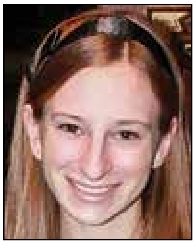
Developing ceramic-matrix composites for more efficient gas turbine engines

By Natalie Larson



Larson

For as long as I can remember, I have loved working with structural composite materials. In my youth, I built wooden forts and crafted furniture and art through years of woodworking classes. Following my passion for working with structural materials, I studied materials science during my undergraduate degree to harness that passion for the development of cleaner and more efficient energy technologies.

During my undergraduate research at the University of Washington, I helped develop carbon-fiber-reinforced polymer composites for lightweight and energy-efficient cars and aircraft. Now, as a National Science Foundation Graduate Research Fellow in the Materials Department at the University of California, Santa Barbara, I am developing SiC/SiC ceramic-matrix composites (CMCs) for more efficient energy production.

The International Energy Agency predicts that, during the next 25 years, fossil fuels will continue to supply more than 50% of global electricity. Further, increasing worldwide energy consumption will drive a 35% increase in fossil fuel use, with commensurate increases in greenhouse gas emissions. One strategy for reducing emissions is to increase the efficiency of systems that consume large amounts of fossil fuels. Gas turbine engines represent one class of such systems. They are used in propulsion systems for planes and ships and for land-based electricity generation.

Gas turbine engines can be made more efficient by increasing their firing temperature. Thus, there is a demand for tough oxidation-resistant materials that can withstand even higher engine temperatures than current nickel-based superalloys. SiC/SiC CMCs have the potential to operate at temperatures up to 1,500°C, offering up to a 150°C increase in firing temperature and up to a 5% increase in thermal efficiency.

SiC/SiC CMCs are composed of SiC fibers held together by a SiC matrix. These composites can achieve high toughness relative to their monolithic counterparts by proper design of a weak fiber–matrix interface. Weak interfaces promote crack deflection at the interface and yield a high in-situ fiber bundle strength. Fiber pullout that occurs subsequent to fiber fracture also imparts high toughness. The weak interface is most commonly created by depositing a thin layer of hexagonal boron nitride on the fibers prior to processing the matrix phase.

Current matrix processing methods, however, have proved ineffective in producing tough SiC/SiC CMCs that can operate for extended periods at 1,500°C. They usually leave behind various defects, such as porosity and impurities that limit durability and oxidation resistance. The current understanding is that, to be cost-effective, the matrices likely will be produced through a multistep process: SiC particle slurry infiltration, repeated polymer infiltration and pyrolysis (PIP) cycles, and chemical vapor infiltration or reactive melt infiltration to fill remaining open pores.

My research in the Zok group at UCSB focuses on studying defect evolution during multistage CMC processing using X-ray computed microtomography (XCT). I have conducted a large part of this research as a doctoral fellow at the Advanced Light Source at Lawrence Berkeley National Laboratory. There I have worked with beamline scientists A.A. MacDowell, D.Y. Parkinson, and H.S. Barnard, who are developing environmental cells for in-situ XCT imaging during material processing and testing. At ALS, I have conducted in-situ XCT imaging during critical high-temperature processing stages. These experiments have revealed for the first time the spatial and temporal evolution of voids and cracks during the first PIP cycle. Future experiments will investigate the use of repeated PIP cycles to further densify the CMC.

I am fortunate to have had numerous opportunities during my graduate studies to interact with members of the global CMC community. The international conferences I have attended in South Korea, Japan, and the United States provided me with invaluable opportunities to develop relationships with international researchers and exchange ideas within the CMC and broader ceramics communities. I have fond memories getting to know conference organizers and fellow graduate students as we climbed thousands of steps up Mount Hallasan after the 2015 PACRIM conference in South Korea.

Credit: Natalie Larson

Natalie Larson sets up a specimen for X-ray computed tomography at the Advanced Light Source at Lawrence Berkeley National Laboratory.

These international experiences and my involvement in diversity initiatives in my community fuel my passion for creating and sustaining diversity in STEM. As an undergraduate at UW, I participated in the Promoting Equity in Engineering Relationships program. At UCSB, I help organize outreach events through the Graduate Students for Diversity in Science organization. Most recently, I helped organize a symposium at TMS 2016 entitled "Transforming the Diversity Landscape," which fostered open discussion about current challenges and opportunities in increasing diversity in the materials community. As I continue my materials research career, I am excited to be a part of the increasingly diverse and collaborative community bringing materials science solutions to global energy challenges.

Natalie Larson is a third-year Ph.D. candidate in the Materials Department at the University of California, Santa Barbara. She is currently an Advanced Light Source Doctoral Fellow at Lawrence Berkeley National Laboratory. Larson also currently serves as an ACerS PCSA delegate on the programming committee.