SAND2019-8425D

Sensitivity Analysis of Glass-Fiber Reinforced Plastic Material Properties

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This project provides a safe time-to-thermal-equilibrium value to experimentalists measuring the coefficient of thermal expansion in epoxy resin cubes. This measurement requires accuracy on every temperature reading. When each resin cube is heated to measurement temperature, the researcher needs to be confident that the temperature is constant through the thickness, that is, the researcher wants to be sure the cube is in **thermal equilibrium.**

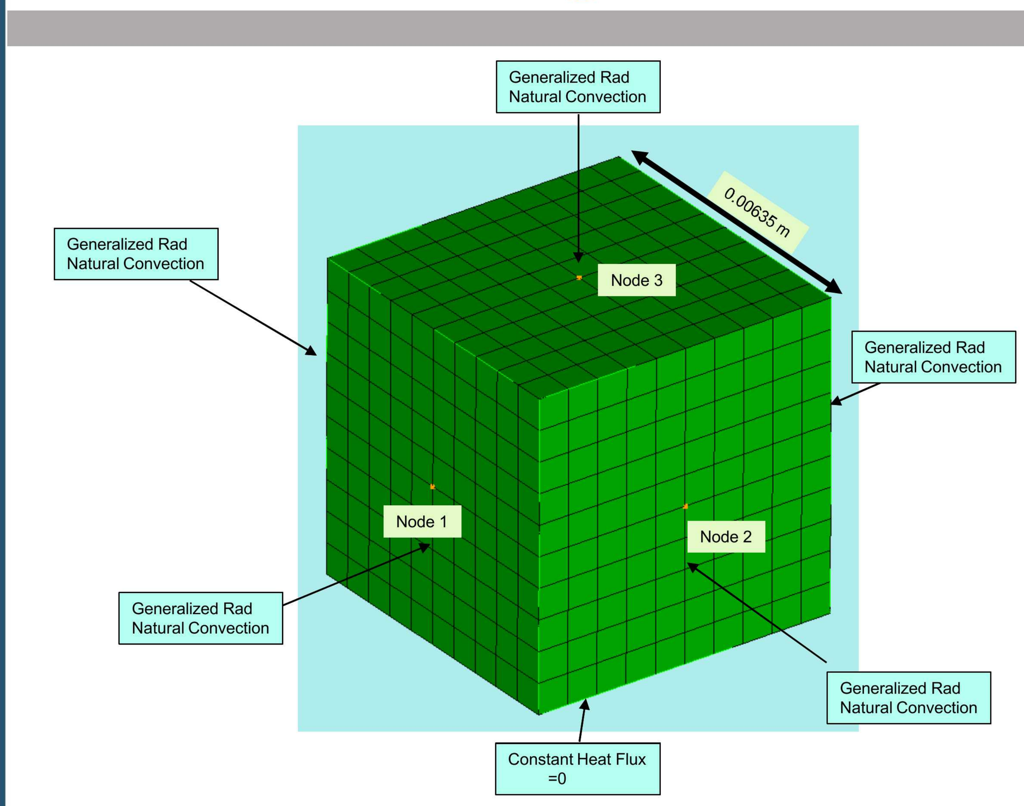

Fig. 1 Finite Element Mesh with BCs

The System

The cube to be tested has a side length of 0.0635 m and is machined from a plate of cured epoxy resin. This geometry was modeled into a 10x10 meshed volume. In the experiment, the cube will be placed on a quartz plate in an environment set to some reference temperature. To account for this, the bottom of the model's mesh was set to a zero-heat-flux boundary condition, while the other five sides were set to both natural convection and generalized radiation boundary conditions.

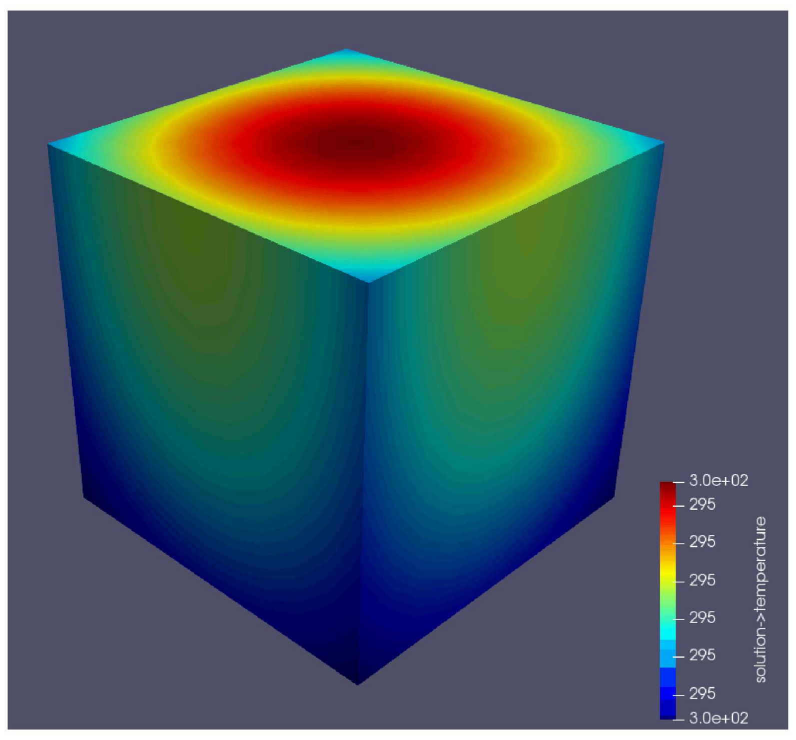

Fig. 2 Aria Simulation of Heated Cube

Modeling the Time to Equilibrium for a Sweep of Reference Temperatures

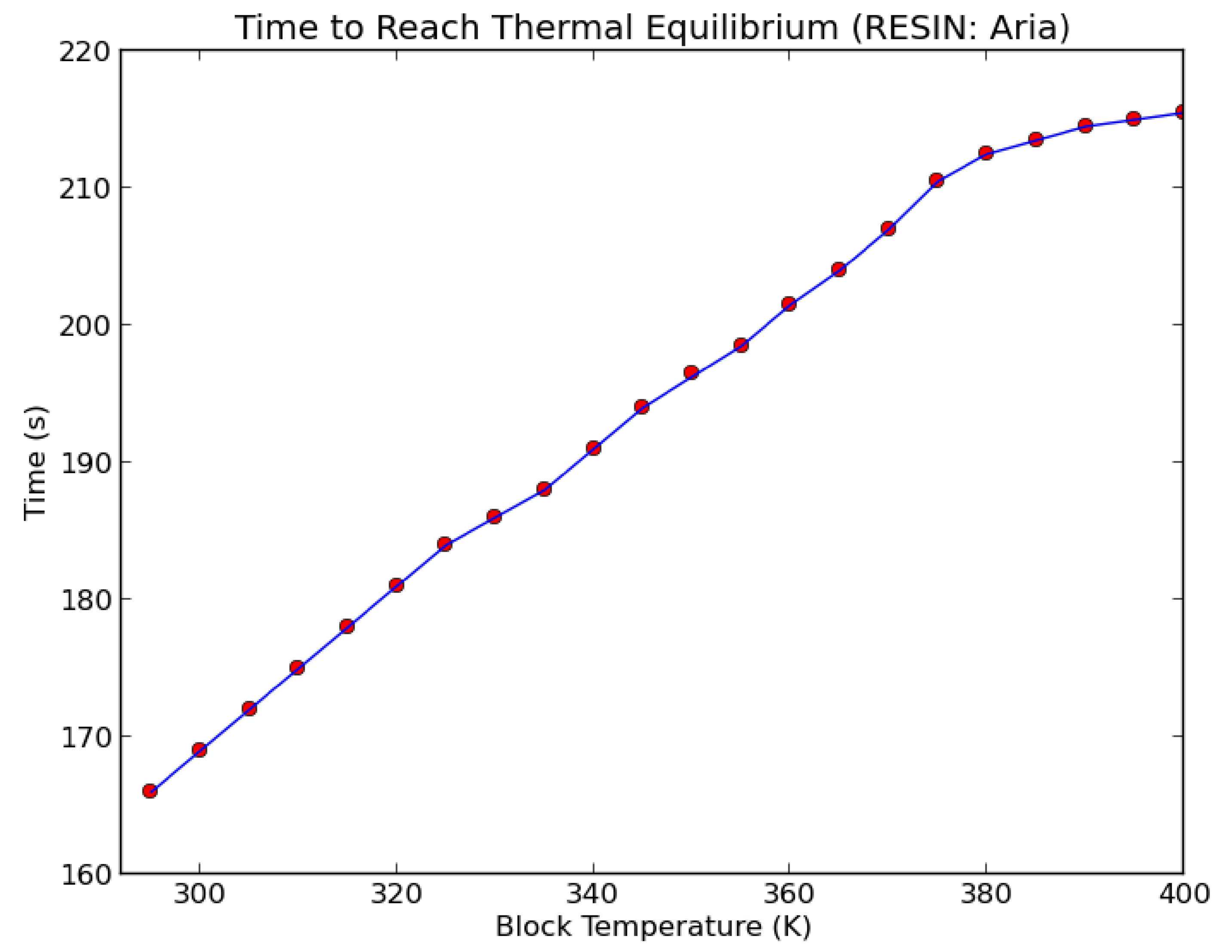

Fig. 3 Aria Simulations of Time to Equilibrium

The time for the block to reach thermal equilibrium from room temperature to various reference temperatures was computed. A computational model was developed in Sandia National Lab's thermal/fluid mechanics solver Aria in parallel with a hand calculation approximation using the Lumped Capacitance method (Eq. 1). The lumped capacitance method failed to represent the model, as the Biot number for the resin's properties was too high (Fig. 5). We can see from the trend of the simulations (Fig. 3) that larger temperature differences will lead to a longer time to equilibrium up until a plateau near 215 seconds. Thus, the time to equilibrium value that we will recommend to experimentalists is $\boldsymbol{t < 4\,min}$.

$$t = \frac{\rho V c_p}{(h_c + h_r)A} * \ln\left(\frac{T_\infty - T}{T_\infty - T_i}\right)$$

$$\text{IF:} \quad \text{Bi} \ll 1 \text{ where } \text{Bi} = \frac{h_c l}{k}$$

Eq. 1 Lumped Capacitance Method

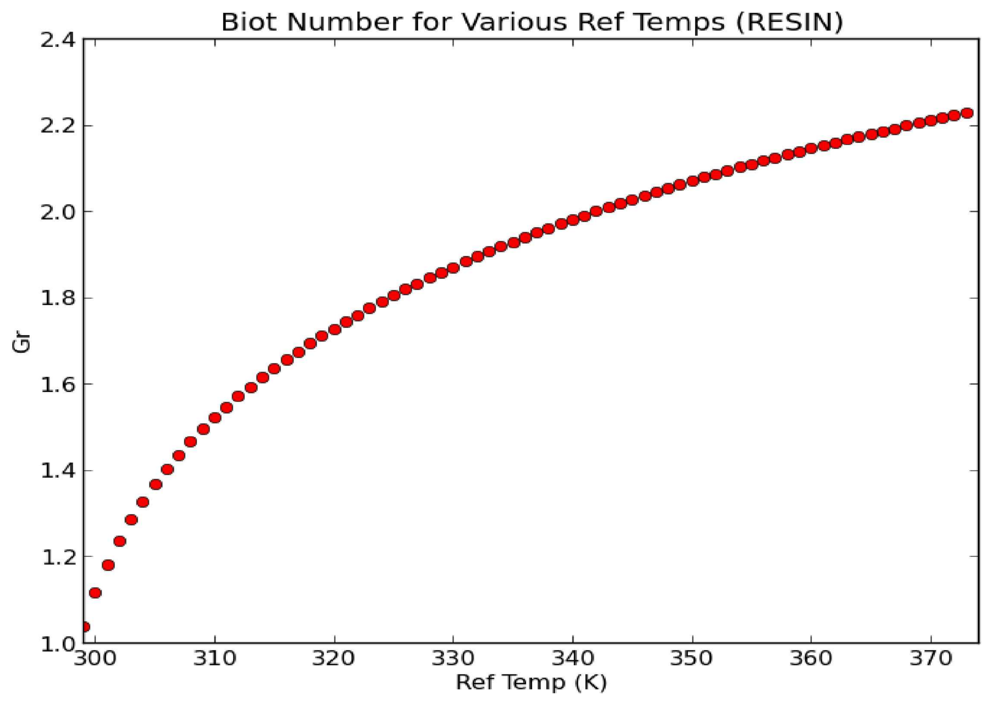

Fig. 5 Resin Biot number

Sensitivity Analysis

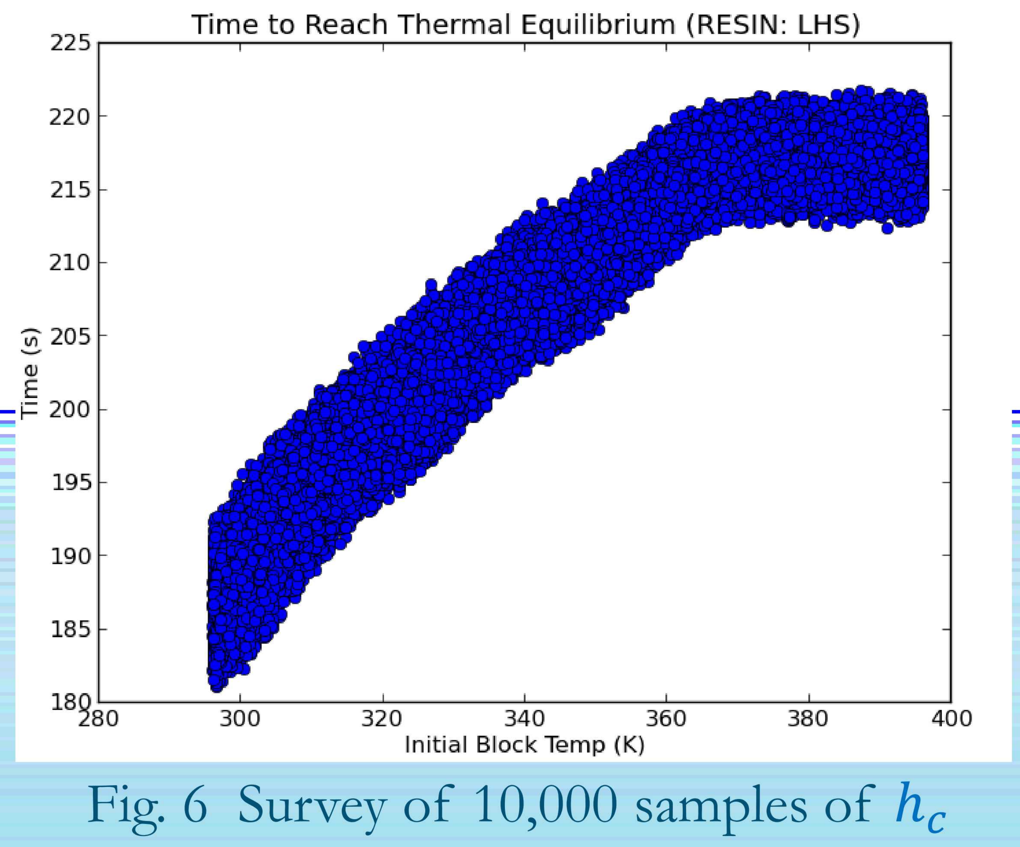

Fig. 6 Survey of 10,000 samples of h_c

The time to thermal equilibrium was provided, but a deeper insight to the influence of each model parameter on the resulting model physics was desired. A parametric sensitivity analysis was performed on the most influential variables in Eq. 1. The model was solved 10,000 times with slight variations of ρ, c_p, h_c, T_i, and l, and the response of the time-to-equilibrium result for an ambient temperature equal to $T_i + 10°C$ was tracked (Fig. 6). The Sobol Indices were calculated (Table 1), which indicated the degree of the variability in the solution of the cube model that comes from each of the varied parameters. The highest degree of equilibrium time clearly comes from the initial block temperature, suggesting the understanding the temperature dependence of the material properties is import. This agrees with the strongly linear relationship between time to thermal equilibrium and block temperature that was shown in Figure 3.

Parameter	Bounds	Sobol Index
ρ	$\pm 2\%$	1.5%
c_p	$\pm 5\%$	0.41%
h_c	$\pm 20\%$	1.3%
T_i	$[296{:}396]$	96.9%
l	$\pm 0.8\%$	0.36%

Table 1 Sobol Indices of Sensitivity Analysis

Conclusions

The time to thermal equilibrium of a resin cube was solved to be less than 4 minutes. Aria solutions for thermal equilibrium were statistically analyzed with a Sensitivity Analysis. A coupled Gaussian process using Latin hypercube sampling showed that the most influential parameter to the time to equilibrium is the block temp.

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