FABRICATION OF MICRO-CHANNELS ON MILD STEEL USING LASER INDUCED MICRO-MACHINING

Sanasam Sunderlal Singh1, Kh. Shantakumar2, Alika Khare2 and S.N. Joshi1*

1Department of Mechanical Engineering, Indian Institute of Technology Guwahati, Guwahati -781 039, Assam, INDIA
2Department of Physics, Indian Institute of Technology Guwahati, Guwahati - 781 039, Assam, INDIA

*Corresponding author: email: snj@iitg.ernet.in

Abstract

Laser Induced Micro-machining (LIMM) uses a focused high power laser beam to remove volume of material by using the phenomenon of ablation. In comparison with mechanical micro-machining operations, it offers better machining efficiency in terms of accurate work or feature geometry, efficient debris removal, and better surface morphology. This is due to the fact that laser can be very precisely focused onto the work piece and results into the removal of material from the focal volume only. In this present work, an experimental study on manufacturing of micro-channels of width 150 µm on mild steel, by focusing the second harmonic of a high power Q-switched Nd:YAG laser, has been presented. Initially two sets of experiments have been carried out by varying the scan speed of the sample. The laser energy was kept constant in both the cases. The work specimen was characterized for dimensional accuracy and shape of the channel generated. These preliminary results are encouraging to manufacture the micro-grating on mild steel as an important component of micro fluidic applications.

Keywords: Laser induced micromachining, micro fluidic, micro-channels

1 Introduction

Microchannel fabrication has been an emerging technology for micro fluidic devices requiring effective functional performance in terms of heat transfer, material transport and separation of particles. The demand for miniaturize microchannel features in PEM fuel cell, VLSI micro heat sink in electronic product and blood diagnosis devices are some of field where effective material transport, heat transfer and separation of particles are preferred respectively. Fabrication of micro fluidic channels have been tremendously increase leading to the development of micromachining which is one of the key technologies that can fuel such requirements. Micromachining indicates ‘micrometer’ and represents the range of 1µm to 999µm. In recent years, laser beam micromachining has emerged as one of the dominant non-contact processing tools in the fabrication of micro-components. Application of lasers has advantages such as ability of narrow cut, minimum heat affected zone (HAZ), accuracy, smooth and flat edges, minimal deformation of a workpiece, and intricate profiles and fast adaptation to changes in manufacturing programs. This laser based micromachining attracts wide range of research.

In laser induced micromachining, laser beam is focused by a lens system and the focused beam is used to irradiate work surface, removing a small portion of the material by melting and vaporization. The process of removing the material is known as ablation. Ablation of metals is caused by the absorption of laser energy and it involves absorption of photons by electrons and transferred of energy to the lattice. It is generally accepted that two phenomena happen during the ablation process i.e. photochemical ablation and photo-thermal ablation. Photochemical ablation involves the absorption of photons leading directly to bond breaking in the material without any intermediate heat dissipation while in photo-thermal ablation, deposited energy will be converted to heat and decomposition happens since heating vaporizes materials. The power density influences the vaporization rate and high vaporization rate causes a shockwave that can reach pressure of more than 50 kbars [Fabbro et al. (1990)]. The high pressure created during the melting and superheating of liquid at the end of laser pulse ejects the material at high speed. The general parameters which control laser machining are laser wavelength, focal length of lens, beam shape, laser intensity, pulse width, pulse repetition rate, dielectric medium, laser power, depth of focus and working environment (vacuum/inert/air/liquid). The output parameters are material Removal Rate (MRR), machining geometry (kerf width, hole width, taper), surface quality (surface roughness, surface morphology), metallurgical characteristics (recast layer, heat
affected zone, dross inclusion) and mechanical properties (hardness, strength).

Investigations have been carried out on machining of glass matrix composite comprising SiC fibres in a borosilicate glass matrix. It has been reported that the material removal primarily depends on the pulse energy than the pulse duration [Ian et al. (1998)]. The effect of cutting parameters on the cut quality of ultra low carbon steel thin sheets has also been studied considering heat affected zone (HAZ) as the output parameter. It was found that HAZ increases with increase in laser power and decreases with increase in scanning speed and gas pressure [Hanadi et al. (2008)]. Rajaram et al. (2003) reported that power plays a major role on the kerf width while feed rate played a minor role for experiments conducted on 4130 steel using CO$_2$ laser. Decreasing power and increasing feed rate generally led to a decrease in kerf width and HAZ. An increasing feed rate generally increases surface roughness and striation frequency. Comparison of CO$_2$ laser cutting with CW and pulsed mode laser operation with different shear gases namely argon, helium and nitrogen were carried out on titanium sheet by Rao et al. (2005). Use of helium as shear gas results in narrow HAZ and low dross as compared to that of Ar owing to high heat convection and shear stress provided by helium. However, the laser cut edge produced by helium results in waviness of the cut. Rough surface and incomplete cutting has been observed on increasing the speed during the pulsed mode laser cutting of 1.2mm thick austenitic stainless steel sheet owing to the pulse separation and insufficient overlapping while increasing the speed with increase in power results in better quality, smoother surface and smaller kerf width in continuous wave mode using Nd:YAG laser as reported by Ghany and Newishy (2005).

The cutting quality of laser machining depends on many input process parameters such as wavelength; pulse energy, pulse duration, optical and thermal properties of the material, composition and pressure of assist gas etc. Therefore, optimization of these process parameters is required to determine the optimal input process parameters. Sharma et al. (2010) employed Taguchi L$_{27}$ orthogonal array to optimize the input parameters for both straight and curved cut profile during Nd:YAG laser cutting of Nickel based super alloy thin sheet. It was observed that the optimum input parameter levels for curved cut profiles are entirely different from straight cut profiles except kerf width. Optimization of the multi performance for Nd:YAG laser cutting of nickel based superalloys has been carried out using grey relational analysis for quality characteristics of average kerf taper and average surface roughness [Sharma and Yadava (2011)]. It was observed that cutting speed was the most significant cutting parameter for minimizing the value of average kerf taper and average surface roughness whereas pulse frequency, pulse width and oxygen pressure were less significant parameters.

Fabrication of microchannel has been carried out in different material such as polymer, glass, ceramic, silicon and metallic material based on their functional suitability [Wang et al. (2006), Bahadorimehr and Majlis (2011), Malecha and Golonka (2008), Tuckerman and Pease (1981) and Lee et al. (2007)]. Fulfillment of low cost [Paulraj et al. (2012)] and high conductivity [Lee et al. (2007)] bipolar plate compared with graphite and silicon bipolar plate has led to fabrication of microchannel stainless steel bipolar plate. Fabrication of microchannel on stainless steel has been carried out using different techniques such as micro-stamping [Chen and Ye (2013)], array thin slotting cutters [Wan et al. (2014)], wet chemical etching[Park et al. (2004)] and combination of UV-LIGA and electroforming for application in PEM fuel cell[Lee et al. (2007)]. All the above methods are time consuming and require multiple step or presence of burr. In this present work, low cost, time efficient and burr free method of microchannel fabrication has been carried out using Q-Switched Nd: YAG pulsed laser on mild steel work sample. The effect of the transverse speed on the width and depth of the micro channel has been evaluated using non-contact high precision profilometer.

2 Experimental details

In order to observe the effect of the scan speed on the surface roughness, laser micro channeling were carried out using Q-switch Nd:YAG nanosecond pulse laser having wavelength of 532nm, frequency of 10Hz, spot size of $8.31 \times 10^{-3}$ cm$^2$ and pulsed duration of 10 ns on work sample in ambient environment. The pictorial view and schematic diagram of the experimentation is as shown in Fig. 1 and Fig. 2 respectively. The work sample used for the experimentation is mild steel of dimension 30X10X3 mm. The sample is finely polished by mounting on a double disc rotating polishing machine. The polished work sample is then irradiated with Q-switched Nd: YAG laser over a scanning length of 15mm. The experimental details are as listed in table 1.

Figure 1 Pictorial view of the experimental set-up
Figure 2 Schematic diagram of the experimental set-up

Table 1 Experimentation details

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Sample 1</th>
<th>Sample 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy intensity</td>
<td>30 mJ</td>
<td>30 mJ</td>
</tr>
<tr>
<td>Focal length</td>
<td>150mm</td>
<td>150mm</td>
</tr>
<tr>
<td>Length of traverse</td>
<td>15mm</td>
<td>15mm</td>
</tr>
<tr>
<td>Speed</td>
<td>1800 step/second (540 µm/sec)</td>
<td>900 step/second (270 µm/sec)</td>
</tr>
</tbody>
</table>

3 Results and Discussion

After irradiation with nanosecond laser of single pass, formation of microchannel has been observed. Figure 3 shows the pictorial view and profilometer image of the microchannel formed as observed by non-contact high precision profilometer. It is observed from the figure that the formed channel is uniform throughout the traversed length. The width and the depth of the channel were being measured from the generated profilometer curve. For the analysis, channel width and depth of cut readings have been taken at four different sections of the channel length namely section A-A, B-B, C-C and D-D. The sections are taken at equal intervals as shown in Fig. 4.

Figure 3(a) Pictorial view and 3(b) Profilometer image of the microchannel

Figure 4 Scanned area and roughness measured at different sections of the microchannel

Figure 5, 6, 7 and 8 shows the roughness profile of the microchannel as generated by the profilometer. Thorough analysis of the roughness profile has been done to determine the width and depth of the microchannel. The readings are as tabulated in Table 1.

Figure 5 Roughness profile of the microchannel at scanning speed of 540 µm/sec showing width of the microchannel

Figure 6 Roughness profile of the microchannel at scanning speed of 540 µm/sec showing depth of the microchannel

Figure 7 Roughness profile of the microchannel at scanning speed of 240 µm/sec showing width of the microchannel
FABRICATION OF MICRO-CHANNELS ON MILD STEEL USING LASER INDUCED MICRO-MACHINING

Figure 8 Roughness profile of the microchannel at scanning speed of 240 µm/sec showing depth of the microchannel

Table 1 Experimental results

<table>
<thead>
<tr>
<th>Sample</th>
<th>Traverse speed</th>
<th>Section</th>
<th>Width (µm)</th>
<th>Depth (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample 1</td>
<td>540 µm/sec</td>
<td>A-A</td>
<td>134</td>
<td>3.93</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B-B</td>
<td>121</td>
<td>4.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C-C</td>
<td>104</td>
<td>3.04</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D-D</td>
<td>100</td>
<td>5.94</td>
</tr>
<tr>
<td>Sample 2</td>
<td>270 µm/sec</td>
<td>A-A</td>
<td>141</td>
<td>3.51</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B-B</td>
<td>156</td>
<td>2.81</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C-C</td>
<td>121</td>
<td>4.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D-D</td>
<td>168</td>
<td>2.46</td>
</tr>
</tbody>
</table>

Figure 9 Effect of laser scanning speed on width of the microchannel at four sections

Figure 9 shows the effect of laser scanning speed on width of the microchannel at four different sections. It is clearly observed from the figure that with increase in scanning speed, the width of the microchannel decreases. This is due to reduce interaction time of the laser beam with the work sample

4 Conclusions

Microchannel upto a width of 100 µm with a depth of 5.94 µm has been successfully fabricated in this present work. Decreasing in width of the microchannel with increase in scanning speed as observed in this work is in agreement with the available literatures. Further analysis can be done to study the effects of fluence, wavelength and pulse duration on the width and depth of microchannel.

References


