Micro-drilling of cone shape holes by ultra-short pulsed laser for fluidic applications

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Abstract

This paper presents the manufacturing of tapered holes by laser drilling, working with ultra-short pulsed laser source and a three axis configuration machine [1], [2]. Hole drilling for fluidic applications usually require a conical shape, to improve the flow rate and reduce pressure drop on it. Mechanical drilling offer high material removal rate, but the geometry of the holes is fixed to the given tool. In the case of rough or medium size drilling, fiber laser applications are offered; nevertheless in micro manufacturing cases ultra-short pulsed laser is required to have fine edges and reduced heat affected zone, HAZ. This paper presents a process to manufacture relative large holes with cone shape, up to 0.4 mm thickness with minimum diameter of 100 µm, in austenitic stainless steel. The drilling process is analysed considering the laser source power output (average up to 10 W), process feed rate (from 5 to 20 mm/min), frequency of the pulses (from 100 kHz to 1 MHz), and different drilling strategies: percussion, trepanning and helical drilling.

1 Laser processing platform, IK-Laser

The work presented in this paper has been carried out in a laser-processing machine developed in-house at IK4-Ideko. Figure 1 shows an overall view of the machine. It is a laser ablation machine with a three axis architecture and a source with three different wavelengths when the beam is pulsed with periods of picoseconds. All the structure is made on natural stone (granite), with aerostatic bearings in the three axes. The stroke of the axis is 300 mm in X, 200 mm in Y and 100 mm in Z. The ultra-short laser beam pulse is given in picoseconds (around 15x10-9 s), it allows very high quality machining with an average output power of 25 kW and up to 1 MHz working frequency. The laser spot is focused in a diameter between 10 µm and 20 µm depending on the wavelength used. These three wavelengths (Ultra Violet 355 nm, Visible Green 532 nm and Infrared 1064 nm) can be used without any change in the optical path, increasing the quality and productivity of the system; and thanks to these different lasers, many kinds of engineering material can be machined. Results for machining austenitic stainless steel (AISI 304) are presented in this work.

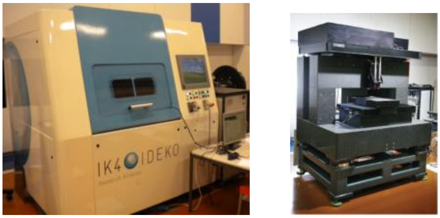

Figure 1: Overall view of IK-Laser machine, internal structure and stages

2 Laser processing conditions and results

The process parameters have been optimized on preliminary tests, trying to achieve the best quality for the machined parts by minimizing burrs, burnt zones and surface roughness. Experiments were carried out in the same material and using working parameters available for very small holes, strongly limited by axis acceleration to achieve the desired scanning speed. This way, the values employed for the process parameters have been: Wave length: 355 nm (UV), Frequency (Q): 200 kHz, Feed rate (F): 5 mm/s, limited by axis acceleration. The axial depth of cut (ap), radial depth of cut (ae) and the average power output values have been adjusted for each processing strategy. In this case, the hole to be drilled has 0.5 mm diameter in one side, and 0.3 mm in the other, machined across 0.4 mm metal sheet thickness. Figure 2 shows the sketch of micro-drilling feature with a conical shape.

Figure 2: Sketch of micro-drilling cone shape hole, dimensions given in millimeters.

Looking for a solution for this challenge, five different processing strategies have been studied. These strategies were developed using CAD/CAM software (Unigraphics NX7.5), defining the path of the spot and the material ablation conditions. Description of the employed strategies and the obtained results for each one of them is presented in Figures 3 and 4:

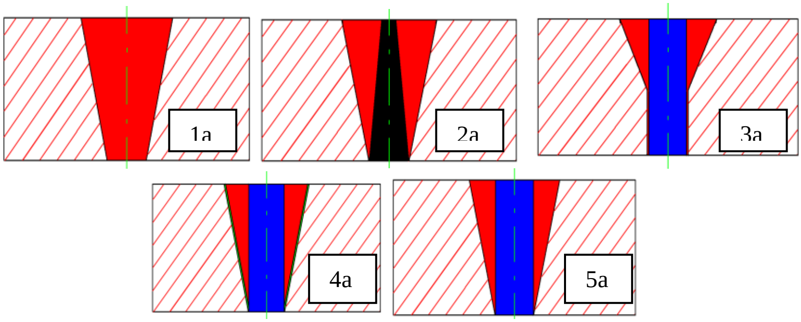

Figure 3: Sketch of five machining strategies

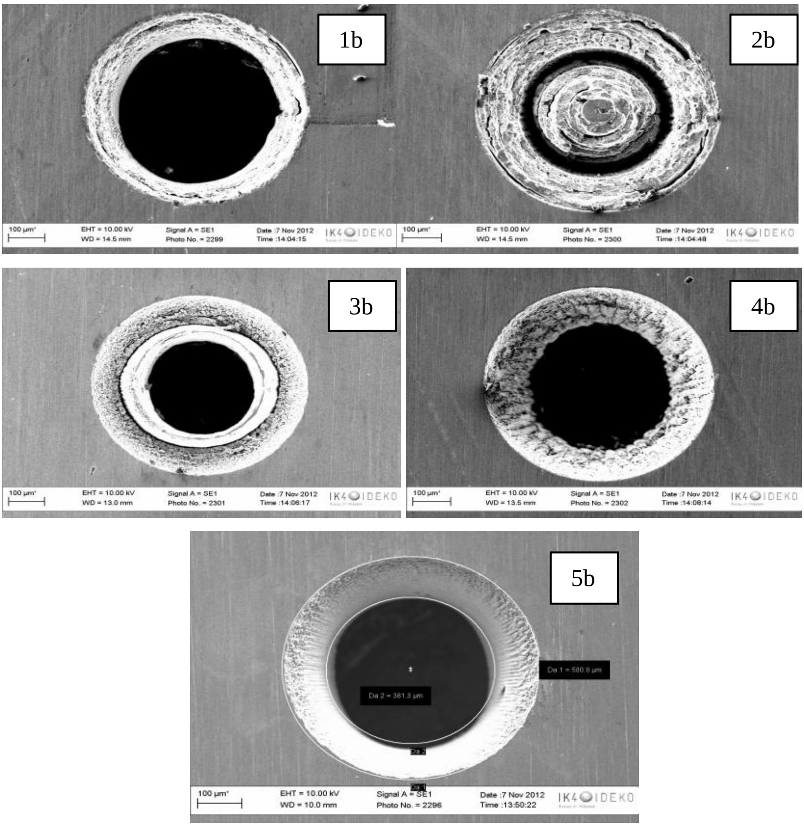

Figure 4: Drilled holes from different machining strategies.

Following the notation shown in figures 3 and 4, the strategies analysed have been:

1: Machining of whole hole in one step at finishing parameters, where the sketch is (1a) and result picture (1b). ***2:*** Machining of inverted cone to avoid overheating in the walls in one step, sketch (2a) and picture (2b). ***3:*** Internal drilling by rough machining parameters, blue, and lateral walls finishing (red), sketch (3a) and picture (3b). ***4:*** Internal drilling by rough machining (blue), lateral walls at semi-finishing conditions (red), and final cone shape at finishing conditions (green), sketch (4a) and picture (4b). ***5:*** Internal drilling by rough machining (blue), final shape in finishing conditions (red), sketch (5a) and picture (5b).

3 Conclusions

The research presented in this paper has shown that cone shaped micro-drilling in austenitic stainless steel is feasible with picosecond pulsed laser processing. The drilling strategy has shown to have a great effect on the obtained hole quality, so that several attempts have been presented with a final optimal solution (Figure 3e). This process strategy has shown a very high quality hole finishing, with minimal burned material or HAZ, while obtaining a final geometry according to the expected dimensions (Figure 2). Process time per hole was around 5 minutes, quite large compared with other laser drilling processes such fiber laser or CO_2. However, the achieved drilling quality and the capability for almost free shape hole making, allows us to affirm that it is a promising machining technology in applications where complex hole geometries are required.

References:

[1] J. Cheng, W. Perrie, M. Sharp, S.P. Edwardson, N.G. Semaltianos, G. Dearden, K.G. Watkins, Single-pulse drilling study on Au, Al and Ti alloy by using a picosecond laser, Appl Phys A 95 (2009) 739–746.

[2] N.N. Nedialkov, P.A. Atanasov, Molecular dynamics simulation study of deep hole drilling in iron by ultrashort laser pulses, Applied Surface Science 252 (2006) 4411–4415.