Bonding Tungsten to Low Activation Ferritic Steel

Glenn Romanoski, Lance Snead, Adrian Sabau, Muralidharan Govindarajan, Joseph Kelly, et al.

March 4, 2005

Fabrication and Characterization
Tungsten Armored Low Activation Ferritic Steel

Objective: Evaluate methods for bonding tungsten to F82H Steel and assess the integrity of these coatings under IFE relevant thermal fatigue conditions.

Approach: Focus on achieving mechanical and thermal similitude at the W-Steel interface.

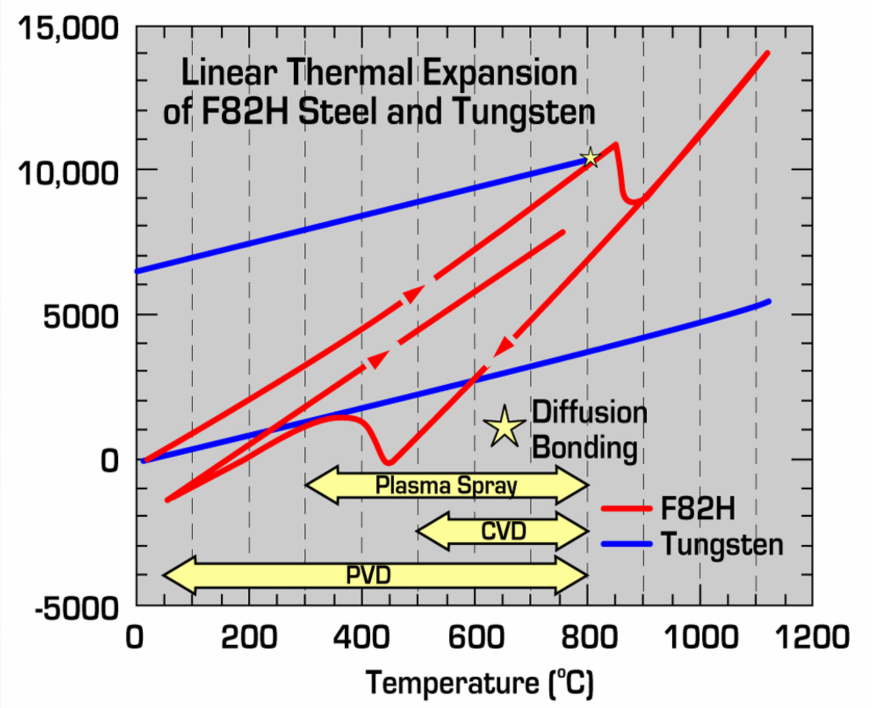
Tungsten Clad LAF
Potential Damage - Failure Modes

a. **Spallation – Stain mismatch**
b. **LCF – Excursions to Ambient**
c. **DBTT in Tungsten – Impurity Issue**
d. **HCF Failure – through thickness and interface cracking**
e. **Thermochemical** and irradiation **stability of F82H at W-LAF interface.**
f. He evolution and spallation
g. Thermomechanical performance of LAF
   Creep and Creep-Fatigue

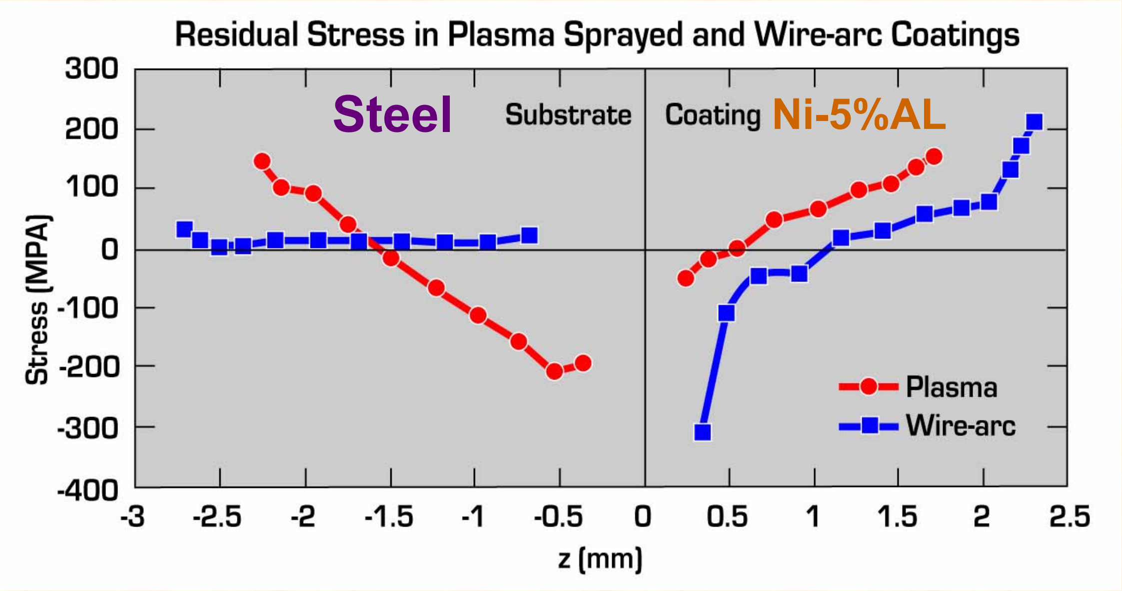
Tungsten Cladding of F82H Steel

Fabrication method defines the initial state of the interface.

- PVD
- CVD
- Plasma Spraying
- Engineered Structures



Interfacial stress in plasma sprayed coatings and substrates can be measured by neutron diffraction.

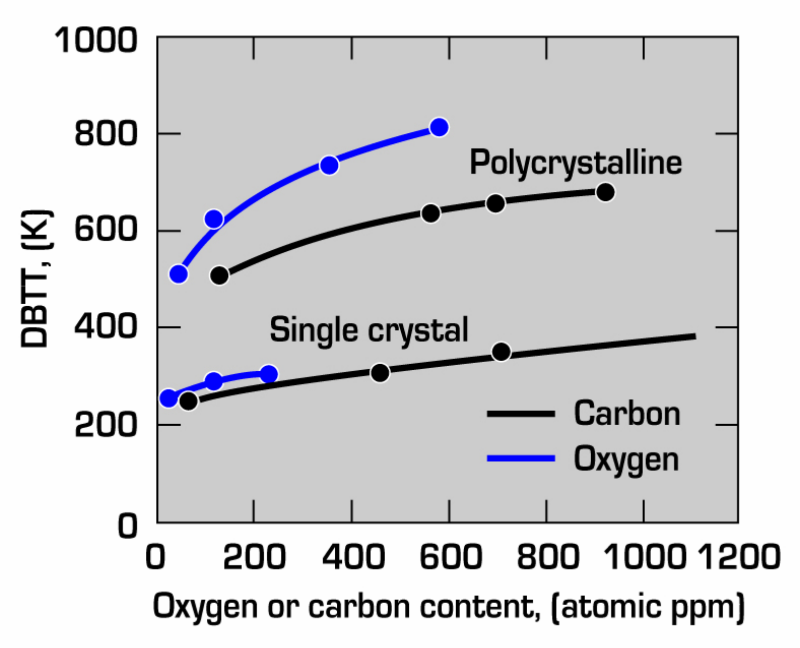


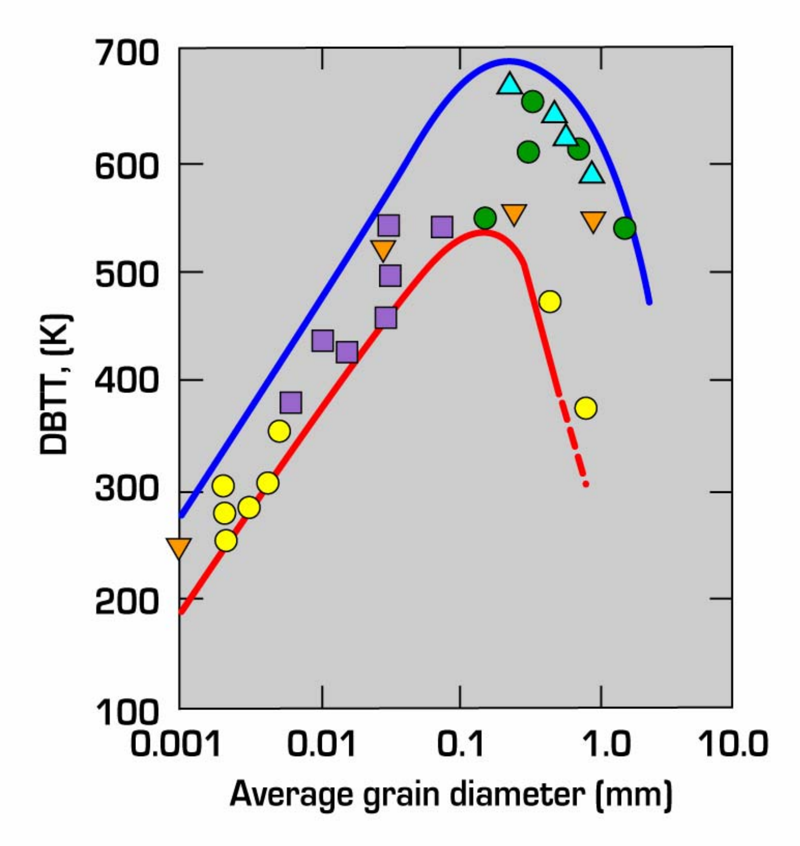
Residual stress meas. by neutron diffraction: ORNL, NIST….

Residual stress meas. by XRD limited to few µm penetration.

Residual stress meas. by mechanical techniques is possible.

Ductile-brittle transition behavior of tungsten is sensitive to impurity levels and processing.

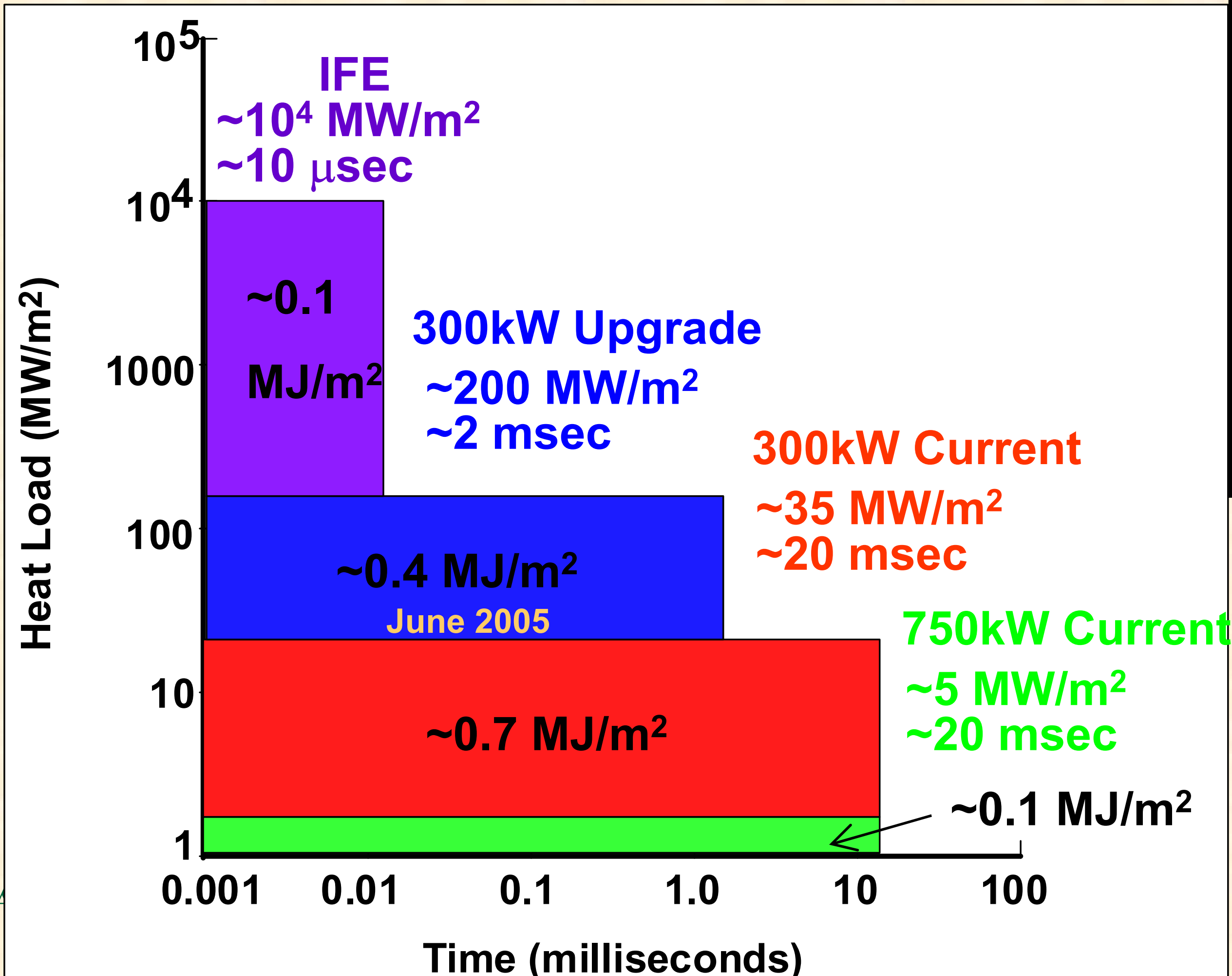




F82H = 0.5 atomic %C …..Target Debris

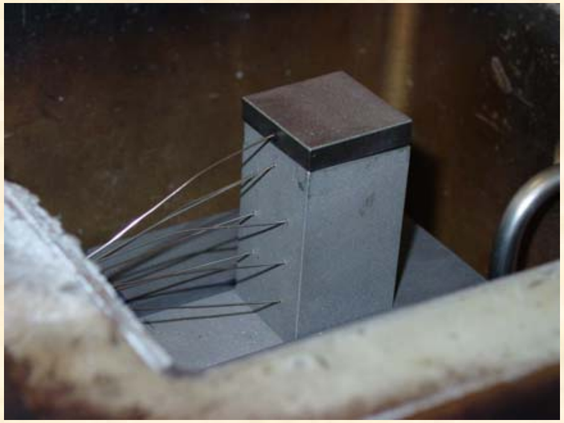
W powder:<25ppm <u>C</u> & <500ppm <u>O</u>

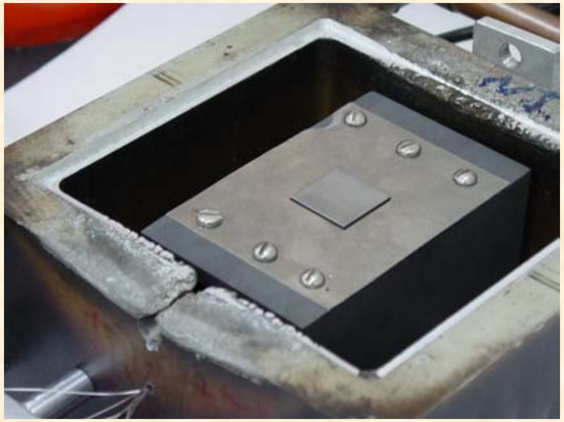
IR Thermal Fatigue Facility is an enabling technology for coating durability studies. Coupon and subscale component testing are possible.



Specimen Size (cm^2)	
300kW Upgrade	10
300kW Current	10
750kW Current	300

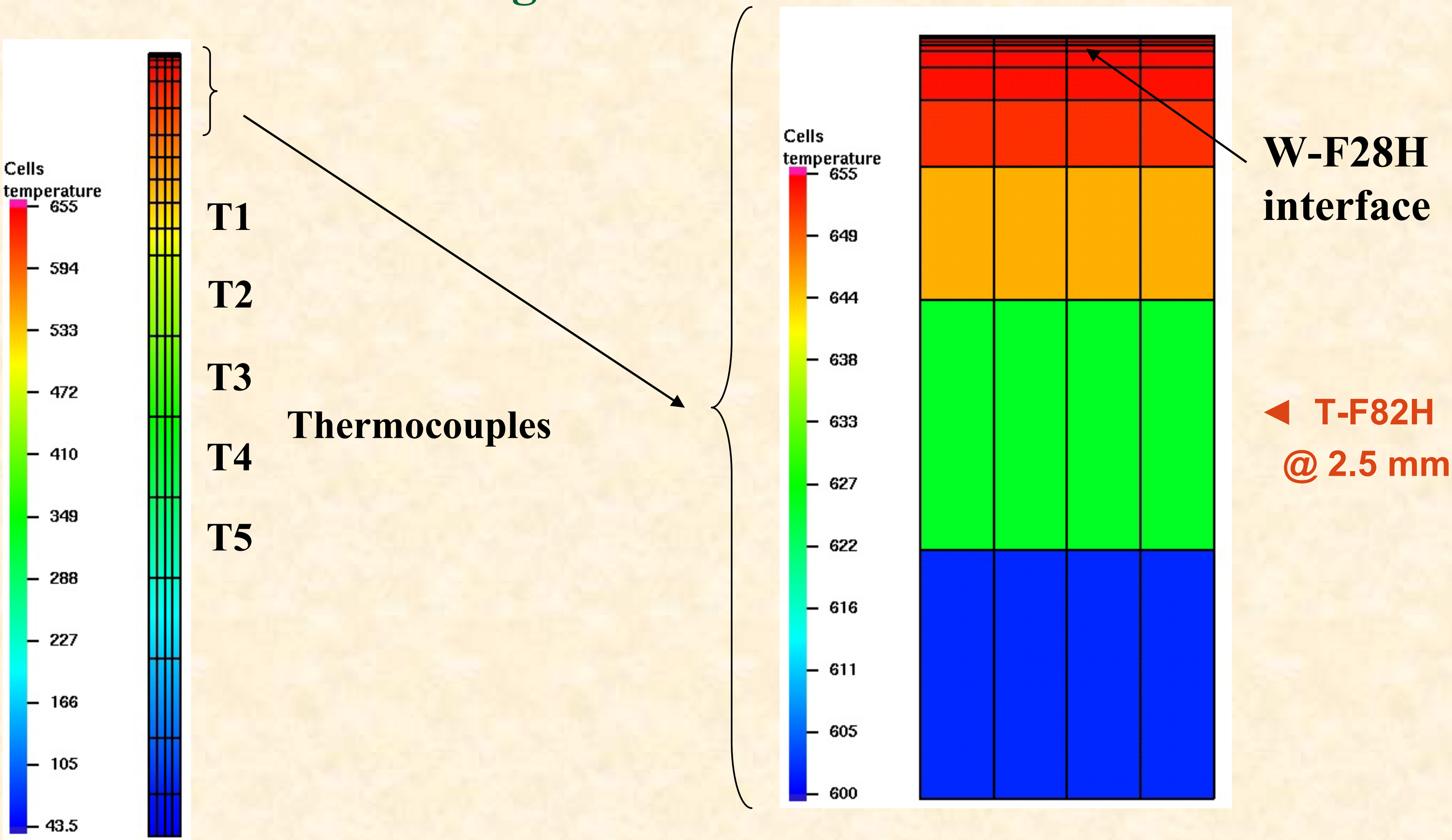
The IR thermal fatigue test has been re-configured to ensure 1-D heat transfer through the W-clad steel specimen



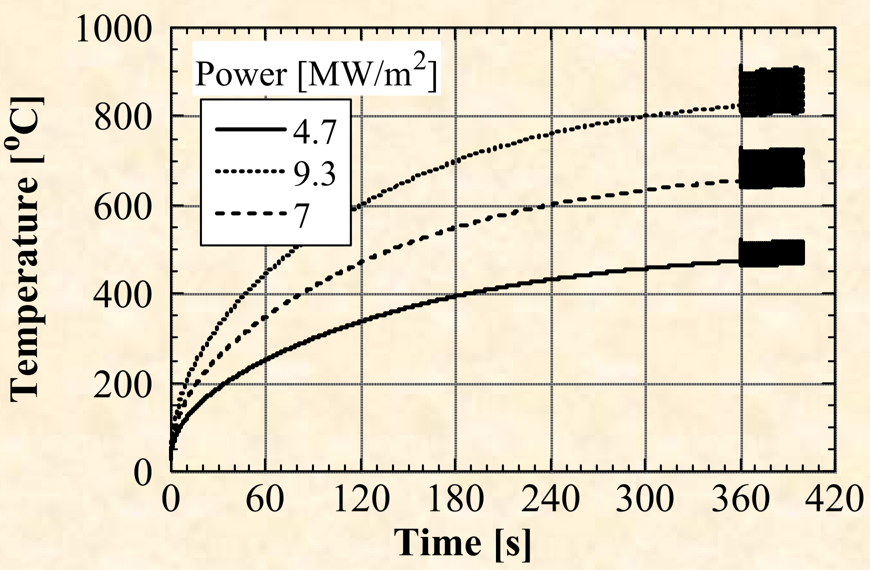


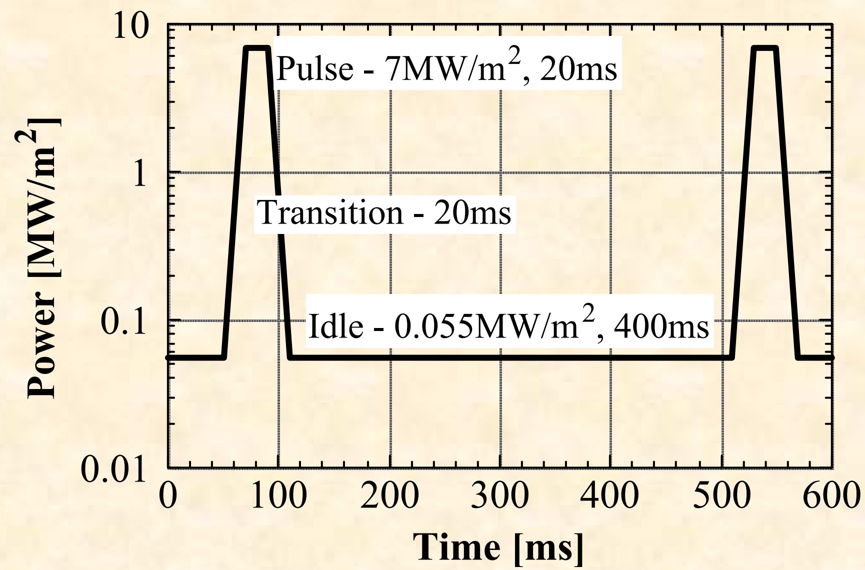
- First TC, at the specimen mid-plane, is 2.5 mm below the W/F82H interface.
- Far-field temperatures are measured by imbedded TC array to give a precise measure of net heat flux.
- TC data is recorded.
- Coolant flow through chill block is controlled.
- Tungsten surface temp. can be confirmed by high rate IR camera if necessary.

A Finite Element Model was developed to simulate thermal gradients in the IR fatigue test for W-clad F82H steel specimens measuring 25mm x 25mm x 5 mm.



Model allows the determination of IR lamp parameters to achieve warm start-up and target interface temp. under steady state pulse conditions.

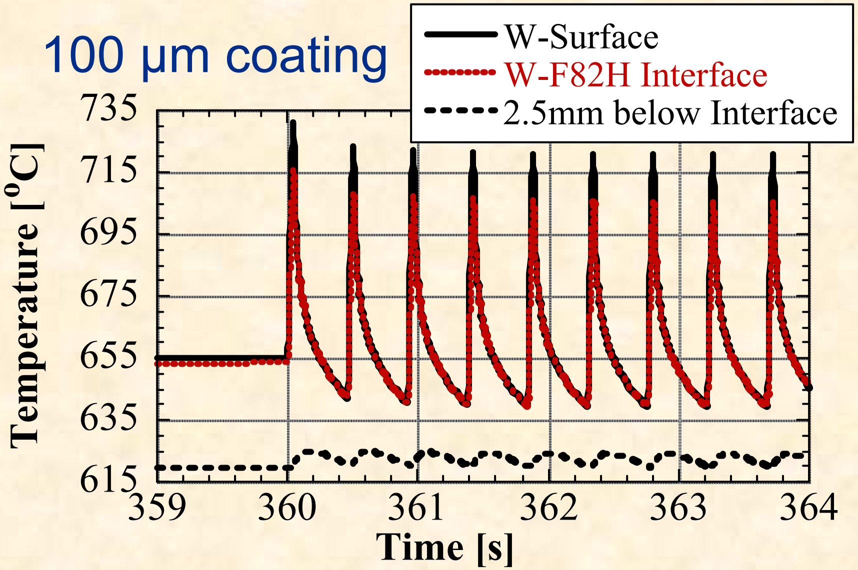




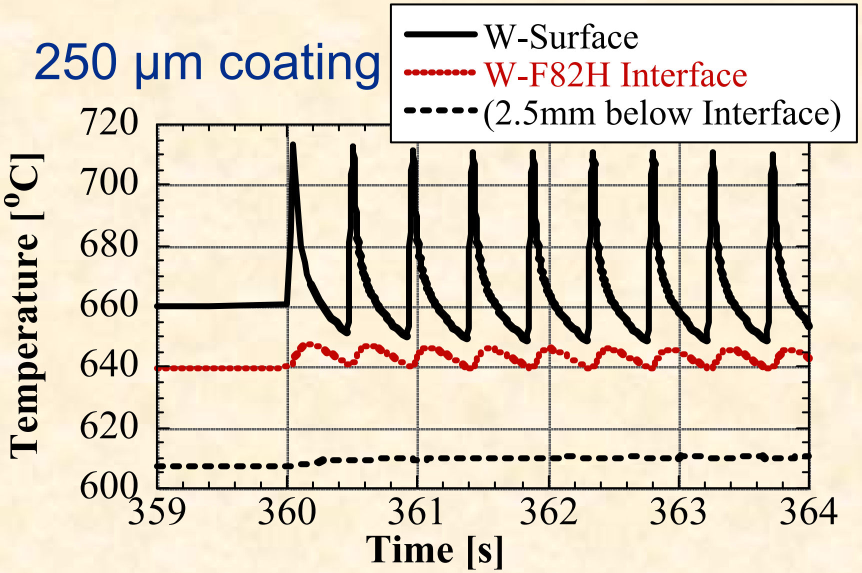
- Constant heat flux was maintained until a steady state temperature was attained.
- Target interface temperatures were attained for 7MW/m2, as indicated by Blanchard and Martin (2004).

Temperature profiles for 100 and 250 μm-thick tungsten coating were calculated.

100 μm coating

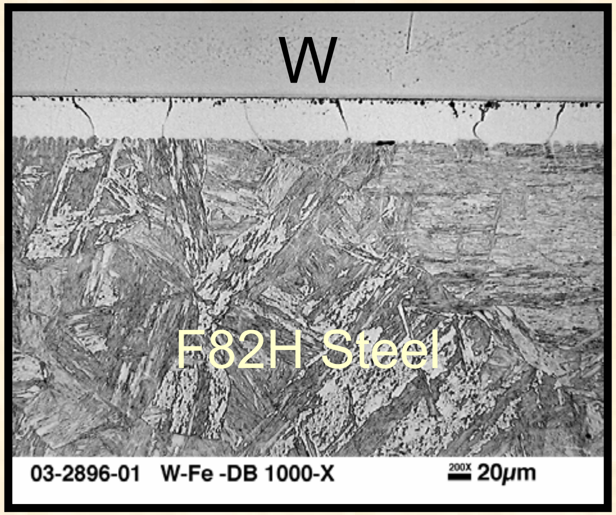


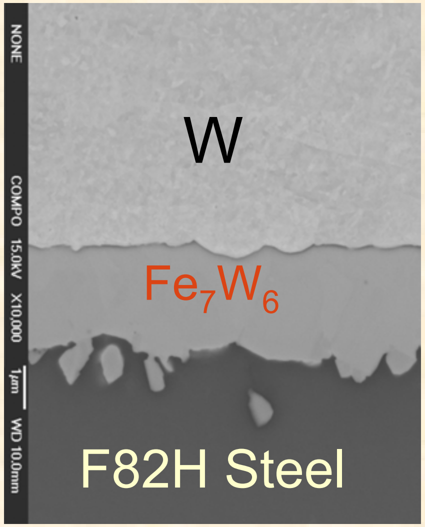
250 μm coating



Variation of IR pulse conditions and coating thickness allow for refinement of the model. The numerical simulation can be calibrated and validated against the TC temperature measurements.

In preliminary thermal fatigue experiments, over-temperature exposure of the W-steel interface demonstrated the potential for chemical instability.

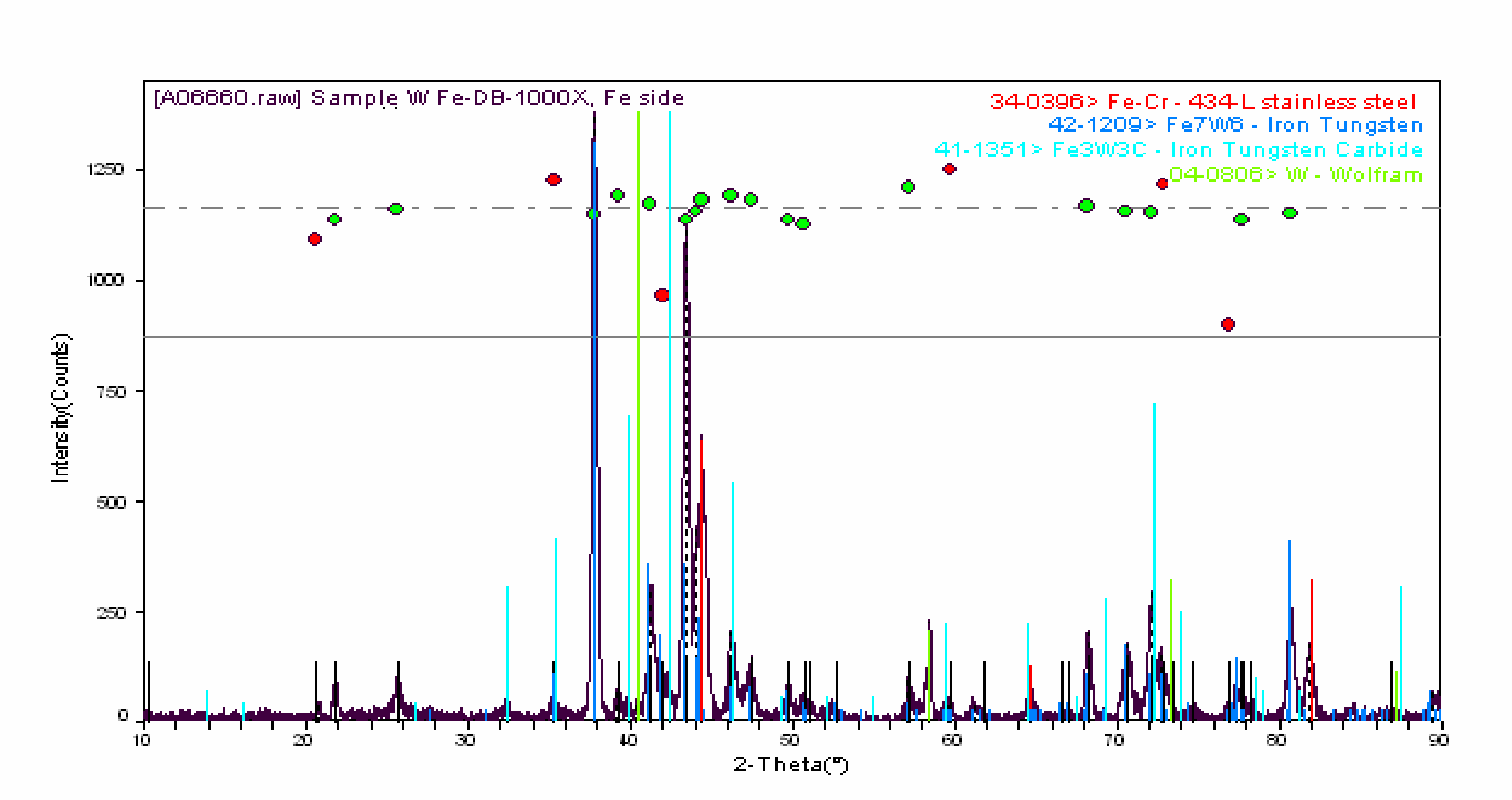




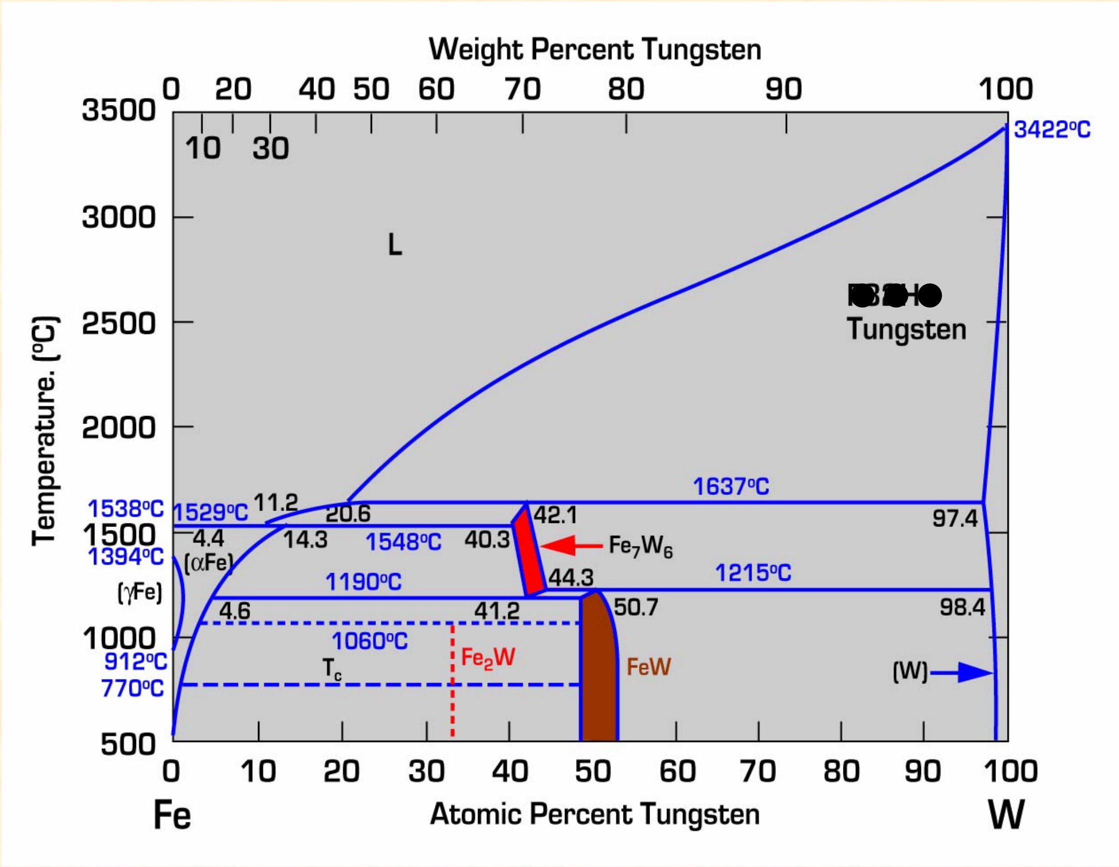
Test conditions: Preheat to 600ºC + 1000 cycles of IR Pulse.

- **XRD of intentionally spalled coating confirmed the compound at the interface to be Fe_7W_6 and Fe_3W_3C.**
- **The presence of this phase in grain boundaries further illustrates the role of solid state diffusion.**

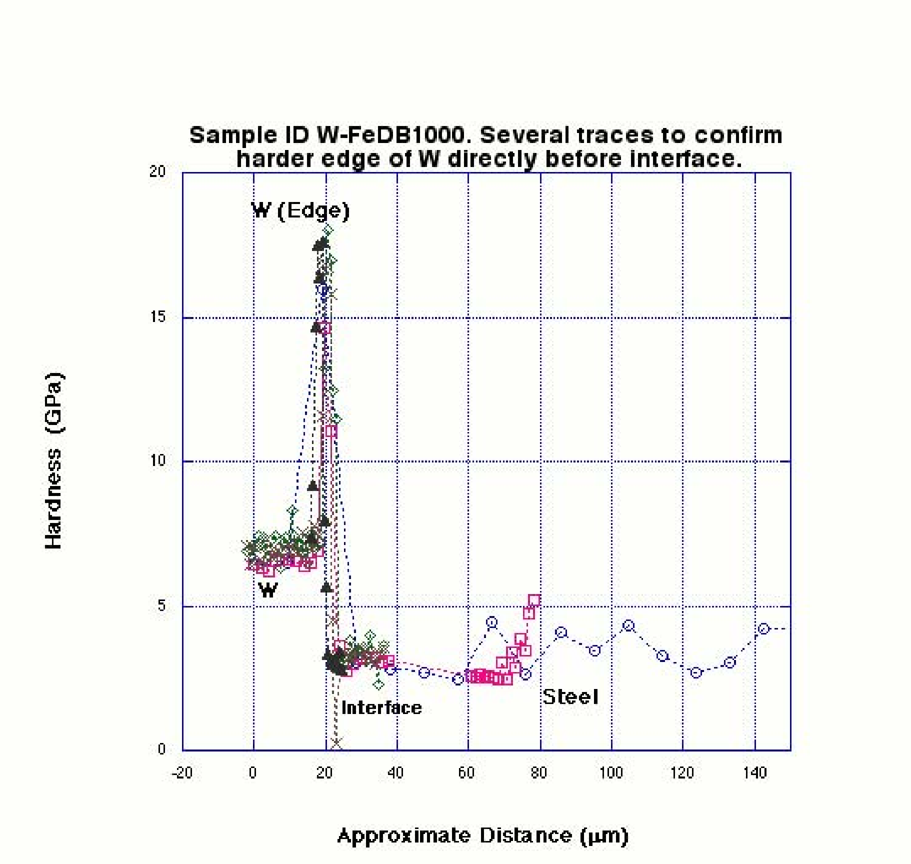
XRD provides an efficient and accurate approach to interface phase identification.



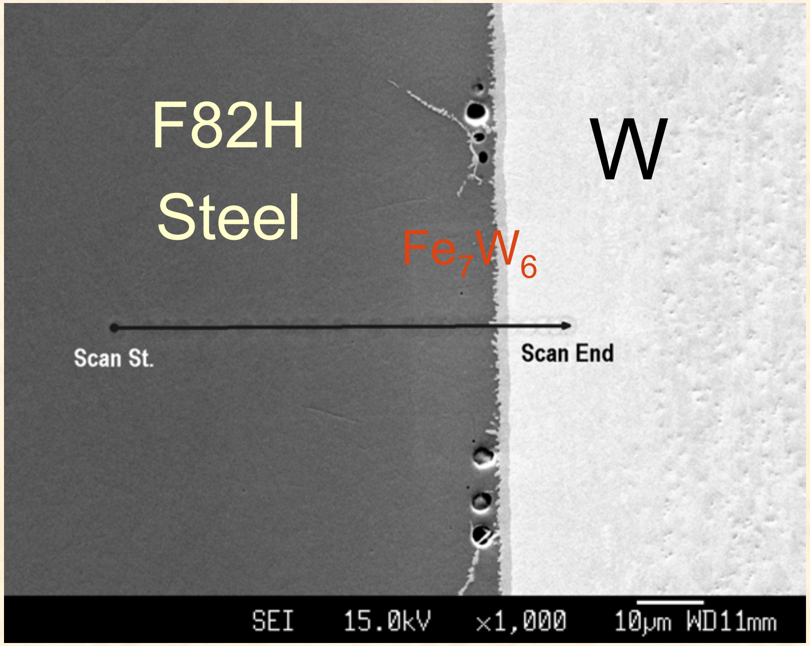
Fe-W binary phase diagram indicates the presence of several intermetallic phases.

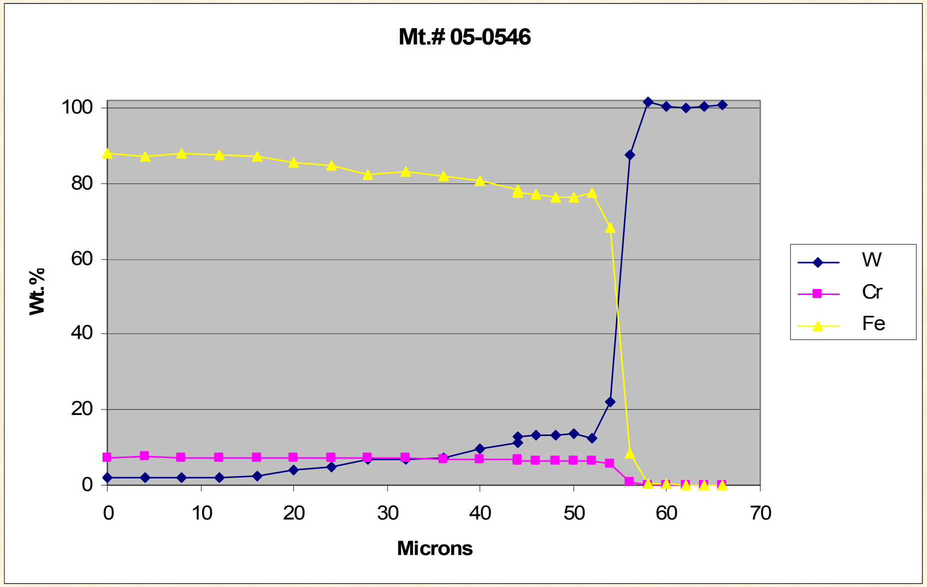


Nanohardness trace illustrates the brittle nature of the interface phase. The mechanical integrity of the interface will be compromised.

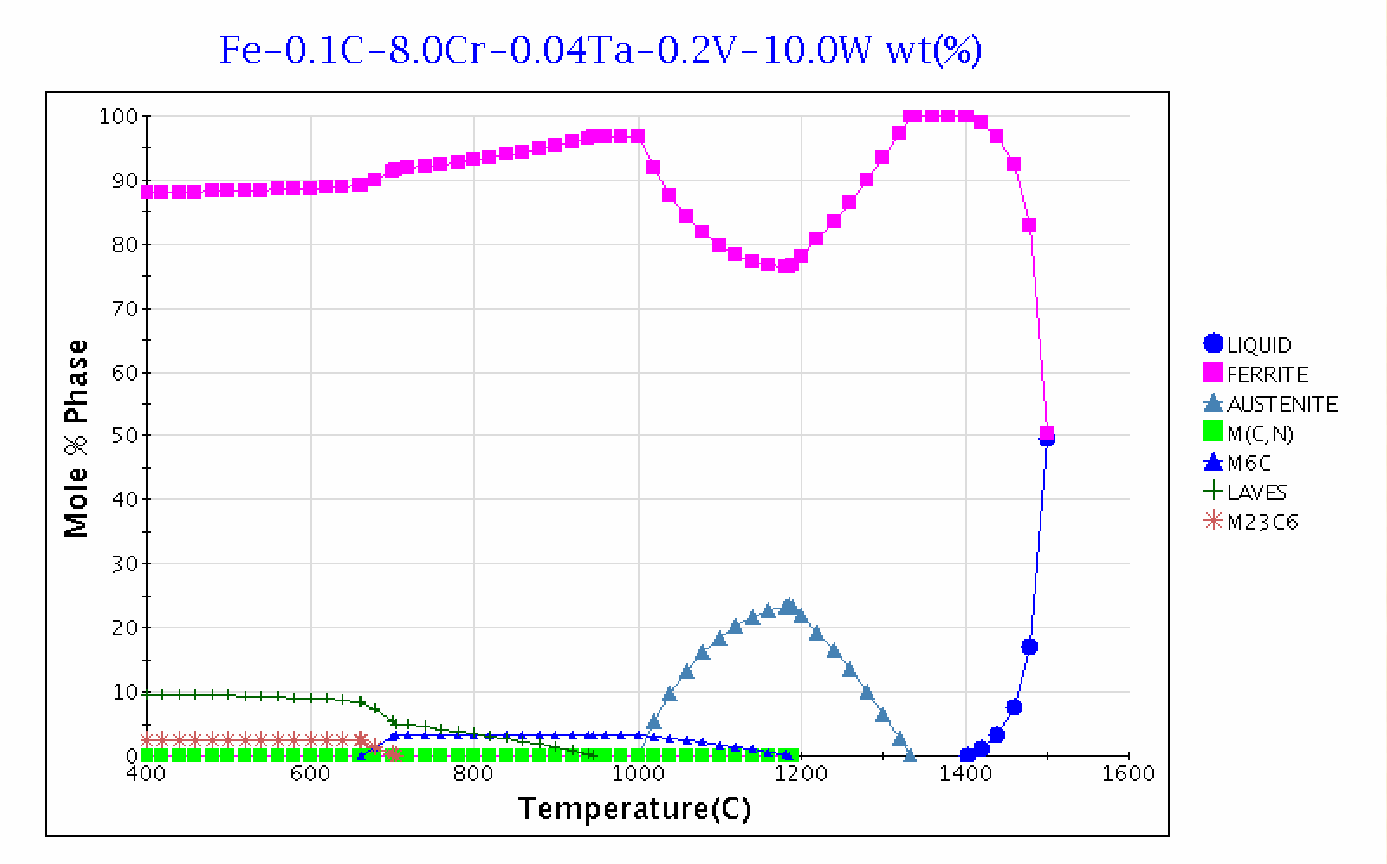


Electron microprobe was used to quantify concentration profiles across the W-F82H interface.



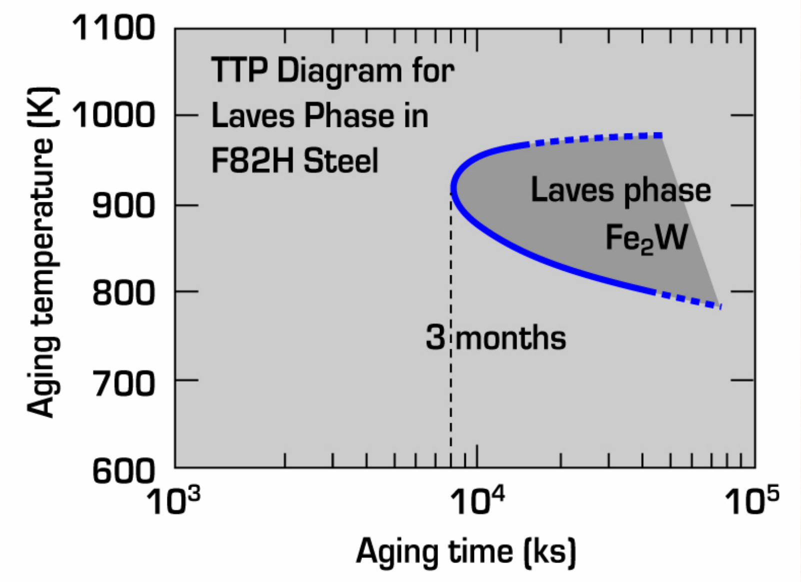


Thermodynamic data bases can be used to predict phase equilibrium in multi-component systems. (JMatPro)

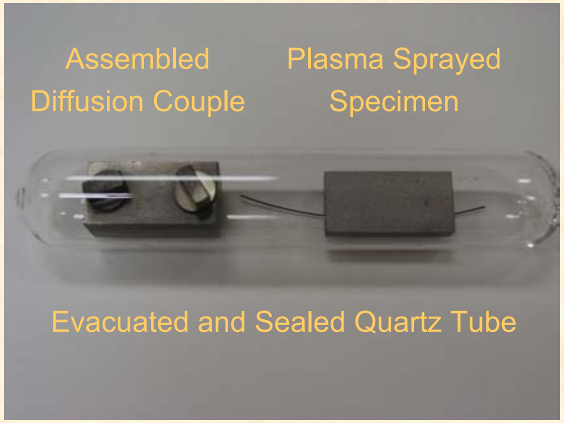


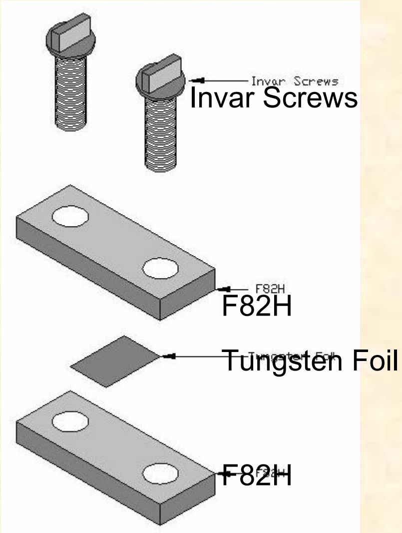
Numerous intermetallic and carbide phases form in F82H Steel during long term aging at elevated temperatures.

Precipitate Phases	Composition
$M_{23}C_6$	$(Cr_{16}FeW)C_6$
MX	(CrV)N
M_2X	W_2C
Z-phase	(CrVTa)N
η - carbide	M_6C
Laves	Fe_2W
Chi	$M_{18}C$ or $Fe_{35}Cr_{12}W_{10}C$
Other Carbides	$(CrFe)_7C_3$ $(FeCr)_3C$ $(FeCr)_4C$ Fe_6W_6C Fe_3W_3C
Other Intermetallics	Fe_7W_6 and FeW



Isothermal aging experiments are underway to systematically characterize the thermochemical stability of tungsten/LAF coating system.

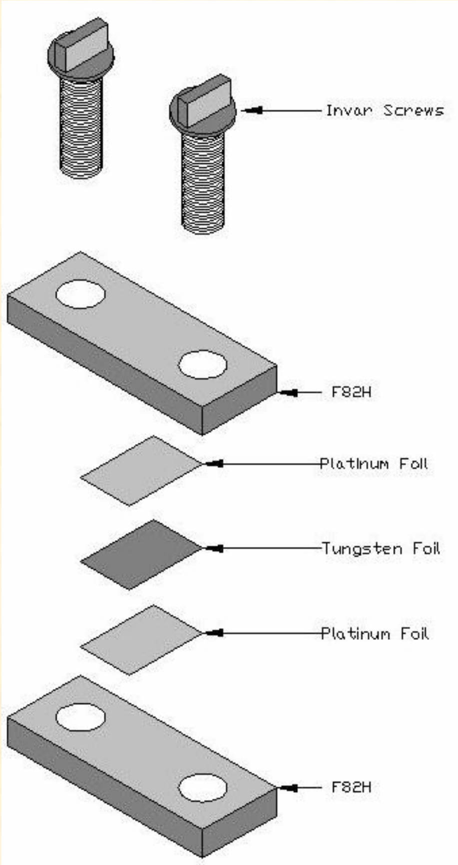




Diffusion Couple

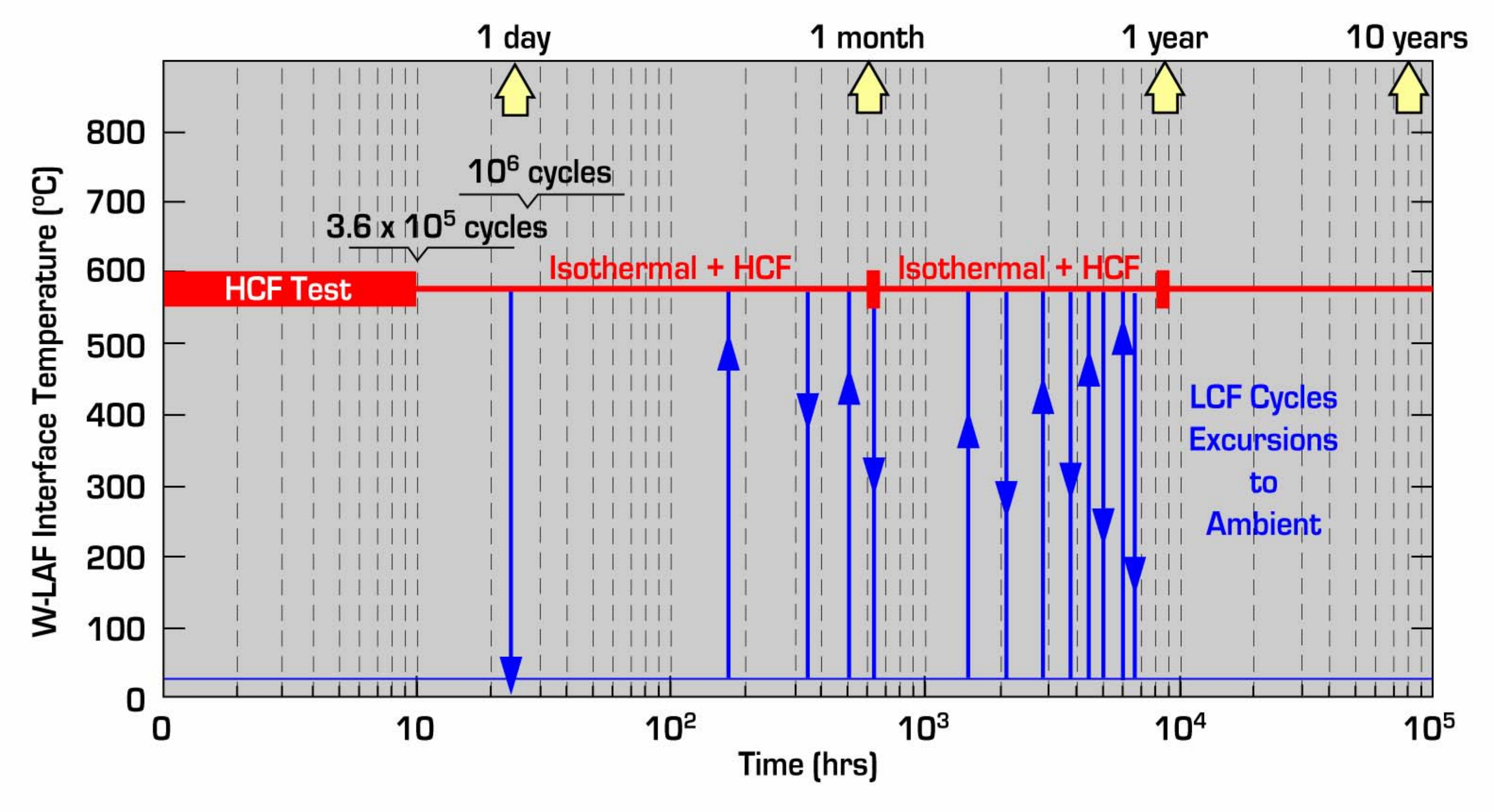
- Tungsten/LAF diffusion couples are being aged at 500C to 900C for times ranging from 100h to 10,000h.
- Post aging analysis of samples will includes:
  - Microchemistry profiles in the steel, interface and coating
  - Phase identification by XRD
  - Phase equilibrium analysis
- Solid state diffusion model will be developed to extrapolate results to longer times

Assembled diffusion couples allow for the assessment of alternative material combinations including diffusion barriers.



- Re has been used as a diffusion barrier between Carbon-Carbon Composites and W for MFE applications.
- Pt will be evaluated since it forms alloys with both W and Fe.

The durability assessment of W-clad LAF steel must address HCF, LCF, DBTT of W and long term thermochemical stability of the interface.



Current Status

- Vacuum plasma sprayed W on F82H Steel is the principal material candidate. A number of material conditions are ready for testing. Additional material conditions exploring W/F82H material options are being produced, e.g., thick tungsten coatings and platinum diffusion barriers.

- The thermal fatigue test has been reconfigured, instrumented and modeled to define and control the tungsten/steel interface condition. Experiments are scheduled to begin the second week of March.

Shorter pulse width, ~ 2msec will be available by late summer.

- Long-term stability of the interface is required. Isothermal aging experiments are underway to assess the stability of the interface for times beyond what is practical for the thermal fatigue test facility.