Optik - International Journal for Light and Electron Optics 171 (2018) 694–705

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.com/locate/ijleo

Original research article

Metal micro-hole formation without recast layer by laser machining and electrochemical machining

Aixi Sun[a], Yubo Chang[b], Hongjun Liu[c,*]

[a] School of Mechanical Engineering, Nanjing University of Science and Technology, Nanjing 210094, China
[b] Nanjing Institute of Advanced Laser Technology, Nanjing 210038, China
[c] School of Mechatronics Engineering, Shenyang Aerospace University, Shenyang 110136, China

ARTICLE INFO

Keywords:
Laser machining
Electrochemical machining
No recast layer
Metal micro-hole
Optimized parameters

ABSTRACT

Laser machining and electrochemical machining (LM-ECM) of metal micro-hole is presented in this study. Millisecond pulsed laser etches metallic materials by thermal effect, and electrochemical machining removes recast layer. No recast layer is produced on the wall of metal micro-holes. Machining accuracy and efficiency are improved. Prefabricated micro-hole modeling of laser machining and metal micro-hole modeling of electrochemical machining are established. The main process parameters of LM-ECM are determined by the models. Effects of the process parameters on experimental results are investigated and the optimized parameters are given. Comparison between LM-ECM and single machining approaches is made. The experimental results revealed that the material surface of LM-ECM is cleaner than single laser machining and do not have molten slag. There is no recast layer on the wall of the micro-holes. Compared to single electrochemical machining, the efficiency and accuracy of LM-ECM are improved by 51.35% and 30.43% respectively.

1. Introduction

Lasers have been employed in hole processing due to fast machining for an automated machining system. Metal sheets were holed with recast layer by Nd:YAG laser [1]. The use of nanosecond laser reduced the amount of recast material with respect to long pulses [2]. In order to further reduce the thickness of recast layer, metals were removed by picosecond pulse laser with pulse width shorted [3]. However, recast layer was produce in the laser processing. Water was applied to solve the problem. Underwater Nd:YAG laser machining reduced the thickness of recast layer [4] and recast layer was not completely removed. Underwater picosecond laser processing reduced recast layer [5], and recast layer was not eliminated. Femtosecond laser machining under

a thin water film resulted in no recast with fine cut surface quality [6]. Machining efficiency of femtosecond laser was low. Electrochemical machining had high accuracy, no heat-affected zone and low efficiency by using mixed electrolyte [7], microtool vibration [8] and other methods. For recast layer removal and improved efficiency, the researchers at home and abroad studied that electrochemical machining was applied in laser processing. Long et al. realized the effect of pulse laser heating owing to laser moving and liquid cooling when a continuous wave (CW) laser heating a material in a liquid [9]. A very serious transverse etching was in the fixed point. Wang et al. noted that machining accuracy was improved by laser electrochemical compound masking microfabrication [10] and the efficiency was low. Zhang et al. studied that the laser shock pressure and electrochemical dissolution removed recast layer totally [11], and laser electrochemical machining had low efficiency. Zhao et al. found that recast and spatter are effectively

* Corresponding author.
E-mail address: 13386878635@163.com (H. Liu).

https://doi.org/10.1016/j.ijleo.2018.06.099
Received 2 May 2018; Accepted 21 June 2018

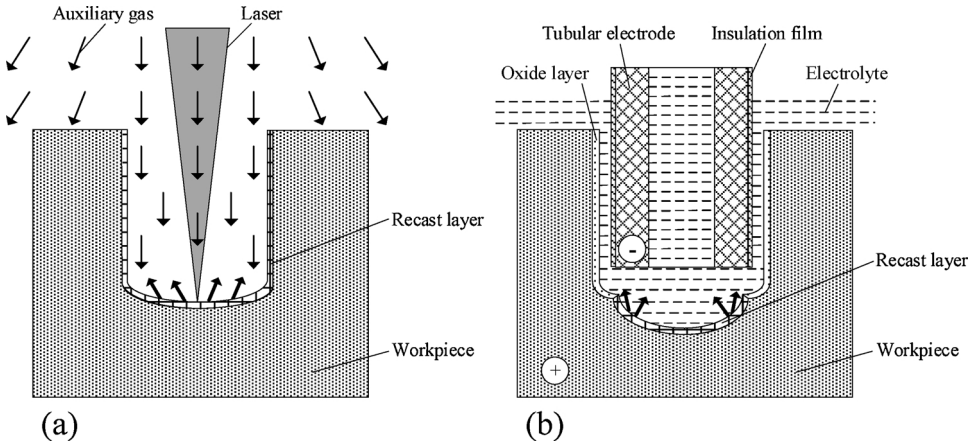

Fig. 1. LM-ECM: (a) laser machining; (b) electrochemical machining.

reduced during the process of laser milling assisted with jet electrochemical machining [12]. Sun et al. proposed that recast layer was removed by electrochemical effect [13]. Machining efficiency was low because of the attenuation of laser beam in electrolyte and small laser energy. Now, there were not the key techniques of high quality machining of metal micro-holes. It is very necessary to study a new machining technique to solve the formation problem of the holes.

LM-ECM of metal micro-hole is presented in this study. Millisecond pulsed laser removes metallic materials by thermal effect, and electrochemical machining removes recast layer. There is no recast layer on the wall of metal micro-holes. Machining accuracy and efficiency are improved. Metal micro-hole modeling of LM-ECM can determine the main process parameters. Effects of process parameters on experimental results are investigated. Comparison between LM-ECM and single machining approaches is made.

2. LM-ECM

LM-ECM is shown in Fig. 1. Metal micro-holes are machined from start to formation in one step. Firstly, under the effect of auxiliary gas, millisecond pulsed laser is focused on metal. Materials are etched rapidly to form a prefabricated micro-hole. Moreover, auxiliary gas carries away molten materials and reduces heat affected zone. Secondly, based on the prefabricated micro-hole, recast layers on the hole wall are removed totally by electrochemical machining. The metal micro-hole without recast layer is machined. High frequency pulse power supply, tubular electrode with a side wall insulation film and low concentration electrolyte are used during the process of machining. The machining efficiency and accuracy are improved.

3. Metal micro-hole modeling of LM-ECM

3.1. Prefabricated micro-hole modeling of laser machining

The three-dimensional equation of heat conduction [14] in the metal can be expressed as:

$$\rho c\frac{\partial T}{\partial t} = \lambda\nabla^2 T + q \tag{1}$$

Where ρ, c, λ, T and q are metal density, specific heat capacity, thermal conductivity, metal temperature after laser pulse and heat flux density of laser, respectively.

Table 1
Process parameters of LM-ECM.

Process parameters	Level			
	1	2	3	4
Pump current (A)	120	200	240	300
Laser pulse width (ms)	2	6	8	10
Laser pulse frequency (Hz)	1	10	20	30
Applied voltage (V)	5.5	7	8.5	10
FS (kHz)	1	6	11	16
DR	0.45	0.5	0.65	0.8
Feeding speed (μm/s)	2	6	8	10
Initial machining gap (μm)	40	45		