High resolution laser micromachining of TiN coatings through the regulation of pulse characteristics

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Abstract

The first part of this work presents the study of micro drilling conditions on TiN coatings with a MOPA fibre laser with pulse tuning capability. Pulse shapes with pulse durations varying between 12-200 ns have been employed. Single and multiple-pulse ablation conditions were mapped for different pulse durations to effect greater control of the two main geometrical attributes, namely diameter and depth. In the second part of the work, the mapped conditions were used to design more complicated micro features with dimensions close to the laser beam diameter (36 µm). Elliptical dimple shape was chosen as a demonstrator case.

1 Introduction

Laser micromachining processes based on material ablation are commonly categorized by the pulse duration regime as: long pulses (*ms*, *µs*), short pulses (*ns*), and ultrashort pulses (*ps*, *fs*) [1]. This categorization is suitable for a primary discretization, but the nature of the ablation processes depends on other pulse related parameters, such as the pulse duration and pulse shape that determine the temporal profile of the energy deposition to the material. Although ultrashort pulsed lasers exhibit superior quality in micromachining, *ns* pulsed lasers cover a large share of industrial laser applications due to their higher productivity, flexibility and robustness. An adequate choice of pulse shape and duration in *ns* regime, along with the regulation of the energetic conditions, can allow effective control of the ablation conditions. Once the ablation conditions for a specific beam-material couple are identified, they can be used to regulate the effective tool diameter to values bigger or smaller than the nominal laser beam diameter, allowing machining more complex shapes in the dimensional range of the laser beam size. This can be exploited in the field of microstructuring of thin surface coatings, where functionalization of the surface by the generation of controlled surface textures is of interest [2]. Accordingly, in this work the ablation conditions were identified to develop machining strategies to increase shape manipulation in direct laser writing, by reducing machining resolution to dimensions smaller than the beam diameter.

2 Experimental

The laser source was a fibre laser based on MOPA architecture with pulse tuning capability (SPI G3 20P-HS). The laser allowed the use of a variety of pulse durations, of which pulses with 12, 30, 65, 100, 150, and 200 ns durations were chosen for this study. Beam manipulation was achieved via a scanner head (Nutfield XLR8-15-1064), which housed a 125 mm focal lens. In this combination the calculated beam diameter was 36 µm. Laser machining was performed on 4 µm thick TiN coatings, deposited on AISI M2 tool steel by PVD process.

2.1 Effect of pulse duration on the ablation of TiN coatings

The effect of pulse duration was initially observed for single pulse ablation. Figure 1 reports the measured ablated area diameters as a function of the laser fluence and pulse duration. It can be observed that the control of pulse duration extends the operation range of the process in terms of achievable dimensions within the range of 20 – 45 µm. A comparison based on ablation conditions with similar pulse energies but different pulse durations reveals that longer pulses allow deeper ablated regions, yet shorter pulses allow larger ablated areas due to the higher peak power contained in the pulse. In the case of multiple pulse ablation for percussion drilling operation, it has been observed that with the same amount of energy, longer pulses are more efficient to remove the same amount of material. On the other hand, shorter pulses result in better control of ablation depth and quality, without generating excessive melt. In fact, longer pulses show an asymptotic trend in the material removal rate while the pulse energy increases, due to the fact that when drilling beyond the coating, they generate more melt due to the lower melting temperature of the steel substrate, which is not effectively expelled from the hole opening (see Figure 2).

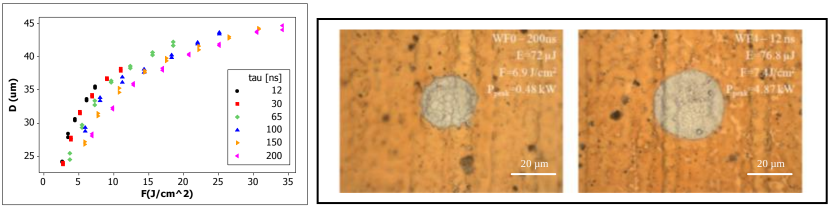

Figure 1: The effect of pulse duration on the ablated region size (left); and a comparison between the ablated zones with similar energy levels for 200 ns 12 ns pulse durations (right).

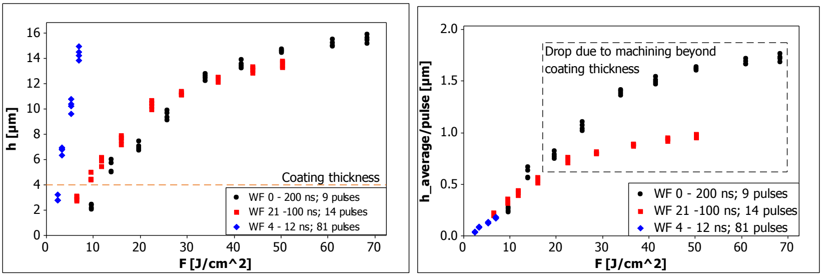

Figure 2: Evolution of hole depth in multiple pulse ablation with different pulse durations.

2.2 Use of identified ablation conditions for flexible shape manipulation

Flexible shape manipulation was achieved by combining different circular craters in the correct spatial order. The ablation studies allowed choosing from different ablation conditions, which were then used as design bits to construct more complicated shapes, as in this case, elliptical dimples were chosen. The feature contour was achieved by positioning different circular craters of different diameters (see Figure 3). To improve the homogeneity in the depth profile, different machining strategies and sequences were investigated (not reported for the sake of briefness). Table 1 reports the processing condition. It can be observed that the elliptical contour with smooth bottom can be obtained with the strategy employed (see Figure 4).

3 Conclusions

Results show that the adequate regulation of laser parameters can be used effectively to control micro feature geometry and size, which can eventually be used to machine a smaller region inside the micro feature itself. The approach presented here can be

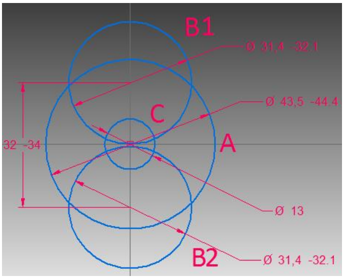

Figure 3: Design of elliptical dimples.

Table 1: Selected processing condition for the elliptical dimples

Pulse durations	For A and B: 100 ns For C: 12 ns
Sequence	B1, B2, A, C
B-B Spacing	34 µm
No of pulses	A:7; B:4; C:25

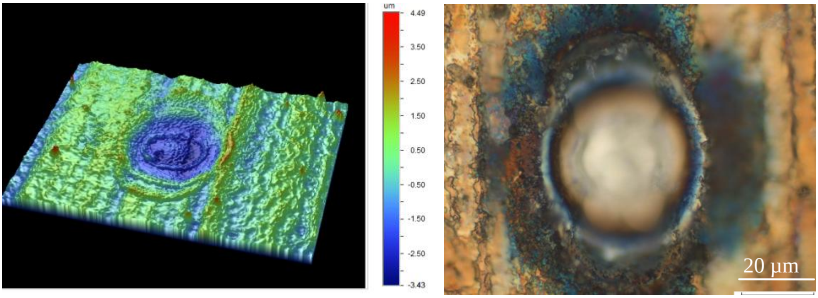

Figure 4: Elliptical dimple obtained with the determined processing strategy.

used for flexible shape manipulation for micro features in laser micromachining, without the need of using masks. A potential application would be laser surface texturing of mechanical components working under high friction and wear conditions, which need robust and productive industrial lasers to cover relatively large surface areas. The application requires flexibility, since texturing is applied on a limited number of components, whereas applied texture pattern may vary individually.

References:

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