Dry Metal Forming Open Access Journal

Fast Manuscript Track

Edited by Frank Vollertsen
Available online at elib.suub.uni-bremen.de

www.drymetalforming.de

Dry Met. Forming OAJ FMT 4 (2018) 009–012 Received January 12, 2018; published February 13, 2018

Laser Drilling of Tool Steel under Plasma Atmosphere

Jakob Barz[1], Paul Reichle[1,2], Georg Umlauf[1,3], Günter E.M. Tovar[3], Ehsan Zahedi[4]

[1]Fraunhofer Institute for Interfacial Engineering and Biotechnology, Fraunhofer IGB, Nobelstraße 12, 70569 Stuttgart, Germany
[2]Hochschule Esslingen, University of Applied Sciences, Kanalstraße 33, 73728 Esslingen, Germany
[3]Institute of Interfacial Process Engineering and Plasma Technology, University of Stuttgart, Nobelstraße 12, 70569 Stuttgart, Germany
[4] Institut für Strahlwerkzeuge (IFSW), University of Stuttgart, Pfaffenwaldring 43, 70569 Stuttgart, Germany

Abstract

Laser drilling of microholes into tool steel (1.2379) with a diameter of about 100 µm and 3 mm depth still constitutes a challenge. Expulsion of the molten metal and its accumulation around the drill hole necessitates a post processing of the surface. Melting processes within the drill hole causes a hole geometry diverging cylindrical shape and the energy input results in microstructure defects and fissures. Concerning this matter, the influence of gas pressure within the scale of vacuum pressure and the use of various process gases (active gas: O_2, air; passive gas: Ar, He, N_2) to the drilling process was analyzed within this thesis. Furthermore, the impact of an additional cold low-pressure plasma, which was generated above the opening of the drill hole, on the drilling process was examined. The aim was to achieve a reduced accumulation of molten metal on the surface, an improved cylindricity of the drill hole as well as a lowered thermal stress on the component through these procedures.

For this purpose, microholes were drilled in a vacuum chamber into tool steel by percussion drilling method at different pressure levels and process gases. The expulsion of molten metal as well as the annealing colors on the sample surface was measured with an optical microscope and laser scanning microscope. By cross-section preparation the drill hole was visualized and measured.

Keywords: laser drilling, plasma, vacuum, low pressure, microhole

1 Fundamentals

Laser-material processing is becoming increasingly widespread in industry. The plasma technology sector is also currently growing. Thus, it is obvious that areas arise in which these technologies overlap and complement each other. For example, it is possible to pattern a surface with a laser and subsequently coat it by a plasma process. However, the two processes work sequential and therefore separate from each other. By contrast, the plasma-assisted laser processes which use both technologies simultaneously are still a marginal phenomenon. However, these processes are a topic with ever-increasing research interest and have already shown some promising research approaches for the future.

One field of research of the institute is surface treatment. Gerhard and Viöl *et al.* showed that plasma assisted laser surface treatment can bring significant advantages over the two separate technologies [2]. It was shown that in the cleaning of surfaces significantly increased erosion of dirt. In this case, the plasma with its high number of free charge carriers and radicals in addition to the ablation effect of the laser causes a particularly good removal of oxide layers and coatings such as paints. [3, 4]

A research work with high relevance present Gerhard and Wienke *et al.* concerning the engraving (microstructuring) of steel [1]. A reduction in spatter formation was demonstrated by the use of a plasma in parallel with laser material processing. For this purpose, a kind of plasma nozzle was used which generates a non-thermal plasma at atmospheric pressure between the nozzle head and the workpiece. A gas stream of 20 slpm of compressed air was fed to the processing site via this nozzle. The laser radiation source used was an Nd:YLF-laser. The engravings were mainly done in stainless steel. The results show that when laser and plasma are processed simultaneously, a significant decrease in the zone of increased spatter formation can be seen. In addition, the zone of molten material is growing, but the total area affected by the process decreased. With sequential implementation of the laser and plasma processing, these effects are recognizable only to a small extent. The increased penetration is due to a pre-

*E-mail address of corresponding author: georg.umlauf@igb.fraunhofer.de

heating of the workpiece due to the plasma and the displacement of the process fume caused by the gas flow. Another decisive factor is a chemical reaction between the ablated material and the radicals of the plasma, to which the decrease in spattering is attributed. [1] The aim of this work is to investigate the influence of an additionally generated plasma on the microhole quality. The influence is closely related to the process gas used and the gas pressure during processing, further aspects need to be considered. The basic ideas are:

- With decreasing gas pressure it is possible to increase the borehole depth.
- The use of different process gases can influence the quality of the microhole.
- An additionally generated plasma above the microhole inlet has a positive effect on the achievable microhole depth and the borehole quality.

2 Experimental Setup

The experimental setup is divided into two main parts, the vacuum chamber and the processing laser. Figure 1 shows a 3D model of the vacuum chamber. Through the top quartz glass (1), the laser is coupled into the chamber from above. The beam passes the electrode (5) through a hole before it hits the sample (3). The sample is clamped by two laterally pressing grub screws. The sample holder is mounted on a screw-out lid, which allows to place the samples always in the same position. The cover of the high voltage feedthrough (6) is made of polytetrafluoroethylene for insulation. It isolates the high voltage feedthrough (4) from the grounded remaining chamber and seals the chamber from the environment.

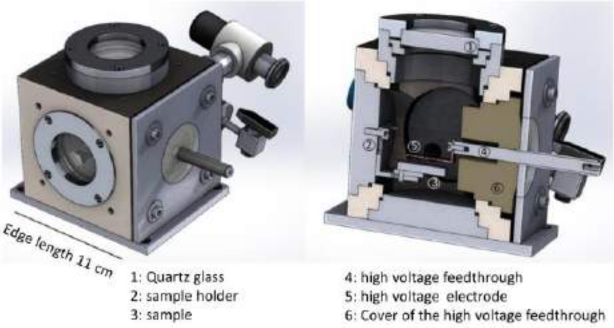

Figure 1: Illustration of the 3D model of the vacuum chamber with a sectional view and inscription of main components.

The drilling experiments took place in a separate test room (see figure 2) to avoid exposure to other workers in the work hall due to laser radiation. As a processing laser, the TruMicro 3040 (Trumpf, Germany) for micromachining such as engraving, cutting and drilling was used. It is an Nd:YLF-laser (wavelength 1047 nm) which is pumped by means of a diode laser. The laser generates pulsed radiation with a pulse duration of 20 ns and a focus diameter of 45 μm. The pulse energy can be freely selected in a range of 0.1 mJ to 4 mJ and the repetition rate of 16 Hz to 4 kHz. In this purpose a pulse energy of 4 mJ was fixed. The repetition rates used were the frequencies 0.5 kHz and 4 kHz. The laser is set up via its own computer with user interface, which can be accessed both in the laser lab and from outside.

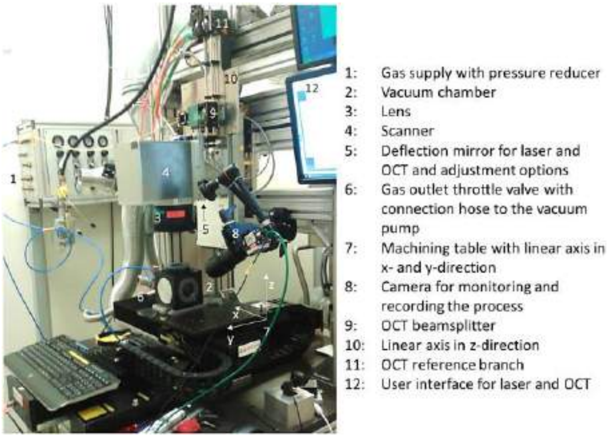

Figure 2: Overview of the laser test stand and its elements.

The sample material used is the high-alloy tool steel 1.2379 (eutectic Ledeburit microstructure) which, due to its wear resistance and high compressive strength, is mainly used in the area of knives for cutting tools and dies for deep drawing and extrusion tools. It has good nitriding and coatability, is rated for durability and low distortion. The edge dimension of the material is 10.3 mm width, 5.2 mm height (tolerance: ±0.2 mm).

2.1 Experiment execution

The experiments were divided into two phases. In the first phase, the effects of gas pressure (<0.1 mbar, 1 mbar, 10 mbar, 100 mbar, 1000 bar), gas type (air, nitrogen, oxygen, helium and argon) and laser repetition rate on the drill hole depth, the ejection and the tempering colors on the surface were investigated. In the second phase, the influence of a plasma on the drilling process was investigated.

2.2 Plasma generating

To generate the plasma, a kilohertz frequency generator (HPG-2, Eni Systems, England) was used. With this generator a voltage in the range of kilovolts, at a plasma excitation frequency of 325 kHz was generated. At the generator, the emitted power (forward) as well as the approximate plasma power (load) can be set. The load setting is equal to the difference between the transmitted power and the reflected power and is about one third of the forward power. The plasma powers have been set in load mode. The set plasma output was 10 W. The plasma excitation frequency was chosen based on preliminary experiments regarding large-area ionization within the vacuum chamber. Since a suitable plasma generation with this type of generator is possible only up to a gas pressure of about 30 mbar, the experiments on the influence of an additional plasma on the pressure levels 10 mbar, 1 mbar and <0.1 mbar were determined. Figure 3 shows the ionization of air in the vacuum chamber at the three pressure levels.

One electrode through which the laser beam passes was made of copper. The counter electrode (electrical ground) was the sample itself.

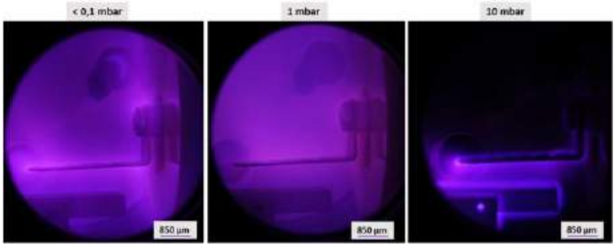

Figure 3: Plasma in the vacuum chamber at different air pressures.

3 Results and Discussion

The investigations were carried out to investigate the influence of gas pressure, process gas, laser repetition rate, and additionally generated plasma on the laser drilling process.

The influence of the gas pressure on the microhole depth showed a different behavior in use several process gases. For the gases oxygen, helium and argon, an increase in the borehole depth with decreasing gas pressure could be proven.

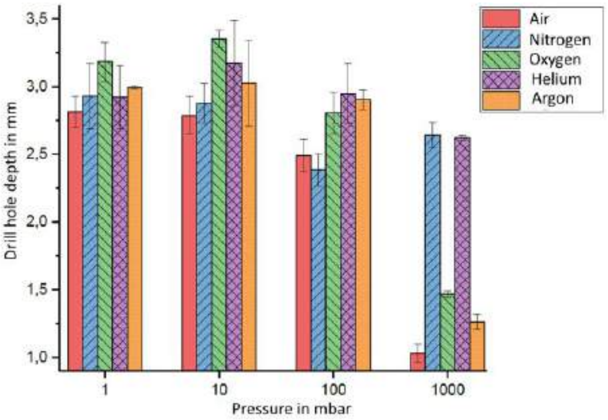

Figure 4: Borehole depth depending on the pressure and the process gas at a repetition rate of the laser of 0.5 kHz.

A reduction of the gas pressure from atmospheric pressure to 100 mbar showed the greatest increase in depth. An increase in the microhole depth of over 100% copaned to atmosphere pressure was found for argon and oxygen at 100 mbar. Helium, on the other hand, showed a smaller increase in the microhole depth, but this is also due to the fact that the use of helium at atmospheric pressure leads to an above-average borehole depth. In the case of the holes drilled as a reference, although an increase in the depth of the drill hole with decreasing gas pressure occurs, the differences are not significant. For nitrogen, no increase in the microhole depth could be detected with decreasing gas pressure. However, in comparison with the other gases tested at atmospheric pressure, the maximum microhole depth was found. Responsible for these effects is the behavior of the material vapor expansion in connection with the ionization processes above the borehole entry. This can be a starting point for possible subsequent investigations. High speed recording of the drilling process (in conjunction with the OCT) could detect absorption events and likely shielding of the borehole due to plasma effects.

The use of the various process gases clearly showed an influence on the formation of the microhole. It should be noted, however, that a thoroughly positive influence compared to the reference under air can not be given. Cylindrical boreholes could be produced by using oxygen as the process gas, but redox reactions take place on the surface which reduces the quality of the surface.

Figure 5: Influence of the process gas on the shape of the borehole at 10 mbar process pressure. Illustrated by micrographs cross sections, etched with Adler.

The nature of these reactions, also considering possible reactions of the steel with nitrogen, were be proven by XPS measurements.

Nitrogen showed, in addition to the mentioned high hole depth at atmospheric pressure, a strong ramification of the bore. That is, often due to melt effects, a clear cylindrical well could no longer be recognized. For the determination of the borehole and the ramifications, a computed tomography (CT) investigation in combination with the used measuring methods could possibly provide further insights. The use of noble gases leads to minor changes in the quality of the borehole. However, with helium, increased curvature of the bore holes from the bore axis was noted which is attributed to plasma processes in the borehole. The use of noble gases leads to a strong formation of tempering colors on the surface. For them, however, processes close to the surface are held responsible and thus do not suggest an increased thermal load on the entire basic material. A heat-affected zone with the formation of fine-grained microstructures could not be demonstrated by etching the metallurgical cross-sections.

A change in the laser repetition rate showed no significant influence on the material deposited around the hole as well as the depth of microhole (see figure 6).

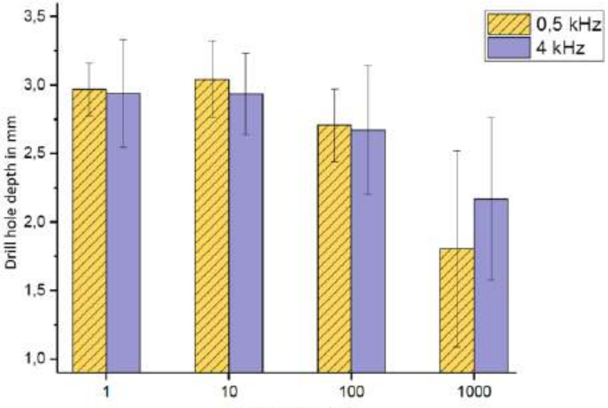

Figure 6: Influence of the repetition rate on the borehole depth at different pressures (summary of all gases used).

In the case of the tempering colors, an influence of the repetition rate appears, which can be explained by different fluid mechanics and ionization processes. However, these changes are not significant either. The use of an additionally generated plasma above the borehole entry does not have a significant effect on the depth of the drill hole, as well as on the quality of the borehole.

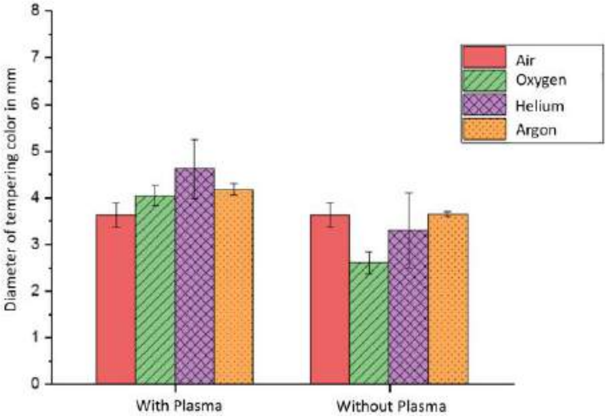

Figure 7: Plasma influence on the diameter of the tempering colors on the surface of the samples at 10 mbar working pressure.

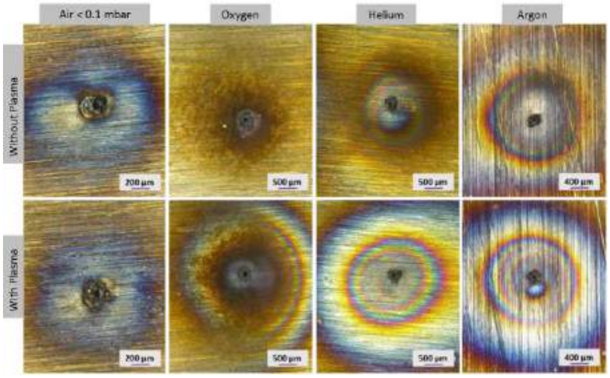

Figure 8: Influence of a plasma on the tempering colors, drilled at 10 mbar working pressure. The reference is a sample drilled under air at a pressure <1 mbar.

It must be kept in mind, however, that the difference in power densities between plasma (≈ 3 W / cm²) and laser (≈ 1 MW / cm²) in this work is very high. A significant influence of the drilling process by an plasma at a higher power density, possibly to be achieved by means of another high-frequency generator or a bundling of the plasma, is hereby not excluded.

Acknowledgement

The scientific investigations of this paper are funded by the German Research Foundation (DFG) within the priority program SPP 1676 Dry Metal Forming - Sustainable Production by Dry Processing in Metal Forming. More Information can be found at: www.trockenumformen.de.

References

[1] Gerhard, C.; Wieneke, S. und Viöl, W. (Hrsg.): *Laser Ablation Fundamentals, Methods and Applications: On The Debris Formation During Atmospheric Pressure Plasma-Assisted Laser Engraving Of Stainless Steel*. Hauppauge, New York: Nova Science Publishers Inc 2015. S. 167-177.

[2] Gerhard, C.; Viöl, W. und Wieneke, S.: Plasma-Enhanced Laser Materials Processing, InTechOpen- Plasma Science and Technology - Progress in Physical States and Chemical Reactions (2016). S. 31–51.

[3] Pflugfelder, C.; Mainusch, N.; Viöl, W.; Castillejo, M. (Hrsg.) *et al. : Lasers in the conservation of artworks: Removal of unwanted material from surfaces of artistic value by means of Nd:YAG laser in combination with cold atmospheric-pressure plasma*. Boca Raton: CRC Press 2008.

[4] Mainusch, N.; Pflugfelder, C.; Ihlemann, J. und Viöl, W.: *Plasma Jet Coupled with Nd:YAG Laser: New Approach to Surface Cleaning*, Plasma Processes and Polymers **4** (2007) S1. S33-S38.