Bio Focus

Twisting and coiling design of polymer fibers better mimics muscles

Fibers that contract and rotate upon stimulation, mimicking human muscles, could transform the design of medical devices, robots, sensors, smart materials, and other tools. As reported in *Applied Physics Letters* (doi:10.1063/1.4966231), scientists at Louisiana State University (LSU) recently fabricated a new artificial muscle with better tensile and stimulation properties than previously achieved.

The performance of a muscle is assessed by its ability to tense up, or contract. In 2014, a team of international scientists created artificial muscles from polymer fibers that could lift more than one hundred times as much weight as similar-sized human muscles (see *Science*, doi:10.1126/science.1246906). Geometry of the fiber was key. When a regular fiber was stimulated by heat, the fiber contracted by as much as 4%. However, after twisting the fiber and then coiling it like a spring, the coil contracted by up to 49% when triggered by heat.

In this new work, a team led by Guoqiang Li of LSU fabricated, characterized, and tested a polymer fiber-based artificial muscle that contracts even further and does so at temperatures more closely matched to the temperature of the human body. They based the design on two factors—the untwisting of the fiber in response to heat and the fiber's negative coefficient of thermal expansion—that Li and other colleagues found that make twisting and coiling a fiber so advantageous.

The team fabricated the fiber from a two-way (2W) shape-memory polymer (SMP) made of a chemically cross-linked poly(ethylene-*co*-vinyl acetate), or cPEVA. Like all SMPs, a 2W-SMP that has been "programmed" into a temporary shape will return to its original shape when stimulated. However, unlike a classical SMP, a 2W-SMP can return to its temporary shape when the stimulation is removed without being reprogrammed. In this work for example, 2W-SMPs contract like materials with negative coefficients of thermal expansion when heated, but expand when cooled.

After fabricating the fiber, the researchers measured the thermomechanical properties before and after twisting and coiling it into an artificial muscle. Compared to muscles based on previous fibers, the new one offers significantly higher tensile actuation.

Two-way SMPs have been intensely studied, according to H. Jerry Qi, an expert on 2W-SMPs at Georgia Institute of Technology who is not affiliated with this research. "Many of the 2W-SMPs require complicated chemical synthesis and yet the actuation is not large enough. In this published work, the actuation strain can be up to 67%, which is among the largest actuation strains reported. This work is very interesting and is significant."

In addition, the new artificial muscle requires a stimulation temperature as much as 100°C cooler and significantly closer to body temperature than previous designs, and it does so within a narrower temperature range. This indicates that artificial muscle technology is moving closer to application.

According to Li, "This new artificial muscle may find immense applications in areas related to ambient temperature beyond just robotics, such as breathable sportswear, drug delivery agents, sensors, and self-healing and self-adapting structures."

In addition to fabricating and testing the 2W-SMP fiber, the team proposed a mechanical model that describes how the thermomechanical properties of the fiber and the macroscale geometry lead to an increase in tensile actuation. Their results are consistent with the experimental results, demonstrating that the model may be a useful guide for future designs.

The researchers are currently exploring ways to increase the energy efficiency of the design, such as by introducing carbon nanotubes into the 2W-SMP to stiffen the fiber and increase its ability to store energy.

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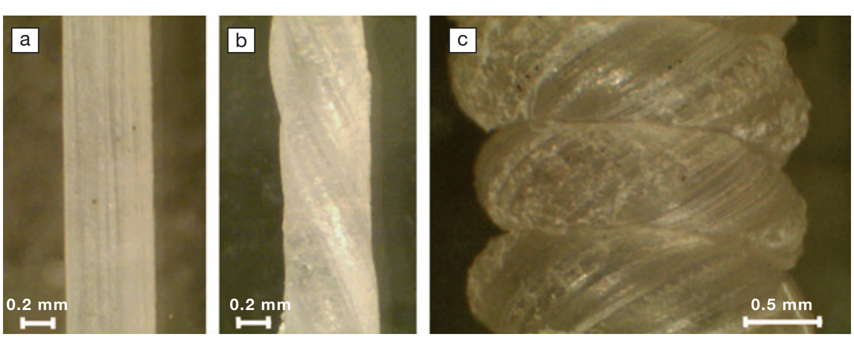

Optical images for (a) the precursor fiber (before twisting), (b) chiral fiber after twisting, and (c) artificial muscle after twisting and coiling the fiber. Reproduced with permission from *Appl. Phys. Lett.* **109**, 183701 (2016); doi:10.1063/1.4966231. © 2016 AIP Publishing.

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