could subtract the absorbed energy due to elastic recovery and gain better insight into the energy required to separate two bundles."

Applying this method to two polymers with different crystallinity and chain flexibility, UHMWPE and PpPTA, it was found that both fibers had similar microstructures and tensile properties, and they showed intermediate scale fibrillation between bundles under tensile failure. However, the interactions between bundles were stronger for PpPTA as compared to UHMPWE, presumably due to more interconnected crystals.

Another interesting finding was that the energy absorbed at the interfaces between the bundles was more than 10 times higher than the energy absorbed at the nanofibril level, of ~13–27 $J.m^{-2}$ and ~0.3–0.5 $J.m^{-2}$, respectively. Although structures fail at their weakest point, the fibrillation happened at the bundles level in their experiments. The researchers point out that to understand the real fracture of the fibers in tension mode, direct *in situ* characterization of nanofibrils and bundles would be required.

This study contributes to our understanding and quantification of the interaction mechanisms in high-performance fibers. This research could lead to further enhancement of fiber properties by developing a drawing process that would result in an optimum microstructure. Among the many avenues the researchers plan to pursue, "further *in situ* multiscale testing and extracting individual nanofibrils and nanofibril bundles to perform tensile tests would be of great value," says Dzenis. "The results can lead to new fundamental scaling models of the discovered unique fractal fracture behavior of hierarchical high-performance fibers."

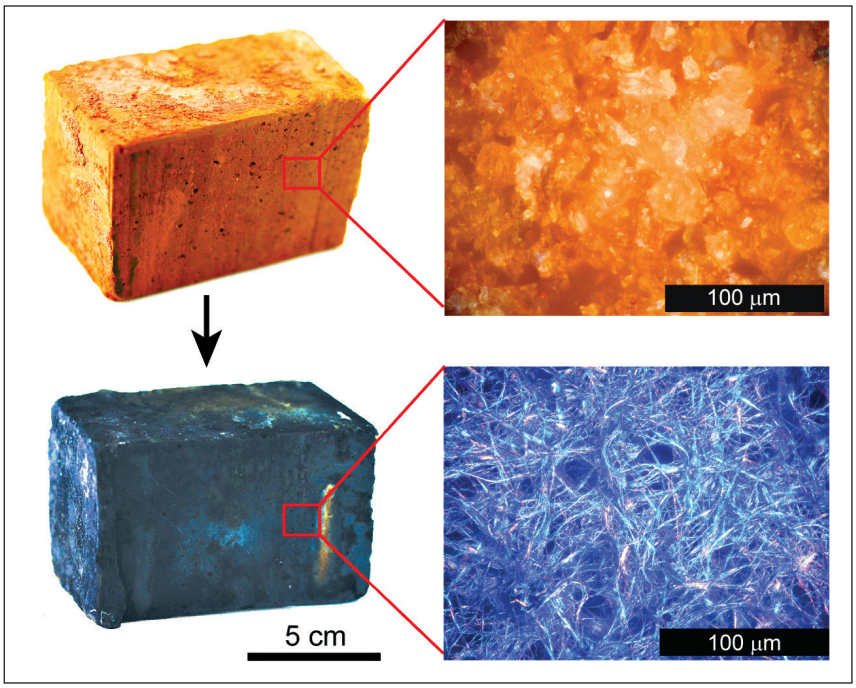
Flavia Libonati, an associate professor at the Università di Genova, Italy, and affiliated with the Laboratory for Atomistic and Molecular Mechanics at the Massachusetts Institute of Technology and who did not participate in this study, says that "the fracture mechanisms resemble the failure of fibers present in natural and biological materials and, in particular, the role of the interfaces in the load transfer and the importance of hierarchy on the amplification of the mechanical performance with respect to the building blocks. A deeper understanding of such mechanisms and of the processing–structure–property relationships, via multiscale modeling and experiments, can pave the way toward the design of better advanced materials."

Hortense Le Ferrand

Electrochemical energy-storage material architecture built brick-by-brick

Red bricks form load-bearing walls, line chimneys, and adorn architecturally aesthetic facades of countless buildings around the world. Most common fired bricks are comprised of silica (SiO_2), alumina, (Al_2O_3), and hematite (iron oxide, or Fe_2O_3)—the latter being responsible for its recognizable red color. Masons have relied on this ubiquitous and inexpensive construction material for thousands of years. Recently, researchers have unlocked a red-hot discovery: everyday bricks can not only provide shelter but also pave the way toward a new electrochemical energy-storage material.

A close examination of a typical fired brick reveals a highly porous microstructure that can easily take up solvents and materials such as polymers. The iron oxide component provides positive iron ions that can promote the synthesis of the polymer poly(3,4-ethylenedioxythiophene), or PEDOT. This conductive polymer coats the inner surfaces of the brick pores, and, owing to its high electronic conductivity and ability to rapidly transfer charge, functions as an active material in an electrochemical capacitor (conventionally known as a supercapacitor). Once an appropriate electrolyte is added to the brick, the resulting functional standalone energy-storage device mimics a "brick-mortar-brick" structure and delivers over 10,000 stable charge/discharge cycles. Areal capacities of these devices reach 1.6 Farads per square centimeter. This storage capability, coupled with



Photograph of a commercially available brick, as well as analysis of its microstructure, before and after it is coated with the polymer poly(3,4-ethylenedioxythiophene) to become an energy-storage module. Credit: D'Arcy Research Laboratory, Washington University in St. Louis.

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the low cost and high versatility of the resulting brick architecture, enables "power walls" of these devices to be incorporated into structural designs of buildings for inexpensive and reliable on-site storage. The researchers published their breakthrough in a recent issue of *Nature Communications* (doi:10.1038/s41467-020-17708-1).

A research group from Washington University in St. Louis spearheaded this work. Principal Investigator Julio M. D'Arcy told *MRS Bulletin*, "My laboratory has advanced science and engineering at the interface of architecture and sustainability by embedding functionality in a universal masonry building material; this enhances versatility for design and construction as load-bearing and energy-storage purposes are literally stacked together."

D'Arcy and colleagues used a vapor-phase reaction of a commercially available brick with hydrochloric acid, and the resulting FeOOH polymerized the subsequently infiltrated 3,4-ethylenedioxythiophene (EDOT) monomers into PEDOT coatings with controllable thicknesses. This approach yielded a uniform nanofibrillar polymer coating—typically 400 µm thick—that adheres to the brick surface and covers its imperfections such as embedded gravel grains. While the polymer changes the brick's color to a dark-red, the chemical process preserves its strength, chemical composition, and load-bearing capacity.

Sulfuric acid electrolyte yielded rapid and reversible charge-transfer reactions that allowed the PEDOT inside of the bricks to store electrochemical charge. The researchers combined the sulfuric acid with poly(vinyl alcohol) to convert it into a gel, which enabled dual functionality of the electrolyte as a separator. The complete device included two stacked symmetrical bricks that acted as the positive and negative electrodes, and an epoxy seal improved the stability of the assembled device in outdoor conditions. This assembly allows stackable arrangements of networks of these modules in tandem. In fact, based on the researchers' calculations, a brick wall comprised of these devices may deliver as much as 1.61 Watt-hours per square meter of wall area—all the while providing mechanical support for the building and shelter for its inhabitants.

Boris Dyatkin

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