Bio Focus

Nanopatterned self-folding origami may open up new possibilities in tissue engineering

Amir A. Zadpoor, an associate professor at Delft University of Technology, The Netherlands, and his research team want to boost tissue regeneration with bio-origami.

Explaining the background of his idea, Zadpoor says, "I was studying the effect of nanotopography on stem cell differentiation and tissue regeneration, and at the same time I was intensively working on 3D [three-dimensional] printing of bio-scaffolds whose macrostructures are also very important for tissue regeneration. I wanted to combine these two aspects, but there was no way to precisely control the nanotopography on the internal surface of a 3D-printed structure."

Then he came across some studies on folding sheets into 3D objects using origami-like patterns. He envisaged flat nanopatterned biomaterials that, upon receiving the right stimulus, change their shape into complex structures that promote cell growth and differentiation.

In such a vision, a flat material is first programmed to self-fold when triggered by a stimulus such as a temperature increase. The easily accessible flat surface is then patterned by conventional planar techniques, for example by nanolithography. Finally, the actuation mechanism is activated and the material self-folds into the desired shape.

The first challenge was how to go from a flat material to a 3D complex object. As reported in *Materials Horizons* (doi:10.1039/c6mh00195e), Zadpoor and his team developed methods to program soft matter to undergo the desired shape changes. In line with other programmable materials proposed in the literature, they designed initially flat structures made of bi- and multilayers of active and passive polymers, bonded together by an adhesive. For the active material, they selected a heat-triggered shape-memory polymer (SMP) with a 2:1 shrinking ratio, good flexibility, and fast shape recovery. For the passive layer, they experimented with different hyperelastic polymers and investigated the influence of their mechanical properties on the overall deformation. The research team showed that basic shape-shifting modes, including rolling, twisting, wrinkling, and their combinations, can be programmed in such structures, based on the arrangement of the hyperelastic and the SMP layers. The final shape depends on the polymers' thermomechanical properties, the geometry and dimensions of the bi- and multilayer, and the activation temperature.

With an eye on tissue engineering applications, the research team demonstrated that complex surface features, such as wrinkles and nanopatterns, can be combined with complex 3D shapes. The researchers explored two techniques: delamination-assisted self-wrinkling and surface patterning using a photosensitive polymer coating. Multiple surface patterns were incorporated into a single self-folding structure.

This experimental study is a proof of concept that anticipates the many possibilities opening up for the development of materials with new functionalities. Asked about the future, Zadpoor says, "We have many things to do! We want to be able to have any complex shape starting from a flat object. To really compete with 3D printing, we have to be able to achieve by shape-shifting what you make with 3D printing." The researchers are now investigating more complex and miniaturized systems made of biocompatible materials to be employed in tissue engineering.

John Dunlop of the Max Planck Institute of Colloids and Interfaces in Potsdam, Germany, who was not involved in the study, says, "This methodology is potentially useful for a systematic study of the influence of nanotopography on cell growth in 3D structures. I would like to see a carefully designed nanopatterned 3D scaffold placed in a cell culture and observe if, and how, cells are affected: understanding that would be really interesting." If a positive effect is found, the scale-up of the process, to make actual implants, might be the next challenge.

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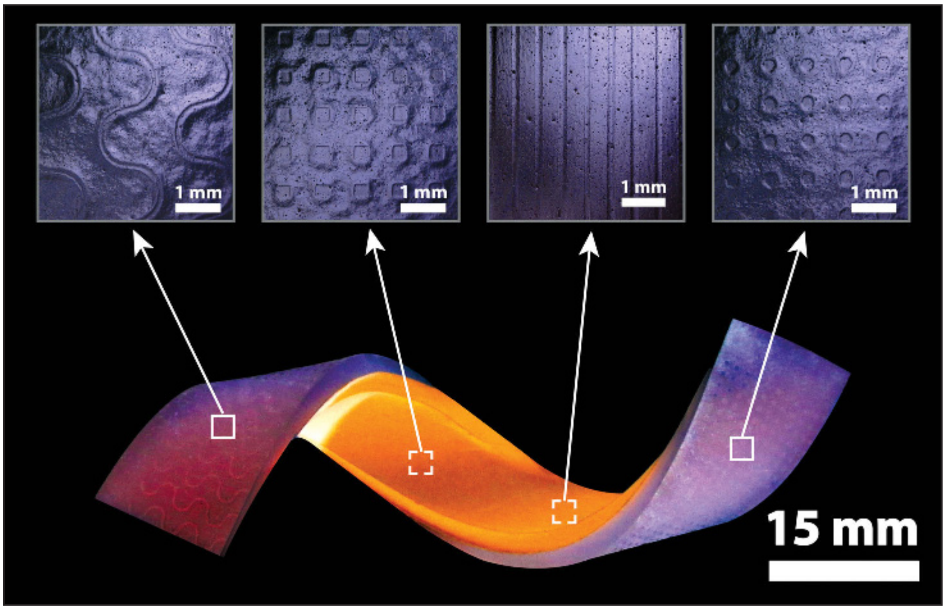

Self-twisted string of a bi-layer composite, showing multiple surface patterns obtained by coating the hyperelastic layer with a photosensitive polymer. The patterns were obtained before shape-shifting, by using appropriate masks during UV curing. The shape change was triggered by submerging the patterned string in a hot water bath at 90°C. Credit: Shahram Janbaz.