# Computational modeling and validation of radiative coefficients of porous composite materials

Ayan Banerjee [1], Yejajul Hakim [1], Cameron Brewer [1], Luis Chacon [1], Ahmed Yassin [1], Michael Renfro [1], and Savio J. Poovathingal [1]

[1]Department of Mechanical and Aerospace Engineering, University of Kentucky, Lexington, KY 40506, USA

## Introduction

During hypersonic entry of space vehicles, emissions from hot gases play a significant role in the transfer of radiative heating into the thermal protection system (TPS). Radiative coefficients of composite materials are required as inputs to material response solvers that capture radiative transport in materials. A Monte Carlo radiation solver has been developed to compute the effective radiative properties of composite materials. In this work, we validate our Monte Carlo radiation solver against experiments performed on two TPS materials.

## Methods

An experiment bench is set up to compute the transmission and backscattering of broadband light from LI2200 TPS material. The light sources include the SLS201L from Thorlabs, covering the 360-2600 nm range, and a PX2 pulsed Xenon light source from Ocean Optics, covering 220-750 nm.

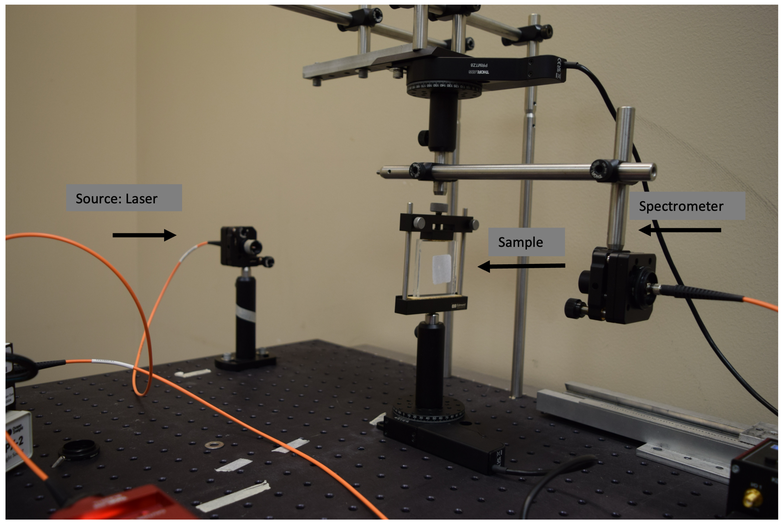
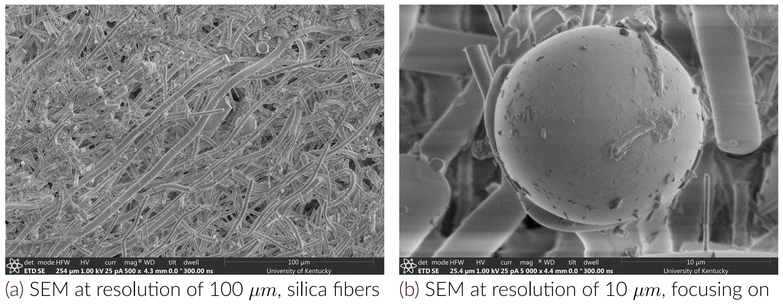



Figure 1. Experiment setup to compute transmission and backscattering.

The light from the laser is incident on LI2200 (material kept between two glass blocks for support). A collimator (to collect the photons for computing the transmission curve) is kept in the line of sight. The lens in the collimator and the laser beam both have a diameter of 0.5 inch. To compute the backscattering, the collimator is rotated from the spindle by 140°-160°.



(a) SEM at resolution of 100 $\mu m$, silica fibers and micro balloons together.

(b) SEM at resolution of 10 $\mu m$, focusing on micro balloons.

Figure 2. SEM images of LI2200.

## Methods

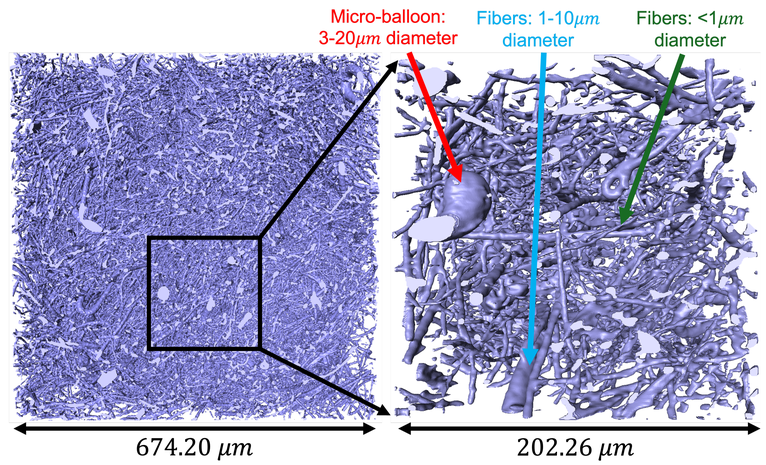
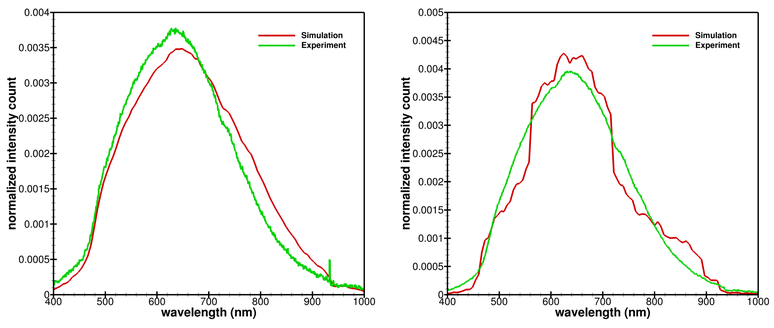



Figure 3. A 674.20 $\mu m$ x 674.20 $\mu m$ x 674.20 $\mu m$ surface rendering is cropped to a 202.26 $\mu m$ x 202.26 $\mu m$ x 202.26 $\mu m$ surface. The presence of balloons and fiber diameter variety are highlighted.

### Main Idea

Validation of the Monte Carlo radiation solver to compute radiative (optical) coefficients.

## Results



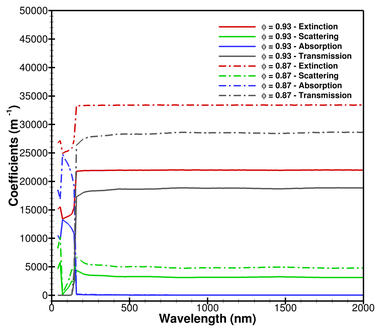

(a) Transmission profile.

(b) Backscattering profile.

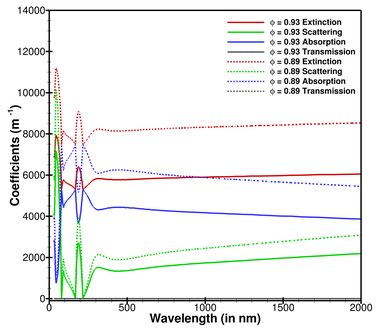
Figure 4. Transmission and backscattering profiles of LI2200.

The transmission and backscattering comparison of LI2200 is shown. For the experiment, the thickness of the sample was kept at 0.4 mm. The simulation was setup where an STL of 0.4 mm thickness was generated and photons were injected in a laser mode onto the sample. The photon boundary hits were computed and then postprocessed to compute interactions with the collimator for transmission and backscattering profile. The final profiles were normalized (both experiment and simulation) for comparison. With the comparisons in place, the radiative coefficients for LI2200 and FiberForm are computed at two different porosities. The asymmetry parameter (g) was also computed for both TPS material.

## Results

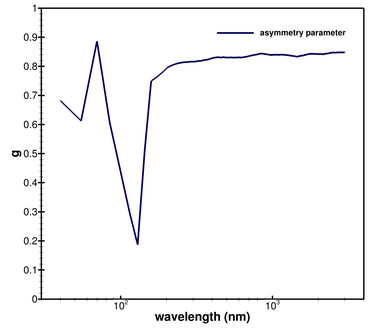



(a) Coefficients of LI2200 at two different porosities.

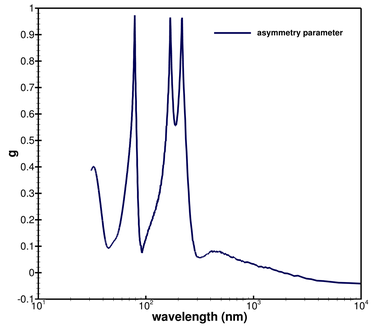



(b) Coefficients of FiberForm at two different porosities.

Figure 5. Radiative coefficients of LI2200 and FiberForm.




(a) LI2200.




(b) FiberForm.

Figure 6. Asymmetry parameter 'g' vs wavelength.

In the visible spectrum, LI2200 has a high forward scattering peak. However in FiberForm it is observed that there is no inclination towards a forward scattering and at certain wavelengths it exhibits a negative value of g.

## Conclusion

With the current validations in place, we have a quantitative understanding that the radiation solver predicts the radiative coefficients of TPS materials. There are additional parametric studies being conducted to understand the effect of refractive index, porosity, and size distribution in TPS materials.

## Acknowledgements

The work is supported by the NASA entry systems modeling project under grant number 80NSSC20K1072 and NASA Space Technology Research Institute (STRI), Advanced Computational Center for Entry System Simulation (ACCESS) under grant number 80NSSC21K1117. The experimental material is based on work supported by NASA and the NASA Kentucky EPSCoR Program under NASA award number 80NSSC22M-0174. We also thank the University of Kentucky Center for Computational Sciences for their support and use of the Morgan Compute Cluster and associated research computing resources.