P91B. Fracture mechanics approach to Be/bronze joint structural assessment

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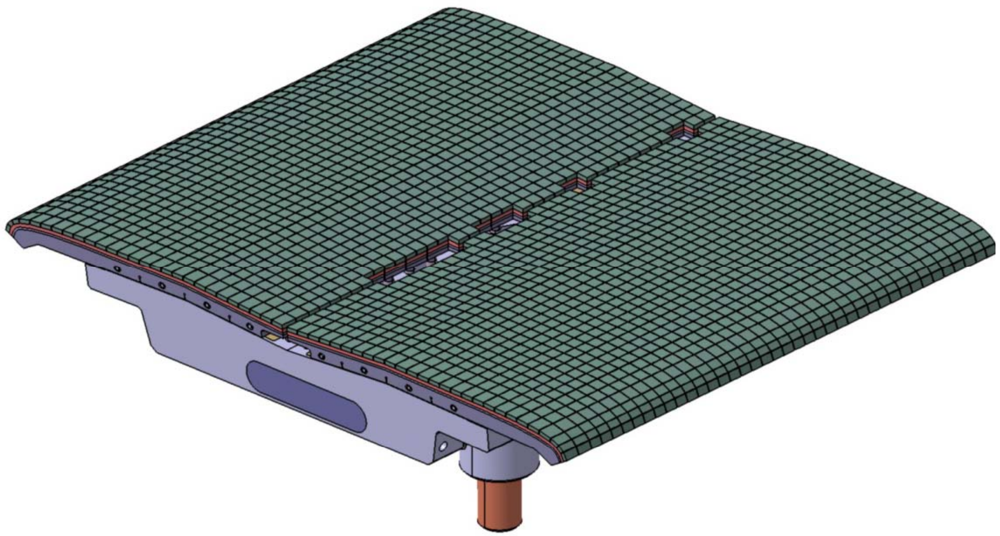
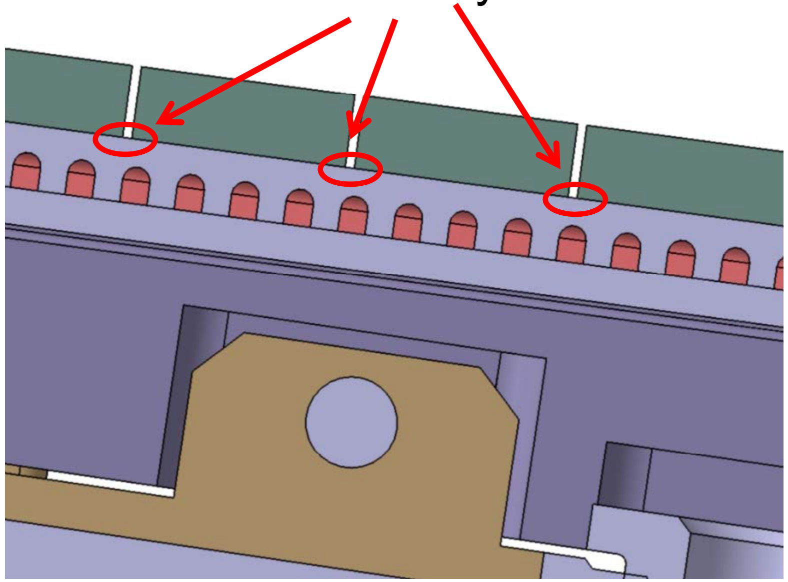
ITER First Wall

FW 14



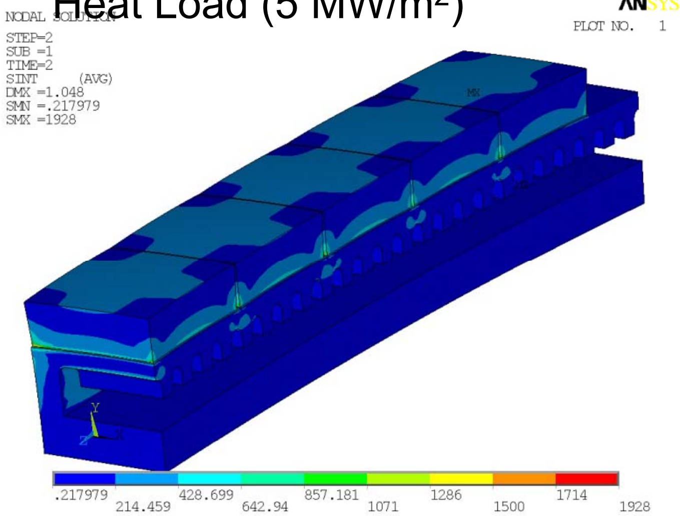
Be-Cu joint - geometrical/structural discontinuity

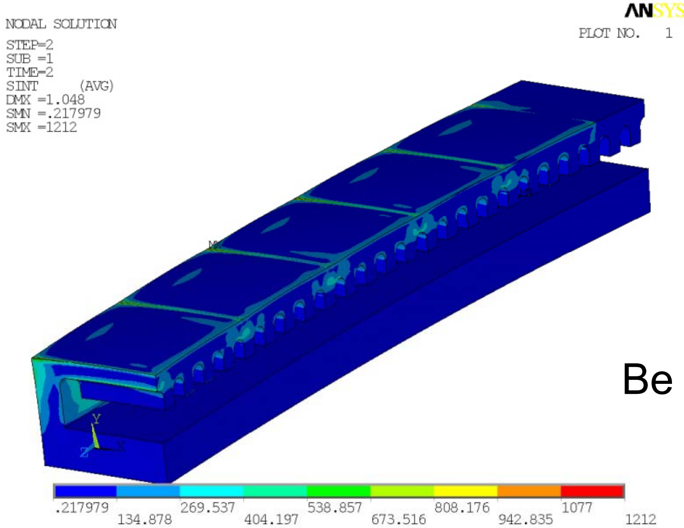


Background (2)

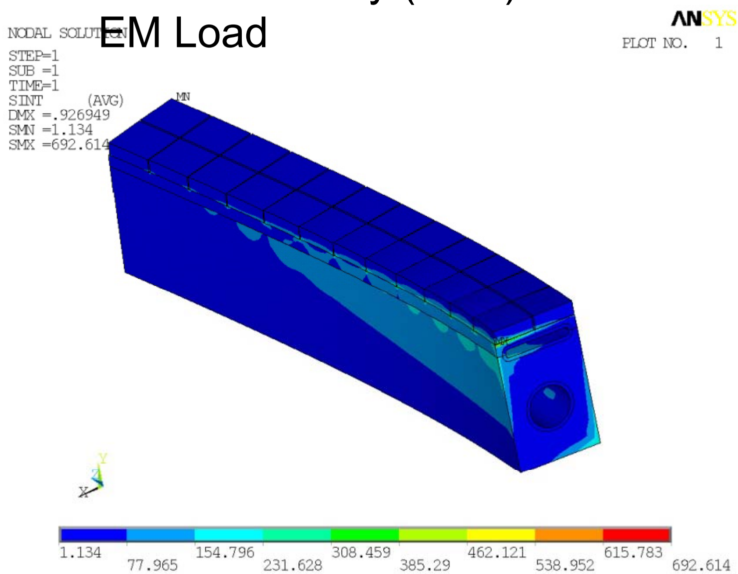
Geometrical/structural discontinuities lead to stress singularities

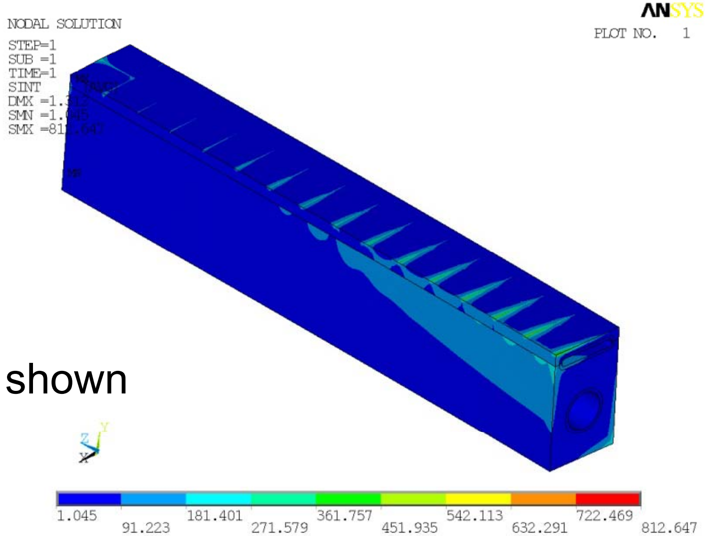
Stress Intensity (MPa) under Heat Load (5 MW/m^2)





Stress Intensity (MPa) under EM Load



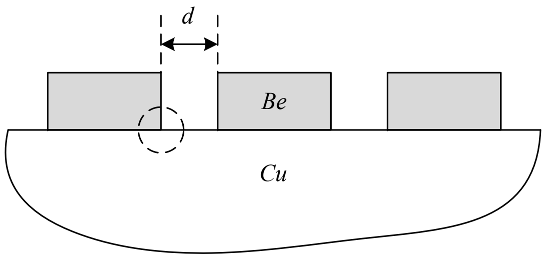


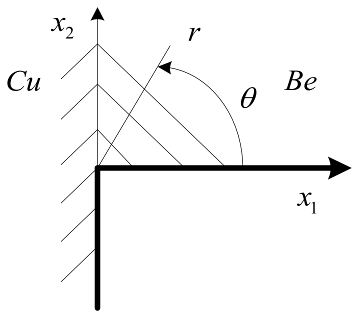
Be tiles are not shown

Application of Fracture Mechanics (1)

Usual FE analysis does not resolve real stress state in the vicinity of Be/bronze joint. The reason is the singularity in the right angle of this joint. Stress is infinite in this point.

Possible solution is:
Approach similar to that used in fracture mechanics (using asymptotic formulas)





$$\sigma \sim K \cdot r^{\lambda} \cdot \Psi(\theta)$$

K – finite stress intensity factor depending on geometry, load, etc.
λ – exponent ($-1 < \lambda < 0$)
r – distance (radius) from the singularity point
$\Psi(\theta)$ – function of the angle

Application of Fracture Mechanics (2)

- Step 1. Analytical

stresses in the vicinity of singularity point (edge) are represented as:

$$\tau_{11} = Kr^{\lambda}\Phi_{11}(\theta), \qquad \tau_{22} = Kr^{\lambda}\Phi_{22}(\theta), \qquad \tau_{12} = Kr^{\lambda}\Phi_{12}(\theta)$$

$$\Phi_{11}(\theta) = (\lambda+1)[\lambda(-A_1\cos(\lambda-2)\theta + A_2\sin(\lambda-2)\theta) + (2A_1 - B_1)\cos\lambda\theta - (2A_2 - B_2)\sin\lambda\theta],$$

$$\Phi_{22}(\theta) = (\lambda+1)[\lambda(A_1\cos(\lambda-2)\theta - A_2\sin(\lambda-2)\theta) + (2A_1 + B_1)\cos\lambda\theta - (2A_2 + B_2)\sin\lambda\theta],$$

$$\Phi_{12}(\theta) = (\lambda+1)\lambda(A_1\sin(\lambda-2)\theta + A_2\cos(\lambda-2)\theta) + B_1\sin\lambda\theta + B_2\cos\lambda\theta$$

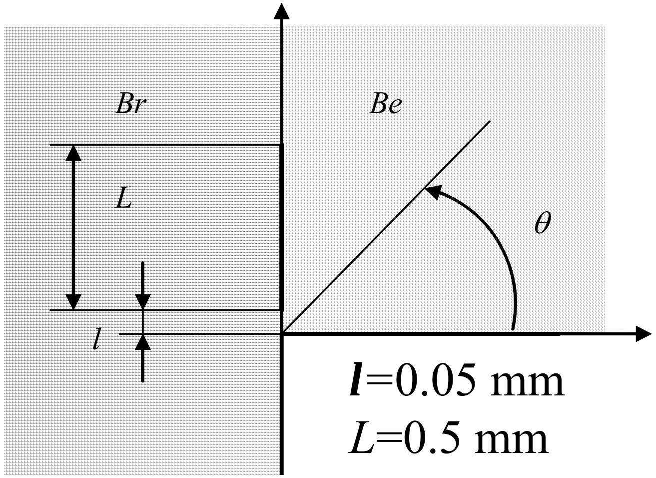
where:
K – unknown value of stress intensity factor (should be found)
λ, A_1, A_2, B_1, B_2 – parameters defined by geometry, material properties, boundary conditions etc. They are calculated using asymptotic formulas.

CuCrZr: *E*=110 GPa, ν=0.33; Be: *E*=288 GPa, ν=0.1

$$\theta = \pi/2 \qquad \tau_{11} = 2.853Kr^{-0.482} \qquad \tau_{12} = 1.682Kr^{-0.482}$$

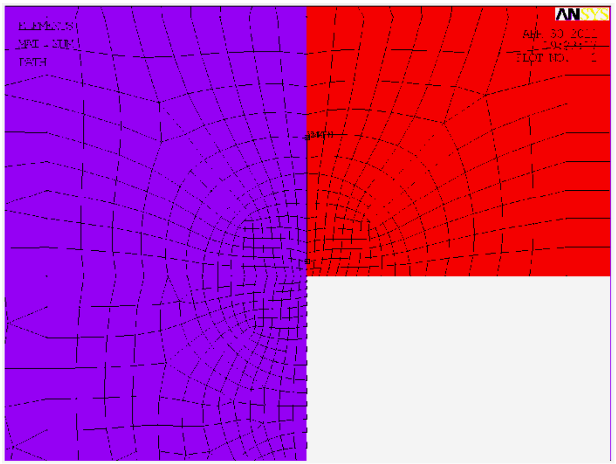
Step 2. FE analysis

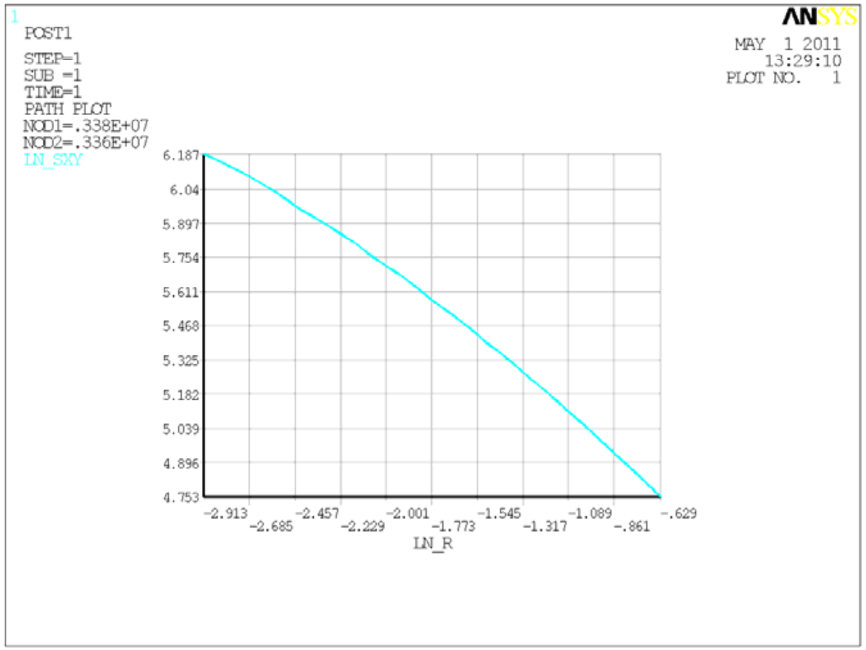
Calculation of stress in the real structure in the vicinity of the singularity point. The sub-modeling technique can be used. At this step the dependence *σ(r)* is found. Then the value of *K* is determined.



$$\tau_{ij}(r,\theta) = K r^{\lambda} \Phi_{ij}(\theta) \Rightarrow \ln \tau_{ij} = \ln K + \lambda \ln r + \ln \Phi_{ij}$$

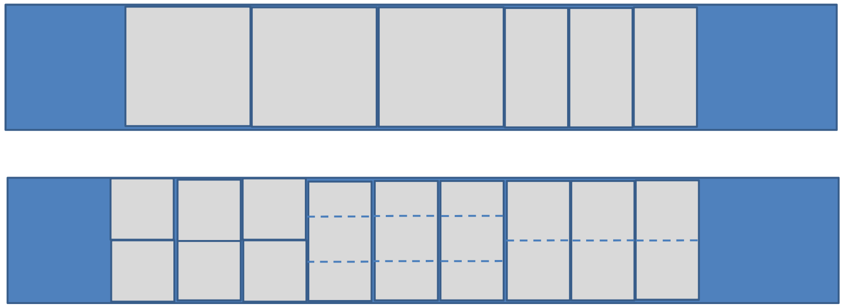
$$\sum_{i=1}^{N} (Y_i - \lambda X_i - b)^2 \rightarrow \min$$



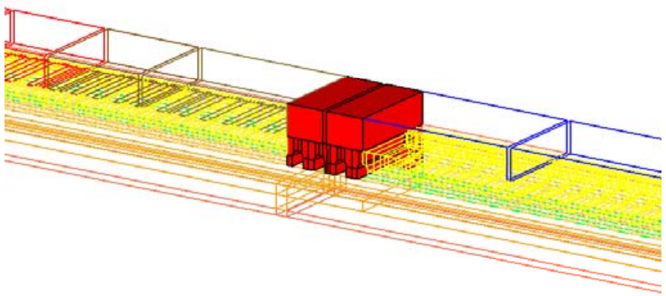


Application of the proposed method to the FW mock-up (1)

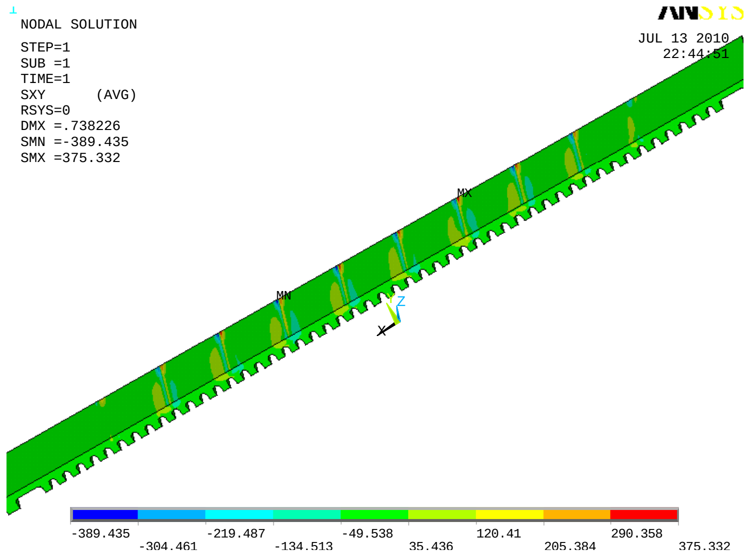
Testing mock-ups with different sizes of Be tiles loaded by the surface heat flux



two options of mock-ups



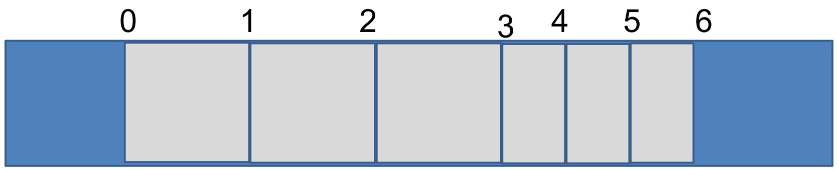
refined stress analysis to obtain stress intensity factor (sub-modeling zone)



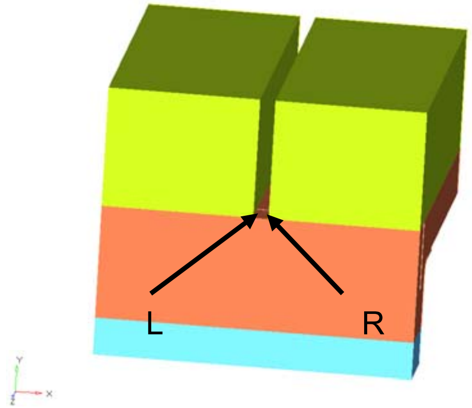
stress in the bronze part of mock-up (whole structure)

Application of the proposed method to the FW mock-up (2)

Results of stress intensity factor estimation (for the mock-up Option 1)



the numbers of slits are shown



		Be tile thickness is 8mm		Be tile thickness is 6mm	
		Heat flux, MW/m^2		Heat flux, MW/m^2	
		5.00	5.75	5.00	5.75
Slit	Face	Stress intensity factor K			
0	R	79.05	97.1	58.46	71.79
1	L	96.35	116.65	77.22	93.33
	R	94.91	114.84	76.04	91.93
2	L	97.7	118.21	78.35	94.7
	R	99.26	120.16	79.21	95.7
3	L	86.51	104.82	71.37	86.3
	R	77.93	94.44	66.67	80.63
4	L	65.7	79.79	59.29	71.72
	R	69.02	83.7	61.19	74.03
5	L	60.94	73.99	53.85	65.2
	R	55.72	67.58	48.95	59.19
6	L	43.82	54.47	33.85	42.11

Summary

We believe that the stress intensity factor characterizes a possible failure in the Be/Cu joint in the most representative way.

Proposed approach applications:

1. for qualitative comparative analysis of the different joints from the static strength point of view;
2. can be extended for analysis of joints with defects;
3. can be used for establishing the equal loading state for the joint (in geometrical/structural singularity) for various geometries

Drawback: No experimental data for matching of obtained *K* values

Experimental verification is planned.

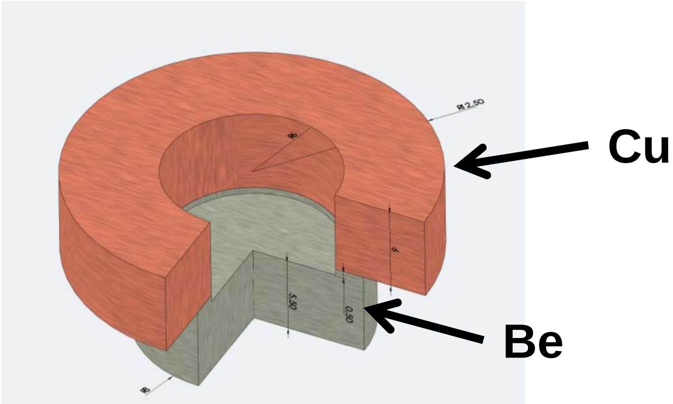
<u>Comparative analysis of 8 and 6 mm tiles</u>:

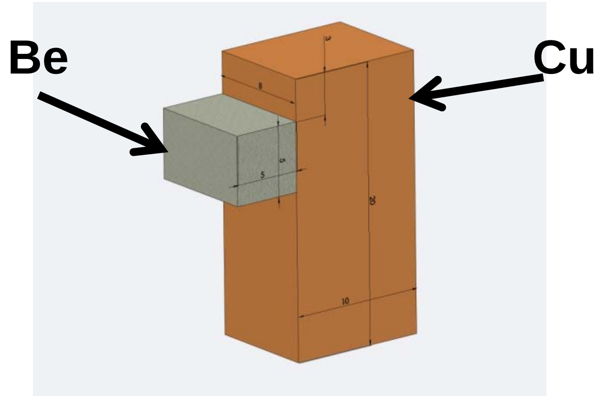
1. Maximum stress intensity factors for 8mm tiles are higher by about 20% than that for 6mm tiles at the same load.
2. The stress intensity factors for the 8mm tiles under 5 MW/m^2 are close to the factors for the 6mm tiles under 5.75 MW/m^2.

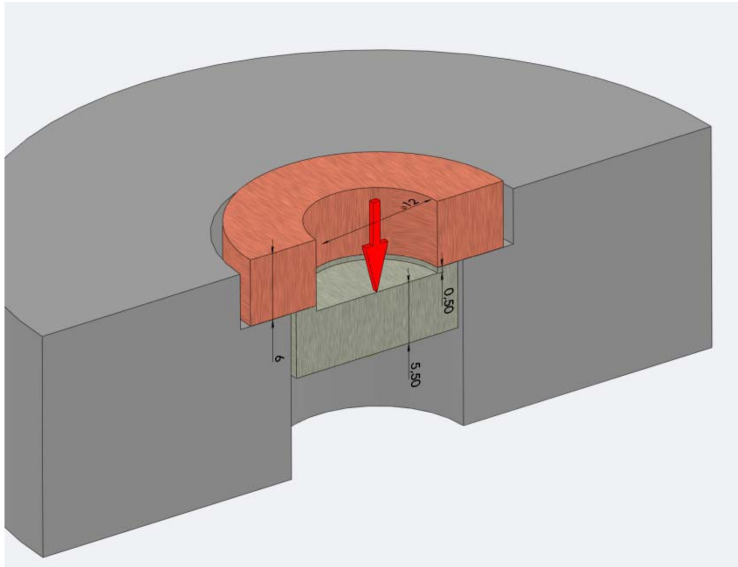
Planed Test Verification

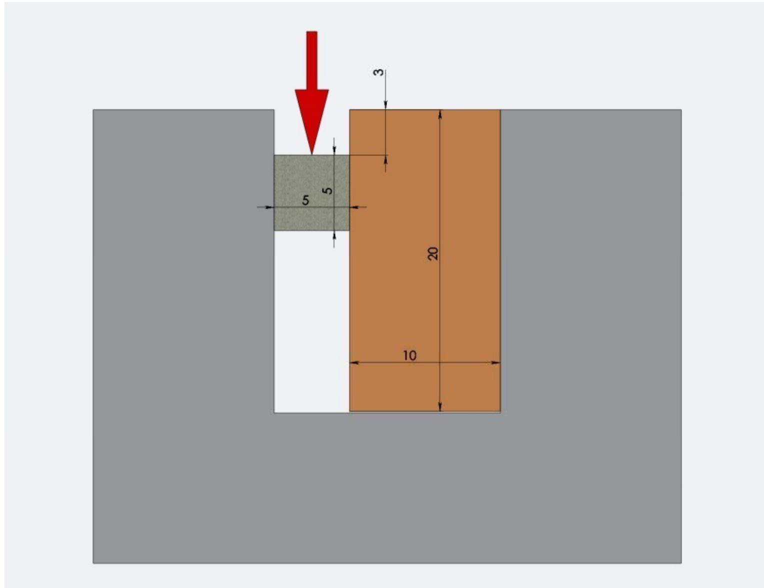
Tensile

Shear









Test results are to be obtained by August 2011