REPORT: Superalloy drilling by Laser MicroJet®

for attention of Anonymous

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TASK

The Laser MicroJet® technology has been tested to drill a superalloy plate. The aim was to drill holes of different diameters with a good quality and without any damage done to the plate fixation (backstrike), and to demonstrate the feasibility of engraving diffusers.

SAMPLE DESCRIPTION AND PREPARATION

SUPERALLOY PLATE	Material	nickel-based superalloy
	Thickness	2mm

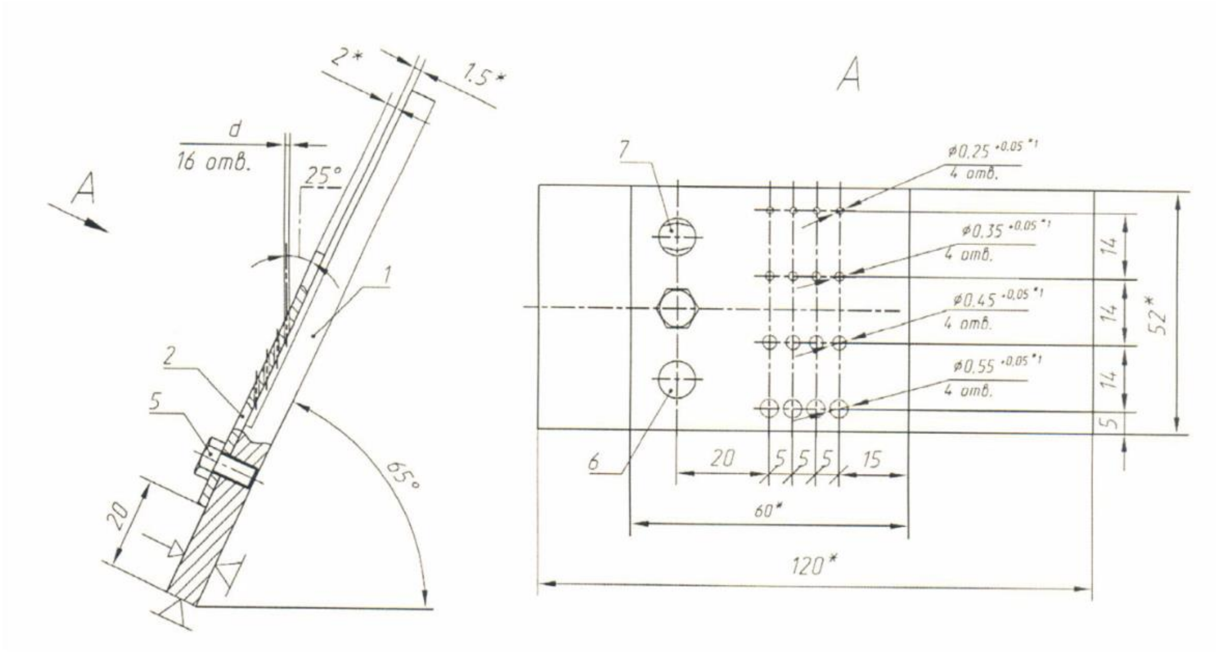

FIGURE A: Illustration of the sample and its fixation, with indications about the holes that had to be drilled.

Release of application report			
	Project Leader		Responsible Application Group
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Date:	11.09.2015	Date:	11.09.2015
Visum:	ROM	Visum:	BC

FIGURE B: Picture of the sample and its fixation

PROCESS: INSTRUMENT & TEST PARAMETERS

For these experiments, two LCS 150 equipped with a frequency-doubled Nd:YAG lasers have been used as the machine configurations 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:

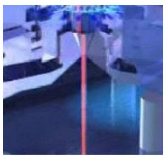
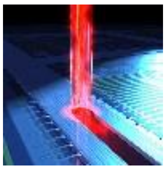
- Cutting of non-conductive materials
- Cutting of arbitrary shapes
- Low heat damage to the material
- Possibility to avoid backstrike damage by blowing air or controlling the jet stability length

The table below summarizes the optimized parameters used in the experiments.

Please note that, because the laser that was available had a high fiber diameter, the laser spot size would not allow using a nozzle with a diameter smaller than 50µm. With a smaller fiber, we could have used a 40µm nozzle, which would have allowed drilling the smallest diameters more easily.

Please also note that, in the case of the straight holes, since these tests aimed at showing that backstrike is avoidable, we adjusted the water pressure and the assist gas so that the water jet would be only as long as necessary and break up suddenly.

In the case of the diffusers, we used a more standard pressure of 300bar and helium as an assist gas, and then kept these parameters to drill the holes. Since the jet was much longer, we used air blowing to disrupt to jet below the holes.

	**SYSTEM**	Machine type	LCS 150	
		Optical head type	compact	
	**MICROJET® PARAMETERS**	Nozzle diameter	50	*µm*
		MicroJet® diameter	42	*µm*
		Water pressure	Straight holes: 160 Diffuser holes: 300	*bar* *bar*
		Assist gas	Straight holes: air, 0.9 Diffuser holes: He, 0.9	*L/min* *L/min*
	**LASER PARAMETERS**	Laser type	L202G (one cavity only)	
		Wavelength	532	*nm*
		Pulse frequency	10	*kHz*
		Power in jet	Hole drilling + finishing: 24 Diffuser engraving: 15	*W* *W*
	**CUTTING PARAMETERS**	Working distance	9	*mm*
		Motion speed	Hole drilling + finishing: 1 Diffuser engraving: 50	*mm/s* *mm/s*
		Steps	Hole drilling: 30 Hole finishing: 1 Diffuser engraving: 25	*µm* *µm* *µm*

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 for the shaped holes.

The holes were drilled using a double-spiral path, as illustrated in Figure C, where the path first follows the blue arrows (inwards) and then red arrows (outwards), and is repeated as many times as necessary. The 30µm 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, a modified spiral path can be used, where the central part is omitted (Figure D).

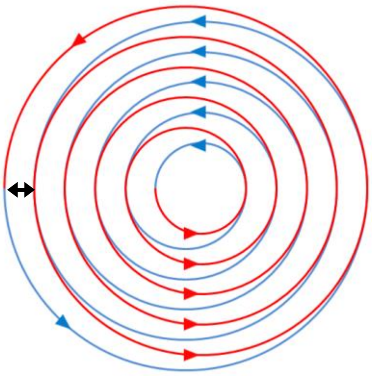


FIGURE C: Illustration of the path used for spiral drilling, following first the blue arrows, then the red ones..

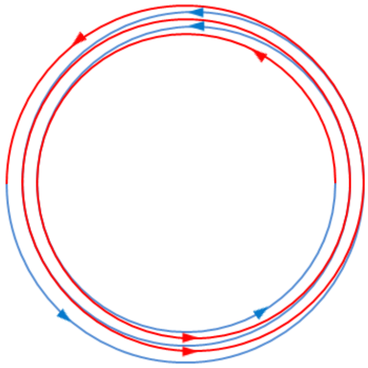


FIGURE D: Illustration of the path used for finishing, where the central part is omitted, and the spiral step is smaller.

The diffuser shapes were processed 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 E. 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 F, with a step of half the nozzle diameter.

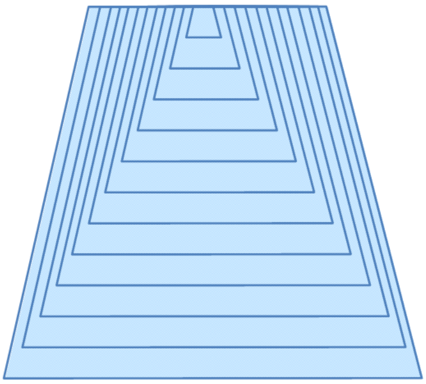


FIGURE E: Illustration of the variation of the size of successive layers

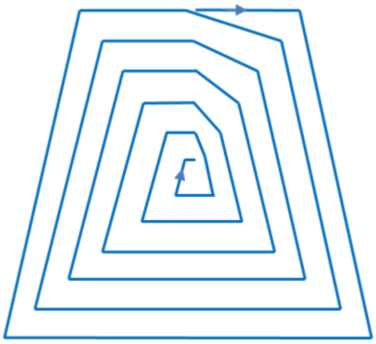


FIGURE F: Illustration of the offset filling used in one layer

RESULTS

The photos below show the processed sample. All the holes with a diameter of 0.35mm or above have been drilled as straight holes. The 0.25mm holes were only drilled inside the three diffusers, where the effective thickness is smaller. This is because the available laser forced us to use a nozzle diameter not smaller than 50µm. But from our experience, using a thinner laser fiber and a 40µm nozzle should allow us drilling 0.25mm straight holes in this thickness.

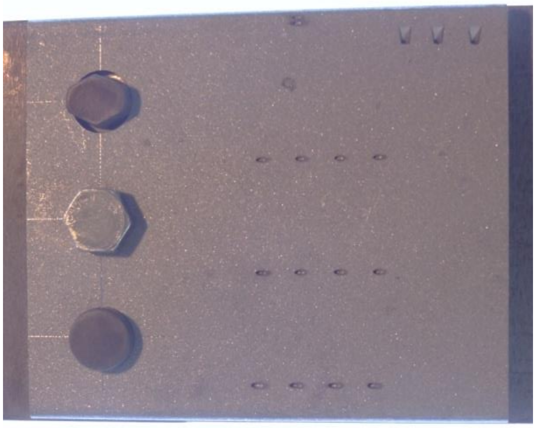


FIGURE G: Photo of the drilled sample. Four rows of three holes were drilled, plus two holes on one side for preliminary tests. Three diffusers were also processed on the side.

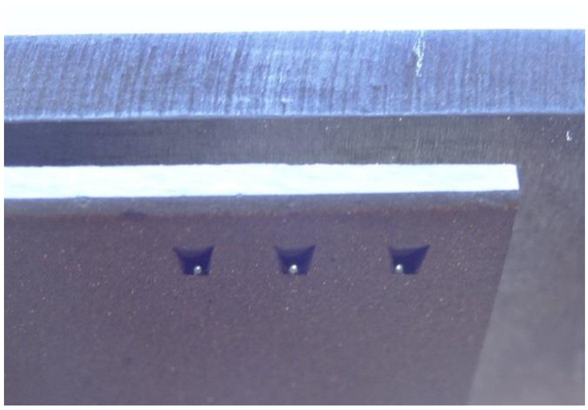


FIGURE H: Close-up on the diffusers, showing the 0.25mm holes that were drilled inside.

Please note that the three rightmost holes on Figure G were drilled using air blow between the plate and the support as an additional protection. It is usually possible to use such a backstrike protection in turbine blades, but since we have no information concerning the design of the actual products, we preferred to show that it was also possible to avoid backstrike just by controlling the jet stability length. We nevertheless used the air blow method on a few holes to show that this technique does not disturb the process.

Figure I below shows the absence of any visible backstrike on the plate fixation below the straight holes. It may not be very easy to see on the picture, but the reason is that we did not want to remove the plate from its fixation. As for the holes drilled inside the diffusers, since we had a much longer water jet, we had to use an air blow to disrupt the jet. Unfortunately, we had issues with the setup, and the air blow was not properly activated for the first two holes. On Figure J, we can therefore see a faint mark below the second hole. There was no more issue with the last diffuser hole, which is the leftmost one on Figures G and H.

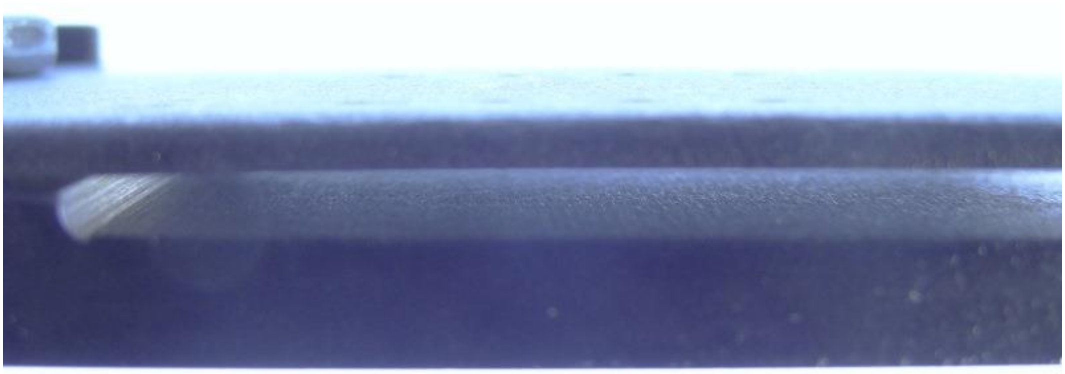


FIGURE I: Photo showing the surface of the plate fixation, below the straight holes. There is no visible sign of backstrike.

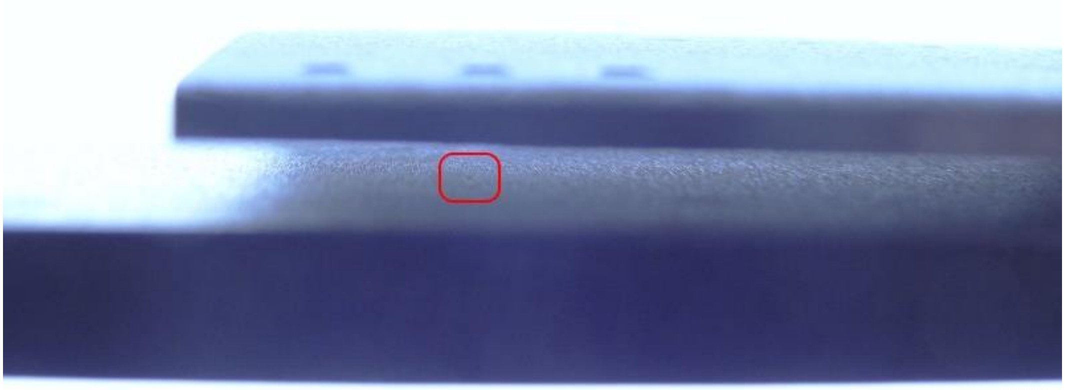


FIGURE J: Photo showing the surface of the plate fixation below the diffusers. There is only a visible little sign of backstrike visible below the second diffuser (as outlined in red), due to an issue with the air blowing setup.

The table below presents the drilling time for each feature. Please note that the tests were focussed on the absence of backstrike, and that the parameters were therefore not optimized for the fastest drilling. In addition, since we had no requirement concerning the taper, and since we could not measure the hole diameter on the backside, we chose high numbers of passes for the drilling and for the finishing. The number of passes is therefore greater than necessary, but ensures that the taper is as small as it can be.

It is interesting to notice that, while diffuser engraving takes time, it also makes subsequent the hole drilling easier faster, which can compensate the time it takes to engrave the diffuser. In this case, the influence of the diffuser engraving is even greater since the 0.25mm holes could not be drilled as straight holes.

Hole diameter	0.55mm	0.45mm	0.35mm	diffuser	0.25mm
Time at breakthrough	70 s	70 s	125 s	Process time: **83 s**	35 s
Total time for drilling	**134 s**	**129 s**	**219 s**		**62 s**
Finishing	+ 179 s	+ 158 s	+ 121 s		+ 81 s

The microscope pictures below show the good quality that was obtained. We have only observed the front side because we did not remove the sample from its holder. The hole shape is well defined, and the heat-affected zone is limited. Please note that we kept the diameter constant as per the drawing, but that the quality on the top surface could be improved by doing a couple of passes with a higher diameter at the beginning, possibly with a lower power (as we usually do when there is a ceramic coating). This is well shown on the diffusers pictures (Figures N and O), which present no trace of discoloration.

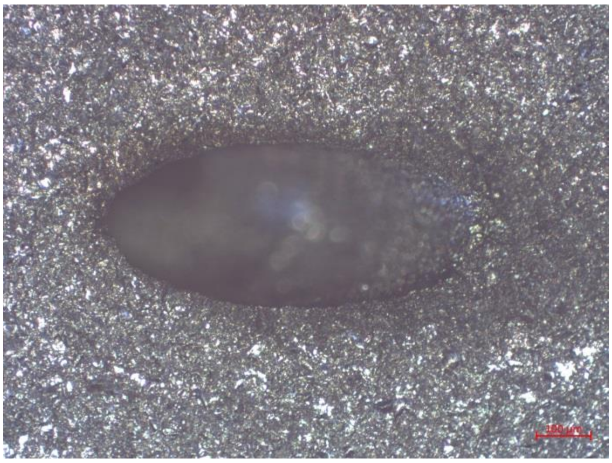


FIGURE K: Front side of a 0.55mm hole.

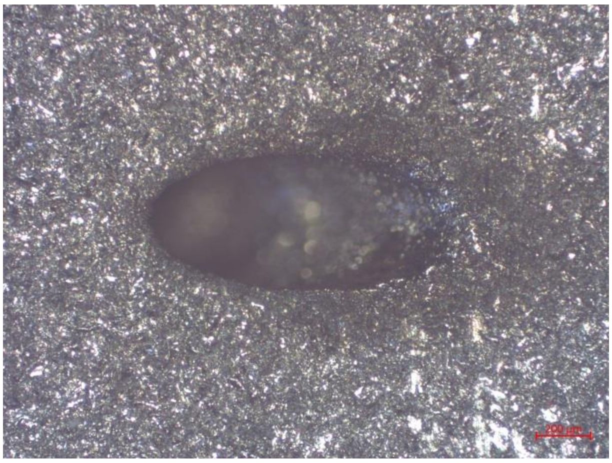


FIGURE L: Front side of a 0.45mm hole.

FIGURE M: Front side of a 0.35mm hole.

FIGURE N: General view of the three diffusers

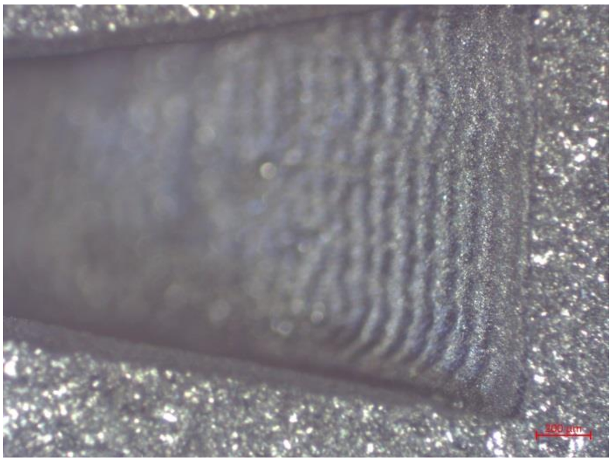


FIGURE O: Close-up on one diffuser

CONCLUSION

The drilling of nickel alloy 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 straight holes with a diameter down to 0.35mm using a 50µm nozzle (with 0.25mm holes requiring a 40µm nozzle);
- engrave a diffuser at the top of the hole, which makes the subsequent hole drilling easier, allowing to drill 0.25mm hole with the same 50µm nozzle;
- avoid backstrike damage, thanks to either a control of the jet stability length, or to an air blow that disrupts the water jet below the hole;
- avoid any visible heat damage by using less power and a higher motion speed at the entrance of a hole, like in a diffuser.

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.