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MATERIALS AND STRUCTURES SYMPOSIUM (C2)
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HEAT TRANSFER MECHANISMS OF MICRO- AND NANO-CHANNELED STRUCTURAL THERMAL INSULATION COMPOSITES (STICS)

Abstract

Sustaining the extraterrestrial presence of humans in the solar system will require the ability to provide structural, thermal insulation composites (STICs) that can be inexpensively manufactured and transported. These lightweight advanced composites must have thermal insulation properties in the range of 10-50 mW/(m-K) and mechanical properties suitable to support an anticipated lunar habitat internal pressure of 30 kPa. We are pursuing a solution to this problem which permits the introduction of micro- and/or nano-scale channels in polymers, in controlled configurations that maximize both thermal insulation and mechanical properties. In this approach, convective heat transfer mechanisms within micro- and nano-scale channels are being exploited to limit thermal energy transfer in the bulk material. Within an epoxy matrix, high volume fractions of micro- and nano-channels have been produced, which lower the overall density and also make convective heat transfer difficult. Both the micro-channeled and nano-channeled materials were created via sacrificial thermal degradation of poly(lactic acid) (PLA) fiber networks embedded in a high-temperature resistant epoxy matrix, which remains intact through the PLA degradation process. As the channel content increases, substantially lower densities and thermal conductivities can be reached while retaining acceptable rigidity and strength. Furthermore, as channel diameter decreases from micro-scale to nano-scale, gas diffusion is expected to be constrained by the Knudsen effect, since the gas molecules will increasingly collide with the channel wall as channel diameter becomes comparable to, or smaller than, the molecules' mean free path. This effect on convective heat transfer may be augmented by reduced conductivity through the epoxy matrix as a result of greater tortuosity or path length imposed by a high population of crisscrossed obstacles, in the form of the poorly conducting nano-channels. The thermal conductivities of the micro-channeled and nano-channeled materials synthesized were compared over a range of channel fractions, providing insight into the mechanisms controlling and limiting heat transfer in these systems.