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Improving component cleanliness during laser remote ablation processes with high-power lasers by optimized emission blower and suction strategies

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Abstract

Laser remote processing with high-performance laser sources enables materials such as metals or fiber composites to be cut, welded or ablated flexibly and quickly. All these manufacturing processes produce process and material specific particulate as well as gaseous emissions. This must be recorded quantitatively and qualitatively in order to implement appropriate protective measures with regard to occupational health and safety as well as to minimize the cross-contamination of the component to be treated. Ideally, an additional cleaning step should be avoided by optimizing the arrangement of the process suction and blower. Particle distributions as well as gas phase analyses during the remote ablation process were recorded during ablation tests on metals or carbon-based composites. The structure quality and the contamination of the sample surface after laser material processing as well as after the additional cleaning process were determined. Subsequently, the samples were thermally joined to evaluate the influences.

Keywords: laser surface treatment; particle analysis; joining; occupational safety

1. Introduction

In the field of laser material processing more and more laser remote applications are finding their way into industrial production. The reason for this is the flexibility of this tool. Cutting and welding as well as surface ablation and structuring tasks within large work volumes or areas of more than 1m² can be highly dynamically processed. This is made possible by highly brilliant laser sources whose radiation can be focused very well on the component surface with the aid of 3D scanners at correspondingly large distances (from

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300 mm to over 2000 mm) from the component surface and deflected by means of dynamic mirrors at speeds of several meters per second. Compared to conventional laser material processing, these enormously short interaction times cause a significantly lower heat input and allow a safer and gentle processing of current lightweight construction materials such as aluminum and titanium alloys as well as fiber composite plastics (CFRP and GFRP). Conventional steel and stainless steel alloys and exotic materials such as native soft and hard woods can be treated too in the laser material area.

Due to the large working areas of more than 1m² with the remote technology, the cleaning of the processed surface areas and their catchment area cannot be realized with a local nozzle or suction firmly mounted on the tool (laser beam). High volume flow-through suction systems and an encapsulated working chamber eliminate most of the gaseous emission [1].

The aim of the presented investigations was the qualitative and quantitative determination of the resulting contamination during the laser remote process using industrially implemented high-performance lasers. The next step was to understand and develop how to minimize residual particle contamination on the components by supporting specific arrangements of a compressed air and suction flow. The cleaning of components using physical methods directly after the laser process was also investigated. This requirement for the cleanliness of the components for subsequent further processing steps is not only set in various standards [2, 3]. It is also a condition of industry and thus one of the key criteria for the success of an efficient process.

2. Laser remote process

During productive laser processing the use of continuous wave (cw)-laser sources with a high beam quality is advantageous. Thereby, the wavelength of approx. 1 µm is used industrially, because it can be easily guided by optical fibers on the one hand, and on the other hand offers an acceptable absorption at the different metallic and fiber composite surfaces.

In the investigations, a laser ablation / structuring process was used, as this is associated with the highest particle amount generation.

The laser beam ablation / surface structuring is conventionally characterized by pulsed laser systems, whereby a very high intensity is generated from laser sources with only a few watts average output power for a few nano up to femto seconds per pulse.

For cw laser ablation, the laser interaction time and the sufficient intensity are the keys to a targeted ablation. Therefore, in the cw laser process, in addition to the highest possible beam quality and a small spot diameter, attention is focused on the high process speeds of more than 8 m/s in combination with high laser powers of typically 1 – 5 kW.

2.1. Laser experimental equipment

A Multi Remote Station (MuReA) was used for the experiments on the ablation of metals as well as CFRP material. Among other things, this system has a highly dynamic axis system, an x-, y- axis table with processing speeds in x and y directions of up to 100 m/min and a z-axis integrated in the axis network for positioning the 3D large-area scanner systems in their cantilever. The processing for the tests was carried out with a 3-axeis scanner (Raylase, Axialscan 50) in "high power" and "high speed" design in combination with a 3 kW single-mode fiber laser (IPG, YLS3000SM). This enables scanning speeds of more than 20 m/s at a maximum working distance of up to 1400 mm (Fig. 1). The processing area is extracted by a variable exhaust hood in combination with a laser particle filter system (ULT, LAS 2000).

Fig. 1. Multi Remote Station (MuReA)

Remote ablation process

The processing of the aluminum alloys (AA2024 and AW6082), the stainless steel (1.4301) as well as the epoxy resin based unidirectional carbon fiber composite was carried out at laser powers between 1.3 kW to 3 kW with a beam diameter of approx. 110 µm and a beam scanning speed of 10 m/s to 18 m/s. The laser beam is guided in meandering pattern over the material surface with a line spacing of approx. 220 µm. The focus of the structuring trials was the identification of process parameters for optimum adhesion and a subsequent material-locking or form-fitting during thermal direct joining [4], illustrated in Fig. 2.

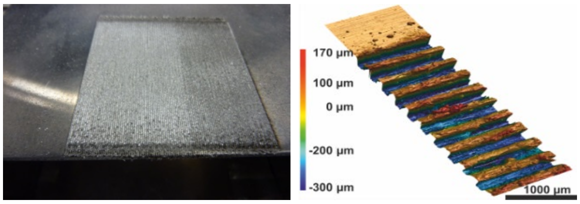


Fig. 2. Aluminium surface after the cw laser ablation process (structuring area: 50 mm x 50 mm; line distance: 220 µm)

3. Measurement equipment

3.1. Particle and vapor phase analysis

A special measurement setup of the equipment was implemented at the MuReA to investigate the particle quantities and size distributions produced during the ablation process and to record the gaseous exhaust products. The measuring instruments used are listed clearly in Table 1.

Table 1. Used devices for gas and particle analytics, the flows are shown in standard liter per minute (slm)

Used instrument	Usage	Flows
FTIR process spectrometer	gas analysis of exhaust gas	4 slm of exhaust gas through measuring cell
Scanning Mobility Particle Sizer (SMPS)	detecting of particles from 10 – 350 nm	0.6 slm passing through device
Aerosol spectrometer (ASM)	detecting of particles from 0.2 – 10 µm	3 slm passing through device

3.2. Experimental setup

The measurements were performed inline during the laser process. The three measuring instruments FTIR process spectrometer, SMPS and ASM were all operated simultaneously, in parallel configuration (Fig. 3.). The laser process time for the measurement was set to 60 – 90 s, while the measuring instruments with the volume flows specified in Table 1 sampled the process air.

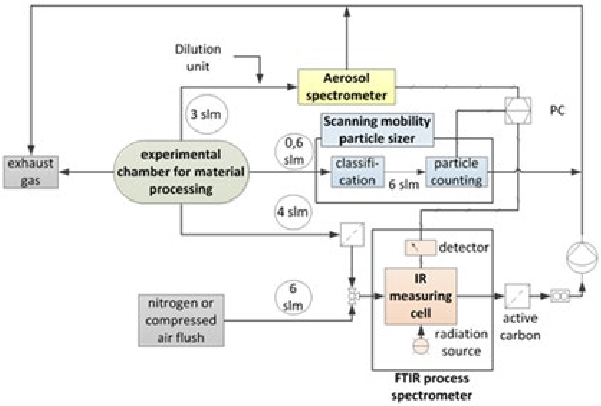
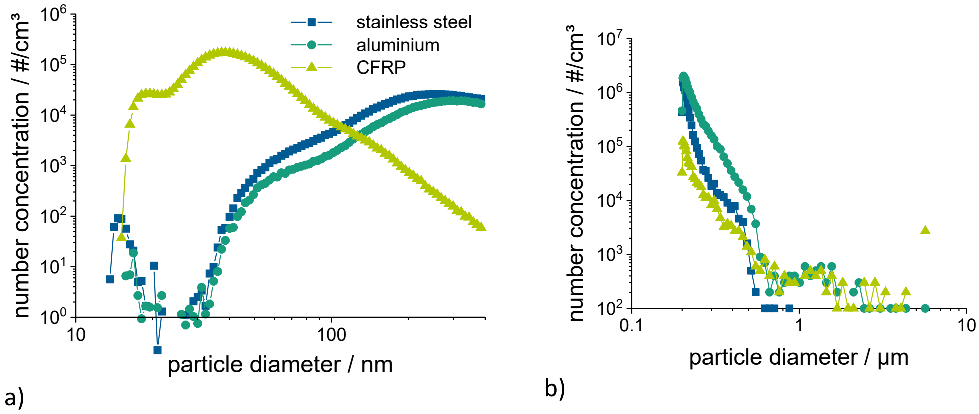


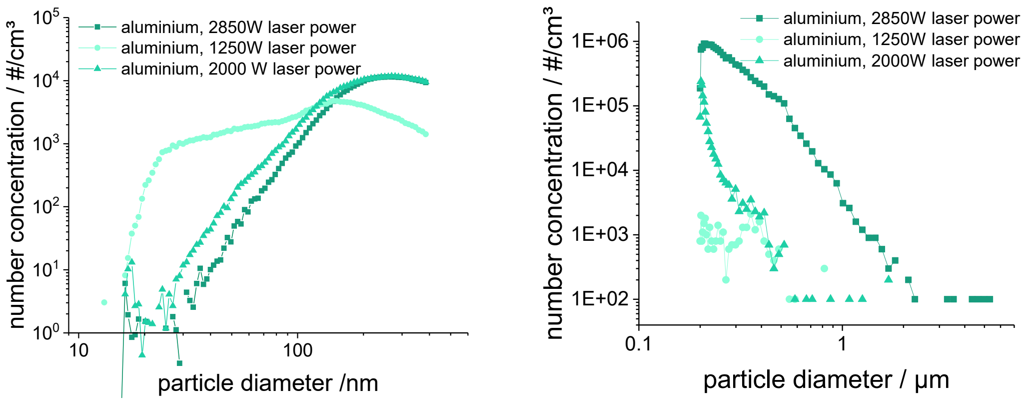
Fig. 3. Test bench for analysis of the exhaust gases and particles generated during remote laser processing

4. Results

4.1. Particle distributions

In the case of particle distribution measurements using SMPS in the size range from 10 nm to 350 nm, most of the particles measured in the CFRP range from approx. 20 nm to 50 nm occur in quantities of more than 10000 particles / cm³. Obviously, the metallic materials behave differently in comparison. The maximum particle sizes for both aluminum and stainless steel are 100 nm – 300 nm. The curves of both metals shown in Figure 4 are similar. The variation of the laser power used during ablation seems to have a certain influence on the particle distribution. With increasing laser power, fewer small particle quantities and marginally larger particles were detected (Figure 4 c-d). These contaminations have to be minimized, because almost all detected particles are smaller the respirable limit of 4.25 µm and thus represent a potential health hazard [5].





c) d)

Fig. 4. a) - b) Particle distribution of aluminium, stainless steel and CFRP measured with SMPS (10 - 350 nm) and ASM (0.2 – 10 µm)
c) - d) Particle distribution of aluminum - variation of laser power - measured with SMPS (10 - 350 nm) and ASM (0.2 - 10 µm)

The measurements with the ASM show maximum particle sizes of up to approx. 5 µm for aluminum and CFRP and 1 µm for stainless steel (Figure 4b). This observation can be explained by the high kinetic energy of the particles. While small particles have a small impulse and therefore behave like a gas flow in the suction, the larger particles from 20 µm – 30 µm have a higher impulse due to the high mass of the particles. These particles can no longer be deflected so easily by a cross jet (gas curtain) and arrive at the area of the processing zone on the material surface being treated.

4.2. Species analytic

In addition to particle investigations (particle size distributions), the gas phase was analyzed using Fourier transform infrared spectroscopy (FTIR). An exemplary result is shown in Figure 5. Thereby in very low concentrations volatile organic compounds (C_2H_2, C_2H_4, ...) occur [6]. Acid gases (NO_2, CO, HNO_2,...), CH_4, H_2CO, HCOOH are produced by evaporation of the epoxy resin during laser processing. The concentration of the harmful CO was calculated at 1300 ppm in the analyzed volume separated from the environment. It is therefore recommended that the operator uses respiratory protection (ABEK class) with an additional filter against CO when processing CFRP. This provides broad protection against all classes of pollutants. For metals such as aluminum and stainless steel, of course, no toxic gases were detected using FTIR, which would require an optical emission spectrometry of the process plasma.

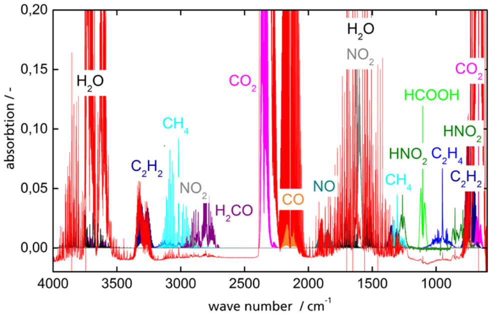


Fig. 5. Infrared spectrum of 3 min permanent structuring of CFRP (red color) Reference spectra: 100 ppm (other colors)

4.3. Flow simulation

This observation is also confirmed by the simulation realized with the FLUENT software. Depending on the position of the cross jet and suction hood, the flight curves of the different sized particles with diameters between 5 µm – 40 µm were calculated in order to minimize the contamination of ablation products on the freshly treated component surface and to carry out a following joining or coating process without a preceding additional cleaning step. Particles with diameters larger than 15 µm are almost no longer deflectable by the air stream due to their mass. These larger particles can only be kept away from the surface of the component by an optimized arrangement of the cross jet and the extraction system (Fig. 6).

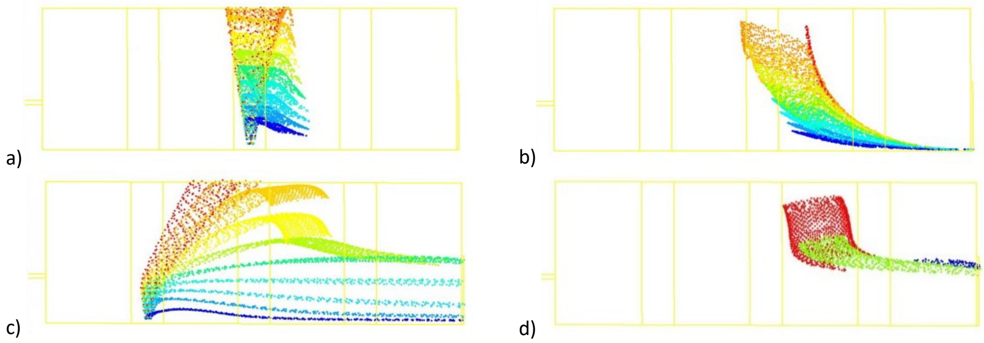


Fig. 6. Simulated trajectory from 5 µm (blue) to 40 µm (red) large aluminum ablation particles using laser suction system:
16 ms after generation a) without cross jet and c) with cross jet
32 ms after generation b) without cross jet and d) with cross jet

4.4. Surface cleaning

The contamination of the components by the particles and also smoke was investigated by various physical methods of cleaning such as electrostatic cleaning in combination with a compressed air nozzle or CO_2 snow blasting. CO_2 snow blasting on the three different materials proved to be a very effective and integrable method. With the help of this method, no significant particles could be registered in the range of

5 µm to 100 µm after evaluation of the component surfaces using laser scanning microscopes [2]. The difference can also be seen very clearly in Figure 7.

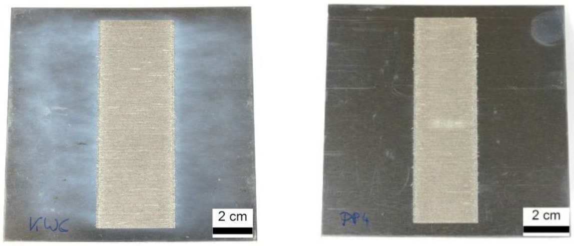


Fig. 7. Aluminum substrates after cw laser remote ablation using a suction directly at the edge of the substrate: left: non-cleaned, right: after CO_2 snow blasting

5. Summary and Conclusion

In the investigations, it was shown that particles from the nanometer to micrometer range are produced during the laser remote process. During the processing of the fiber composites, harmful gases can be produced. Therefore an extraction and encapsulation of the process is necessary for industrial safety reasons. The size distributions are mainly dependent on the material, secondary also on the used laser intensities.

To achieve a clean remote process a suction system and a cross jet are necessary. The flow simulation shows that the design of the arrangement provides an important basis for optimization with regard to particle removal from the component surface. The processes supporting cleaning by means of CO_2 snow blasting can completely removes particle contamination from the components and thus guarantee direct further processing.

Acknowledgements

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