Modeling of HAPL FW Tests

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October 2004

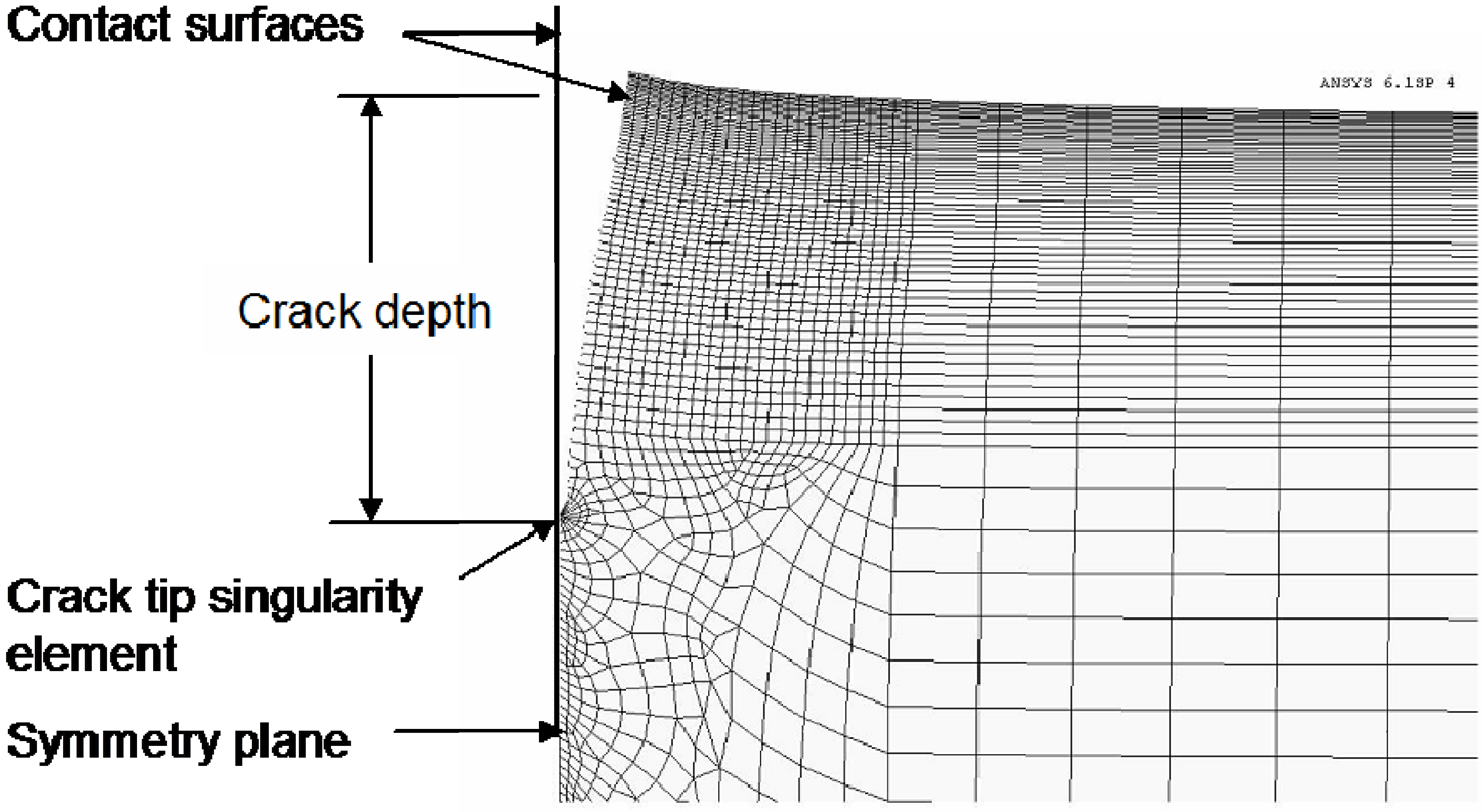
Outline

- Fracture Modeling for Surface Tests (short pulse – XAPPER, RHEPP, Z, Dragonfire
- Flat Specimens in IR facility
- Cooled Specimens in IR facility

Purpose of Modeling

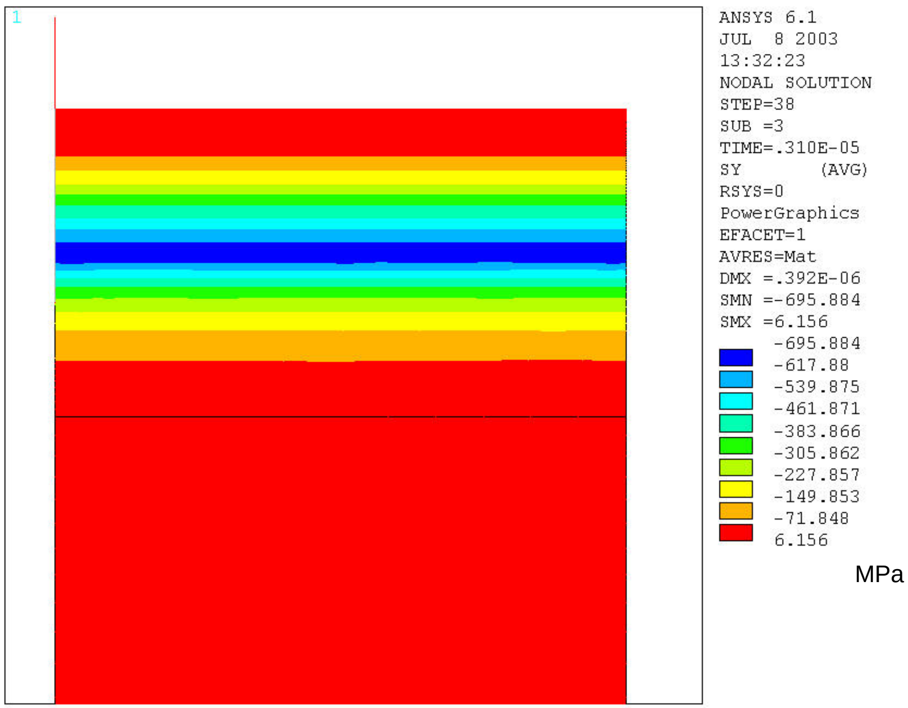
- Goal: Ensure wall survival
- Tests will help us determine design limits of tungsten-coated steel walls
- Modeling is required to help us understand failure mechanisms
- Hypothesis is that damage is thermomechanical
- Combination of tests and modeling will help with design
- Previous analyses predicted cracking at tungsten surface

Fracture Model

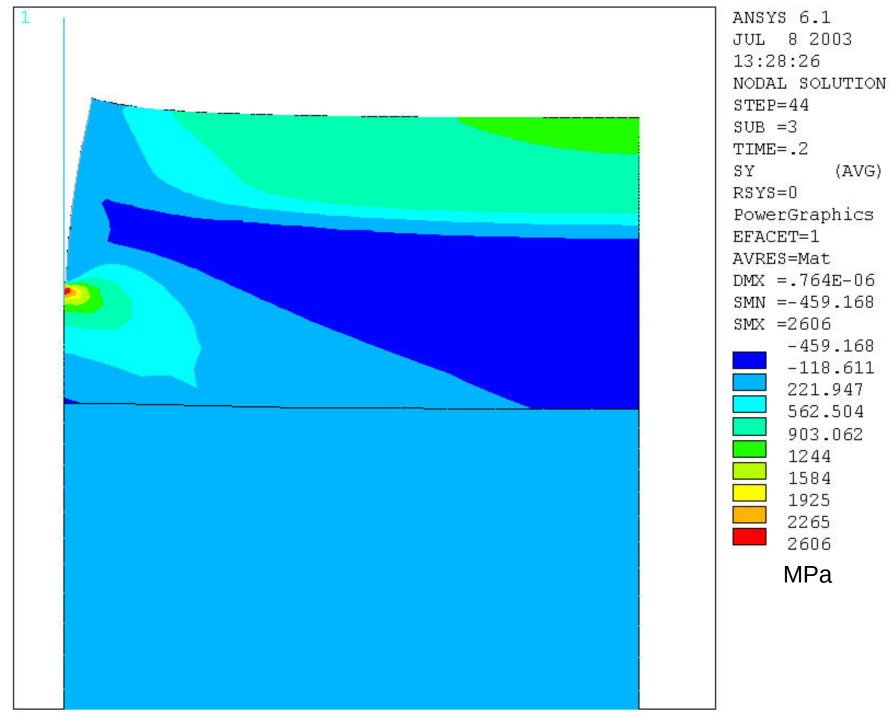


Typical Behavior in HAPL Chamber

Stresses at Maximum Temperature

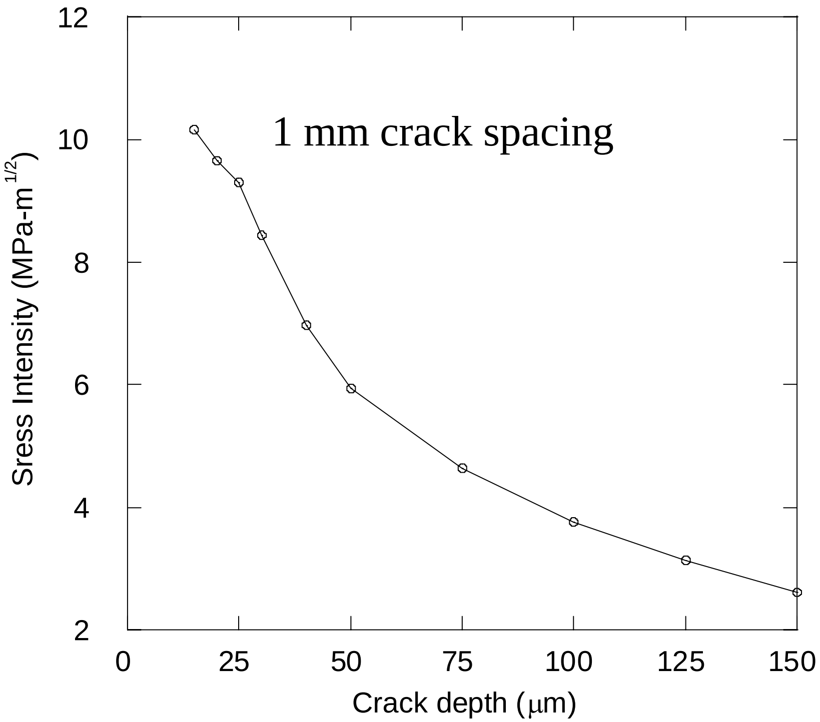


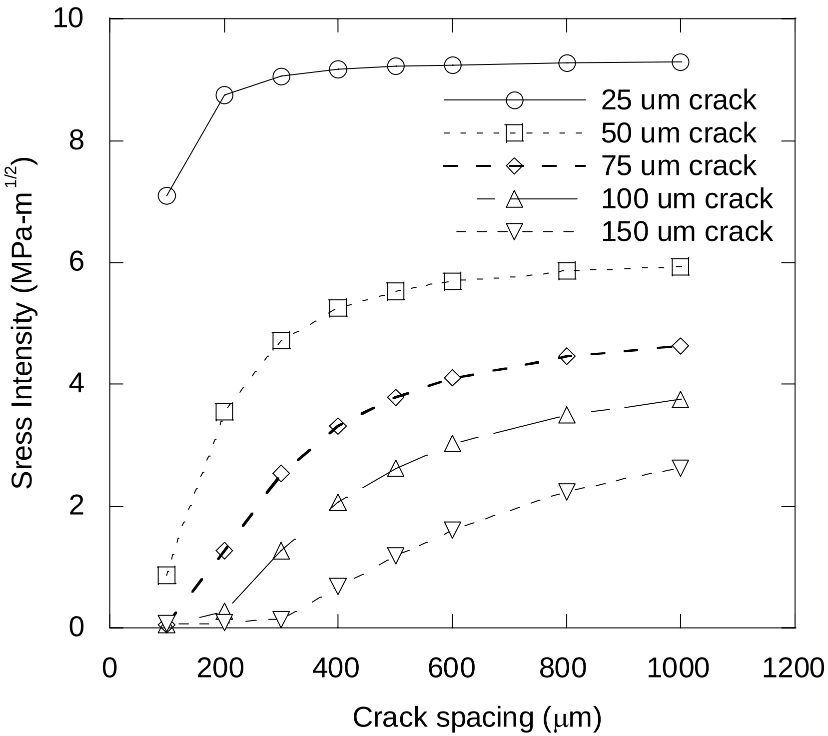
Stresses After Cool Down



Fracture Mechanics Analysis Results

250 microns W
7 m Chamber
150 MJ Target





Validation Tests

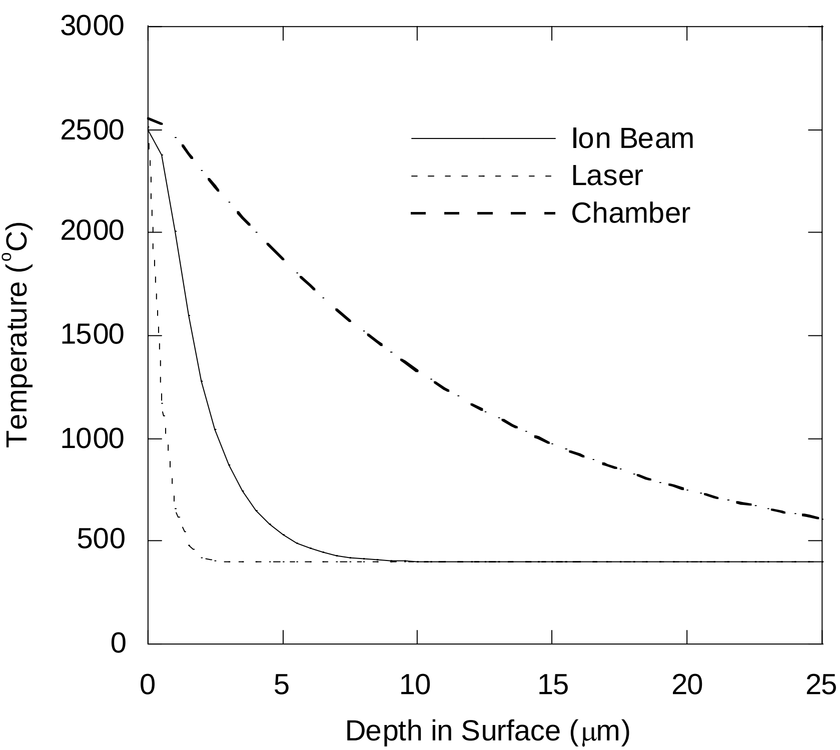
- To validate modeling, several tests are under way
  - **Ions at SNLA**
  - **X-Rays at LLNL (XAPPER) and SNLA (Z-Machine)**
  - **Lasers at UCSD**
  - **Infrared at ORNL**
- First three tests are shorter pulse times and higher intensity
- Infrared is longer pulse (excellent model for interface stresses)

Test Parameters

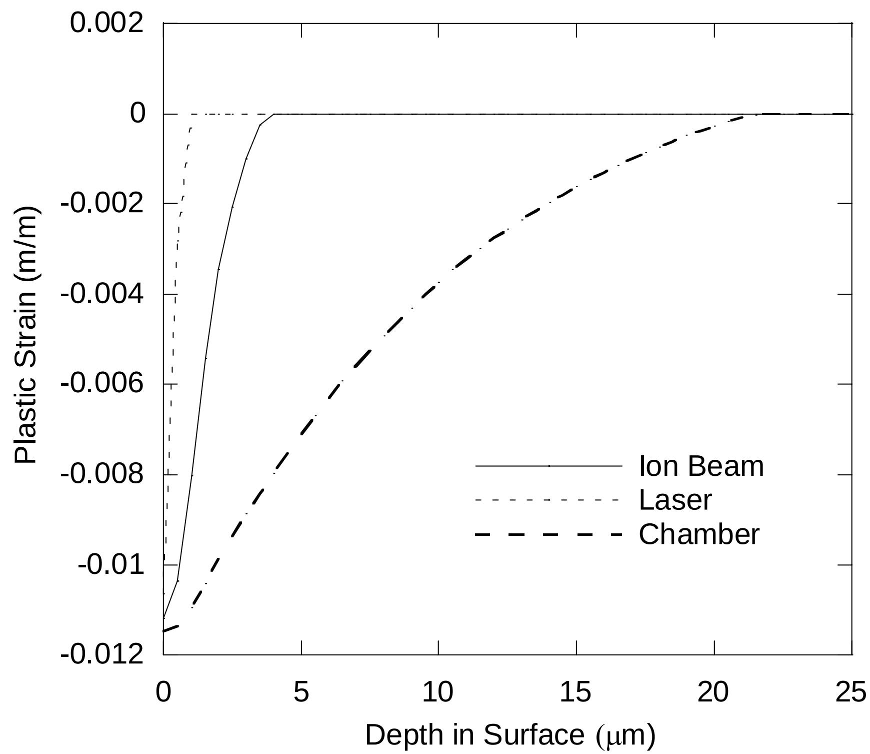
Type	Energy (keV)	Maximum Fluence per Pulse (J/cm^2)	Depth of Energy Deposition (microns)	Flat Top Pulse Width (ns)
RHEPP	750	7	1-10	100
XAPPER	0.8-1.2	3000	1-2	6
Z	0.1-0.4	7	1-2	30-50 (FWHM)
Laser		0.7	0	8

Representative Temperature and Strain Comparisons

Temperature

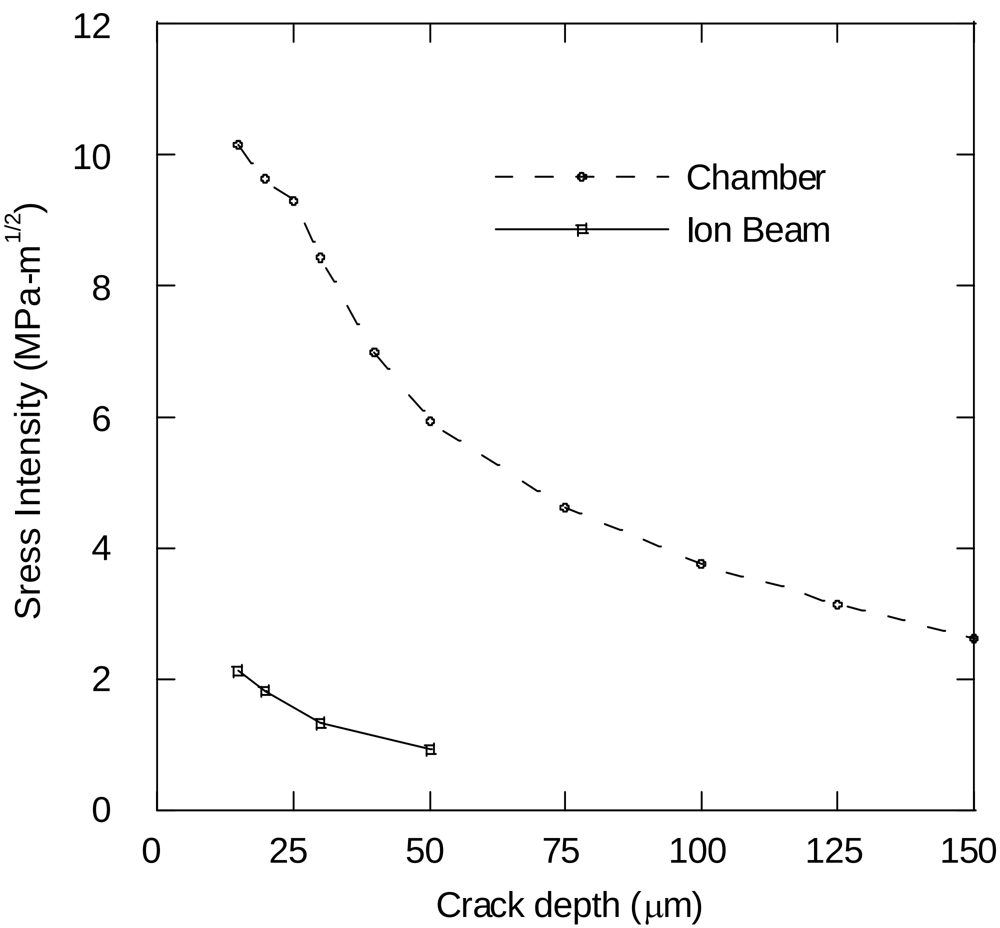


Strain



End of Pulse

Fracture



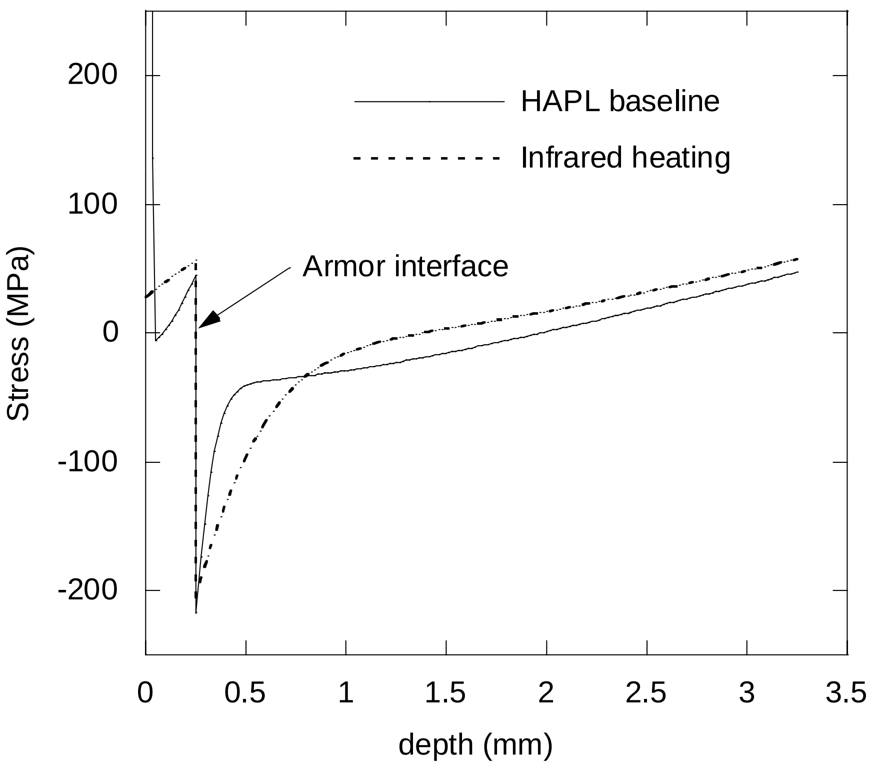
- •Tests are not conservative from fracture point of view
- •Cracks will stop at a more shallow position
- •Simulations should allow us to correlate growth rates and make conclusions relevant to chamber

IR Tests

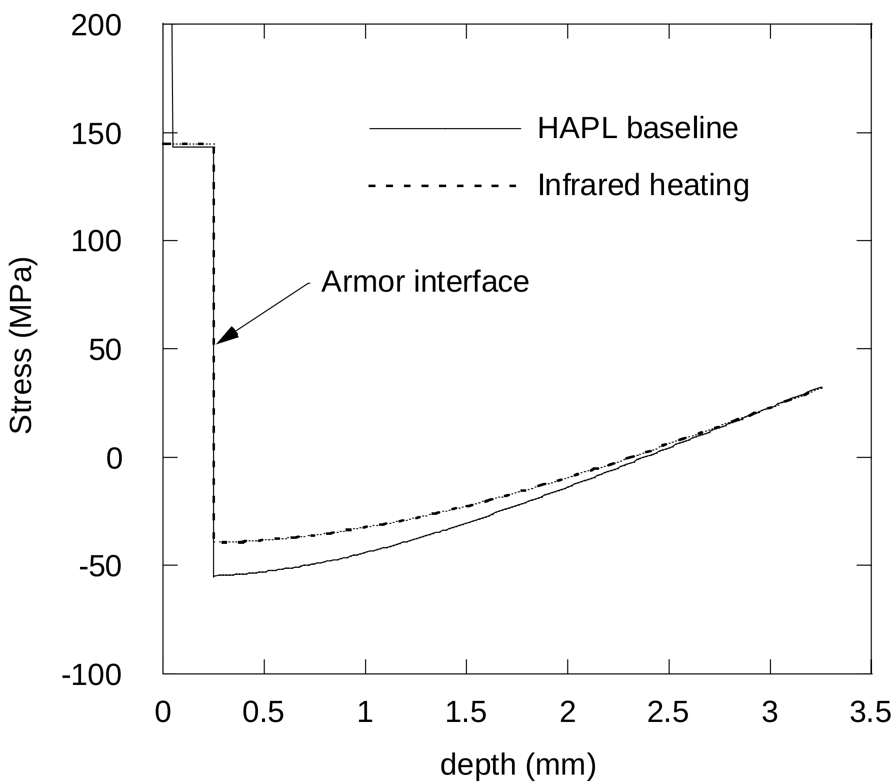
- The IR tests are longer pulses (~20 ms, moving towards 1 ms or less), but have high average power
- Matching time-averaged power provides good simulation of interface behavior
- Hence, IR complements the other tests

Infrared Testing

End of 50th pulse



Prior to next pulse



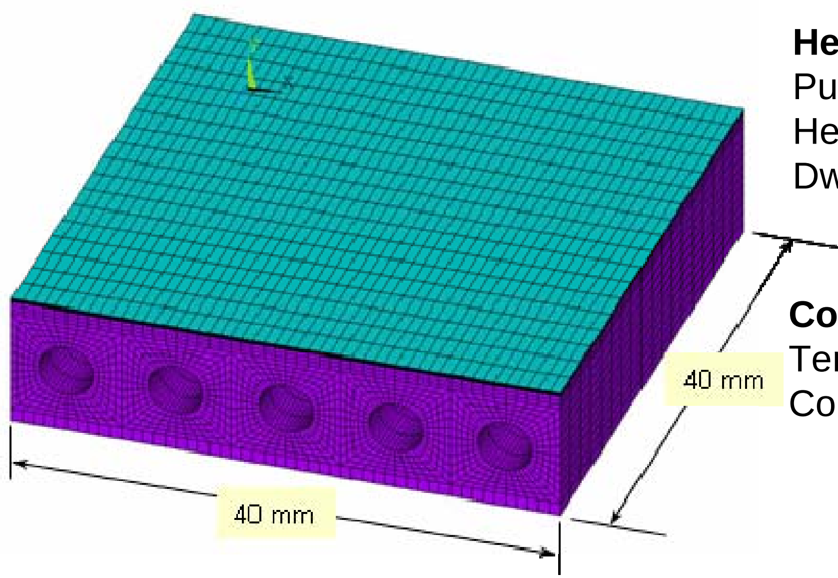
Next Phase

- To demonstrate next level of operation, we need to demonstrate interface survival in a more realistic component
- Approach is to design cooled sample with sufficient surface area to avoid edge effects

Infrared Heating Test Specimen with Internal Cooling Channels

Tungsten armor

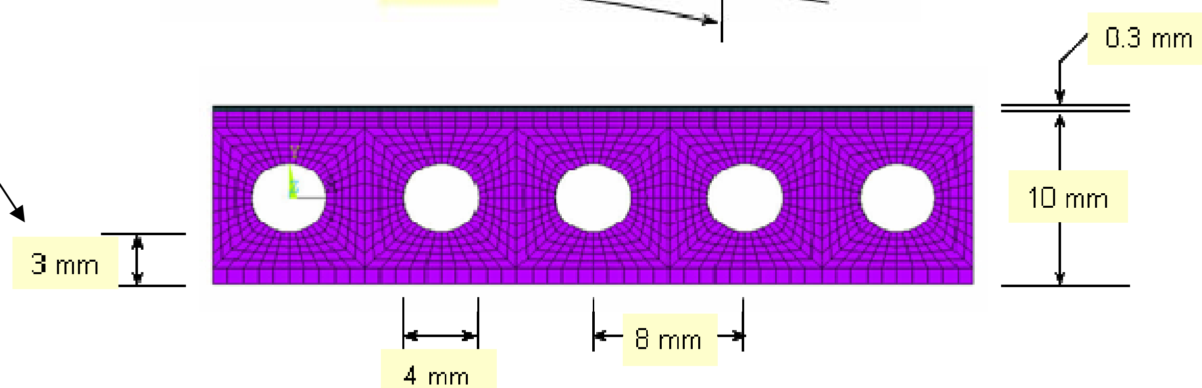
Ferretic steel



Heating Conditions
Pulse width - 20 ms pulse width
Heat flux - 7.2 MW/m^2
Dwell time - 400 ms

Coolant Conditions
Temperature – 100 C
Convective Coef – 10000 W/m^2-C

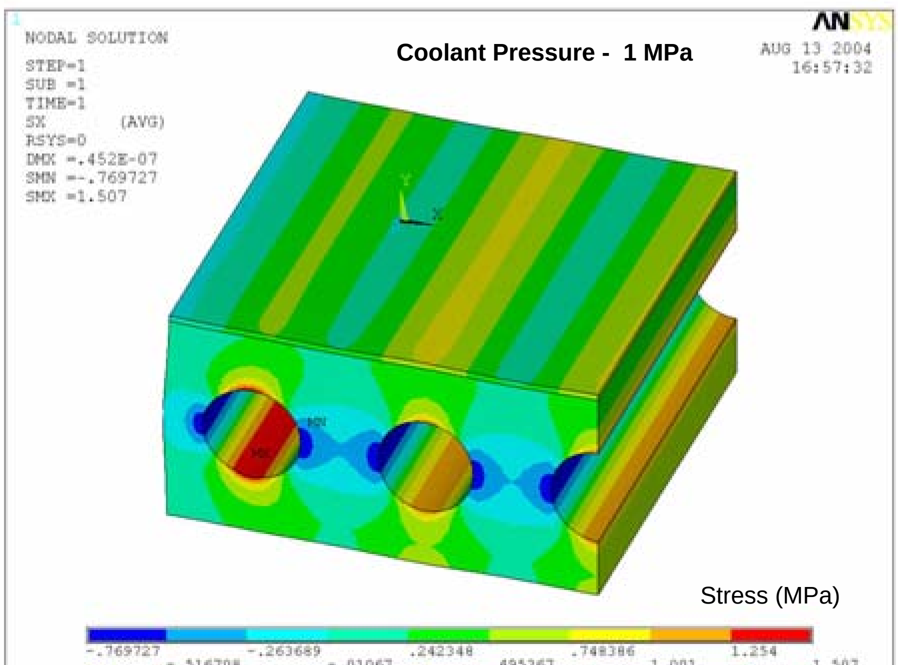
Cooling channel



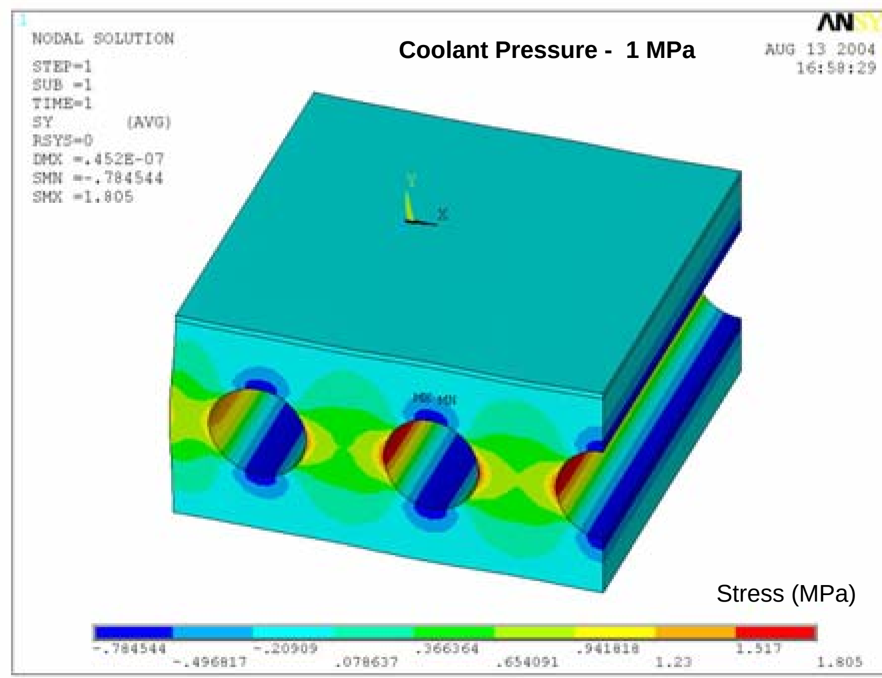
Stresses Produced by Pressure in Coolant Channels

- Additional stresses will be produced by the coolant pressure which has yet to be determined
- Maximum stress for 1 MPa pressure is 1.8 MPa and less than 1 MPa at the tungsten to steel interface

Stress in Horizontal Direction



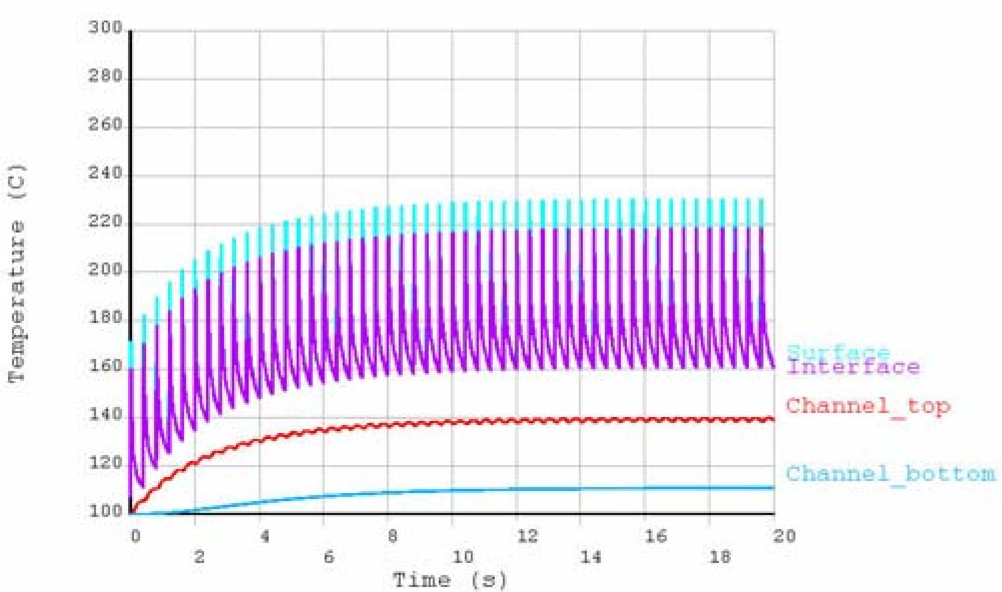
Stress in Vertical Direction



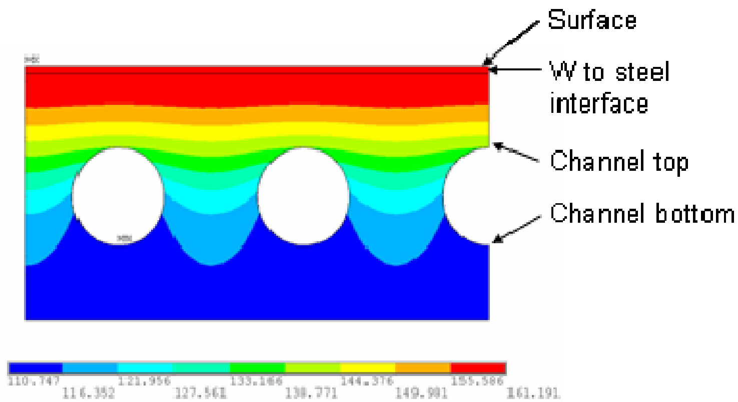
Infrared Test Specimen Transient Thermal Response

- **At interface temperature changes nearly 60 C during cycle**
- **An equilibrium condition is reached after 25 cycles**

Transient Temperatures (50 Pulses)



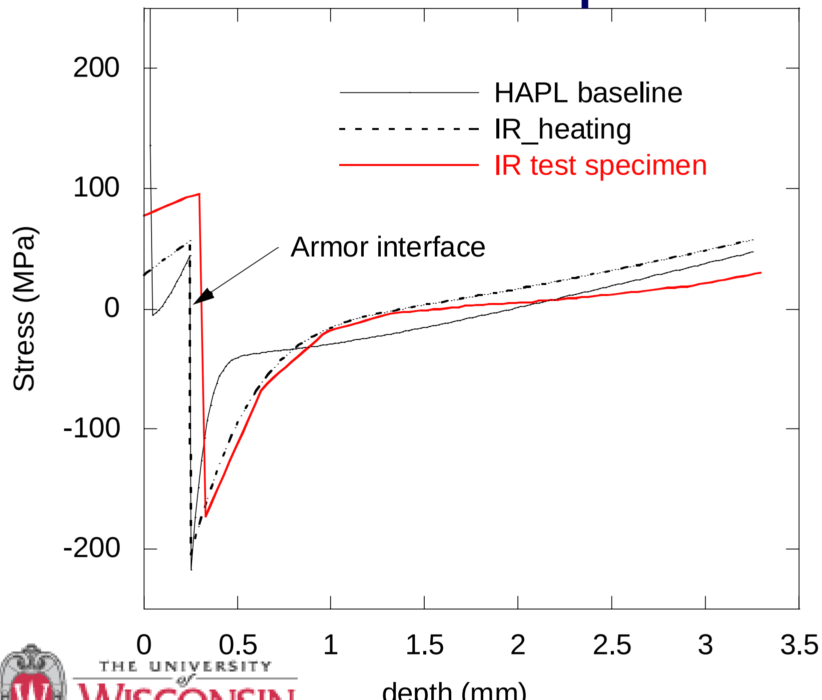
Temperature Before 51st Pulse



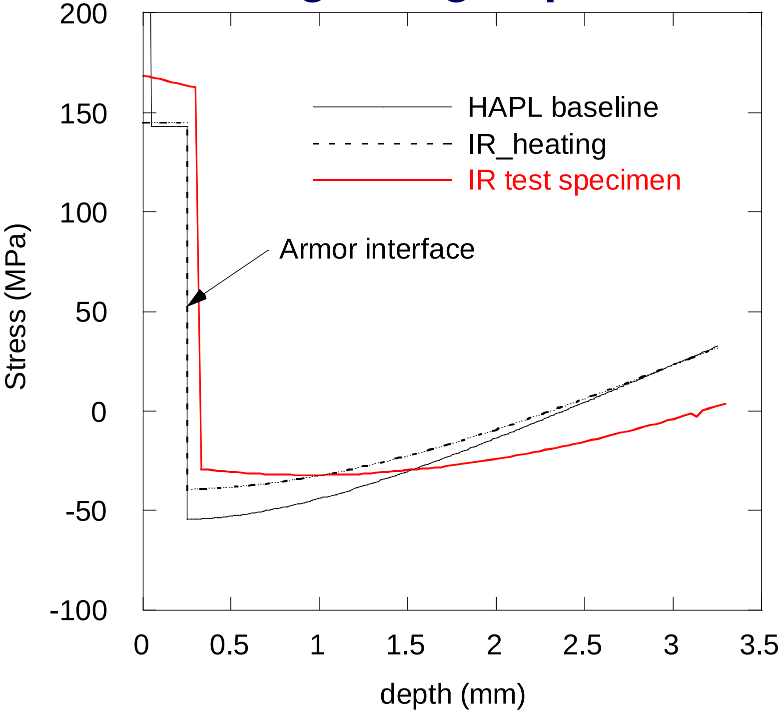
Comparison of Specimen Stresses with HAPL wall design with baseline and IR Heating

- Stresses through the thickness compared at center of specimen
- HAPL and IR cases are for 250 μm armor on 3 mm thick steel with direct backside cooling
- Specimen stresses are slightly higher due to slightly higher temperature rise compared to coolant (reference) temperature

Stress variation thru thickness at end of pulse



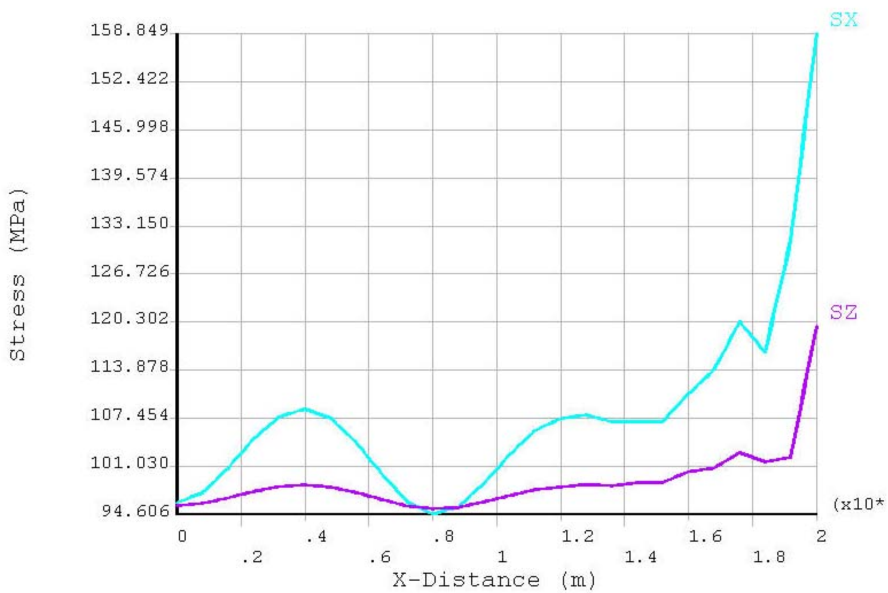
Stress variation thru thickness at beginning of pulse



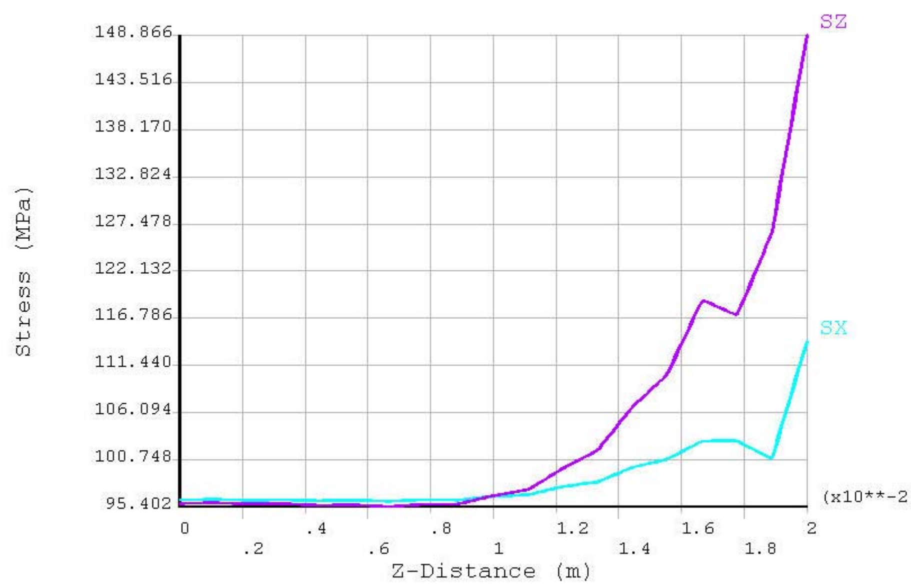
Tungsten Interface Stress Variations along Length and With of Specimen

- **Large area of uniform stress exists at center of specimen**
- **Stresses increase by 50% near edges of specimen**
- **A 15% stress increase is observed over cooling channel**

Stress variations normal to cooling channels



Stress variations parallel to cooling channels



Conclusions

- Tungsten walls will crack, but cracks are expected to arrest for sufficiently deep tungsten layers
- Surface experiments will underestimate depth of arrest
- IR tests are excellent models for interface stresses