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APPLICATION REPORT

Report No: 1310-6
Sample No: N.A.

CONFIDENTIAL

REPORT: Cooling-hole drilling in nickel superalloy by Laser MicroJet®

for attention of Anonymous

by Ronan Martin, Synova SA

TASK

The Laser MicroJet® technology has been tested on ceramic-coated nickel-superalloy plates. The aim was to drill different holes with diffuser features.

SAMPLE DESCRIPTION AND PREPARATION

PLATES	Material	Ceramic-coated nickel superalloy
	Thickness	4 *mm*
	Quantity	3 *pcs*

The objective was to drill several rows of holes with different diameters: 20mil, 15mil and 10mil, with an angle of 30° between the water jet and the plate's surface. A diffuser feature had also to be grooved on the ceramic-coated side, as illustrated in Figure 1.

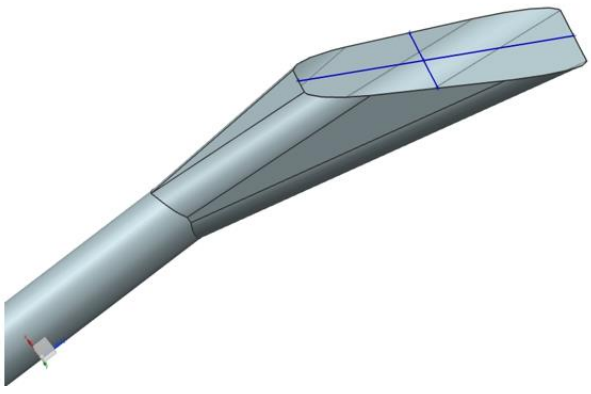

FIGURE 1: Example of hole with diffuser feature

Release of application report			
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Date:	28.10.2013	Date:	29.10.2013
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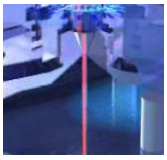
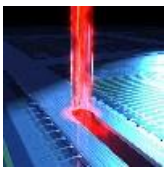
PROCESS: INSTRUMENT & TEST PARAMETERS

For these experiments, an LCS 300 equipped with a frequency-doubled Q-switched Nd:YAG laser has been used as the machine configuration in our lab. It is a manually loaded machine, allowing cutting and drilling any kind of metal piece.

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

- Cutting of non-conductive materials
- Advantageous process rates
- Cutting of arbitrary shapes
- Low heat damage to the material

In the table below, the optimized processing parameters used in the experiments are summarized. More details concerning each sample are given in their respective sections.

	**SYSTEM**	Machine type	LCS 300
	**MICROJET PARAMETERS** 15mil / 20mil	Nozzle diameter	50 / 60 *µm*
		MicroJet diameter	42 / 50 *µm*
		Water pressure	200 *bar*
		Working distance	12 *mm*
		Assist gas	He (0.9 *L/min*)
	**LASER PARAMETERS** 15mil / 20mil	Laser type	L202G (one cavity)
		Wavelength	532 *nm*
		Frequency	10 *kHz*
		Internal power for grooving	20 / 30 *W*
		Internal power for drilling	35 / 60 *W*
		Power transmission to the jet	60 – 65 *%*
	**CUTTING PARAMETERS** 15mil / 20mil	Grooving motion speed	50 *mm/s*
		Drilling motion speed	1 / 2 *mm/s*
		Step for grooving and drilling	25 / 30 *µm*
		Grooving time	45 / 55 *s*
		Drilling time	155 / 120 *s*

In blue the parameters for 15mil holes and in red the parameters for 20mil holes.

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 plates were glued on a goniometer set at an angle of 30°.

The diffuser shape was processed before hole drilling. We wrote an NC program that simulates the slicing of a diffuser shape into several layers. Because there is no focal point in our technology, the slicing is parallel to the surface of the material.

Each layer has the shape of a rounded trapeze. The layers become successively smaller (while the corner radius is kept constant) as seen in Figure 2A. The amount by which each layer decreases is inversely proportional to the number of layers.

Each layer is grooved by offset filling, as shown in Figure 2B, with a step of half the nozzle diameter (i.e. 30µm or 25µm).

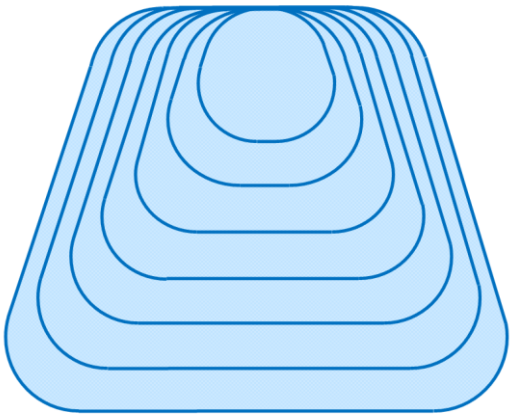


FIGURE 2A: Variation of the size of successive layers

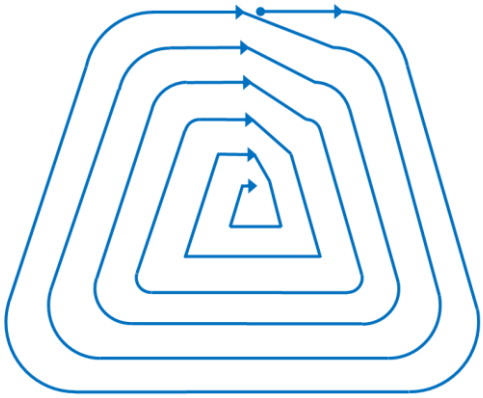


FIGURE 2B: Offset filling in one layer

After processing the diffuser, the holes were drilled using a double-spiral path, as illustrated in Figure 3, where the path first follows the blue arrows (inwards) and then red arrows (outwards), and is repeated as many times as necessary. The 30µm or 25µm step value given in the table above corresponds to the distance indicated by the black double arrow. It corresponds to half of the nozzle diameter.

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. This method also ensures that no part can fall inside the turbine bucket.

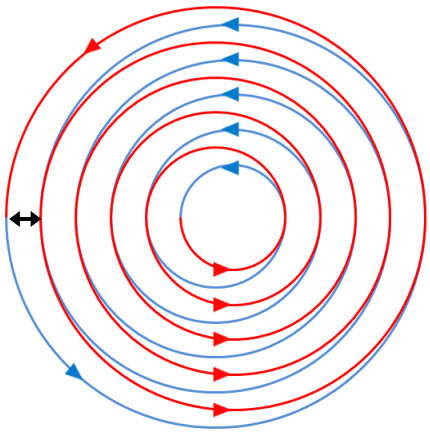


FIGURE 3: Illustration of the path used for spiral drilling, following first the blue arrows, then the red ones.

RESULTS

One plate was used for preliminary tests. These tests were done with three nozzle diameters: 60µm, 50µm and 40µm. The 60µm nozzle allowed drilling the 20mil holes easily, but not the 15mil holes. Switching to a 50µm nozzle allowed drilling 15mil holes, but not smaller ones.

We also made an attempt for 10mil holes with a 40µm nozzle on another machine (LCS 150), but it was not successful. We had to use this machine because it had a smaller laser fiber (100µm instead of 200µm) that gave us the smaller laser spot size that is required for such a small nozzle. (For reference, we used an internal power up to 25W at 6kHz, and 36W at 10kHz.)

In the two other plates, we processed two rows of ten holes each. The hole diameter was 20mil (0.508mm) in one plate and 0.15mil (0.381mm) in the other. The 20mil holes were processed with a 60µm nozzle, and the 15mil holes with a 50µm nozzle. We can see on Figure 3B that two attempts were needed for the 20mil holes. As you would observe, this happened because the plate moved during the process, due to a fixation problem. The plate had therefore to be re-glued before the process was restarted on the opposite side of the plate.

It is worth noticing that the diffuser decreases the effective depth for hole drilling. This allows processing the hole faster, or even processing holes in a thickness larger than otherwise possible.

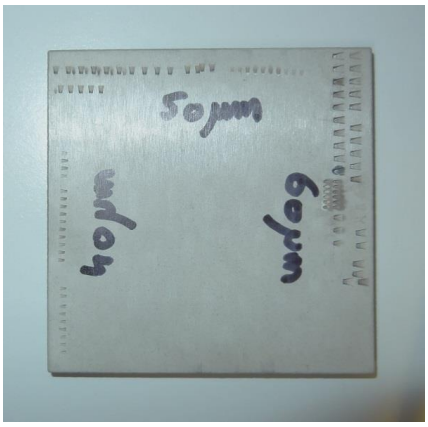


FIGURE 3A: Plate used for preliminary tests, involving three different nozzle diameters.

FIGURE 3B: Plate used for the 20mil holes (60µm nozzle). A fixation issue occurred for the holes at the bottom (red highlight).

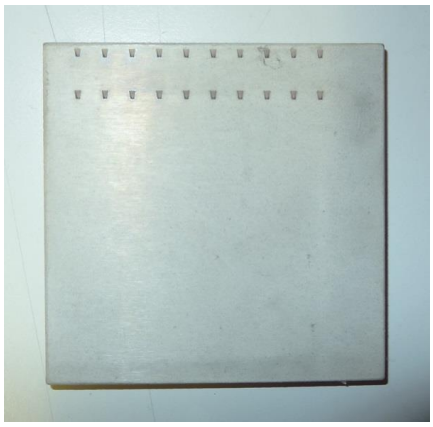
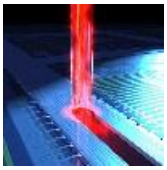


FIGURE 3C: Plate used for the 15mil holes (50µm nozzle).

- **20mil HOLES**

The cutting parameters used for the twenty 20mil holes are presented in the table below.

	**CUTTING PARAMETERS diffuser grooving / hole drilling**	Processing time per hole	55 + 120	*s*
		Motion speed	50 / 2	*mm/s*
		Number of layers	80	
		Number of double spirals	20	
		Step for grooving and drilling	30	*µm*

Please note that the process time could be decreased easily with further optimization. For example, the drilling process involved 20 double spirals in order to ensure to minimize the taper, although about 10 were enough to drill through the center of the hole. In a real production, the NC program should be modified so that, after the hole is though in its center, the path does not run in the center anymore.

The good quality can be observed in the images below. Damage in the coating seems minor, as well as the heat damage in the metal. If an even higher quality proves to be necessary, we could use less power at the beginning of the grooving, and increase the power more gradually.

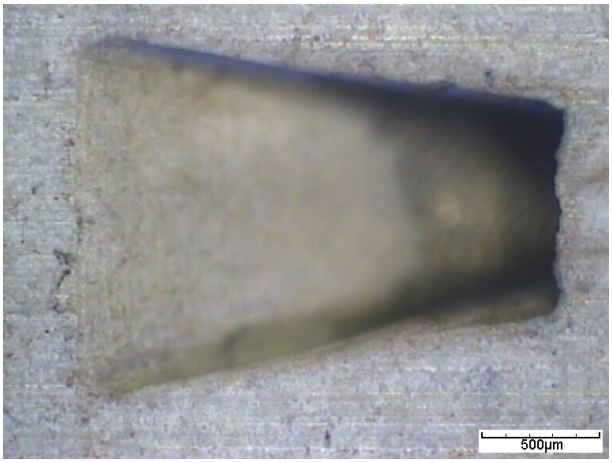


FIGURE 4A: Front side of a 20mil hole

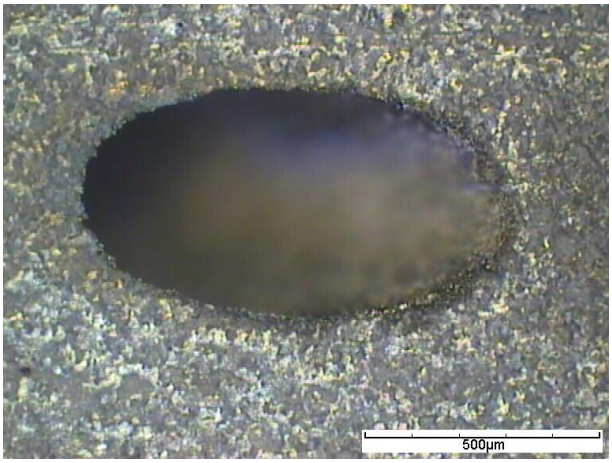
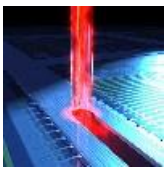


FIGURE 4B: Back side of a 20mil hole (close up)

It was noticed during your visit that the ceramic coating in one of the hole rows appeared more dirty than the other. As was explained, this is because metal particles that are expelled from the holes may deposit on previously processed diffusers.

- **15mil HOLES**

The cutting parameters used for the twenty 15mil holes are presented in the table below. In order to ensure that the hole had a regular shape on the back side, an additional "finishing" process was used, also using a double-spiral path, but with a lower speed and a higher power than for drilling.

	**CUTTING PARAMETERS** **Grooving / drilling / finishing**	Processing time per hole	45 + 155 + 33	*s*
		Motion speed	50 / 1 / 0.5	*mm/s*
		Number of layers	80	
		Number of double spirals	20 + 3	
		Step for grooving and drilling	25	*µm*

The quality is again very good, as in the previous holes.

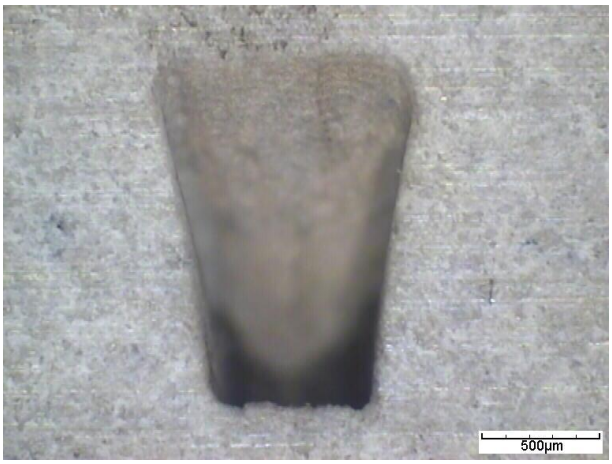


FIGURE 5A: Front side of a 15mil hole

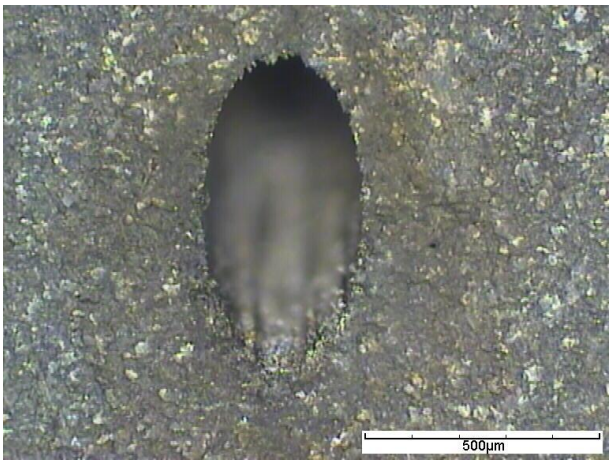


FIGURE 5B: Back side of a 15mil hole (close up)

CONCLUSION

The drilling of cooling holes in a ceramic-coated nickel superalloy was investigated on a Synova LCS300. 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, advantages that are essential for cutting and grooving metals with high quality.

In these tests, the feasibility of drilling cooling holes with diffusers in turbine buckets was demonstrated. We processed:

- two sets of twenty holes, with a diameter of either 20mil (0.508mm) or 15mil (0.381mm)
- with their respective diffusers (preliminary grooved with a lower power)
- with an angle of 30° between the water jet and the sample's surface
- in a material thickness of 4mm.

The respective process times of the 20mil holes and 15mil holes were 175s and 233s, and could be decreased by optimizing the process strategy, as well as the laser parameters.

A hole diameter below 15mil could not be reached during these tests, but this limit may be decreased in a next test iteration.

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.