Investigation of Non-Destructive Examination (NDE) Methods for the Analysis of Be to Cu alloy Bonded Samples

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Introduction

Sampling and destructive testing for QA purposes is not ideal for the First Wall Panels (FWPs) given their high cost of fabrication, yet leaving the possibility that flawed components could remain unrevealed. NDE methods are therefore attractive, both prior to use and during service.

Ultrasonic inspection to date has been the main inspection method used. However, water as a coupling medium presents corrosion risks, and the higher attenuation of oil reduces resolution.

Three other NDE methods have been investigated: X-ray Diffraction, Electrical Resistance Tomography and Pulsed Thermography. The status of on-going work is summarised here. Techniques have been evaluated experimentally and/or via simulation. Plans for further work are also summarised.

The 'defect' considered is a region of debonding at the Be-CuCrZr interface. Defects are therefore flat within the plane of the bond at 10mm depth.

Project Background

The work reported is part of a broader scope to address the following in the context of the Be-CuCrZr bond within the FWPs:

- **Manufacturing optimisation** – characterisation of processes influencing bond formation and performance.
- **In-service performance** – expected bond to performance in the fusion environment.
- **NDE methods** – examination of final bond to verify component integrity.

X-Ray Diffraction (XRD)

XRD can be used to determine change in crystal lattice spacing and therefore strain. Multiple measurements can derive full stress tensor[1].

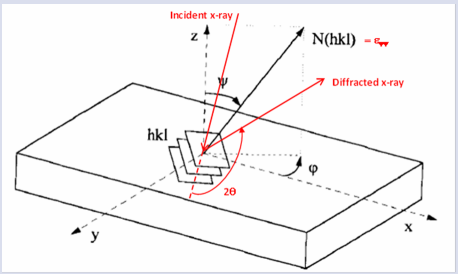

Figure 1 Principle of Strain Measurement via XRD[1]

Whereas measurements are normally restricted to a component surface, Be has low x-ray attenuation properties[2], potentially permitting measurement of residual stress at the Be-CuCrZr bond with sufficiently energetic x-rays. This could support quantitative evaluation of bond integrity and/or validation of HIP simulations. Stress discontinuities may also be used to indicate debonding.

In practice, high background radiation was encountered, attributed to incoherently scattered x-rays in the Be, swamping any weaker diffraction that might originate from the bond interface. Background intensity increased with reduced x-ray path through Be in near-edge measurements (see Figure 2). Scattering is lower for lower energy x-rays, but conversely gives less penetration depth.

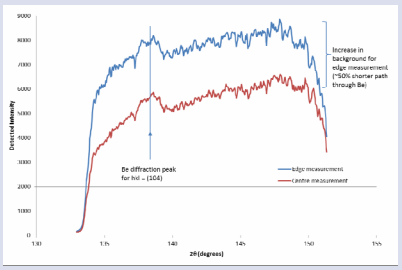

Figure 2 Single Exposure X-ray Profiles for Middle and Edge Measurements

Example results in Figure 3 from Be-diffractions verify sample origin as a corner piece of larger HIP'ed block. Due to the large penetration depth, magnitudes represent an average through Be thickness. The large stress gradient towards edge could not be captured with 2mm collimator used in this case. Collimator size therefore limits resolution of near-edge stresses.

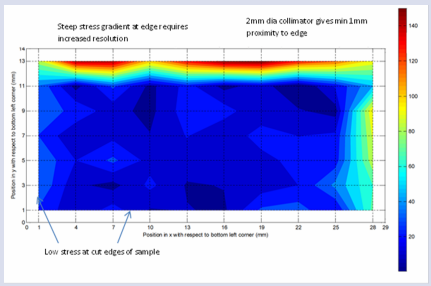

Figure 3 Contour Plot of Maximum Shear Stress Measured within Bonded Sample (preliminary)

Further work will aim to better understand Be/x-ray interactions and thereby develop techniques for filtering/masking to minimise the observed background. A synchrotron source will also be used to access a wider spectrum of energies and for depth profiling.

Electrical Resistance Tomography (ERT)

Technique involves injection of current between pairs of electrodes to yield a distribution of conductivity through measurements of electrical potential around the component. Bond defects are detectable as discontinuities in the conductivity distribution. This method is non-invasive and may also detect disbonds without an air-gap, as is required in ultrasonic measurements.

FEA has been used initially evaluate this technique. Simple 2D and 3D FE models have been analysed using the electrical conduction models available in Abaqus [3] for 10A steady state (d.c) current injection.

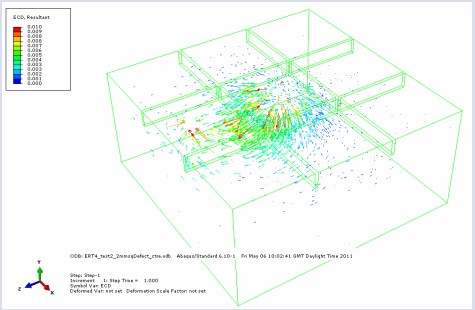

Figure 4 FEA of Electrical Conductance (9-tile)

Key findings include:

- High conductance of Be and CuCrZr with depth gives low, but measurable, voltages for a practical current of 10A (0.1-0.5 mV)
- Low frequency (1 – 10Hz) needed to optimise skin depth[4], but additional processing is required for higher signal noise in practice.

Further work will aim to determine configurations of electrodes for optimal sensitivity to defects.

Pulsed Thermography

Thermal energy is delivered by means of photographic flashes to a surface. Discontinuities provide resistance to thermal conduction detectible using an IR camera. Signal processing routines (e.g. FFT, TSR [5]) improve resolution. Technique is simple and inexpensive with minimal safety concerns compared to ultrasonic (wet) and x-ray methods.

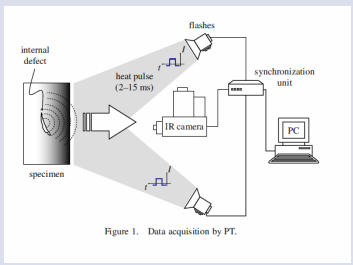

Figure 5 Pulsed Thermography System[4]

A system delivering 12kJ of energy in a 0.32 second pulse has been trialled with a defect-free sample. Further tests of samples with defects is pending and will be reported in later work. In interim, FEA used to evaluate technique for bond defects.

Key observations:

- High thermal conductance of Be and CuCrZr requires fast sampling rate to capture rapid temperature changes
- Although bond defect clear in FEA results, surface temperatures vary by < 0.1°C, which is close to the camera limit of 0.01°C
- Clearest evidence of defect from surface temperatures occurs shortly after heat pulse, which can be improved using FFT

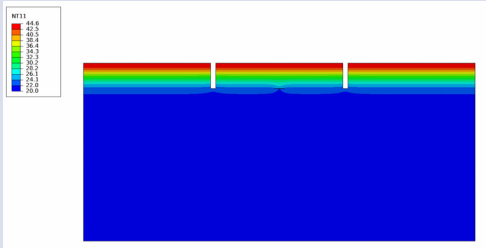

Figure 6 Transient Heat Transfer Analysis of Heat Pulse in Abaqus

References

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3.Abaqus/CAE and /Standard, Version 6.10-1, Simulia Inc.

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