Plasma-sprayed Be-armored FW mock-ups for ITER

VLT Teleconference

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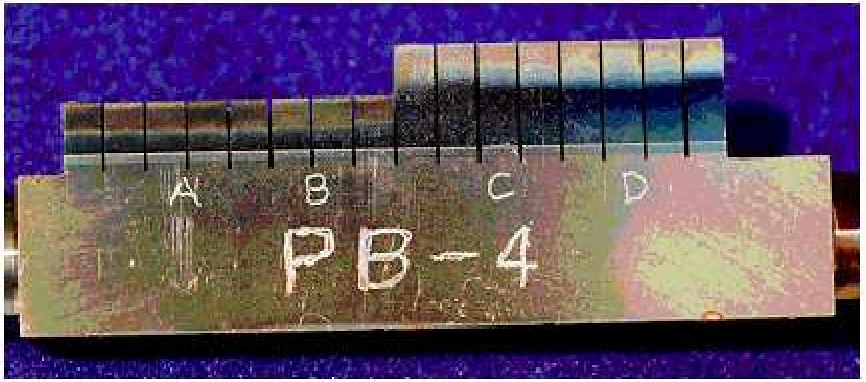
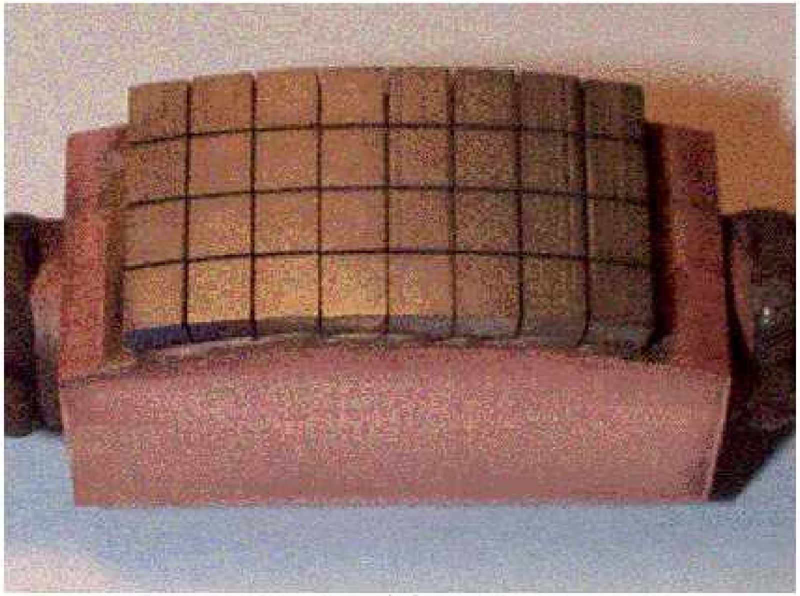
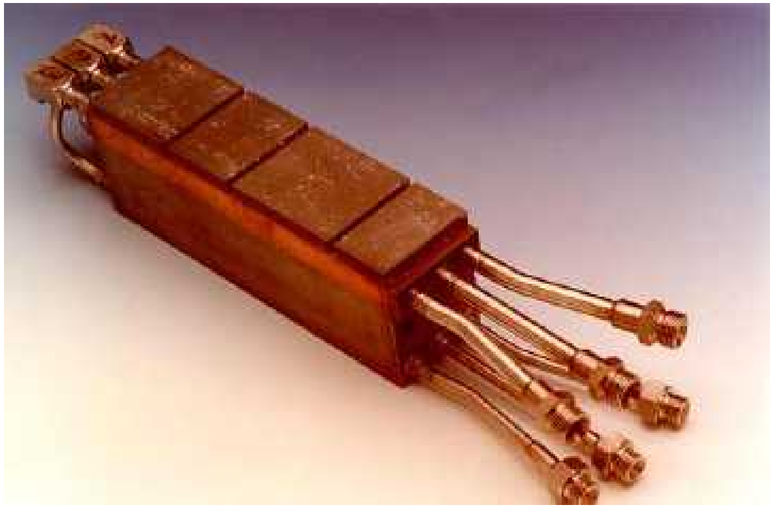
Cu/Be Tile Test Parts



US HIP bond w/AlBeMet interlayer (1000 cycles at 10 MW/m^2)



Russian Fast Amorphous CuInSnNi Braze (4500 cycles at 12MW/m^2)



EU HIP bond with Ti interlayer (1000 cycles at 2.5 MW/m^2)

Tile Bonding Versus Plasma Spray

Powder
↓
Hot Press Log
↓
Machine Tiles
↓
Braze or HIP Bond
↓
Replace for Repair
↓
Long Downtime

Powder
↓
Plasma Spray
↓
In-Situ Repair
↓
Resume Operation

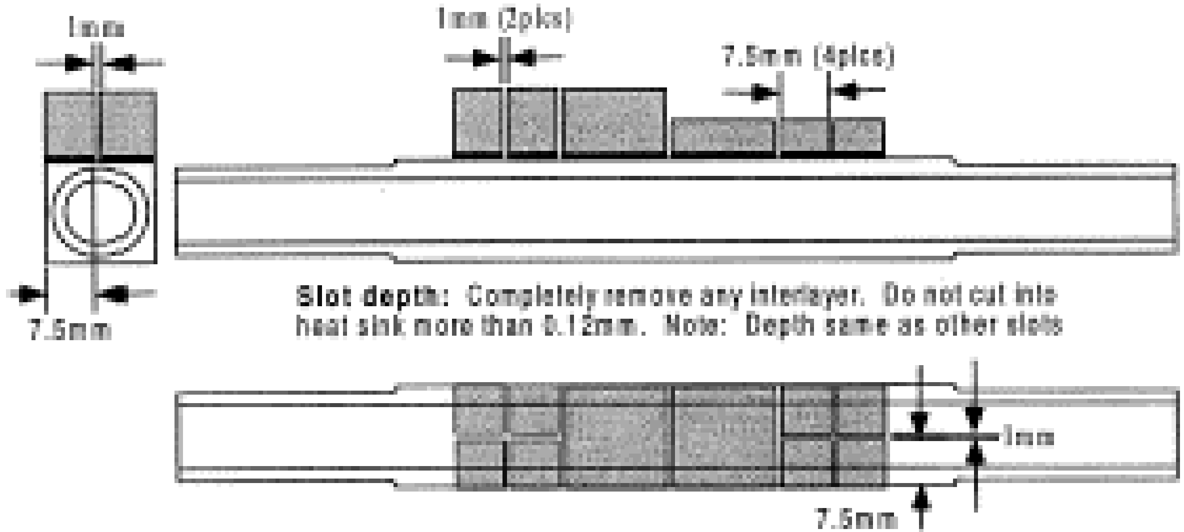
Edge Lifting for SS Sample

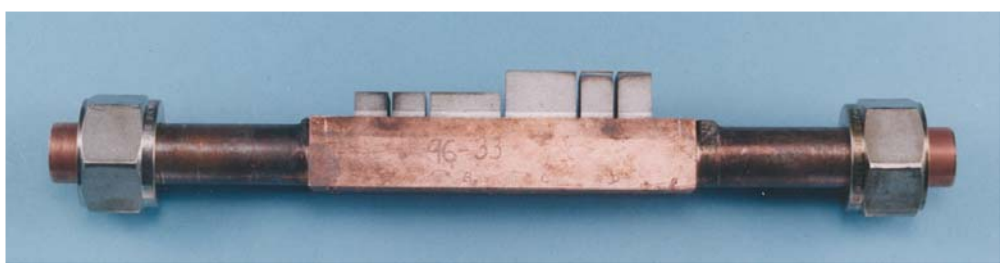
Spray induced stresses limit size scale-up!

Previous Method for Stress Control

- Functionally graded material interface to avoid the abrupt CTE change between the Cu alloy and Be
- Cu-Be diffusion barrier to avoid formation of brittle intermetallic
- Castellation of coatings in 16 mm and 7.5 mm square areas (for testing)
- Compliant interlayer to accommodate strains by plastic deformation

Post-Spray Castellation/Interlayer



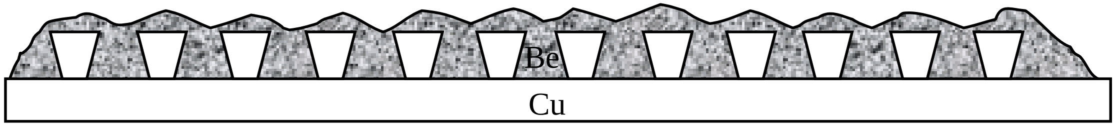


ITER needs robust Be/Cu joints.

*Thermophysical properties of materials and the thermomechanical limitations of PFCs are fundamental. Like the W-rod pfcs, we seek to control fatigue cracking and inhibit armor delamination through engineering.

LANL plasma spray concept presents opportunities.

- **Control of thermal fatigue cracking & scale-up to larger pfc sizes**
- **Mechanical interlocking to castellated copper**
- **Minimize P.S. splat boundaries**
- ***In situ* repair**



Spray Conditions

Torch Current: 550 A

Torch Arc Gas: 50 slm Ar-4%H_2

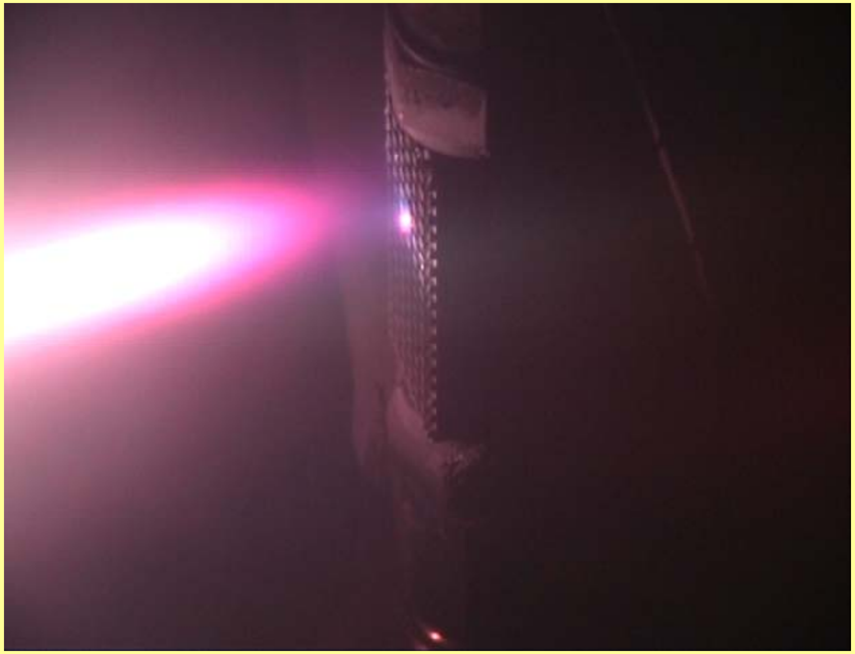
Powder Gas: 2.5 slm Ar

Standoff Distance: 95 mm

Substrate Temperature: 600-650°C

Substrate: CuCrZr

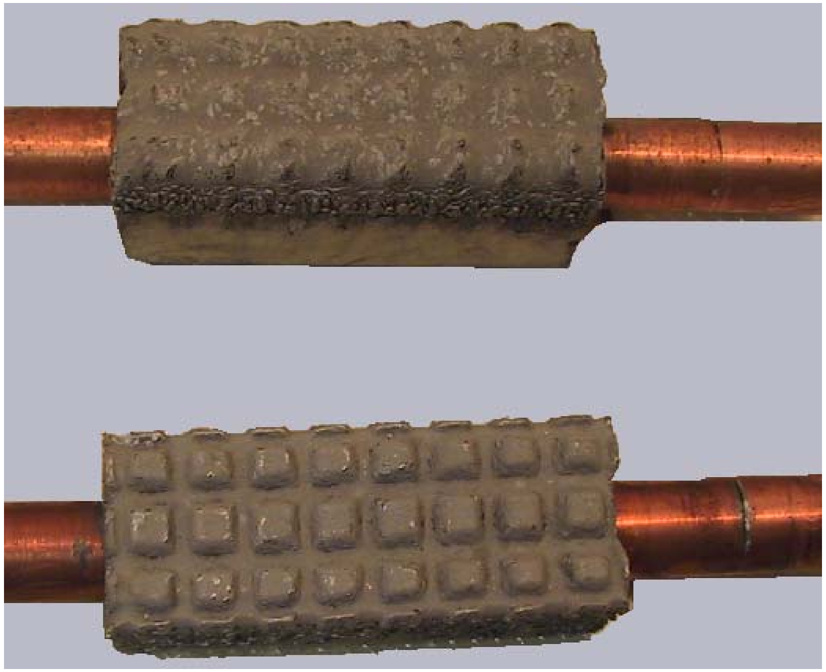
TA pre-cleaning and cleaning during deposition

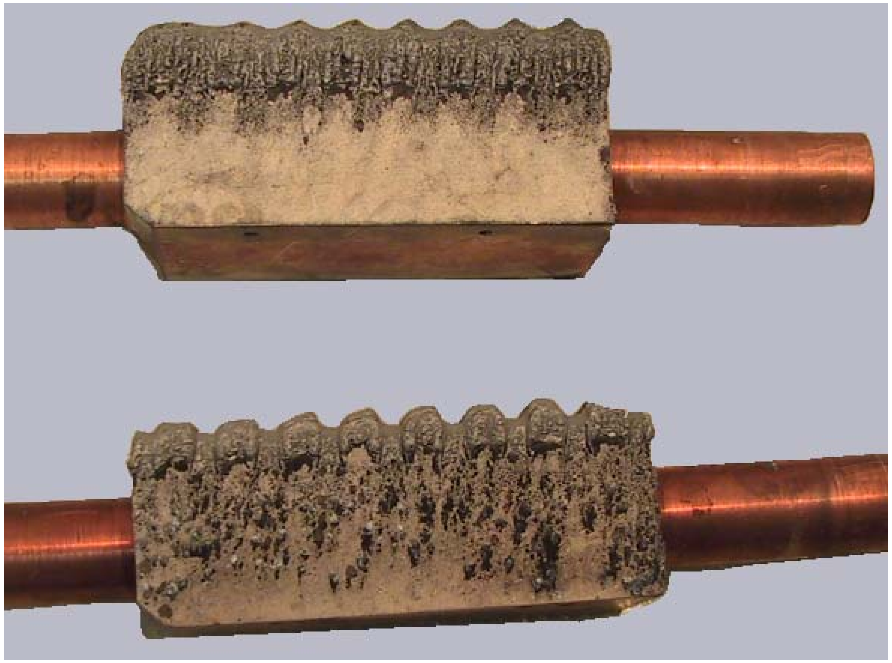


Deposition of 5 mm coating

LANL Plasma-Sprayed FW Be armored mock-ups

5 mm and 10 mm P.S. Be on Cu castellations





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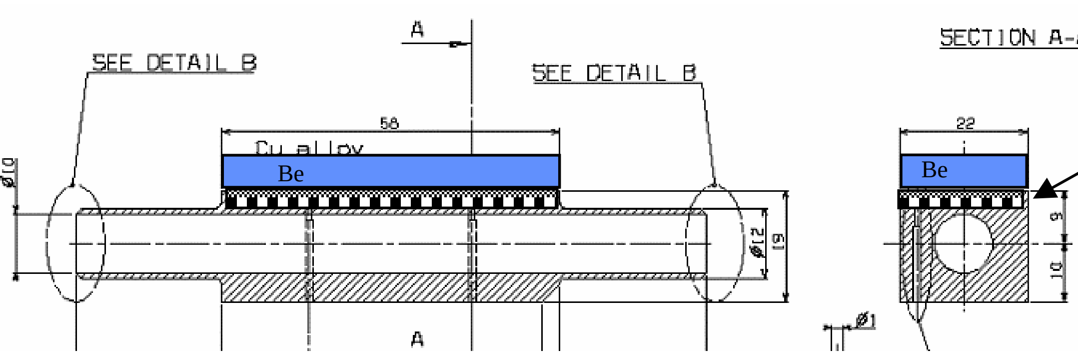
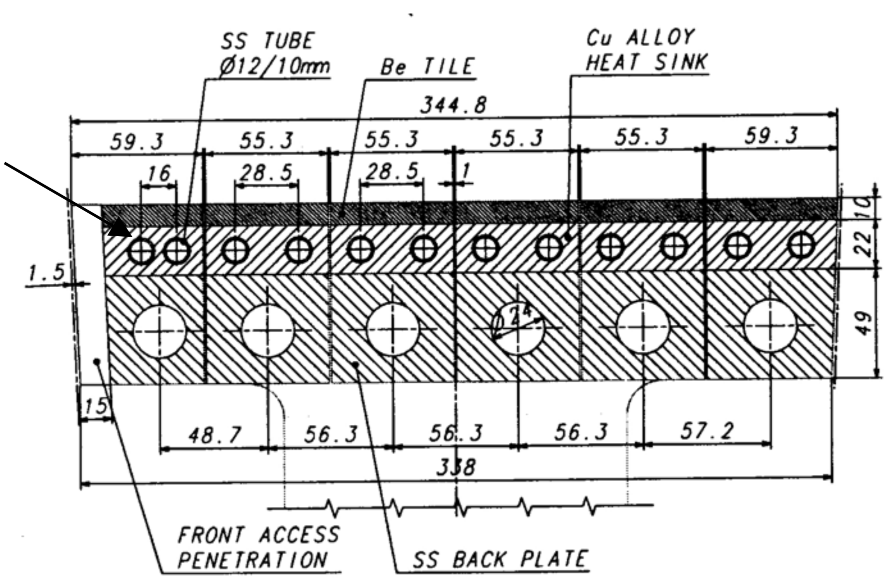
The EFDA mock-ups actually have less Cu alloy under the Be than current ITER FW design.

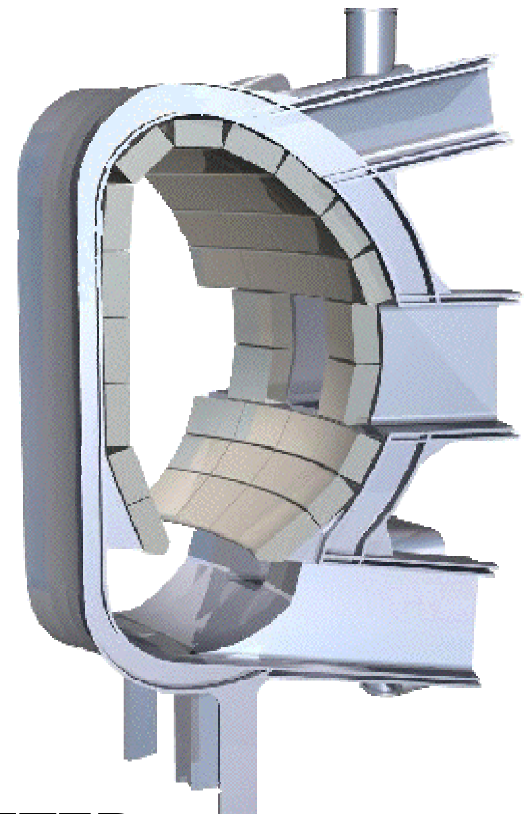
LANL mock-ups



3.5 mm Cu

5 mm Cu





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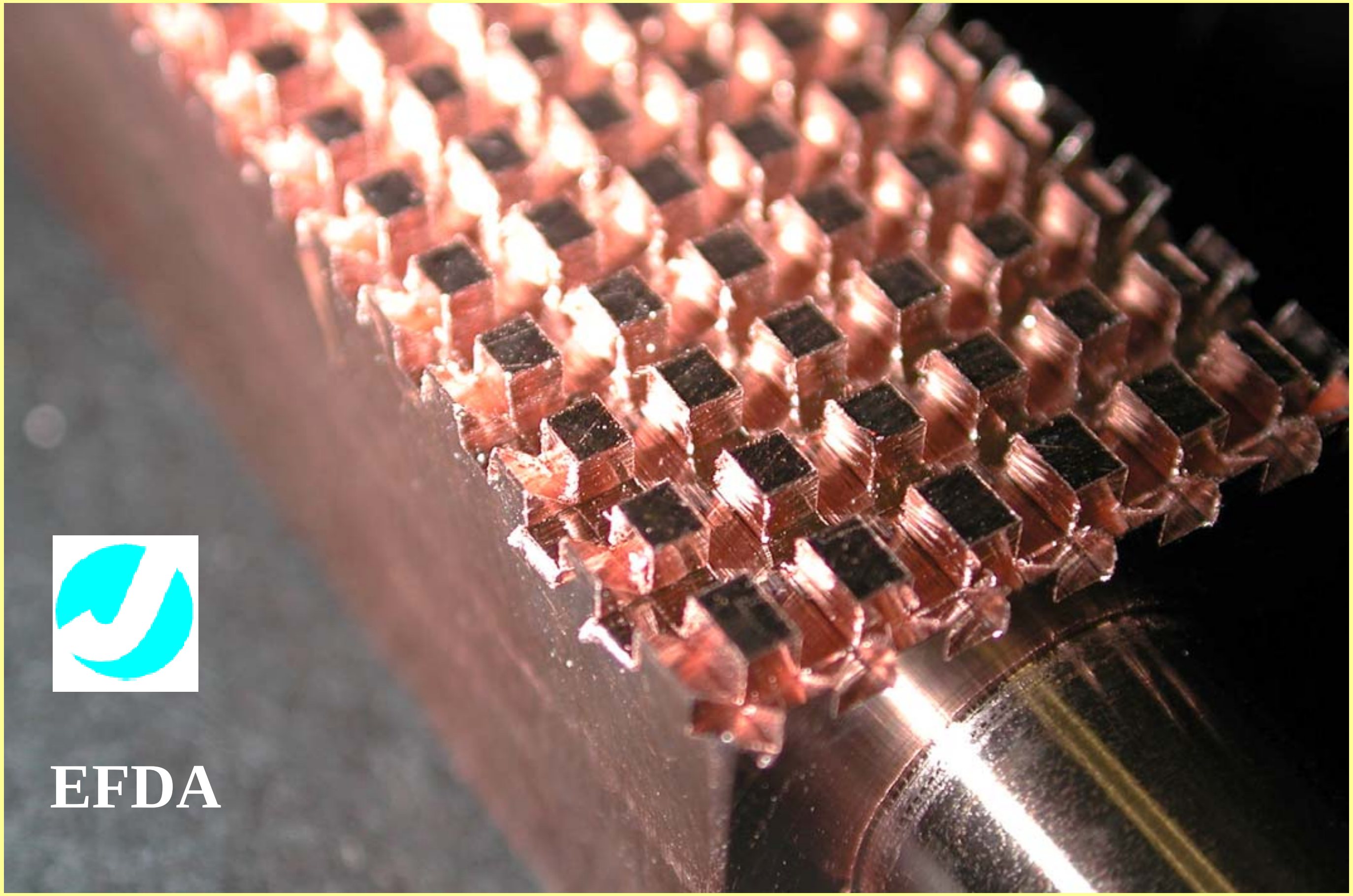
Cu Pattern for 5mm Coating

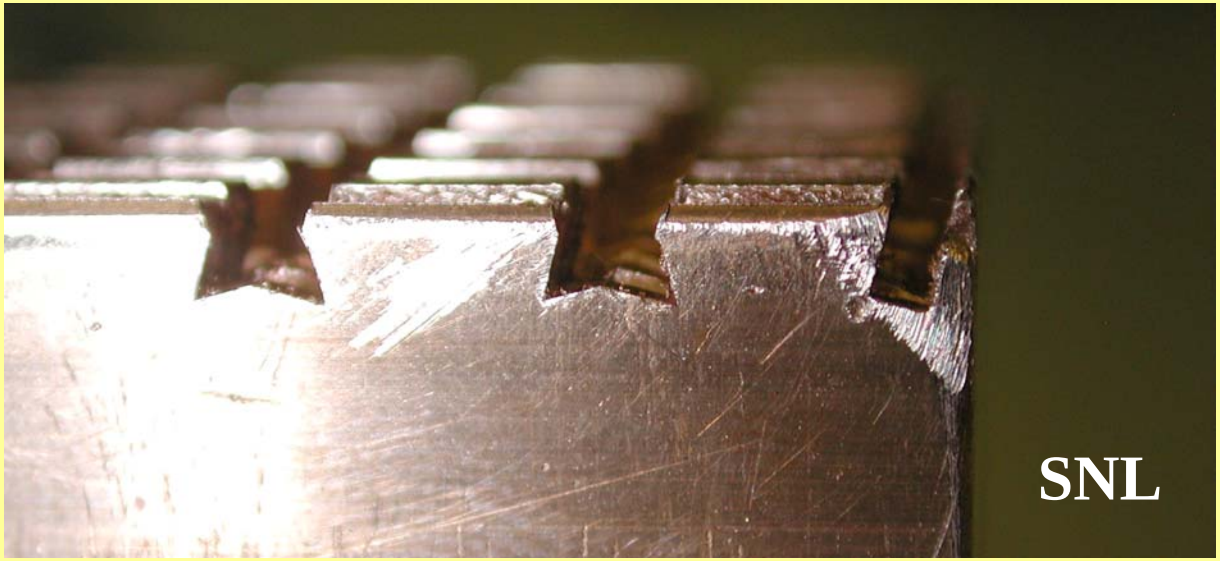


1.5 mm feature height – parallel grid

Requirements for EFDA Project

- 5 and 10 mm thick Be coating on 22 mm x 58 mm CuCrZr alloy to withstand high heat flux
- Cu alloy temperature below 650°C to maintain strength (prevent over aging)
- Minimal post-spray machining (none if possible)
- No intermediate layers between the Cu alloy and the Be coating

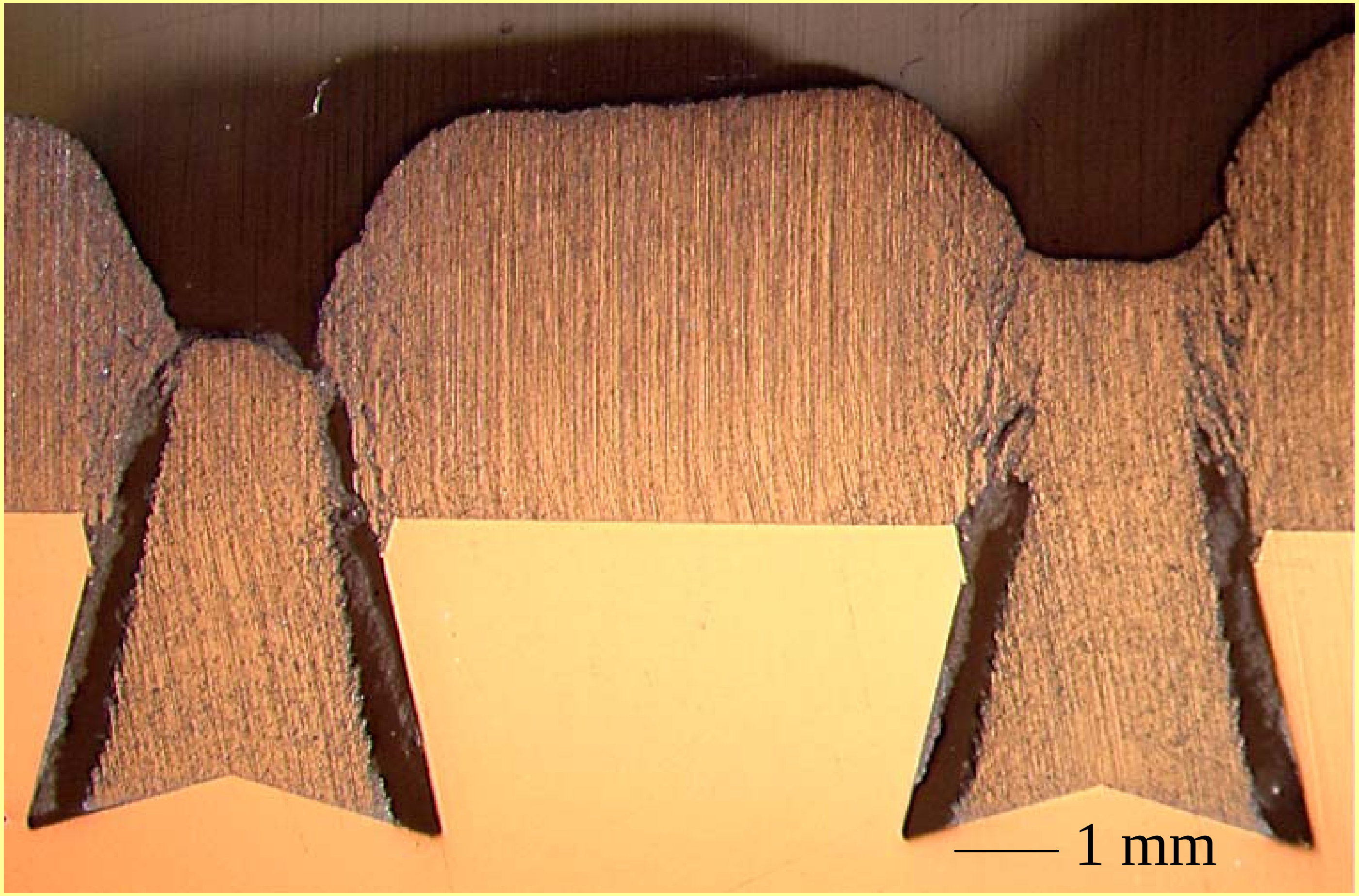
Dovetail Pattern



•Better mechanical locking

•More defined weak bands

BeAl on Cu Dovetail



Improvements of New Approach

- No edge lifting observed - better performance
- No run off plates used during spraying - less material used and no Be machining required
- Segmented structure without Be machining
- Scale up is more feasible since segmenting occurs during fabrication instead of afterward

High Heat Flux Testing

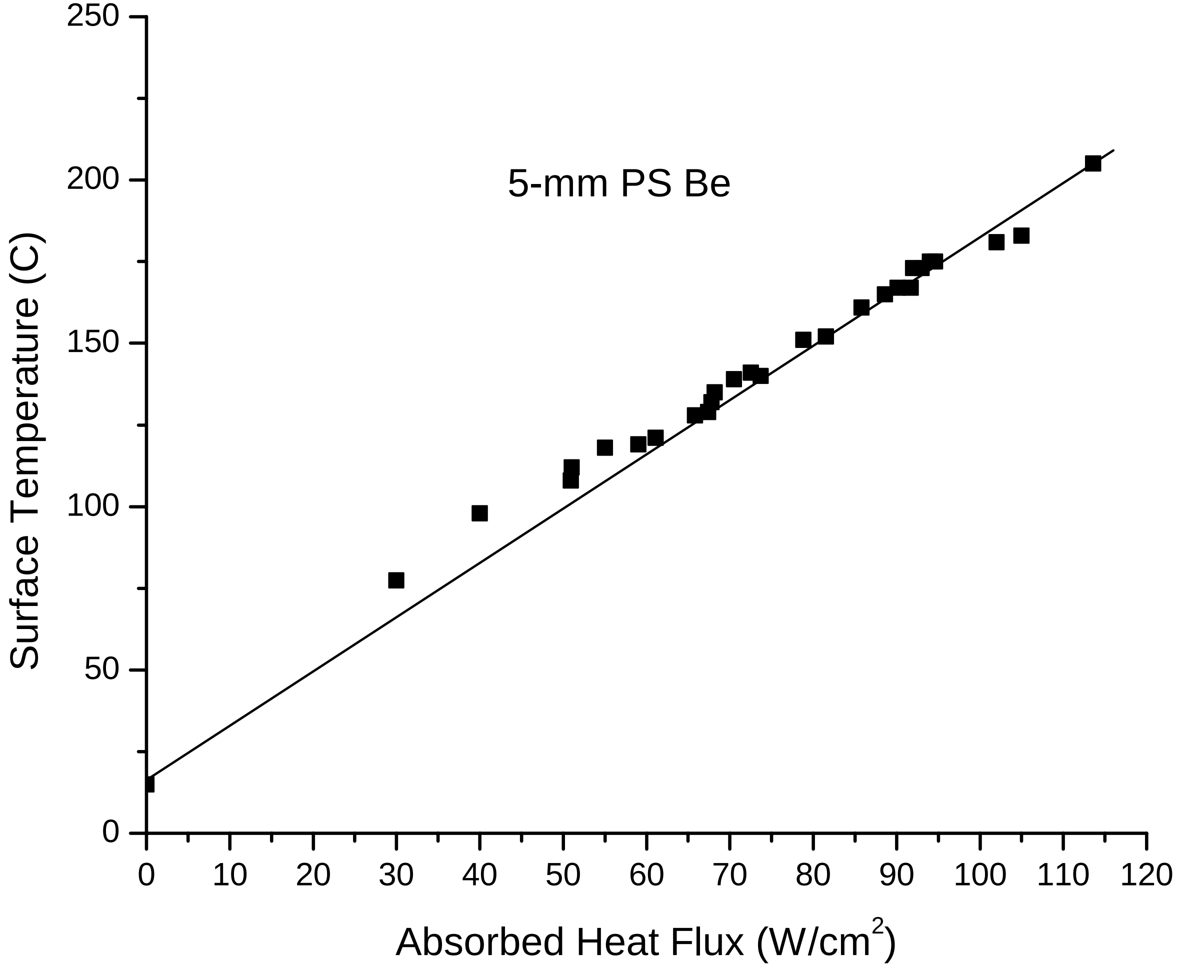
- Square projection 5 and 10 mm samples were tested in the JUDITH electron beam facility at Forschungszentrum Jülich (FZJ), Germany (5-mm survived 1000 cycles @ 3 MW/m^2,10-mm 1000 cycles @ 1.5 MW/m^2)
- Dovetail projection 5 and 10 mm samples now being tested in the EBTS at Sandia National Laboratories-New Mexico. (5-mm survived 1000 cycles @ 1 MW/m^2)

Synopsis of SNL test plan

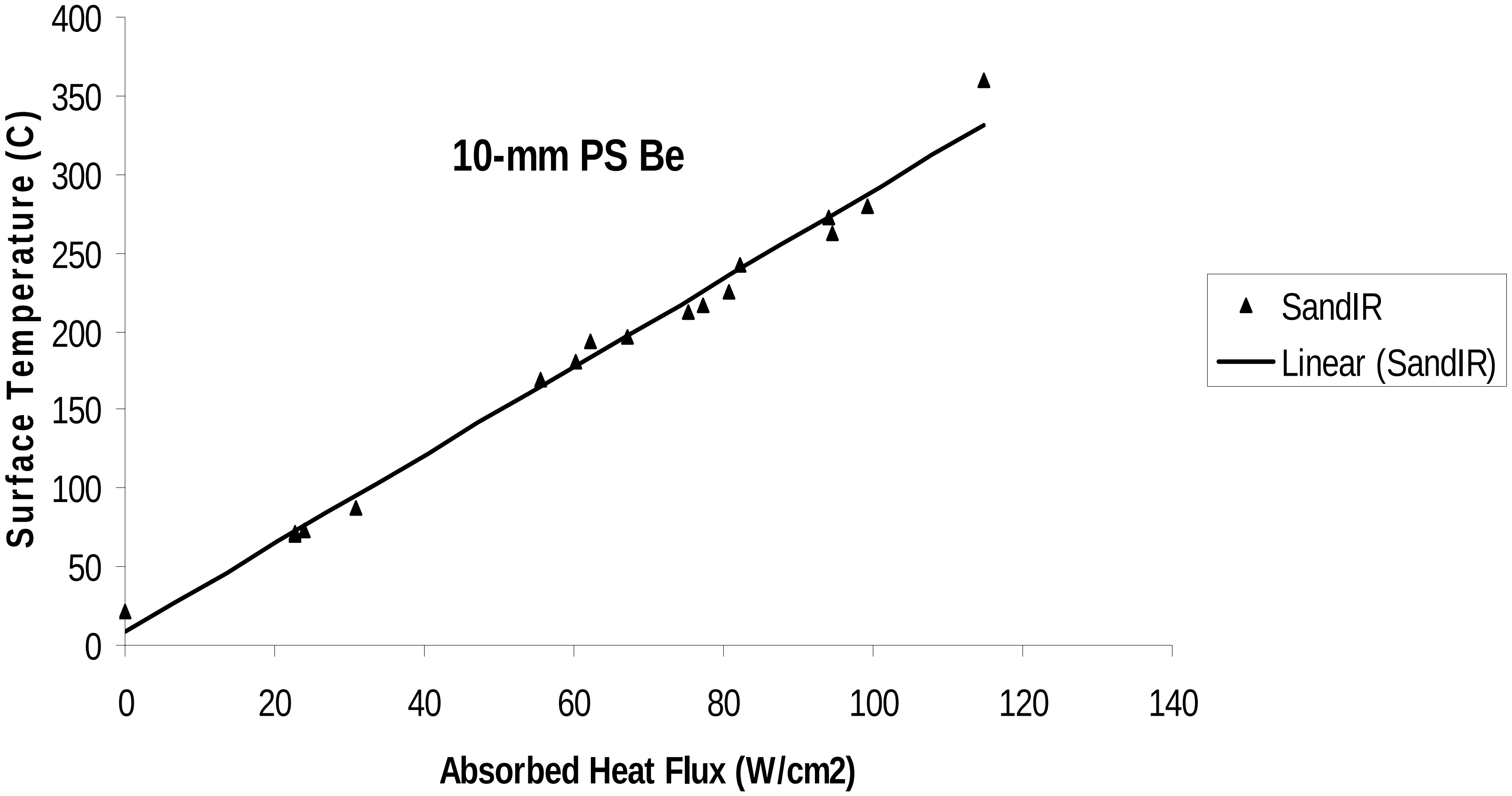
- Thermal response curve
- 5-mm to 2 MW/m^2, 10-mm to 1 MW/m^2
- Fatigue cycles
- Borescope inspections every 200 cycles
- Pyrometer/IR calibrations every 400 cycles

Flow: 10 m/s, 1.0 MPa, 16-20 ^oC water

Completed thermal response of 5-mm-mock-up to 1 MW/m².



Completed thermal response of 10-mm-mock-up to 1 MW/m^2.



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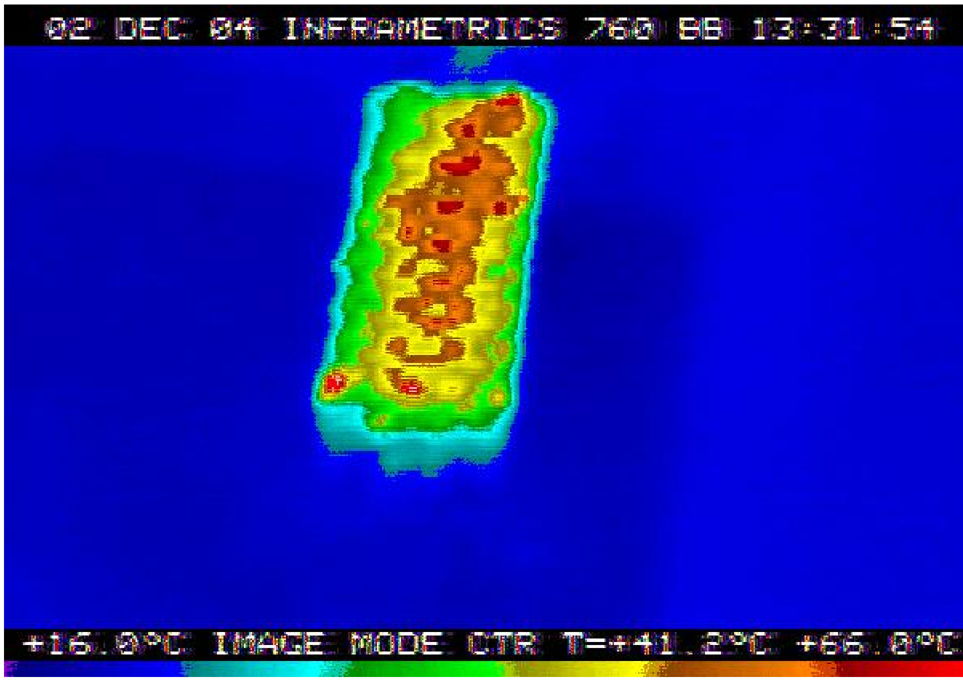
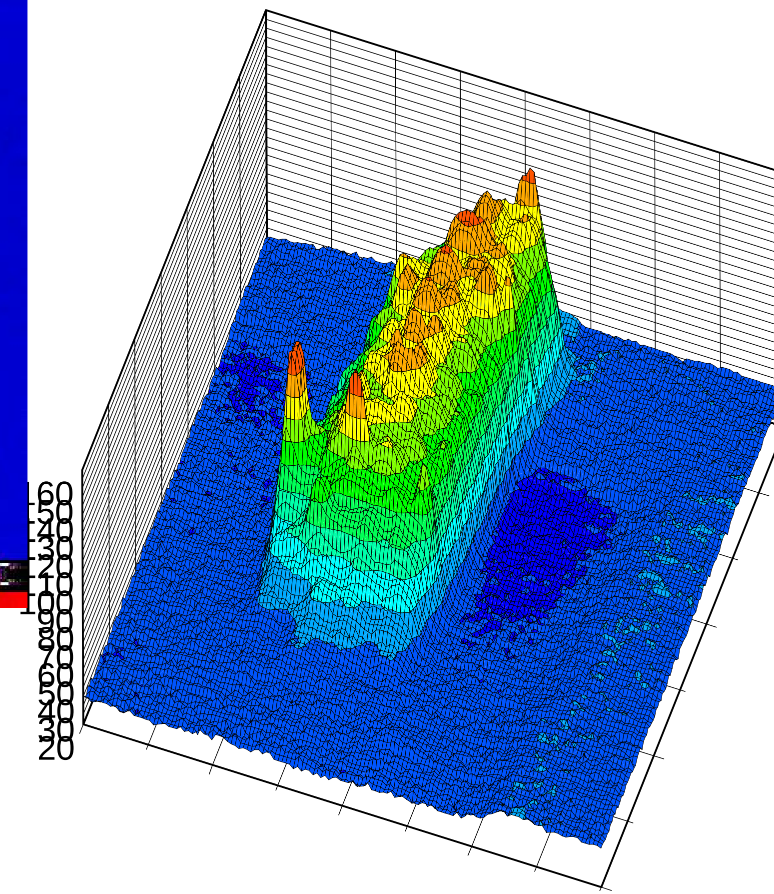
Consistent surface temperature distribution during fatigue cycling





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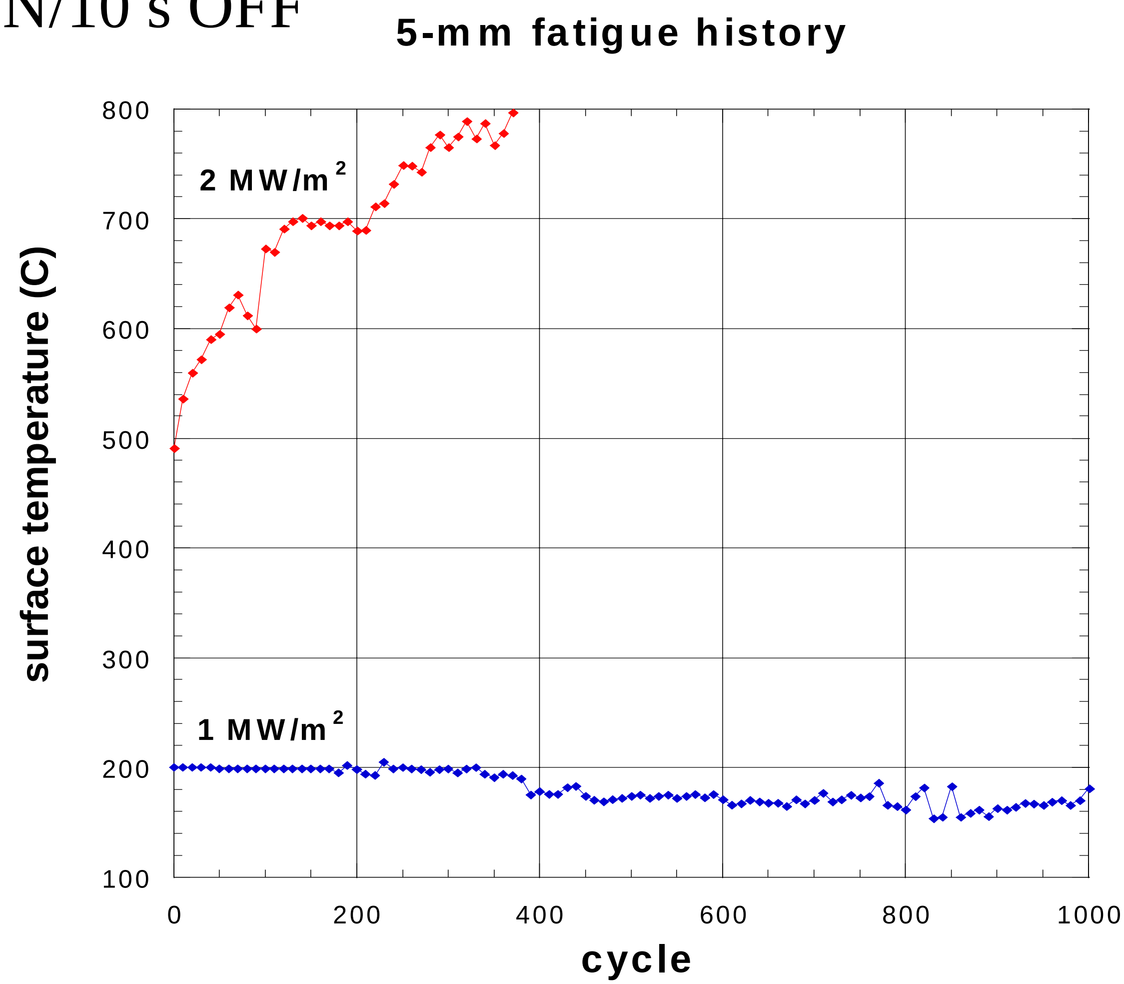
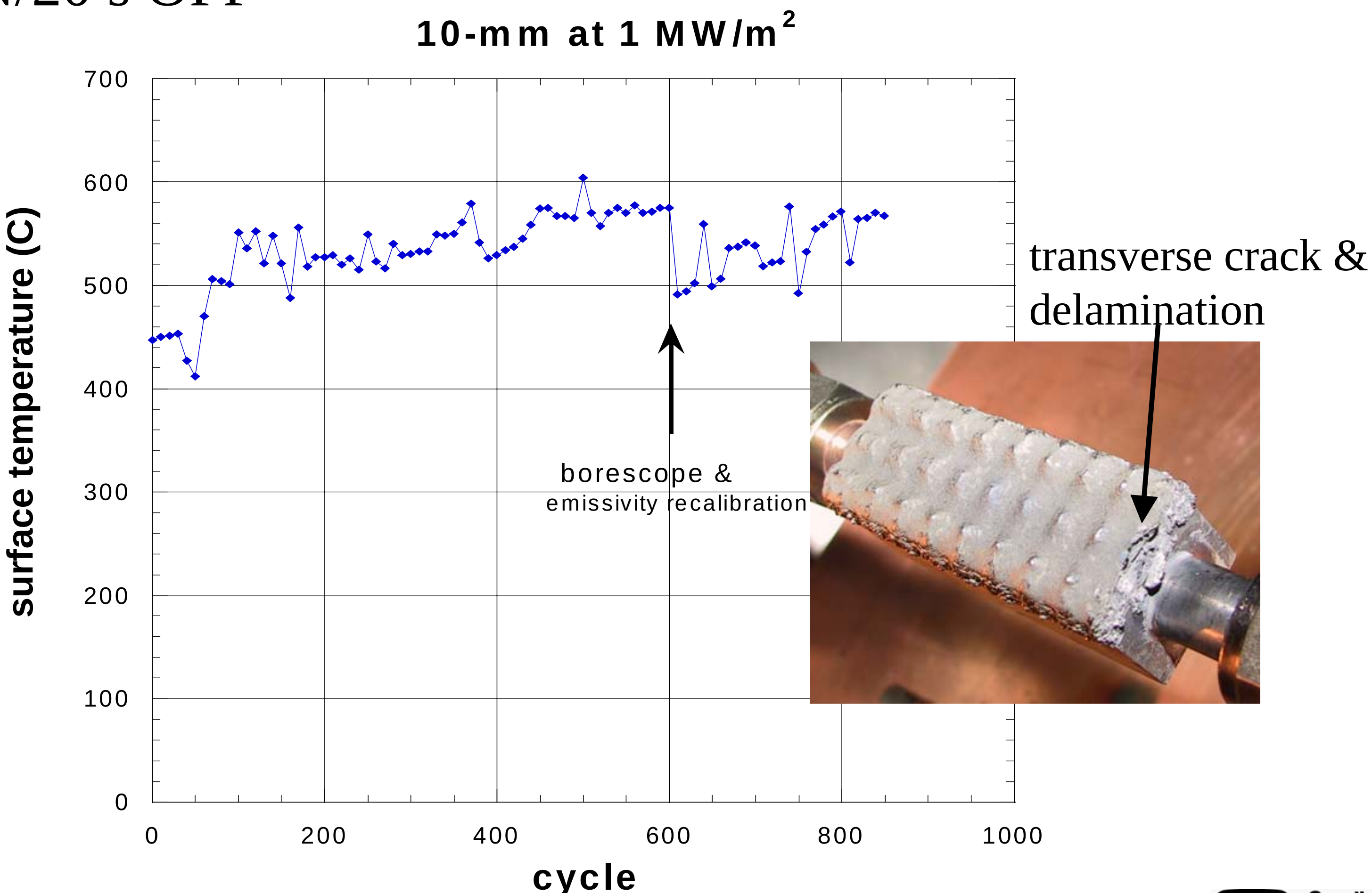
1000 cycles at 1 MW/m² with no damage.

10 s ON/10 s OFF



Survived 856 cycles at 1 MW/m^2 before damage.

15 s ON/20 s OFF



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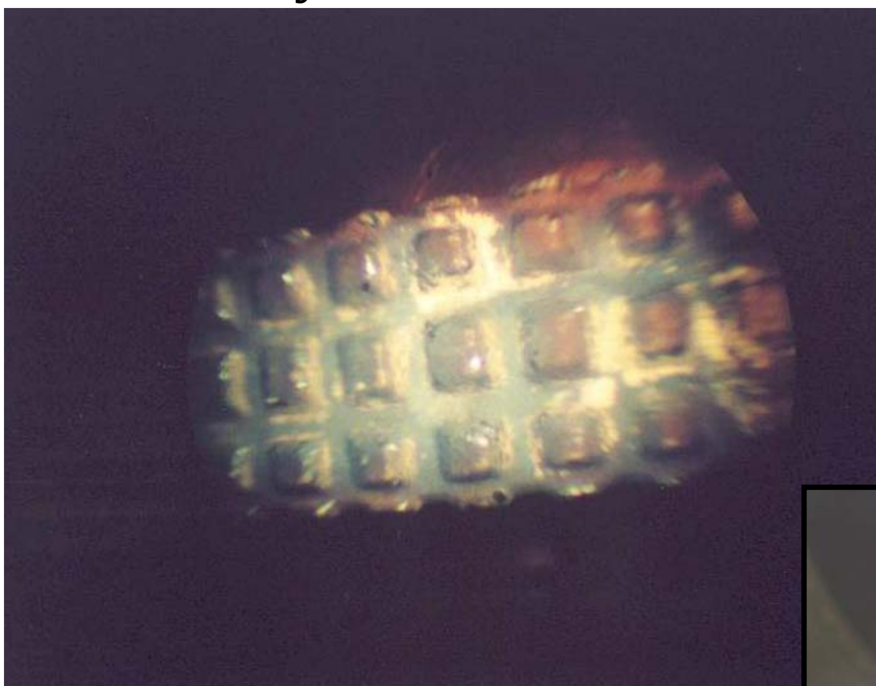
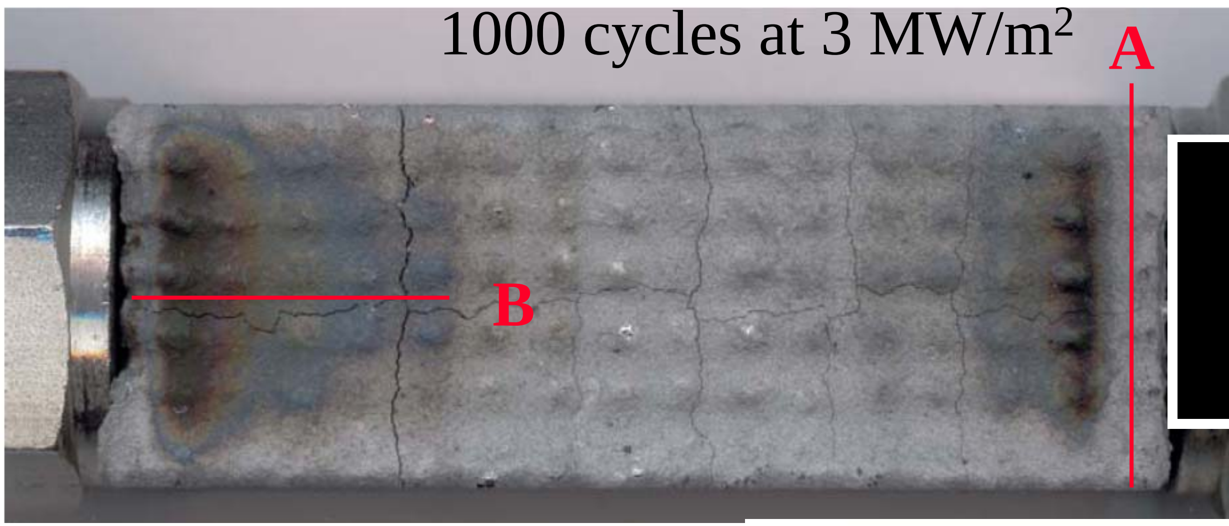
Borescope inspections performed every 200 cycles.

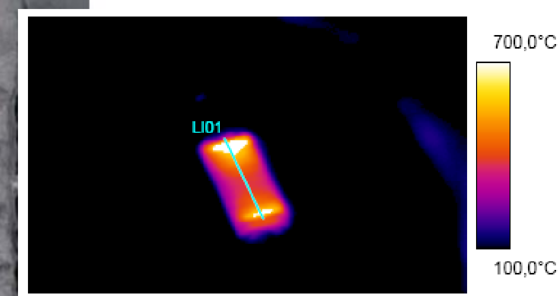
200 cycles at 1 MW/m^2

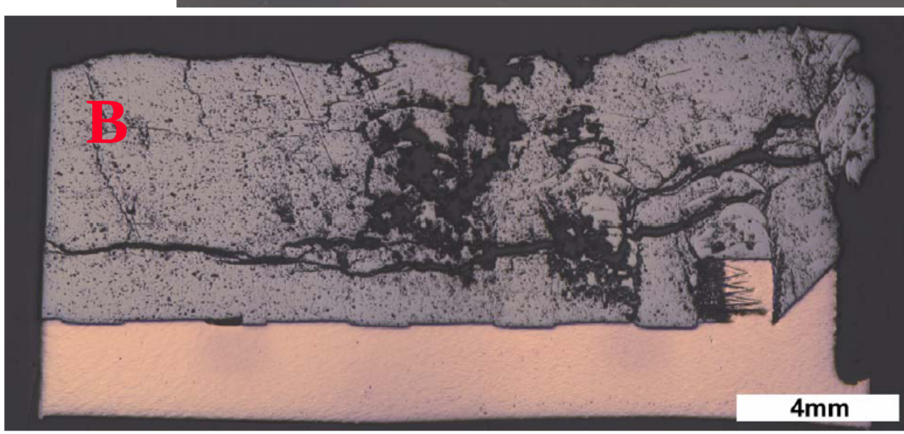


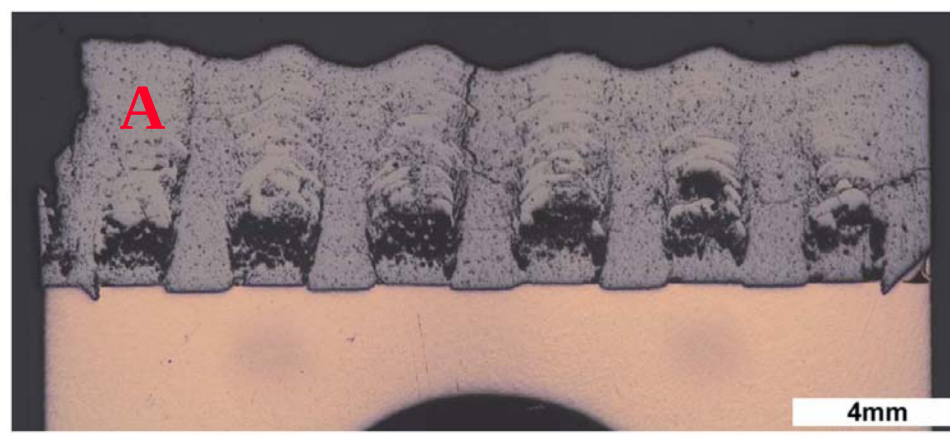
initial condition

Fatigue cracking on the EFDA samples was mostly in the preferred direction.









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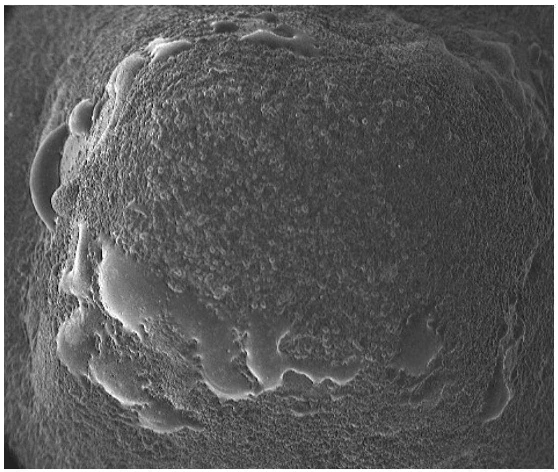
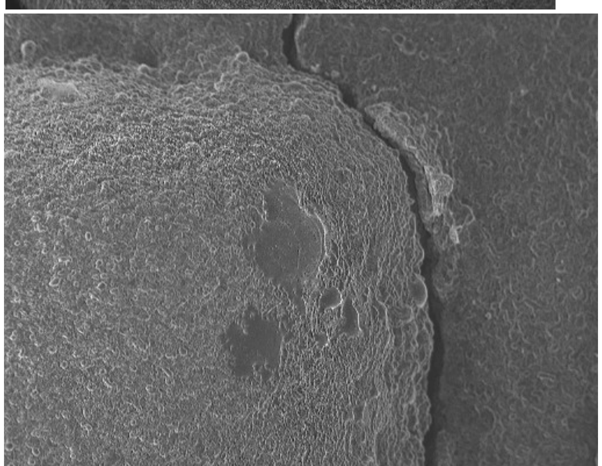
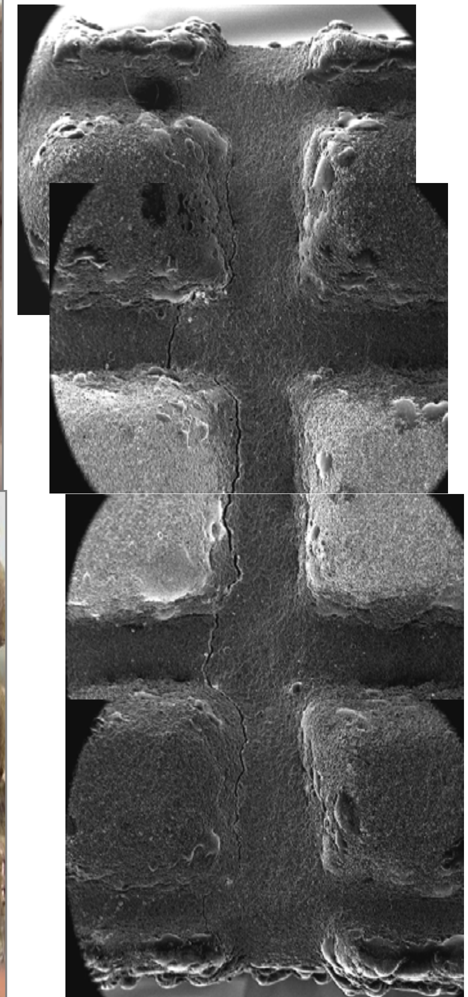
The US samples experienced localized melting at the peaks and transverse cracking only.

5-mm sample







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Conclusions

- Castellation of substrate to control cracking in plasma-sprayed Be appears promising
- FW heat loads, thermal fatigue not an issue
- Plasma spray offers possibility of *in situ* repair
- 3-d castellations needed – develop manufacturing techniques
- Issues regarding adaptation to ITER FW geometry remain
- Good collaborations exist to carry forward