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Fiber fabrication based on pulling velocity and hardening force control

Abstract: In this study we propose robotic fiber fabrication method based on pulling velocity control and hardening force control to improve the strength of the fabricated fibers.

Keywords: Fiber fabrication, force and velocity control.

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1 Introduction

Fiber-shaped materials are highly desirable in making various functional three-dimensional (3D) objects. For example, hydrogel microfiber structures have been used to recapitulate biological tissues' architecture and functionality at the microscale [1]. fibers have also been used in actuators and sensors with at macro- and microrobotics[2]–[5], as well as flexible microfiber strain sensor with a beads-on-a-string structure [6]. A variety of techniques have been used for fiber fabrication, e.g., wet-spinning [7], dry-spinning [8]. So far, their strength can reach only about one-fifth of that of natural fibers such as spider silk fiber [9]. One of the reasons is that the fabrication process is either manual or based on open-loop regulation. As continuation of our previous work [10][11], in this study, we propose robotic fiber fabrication method based on pulling velocity control and hardening force control to improve the strength of the fabricated fibers. Dextran material is used as the specimen in the experiments.

2 Materials and Methods

The experimental setup shown in Figure 1 is designed to implement the fiber threading and characterization experiments for different materials.

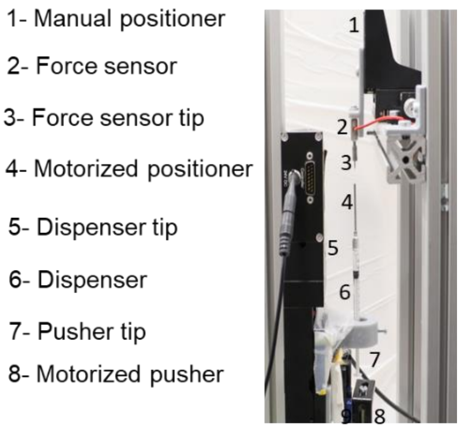

Figure 1: The experimental setup for robotic fiber fabrication. The force sensor is fixed on a frame, and the Dextran dispenser is mounted on a motorized precision stage.

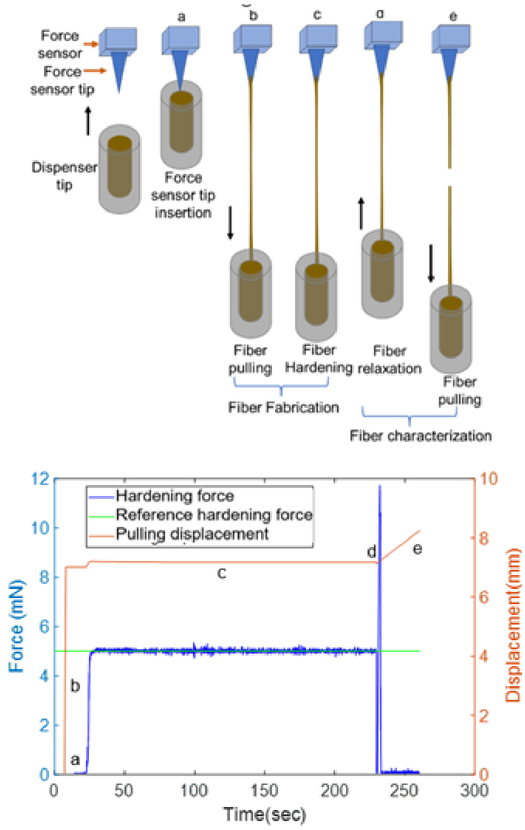

Figure 2: The fiber threading experimental protocol. a) inserting the force sensor tip in the dispenser tube until it contacts the Dextran material; b) the dispenser moves away from the force sensor pulling the Dextran into a fiber until certain criteria are satisfied, e.g., in displacement or force; c) the system stalls for a certain amount of time to allow the fiber to harden under hardening force control, in this example the pulling velocity is 25 mm/s and the controlled hardening force is 5 mN ; d) the fiber is relaxed until e) the fiber is pulled further until it breaks.

The setup consists of a dispenser (Nordson EFD, model Performus V) held on a motorized precision positioner (Physik Instrumente, model M404.4PD) to dispense and pull the silk. A needle is held on a force sensor (LCM Systems, model LCM UF1), which is fixed, to sense the pulling force after contacting the silk. The motorized precision positioner is controlled via a controller (Physik Instrumente, model C-884.4CD) using Matlab/Simulink. The measurement of the force sensor is acquired using a data acquisition (DAQ) board (National Instrument, model PCIe-6363). The dispenser is controlled also via the DAQ board. The whole setup is constructed on a vibration isolation table.

The fiber threading experimental protocol is shown in Figure 2 consisting of the fabrication and

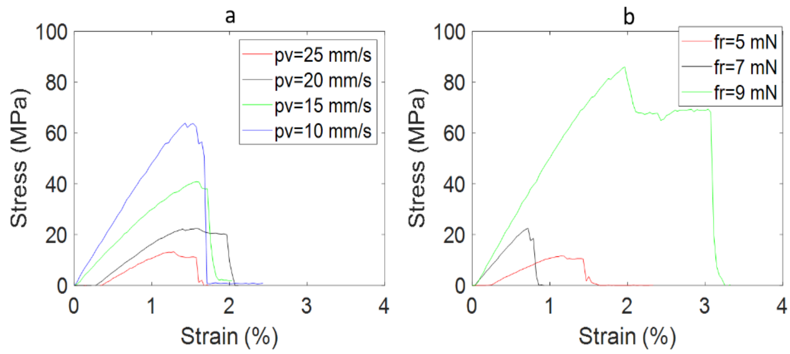

Figure 1: The obtained breaking force with respect to the strain from characterization of the fibers fabricated with four different pulling velocities of 10, 15, 20, and 25 mm/s. b) The obtained breaking force with respect to the strain from characterization of the fibers fabricated with three different hardening forces of 5, 7, and 9 mN.

characterization phases. In the fabrication phase, a sessile droplet is firstly dispensed on the top of the tip of the dispenser needle, a); then the tip with the droplet approaches and contacts the tip of the force sensor, b); after that, the dispenser moves away from the force sensor pulling the droplet into a fiber, c); the system then stalls for a certain period to allow the fiber to harden under hardening force control, e). In the characterization phase, the fiber is pulled further until the fiber breaks while the pulling force is recorded. From the characterization by tensile testing, stress-strain curve can be obtained. All the experiments have been done under constant environmental conditions: temperature and relative humidity of 24 °C and a 63% respectively. All the experiments have been done under constant environmental conditions: temperature and relative humidity of 24 °C and a 63% respectively.

3 Results

To study the influence of the pulling velocity of the fabricated fibers, we applied four different pulling velocities 10, 15, 20, and 25 mm/s. We can notice that the strength has a negative correlation with respect to the pulling velocity. The influence of the hardening force on the strength is also studied, we applied three different hardening forces for 5, 7, and 9 mN. We can notice that the strength is directly proportional to the hardening force.

4 Conclusions

Artificial fibers are widely used in a variety fields, such as, soft robotic, electronics, and textile technology. In order to improve the strength of the artificial fiber, a new robotic fiber fabrication method was proposed. The proposed method is based on controlling the pulling velocity and the hardening force. The correlation between the pulling velocity and strength was studied. The correlation between hardening force and the strength was studied as well.

5 Acknowledgement

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