MULTISCALE POROUS HIGH-TEMPERATURE HEAT EXCHANGER USING CERAMIC CO-EXTRUSION

Xiangyu Li, Department of Mechanical Engineering, MIT, USA
li1215@mit.edu
Chad Wilson, Department of Mechanical Engineering, MIT, USA
Olivia Brandt, School of Materials Engineering, Purdue University, USA
Rodrigo Orta-Guerra, School of Materials Engineering, Purdue University, USA
Jeffrey Youngblood, School of Materials Engineering, Purdue University, USA
Rodney Trice, School of Materials Engineering, Purdue University, USA
Evelyn N. Wang, Department of Mechanical Engineering, MIT, USA

The efficiency of a heat engine can be significantly improved by operating in a high-temperature and high-pressure environment. However, such extreme operating condition poses a severe challenge to the heat exchanger design. Although recently developed super alloys and ceramics can survive high temperatures and high-pressure loads, using these materials in a traditional heat exchanger design requires high cost and yields low power density. In this work, we propose a high power density ceramic heat exchanger for high-temperature applications enabled by a multiscale porous design. By optimizing the design of centimeter-scale macrochannels and micrometer-scale microchannels, significant improvement to both the heat transfer and structural strength are predicted, with a negligible pressure drop penalty, compared to current state-of-the-art solutions. An optimized design is expected to achieve high power density, light weight, low cost along with less than 4% pressure drop penalty. Furthermore, the heat exchanger design is customizable for different applications in hybrid and electric aerospace applications, as well as terrestrial power generation such as nuclear power generation and concentrated solar power generation, promising more than 2.5x thermal performance compared to state-of-the-art solutions utilizing commercially available superalloy and ceramic materials, while providing the benefits of low cost, scalable fabrication, low pressure drop and high structural strength.

Caption: The counterflow heat exchanger consists of macrochannels (white dashed box) in a checker-board pattern. A single macrochannel comprises the microchannel array. The microchannel array significantly enhances the heat spread in the macrochannel due to lower thermal resistance of the thin solid walls, resulting in better heat transfer. The microchannel walls also reinforce the mechanical strength, as they help support the pressure difference between working fluids.