REPORT: Superalloy drilling by Laser MicroJet®

for attention of Anonymous

by Ronan Martin, Synova SA

TASK

The Laser MicroJet® technology has been tested to drill coated and uncoated superalloy plates. The aim of these tests was to drill holes and run some ablation tests. Some holes were drilled as straight holes while some others had a trapezoidal diffuser shape at the top.

SAMPLE DESCRIPTION

Four superalloy plates were provided for the tests: two with coating and two without.

UNCOATED PLATES	Material	superalloy
	Thickness	2mm
COATED PLATES	Material	superalloy with ceramic coating
	Thickness	2.5mm

Using these samples, we were requested to:

- drill holes with a diameter of about 0.5mm;
- engrave a wedge shape of dimensions 3 x 1 x 0.3 mm^3;
- remove 0.5 mm^3 of material in order to calculate the ablation rate.

In addition, we also engraved a few holes with trapezoidal diffusers.

Release of application report			
Project Leader		Responsible Application Group	
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Date:	06.11.2015	Date:	06.11.2015
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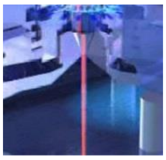
PROCESS: INSTRUMENT & TEST PARAMETERS

For these experiments, an LCS 150 equipped with a frequency-doubled Nd:YAG laser has been used as the machine configuration in our lab. These machines allow cutting most ceramics and any kind of metal.

Major advantages of the Laser MicroJet® technology with regards to your application are:

- Cutting of non-conductive materials
- Cutting of arbitrary shapes
- Low heat damage to the material
- Possibility to avoid backstrike damage by blowing air or controlling the jet stability length

The table below summarizes the optimized parameters used in the experiments. More details will follow in the result section.

	**SYSTEM**	Machine type Optical head type Diaphragm	LCS 150 Compact Brass, 0.1mm
	**MICROJET PARAMETERS**	Nozzle diameter	50 *µm*
		MicroJet® diameter	42 *µm*
		Water pressure	180 *bar*
		Working distance	10 *mm*
		Assist gas	He, 0.9 *L/min*
	**LASER PARAMETERS**	Laser type	L202G (one cavity only)
		Wavelength	532 *nm*
		Pulse frequency	12 *kHz*
		Power in jet	Engraving: 14 *W* Drilling: 29 *W* Wedge ablation: 7 *W*
		Pulse width	Engraving: 450 *ns* Drilling: 300 *ns* Wedge ablation: 500 *ns*

A diaphragm (small metal plate put below the nozzle) was used in order to protect the nozzle from particle contamination and from water-jet instabilities due to feedback. This is a standard procedure in this type of application.

The sample was held with an angle of 25° compared to the jet in order to process the holes, while it was held perpendicular to the jet for the ablation tests.

The holes were drilled using a double-spiral path, as illustrated in Figure 1, where the path first follows the blue arrows (inwards) and then red arrows (outwards), and is repeated as many times as necessary. The 40µm step value given in the table above corresponds to the distance indicated by the black double arrow.

A spiral path is necessary to drill deep holes with a high aspect ratio. In this case, the hole begins to be cut through in the center, and gets progressively wider on the backside, minimizing the taper. In order to optimize the process time on the final passes which ensure that the taper is minimized, it is possible to use a modified spiral paths, where the central part is omitted.

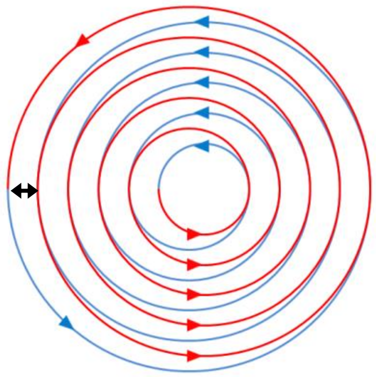


FIGURE 1: Illustration of the path used for spiral drilling, following first the blue arrows, then the red ones..

In order to limit heat damage on the top surface of the material, especially in the ceramic coating, an engraving process was performed before the drilling, with a lower power and a higher motion speed.

For the straight holes, the engraving path was also a double spiral, with a slightly larger diameter than the hole. (The difference was 80µm. It would be possible to increase this diameter even more in order to make a kind of conical diffuser.)

The trapezoidal diffuser shapes were also engraved before hole drilling. We wrote NC programs that simulate the slicing of a diffuser shape into several layers. Because there is no focal point in our technology, the slicing can be done parallel to the surface of the material. Each layer has the shape of a trapeze. The layers become successively smaller as seen in Figure 2. The amount by which each layer decreases is inversely proportional to the number of layers. Each layer is engraved by offset filling, as shown in Figure 3.

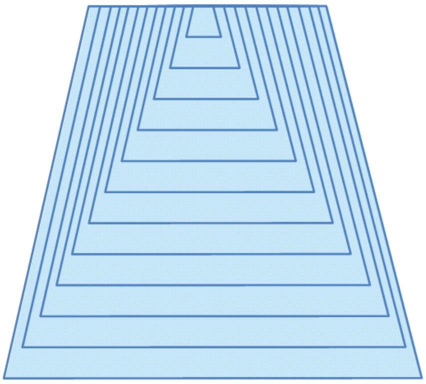


FIGURE 2: Illustration of the variation of the size of successive layers

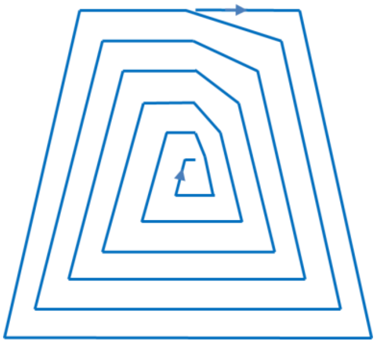


FIGURE 3: Illustration of the offset filling used in one layer

RESULTS - OVERVIEW

Two samples (one uncoated and one coated) were processed with the optimized parameters, as seen below in Figures 4 and 5. More details will follow in each respective result section.

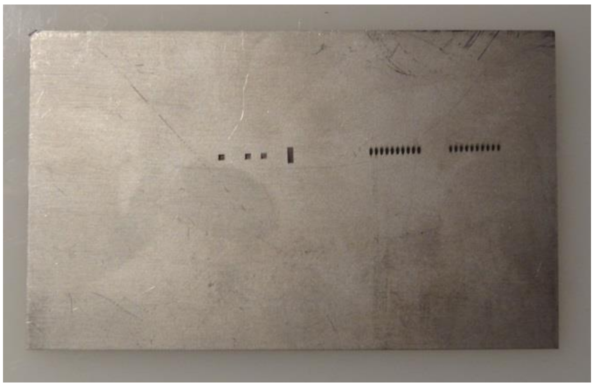


FIGURE 4: Photo of the uncoated sample.

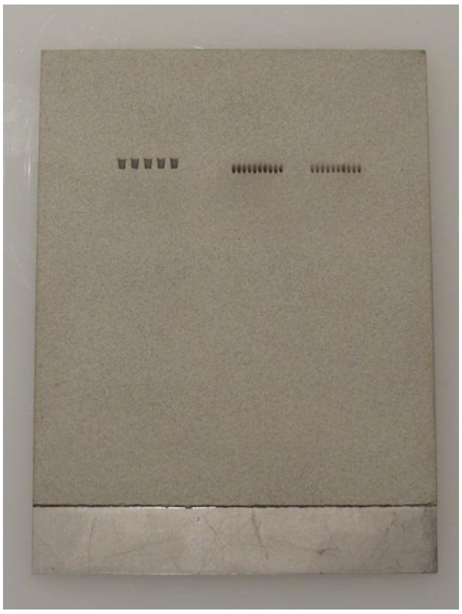


FIGURE 5: Photo of the coated sample.

In the **uncoated sample** (shown in Figure 4), two groups of ten straight holes were drilled, with diameters of about 0.4mm and 0.5mm. A lower power and higher motion speed was used for the first passes, in order to minimize thermal damage on the front side.

As requested, we also ablated a wedge shape (which appears as a rectangle on the picture above), with a length of 3mm, a width of 1mm and a depth of 0.3mm on one short side.

We also ran ablation tests in order to remove about 0.5mm^3, with the two laser parameters used for hole drilling. We chose to ablate 1mm squares. The two squares close to the wedge were ablated using the lower power, and the last square using the higher power. Two squares were processed with the lower power because of a mistake in the NC program of the first square, which created a rough wedge shape instead of a flat bottom.

In the **coated sample** (shown in Figure 5), we drilled the same two groups of straight holes as in the uncoated sample.

In addition to these straight holes, five diffuser holes were processed, with a diameter of 0.4mm.

RESULTS – HOLE DRILLING

The table below presents the parameters used for all the holes.

There are a few important things to note:

- After breakthrough occurs in the center of the hole, it is necessary to make a few more passes in order to get a cylindrical hole. In our case we nearly doubled the number of passes, but the required total number of passes should be a bit lower than that, depending on the requirements on the taper.
- After breakthrough, the spiral path can also be optimized so that it omits the center of the hole, and drill only where necessary. This would decrease the process time.
- The difference of diameter between the top and the bottom of the holes was about 40µm. It looks bigger than that on the pictures below, but the preliminary engraved part at the top of the straight hole should not be taken into account, because it has a diameter larger by 80µm.
- The speed used for engraving was relatively high in order to minimize heat damage, but the machine configuration that we used for these tests could not guarantee a perfect geometrical precision at such speeds. That is why while the drilled holes have a well-defined shape on the back side, the front side is quite irregular in comparison. As attested by the geometry on the back side, this is not due to the process, but just to the machine axes.

		Uncoated plate		**Coated plate**		
		0.4mm straight	**0.5mm straight**	**0.4mm straight**	**0.5mm straight**	**0.4mm diffuser**
Engraving	**Motion speed**	5 mm/s				15 mm/s
	Step	40 µm				
	Passes / diffuser layers	2 passes		5 passes		40 layers
	Engraving time	**5 s**	**7 s**	**11 s**	**15 s**	**63 s**
Drilling	**Motion speed**	3 mm/s				
	Step	40 µm				
	Passes at breakthrough	13	8	13	8	8
	Total passes	20	15	20	15	15
	Time at breakthrough	**≈ 25 s**				**16 s**
	Total drilling time (not optimized)	**43 s**	**48 s**	**43 s**	**48 s**	**32 s**

The following pictures show the quality that was obtained in the coated and uncoated plates. There is very little heat damage, with nearly no recast in the metal, and no crack or delamination in the coating. The shape is well defined on the backside, and would be the same on the front side if the used machine prototype had had precise enough axes.

FIGURE 6 A&B: Microscope images of the front side of the holes drilled in the uncoated plate (left: 0.5mm, right: 0.4mm, engraved part80 µm larger)

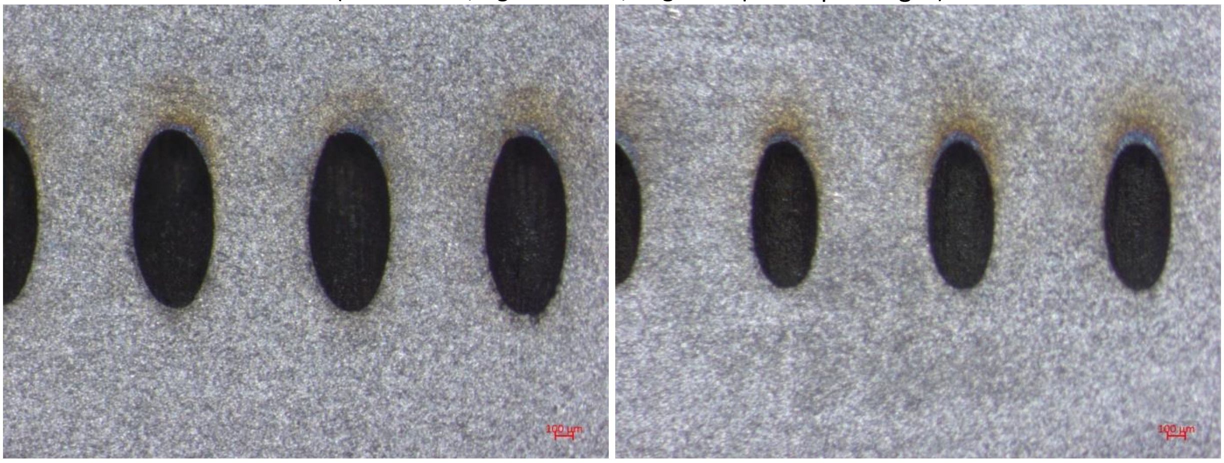


FIGURE 6 C&D: Microscope images of the back side of the holes drilled in the uncoated plate (left: 0.5mm, right: 0.4mm)

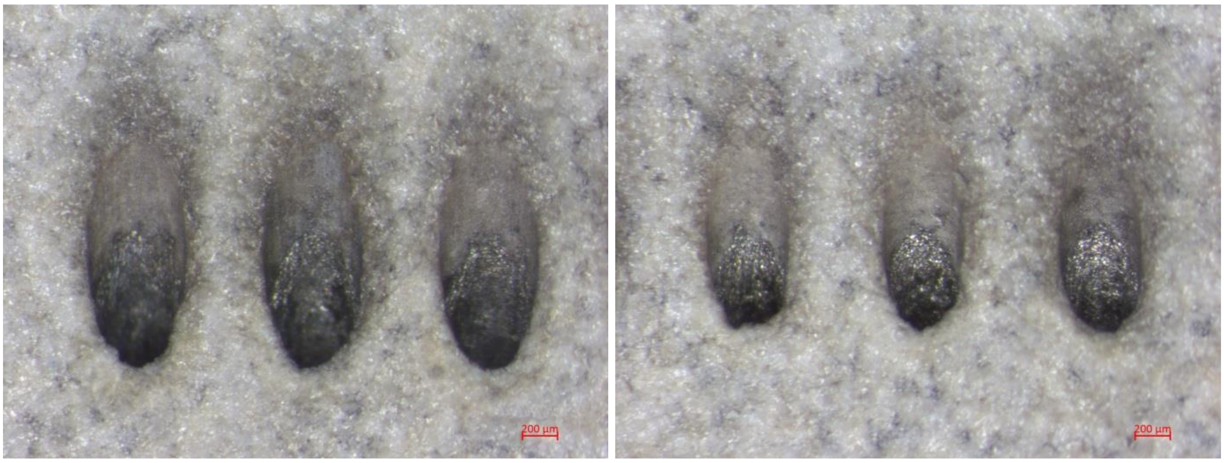


FIGURE 7 A&B: Microscope images of the front side of the holes drilled in the coated plate (left: 0.5mm, right: 0.4mm, engraved part 80µm larger)

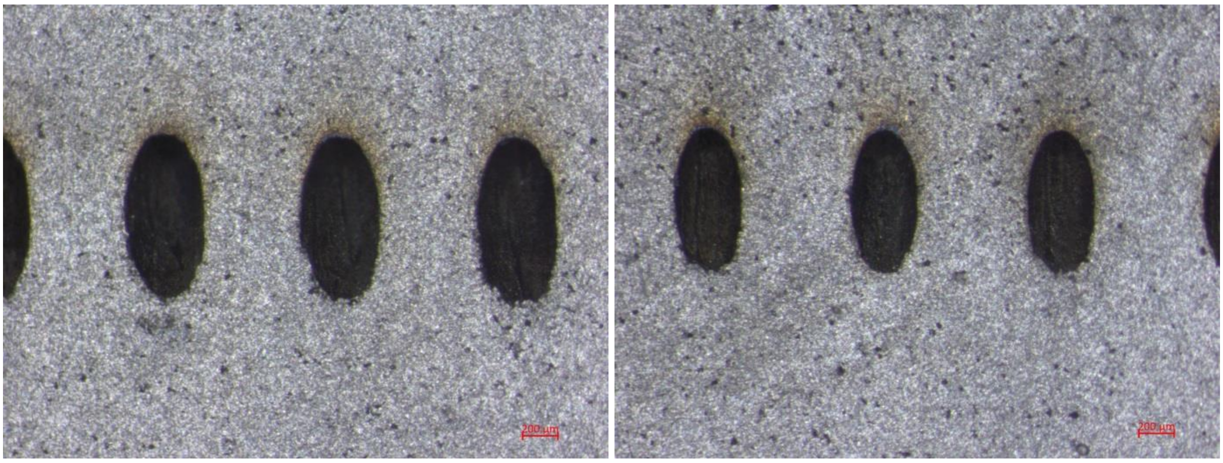


FIGURE 7 C&D: Microscope images of the front side of the holes drilled in the coated plate (left: 0.5mm, right: 0.4mm)

FIGURE 8 A&B: Microscope images of the front side of the diffuser holes drilled in the coated plate

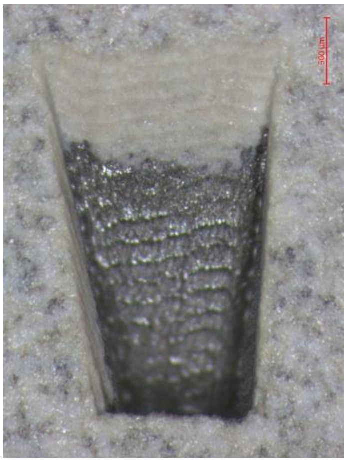


FIGURE 8C: Close-up on a diffuser

FIGURE 8C: Microscope image of the back side of a diffuser hole (0.4mm diameter)

RESULTS – ABLATION

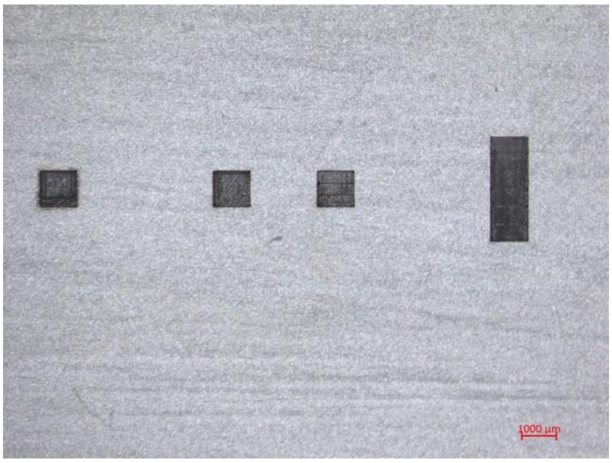


FIGURE 9: Close-up on the ablated test

The table below presents the parameters used for all the ablation tests. The calculated ablation rate values are to take with caution, because, on such small shapes, the edges can have some effect on the stability of the water jet, and the speed cannot be kept constant. The sharp angles on the path can also create some instability, as it seems to have happened on square engraved using the drilling power (i.e. the leftmost square on Figure 9).

	Wedge (7W in the jet)	**Square (engraving power: 14W)**	**Square (drilling power: 29W)**
Motion speed	30 mm/s	10 mm/s	
Step	20 µm	40 µm	
Layers	6	3	2
Time	25 s	17 s	12 s
Ablation rate	2.2 mm^3/min	1.8 mm^3/min	2.5 mm^3/min

CONCLUSION

The drilling of coated and uncoated superalloy was investigated on a Synova LCS150. This machine is based on the Laser MicroJet® technology and combines the advantages of a high-energy pulsed laser with a hair-thin water jet. While the laser is used for material ablation, the water jet is used for guiding the laser light, cooling the edges and preventing the sample from particle contamination.

In these tests, we showed that we can:

- Drill both the metal and the ceramic coating with extremely limited heat damage.
- Reach a diameter down to 0.4mm.
- Engrave diffuser shapes.

We thank you for your interest in our technology. We will contact you soon to receive your feedback and the analysis of these results and to discuss the further steps.