Electronic Supplementary Material

Fingerprint-inspired surface texture for the enhanced tip pinch performance of a soft robotic hand in lubricated conditions

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Materials

The mechanical properties of two materials were measured using a single-arm uniaxial stretcher (LN-0939CS, Guangdong LiNa Industrial), with the spindle tensile specimens shown in Fig. S1. The stress–strain curves of the Mold star 30 and Eco-Flex 00-50 silicone materials are shown in Fig. S2.

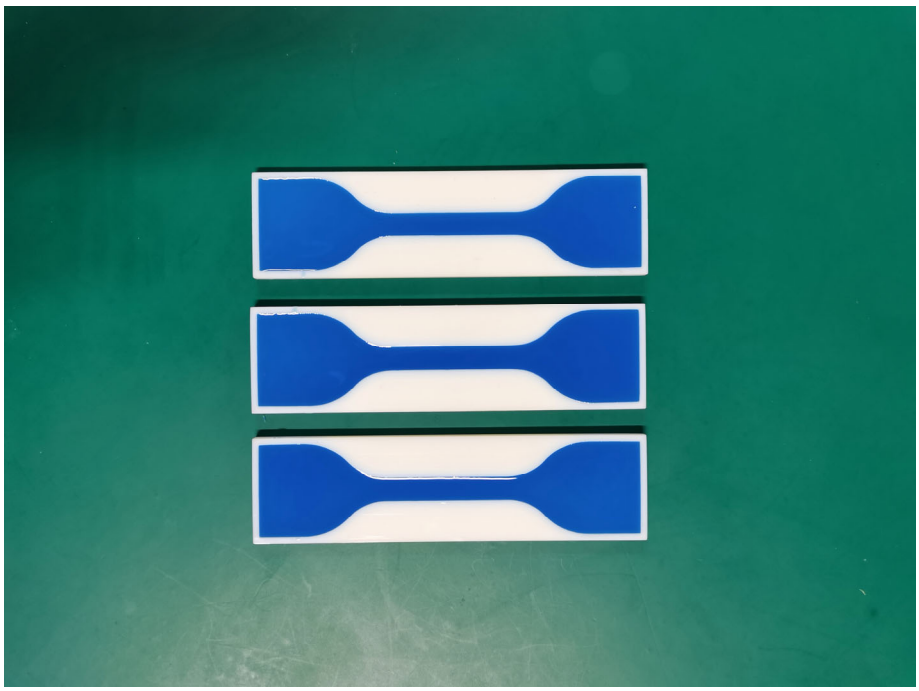

Fig. S1 Spindle tensile specimen.

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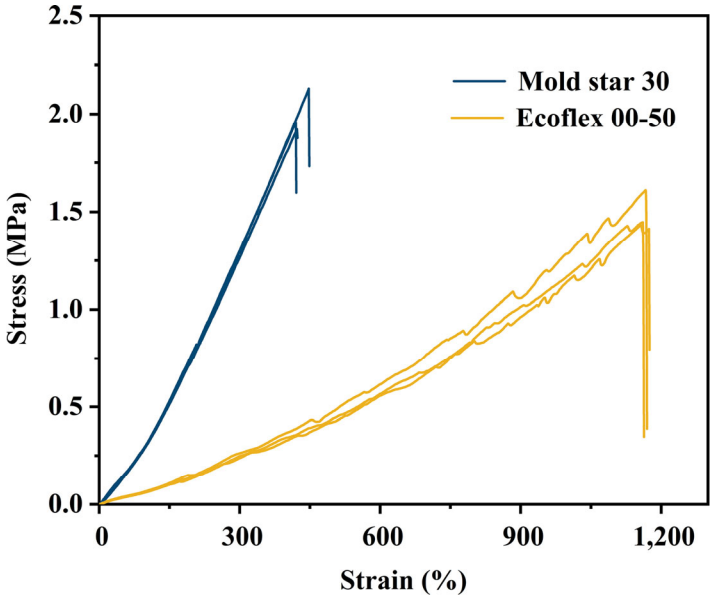

Fig. S2 Stress–strain curves of silicone materials, Mold star 30, and Eco-Flex 00-50.

Preparation of the friction test platform

Molds with different patterns (loops, whorls, and arches) were printed using a PolyJet 3D printer (J750, Stratasys) and photosensitive resin (VeroWhite FullCure 835). Two silicone rubber liquid components were mixed until completely homogeneous and placed in a vacuum box, where a rotary-vane vacuum pump (VP-1, ZhengKong) was used for degassing the bubbles. Then, a thin layer of mold release agent (Ease Release 200, Smooth-On) was applied to the molds, after which the degassed silicone rubber was poured inside. Allow 24 h to fully cure and remove the films. The films were then treated in an ultrasonic cleaner for 15 min to remove the residual release agent on the surface.

Tribological test

During the tribological test, the soft film moved horizontally on the smooth rigid surface (glass plate) under a specific load to imitate the tribological phenomenon between the finger pad and the object when the soft robotic hand realized an antipodal precise grasping action. The glass plate was cleaned sequentially with absolute ethanol and deionized water. The tests were conducted by controlling a single variable. The relative displacement was fixed at 10 mm at an acceleration of 1.5 mm/s^2. The tribological tests were performed in dry conditions at different maximum relative motion speeds and loads. The maximum speed was selected according to gradients of 0.5, 1, 1.5, 2, and 2.4 mm/s. The upper limit of the speed of the motorized linear translation stage was 2.4 mm/s. As shown in Fig. 1, the contact load was achieved by replacing the counterweight (iron block) at 2.38, 3.03, 3.79, 4.99, 7.79, 10.17, and 11.79 KPa, respectively. During the tribological test of the smooth-surfaced silicone rubber, the side in contact with the glass plate (above) flowed naturally during the pouring process, unlike the side in contact with the mold.

The tribological lubrication tests were conducted at a load of 7.79 KPa and a sliding speed of 0.5 mm/s in water-lubricated and oil-lubricated conditions. Before each experiment, full contact was facilitated between the lubrication medium and the soft friction pair to ensure complete lubrication. Each tribological test was performed in ambient conditions and was repeated at least fifteen times.

Tip pinch test using soft robotic fingers

As shown in Fig. S3, air (40 KPa) was used to stretch out the thumb and index finger of the soft hand to complete the tip pinch action. The soft hand was allowed to clamp the smooth plastic box in dry and oil-lubricated conditions. Then, quartz sand was continuously added to the plastic box until noticeable slippage occurred, and the weight of the counterweight box was recorded. During the underwater tip pinch tests, the soft hand and the counterweight box were completely immersed in water. Since quartz sand would partially dissolve in the water, preventing an accurate weight measurement, ceramic sand was used instead. Before the tests, the ceramic sand was cleaned with water and heated in a drying oven until completely dry. The quartz sand and ceramic sand were shown in Fig. S4.

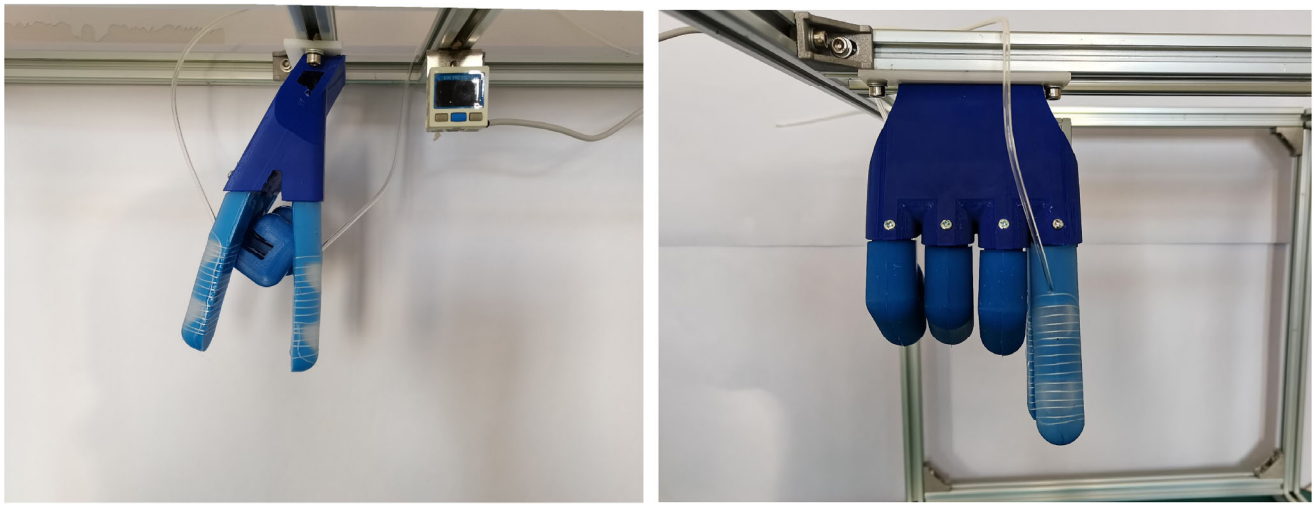

Fig. S3 Side view and front view of the soft robotic hand.

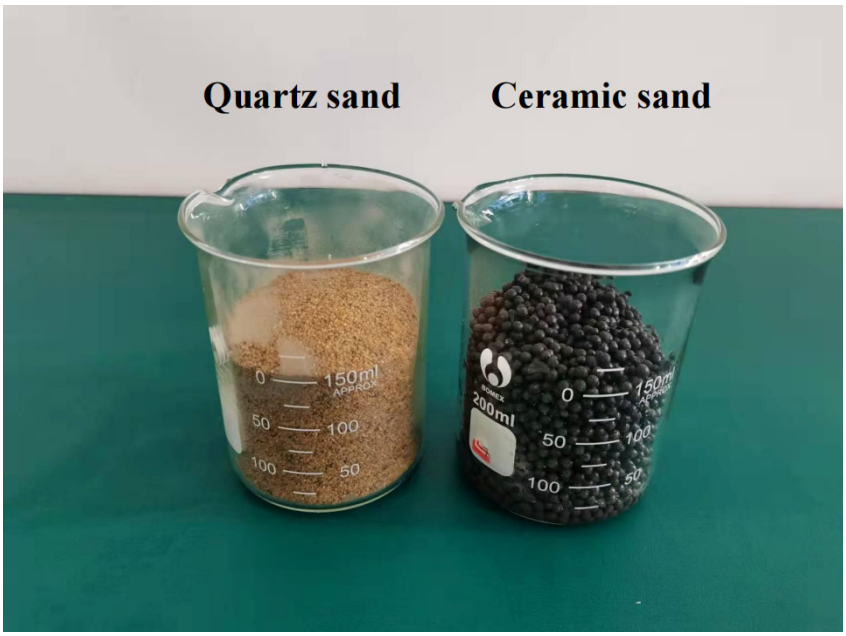

Fig. S4 Quartz sand and ceramic sand.

Surface characteristics

As shown in Figs. S5(a) and S5(b), edge detection was performed on the line composed of blue pixels to obtain a binary edge image with white edge lines. Line detection algorithms based on the Hough transform were used to detect a continuous set of points, as shown in Fig. S5(c).

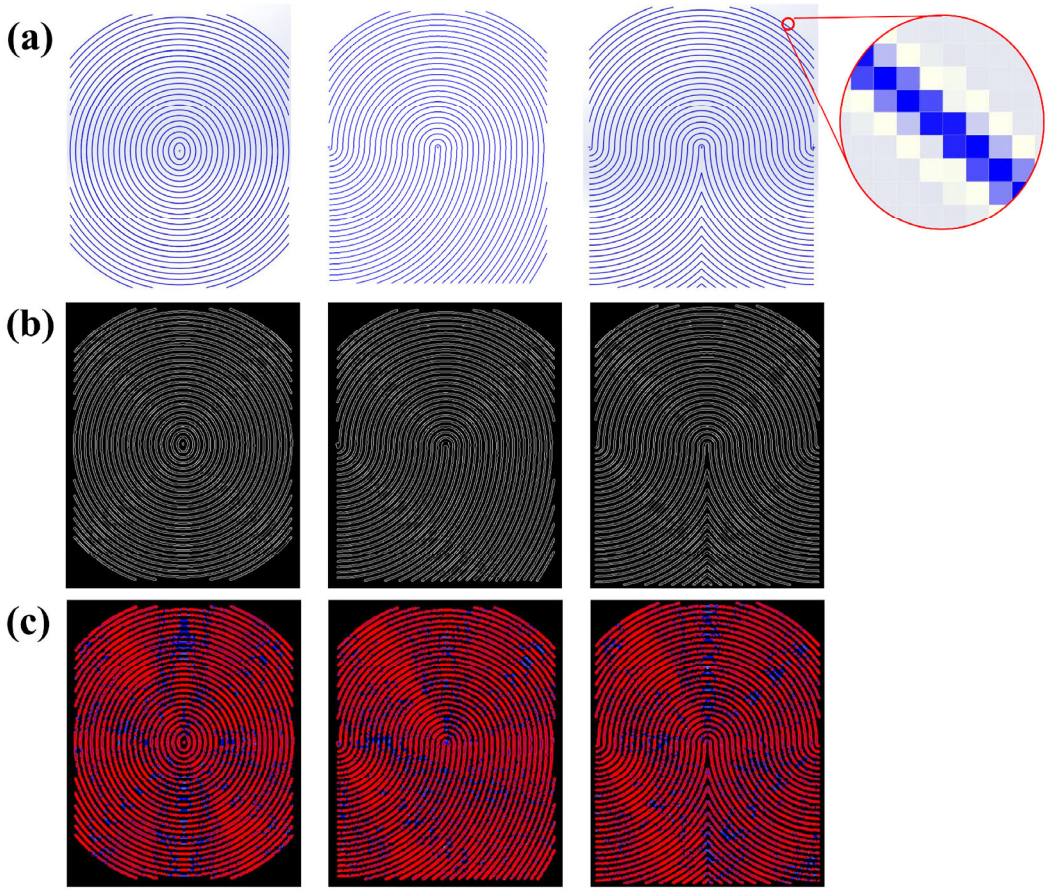

Fig. S5 (a) Original images of the fingerprint-like patterns (Inside the red circle is an enlarged view of part of the line), (b) edge binary image, and (c) image obtained by line detection based on Hough transform.