COMSOL CONFERENCE INDIA 2012

Thermo-mechanical Analysis of Divertor test mock-up using Comsol Multiphysics

Presented by

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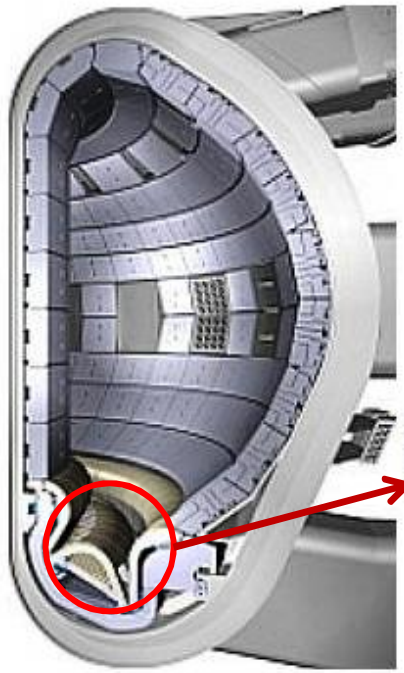
Outline

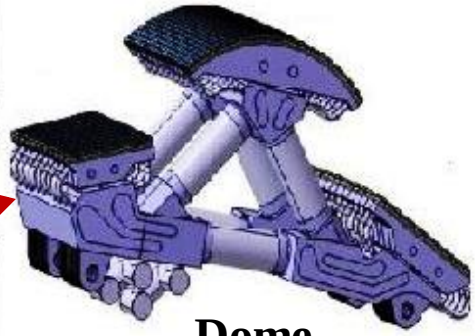
- ✓ Introduction and motivation
- ✓ Mathematical model
- ✓ Thermal properties of a brazed joint using Comsol
- ✓ 3D Comsol model for HHF test & boundary conditions
- ✓ Results
- ✓ Conclusions

Introduction and motivation



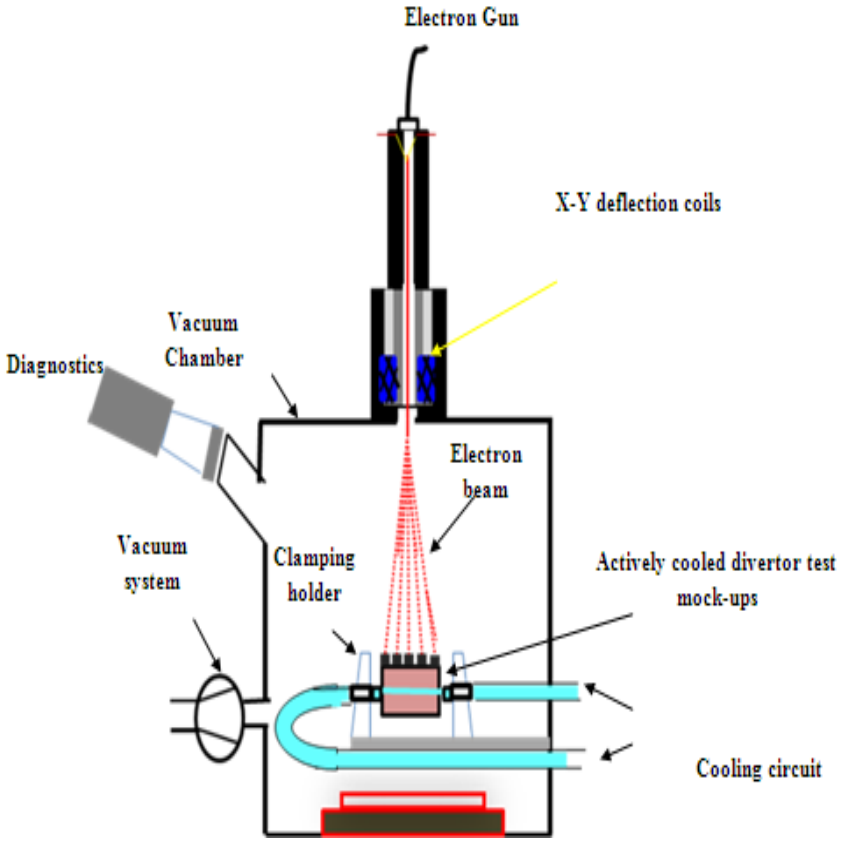
Divertor

Graphite mock-up



Dome

Vertical cross section of ITER like fusion reactor & Dome of divertor (www.iter.org)

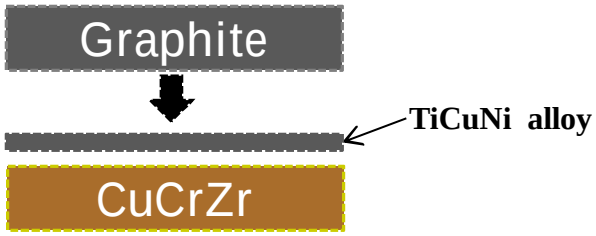


Schematic diagram of High heat flux(HHF) test set-up

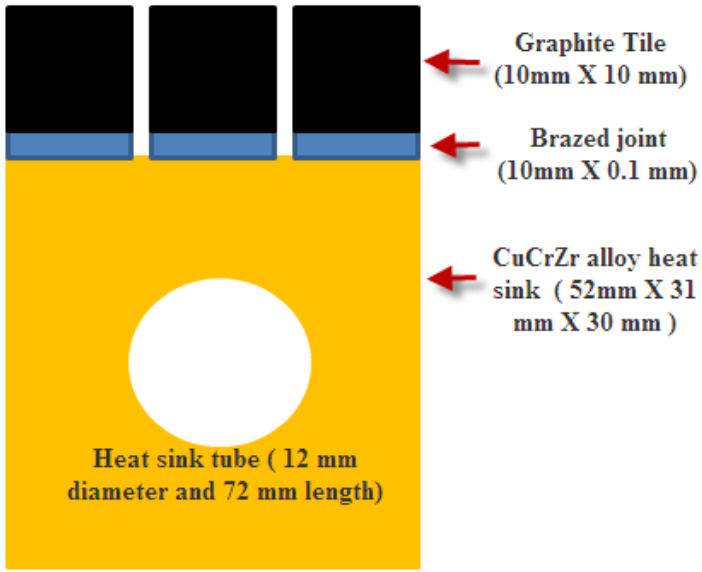
Plasma facing components namely Inner vertical target, Outer vertical target, Dome of divertor is exposed to a thermal load of 5MW/m^2 to 20 MW/m^2.

Graphite macro-brush type mock-up was exposed to 10 MW/m^2 using High energy electron beam HHF facility.

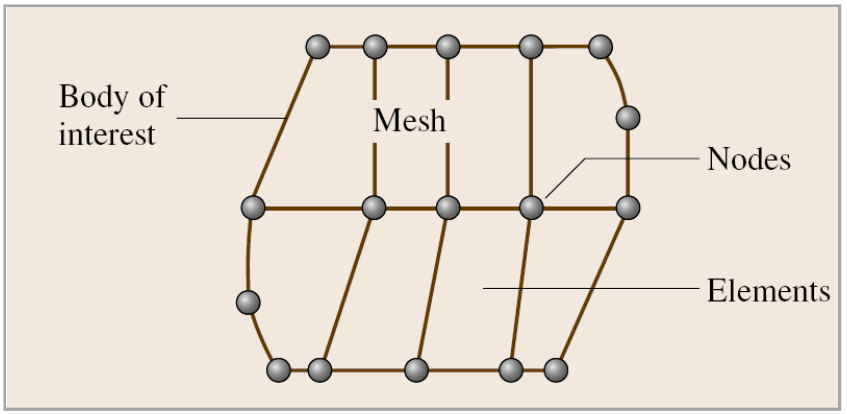
Mathematical model



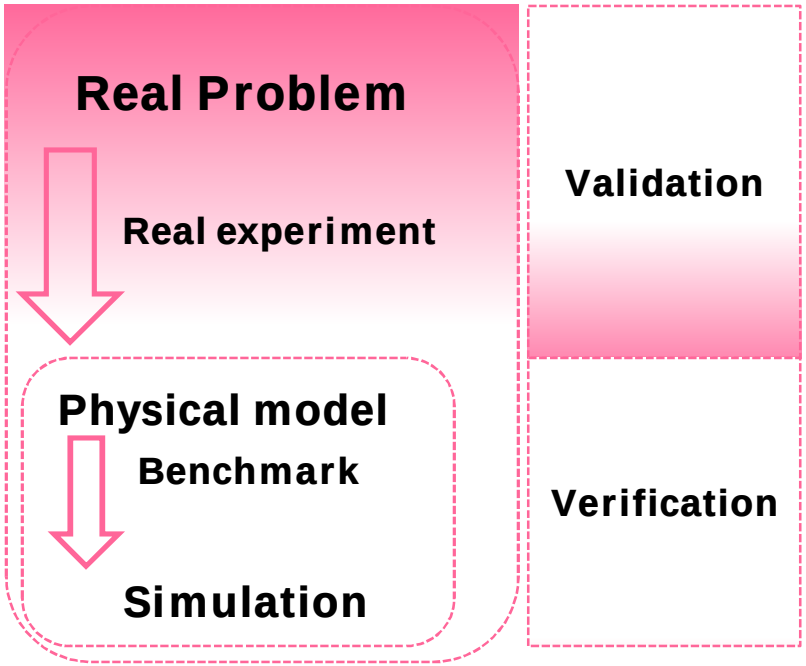
Graphite Tiles were brazed with heat sink using TiCuNi-70 @980°C



Schematic diagram of Graphite mock-up



Typical Finite element mesh



Mathematical model

Governing Equation

$$\rho Cp\frac{\partial T}{\partial t} - \nabla.(k\nabla T) = Q$$

Boundary Condition

Heat flux

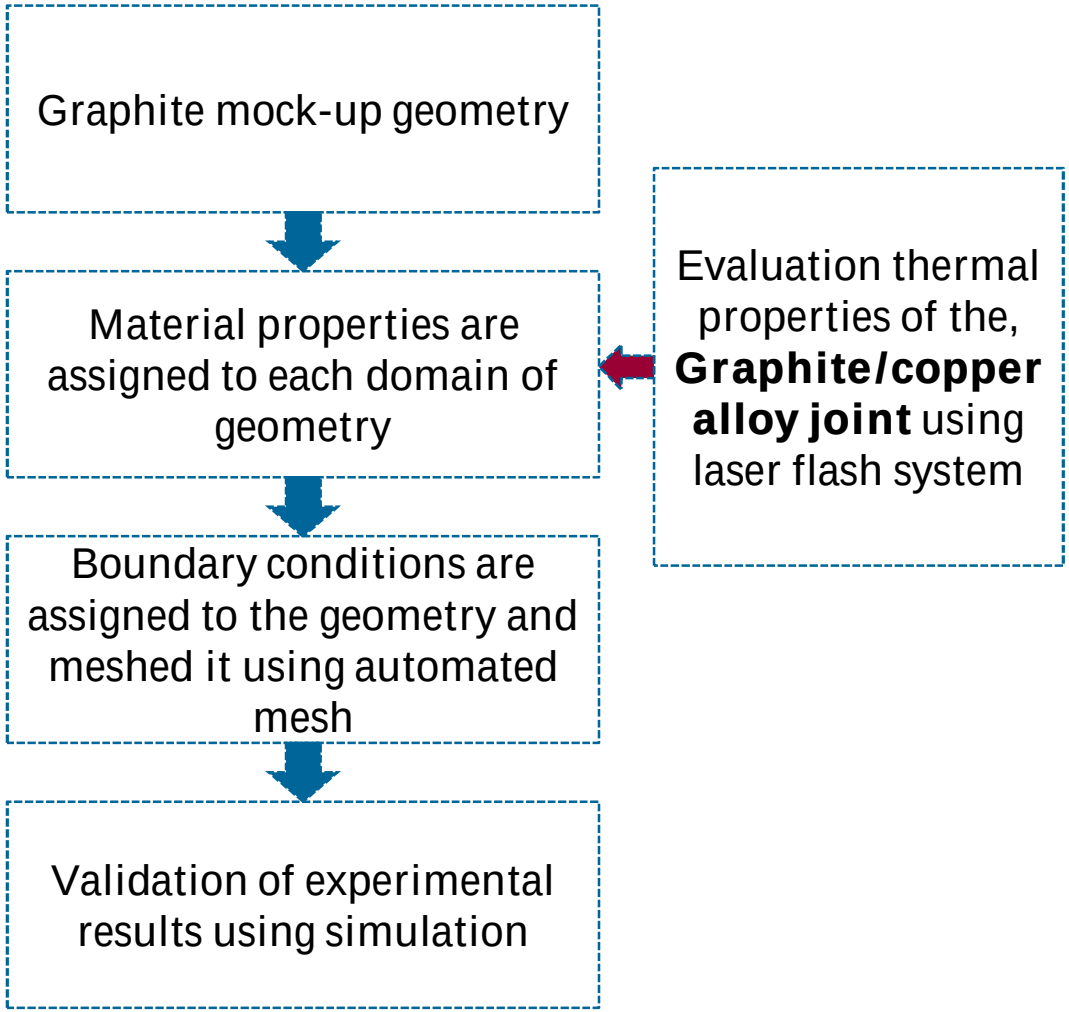
$$-\vec{n}.(-k\nabla T_1) = q + h(T_{inf} - T_1)$$

Thermal insulation

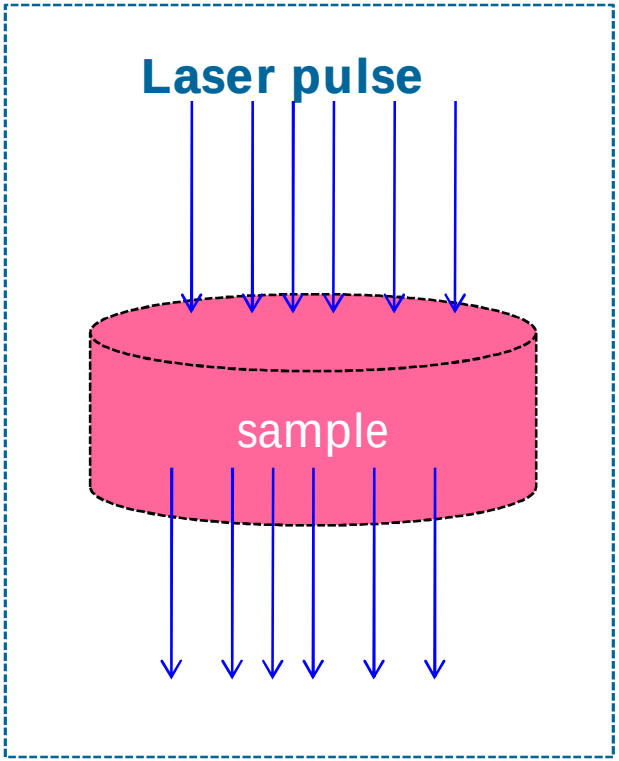
$$-\vec{n}.(-k\nabla T_1) = 0$$

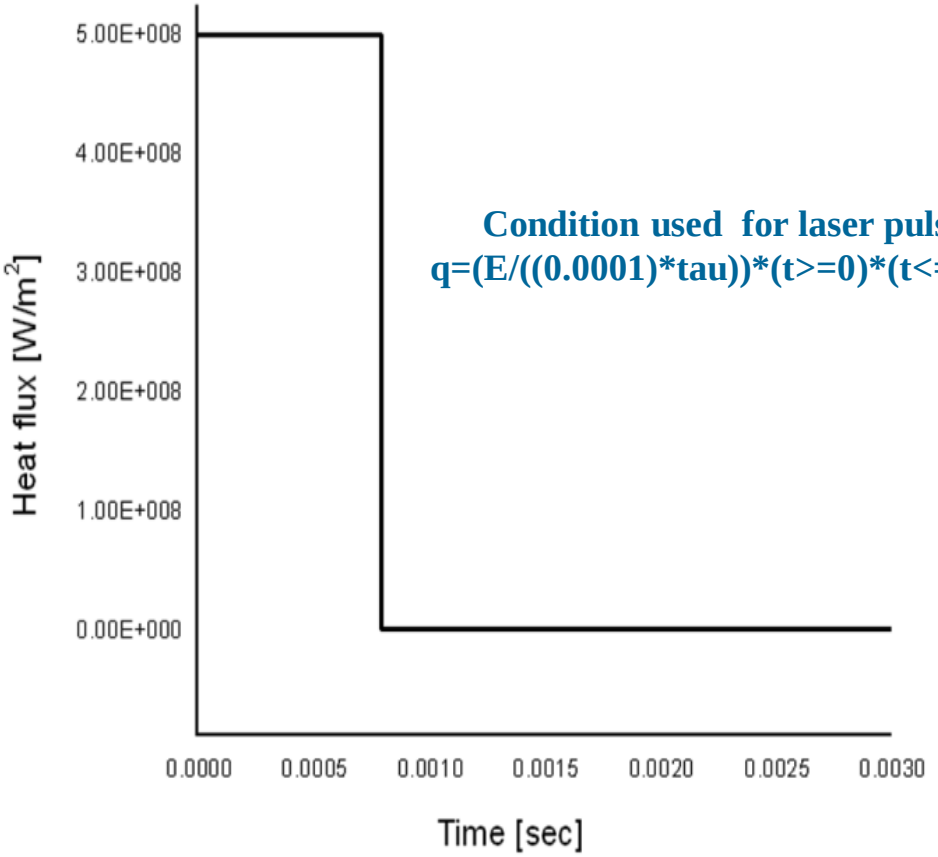
Where,
ρ= density of material,
Cp=Specific heat capacity,
k = Thermal conductivity,
Q= heat source
q = heat flux, h =heat transfer coefficient
T(x, y, z, t) = temperature, T_{inf} =external temperature , T1=initial temperature

Model flow chart



Thermal properties of a brazed joint using Comsol





Condition used for laser pulse
q=(E/((0.0001)*tau))*(t>=0)*(t<=tau)

Laser pulse used for Comsol model

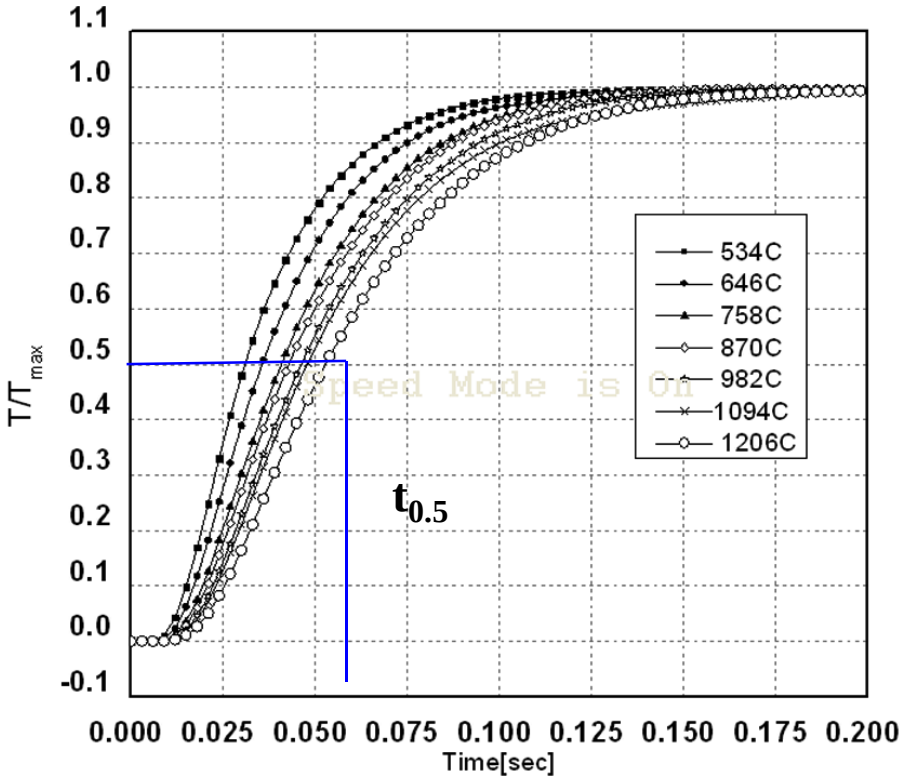
$$\alpha = \frac{0.1388\, L^2}{t_{0.5}}$$

Where, α: Thermal diffusivity,
L:Thickness of sample, $t_{0.5}$: t half

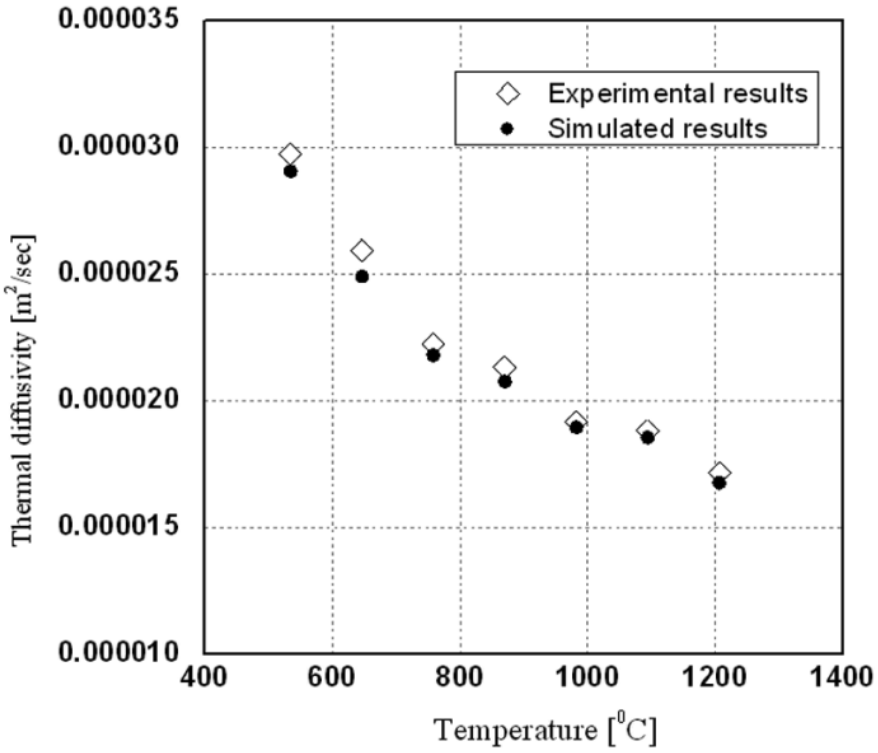
Pulse energy (E) = 40J ,
Pulse width(tau)=0.8milisec,
P_{in} = 5 x10 ^{8} W/m^2

W.J. Parker, et al.; Journal of Applied Physics, Vol.32 (1961) p1679

Thermal properties of a brazed joint using Comsol (Benchmark)



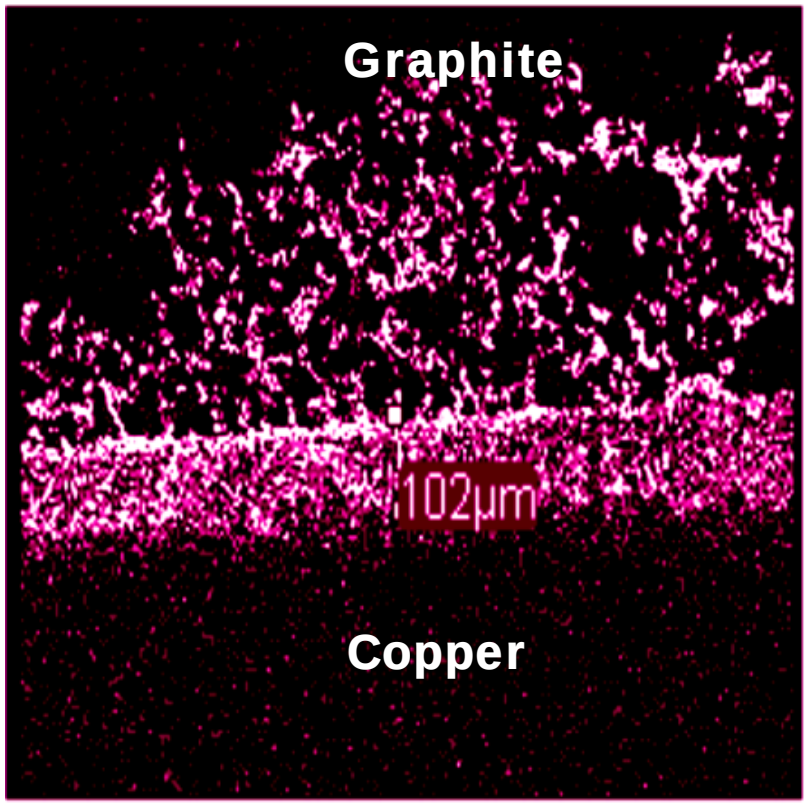
T/T_{max} Vs time plot generated of FP479 Graphite using Comsol Multiphysics



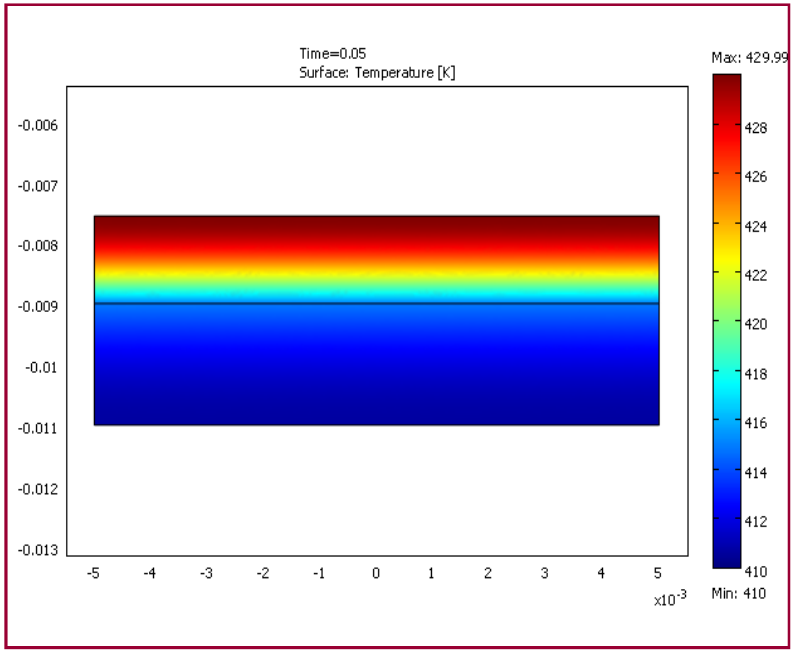
Comparison experimental results with simulation results

Simulation results are nearly match with experimental results.

Thermal properties of a brazed joint using Comsol



SEM of Graphite/TiCuNi/Copper joint



2D model of Graphite/copper joint

$$Q = \frac{\Delta T}{\frac{d_1}{k_1} + \frac{d_2}{k_2} + R_{joint}}$$

2D model of Graphite/ Copper joint was developed in Comsol Multiphysics and using iterative method thermal properties of the brazed joint was evaluated for temperature range 50˚C to 600˚C.

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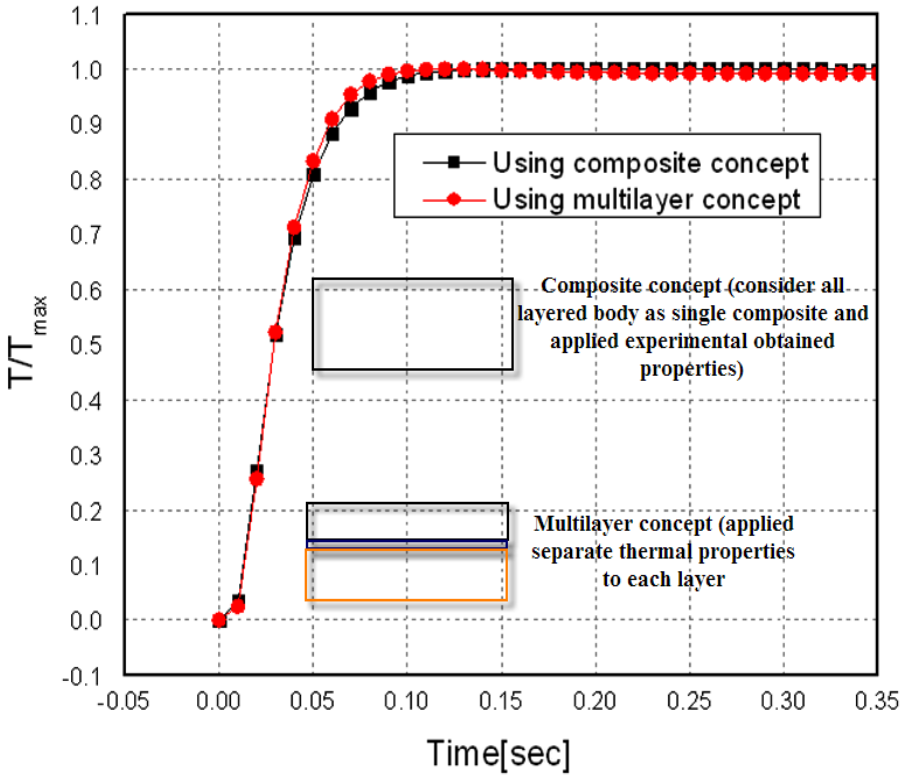
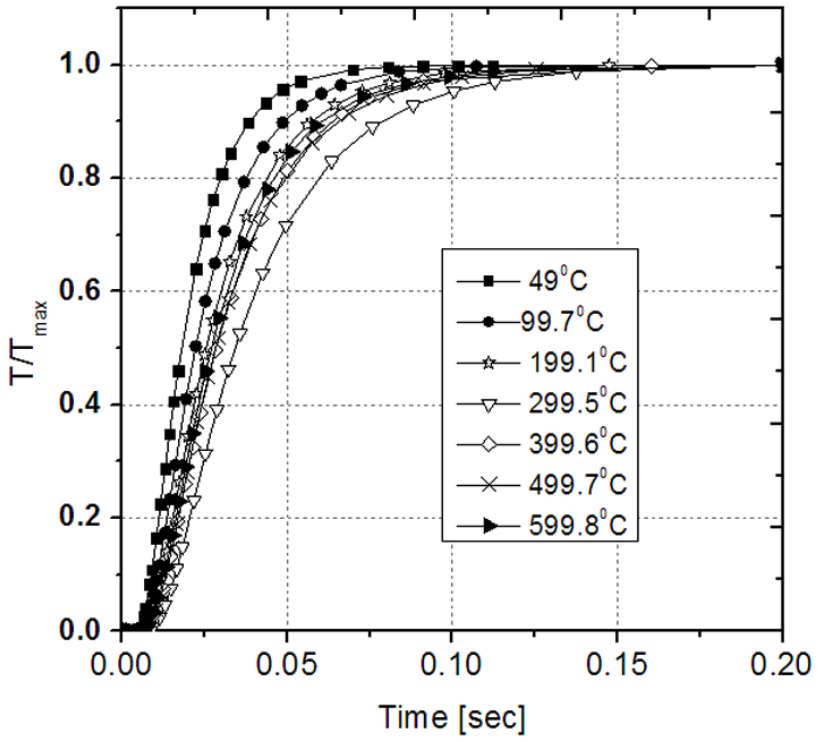
Thermal properties of a brazed joint using Comsol



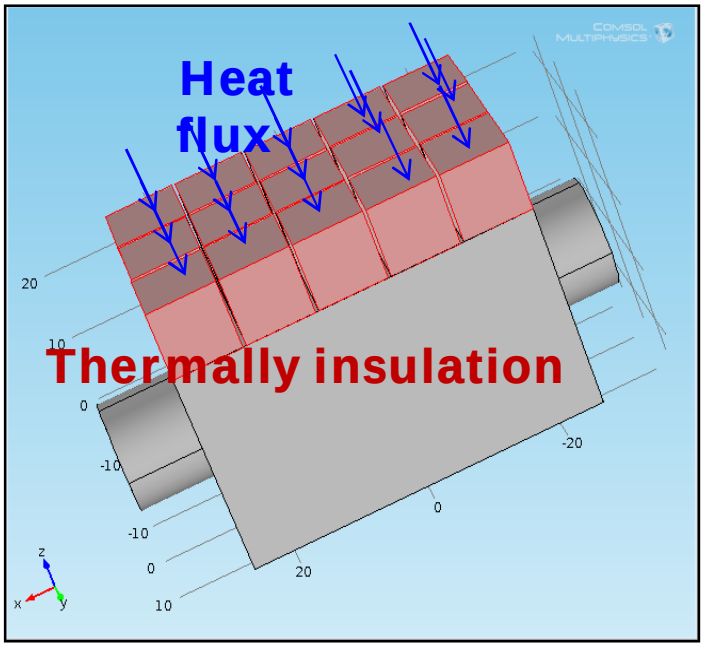
Raw plot generation using experimental thermal properties

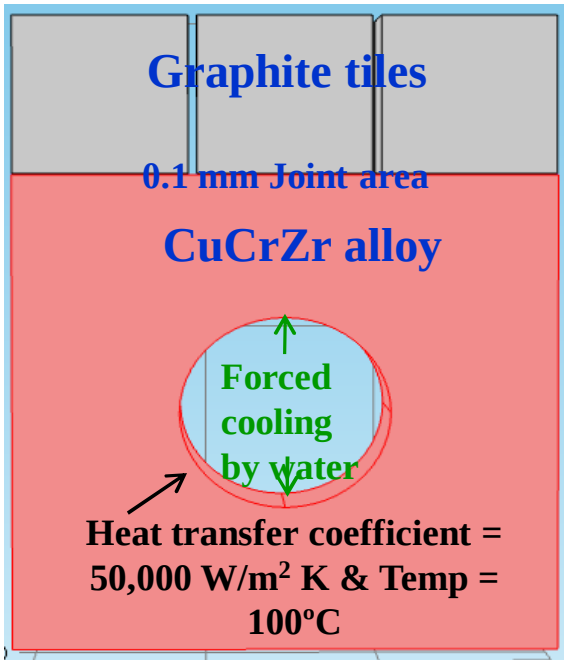


T/T_{max} Vs time plot generated using Comsol Multiphysics

Thermal conductivity of joint interlayer is in the range 16 W/m K(50°C) to 5.4 W/m K(600°C) and further used for HHF model.

Comsol model & boundary conditions





Input Heat flux is an extracted heat flux by mock-up 7.2 MW/m^2

Heat Transfer Coefficient h = Nu. k / d

Where, **Nu = 0.023*Re$^{0.8}$*Pr$^{0.4}$; Pr = μCp/k; Re = ρ Vd/μ; m = ρ AV**

Graphite

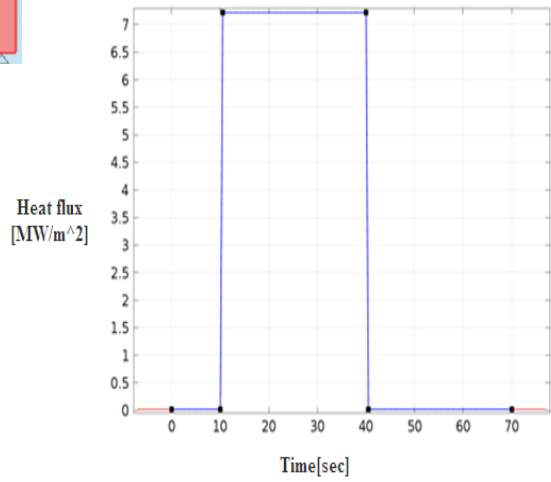
Temperature [°C]	Thermal conductivity [W/m K]	Specific Heat (J/kg K)
20	155	719.78
300	118	1379.12
500	92	1598.9
800	69	1802.19
1200	53	2021.97
1600	47	2098.9
2000	40	2159.34

Density = 1.820 gm/cc

CuCrZr alloy

Temperature [°C]	Thermal conductivity [W/m K]	Specific Heat [J/K. kg]
20	384	3.78E+02
200	372	4.05E+02
400	359	4.25E+02
600	355	4.43E+02
800	350	4.58E+02

Density = 8.96 gm/cc



Incident heat flux

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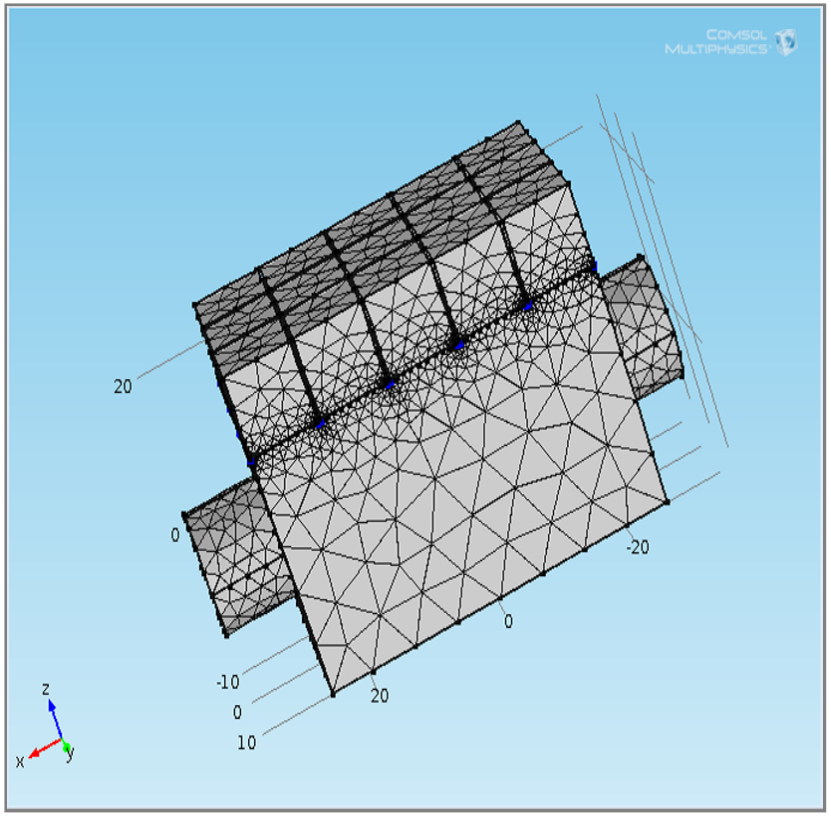
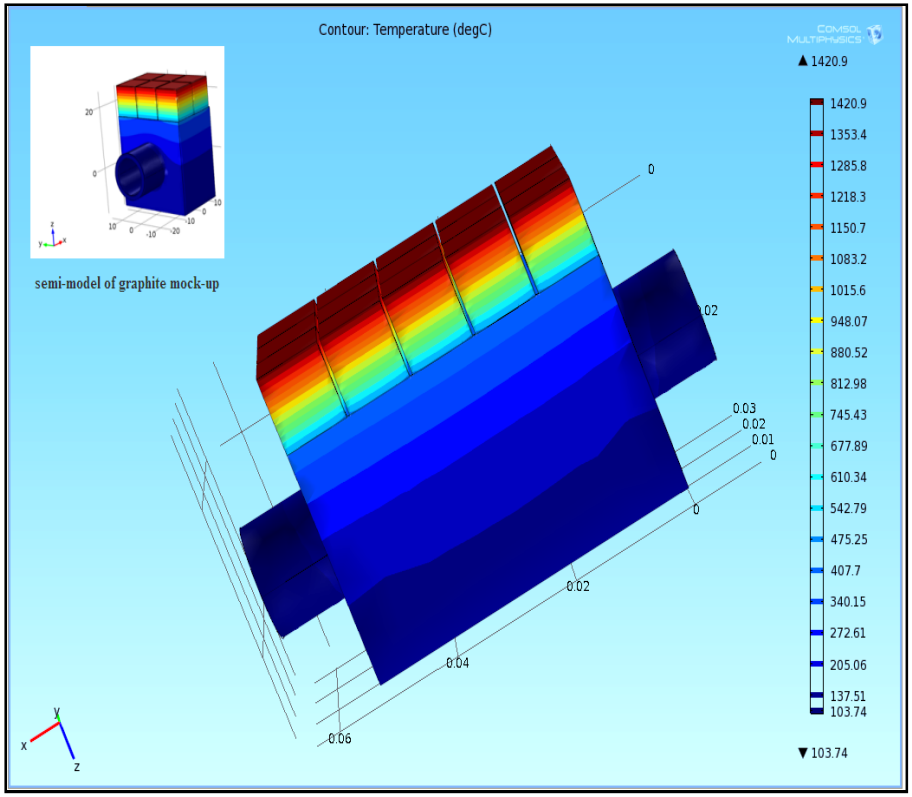
Results



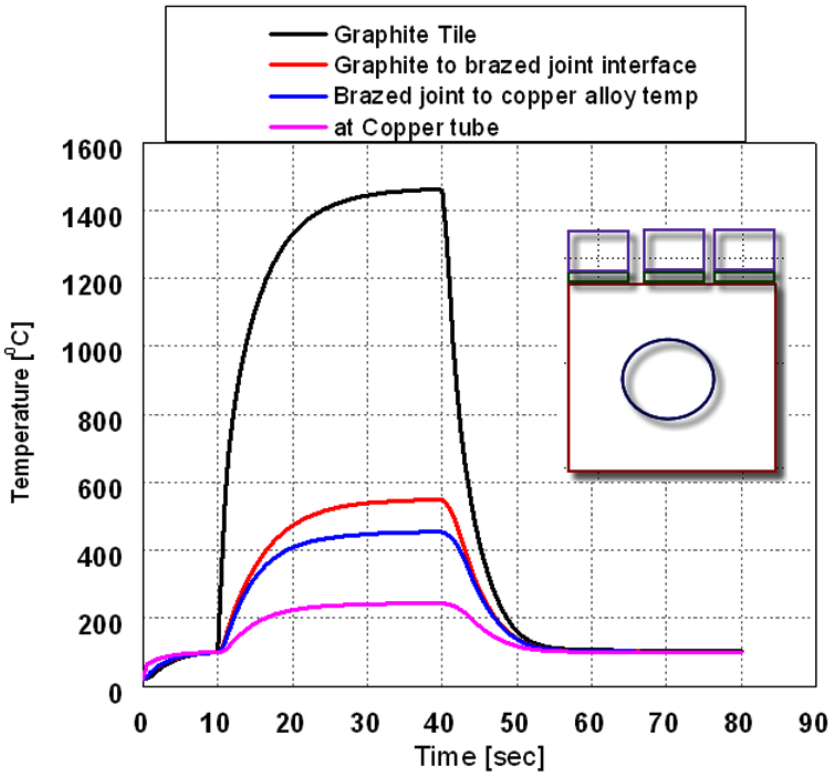
Complete mesh consists of 40799 elements

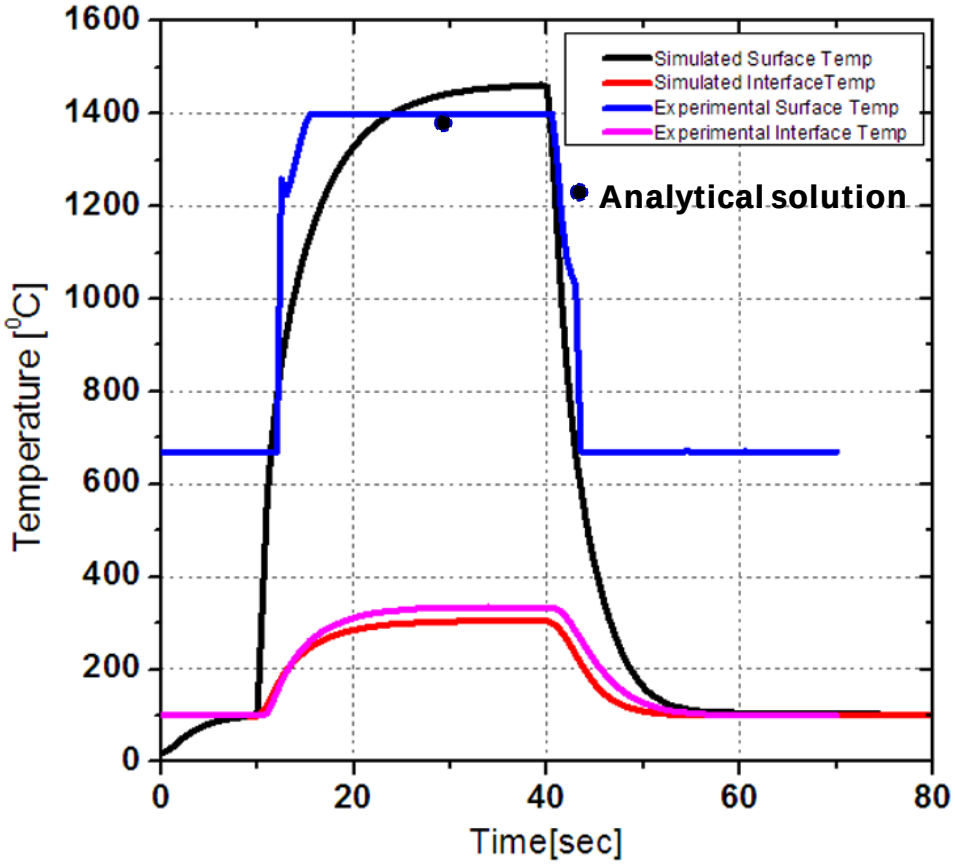


3D contour plot of temperature profile at 31 sec

The linear solver UMFPACK is used for the problem. Time is set for 0 to 80 sec with 0.1 sec time step.

Results





Analytical surface temperature of a mock-up is calculated using 1D steady state conduction equation q= k dT/dx.

Conclusions

The paper deals with the numerical modeling of Graphite mock-up during transient heat loads, which used for validation of experimental results. Maximum surface temperature observed during simulation is 1420ºC.

Acknowledgements

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THANK YOU