SYNOVA Ch. Dent-d'Oche CH-1024 Ecublens Switzerland www.synova.ch	APPLICATION REPORT	Report No: 1312-9 Sample No: N.A. **CONFIDENTIAL**

REPORT: Hole & Diffuser Drilling by Laser-MicroJet®

for Anonymous

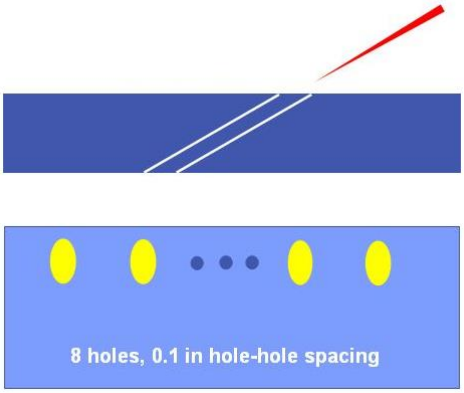
by Jerry Chera; Synova USA

TASK/OBJECTIVES

The Laser-MicroJet® technology has been tested for drilling Round round and shaped holes (diffusers) in R142 alloy, HS188 alloy with TBC coating, and HastX alloy with TBC coating.

Objective#1:

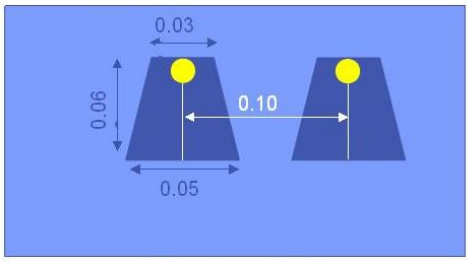
To drill one rows of 8 holes with diameter of 15mil, with an angle of 30° between the water jet and the plate's surface.



Release of application report			
	Project Leader		Responsible Application Group
Name:	Jerry Chera	Name:	Dr Benjamin Carron
Date:	12.20.2013	Date:	12.20.2013
Visum:	JC	Visum:	BC

Objective#2

Drill one row of 8 trapezoid shaped diffusers with the trailing hole dia of 15mil at an angle off 30° between the water jet and the plate's surface.



All units are inch
(tolerance ±.010)

SAMPLE DESCRIPTION AND PREPARATION

PLATE #1	Material	RS142 alloy
	Dimensions	1x2.4x0.06 inch
	Thickness	0.06 inch
	Quantity	2
PLATE #2	Material	HS188 alloy with TBC coating
	Dimensions	0.5x4x0.11 inch
	Thickness	0.08 inch + 0.03 inch TBC coating
	Quantity	2
PLATE #3	Material	HastX alloy
	Dimensions	4x6x0.1 inch
	Thickness	0.063 inch + 0.035 inch TBC coating
	Quantity	2

SAMPLE PICS

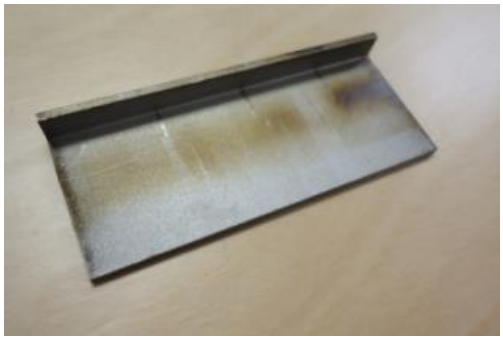


Fig. 1A – Plate #1

Fig. 1B – Plate #2

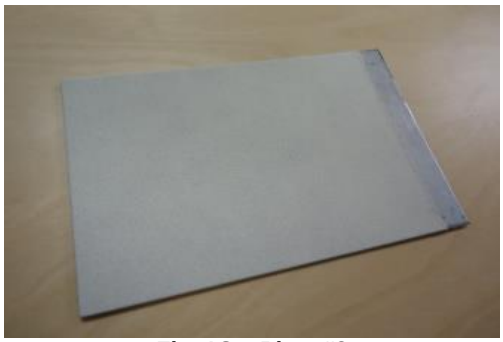


Fig. 1C – Plate #3

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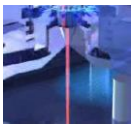
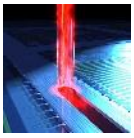
PROCESS: INSTRUMENT & TEST PARAMETERS

For these experiments, an LDS 200 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.

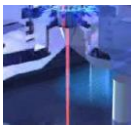
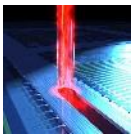
Major advantages of the Laser MicroJet technology with regards to your application are:

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

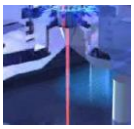
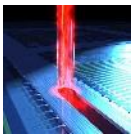
In the table below, the optimized processing parameters used in the experiments for **plate #1** are summarized:

	**SYSTEM**	Machine type	LDS200
	**MICROJET® PARAMETER**	Nozzle diameter	50 *µm*
		MicroJet® diameter	42 *µm*
		Water pressure	150 *bar*
		Assist gas	He (1.00 *L/min*)
		Working distance from diaphragm	7 *mm*
	**LASER PARAMETERS**	Laser type	LDP-200MQG
		Wavelength	532 *nm*
		Pulse frequency	10 *kHz*
		Internal power for drilling hole	36 *W*
		Internal power for trapezoid groove	8 *W*
		Pulse width for drilling hole	250 *ns*
		Pulse width for trapezoid groove	480 *ns*
		SHG temp.	31 *deg*
	**CUTTING PARAMETERS**	Speed for trapezoid groove	50 mm/sec
		Speed for hole drilling	1 mm/sec
		Step for grooving and drilling	25 *µm*
		Trapezoid grooving time	65 sec
		Hole Drilling time	60 sec

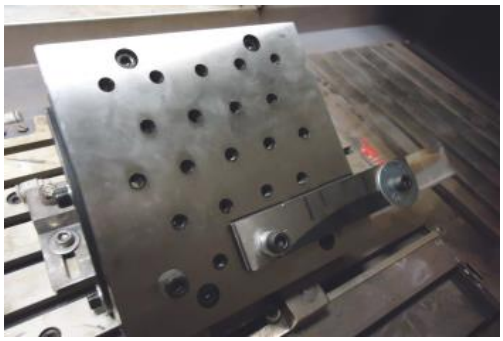
In the table below, the optimized processing parameters used in the experiments for **plate #2** are summarized:

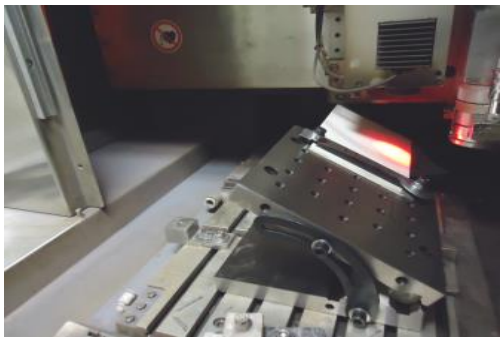
	**SYSTEM**	Machine type	LDS200
	**MICROJET® PARAMETER**	Nozzle diameter	50 *µm*
		MicroJet® diameter	42 *µm*
		Water pressure	150 *bar*
		Assist gas	He (1.00 *L/min*)
		Working distance from diaphragm	5 *mm*
	**LASER PARAMETERS**	Laser type	LDP-200MQG
		Wavelength	532 *nm*
		Pulse frequency	10 *kHz*
		Internal power for drilling hole	40 *W*
		Internal power for trapezoid groove	16 *W*
		Pulse width for drilling hole	250 *ns*
		Pulse width for trapezoid groove	490 *ns*
		SHG temp.	31 *deg*
	**CUTTING PARAMETERS**	Speed for trapezoid groove	50mm/sec
		Speed for hole drilling	1 mm/sec
		Step for grooving and drilling	25 *µm*
		Trapezoid grooving time	65 sec
		Hole Drilling time	60 sec

In the table below, the optimized processing parameters used in the experiments for **plate #3** are summarized:

	**SYSTEM**	Machine type	LDS200
	**MICROJET® PARAMETER**	Nozzle diameter	50 *µm*
		MicroJet® diameter	42 *µm*
		Water pressure	150 *bar*
		Assist gas	He (1.00 *L/min*)
		Working distance from diaphgram	5 *mm*
	**LASER PARAMETERS**	Laser type	LDP-200MQG
		Wavelength	532 *nm*
		Pulse frequency	10 *kHz*
		Internal power for drilling hole	40 *W*
		Internal power for trapezoid groove	16 *W*
		Pulse width for drilling hole	250 *ns*
		Pulse width for trapezoid groove	510 *ns*
		SHG temp.	31 *deg*
	**CUTTING PARAMETERS**	Speed for trapezoid groove	50mm/sec
		Speed for hole drilling	1 mm/sec
		Step for grooving and drilling	25 *µm*
		Trapezoid grooving time	65 sec
		Hole Drilling time	60 sec

The sample was held on to sine plate. This sine plate was set at an angle of 30°. The plate was clamped onto the chuck to for firm grip. Below are the setup pics.





STRATEGY:

The diffuser shape was processed before hole drilling. We used 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 (25µm)

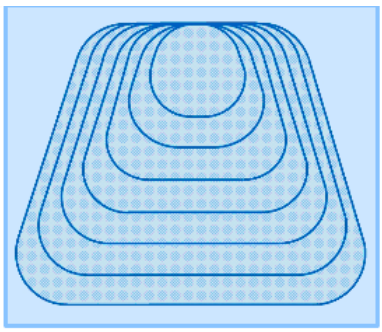


FIGURE 2A: Variation of the size of successive layers

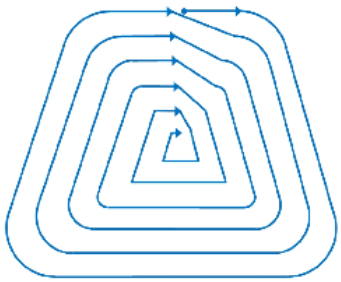


FIGURE 2B: Offset filling in one layer

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 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.

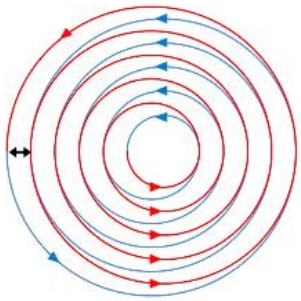


FIGURE 3: Illustration of the path used for spiral drilling, following first the blue arrows, then the red ones.

RESULTS

The following pics show the processed part. There are eight round holes and eight diffuser *Shapes (Trapezoids with trailing holes)*

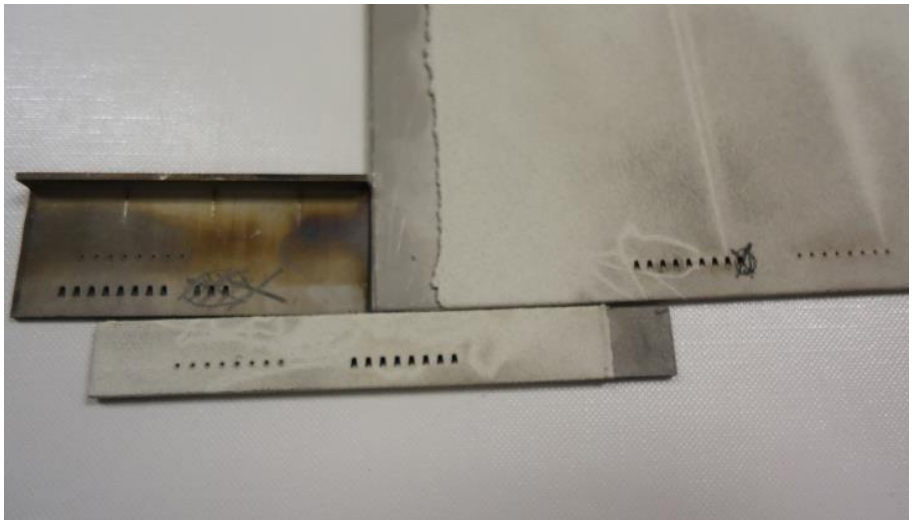


Fig. 4 – ***Please ignore the cuts indicated by crossed pencil marks.***

Microscopic Pictures:-

The following microscope pictures give an overview on the quality obtained with the Laser-Microjet® technology.

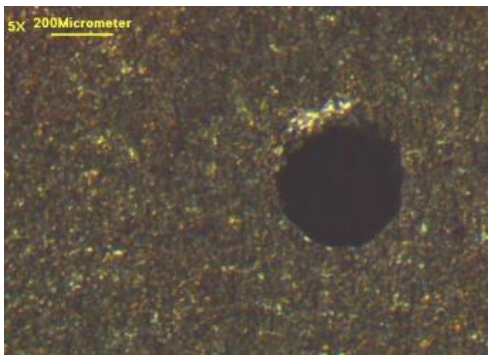


Fig 5: Front side of 15 MIL hole. Plate #1

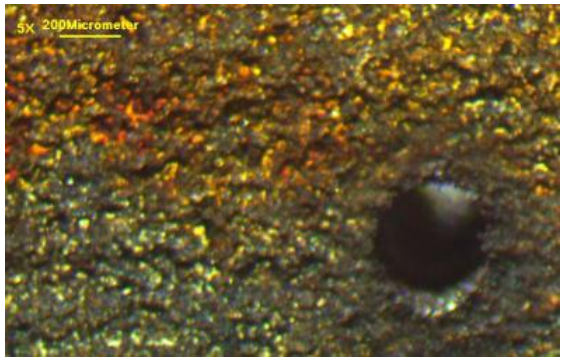


Fig 6: Back side of 15 MIL hole. Plate #1

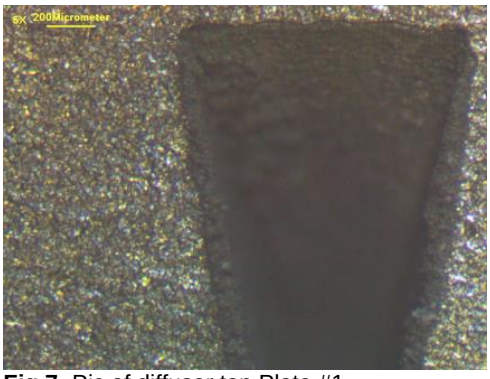


Fig 7: Pic of diffuser top Plate #1

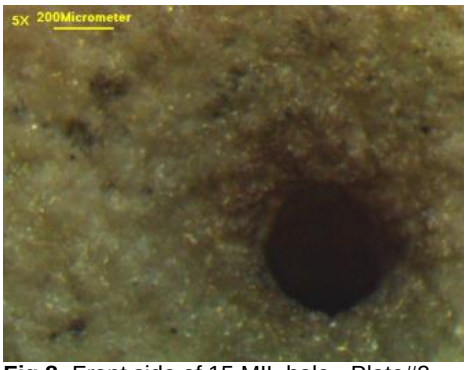


Fig 8: Front side of 15 MIL hole - Plate#2

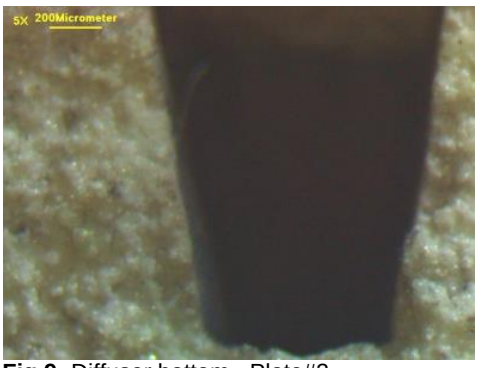


Fig 9: Diffuser bottom - Plate#2

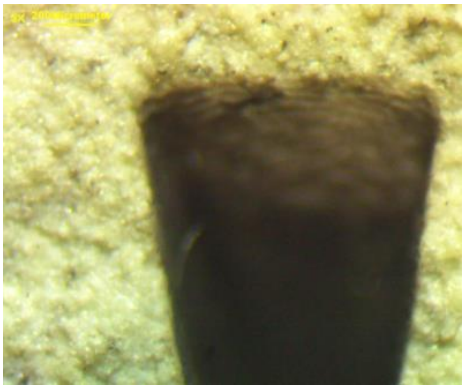


Fig 10: Diffuser top – Plate #2

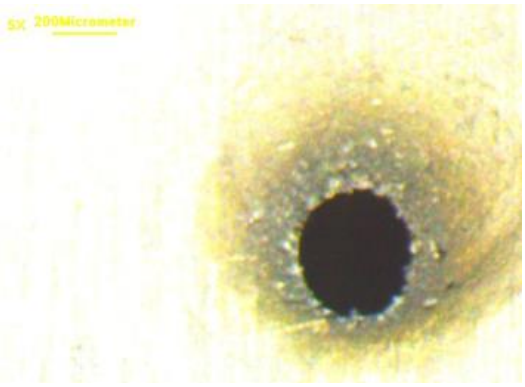


Fig 10: Back side of 15MIL hole – Plate #2

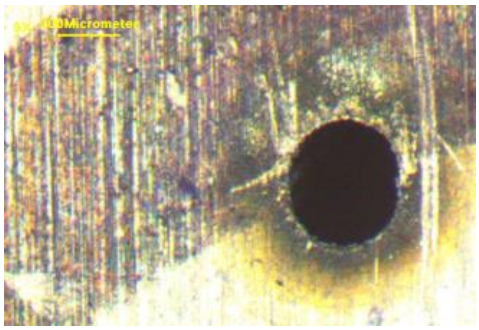


Fig 11: Back side of hole under diffuser – Plate #2

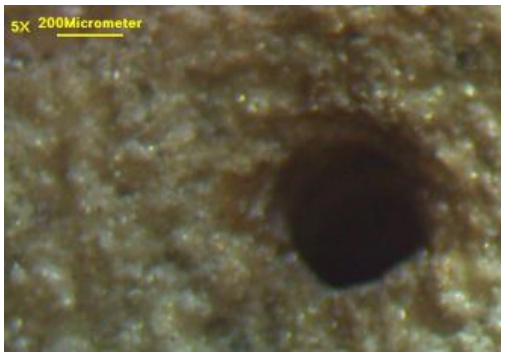


Fig 12: Front side 15 MIL hole – Plate #3

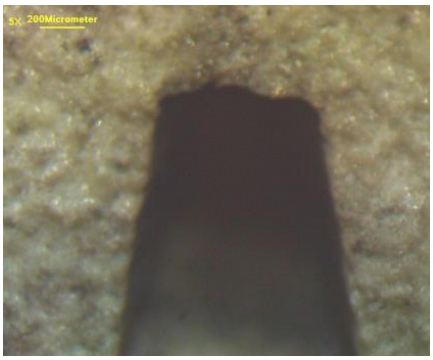


Fig 13: Diffuser top – Plate #3

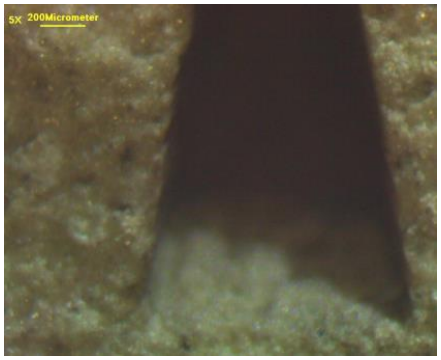


Fig 14: Diffuser bottom – Plate #3

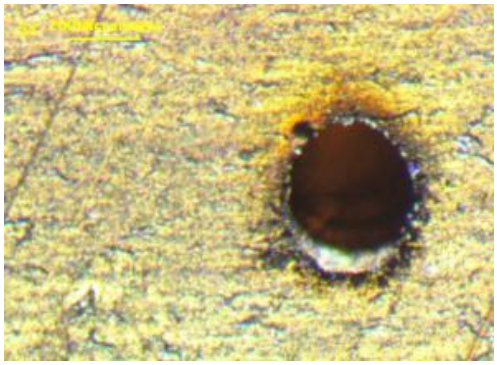


Fig 15: Back side hole top – Plate #3

One out of two pieces was used for preliminary tests. These tests were done with different laser power and speed settings to come up with most optimized parameters.

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.

There was some chipping observed at the TBC coating. This chipping can be further reduced by increasing the frequency for drilling through TBC and then reducing the frequency to drill through alloy in the same program.

Below are the processing times for each of the plates

Plate #1

The time to drill eight holes came was 6 mins and 7 secs
The time to groove eight trapezoids was 8 mins and 38 secs
Total time to create eight diffusers (trapezoids and than holes) is 12 mins and 10 secs.

Plate #2

The time to drill eight holes came was 6 mins and 7 secs
The time to groove eight trapezoids was 8 mins and 38 secs
Total time to create eight diffusers (trapezoids and than holes) is 11 mins and 50 secs.

Plate #3

The time to drill eight holes came was 6 mins and 50 secs
The time to groove eight trapezoids was 8 mins and 38 secs
Total time to create eight diffusers (trapezoids and than holes) is 11 mins and 50 secs.

CONCLUSION

Drillling of holes and diffuser on ceramic coated nickel superalloy was investigated on SYNOVA LDS200. This machine is based on the MicroJet® technology and combines the advantages of the 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 of such kind of materials with high quality.

A row of eight 15 MIL dia holes was drilled. The jet angle was kept at 30 degree with respect to the sample surface during these tests.

The process time and chipping on TBC coating can be further decreased by optimizing the process strategy, as well as adjusting laser parameters.

Finally, we thank you for your interest in our technology and we will wait for your feedback about the analysis of these results and to discuss with you the further steps to improve the process.