Romanian Reports in Physics, Vol. 67, No. 4, P. 1616–1624, 2015

Dedicated to
International Year of Light 2015

LASER CUTTING OF SMALL-DIAMETER HOLES IN ALUMINUM AND CARBON-STEEL SHEETS

G.D. CHIOIBASU, C. VIESPE

National Institute for Laser, Plasma and Radiation Physics, PO Box MG-36,
RO-077125 Bucharest – Magurele, Romania,
E-mails: chioibasu.georgiana@inflpr.ro, cristian.viespe@inflpr.ro

Received September 29, 2015

Abstract. This paper experimentally investigates the laser cutting of small-diameter holes by a continuous solid-state laser, connected by optical fibers to a computer numerical control machine. The effects of the laser power and the assisting gas pressure processing parameters were evaluated. The holes were cut into aluminum and carbon-steel sheets.

Key words: laser cutting, laser processing parameters, small-diameter holes, tapered holes.

1. INTRODUCTION

Laser-cutting technology, established in 1970, is the most common and important industrial laser application. This is primarily due to the accuracy, speed, production flexibility, and high quality of the final product. These are just a few of the advantages of laser-cutting technology compared with other cutting methods such as flame, plasma, and water jet [1–5].

During the laser-cutting process, the laser beam is focused onto the material, which causes rapid heating of the metal until fusion. A high-pressure gas jet is used to protect the lens, remove melted material, and keep the workpiece cool. There are certain processing parameters that are important for laser-cutting technology, *e.g.*, laser power, type of gas jet, speed of movement, and nozzle diameter [6–8]. Even if there is no mechanical contact between the workpiece and the cutting tool, the high temperatures generated during the process may lead to structural changes and deformations of the part [9–10].

The main purpose of these experiments was to optimize the cutting parameters for cutting holes with diameters of 200–300 μm in aluminum and carbon-steel sheet. The study focused on optimizing the laser power and gas pressure; the former ranged from 200–800 W and the latter was varied from 8–20 bars. Such small-diameter holes could be used in filters in various fields, such as aerospace and the civil construction industry.

2. EXPERIMENTAL

A schematic diagram of the laser-cutting process is shown in Figure 1. The sketch highlights the working principles of the laser-cutting process. The laser beam is directed to a certain focal length (150 mm) by adjusting the nozzle diameter (1.2 mm). The material melts at the moment of contact of the laser with the substrate. Nitrogen is used as the cutting gas (industrial gas of 4.6% purity) to protect the lens against the smoke and dust generated during cutting, to remove ejected molten material, and to cool the workpiece.

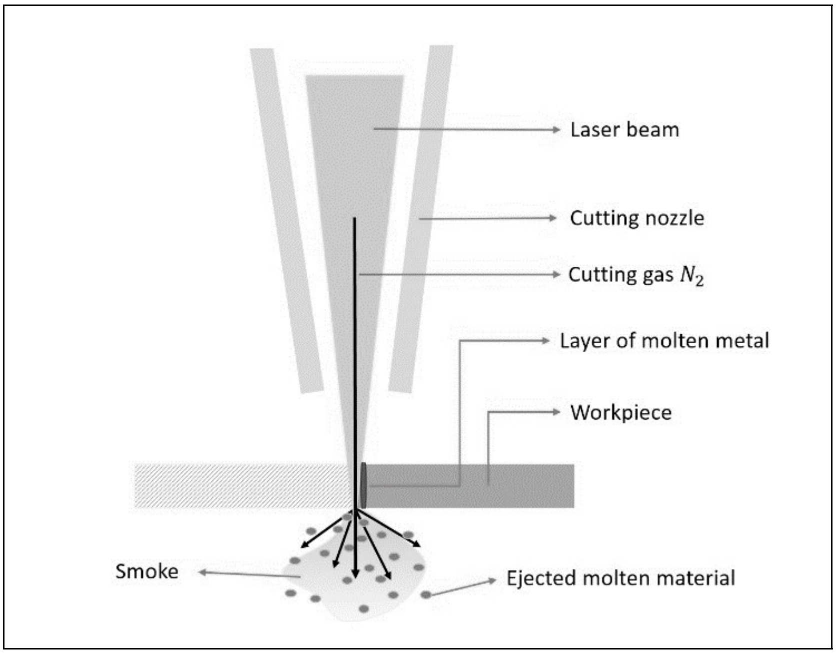


Fig. 1 – Laser-cutting process.

Holes were cut in the materials by a diode-pumped solid-state laser (TruDisk 3001, Trumpf, Germany), which was connected by 100 μm diameter optical fibers to a computer numerical controlled (CNC) machine (TruLaser Cell 3010). The TruDisk 3001 is a Yb:YAG laser with a maximum power of 3000 W, which is sufficiently powerful to cut through metals up to 2.5 cm thick. The laser cutting parameters are presented in Table 1. The TruLaser Cell 3010 is a highly flexible five-axis laser machine that permits cutting and welding in two or three dimensions. The CNC machine has 15 μm accuracy and 50 m/min maximum speed.

Table 1

Laser parameters for cutting

TruDisk 3001	Wavelength	Laser power	Beam quality
	1030 nm	3000 W	4 mm*mrad

A block diagram of the cutting system (Fig. 2) shows the main components: the chiller, laser system, charge-coupled device (CCD) camera, cutting head, optical fibers, machine table, and metal sheet.

Laser radiation is transported through the optical fibers to the machine. The system is entirely computer-controlled. Process visualization is possible *via* the CCD camera. A trinocular stereozoom microscope (SZM–LED2, Optika, Italy) connected to an Optikam Pro3 (Optika, Italy) video camera was used to analyze the quality of the holes.

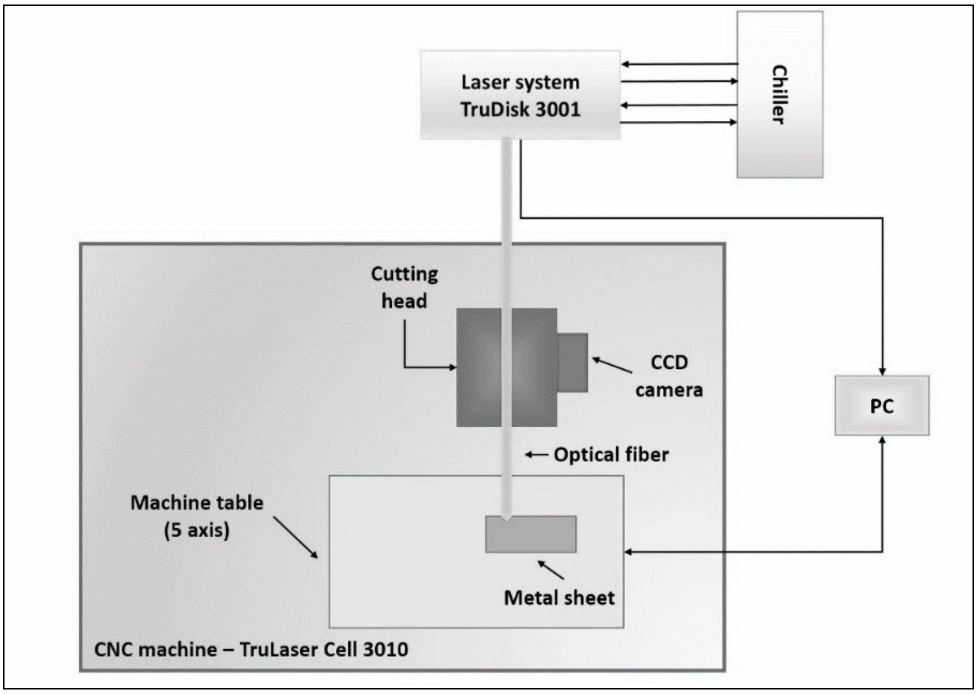


Fig. 2 – Cutting system.

Cutting of the small holes was optimized by varying the laser power and gas pressure. In total, 66 tests were performed using two types of materials, with 33 tests for aluminum and 33 tests for carbon-steel. The material thickness was 1 mm for both. Six holes were made for each test, separated by 600 μm center-to-center (Fig. 3).

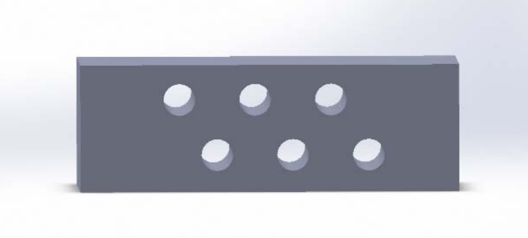


Fig. 3 – Hole representations.

The laser power was varied from 200–800 W and the gas pressure from 8–20 bar. These values were incrementally changed as follows. Given a specific laser power, the gas pressure was varied, and vice versa. Other important cutting parameters include the speed, nozzle stand-off (the distance between the nozzle and the workpiece), focus line setting value (automatic adjustment of the focus position to the material type and sheet thickness), gating frequency (the number of cycles per unit time) and kerf (the groove or slit cut in the workpiece); however, these parameters remained constant, because it was observed that they did not have a significant influence on the shape or dimension of the holes. The values of these fixed parameters are listed in Table 2.

Table 2

Cutting parameters

Speed	3.200 m/min
Nozzle stand off	0.70 mm
Focus Line setting value	– 0.6 mm
Gating frequency	20000 Hz
Kerf	0.040 mm

3. RESULTS AND DISCUSSION

Figure 4 shows the best-quality holes made in the aluminum sheet (when no smoking occurred and the minimum amount of material melted). The processing parameters for these holes were 600 W laser power and 16 bars gas pressure. The holes were larger at the laser entrance than on the side where the laser exited. The diameters ranged from 290–330 µm on the entrance side, while at the exit the diameters ranged from 195–230 µm.

Figure 5 shows the best-quality holes made in the carbon-steel sheet. The processing parameters of these holes were 700 W laser power and 10 bars gas pressure. The holes were larger at the laser entrance than at the laser exit. The diameters ranged from 300–350 µm at the laser entrance, and between 200–255 µm at the laser exit.

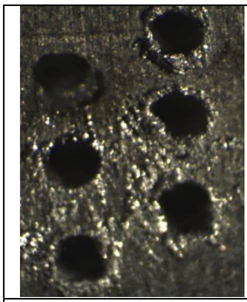
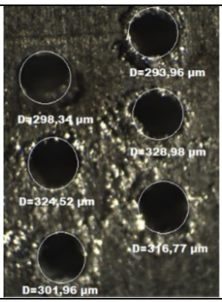
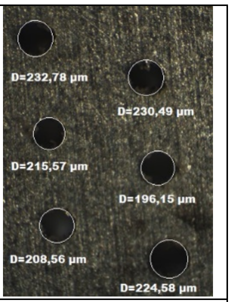
			
Entrance laser	The diameters of the holes – Entrance laser	Exit laser	The diameters of the holes – Exit laser

Fig. 4 – Aluminum sheet: best-quality holes.

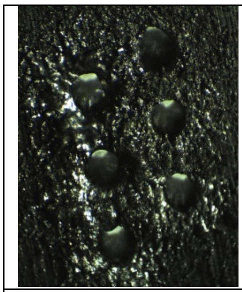
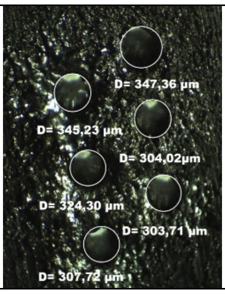
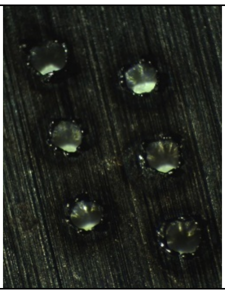
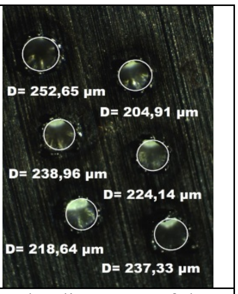
			
Entrance laser	The diameters of the holes – Entrance laser	Exit laser	The diameters of the holes – Exit laser

Fig. 5 – Carbon-steel sheet: best-quality holes.

Figures 6 and 7 show poor-quality holes. Those in the aluminum sheet were made at 300 W laser power and 10 bars gas pressure. These holes show evidence of considerable molten material around the cutting area (Fig. 6).

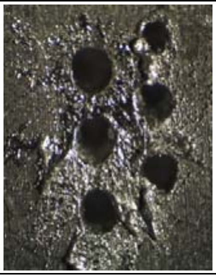
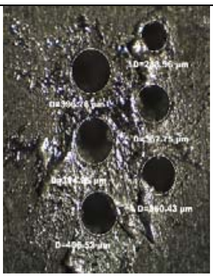
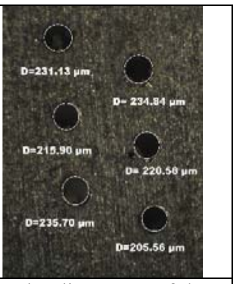
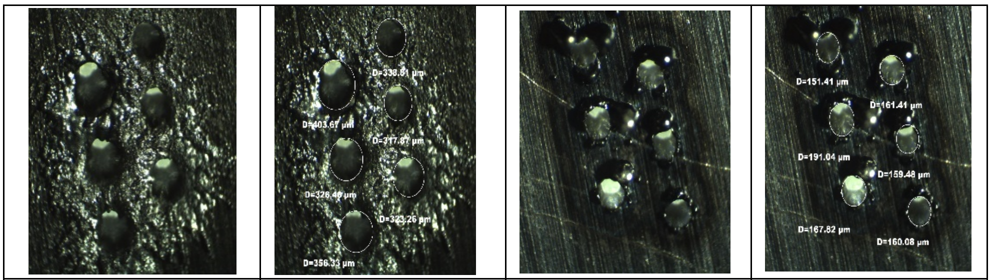
			
Entrance laser	The diameters of the holes – Entrance laser	Exit laser	The diameters of the holes – Exit laser

Fig. 6 – Aluminum sheet: poor-quality holes.

For the carbon-steel, poor-quality holes were formed at 300 W laser power and 10 bars gas pressure (Fig. 7).



Entrance laser	The diameters of the holes – Entrance laser	Exit laser	The diameters of the holes – Exit laser

Fig. 7 – Carbon-steel sheet: poor-quality holes.

The holes processed by laser-cutting technology are tapered. The taper (T) can be calculated as follows:

$$T = \frac{D_{\max} - D_{\min}}{t}, \tag{1}$$

where D_{max} and D_{min} are the hole diameters at the laser entrance and exit, respectively, and t is the sheet thickness (1 mm).

Figure 8 shows the variation in the hole taper for the aluminum sheet as a function of the gas pressure and laser power. The hole taper *decreased* as the laser power and the gas pressure increased.

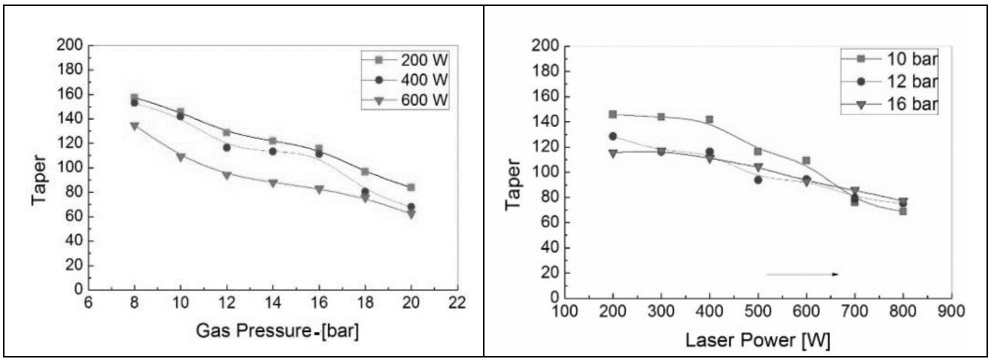


Fig. 8 – Tapered holes in the aluminum sheet.

Figure 9 shows the variation of the hole taper for the carbon-steel sample as a function of the gas pressure and laser power. Here, the hole taper *increased* as the laser power and gas pressure increased.

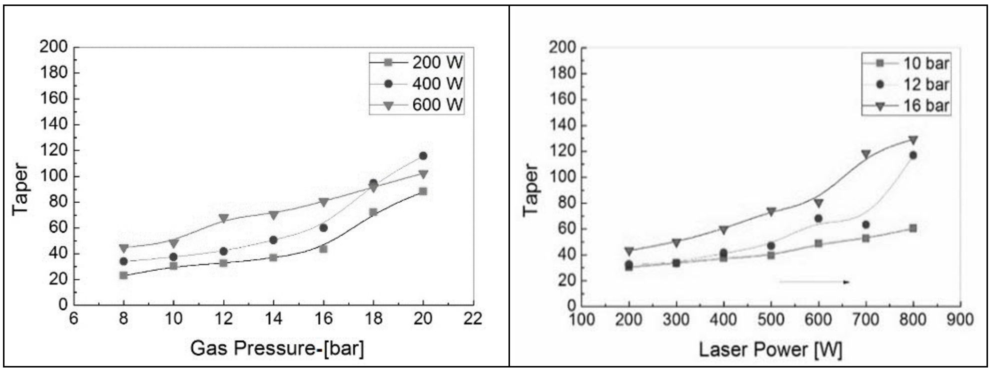


Fig. 9 – Tapered holes in the carbon-steel sheet.

The different trends in hole tapering observed for the aluminum and carbon-steel sheets likely stem from differences in key physical properties of the materials, in particular the thermal conductivity: 266 *vs.* 66 W/m·K for aluminum and carbon steel, respectively [11]. The dependence of the taper on the laser power would seem to support this hypothesis [12].

4. CONCLUSION

A continuous-wave solid-state laser connected to a five-axis CNC machine was used to cut small-diameter holes in aluminum and carbon-steel sheets. Industrial nitrogen was used as the gas. The average hole diameters were between 200 μm (on the back) and 300 μm (on the face).

The diameter of the tapered holes in the aluminum sheet decreased with increasing laser power and gas pressure. The best-quality holes were obtained at 600-W laser power and 16 bars gas pressure.

For the carbon-steel sheet, the hole taper increased with increasing laser power and gas pressure. For the carbon-steel sheet, the best hole quality was obtained at 700 W laser power and 10 bars gas pressure. The molten material exiting the table during the laser-cutting process was not completely removed even with 20 bars of gas pressure.

The hole taper depended on the laser power and gas pressure for both the aluminum and carbon-steel sheets.

Acknowledgements. This work was supported by a grant of the Romanian National Authority for Scientific Research, CNCS – UEFISCDI, projects number LAPLAS 4 PN 09 39 01 05, PN-II-PT-PCCA-2011-3.2-0762 and PN-II-RU-TE-2014-4-0342.

REFERENCES

1. A. Goeke, C. Emmelmann, *Influence of Laser Cutting Parameters on CFRP Part Quality*, Physics Procedia, **5**, 253–258 (2010).
2. K. Kellens, G.C. Rodrigues, W. Dewulf, J.R. Duflou, *Energy and Resource Efficiency of Laser Cutting Processes*, Physics Procedia, **56**, 854–864 (2014).
3. A.F.M. Arif, B.S. Yilbas, B.J. Abdul Aleem, *Laser cutting of thick sheet metals: Residual stress analysis*, Optics & Laser Technology, **41**, 224–232 (2009).
4. W. Steen, J. Mazumder, *Laser Cutting, Drilling and Piercing, Laser Material Processing*, 535, 2010.
5. A. Riveiro, F. Quintero, F. Lusquiños, R. Comesaña, J. del Vala, J. Pou, *The Role of the Assist Gas Nature in Laser Cutting of Aluminum Alloys*, Physics Procedia, **12**, 548–554 (2011).
6. M. Harničárová, J. Valíček, A. Öchsner, R. Grznárik, M. Kušnerová, J. Neugebauer, D. Kozak, *Predicting residual and flow stresses from surface topography created by laser cutting technology*, Optics & Laser Technology, **52**, 21–29 (2013).
7. K. Kheloufi, E. H. Amara, *Numerical Investigation of the Effect of Some Parameters on Temperature Field and Kerf Width in Laser Cutting Process*, Physics Procedia, **39**, 872–880 (2012).
8. G. Costa Rodrigues, H. Vanhove, J.R. Duflou, *Direct diode lasers for industrial laser cutting: a performance comparison with conventional fiber and CO2 technologies*, Physics Procedia, **56**, 901–908 (2014).
9. B.S. Yilbas, S.S. Akhtar, O. Keles, *Laser hole cutting in aluminum foam: Influence of hole diameter on thermal stress*, Optics and Lasers in Engineering, **51**, 23–29 (2013).
10. B.S. Yilbas, A.F.M. Arif, B.J. Abdul Aleem, *Laser cutting of holes in thick sheet metals: Development of stress field*, Optics and Lasers in Engineering, **47**, 909–916 (2009).
11. J.R. Davis, *Stainless Steels*, ASM International, 490 (1994).
12. C.J. Wang, G. Chen, D. Luan, P. Zhang, *Effect of Laser Power on the Quality of Drilled Micro Hole Using Cu50Zr50 Amorphous Alloys Foils*, Micromachines, **5**, 1061–1068 (2014).