Supporting Information

Procise micromachining of carbide reinforced NbMoTaW refractory high entropy alloy with ultrathin heat effected area using water-jet guided laser technology

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Sample preparation and test seetings:

All the processing experiments were performed with the same following parameters. Grooving, slicing and drilling were performed with 532 nm laser (Repetition frequency: 6 K, pulse width: ~220 ns), 50 μm nozzles and 30 MPa water pressure.

For grooving, laser power was set at 5, 10 and 15 W under 10 mm/s and repeated for 10 cycles. For slicing, scanning speed was set at 5, 10, 15 and 20 mm/s under 20 W. For drilling, laser power was set at 15, 20, 25 and 30 W under speed varied from10, 15, 20, 25 and 30 mm/s. And the quality evaluation of drilled sample was processed with 20 W and 5 mm/s.

The XRD tests were performed under 40 kV, 40 mA, 10-100°, 6°/min (step: 0.02°) and Cu was selected as target material. The lattice constant was calculated as following:

$$2d_{hkl} * \sin\theta = n\lambda$$

Where λ = 1.5406 Å, n =1, $2\theta_B$ = 37.8 ° and 40.2 ° from XRD data. θ_B is Bragg angle in lattice diffraction. d_{hkl} = interplanar spacing of the (hkl) crystal plane (unit: nm), (hkl) = (110) for BCC1 and BCC2;

And the lattice constant "a" can be calculated with the following equation.

$$a = d_{hkl} \times \sqrt{h^2 + k^2 + l^2}$$

The processed samples were subjected to ultrasonic treatment with an ethanol solution for 10 minutes, and then dried using compressed air with a filter set. The cleaned samples are directly attached to the sample platform for observation. The EBSD sample was embedded in one-inch resin. And the embedded sample was ground and polished. The surface was free of scratches and the overall appearance was smooth and bright. Before the test began, a 5 nm thickness of gold layer was deposited for conductivity improvement and morphological observation.

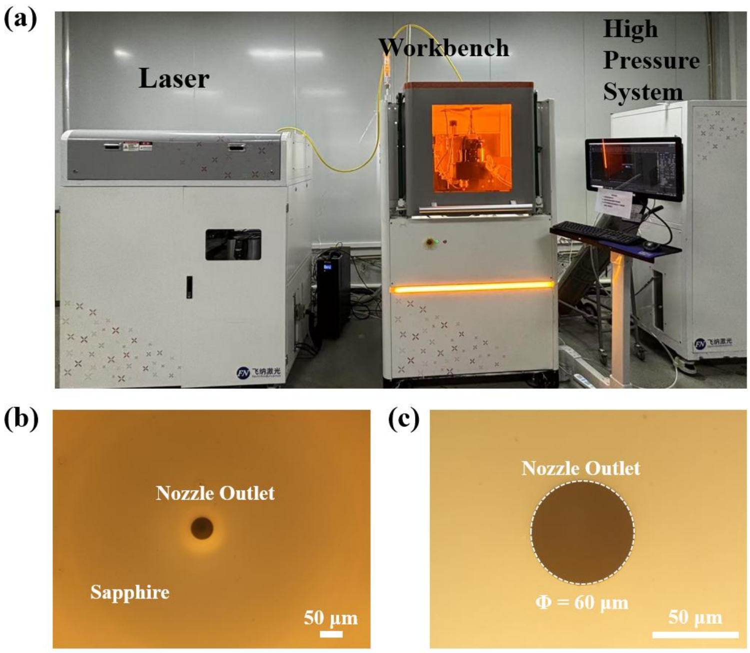


Fig. S1 (a) Experimental device includes three parts from left to right: laser system, work platform and high-pressure water system. The laser energy is transmitted through the optical fiber to the cutting head and is coupled into the water-jet. (b-c) Optical microscope images of sapphire nozzle.

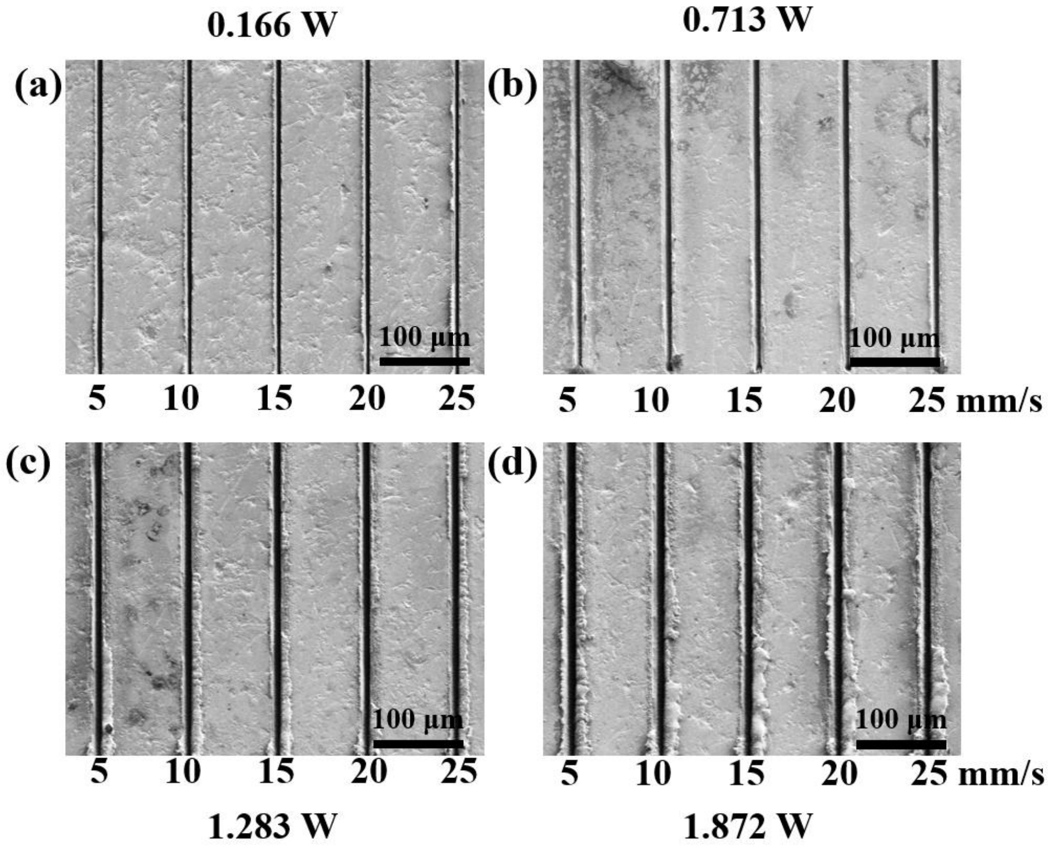


Fig. S2 (a-d) SEM images of alloy sample processed under 5-25 mm/s at different laser power by femtosecond laser system.

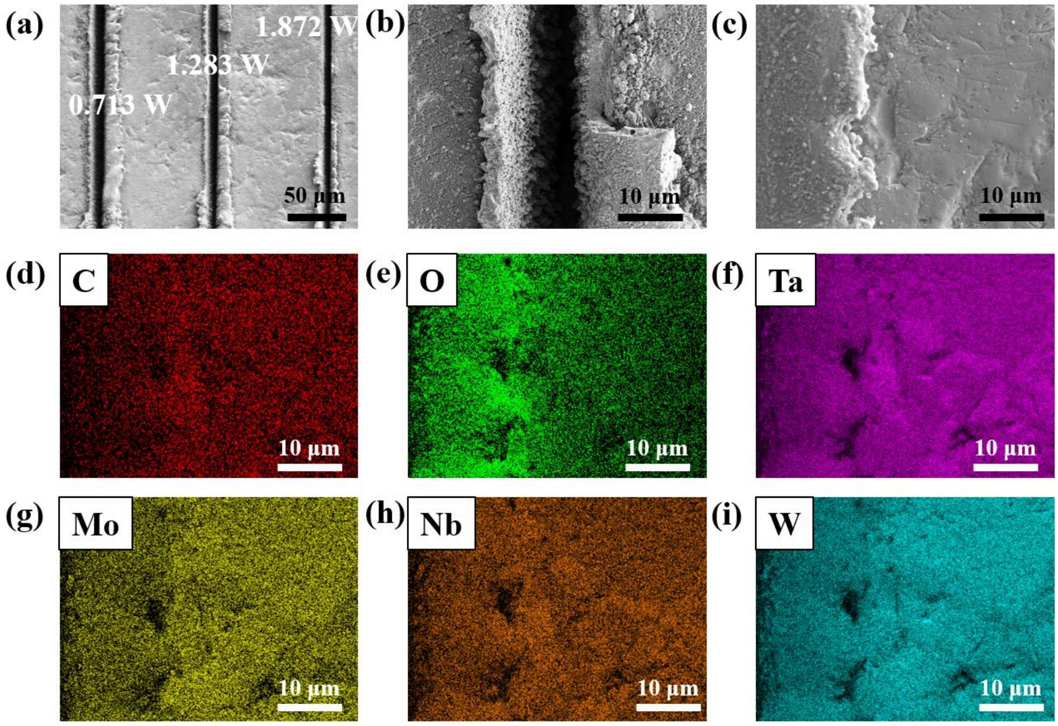


Fig. S3 (a-c) Sem images of grooves processed by femtosecond laser. (d-i) Elements mapping of projections at the side of groove corresponding to Fig. S6 c.

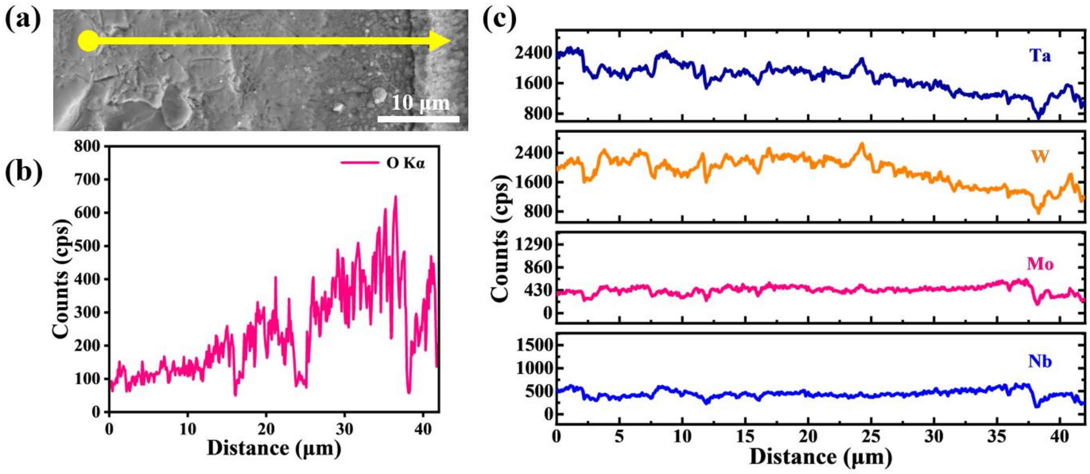


Fig. S4 (a-c) Data from the element line scans of the debris at the edge of the groove and the base material. The sample is processed by femtosecond laser.

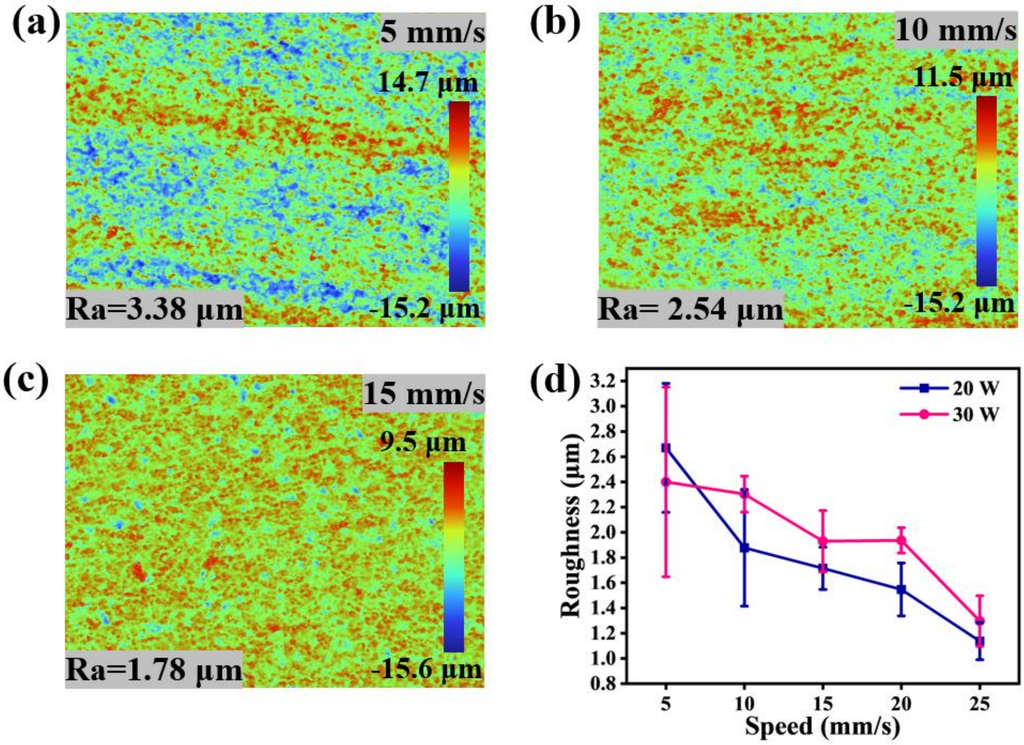


Fig. S5 (a-c) The 3D interference profile of slices diced by WJGL. (d) Statistical roughness results of WJGL sliced surface. The data is extracted from 3 pieces slices and 4 positions of each slice.

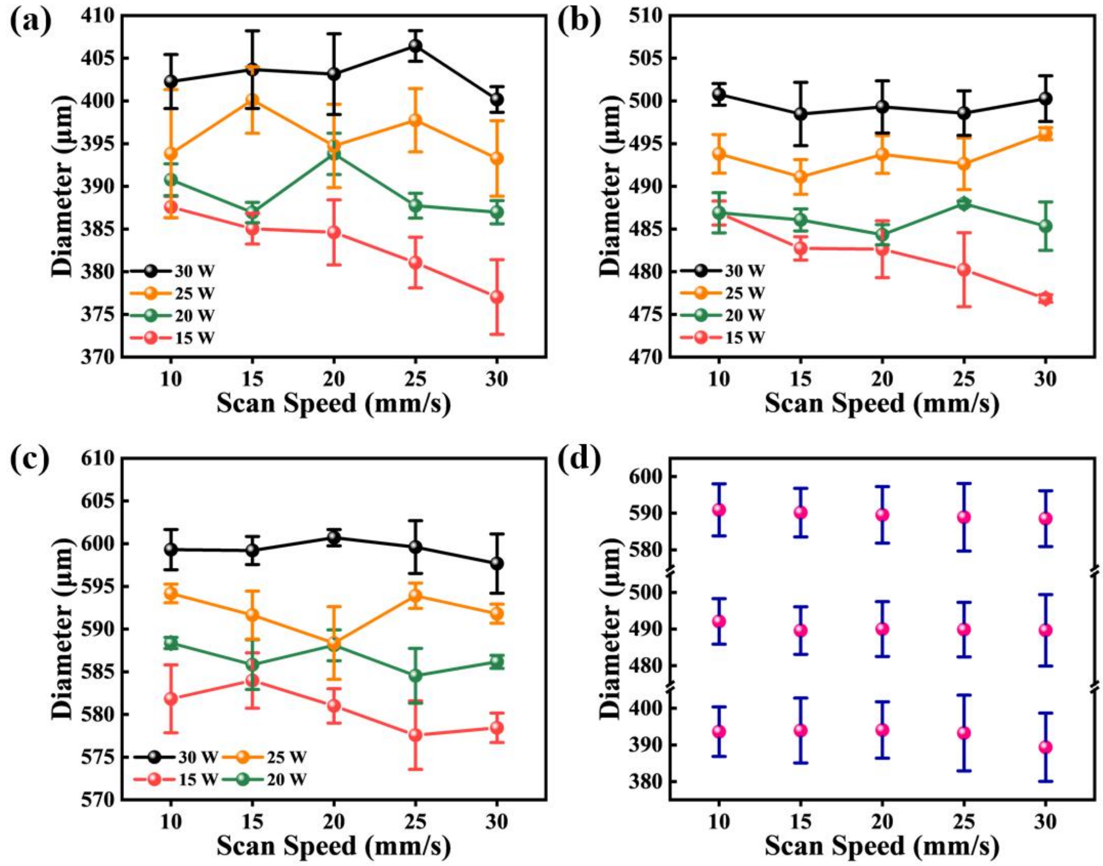


Fig. S6 (a-c) Statistical drilling diameter of varied scan speed and laser power. (d) Statistical roughness results of WJGL sliced surface. The data is extracted from 3 pieces slices and 4 positions of each slice.

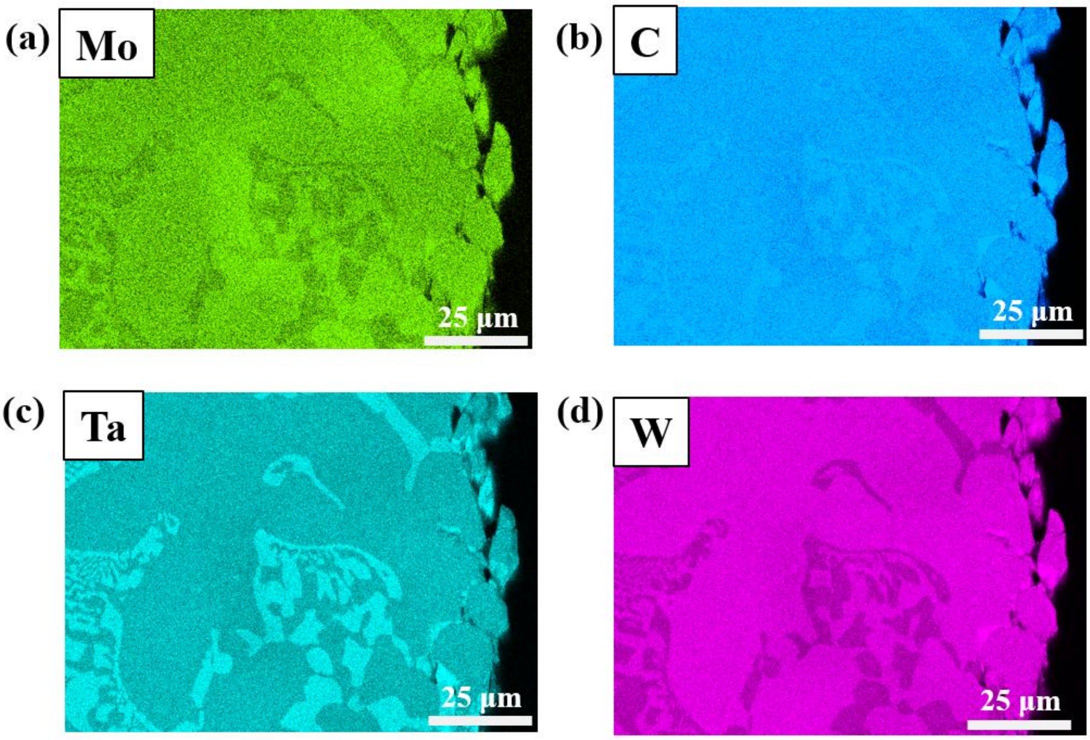
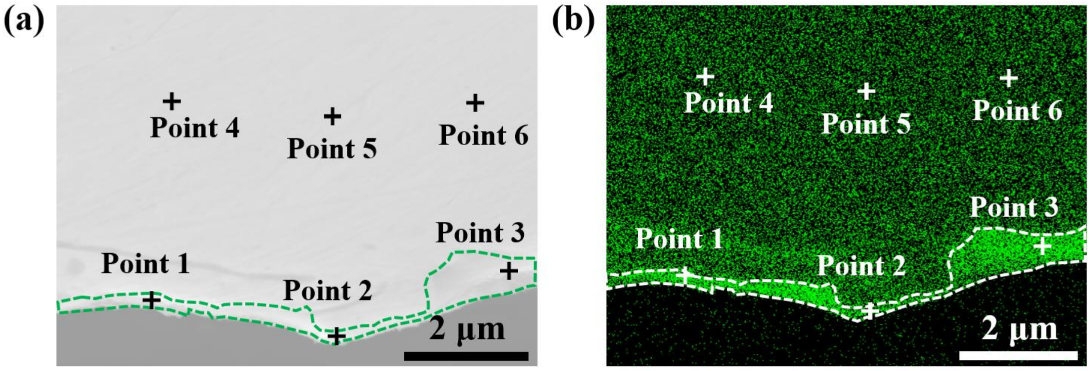


Fig. S7 (a-d) Element mapping including Mo, Ta, C and W of WJGL processed sample.



Element / At%	Point 1	Point 2	Point 3	Point4	Point5	Point6
O	5.9%	11.6%	25.1%	3.7%	3.7%	3.6%

Fig. S8 (a-b) The oxygen point-scan results at the HAZ of the WJGL processed sample. HAZ is marked with green dash line.

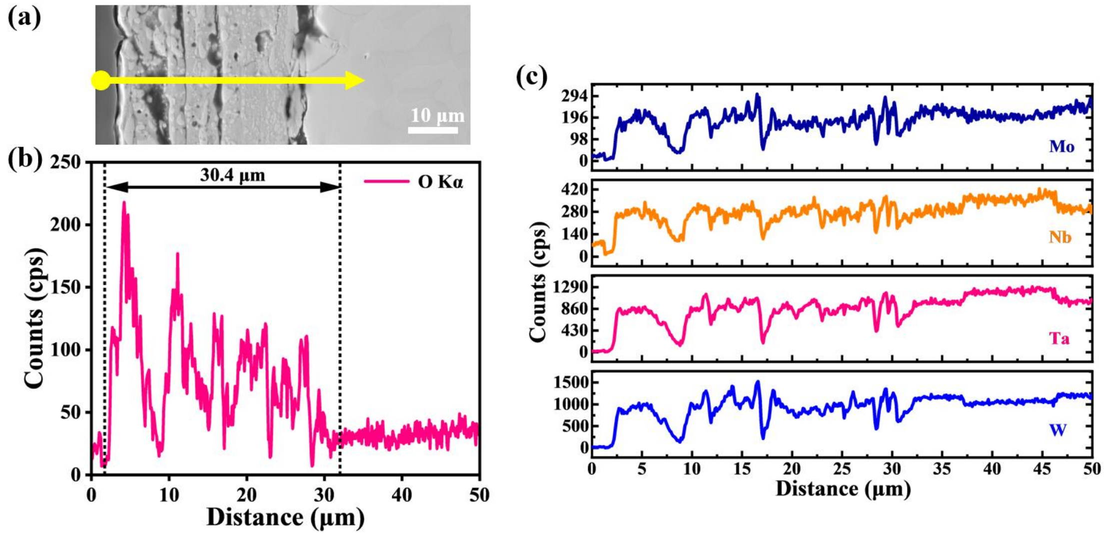


Fig. S9 (a-c) The line scan results of the HAZ of the CNL processed sample.

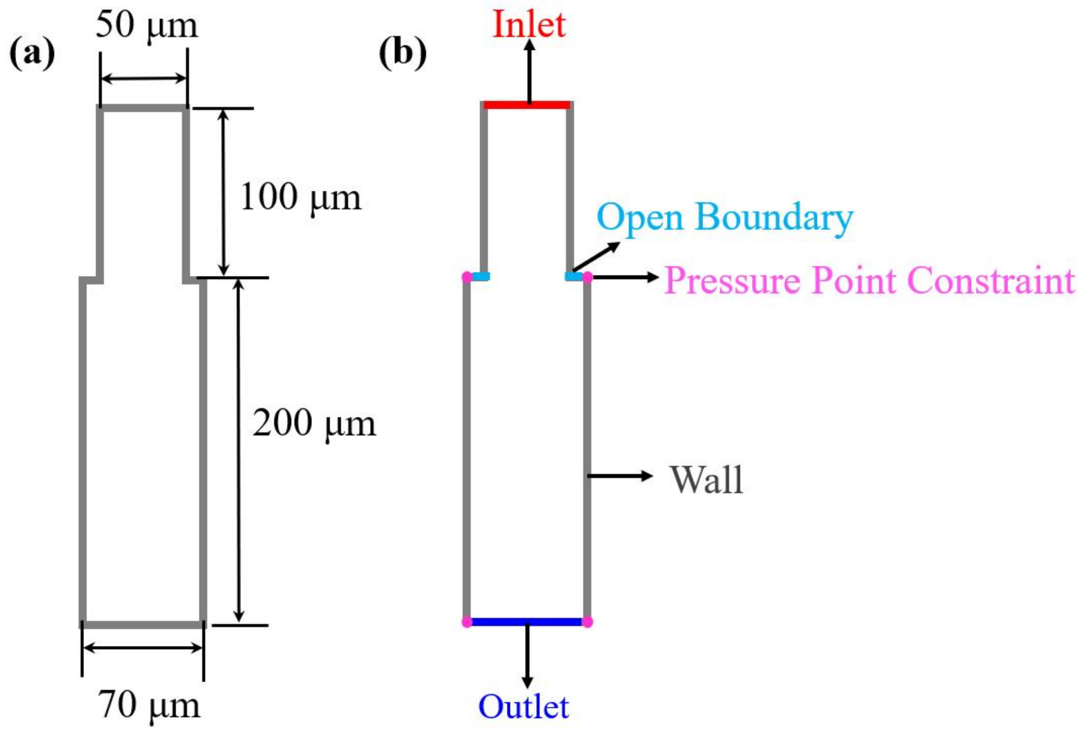


Fig. S10 (a) The geometric dimensions of the model. (b) Boundary definition in the geometric model. Here, we choose the turbulent k-ε model to simulate the single-phase fluid flow under high Reynolds numbers. The material is defined as water throughout the simulation domain. Set the condition at the entrance to be a jet with an incident velocity of 240 m/s. The condition of outlet is defined as the atmospheric pressure as the boundary condition for the net outflow domain. The opening of the boundary is used to simulate the reverse overflow of the jet. The pressure point constraints are used to set the pressure conditions at the boundaries. The grid division is controlled by the physical field and is refined at the walls to accurately solve the fluid motion at the wall surface.

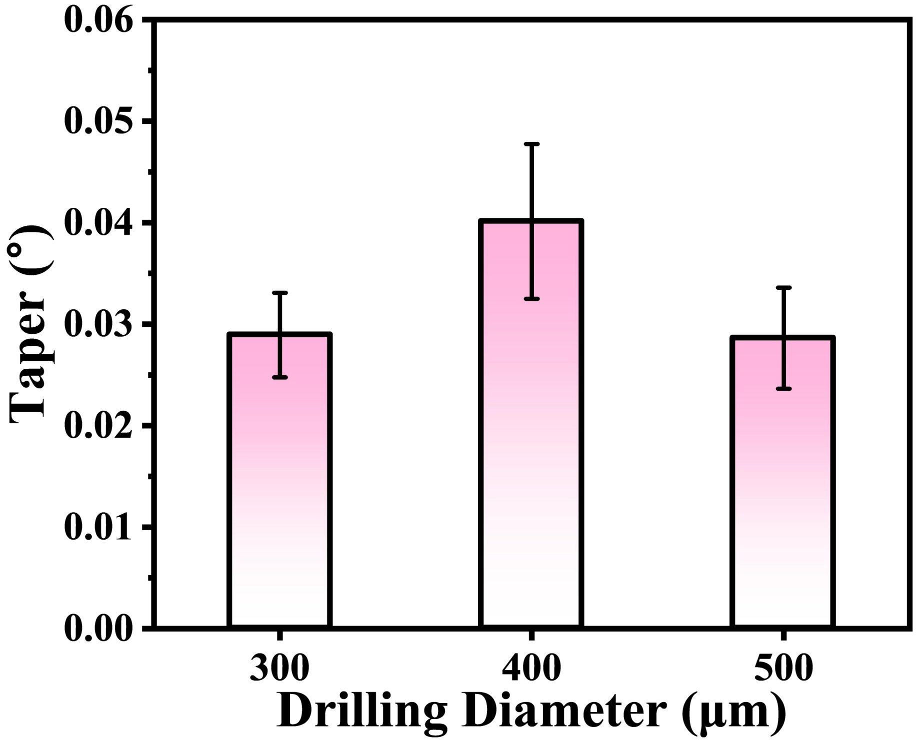


Fig. S11 Taper statistic results of drilled holes.

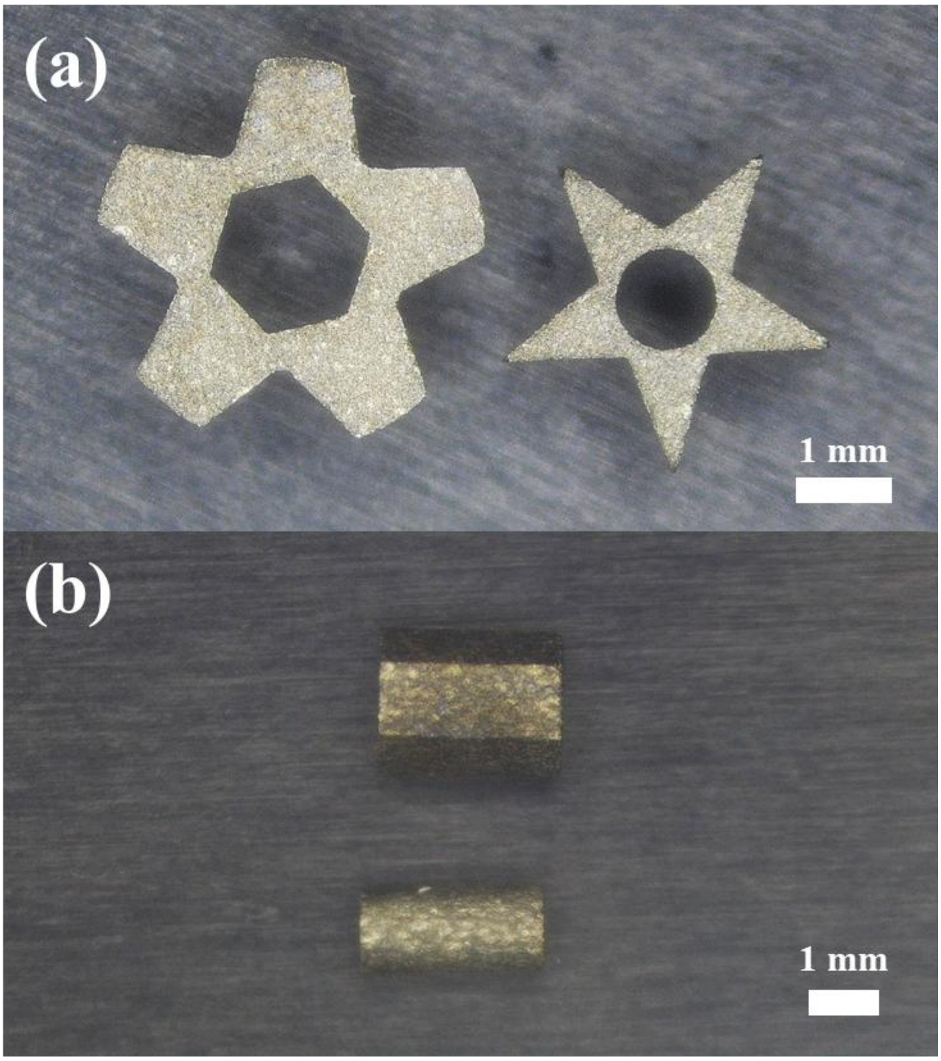


Fig. S12 Size comparison of WJGL processed samples.

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