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@inlpr.ro, cristian.viespe@inlpr.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.

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

<table>
<thead>
<tr>
<th>Laser parameters for cutting</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TruDisk 3001</strong></td>
</tr>
<tr>
<td>1030 nm</td>
</tr>
</tbody>
</table>

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.

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 carbone-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).
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

<table>
<thead>
<tr>
<th>Cutting parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed</td>
<td>3,200 m/min</td>
</tr>
<tr>
<td>Nozzle stand off</td>
<td>0.70 mm</td>
</tr>
<tr>
<td>Focus Line setting value</td>
<td>−0.6 mm</td>
</tr>
<tr>
<td>Gating frequency</td>
<td>20000 Hz</td>
</tr>
<tr>
<td>Kerf</td>
<td>0.040 mm</td>
</tr>
</tbody>
</table>

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

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

\[
T = \frac{D_{\text{max}} - D_{\text{min}}}{t},
\]

where \(D_{\text{max}}\) and \(D_{\text{min}}\) 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.

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.
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