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REPORT: Drilling and grooving in various metals by Laser MicroJet®

for attention of Anonymous

by Ronan Martin, Synova SA

TASK

The Laser MicroJet® technology has been tested for drilling and drilling carious shapes in stainless steel, Inconel, a ceramic-coated nickel superalloy, and *ferro-titanit-C-spezial*. After the tests, the samples were taken back by the customer for evaluation, so the purpose of the present report is essentially to give a summary of the parameters used during the various tests for future reference.

PROCESS: INSTRUMENT & TEST PARAMETERS

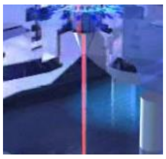
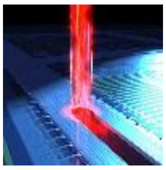
For these experiments, an LCS 300 equipped with a frequency-doubled Q-switched Nd:YAG laser with dual cavity has been used as the machine configuration in our lab. It is a manually loaded machine, allowing cutting and drilling any kind of metal part.

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
- Cutting in 3D, no focusing problem
- Low heat damage to the material
- Low contamination

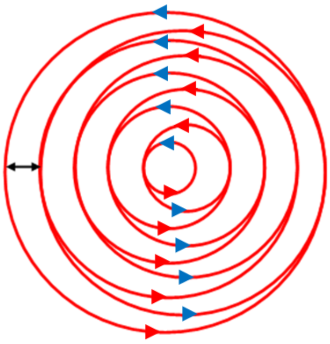
In the table below, the usual processing parameters used in the experiments are summarized. More details concerning each sample are given in their respective sections.

Release of application report			
Project Leader		Responsible Application Group	
Name:	Ronan Martin	Name:	Benjamin Carron
Date:	17.10.2012	Date:	17.10.2012
Visum:	ROM	Visum:	BC

	**SYSTEM**	Machine type	LCS 300	
	**MICROJET® PARAMETERS**	Nozzle diameter	60	*µm*
		MicroJet® diameter	50	*µm*
		Water pressure	200	*bar*
		Assist gas	He	
	**LASER PARAMETERS**	Laser type	L202G (one cavity)	
		Wavelength	532	*nm*
		Pulse frequency	14	*kHz*
		Average power	from 20 to 70	*W*
		Pulse width	about 130	*ns*
	**CUTTING PARAMETERS**	Working distance	10	*mm*
		Motion speed	1	*mm/s*
		Step for spiral drilling	30	*µm*

Most of the holes were drilled using a spiral path, as illustrated in the picture below, where the path first follows the red arrows (inwards) and then blue arrows (outwards). The 30µm 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.

Such a spiral path was found necessary to cut deep holes with a high aspect ratio, since a simple circle was not sufficient. In this case, the hole begins to be cut through in the center, and gets progressively wider on the backside, minimizing the taper. An advantage of this method is that it produces no waste part that could fall. A similar method was used in the case of square spirals.



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

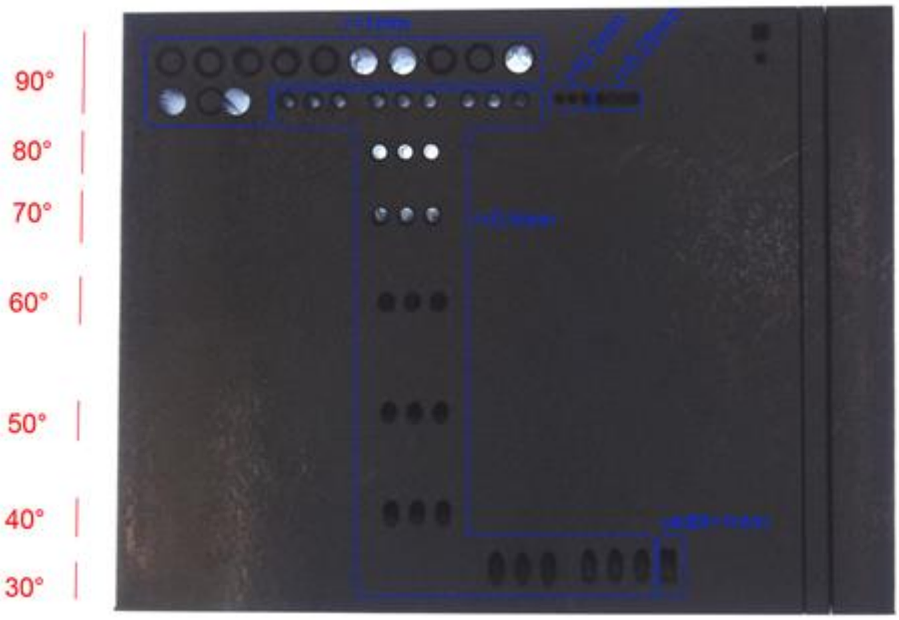
In order to protect the nozzle from contamination and waterjet instabilities, a diaphragm was used. This is a small metal sheet that is fixed under the coupling unit and where a small hole is drilled by the Laser MicroJet®.

RESULTS

- **STAINLESS STEEL**

Please note that the radius values are always the input ones. The actual radius is about 40µm larger.

The picture below presents all the different shapes processed in the steel sample. We drilled some series of holes with an incidence angle ranging from 90° to 30°, as indicated in the picture below, and grooved two lines and two squares.



PICTURE 2: Close-up on the processed part of the sample

HOLES CUT AT 90°

- Radius 1mm: Not very repeatedly cut. The first row was cut at 120W with an 80µm nozzle while the second row was cut at 70W with a 60µm nozzle. Instead of trepanation, we decided to use a double spiral path to process the next holes in order to increase the reliability. A diagram of the path is provided in the attachments. The step is 30µm.
- Radius 0.2mm: Not through
- Radius 0.25mm: Cut through at 60/70W, with 20 passes at 1mm/s (4min40s)
- Radius 0.5mm: 3 series of 3 holes, cut through at 70W, 60W and 50W, with 10 passes at 3mm/s (3min2s per hole)

HOLES CUT AT OTHER ANGLES (0.5mm radius, 60W)

- 80°: 3 holes cut with 10 passes at 3mm/s (3min2s per hole).
- 70°: Same.
- 60°: Same.
- 50°: Same.
- 40°: 3 holes cut with 12 passes at 3mm/s (3min36s per hole).
- 30°: The first 3 holes were not cut through because of nozzle damage. A new series of 3 holes was cut using a new nozzle a diaphragm. These 3 holes were cut with 14 passes at 3mm/s (4min12s per hole).

- 30°: A square hole was also processed, using a similar double squiral path with 30µm step. We used 16 double passes at 3mm/s (6min15s)

LINE GROOVING

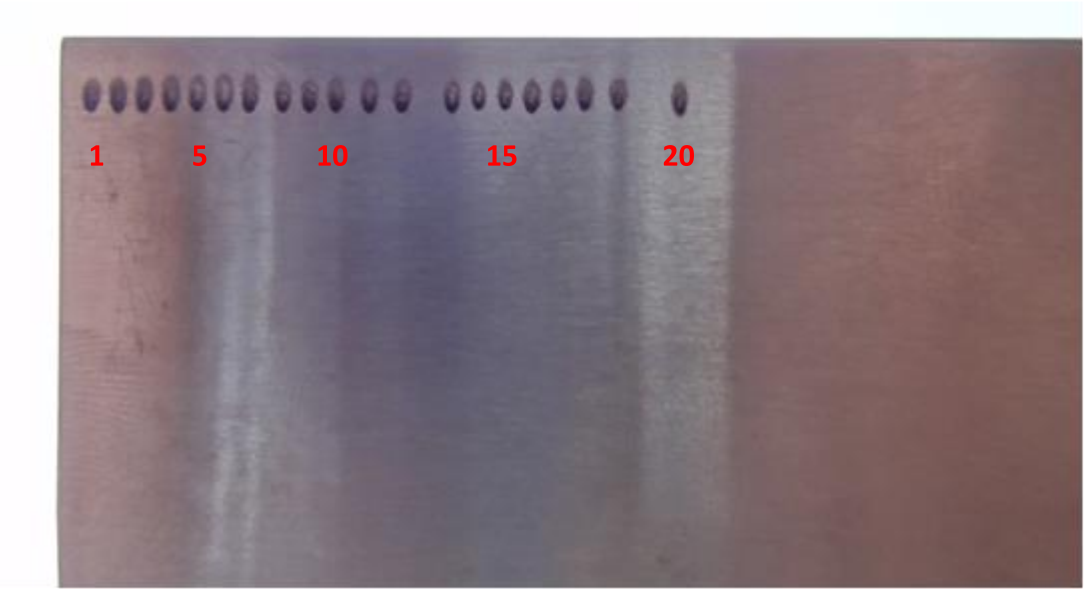
- One thick line grooved at 60W, actually processed using 5 lines with a 20µm offset, repeated 30 times, in 7min13s.
- Another line with the same parameters, except for a power of 30W.

SQUARE GROOVING

- The bigger groove (1mm width), was made using a similar double squiral path with 30µm step. We used 5 double passes at 3mm/s (1min58s).
- The smaller groove (0.5mm width), was processed with the same parameters (31s).

- **INCONEL SAMPLE**

20 holes were processed in order to optimize the process parameters for the next samples (ceramic-coated superalloy). The parameters for each hole are given in the table below. The holes are numbered from the left to the right as seen on the picture below.



PICTURE 3: Close-up on the processed part of the sample

Hole	Working distance (mm)	Radius (mm)	Power (W)	Frequency (kHz)	Pulse width (ns)	Speed (mm/s)	Passes	Time (s)
1	10	0.35	60	14	130	3	**10**	91
2	10	0.35	60	14	130	3	**12**	110
3	10	0.35	60	14	130	3	**14**	127
4	**15**	0.35	60	14	130	3	12	109
5	**20**	0.35	60	14	130	3	18	164
6	**25**	0.35	60	14	130	3	40	364
7	**5**	0.35	60	14	130	3	10	91
8	10	0.35	**50**	14	130	3	**12**	91
9	10	0.35	**50**	14	130	3	**14**	91
10	10	0.35	**30** **50** **70**	14	130	3	**5** **+14** **+6**	228
11	10	0.35	60?	14	130	**10**	42	110
12	10	0.35	58	14	**205**	3	12	110
13	10	0.35	**30**	8	205	3	20	182
14	10	0.25	**30**	8	205	3	40	188
15	10	0.25	**30**	8	205	1	15	211
16	10	0.35	**35**	8	205	3	14	127
17	10	0.25	**35**	8	205	3	30	141
18	10	0.25	**40**	8	205	3	30	141
19	10	0.25	**60**	14	130	3	30	141
20	10	0.25	**20** **40** **60** **60** **70**	14	130	**20** **10** **5** **3** **3**	**10** **+10** **+40** **+10** **+10**	246

- **CERAMIC-COATED SUPERALLOY**

Two samples were provided: one with a thicker coating, and the other with a thinner one. Series of four holes, with an incidence angle of 30°, were cut with two different diameters. The power was gradually increased to limit heat damage, especially in the coating, while still getting a regular shape down to the backside. As can be seen on the pictures below, this strategy worked pretty well.

Sample	Radius (mm)	Power (W)	Speed (mm/s)	Passes	Time / hole (s)
Thick coating	0.25	20/40/60/70	10/5/3/3	10/10/35/5	229
	0.35			10/10/10/5	248
Thin coating	0.25			5/5/25/5	163
	0.35			5/5/10/5	178

THICK COATING

PICTURE 4A: Microscope image of a hole with 0.25mm radius (frontside, thick coating)

PICTURE 4B: Microscope image of a hole with 0.35mm radius (frontside, thick coating)

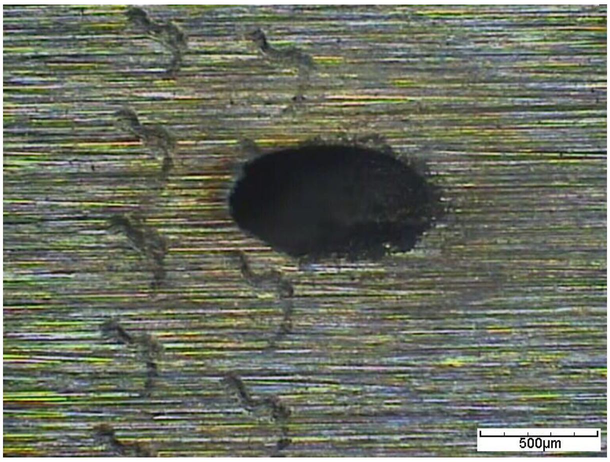
PICTURE 4C: Microscope image of a hole with 0.25mm radius (backside, thick coating)

PICTURE 4D: Microscope image of a hole with 0.35mm radius (backside, thick coating)

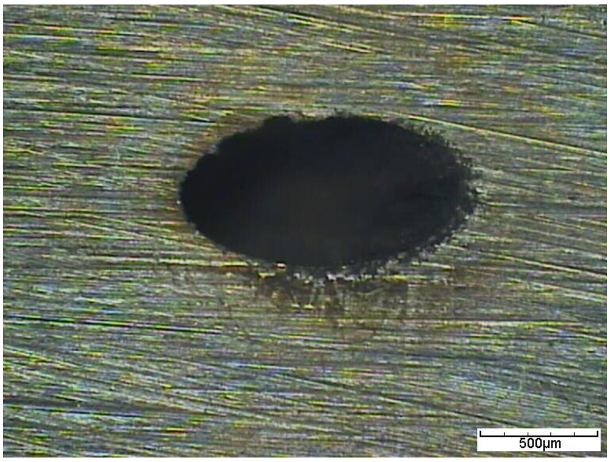
THIN COATING

PICTURE 5A: Microscope image of a hole with 0.25mm radius (frontside, thin coating)

PICTURE 5B: Microscope image of a hole with 0.35mm radius (frontside, thin coating)



PICTURE 5C: Microscope image of a hole with 0.25mm radius (backside, thin coating)



PICTURE 5D: Microscope image of a hole with 0.35mm radius (backside, thin coating)

- **FERRO-TITANIT-C-SPEZIAL**

Two squares and one line were grooved in *ferro-titanit-C-spezial*:

- The square on the left of the picture below was grooved at 20 W with 2 double squirals (as described previously) at a motion speed of 3mm/s (49s).
- The other square was grooved at 40 W with 1 double squiral at 3mm/s (96s).
- The 5mm line was grooved at 40W with 50 passes at 20mm/s (14s).

The heat damage was very limited, with no visible cracks.

PICTURE 5: Processed sample

CONCLUSION

The feasibility of drilling holes in turbine buckets was further investigated in a series of tests in the presence of the customer. Several samples were successfully processed, exploring and demonstrating the capabilities of Laser MicroJet® technology.

During these tests, we processed:

- in stainless steel: holes with various angles, as well as different grooves
- in inconel: 20 holes at 30° in order to optimize the process parameters
- in ceramic-coated superalloy: series of holes at 30° with a high quality
- in *ferro-titanit-C-spezial:* different grooves with low heat damage and no cracks

Since we were focused on the quality and reliability of the process, it is likely that the process time could be significantly decreased in further optimization steps.

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