CJT

Alignment Accuracy



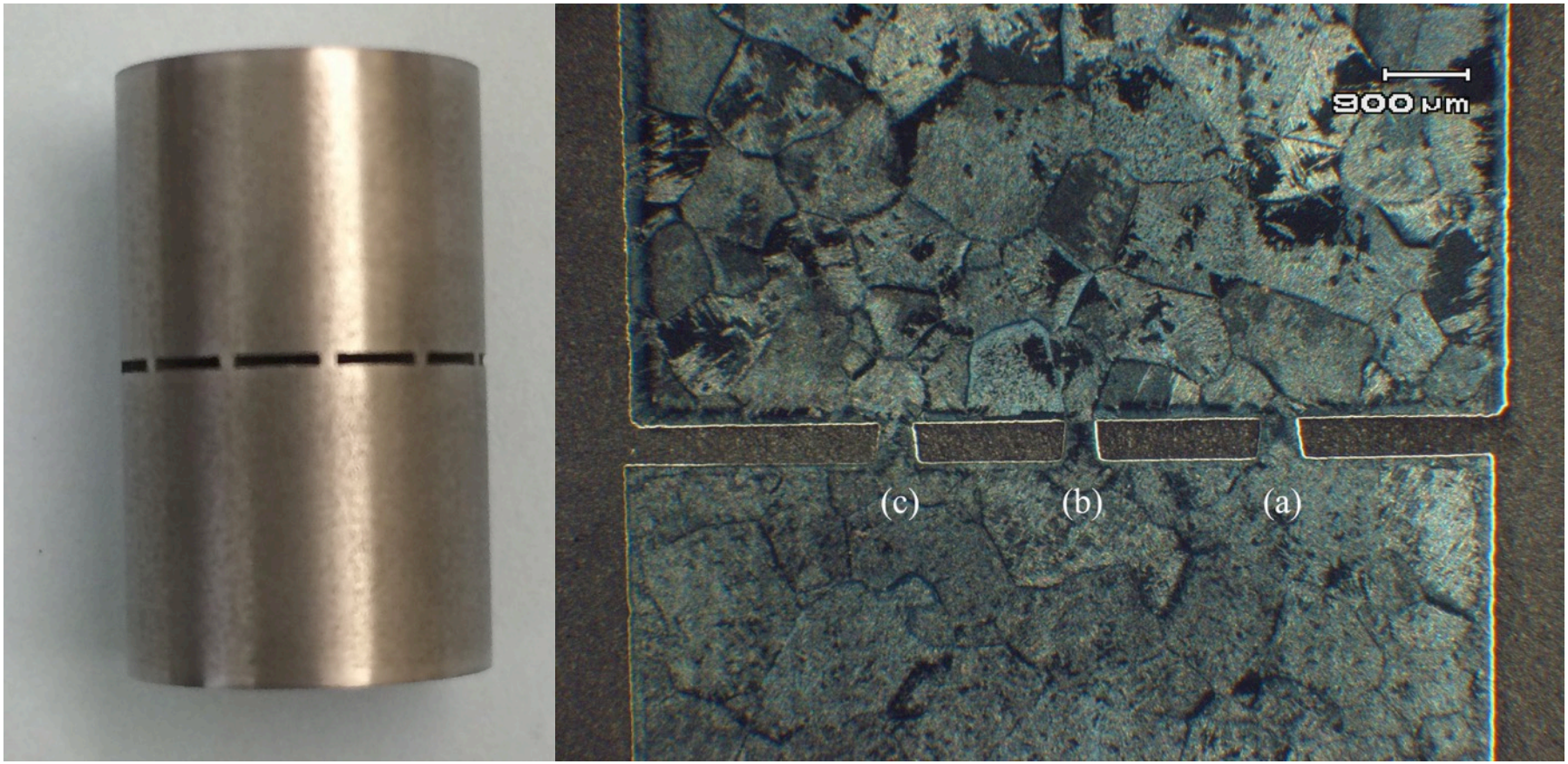
Gap	Micron
A	517
B	517
C	508
D	512
E	517
F	512
G	497
H	491
I	497
J	491
K	491
L	497
M	502

Max error = +/- 13 micron

The Open University

CJT

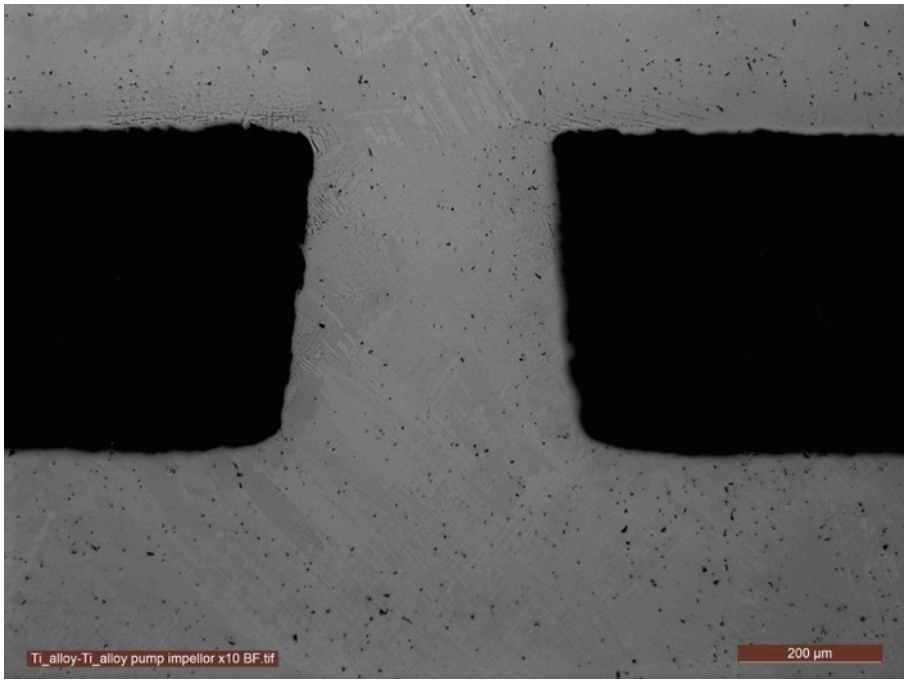
High precision diffusion bonding of Ti-based shrouded turbocharger

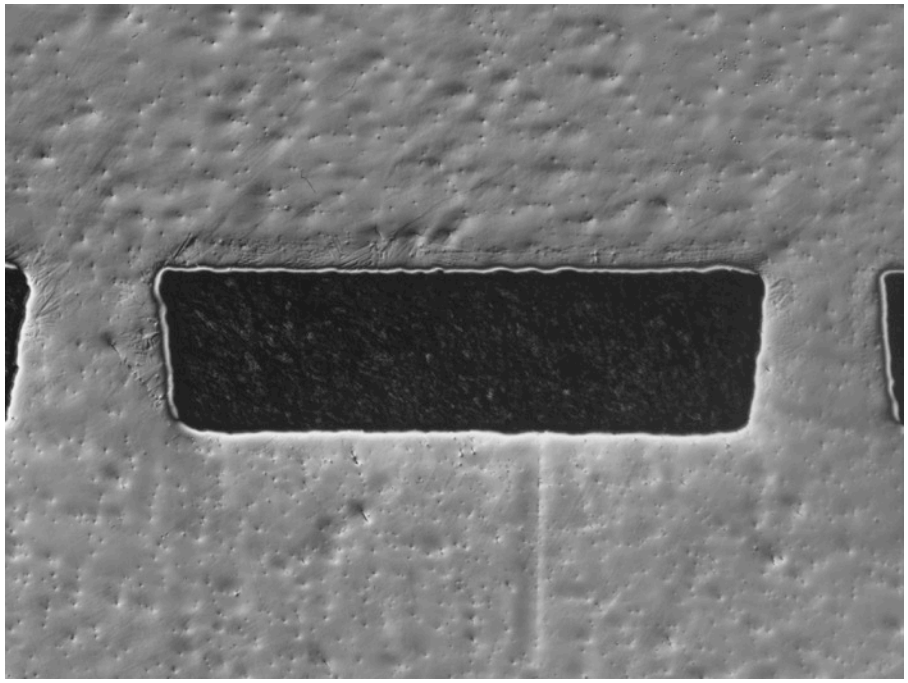


The Open University

CJT

High precision diffusion bonding of Ti-based shrouded turbocharger

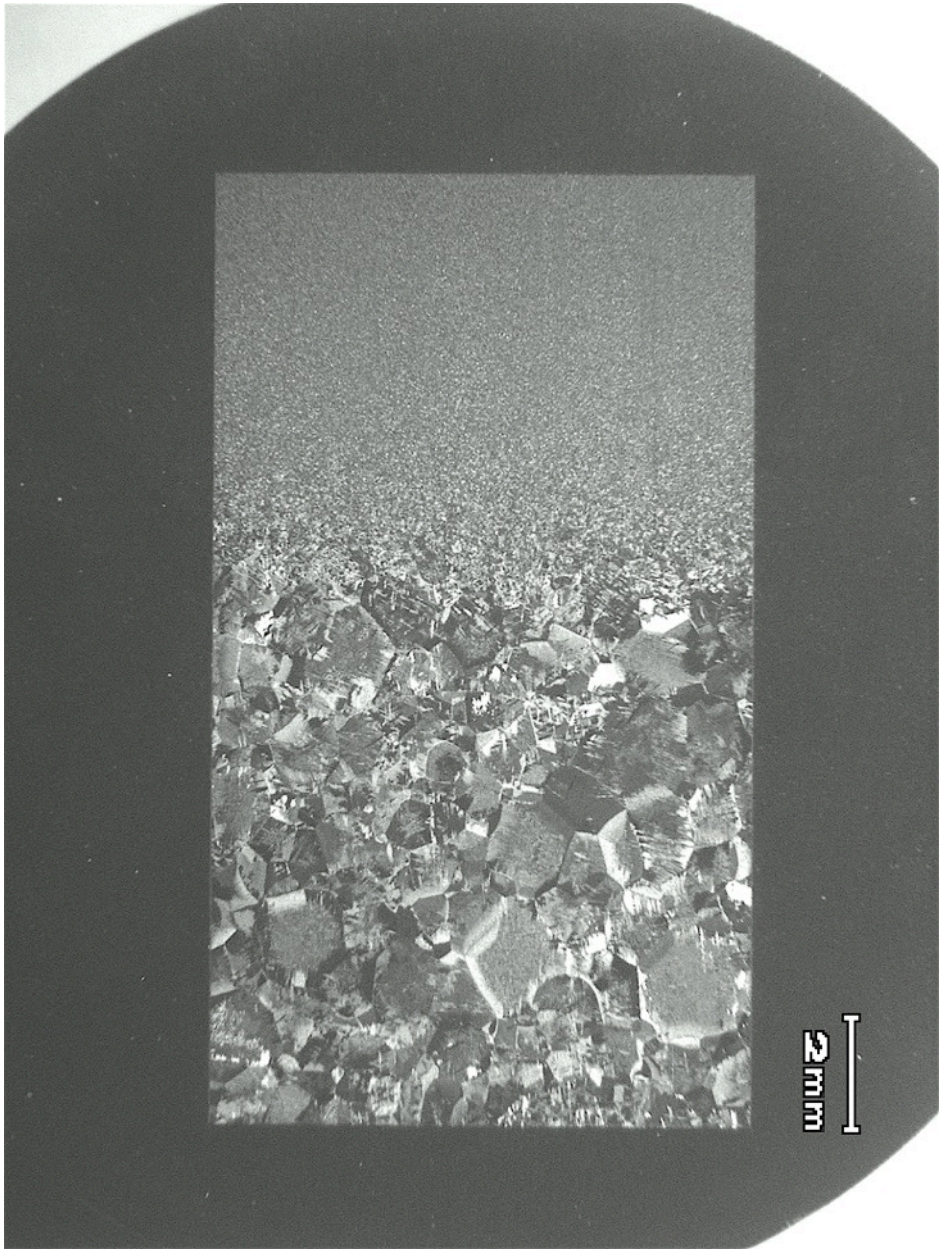


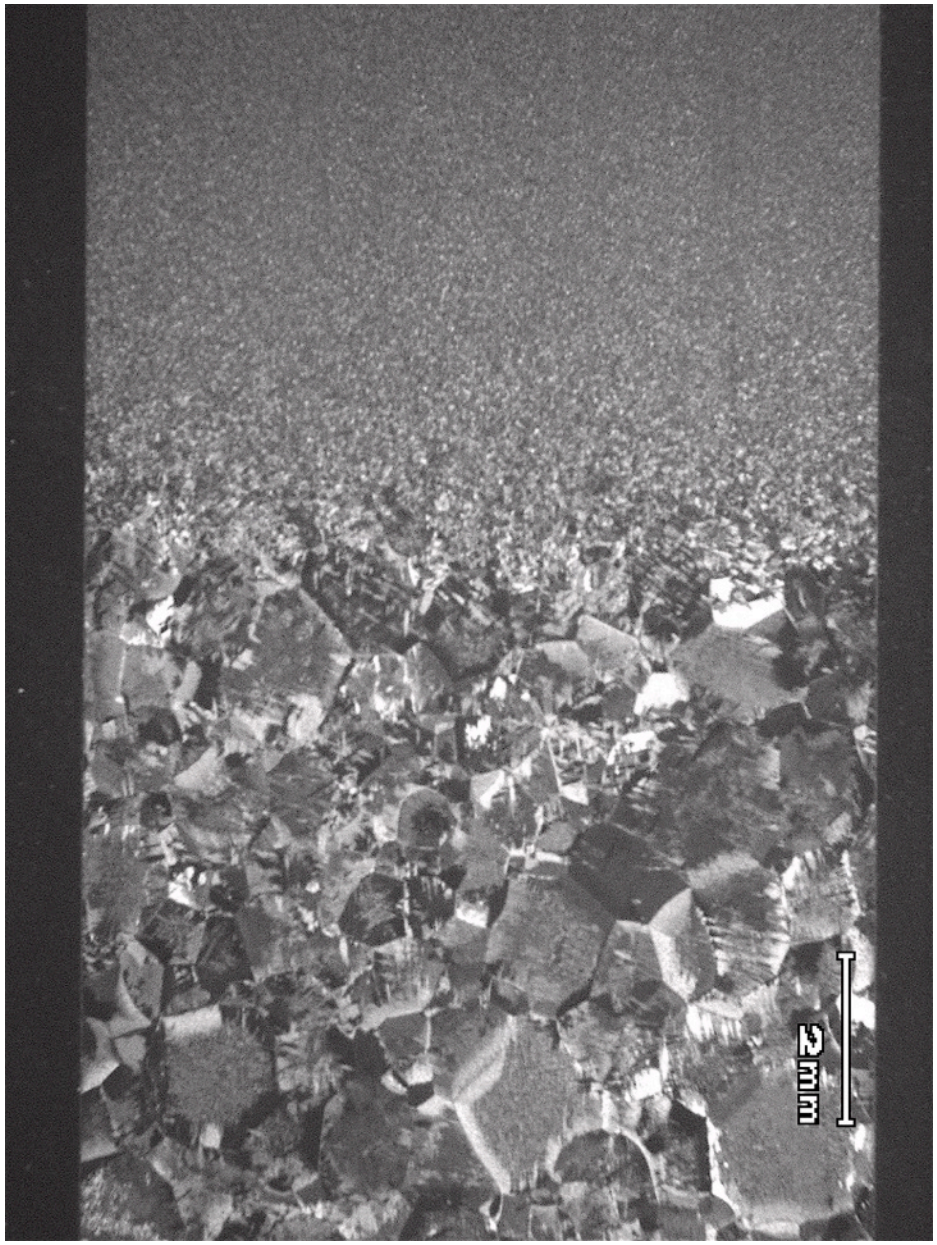


The Open University

CJT

High precision diffusion bonding of Ti-based shrouded turbocharger





High precision diffusion bonding of Ti-based shrouded turbocharger

Virtually invisible bond line

The Open University

CJT

Any questions ?

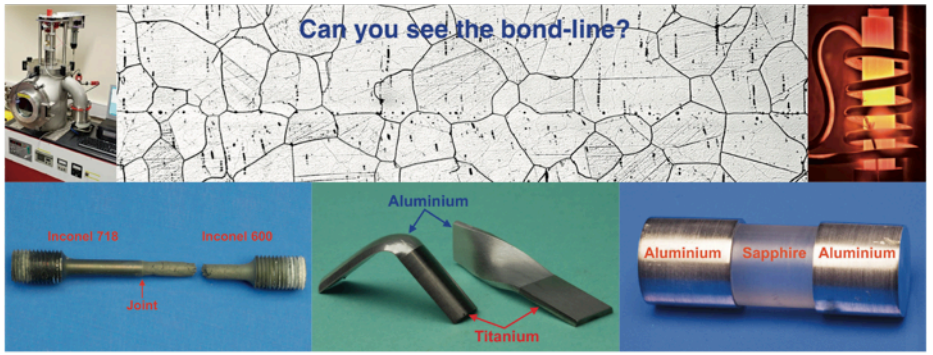
SYMPOSIUM OF WORLD EXPERTS IN DIFFUSION BONDING (WEDB)

The Open University, UK | 20–21 June 2017

ART OF JOINING UN-WELDABLES

"I cordially invite experts in Diffusion Bonding to join this non-commercial symposium in order to exchange ideas and present their research to potential users."

Dr Amir Shirzadi (Chairman)



Sponsors & Contributors

FURTHER INFORMATION & REGISTRATION

mcs.open.ac.uk/wedb/

Google "Diffusion Bonding Experts Symposium"