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Ti surface laser polishing: effect of laser path and assist gas

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Abstract

Laser polishing is a process by which the surface roughness of machined parts can be reduced avoiding ablation phenomena. In this process the laser spot irradiates the sample surface with short laser pulses at a power density that causes a surface melting of the order of few nanometers. Compared to conventional polishing process (as grinding) it ensures the possibility of avoiding any surface orientation, no tool wear, no abrasive or liquids, no debris and less machining time; moreover coupled with a galvo system it results to be more suitable in case of 3D complex workpieces.
Nowadays, on this process, several authors are focusing their attention on the wavelength and pulse length effect but a lack of knowledge concerning the effect of other process parameters still exists.
In this work the effects of laser path and assist gas were tested by the authors. Nd:YVO4 laser source, characterized by a wavelength equal to 532 nm, was used in the experiments and Ti grade 2 samples were selected. A full experimental plan was designed to investigate the influence of process parameters in terms of average roughness reduction achieved.

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Keywords: laser polishing; Titanium; roughness reduction

1. Introduction

Polishing is a finishing process for smoothing a workpiece surface by roughness reduction; it is often used to enhance properties as surface wear and workpiece design in case of visible parts. Moreover, this process is used to remove oxidation, respect tolerances, create a reflective surface, or prevent corrosion (i.e. in case of in pipes). Benefits of this process are also achieved in case of large metallic surfaces finishing within the die and mold industry.

Mechanical polishing is the conventional technique used to machine surfaces and it consists of many different grinding and polishing steps realized with an abrasive tools.

Besides the benefits the mechanical polishing requires an high effort due to low polishing rates and a lack of performance is registered in case of workpiece characterized by high hardness, limited accessibility of a part, micro dimensions or 3D free form surfaces. These aspects are critical because of the need of a physical contact between the surface and the tool so that at present the final polishing operation is sometimes carried out manually with an high increase of total manufacturing time.

Nowadays a different technique available to improve surface roughness is the laser polishing process. The polishing principle is based on focused radiation of a laser beam that melts a microscopic layer of surface material [1] (figure 1).

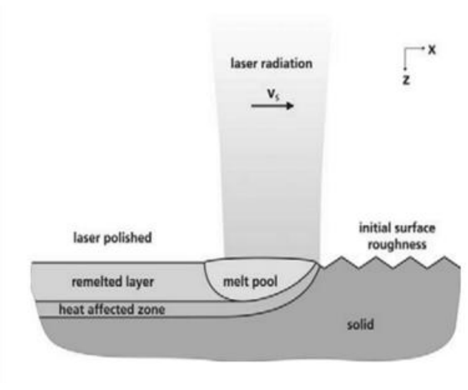

Fig.1. Principle of polishing laser radiation in cross section [1]

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The process parameters optimization aims to obtain a laser beam that only melts the surface peaks of the material; due to capillary pressure the melted material fills the valleys producing a smoother topography with respect to the initial one [2].

Compared to conventional polishing process (as grinding) it ensures:

- the possibility of avoiding any surface orientation;
- no tool wear;
- less pollution (no abrasive or liquids);
- no debris;
- less machining time;
- coupled with a galvo system it results to be more suitable in case of 3D complex workpieces

Figure 2 reports an example of surface part polished with laser radiation.

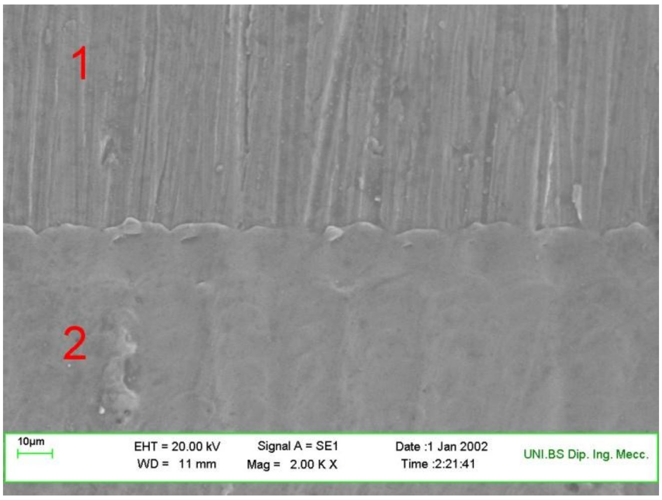


Figure 2: comparison between raw surface (1) and laser polished surface (2) on a Titanium sheet

In literature recent researches are available on this topic focusing their attention on the laser source (pulsed or continuous) [3-4]; laser spot size [5], overlap between laser beam tracks [6], power intensity distribution [1] and in the modeling of surface prediction [7,8].

In order to enhance the knowledge about this new polishing process, the effect of laser path and assist gas was investigated in the present work. Nd:YVO_4 laser source, characterized by a wavelength equal to 532 nm, was used in the experiments and Ti grade 2 samples were selected. A full experimental plan was designed to investigate the effect of process parameters in terms of average roughness reduction achieved.

2. Experimental set up

The set of the experiment is reported in figure 3. A LEP Lee Laser (Nd:YVO_4, 8 W q-switched, λ=532 nm) was used for the experimental campaign. The outgoing laser beam is collimated in a galvo system to impose a remote control. A sheet of Titanium grade 2 (0.5 mm thick) was selected as sample. The sheet was fixed on a frame at a distance equal to the focal distance (160 mm) from the galvo head. Nitrogen was set as assist gas; the gas feeding is realized with an hollow rubber pipe fixed on a support to obtain an homogeneous flux oriented at 45° with respect to the specimen.

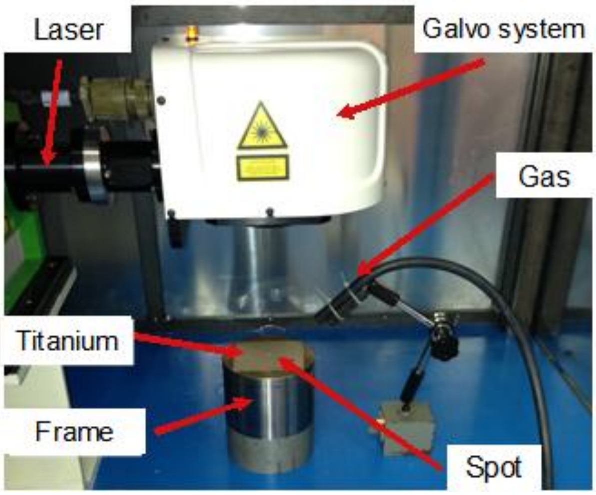


Figure 3: Set up of the experiment

Following the mentioned set up, different tests were executed in order to study the laser polishing process. For each test a laser polished square sample with a dimension equal to 25 mm^2 was realized on the Titanium sample. In order to start with an homogeneous and oriented initial surface, typical of traditional cutting processes, each sheet was grinded with abrasive paper. After the grinding step, the samples were fixed on the frame and machined with the laser beam. Figure 4 reports a sample polished under the mentioned procedure.

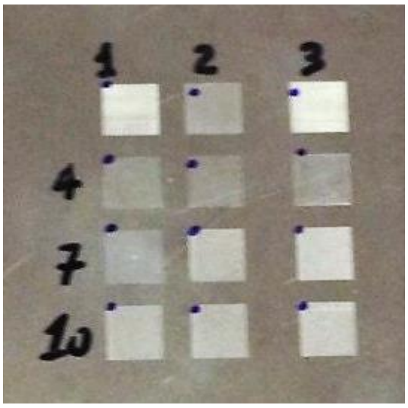


Figure 4: laser polished samples on Titanium sheet

For the selection of the process parameters, a preliminary experimental campaign was executed in order to fix the laser parameters not studied in this research such as: laser power, frequency, pulse duration, duty cycle, laser scan speed, spot diameter and number of loops. About the scan strategy (also called filling strategy) for realizing the polishing process the software Laser Marking Studio (LMS), integrated with the galvo system, can work according to four different laser paths: two line, three line, in-to-out line and out-to-in line. For each laser path the filling line gap was set equal to 0.075 mm.

A scheme of the different laser paths available are shown in figure 5.

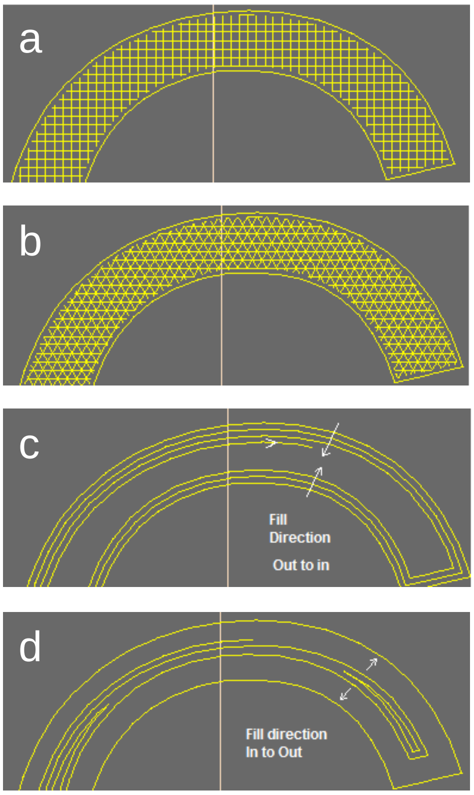


Fig. 5. Different laser filling path tested: (a) two line, (b) three line, (c) out-to-in line, (d) in-to-out line.

In the present research the effect of laser polishing process was studied as a function of these laser paths and of three different levels of assist gas (no gas, 5 bar and 10 bar). A resume of the material, sample and laser process parameter values set for the experimental campaign is reported in table 1.

Tab. 1: set up and process parameter

Material	Titanium grade 2
Sheet thickness [mm]	0.5
Square laser polished sample [mm^2]	5x5
Frequency [kHz]	200
Duty cycle [%]	1
Pulse duration [ns]	5
Laser speed scan [m/s]	5.5
Spot Diameter [mm]	0.06
Average power [W]	2.55
Number of loops	1
Gas [bar]	0, 5, 10
Laser path	two line, three line, out-to-in line, in-to-out line
Filling line gap [mm]	0.075

The duty cycle is expressed as a function of the pulse duration (dt) and the frequency (f) by the formula:

$$Duty\ Cycle = dt\ [ns] * \ f\ [kHz] * \ 10^{-6} \qquad (1)$$

3. Results and discussion

Two different analysis were executed in order to measure the experimental results: a qualitative analysis to study the texture and a quantitative analysis to measure the roughness reduction. The texture was analyzed with a SEM microscope Leo EVO 40, the roughness with a confocal laser microscope Olympus OLS 4100. Figures 6,7,8 and 9 report the images acquired with the SEM microscope for the qualitative analysis as a function of the laser path (columns) and assist gas (rows).

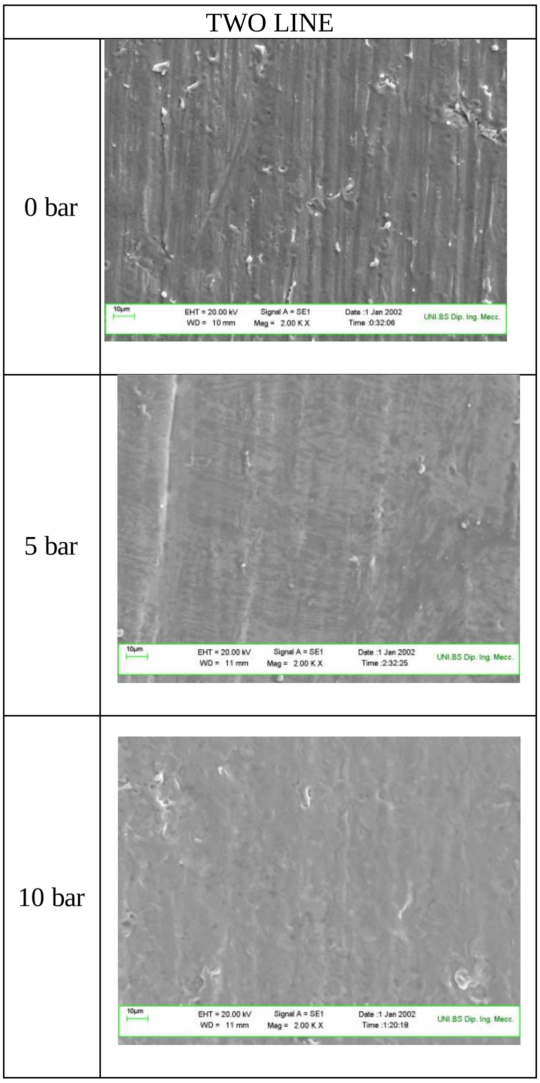
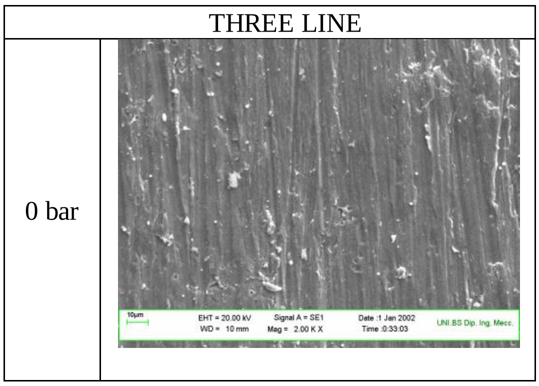


Fig. 6. SEM analysis of the two line campaign



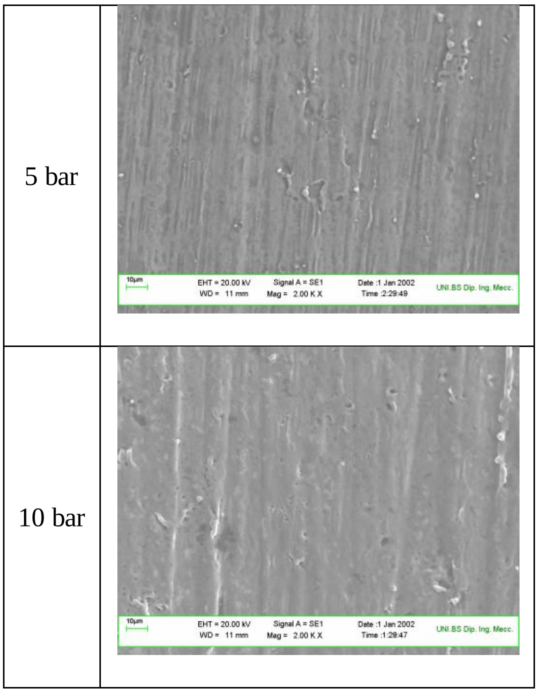


Fig. 7. SEM analysis of the three line campaign

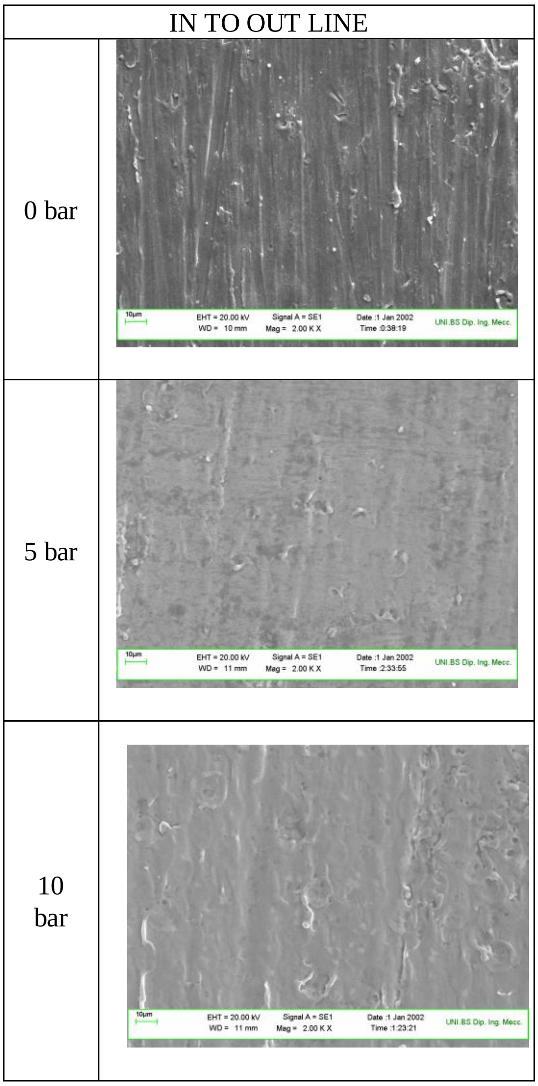


Fig.8. SEM analysis of in to out line campaign

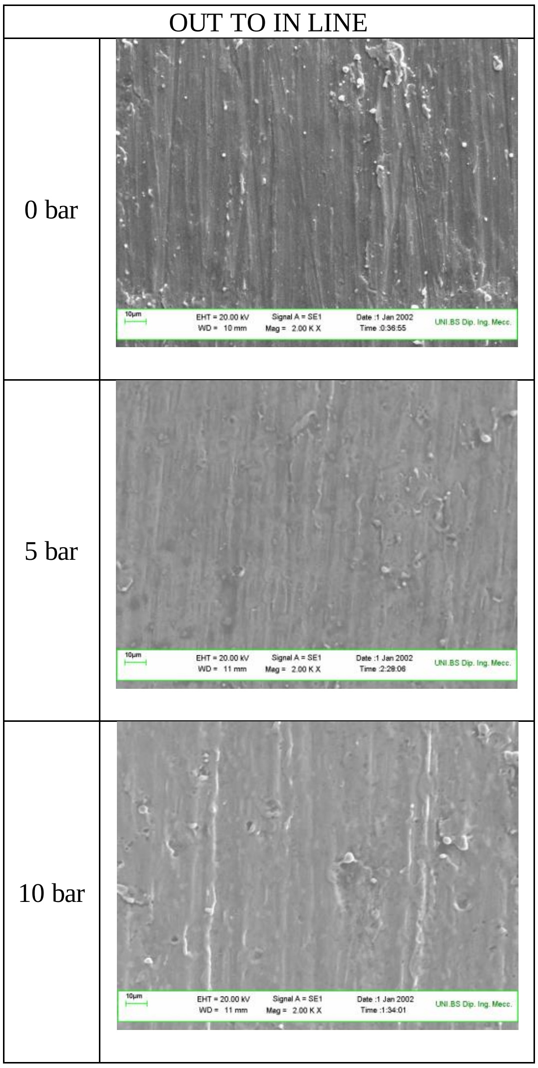


Fig. 9. SEM analysis of the out to in campaign

The most important results of the qualitative analysis can be resumed in the following points:

- the effect of the different laser path strategy is not evident at the SEM microscope;
- on the contrary, it is possible to appreciate the effect of the gas assist. In particular when the gas assist is not present (0 bar tests) the machined surface is characterized by the presence of localized molten drops and oxidation zones, while, when the gas pressure is too high (10 bar tests), a smoother surface is registered.

Starting from these results the quantitative analysis was carried out. Since the starting surface is oriented along the Y direction, the X roughness values will be analyzed. From each test an area equal to 640 μm^2 was selected to evaluate the average roughness on 3 linear acquisitions and the medium average roughness was calculated. The results were compared with the medium average roughness of the raw surface (always acquired along the X direction). The main results, including the machining time, are reported in table 2; as can be observed in figures 10 and 11 the medium average roughness, coupled with the relative standard deviation, are compared with the initial roughness as a function of laser path and assist gas.

Tab. 2. quantitative analysis results

Laser Path	Gas [bar]	R_{a_med} [μm]	σ
BASE MATERIAL		0.58	0.082
	0	0.42	0.069
TWO LINE (2.371 s)	5	0.49	0.040
	10	0.53	0.058
	0	0.44	0.046
THREE LINE (3.557 s)	5	0.50	0.045
	10	0.54	0.049
	0	0.47	0.046
IN-TO-OUT (1.357 s)	5	0.49	0.068
	10	0.55	0.057
	0	0.47	0.076
OUT-TO-IN (1.404 s)	5	0.51	0.084
	10	0.58	0.065

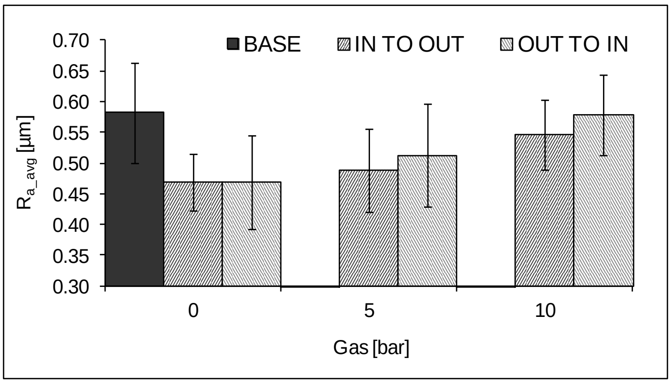


Fig. 10. Medium average roughness evaluated from the two and three line campaign

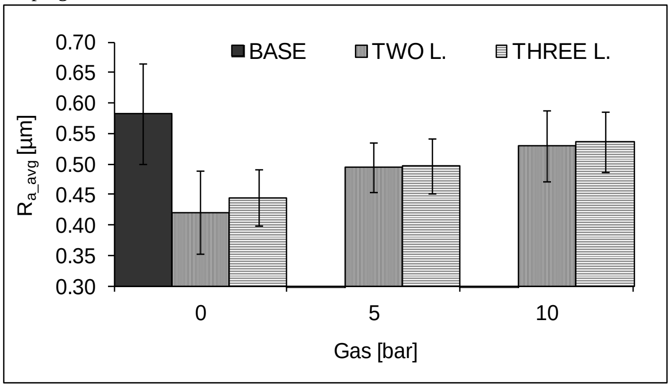


Fig. 11. Medium average roughness evaluated from the in-to-out and out-to-in line campaign

From the results of the quantitative analysis different considerations can be derived:

- as highlighted also in the SEM analysis, the effect of the assist gas is to limit the roughness reduction: the higher the gas pressure, the lower the improvement of laser polishing. Moreover, it is possible to observe that when the pressure is higher (10 bar), the effect of the laser path becomes negligible.
- the laser path strategy affects the quality of machining: in particular strategies that avoid the sample boundary (two line and three line) seems to be more effective with respect to the in-to-out and out-to-in paths; however, it must be taken into account that the improvement, in terms of average medium roughness, is less than in the cases of assist gas use.

Table 3 reports the percentage improvement of the laser polishing process with respect to the base material as function of the process parameters. Positive terms correspond to average and standard deviation roughness values reduction.

Tab. 3: percentage improvement of the laser polishing process

Laser Path	Gas [bar]	% R_{a_avg}	% σ
	0	28%	16%
TWO LINE	5	15%	51%
	10	9%	29%
	0	24%	44%
THREE LINE	5	15%	45%
	10	8%	40%
	0	20%	44%
IN-TO-OUT	5	16%	17%
	10	6%	31%
	0	19%	7%
OUT-TO-IN	5	12%	-2%
	10	1%	21%

Analyzing the data reported in table 3, it is evident how the best condition can be obtained polishing the part without the use of the assist gas and imposing the two line laser path. However, there are some critical aspect concerning this strategy. The assist gas is fundamental to avoid molten drop on the polished surface (first row of fig. 6,7,8 and 9), to protected the area from oxidization phenomena and to increase the process yield by removing from the working zone the plasma typical of laser machining. At least it is possible to observe in table 3 how gas presence aids to a homogeneous polishing; indeed a higher standard deviation reduction is registered for all the executed tests with gas with the exception of the in-to-out line path. However, as discussed before, this parameter must be carefully set because a too high gas pressure can generate an undesired turbulence flow and limit the roughness reduction.

About the laser path it was already underlined how the two and three line paths guarantee more benefits with respect to the other two tested paths but, as reported in table 3, because of its trajectory, the three line path guarantees also a more homogenous process due to the higher standard deviation reduction regardless of gas pressure.

Concluding the best fits of process parameters for obtaining the best polishing process corresponds to a low gas pressure and a three line path. Even if this set could not guarantee the best roughness reduction, it guarantees the most stable polishing process. Once a stable process is achieved, it is possible to improve the process performance by increasing the number of loops.

4. Conclusion

In the present paper the performance of a polishing process executed with a laser radiation have been studied and reported. This technique is able to guarantee a polished surface without any surface orientation, tool wear, abrasive or liquid and debris. At present the laser polishing technique is still new and, consequently, under investigation in order to improve the process performance. The results of an experimental campaign focused on the laser path and assist gas influence on the process are reported. Nd:YVO4 laser source, characterized by a wavelength equal to 532 nm, was used in the experiments and Ti grade 2 samples were selected. Results highlight that a path that avoid the surface boundary and the presence of a low pressure assist gas guarantee a homogeneous roughness reduction avoiding any molten drop or oxidization phenomena.

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