ABSTRACT

Title of Dissertation: ENGINEERING THERMAL CONDUCTIVITIES FOR ENERGY APPLICATIONS

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The increasing demand for efficient energy utilization and sustainability underscores the urgency for innovations in thermal management materials and structures. Thermal conductivity engineering stands at the forefront of these innovations, aiming to optimize the transfer or insulation of heat for various energy applications. This dissertation explores the frontier of thermal conductivity engineering, emphasizing the importance of structure-property relationships in thermal management materials to addressing the pressing needs of energy applications. In the first part of this dissertation, a novel approach is proposed to develop vacuum insulation panels (VIPs) featuring multilayer structures using a flexible and cost-effective 3D printing process. By optimizing the number of interlayers in the VIPs, an effective thermal conductivity substantially lower than that of air is achieved. The study also provides insights into key parameters affecting thermal insulation, such as the internal gas pressure and emissivity. In the second part of this dissertation, phase change materials (PCMs) integrated with 3D graphite foams (GFs) are studied, focusing on thermal conductivity enhancement and its effect on thermal energy storage and thermal management. Vacuum infiltration technique was employed to create PCM/GF composites, enhancing the thermal conductivity of RT25 paraffin and Cerrobend significantly. A novel numerical model was also developed to predict the anisotropic thermal conductivities of GFs and the composites from the anisotropic structure. In the third part of this dissertation, a novel extrusion-based 3D vertical printing method is introduced, assembling 2D materials into multiscale aligned structures. This method yields vertically aligned boron nitride (BN) rods with exceptional through-plane thermal conductivities, presenting a scalable strategy for enhanced thermal management. Through experimental studies and numerical analyses, this dissertation demonstrates that the integration of 2D/3D fillers and strategic structural design can profoundly influence the thermal performance of materials, creating materials with enhanced thermal conductivities or thermal insulation. The importance of structure-property relationships is shown in the studied multilayer structures, 3D connected anisotropic structures, and multiscale aligned structures through analysis of experimental and numerical results. Moreover, the feasibility and advantages of additive manufacturing in enabling strategic structural design are demonstrated, paving the way for advanced manufacturing of materials with optimized thermal conductivities. The findings in this dissertation would contribute to the ongoing development of thermal conductivity engineering, suggesting scalable and potentially efficient solutions to addressing complex demands of contemporary energy applications.