Supporting Information

3D Helical Micromixer Fabricated by Micro Lost-Wax Casting

Daiki Tachibana[1], Ken Matsubara[1], Ryosuke Matsuda[1], Taichi Furukawa[1,2], Shoji Maruo[1,2], Yoshimi Tanaka[3], Ohmi Fuchiwaki[1,2], Hiroki Ota[1,2]**

[1]Department of Mechanical Engineering, Yokohama National University, 79-5 Tokiwadai, Hodogaya-ku, Yokohama 240-8501, Japan
[2]Graduate school of system integration, Yokohama National University, 79-5 Tokiwadai, Hodogaya-ku, Yokohama 240-8501, Japan
[3]Graduate school of environment and information science, Yokohama National University, 79-5 Tokiwadai, Hodogaya-ku, Yokohama 240-8501, Japan

*Correspondence should be addressed to H. O. (ota-hiroki-xm@ynu.ac.jp), O. F. (fuchiwaki-ohmi-xk@ynu.ac.jp) is an equal corresponding author

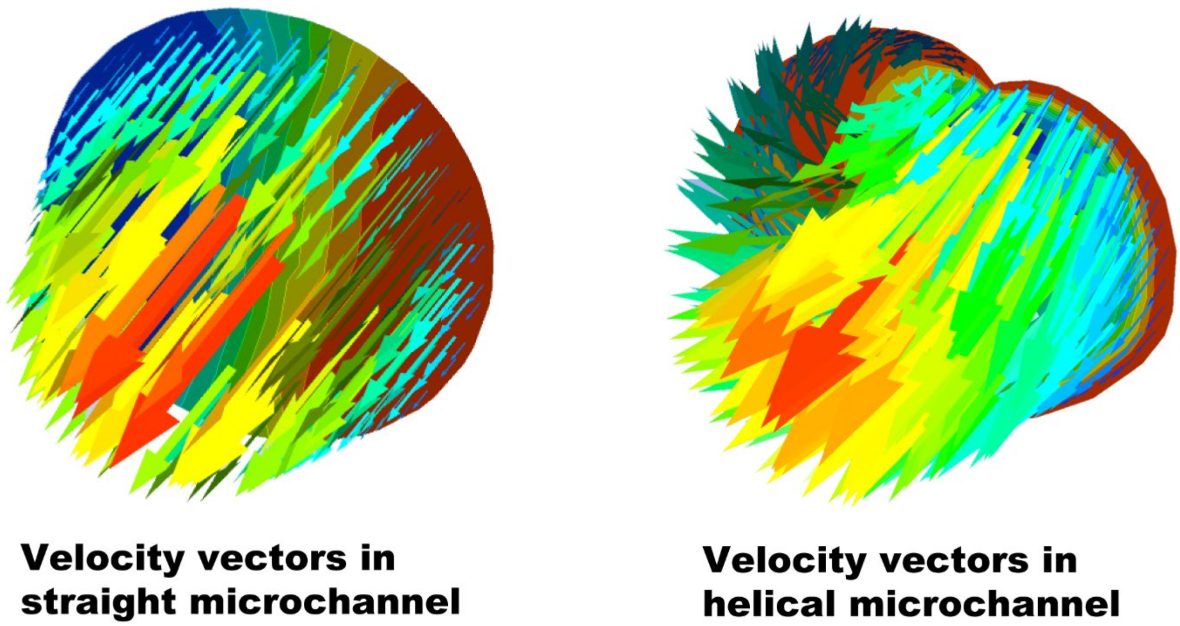

Figure S1. Cross-sectional views of velocity vectors in a straight channel (left) and helical channel (right).

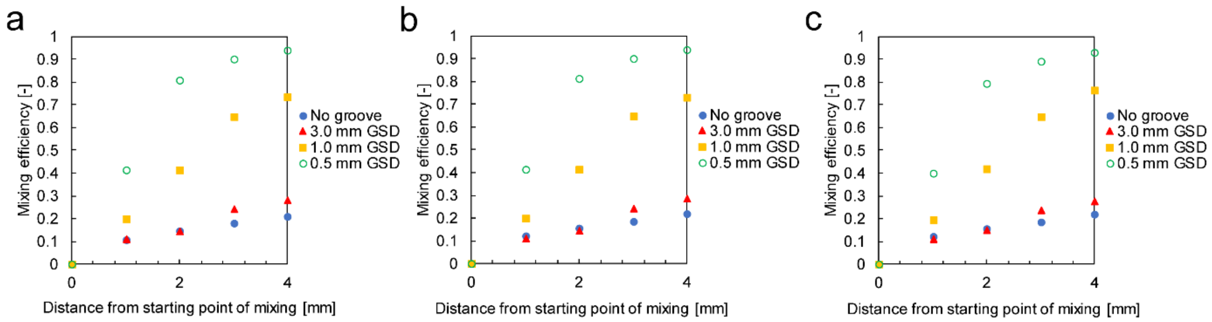

Figure S2. Mixing efficiency at different distances from the starting point of mixing of two fluids of different viscosities. a. The change of mixing efficiency for two fluids of 1.003 mPa·s viscosity which is the same as that of water. **b**. The change of mixing efficiency by two fluids of 1.003 and 0.99 mPa·s viscosities which are the same as those of water and a commercial ink, respectively. **c.** The change of mixing efficiency by two liquids of 1.05 and 1.16 mPa·s viscosities which are the same as those of two commercial inks.

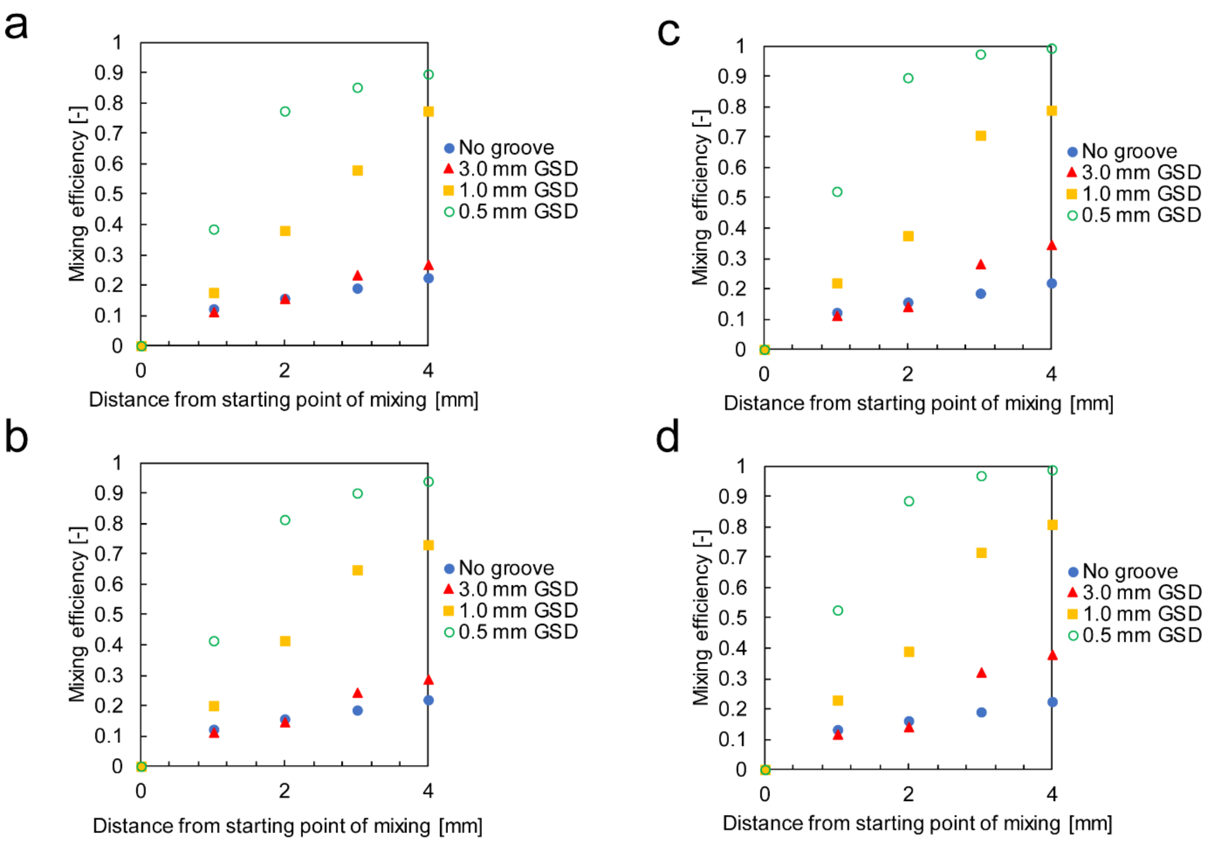

Figure S3. Mixing efficiency at different distances from the starting point of mixing of two fluids when volumetric flow rate was altered. Flow rates were: **a**, 0.2 mL/min; **b**, 0.3 mL/min; **c,** 0.6 mL/min; and **d,** 1.0 mL/min.

Supplementary information 1

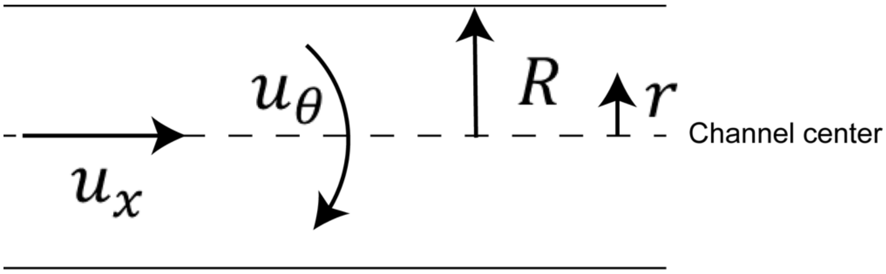

Figure S4. Definitions of terms for the swirl number calculation.

The swirl number is used as a parameter to represent the degree of a rotational flow compared with that of an axial flow in channels. The larger the swirl number is, the stronger the swirl in the flow channel is. It is calculated using the following equation.

$$S = \frac{\int r^2 u_x u_\theta dr}{R \int r u_x^2 \, dr} \tag{2}$$

u_x represents an axial velocity, u_θ represents a circumferential velocity, R represents the channel radius, and r represents the distance of the calculation point from the channel center as shown in Figure S4. The axial and circumferential velocities at about 20000 points equally spaced on a cross section were analyzed and the same number of points were used for measuring the mass fractions.

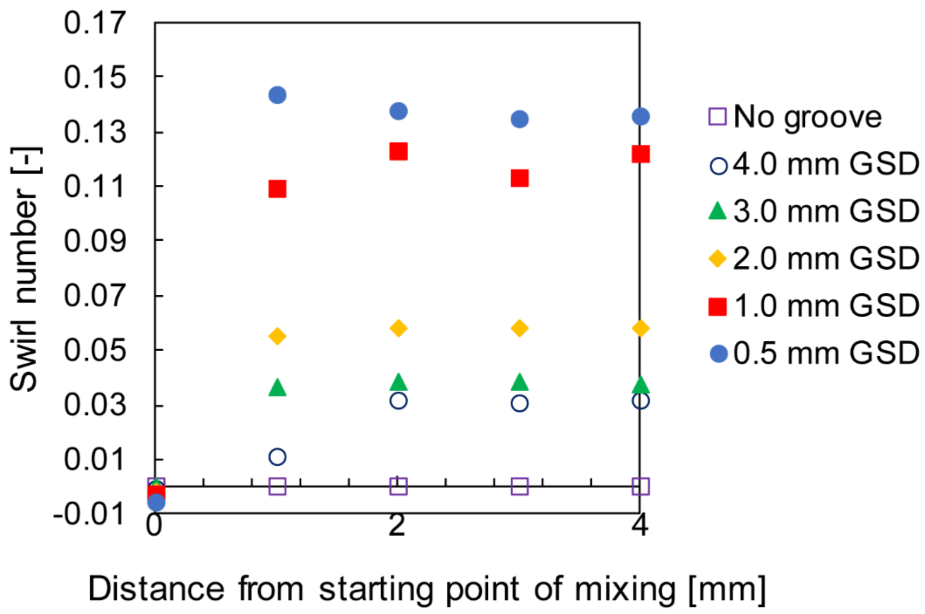

Figure S5. Simulation of swirl number for different cross sections in the flow. Swirl number changed as a function of distance from the starting point of mixing.

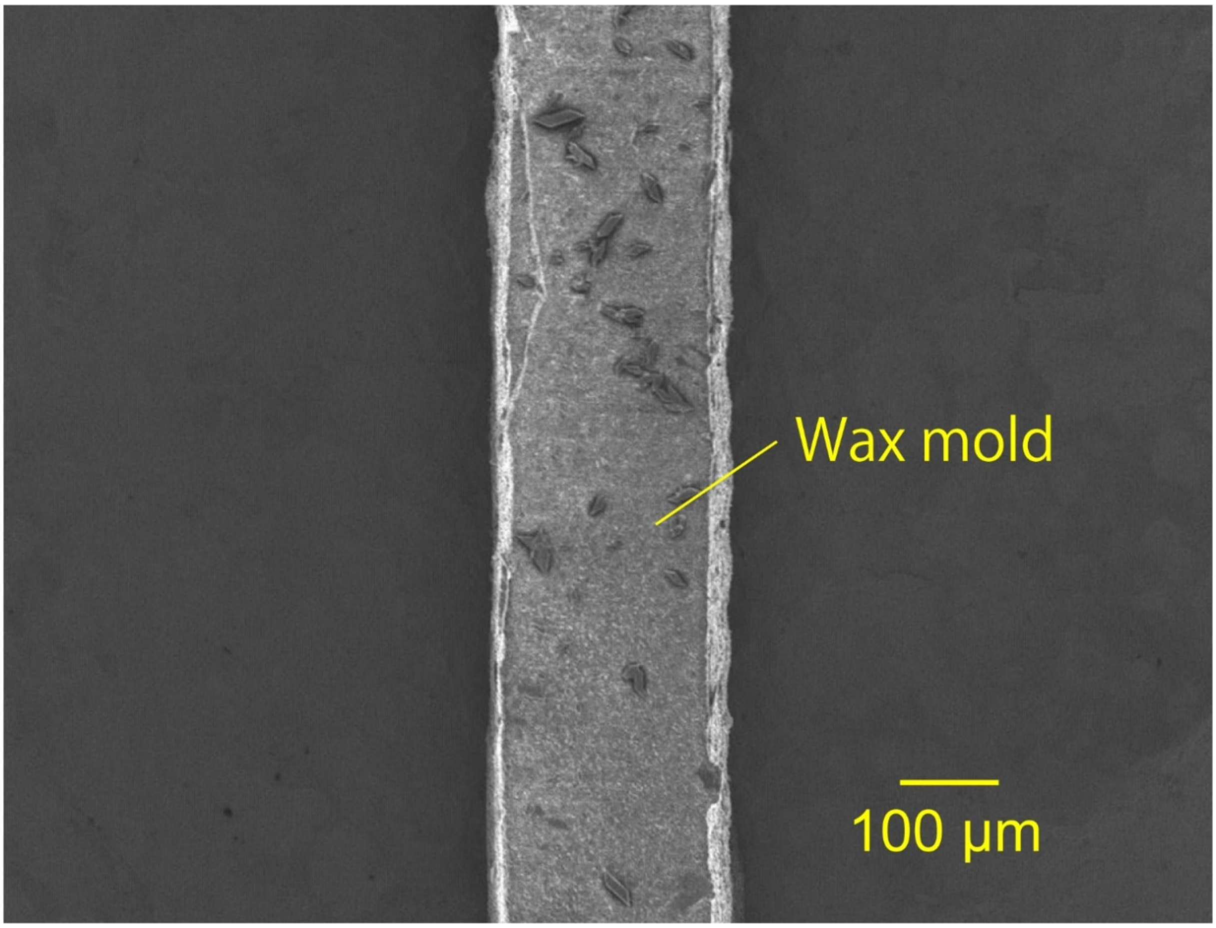

Figure S6. **SEM image of wax mold. The design diameter of the microchannel was 200 µm.**

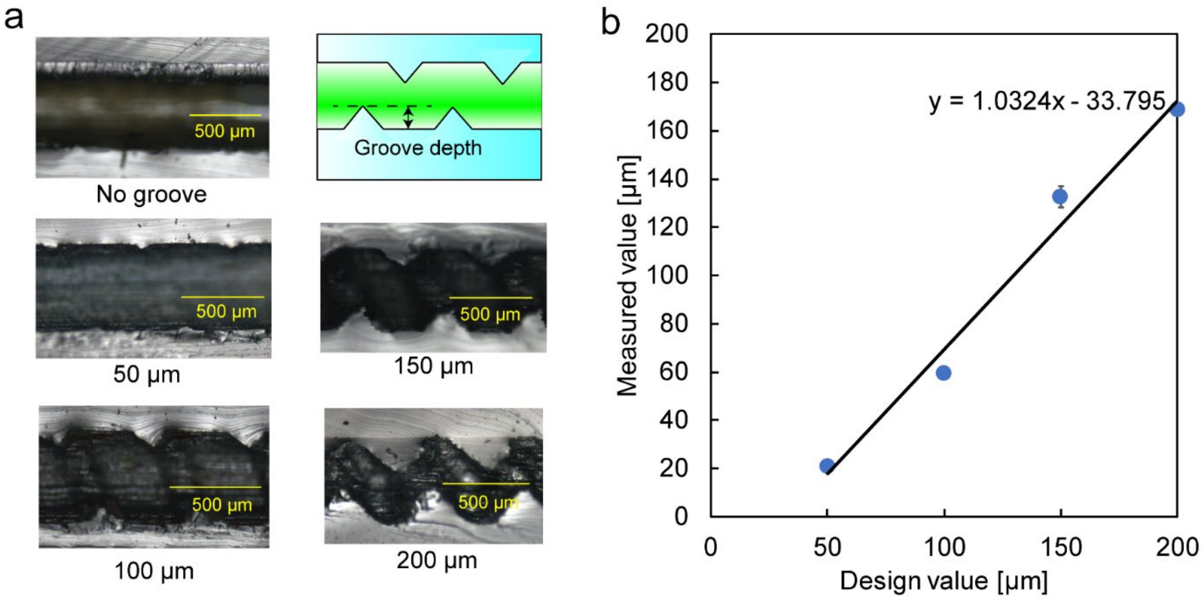

Figure S7. Fabrication accuracy of a helical microchannel. a. Cross section images of microchannels. **b**. Relationship between design and measured value of groove depths of microchannels.

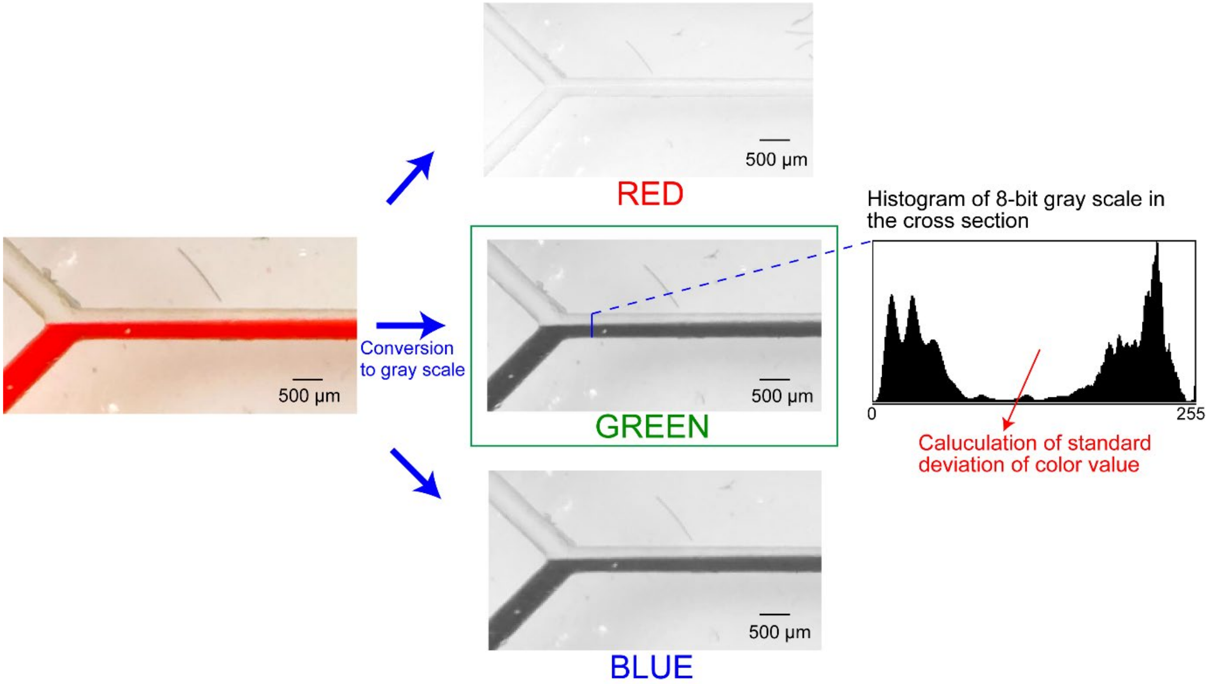

Figure S8. Calculation process of mixing efficiency using an actual micromixer. Standard deviations of the complementary color (green) to red in the cross sections were calculated from histograms of an 8-bit gray scale image converted from the image for which green was extracted.

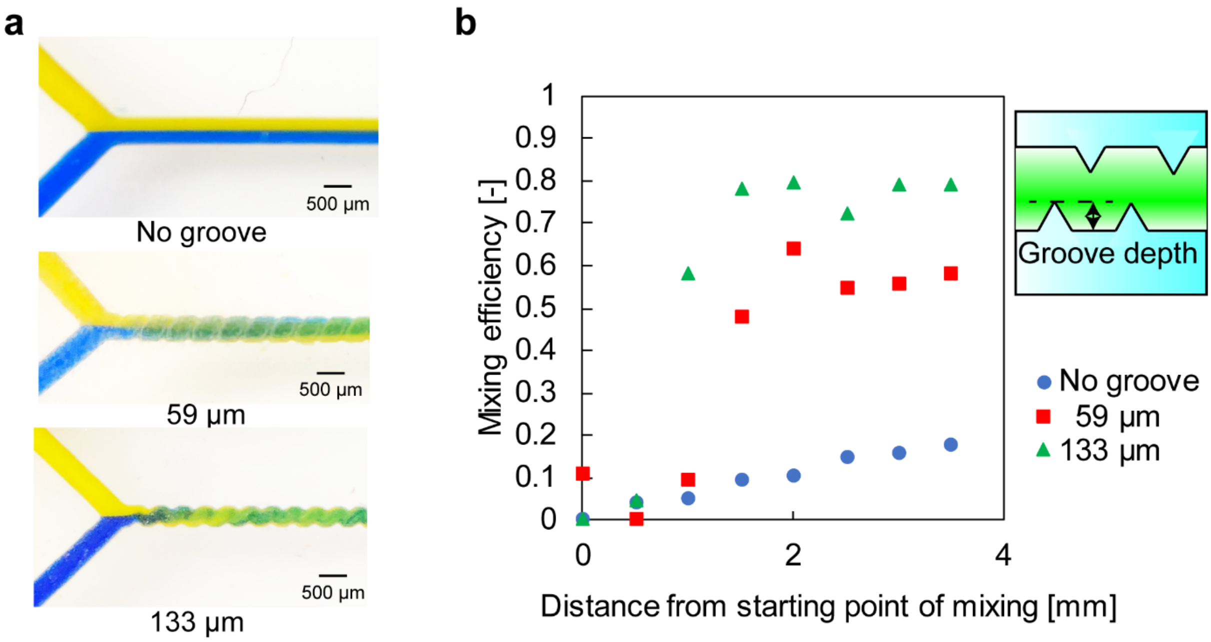

Figure S9 Mixing of two fluids inside a 3D helical micromixer with dependence on groove depth in the microchannel. a. Photographs of mixing in the straight and helical microchannels having 59 and 133 µm depth grooves. In the straight channel, yellow and blue fluids flowed in parallel. In the 3D helical micromixer having 59 µm depth grooves, yellow and blue colors were rotating inside the microchannel. In the helical micromixer having 133 µm depth grooves, the green color appeared as soon as yellow and blue fluids contacted at the starting point of mixing. **b**. Standard deviation of gray scale color on a cross section of the microchannel with respect to distance from the starting point of mixing. The standard deviation increased with respect to the groove depth.

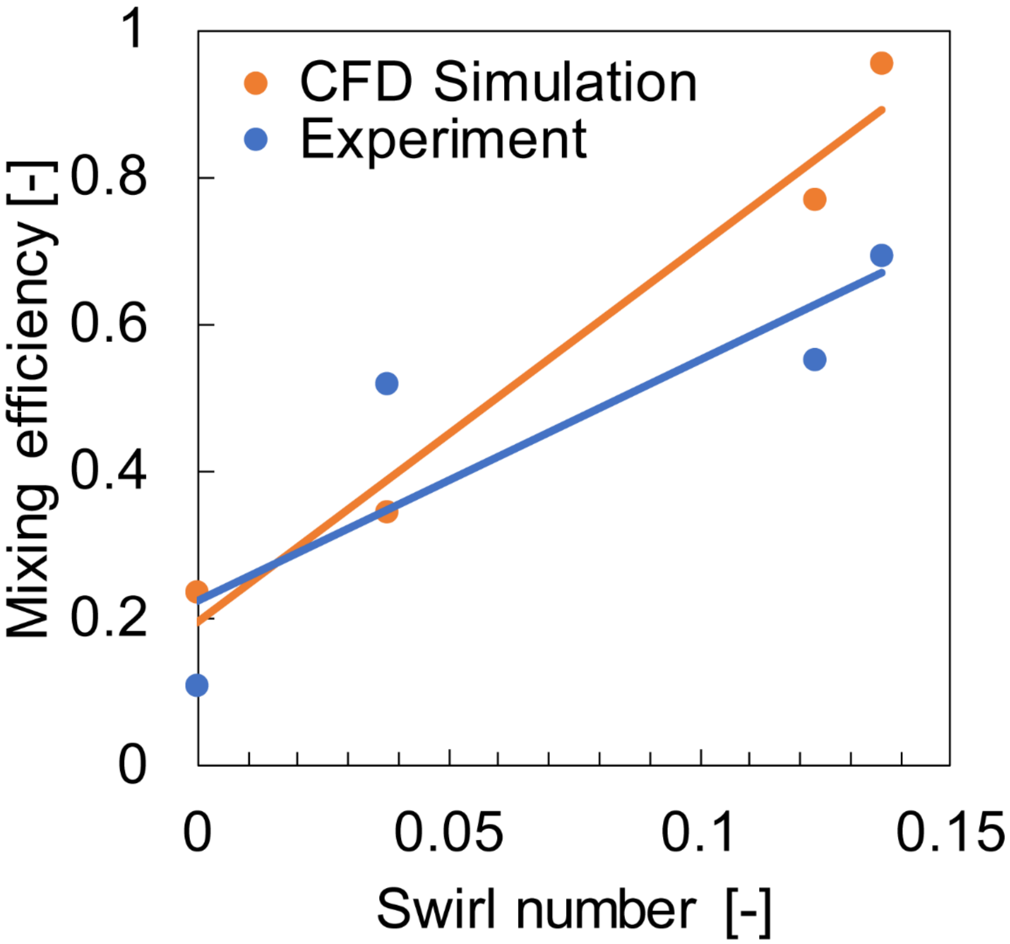

Figure S10. Relationship between swirl number and mixing efficiency.

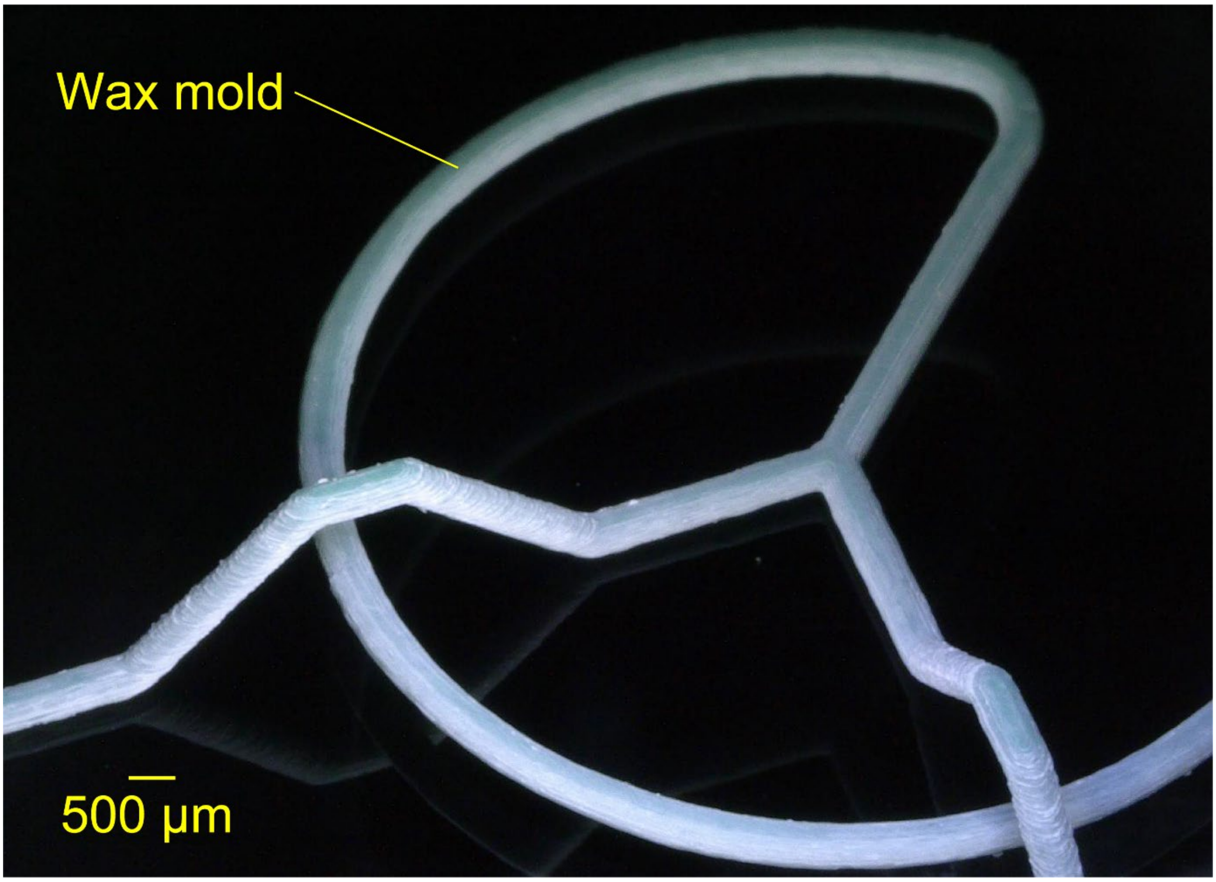

Figure S11. Wax mold with straight and 3D bridge structures.