Computational Materials Techniques for Thermal Protection Solutions: Materials and Process Design

Example 1: Materials Design for Solar Thermal Propulsion

Solar thermal propulsion (STP) is a leading candidate for high-speed travel into the interstellar medium (enables 15 AU/year compared to Voyager’s speed of 3.6 AU/year). STP requires a close approach to the sun (3-4 solar radii) to heat a hydrogen (H₂) fuel to 3100-3500 K, which will then be ejected through a nozzle for thrust.

STP requires a heat exchanger material to transfer solar radiation to the fuel. The leading candidate is a coated carbon/carbon material. The goal is to ablate by 1-3 mm. Carbides are found to react minimally, prevent significant hydrogen intercalation and diffusion, and size to prevent ablation from vaporization.

To summarize, coating materials have been computationally screened for suitability in a heat exchanger for solar thermal propulsion. Overall, high-temperature carbides are found to react minimally, prevent significant hydrogen intercalation and diffusion, and ablate by 1-3 mm during operation and represent the most promising candidates.

Example 2: Process Design for Heat Shield Composites

The 3-Dimensional Multi-functional Ablative Thermal Protection System (3DMAT) is a fused quartz / cyanate ester composite used as the compression pad on the Orion EM-1 vehicle. This effort set out to produce fully densified 3-D orthogonally woven composite with less than 2% porosity.

After infusing and the fused quartz preform with cyanate ester and curing, a large void has been observed in the center of some material samples. The void more frequently appears in large sized samples. Computational techniques are used to examine potential sources of the void, which include trapped residual gases and resin shrinkage during the cyanate ester cure phase.

To summarize, a computational process design study has been performed on resin infusion and cure for the 3-Dimensional Multi-functional Ablative Thermal Protection System to prevent the formation of voids. The results indicate moisture adsorption and resin shrinkage can lead to void formation in a symmetric curing configuration. An asymmetric curing configuration would not promote the formation of central voids.

aCollaboration with: Don Ellerby (NASA), Dean Cheikh (Jet Propulsion Laboratory)
bCollaboration with: Jay Feldman (NASA), Peter Gage (Neerim Corp.)