PRECISION LASER MICROMACHINING – THE BALANCE BETWEEN SPEED AND QUALITY

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All suppliers of laser machining services will have, at some stage, been asked a question along the lines of: "*What is the best way to machine material X*"? The subtext of this question is usually that the customer wants to know what the time and cost of machining material X will be given a particular design. In the world of precision micromachining, there is usually no simple single answer to the above question - it really depends on a number of factors, mainly related to the quality required. As precision laser micromachining usage grows, it is perhaps useful to put this idea into some context and to highlight the main issues. This article aims to present this using the laser micro-cutting of thin metals as an example. The discussion which follows is necessarily quite general but it is hoped that this approach can serve to put across a number of ideas about how laser micromachining should be approached and how it compares with other methods.

Mechanical & Laser Machining

Those people approaching laser machining from more established (usually mechanical) machining backgrounds will have become familiar with being able to prescribe what will occur when a particular tool is used, e.g. a drill bit can be selected and it will produce a hole of a certain size, depth and quality in a metal, and all this can be predicted and costed before any work is done. We are all familiar with this and it forms the background to some of the misconceptions around laser machining. The same is true of milling. A properly set mechanical milling machine will produce a milled part to a certain depth and it will not matter if the milling bit retraces a path since it will not mill any deeper. With lasers, however, milling is quite a different proposition: the laser will mill deeper if it's path is retraced over the part. Hence *how* laser milling is undertaken determines what the result will be, whereas the result is far more predictable with a mechanical milling machine.

Mechanical machining has obviously been around for centuries whereas laser machining is still only 40 years old but, nonetheless, there is great maturity in certain sectors of the laser industry. Amongst these is the cutting of sheet metals, for example. In this area, there are around 100 or so companies in the UK alone which provide the laser cutting of parts as an off-the-shelf service with standard processes and prices. In this sector, the cut quality is essentially a known parameter for a particular metal/thickness combination and so the customer knows what can be expected. In addition, because the parts being made are usually large, a small laser-affected region around the cut has less significance to the overall part (or the affected region can be treated post-cutting). In essence the laser cutting of sheet metals uses the same lasers and the same processes (laser power, use of gases) across the industry and, therefore, the results are 'standardised'. This also means that the customer can choose between competitors offering the same service and there is a high level of confidence as to what will be delivered. This is not the case when laser *micro*machining is considered, however.

The differences in the laser micromachining sector arise mainly because:

(a) there are a wider range of materials being used;
(b) materials are thinner, more delicate;
(c) sample sizes are small;
(c) features being machined are very small;
(d) there is more significance to any laser-affected area;

Due to the above and the relative immaturity of the laser micromachining sector, there are very few, if any, 'standard' processes available. This means that the result is determined as much by who is doing the work and how they undertake it rather than the task itself. This makes predicting the outcome more uncertain.

To illustrate this point, we have carried out a simple demonstration of the cutting of 50 micron thick stainless steel 316 foil (obtained from Goodfellow). In this work we chose to cut out a 1mm square from the SS316 foil using different lasers and different processes with the aim of showing the differences in quality which are obtained for different overall speeds of processing. Since time is usually the major cost driver in this kind of work, this approach can highlight how it is crucial to appreciate what quality will be acceptable for the customer and what impact such choices have on the cost.

Laser Cutting of Stainless Steel

It is well known that SS316 can be cut with a number of different lasers. In this demonstration, we chose to use a Nd:vanadate nanosecond-pulse laser operating at 532nm ('Laser A') and a Ti:sapphire ultrashort-pulse laser operating at 800nm ('Laser B').

A simple basic assessment can be made of how a particular laser can cut a material by varying three process conditions – laser power, number of passes, speed of cutting. Obviously there are other parameters which can also be optimised (e.g. focus position, laser rep rate, use of gases, pulsewidth etc.) but only these three main parameters were used in this case for simplicity. Figure 1 shows the variation of cutting in SS316 foil under three different power settings against number of passes and speed of cutting. Although it is clear that a broadly similar range of conditions results in the squares being cut out, the quality does change significantly (as noted by the edge damage and the ease of the squares being removed from the foil). As an aside, it should be noted that the use of gas nozzles in the cutting of thin metals does give excellent results and fast processing. In many micromachining applications, however, such gas-assisted cutting cannot be easily used since the parts may be embedded in holders or may have other components close to the cut site, thereby making the use of short working distance gas nozzles impractical.

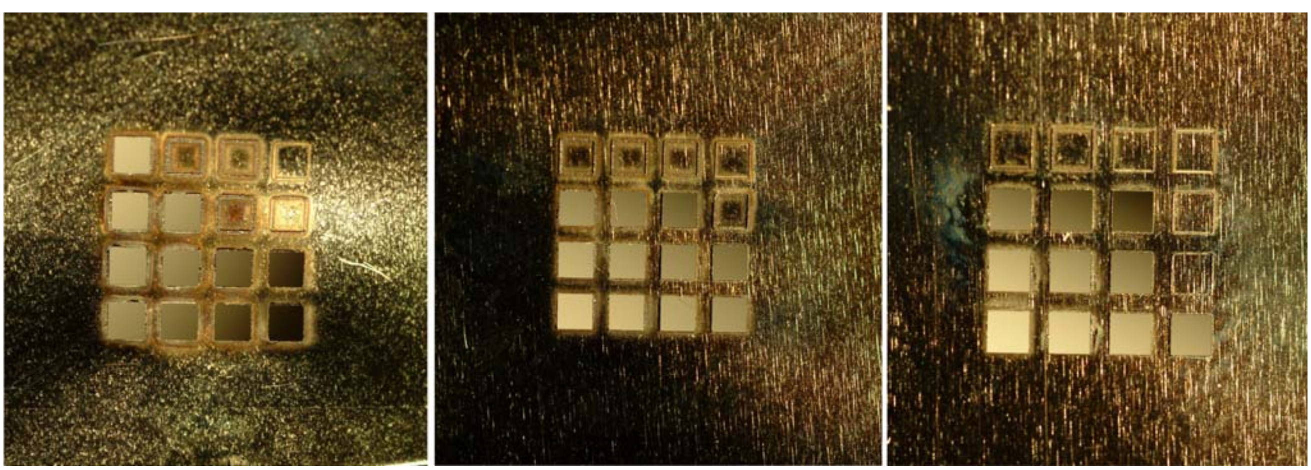

Figure 1. Matrices of cutting trials with different speeds and number of passes using Laser A. Laser power is 100% (left, 85% (middle) and 75% (right).

Figure 2 shows the cut-out from the foil at the fastest process speed for each of the three different power levels. The speeds of each cut were 8mm/s (100%), 4mm/s (85%) and 2mm/s (75%) and the improvement in edge quality is clearly evident for the lower power (slower speed) process.

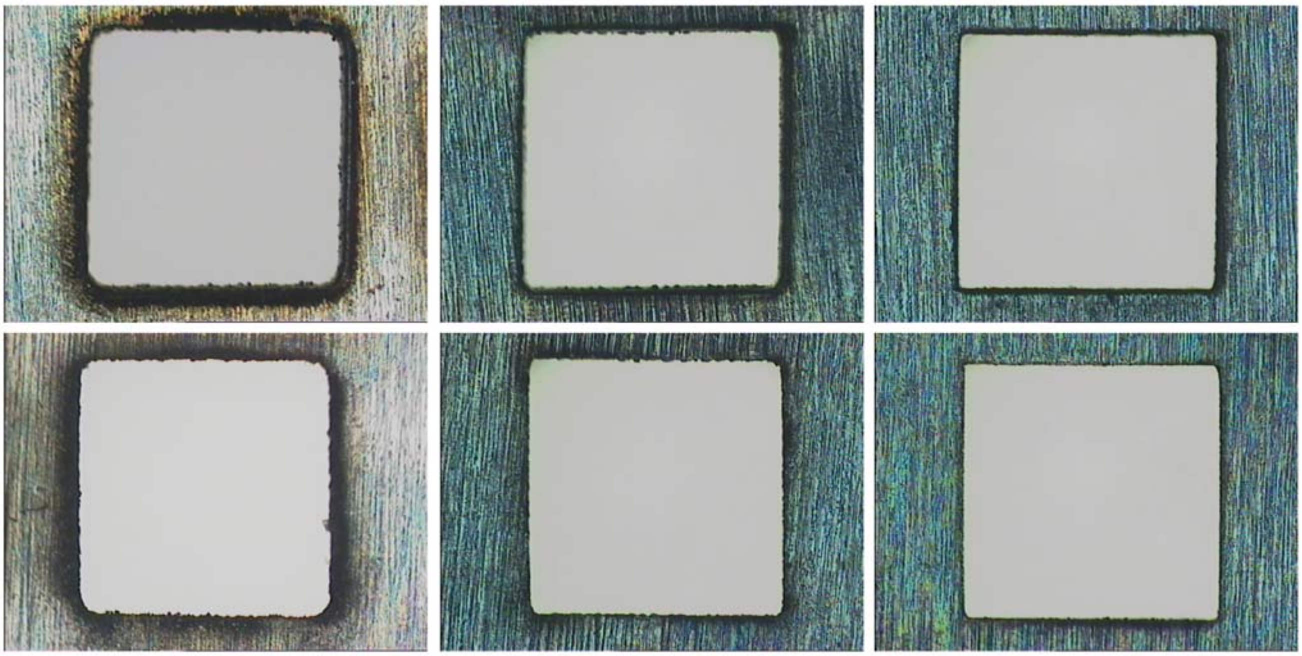

Figure 2. Details of fastest cuts at each power level using Laser A. Top row shows the entrance side and the bottom row the exit side of the cut foil. The power level changes from 100% (left column) to 75% (right column).

The cut-out from the P=75% conditions of Laser A (right hand side of figure 2) is shown in figure 3. The tapering of the cut is also evident, i.e. the dimensions on the top surface are smaller than the dimensions of the exit face, something which can be seen from the entrance side picture.

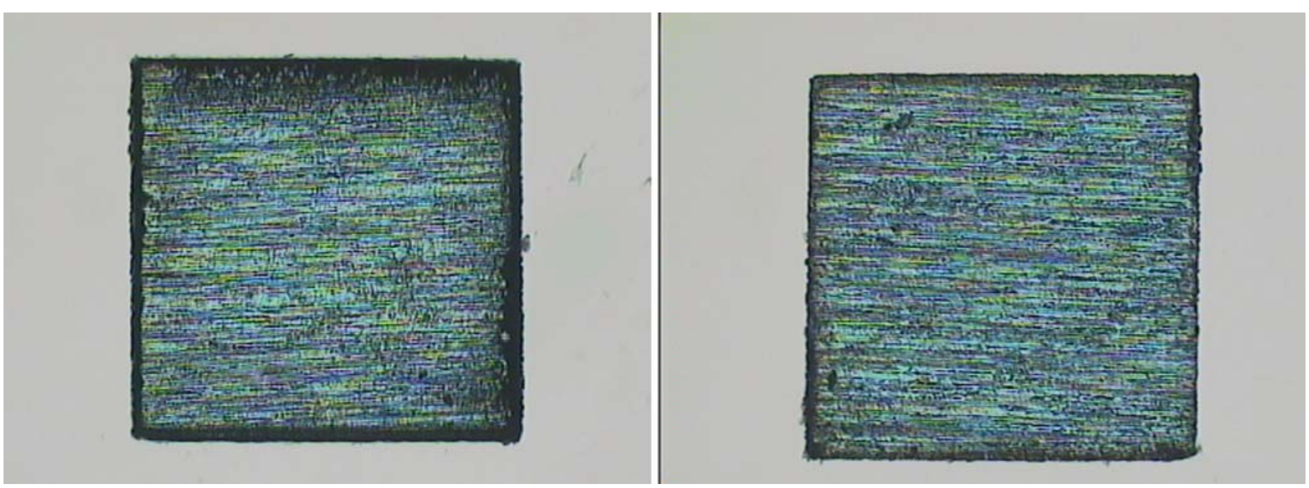

Figure 3. Cut-out produced using P=75% setting of Laser A with entrance side (left) and exit side (right).

The same approach was used with Laser B and 1mm squares were cut-out under different conditions. Figure 4 shows the 'best' cut squares which were produced at an effective cut speed of 0.1mm/sec. Although the quality is clearly better with Laser B than with Laser A, the difference in quality is not as varied as the cutting rates for each laser – the cutting speed difference is of the order of x20 whereas it is not clear that the Laser B squares are twenty times better quality.

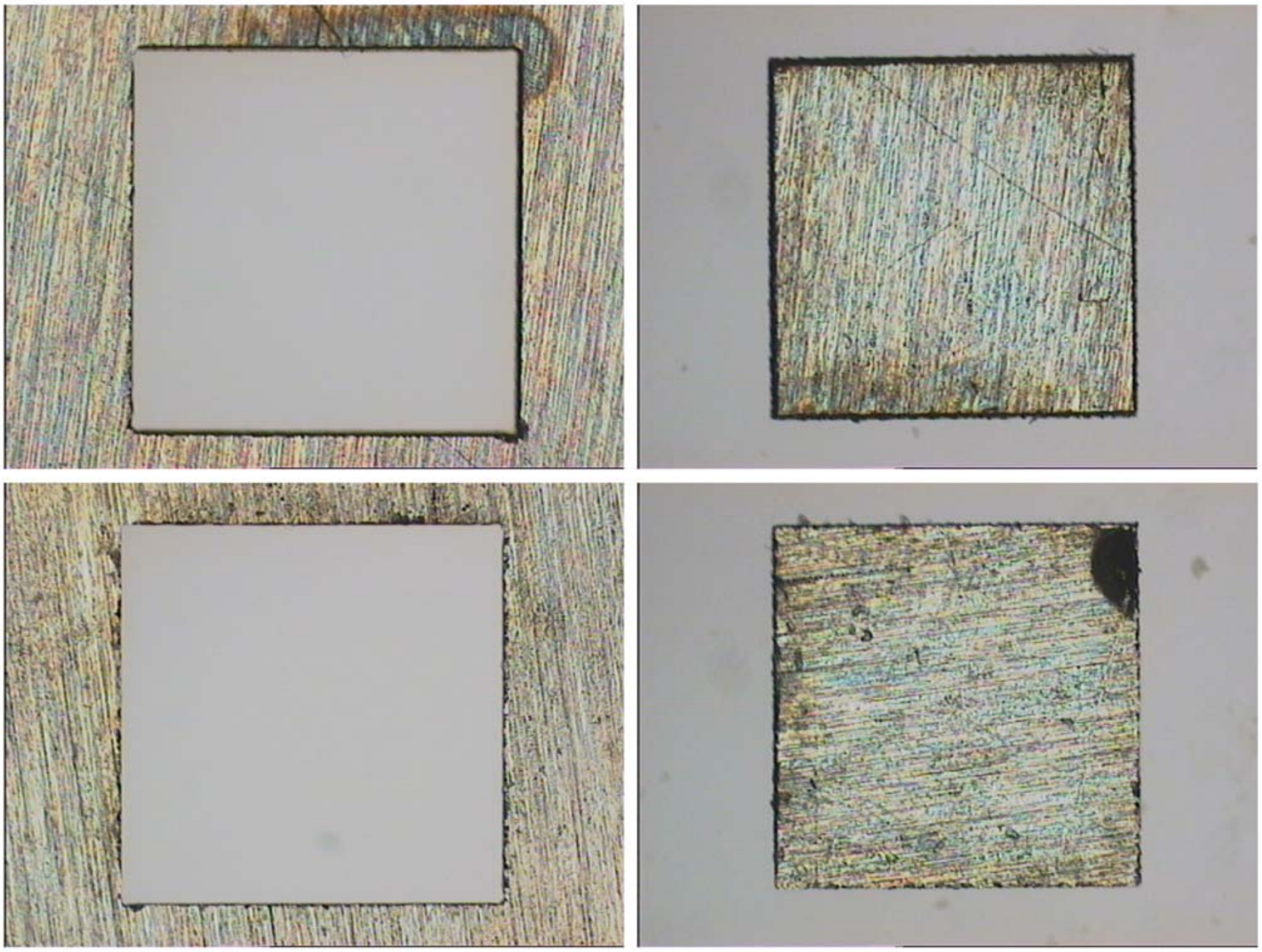

Figure 4. Cutting of 1mm square in SS316 using Laser B showing entrance sides (top) and exit sides (bottom).

Discussion

The comparative cutting speeds and quality differences shown in figures 1-4 will translate into a cost difference of ~80 times assuming the time is the only driving cost factor, i.e. the 'P=100% Laser A' process is 80 times faster than the '75% Laser B' process. Since there are faster and slower processes still, it is obvious that a huge choice exists. Often customers start with the statement that they require the 'best' quality in any job – what is more critical is what's the *acceptable* quality for the job. Once this message can be taken on board, the most economic and fit-for-purpose work can be delivered.

Standard 'off-the-shelf' processes are growing in laser micromachining as it's take-up in different sectors grows. Education will also be a key factor in allowing users to get the best out of laser technologies and this is something which AILU is already at the forefront of, for example the Photonics KTN and Design for Laser Manufacture. The main message for users of laser micromachining has to be that there is a huge potential which can be exploited but that this benefit will be far greater if some of the subtleties of laser machining can be appreciated better.