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Establishing optimal parameters for laser cutting of thin semi-transparent organic material

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Abstract

The manufacturing challenge of laser cutting thin, light weight, semi-transparent, organic material is address in this work. A novel glass-sandwich fixturing method is developed. This increases the ease of material manipulation and permits cutting in a sterile environment. The transparency of the glass sandwich to fibre laser radiation (2kW IPG 200S fibre laser, λ = 1070nm) is exploited, allowing the sandwiched material to be cut. A process window is determined using powers and translation speeds of up to 600 W and 1200 mm/s respectively. An approximately linear relationship is observed for the maximum cutting speed at any given power. Cut width and heat affected zone dimensions are investigated as a function of cutting speed and power. The organic material has extensive site to site and sample to sample variations in material thickness and transparency. A process robustness analysis is carried out to determine optimal cutting parameters.

Keywords: cutting; organic material; semi-transparent; fibre laser; fiber laser; amniotic membrane;

1. Introduction

The non-contact nature of laser materials processing makes it a good choice for traditionally difficult to machine materials. This has been widely demonstrated in processes such as laser drilling of superalloys (Voisey, 2004) and laser cutting of a wide variety of tough and hard materials that would otherwise result in extensive tool wear (Dubey, 2008). This work exploits another advantage of laser materials processing: the fact that the lack of contact means that delicate materials can be processed without damage, as long as

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suitable material handling methods are used. NuVision® Biotherapies commercialises a human amnion-derived biological matrix, Omnigen®, for therapeutic application in soft tissue regeneration situations. The material is a thin, semi-transparent organic material that is processed sterile. The dry material is extremely light it will move when subject to the slightest of air movement of static. The manufacturing challenge addressed by this work was how to laser cut amnion material whilst maintaining a sterile environment and without damaging the delicate amnion material.

Laser material processing frequently makes use of laser transparent as well as laser absorbing materials. Applications where laser transmission through a transparent material are exploited include laser peening, where a water layer both permits sufficient transmission of the laser to enable peening to occur and acts as a confinement layer to ensure the pressure pulse generated is properly directed into the material being peened (Montross, 2002). Another example is TWI's clearweld process, where the laser then passes through the upper, transparent, layer to be absorbed, and generate melting, at the material interface where a laser absorbent material has been placed, thereby generating the weld (Jones, 2002). In addition, laser transparent windows are widely used to allow laser beams into hermetically sealed environments.

This work uses a glass sandwich sample holder to both enable easy holding and handling of the delicate amnion material and to enable the cutting to be done without compromising the sterility of the material. The high transparency of glass at the 1 micron fibre laser wavelength means that fibre laser radiation can pass through the upper layer of glass without being attenuated or causing any damage. Absorption of the radiation by the amnion material enables cutting to take place. The excess laser beam then exits the sample holder through the rear plate of glass, again without causing any damage. This is the same principle of differential absorption which allows lasers to cut one layer in a multilayer without damaging other layers (Chow, 2009).

2. Experimental methods

Dry sheets of the amnion material used was provided by NuVision. The as-supplied material had been harvested, dried and sterilised using their standard patented and regulatory approved clinical Tereo® manufacture processes. In its dehydrated state, the material is very thin, typically 44-55 µm, with recent products being ~100µm, and resembles a single ply of tissue paper (Marsit, 2019). There is significant site to site variation within individual samples as well as from sample to sample. The material also easily creases which effectively adds to site to site variation.

An IPG YLR-2000S Nd:YAG fibre laser with maximum power of 2 kW, a 200 µm focussed spot size, and a wavelength of 1070 nm was used. Throughout this work the laser head remained stationary, with the material to be cut fixed to a motorised stage. The laser beam was vertically incident. A variety of power – speed combinations were used. All cuts made were straight line cuts, with the table being allowed to accelerate to speed before cutting commenced. There was a separation of at least 3 mm between adjacent cuts.

Initial, trial cuts were carried out in air, with the laser focussed on the amnion, used powers in the range of 80 – 900 W and speeds of 14 to 133 mm s 1. The laser was focussed on the top surface of the amnion with a focussed spot diameter of 200 µm. The amnion material was simply clamped in place above a slot, i.e. with free space directly below it. No assist gas was used.

The work carried out using the glass sandwich used powers of 100 – 600 W and speeds of 4 - 26 mm s 1, with the focal position 2 mm above the surface of the amnion, again no assist gas was used.

After cutting kerf width and heat affected zone (HAZ) measurements were made using an Alicona G5 infinite focus optical microscope. All such measurements were carried out while the amnion was still encased in the glass sandwich. Kerf width measurements presented are the average from three separate cuts. HAZ measurements measured the extent of the yellow/brown discoloured region at the edge of the cut. The results presented are the average of three separate measurements.

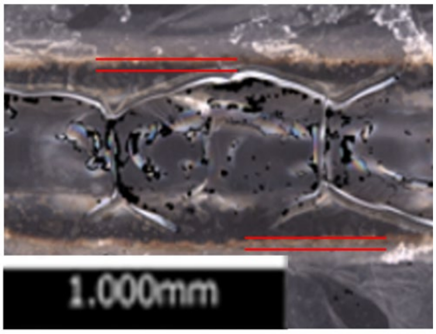

Fig. 1. Optical micrograph showing HAZ discolouration either side of the cut. The superposed parallel lines indicate the region measured as the HAZ.

3. Results and discussion

3.1. Initial trial cuts

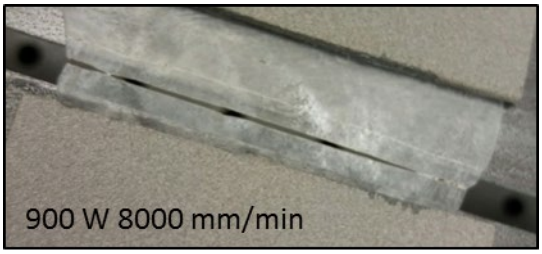

Fig. 2. Trial cut carried out in air.

The trial cuts confirmed that sufficient laser-material interaction occurred to enable cutting (Figure 2). Exploration of the parameter space (Figure 3) showed that as speed increased, the power required to generate a complete cut also increased. This is to be expected and is frequently seen in laser cutting. The results, particularly for 600 W, show some considerable scatter. There is significant overlap between parameter combinations that generate full and incomplete cuts. This is attributed to the significant site to site and sample to sample variation in the, organic, amnion material.

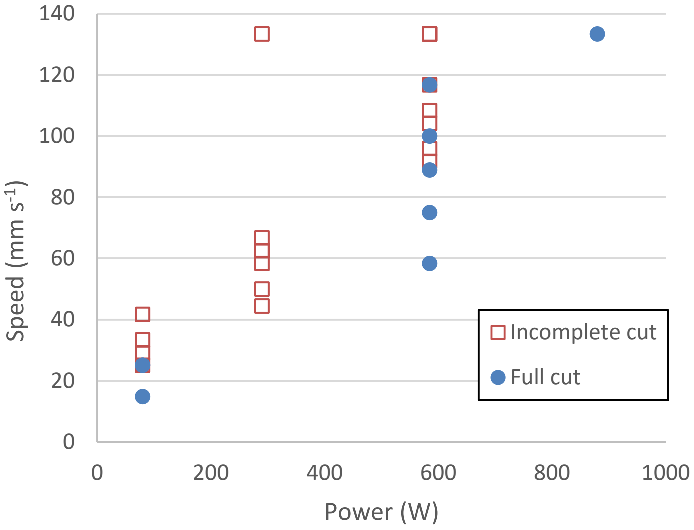

Fig. 3. Results from trial cuts showing parameter combinations that achieved full or incomplete cuts.

3.2. Cuts carried out in glass sandwich

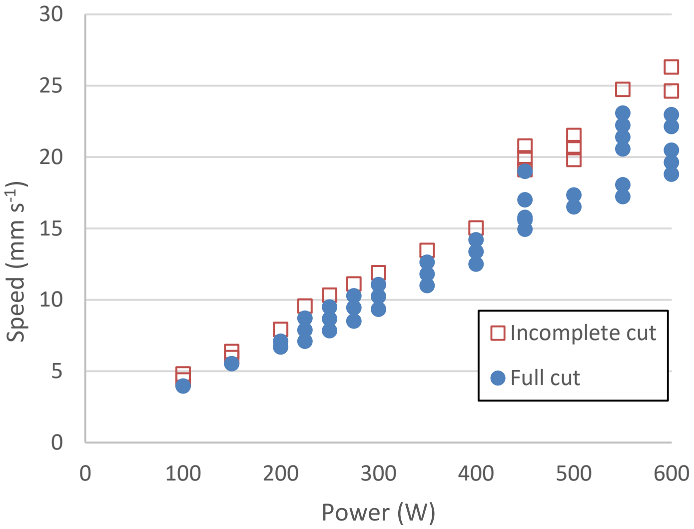

Fig. 4. Results from cuts made in amnion in glass sandwich showing parameter combinations that achieved full or incomplete cuts.

Figure 4 shows the results achieved when cutting the amnion in the glass sandwich. Here, in order to ensure that a robust process window is established, "full cut" indicates that complete cutting was achieved for each of three cuts made with the indicated parameters. The process window was established by fixing the laser power and incrementally changing the material translation speed until full cutting was no longer achieved. Again, as power increases, the maximum cutting speed achievable also increases. There is an approximately linear increase in maximum cutting speed with power: at 300 W maximum speeds of approximately 10 mm s^{-1} are seen whereas this double to approximately 20 mm s^{-1} when the power is double to 600 W.

It is clear that using the glass sandwich set up has significantly decreased the cutting speeds that can be achieved for any given power level: at 600 W speeds of 90 mm s^{-1} were seen in the trial cuts but this decreased to approximately 20 mm s^{-1} for the glass sandwich. This is simply due to the laser being used out of focus in the glass sandwich cuts, meaning a larger spot size and consequently lower power densities for the same power compared to the trial cuts.

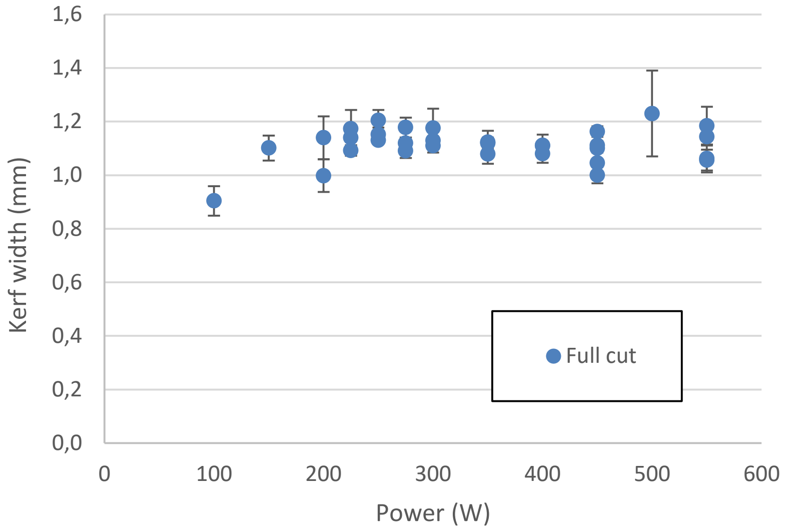

Fig. 5. Measured kerf widths for full cuts made in amnion material in the glass sandwich. Error bars indicate one standard deviation.

Figure 5 shows that the measured kerf width is approximately constant at about 1.1 mm for all full cuts achieved in the amnion material within the glass sandwich. Figure 6 clearly shows that there is much more scatter in the measured HAZ results. The HAZ varies between 22 and 55 µm across the range of powers used. It is also notable, from the error bars, that there is significant variation in the HAZ for any given parameter combination. This may be partly due to the somewhat subjective nature of HAZ measurement, which depends on a judgement being made as to where the HAZ colour change ends. The inherent variation in the amnion material will also have contributed to this variation. However, it must be noted that the HAZ only extends over a few tens of micrometers either side of an approximately 1 mm wide kerf, i.e. the HAZ is proportionally small.

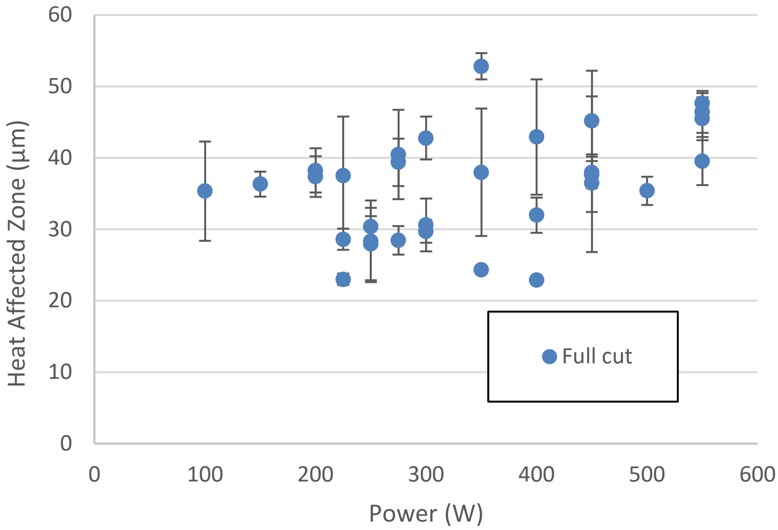

Fig. 6. Measured HAZ for full cuts made in amnion material in the glass sandwich. Error bars indicate one standard deviation.

4. Conclusions

- Laser cutting of amnion material within a sterile glass sandwich with a Nd:YAG fibre laser has been demonstrated.
- A robust process window has been established which takes into account the natural variation inherent in the amnion material.
- There is an approximately linear relationship between the maximum cutting speed and the laser power used.
- The maximum cutting speed achieved for amnion material in the glass sandwich was 23 mm s^{-1}, for a power of 600 W.
- For the cutting parameters used, kerf widths of 1.1 mm were achieved, with a HAZ of up to 55 µm extending either side of the cut.

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