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Water Jet Guided Laser Turning for Micro-Drill Blanking

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Abstract

Micro-drills are an important tool in many industries, however the creation of them is challenging, especially as ever more slender tools are desired. Laser processing is a highly flexible option for manufacturing of such tools. The Water Jet Guided Laser (WJGL) is an especially attractive technology for the manufacture of tool blanks, prior to the generation of flutes and cutting geometries. This paper documents the development of the WJGL turning process for micro-drill blanking. A two-stage process is employed, with faceting and finishing steps. The main focus of this work was to understand the influence of federate, depth of cut, and number of passes during the finishing step. Various different stock and final diameters were trialed. This work shows, in high-tensile steel, geometries of under 0.5 mm diameter, and a surface roughness less than 1 µm Ra are readily achievable. The WJGL turning process has shown to be highly capable for blanking of micro-drills in preparation for further processing.

Keywords: Water Jet Guided Laser; Laser Turning; Micro Drills;

1. Introduction

Micro-drills are extensively used in industry for hole drilling in electronic printed circuit boards, in jewelry, micro packaging and for wider miniaturised applications. Micro drills, nominally of less than 2mm in diameter, incorporating a polycrystalline diamond (PCD) tip mounted onto a cemented carbide shank are particularly challenging to produce using conventional mechanical processes such as diamond grinding. This is primarily due to the high contact loads necessary to produce the required diametric shape and the detailed primary cutting and secondary clearance geometries on the slender form of the drill shank. While Electro-Discharge Grinding (EDG) significantly reduces the contact forces, as the process is dominated by electrical erosion, preferential erosion of the metallic binder in both the PCD tip and cemented carbide shank takes place when using this process which can weaken the structure and substantially shorten drill lives. Laser turning of the drill shank offers a promising alternative for producing the slender blanks required in micro drill manufacturing, enhancing drill integrity and useful life, as presented by Butler-Smith, et.al, 2016.

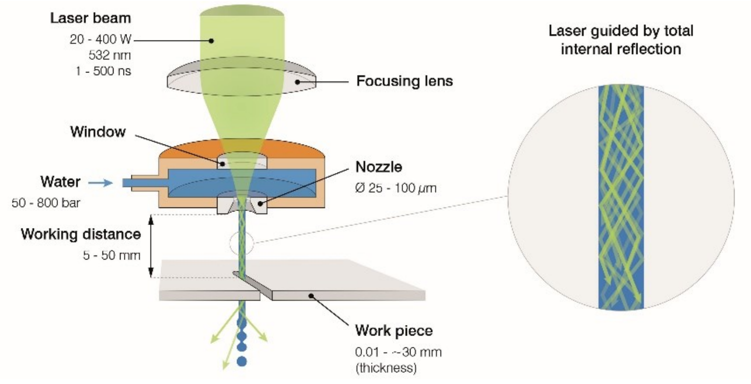

Fig. 1: Schematic of Water Jet Guided Laser processing, Synova S.A., 2024

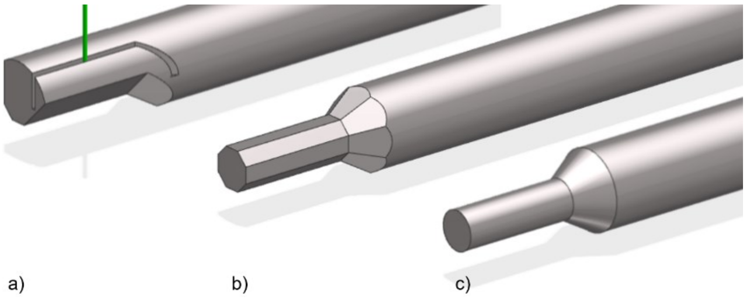

Fig. 2: Key steps in the WJGL process. (a) roughing, (b) rough shape, (c) final geometry, from top to bottom

Laser turning has been previously investigated and falls broadly into two categories, tangential and radial, describing how the laser beam interacts with the material. Published literature is scant. Zettl, et al., 2021 investigated tangential picosecond laser turning of a cobalt chrome steel. They noted that with a small depth of cut, the irradiated area is large due to the incidence angle on the cylindrical workpiece. The irradiated area then reduces to a minima where the defocus distance corresponds to the Rayleigh range, before increasing as the beam divergance becomes significant. In contrast, radial turning is more similar to bulk machining, where the laser is directed to intersect with the rotation axis. Kibria, et al., 2010 investigated millisecond laser radial turning, identifying the importance of selecting an appropriate axial feedrate, pulse frequency, and laser power to achieve the desired depth of cut and surface roughness. The work highlights the key benefit of tangential turning, namely that the resulting profile is independent of the laser parameters (power, frequency etc.) and instead is controled by the kinematic settings (feedrate, path). This reduced sensitivity, and greater control of the resulting geometry, is essential for the reliable manufacture of micro-scale features.

The Water Jet Guided Laser (WJGL) is a unique technology, whereby focused laser energy is captured within a narrow, laminar waterjet. The water jet cools and cleans the cut, minimizing recast, spatter, and thermal damage, while also eliminating beam divergence. This results in a nearly cylindrical beam over many tens of millimeters, removing the need for careful focus control with respect to the workpiece. A schematic of the WJGL concept is shown in fig. 1, Synova S.A., 2024.

WJGL turning process falls into the tangential category, as the beam is directed tangentially to the rotating workpiece. There is no published literature discussing the technique, however, Synova have documented the capabilities of WJGL turning processing in the manufacture of a complex geometric component Synova. S.A., 2025.

This study aims to explore the potential of WJGL turning for the reduction of shaft diameters to the sub-millimetric scale and to develop a baseline process using the unique characteristics the WJGL beam delivery to enable the manufacture of micro-drill blanks.

2. Turning process development

This work focusses on the programming development for WJGL turning. A two-step laser turning strategy was developed, which is shown schematically in fig. 2. Firstly, conventional cutting of several facets (typically 6 to 10) is carried out to generate a rough profile. This is followed by the turning operation, with continuous workpiece rotation while the WJGL traces the part's desired geometry. The WJGL is applied tangentially to the edge of the cylindrical sample. The main aspects of interest for the development of the WJGL turning process were the relationships of the number of passes during the roughing and finishing steps, laser power, and nozzle diameter. Also of interest was the effect that these process parameters had on the achievable feature size and surface roughness.

The system used was a 5-axis Synova LCS 305, fitted with a 350 W average power, nanosecond laser source emitting at 532 nm (green) wavelength. To enable turning processes the C-axis was used as the spindle, with a maximum rotation speed of 25 rpm (limited by the machine). In all tests, the target geometry was a cylindrical section, bounded on one end by the end of the sample, and the other by a 30° taper to the stock diameter as shown in fig. 3. Cutting speed for the roughing step was maintained at 5 mm/s for all tests. The number of passes for the roughing was set to ensure the facets were fully formed.

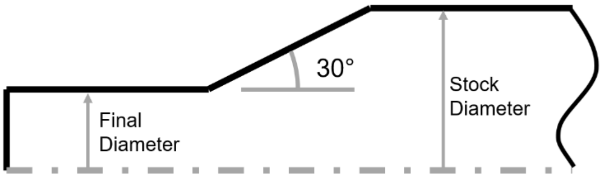

Fig. 3: Drawing showing the target geometry for WJGL turning.

Sample workpieces of high-tensile steel (ISO grade 12.9) were held in a collet chuck suitable for the diameter for all tests. The collets are specified to have a concentricity better than 10 µm. Part diameters were measured using digital calipers. Surface roughness was evaluated using a Sensofar Smart optical profilometer, using the focus variation technique. Details of the objectives used are given in table 1. Axial profiles were extracted from the measured data (averaged over 60 circumferential points). Data processing applied was; levelling by least-squares line, a 2.5 µm cutoff robust gaussian λs filter to remove microroughness and measurement noise, and finally a 0.8 mm cutoff robust gaussian λc filter to separate roughness and waviness components. Roughness was characterized by the arithmetic mean height (Ra).

Table 1: Objective specifications used to measure surface roughness (Sensofar Metrology 2024).

Objective magnification	10 ×	20 ×
Numerical aperture	0.3	0.45
Working distance (mm)	17.5	4.5
Field of view (mm)	1.7 × 1.4	0.85 × 0.7
Pixel size on surface (µm/px.)	1.4	0.69

3. Results and discussion

The first tests were performed on a 5 mm diameter sample, turning to a final diameter of 2.5 mm. The kinematic parameters are detailed in Table 2. The laser power used was 55 W, and the water jet nozzle 70 µm. The resulting sample is shown in figure 4. As can be seen, Cut A shows significant residual texture after WJGL turning. This is due to the finishing speed (50 µm/s) and spindle speed (25 rpm) giving a federate of approximately 150 µm/rev, significantly larger than the nozzle diameter. This effect was not reduced with repeated passes in alternating directions. The measured roughness was 7.05 µm Ra.

Table 2: Kinematic parameters for initial samples.

Parameter		A	B	C
Finishing speed	µm/s	50	10	10
Finishing Depth of Cut	µm	100	50	50
Finishing passes		20	4	2

Reducing the finishing speed to 10 µm/s (Cuts B and C) gave a federate of 24 µm/rev and eliminated the residual texture. The measured roughness was 1.69 µm and 3.54 µm with 2 and 1 repeat passes respectively. This showed the beneficial effect of multiple finishing passes when the other kinematic parameters are specified appropriately.

Subsequent samples used 3 mm diameter stock, and targeted reducing the target diameter to 1 mm and 0.4 mm. Both used a 70 µm nozzle with an average power of 68 W. Kinematic parameters used were 10 µm/s finishing speed, 30 µm depth of cut, and 2 finishing passes. The achieved roughness was 5.01 µm and 1.53 µm respectively. This difference in roughness was attributed to the lower circumferential surface speed on the smaller diameter. At 1 mm diameter and 25 rpm, the surface speed is 1.3 mm/s, while at 0.4 mm diameter, the surface speed is 0.5 mm/s. This reduced speed increases the laser-material interaction time at a given location, in turn allowing more opportunity for the laser to remove the high peaks on the surface. Under scanning electron microscopy (figure 5), the 0.4 mm diameter sample showed an irregular surface topography, with many distributed asperities and evidence of material smearing across the surface. Micrographs show the resulting geometry was a consistent diameter along the entire length. It is clear that the material is not flexing under the water jet pressure to cause any anomalies or distortions. This is because, while the jet pressure is reasonably high at 150 bar, the mass flowrate is very low, around 30 g/s, and thus the kinetic energy is also low. Additionally, the engagement

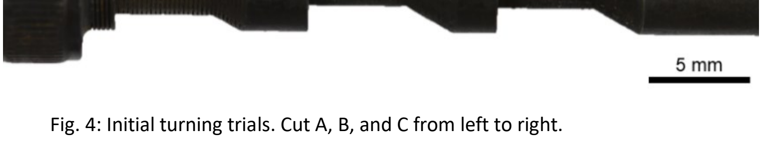

Fig. 4: Initial turning trials. Cut A, B, and C from left to right.

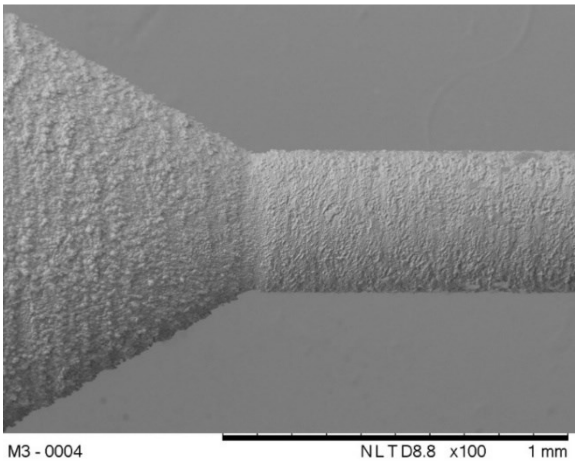

Fig. 5: Scanning electron micrograph showing surface of WJGL turned part to 0.4 mm diameter.

between the jet and the workpiece was very small, approximately ¼ the jet cross section when accounting for the depth of cut and federate used. Based on this, it is evident that narrower, or longer features are possible when using the WJGL turning technique. Furthermore, this shows that the technique is suitable for brittle materials, where excessive cutting forces are liable to fracture the part.

A test piece was manufactured using a larger nozzle (120 µm), to turn a 5 mm stock to 0.7 mm final diameter. 102 W average power was used along with four finishing passes to target a very smooth resultant topography. Despite the increased power, the power density was reduced by approximately 50% due to the larger nozzle diameter. The resulting part is shown in figure 6. The SEM micrograph shows evidence of individual laser passes with parallel, circumferential ridges. The roughness was measured at 0.95 µm Ra, with a high shine and no visual blemishes. It is hypothesized that the reduced power density, and larger nozzle used limits the temperature rise and spreads the thermal gradient, thereby reducing the roughness. Comparing figure 6 with figure 5, the uneven surface may be due to disturbances caused by the metal boiling, or molten metal being disturbed by a combination of photon irradiation and water flow, before rapidly cooling and solidifying into the irregular form observed.

On each of the previous samples, the resulting surface was visually dull and began to oxidize after several days in ambient laboratory conditions. The sample turned to 0.7 mm, however, had a high shine and exhibiting no oxidation even after many weeks in the same environment. Electron dispersive x-ray analysis confirmed no elemental change in surface chemistry had occurred. It is possible that the smooth surface has been conditioned in some way, thereby preventing the formation of iron oxide. This effect deserves further research effort, and if confirmed, holds potential utility for applications where corrosion resistance is essential.

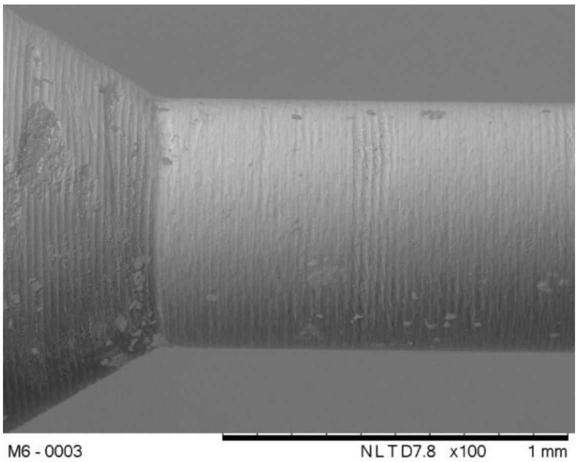

Fig. 5: Scanning electron micrograph showing surface of WJGL turned part to 0.7 mm diameter.

4. Conclusions and further work

This work has developed the capability to use a 5-axis Synova LCS 305 machine for turning. This work has demonstrated, for steel workpieces, a minimum cross section diameter below 0.5 mm, and a surface roughness under 1 µm Ra can be achieved. Both of these indicate significant potential for the utility of the WJGL to create micro-scale turned parts. The achievements documented here already show geometry suitable for the manufacture of micro-drills, with application in industries such as electronics.

Development of the process is ongoing, with work focusing now on applying to tungsten carbide and polycrystalline diamond workpieces, the current state of the art for micro-drills. Work is also ongoing to combine the WJGL turning with ultrashort pulse laser micro machining to realize the flutes and cutting-edge geometries required for a final micro-drill.

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