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

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D. L. Youchison
Sandia National Laboratories

K. J. Hollis
Los Alamos National Laboratory

M. Rodig
Forschungszentrum, Juelich

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Cu/Be Tile Test Parts

US HIP bond w/ AlBeMet interlayer (1000 cycles at 10 MW/m²)

Russian Fast Amorphous CuInSnNi Braze (4500 cycles at 12 MW/m²)

EU HIP bond with Ti interlayer (1000 cycles at 2.5 MW/m²)
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

Slot depth: Completely remove any interlayer. Do not cut into heat sink more than 0.12mm. Note: Depth same as other slots.
ITER needs robust Be/Cu joints.

*Thermophysical properties of materials and the thermomechanical limitations of PFCs are fundamental. Like the W-rod pfc, 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%H₂
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
The EFDA mock-ups actually have less Cu alloy under the Be than current ITER FW design.

LANL mock-ups
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/m², 10-mm 1000 cycles @ 1.5 MW/m²)

• 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/m²)
Synopsis of SNL test plan

• Thermal response curve
• 5-mm to 2 MW/m², 10-mm to 1 MW/m²
• Fatigue cycles
• Borescope inspections every 200 cycles
• Pyrometer/IR calibrations every 400 cycles

Flow: 10 m/s, 1.0 MPa, 16-20 °C water
Completed thermal response of 5-mm-mock-up to 1 MW/m².
Completed thermal response of 10-mm-mock-up to 1 MW/m².
Consistent surface temperature distribution during fatigue cycling
1000 cycles at 1 MW/m² with no damage.

10 s ON/10 s OFF  

5-mm fatigue history

![Graph showing surface temperature over cycles with two lines representing 1 MW/m² and 2 MW/m².](image)
Survived 856 cycles at 1 MW/m² before damage.

15 s ON/20 s OFF

10-mm at 1 MW/m²

transverse crack & delamination

borescope & emissivity recalibration

Surface temperature (°C)

Cycle
Borescope inspections performed every 200 cycles.

200 cycles at 1 MW/m^2
Fatigue cracking on the EFDA samples was mostly in the preferred direction.
The US samples experienced localized melting at the peaks and transverse cracking only.

5-mm sample
Conclusions

• Castellations 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