Lasers in Manufacturing Conference 2017

High speed and high power laser material processing: First determination of process limits

Jens Hildenhagen[a,*], Paul Bant[b], Klaus Dickmann[a]

[a]*Laser Center of the University of Applied Sciences Muenster, Stegerwaldstr. 39, 48565 Steinfurt, Germany*
[b]*ILT Fineworks BV, 7547 TG Enschede, The Netherlands*

Abstract

The increasing output power and brilliance of laser sources allows in principle faster material processes but needs novel handling technologies, e.g. beam guiding systems. Current developments like polygon scanner are dissolving consisting restrictions and finally physical properties (e.g. primary thermal conduction and heat capacity) will be the remaining limitations for process speed. However, depending on the scope of application and technological progress it will still take years to reach industrial requirements. First investigations should give an outlook what might be possible in the field of high speed laser material processing when the above listed technical limitations have been overcome. Therefor different samples (e.g. prevail coated materials like corroded steel or anodized aluminium), were mounted on a fast rotating cylinder (circumferential speed up to 120 m/s) and treated with a 30 kW (cw) fiber laser. At this speed the applied laser spot diameter of 200 µm lead to an interaction time of 1.7 µs and intensity of 10^8 W/cm². These specifications are known from pulsed laser systems and enabled distinct surface modification or even ablation by a single laser pulse. The high speed - high power setup allows to transfer such laser parameters in a continuous process with comparable raise of ablation rate. Thus it was possible to remove oxide layer or other resistant coatings with an output of several square meter per minute.

Keywords: high speed, high power, surface cleaning

1. Aim of study

The availability of laser output power in cw mode is nowadays less a question of technical feasibility than need for applications and profitability. The vast majority of laser based processes using cw-mode cannot be handled with more than a few kilo watts. Higher levels of output power lead to unsuitable increasing of intensity and worsened production quality. Acceleration of feed rates to spread an abundance of laser energy onto a larger processing area could only be a solution for applications where no expanded heat

* *E-mail address:* hildenhagen@fh-muenster.de .

transfer and thermal interaction is needed. These applications are typically machined with short and ultrashort pulsed laser systems. Limited interaction time and high peak energy generate modification or ablation effects on surfaces with manageable heat influence. The dominating factor for economic success is the ablation/modification rate ergo costs per square meter.

According to the pulse/pause ration the average output power of a pulsed laser system is much lower as comparable system in cw mode. The latter would offer a high productivity level as it could use for according application with overall performance. The following study should give first indications whether high power laser radiation in cw mode in combination with high feed rates could realize comparable results like a short pulse laser or might offer novel options for laser material processing.

2. Experimental setup

To analyze the laser material process behavior for different material by high speed and high power, a specific mobile setup was constructed. Hereby samples of 40x22 mm² were fixed on a rotating cylinder with a diameter of 320 mm with a circumferential speed up to 120 m/s, see Fig 1. This flexible system can be used in different high power laser systems and fixed optics. By means of a position monitoring the laser was triggered thus only the samples surface were irradiated. Within this study different fiber lasers up to 30 kW have been used to investigate the possibilities for material processing.

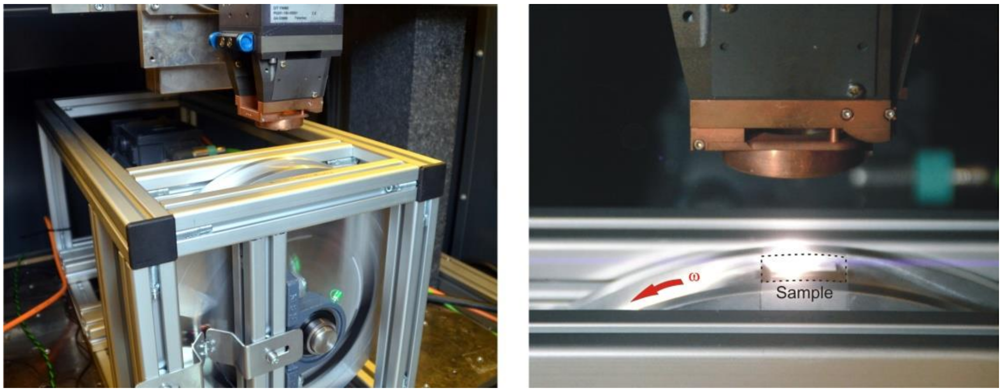

Fig. 1. Mobile high speed setup: Rotating cylinder with sample below a multi-kW fiber laser. Overview (left) and machining zone (right).

3. Results

This study should explore the speed range above 30 m/s. First experiments using fiber lasers in the power class of 1-5 kW clarify that notable results need more output power. Hence the mobile setup was combined with a 30 kW fiber laser at the application laboratory of IPG Laser GmbH. Due to this laser energy the maximal feed rate of 120 m/s could be applied.

As mentioned above, processes based on expanded heat transfer, like welding or cutting, could not be realized in the aimed speed range. A few tests with 0.1 mm thin stainless steel confirms this assumption – already the lowest feed rate of 30 m/s with an interaction time of 12 µs deposited not sufficient energy to fuze the reverse side. As intended the study focuses on “close to surface” processes which rest on immediate interaction processes between irradiation and upper layer of the material. The necessary intensity of 10^6 W/cm² was easily achieved by the 30 kW fiber laser system with a spot size of 0.2 – 0.4 mm. The maximum value for the intensity was 10^8 W/cm². The used feed rate about 30 - 120 m/s causes an exposure time of 1.7 – 12 µs and ensured a limited deposition of energy.

3.1. Ablation of coatings

The removal of well-bonded top layer like anodized layer on aluminium, rust on steel or varnish on tinplate could be carried out at all possible feed rates, provided by the maximal output power, see Fig 2. Even with the highest speed of 120 m/s all named layer were residue-free removed. In the case of scale layer on steel and powder coating on aluminium a sufficient removal in one pass stops above 60 m/s and for enameled cupper wire a maximal speed of 45 m/s was detected. Projected on a continuous process, an area of 2-4 m² per minute could be cleaned.

SEM analyses offers for all exposed surfaces thermal influences in microscopic scale, like micro zones of fusing or erosion, with exception of cupper.

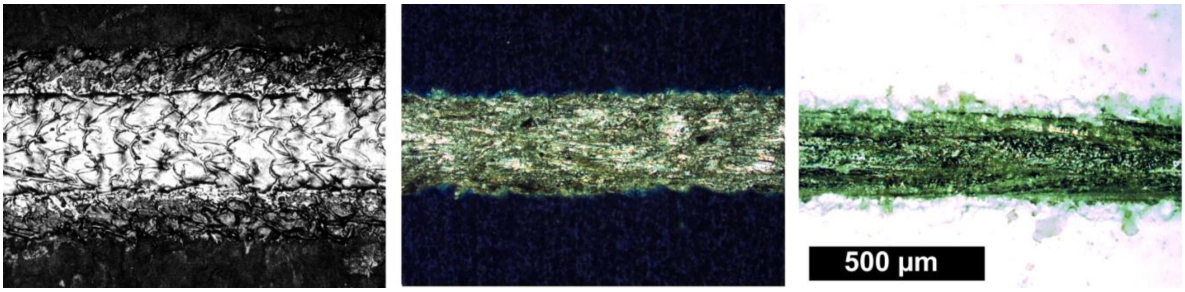

Fig. 2. Test series for high speed ablation of coating with fiber laser (output power 30 kW): rust on steel, feed rate 45 m/s (left), anodized layer on aluminium, feed rate 120 m/s (middle) and white powder coating on aluminium, feed rate 30 m/s (right).

3.2. Surface modification

Due to the interaction time range of a few microseconds all modification effects are thermal based. The deposited laser energy melted all iron materials to a depth of a few micrometers. During the melt phase the centrifugal force leads to the formation of streaks and droplets. All structures are orientated in the direction of rotation, see Fig 3. This preferred direction might be used in future applications in order to generate functional surfaces with direction-dependent properties like different friction factors.

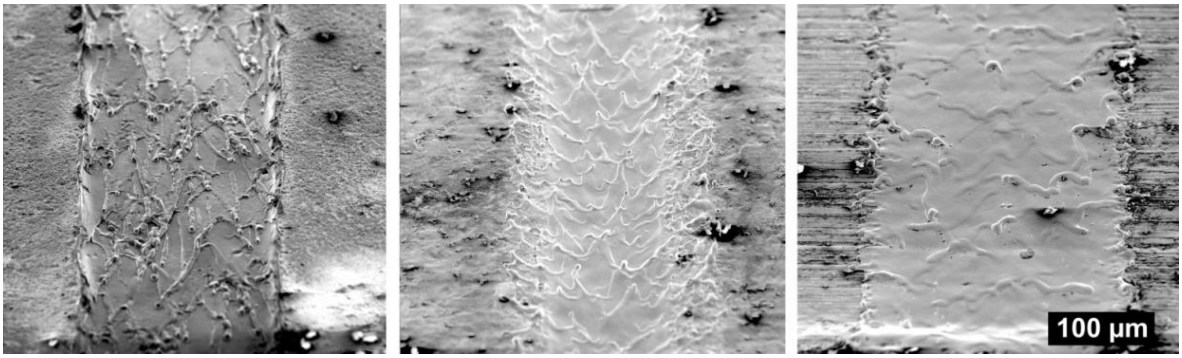

Fig. 3. SEM picture of surface modifications, caused with fiber laser (output power 30 kW): Exposed tinplate, feed rate 45 m/s (left), exposed mild steel, feed rate 30 m/s (middle) and stainless steel, feet rate 90 m/s (right).

Type and strength of these solidification structures vary only slightly with the feed rate. Probably lower centrifugal forces would be compensated by longer interaction time with stronger melting effects and higher viscosity. Substantially more influence will have the material properties. Different kinds of steel materials generate more or less distinct structures. Aluminium offers a few and copper none of these geometric formations, because of their higher levels for thermal transfer and capacity, see Fig 4.

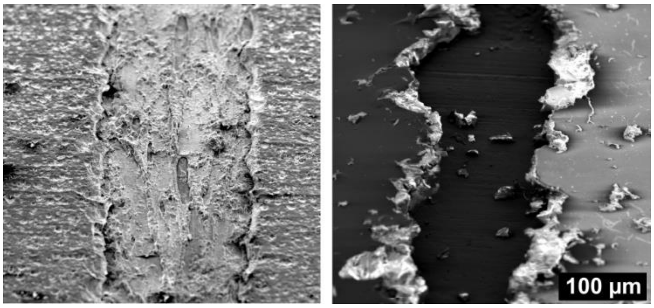

Fig. 4. SEM pictures of exposed samples of anodized aluminium, laser power 30kW, feed rate 120 m/s (left) and enamelled cupper wire, laser power 30 kW, feed rate 30 m/s (right).

4. Summery and Outlook

The combination of high laser power in cw mode with high feed rate allows an alternative approach to ablate undesired coatings with high speed. Actually thermal side effects on microscopic scale could not be avoided, but should be reducible with optimize parameters. Only exception, copper allows the removal of enameled layer without thermal impact on the bulk layer.

The achieved modification effect on surfaces were not comparable to those of ultrashort pulsed systems as the interaction time of several microseconds is still excessively long. But the combination of short time surface melting and strong centrifugal force seams to offer new options for surface modifications. The direction-dependent agglomeration of microstructure should be researched more detailed and might be applicable for new functionalization effects.

Further studies should include a higher variety of materials, especially plastics and ceramic. Moreover, the output power must be adjusted to the feed rate. In many cases, the applied overall power of 30 kW was at the maximal feed rate of 120 m/s to high.

Acknowledgements

This project is funded by INTERREG V - EUREGIO, Projekt-Nr. 142014. Further thanks to IPG Laser GmbH for providing high power fiber laser systems.