Pulsed Laser Micro Polishing of Metals Using Dual-Beam Technology

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Abstract: ***In this paper laser micro polishing with an additional laser beam for pre-heating of the surface is examined. The influence of the following process parameters on the surface roughness is examined: Pre-heating laser power, scanning velocity, beam offset of the two laser beams, and intensity distribution of the pre-heating laser beam. The two materials which were used for the experiments (martensitic tool steel and TiAl6V4) showed a different behavior: For martensitic tool steel the micro roughness was increased in comparison to conventional laser polishing with only one laser beam (single-beam technology) due to increasing formation of martensite. For TiAl6V4 the meso roughness of the surfaces was decreased in comparison to conventional laser micro polishing due to longer melt duration, so smoother surfaces were obtained (up to 36% lower surface roughness for one spatial wavelength regime).***

Keywords: Laser micro polishing, Dual-beam technology, Pulse duration, Martensite formation

1. Introduction

Laser micro polishing with pulsed laser radiation is a surface finishing process to reduce the micro roughness. There have been several investigations on the fundamentals of this process, for example in Perry,2009,Willenborg, 2005,and Nüsser et al., 2011. It has been investigated that the two most important parameters influencing the surface roughness after the polishing process are the power density, i.e. the intensity distribution, and the pulse duration. The intensity distribution must be homogeneous, i.e. top-hat like, and the pulse duration must be as long as possible for obtaining a low surface roughness after the polishing process (investigated pulse duration: 20-1.500 ns).

In this examination the influence of an additional laser beam for pre-heating of the surface is investigated. It is assumed that this process variant leads to a lower surface roughness in comparison to the single-beam technology (conventional laser polishing).

UW–Madison researchers have developed a two-regime method to reduce rough surfacefeatures using a multiple-pass PLµP approach. In the first regime, melt pools are created on the surface using energy pulses, which generate higher temperatures where the beam is focused. Thermo capillary flow pulls down asperities into the melt pools. This can cause material to push up at the edge of the pools as they resolidify. A second regime applies different energy pulses to remove and/or rearrange the upwelled material.

2. Experimental Setup

For the investigations an experimental setup is used that allows the independent alignment and superposition of two laser beams, fig.1. The laser radiation is guided to the setup by optical fibers.

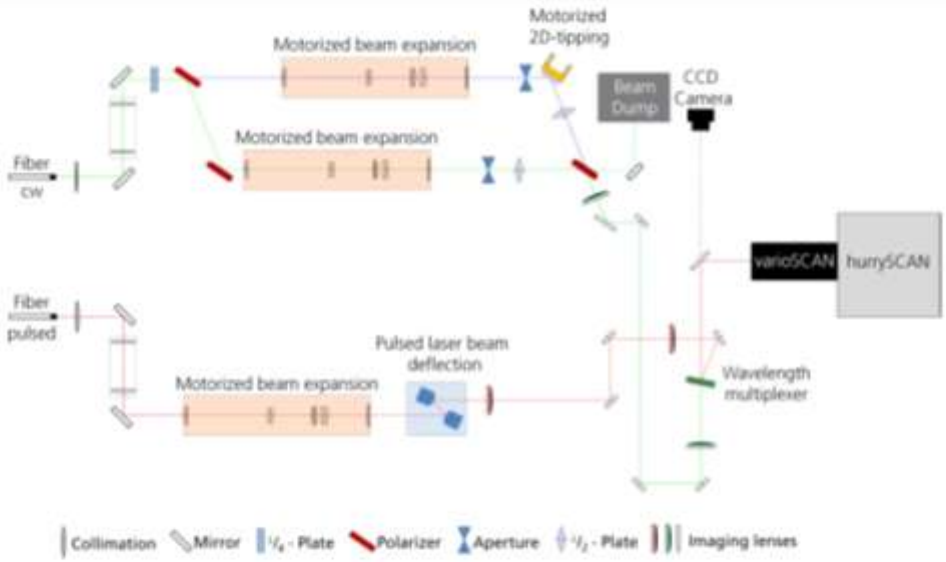
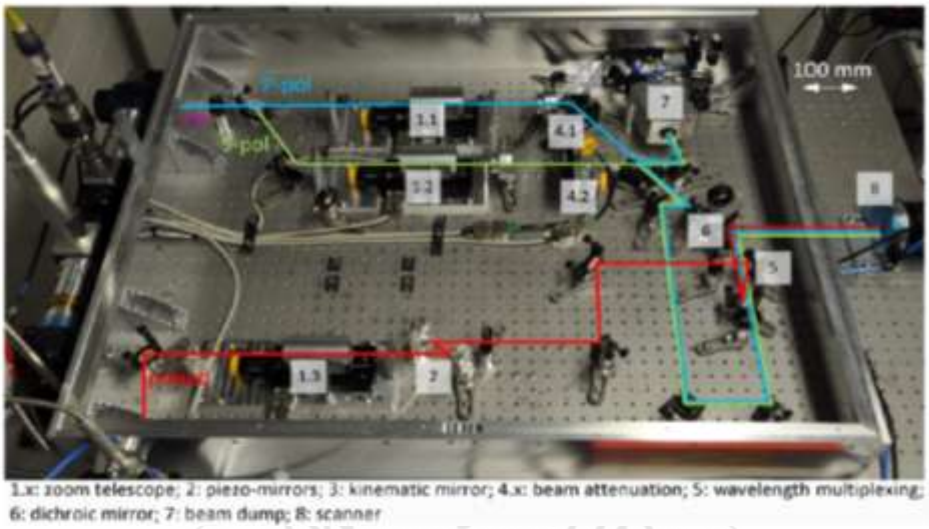


Figure 1: Experimental setup (Temmler et al., 2013)

The diameters of the cw (green) and pulsed (red) laser beam can be aligned with motorized beam expanders. The optical setup allows the independent alignment of the p- and s-polarized parts of the cw laser beam, but this feature is not used in this investigation, the diameter of both parts is the same in all experiments. The position of the pulsed laser beam to the cw laser beam can be shifted relatively with two piezo elements. The positioning of the beam is fast enough to realize a meanderly scanning of the surface, fig. 2.



The two laser beams are finally super positioned by a wavelength multiplexer and guided into a scan head. A more detailed description of the setup can be found in Temmler et al., 2013.

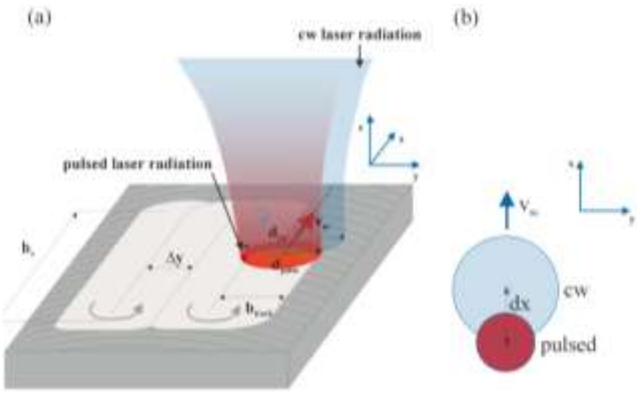


Figure 2: (a) Strategy for guiding the laser beams over the surface; (b) Top view of the two laser beams

The properties of the two laser beam sources TruMicro 7050 (TRUMPF GmbH + Co. KG, Ditzingen (Germany)) and HPQL (developed by Fraunhofer ILT) used in this investigation are given in table Beam diameters of laser beams with a circular geometry in the focal plane are named "d", the lengths of the edges of laser beams with a square geometry are named "dsq".

Table 1: Properties of the laser beam sources used for the experiments

Laser beam source	TruMicro 7050	HPQL (Fraunhofer ILT)
Laser crystal	Yb:YAG (disk)	Nd:YAG (rod)
Wavelength	1030nm	1064 nm
Maximum laser power at work piece	560 W	50 W
Pulse frsequency	Cwmode	20 kHz
Pulse duration (FWHM)	-	1,000 - 100 ns @ 20kHz
Geometry and diameter of coupled fiber	circular,d=200µm square, dsq=300µm	circular, d=300µm
Beam diameters used in experiments	d=450µm dsq=440µm	d=250µm

The examinations are carried out on turned and cw-remelted martensitic tool steel X38CrMoV5-1and turned Titanium TiAl6V4 using the fiber-coupled disk laser in cw-mode for preheatingand the fiber-coupled rod laser for polishing of the surface. The disk laser is equipped with a fiber with a circular profile or with a fiber with a square profile resulting in a Gaussian-like and a top-hat intensity distribution, respectively.

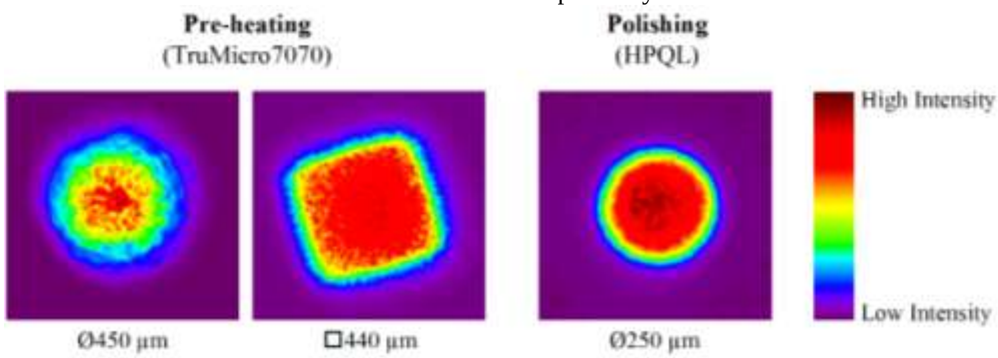


Figure 3: Intensity distribution of the laser radiation used in the investigations

The aim of dual-beam laser polishing is to pre-heat the surface as high as possible without melting the surface. Hence, small test fields with varying laser power of the cw laser beam Pcw are preheated by meanderly scanning with the laser scanner and examined under a microscope. Since melting of the surface leads to visible remelted tracksmthe highest laser power examined that does not lead to surface melting is used for the polishing experiments.

Table 1: Process parameters used in the investigations

Process parameter	*Value / unit*
Pulse duration (FWHM)	290-145 ns
Scanning velocity	1,000 mm/s
Track offset Δy	30 µm
Pre-heating beam diameter	Ø450 µm (tool steel) 440 µm (TiAl6V4)
Polishing beam diameter	Ø250 µm
Beam offset dx	0 µm

3. Results and Discussion

The investigation of the influence of the pre-heating laser power on the surface roughness of tool steel showed that with increasing pre-heating laser power more martensite is formed. The surface roughness is not lower, but in some cases even higher than the roughness of the surface polished with only one laser beam. For TiAl6V4 polishing with additional pre-heating has the same effect as using longer laser pulses. The micro roughness achieved was the same for single- and dual-beam laser polishing, but with increasing pre-heating laser power the reduction of the meso roughness is increased (up to 36% lower surface roughness for one spatial wavelength regime).

The investigation of the influence of the scanning velocity showed that there was no effect on the meso roughness, but with increasing scanning velocity the micro roughness decreased, but none of the surfaces polished with dual-beam technology was as smooth as the surface polished with single-beam technology. For TiAl6V4 the meso roughness decreased with decreasing scanning velocity, while there was no effect on the micro roughness. The meso roughness of all surfaces polished with dual-beam technology was smoother than that polished with conventional laser micro polishing (up to 36% lower surface roughness for one spatial wavelength regime).

The investigation of the influence of the beam offset showed that for tools steel it is advantageous when the polishing beam runs after the pre-heating beam. The highest offset in this case led to the smallest micro roughness, which was almost at the same level of single-beam polishing. For TiAl6V4 no influence of the beam offset could be seen, for both offsets investigated the meso roughness of the surfaces was lower than the meso roughness of the surface polished with conventional laser micro polishing (up to 24% lower surface roughness for one spatial wavelength regime). For tool steel, pre-heating with a Gaussian-like intensity distribution led to a lower micro roughness than the use of a top-hat intensity distribution. It was assumed, that the cooling rate was higher in this case or that the melt was less disturbed by the pre-heating beam.

Overall, dual-beam technology did not allow smoother surfaces than conventional laser micro polishing for martensitic tool steel due to increased martensite formation. For TiAl6V4 the meso roughness is reduced and the critical spatial wavelength increases by pre-heating of the surface due to longer melt duration, which is the same effect as using longer laser pulses. In the investigations it was advantageous when

- The pre-heating laser power was as high as possible (without melting of the surface)
- The scanning velocity was low
- The pre-heating beam and the polishing beam did not overlap.

Applications

- Polishing metallic parts
- Creating mirror finishes
- Microfabricated and micro manufactured parts, particularly for biomedical applications
- Useful for tool and die makers, including plastic injection molders and optical part manufacturers.

Figure 4: Blow mold

4. Advantages and Limitations

4.1Advantages

- Smoother surfaces
- No debris
- No change in the dimensional form
- Much easier to polish features with tight dimensional tolerances
- Enables very fast selective polishing
- Can polish micro scale features and parts
- Reduces height of high and low-frequency surface asperities

4.2 Limitations

- The process is applicable to the metallic and a few nonmetallic components.
- Output energy of laser is difficult to control precisely.
- High initial cost and maintenance cost.

5. Conclusions

1) The time between the end of the pulse and the re-solidification of the melt pool increases. In this time the amplitudes of the roughness can decay without any disturbing influences of the laser beam.
2) Due to the smaller amount of heating by the polishing beam, the influence of irregularities of the intensity distribution (local areas with a higher or lower intensity than the average intensity) decreases.

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