Diamond & Related Materials 60 (2015) 99–110

Contents lists available at ScienceDirect

Diamond & Related Materials

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

On the laser-driven integrated dressing and truing of bronze-bonded grinding wheels☆

Genyu Chen [a,b], Song Cai [a,*], Cong Zhou [a]

[a] State Key Laboratory of Advanced Design and Manufacturing for Vehicle Body, Hunan University, Changsha, Hunan 410082, China
[b] Laser Research Institute, Hunan University, Changsha, Hunan 410082, China

ARTICLE INFO

Article history:
Received 11 June 2015
Received in revised form 8 October 2015
Accepted 23 October 2015
Available online 5 November 2015

Keywords:
Laser ablation
Bronze-bonded diamond grinding wheel
Heat transfer model
Numerical analysis

ABSTRACT

This paper analysed the physical process of multipulse laser ablation of a bronze–diamond grinding wheel. The analysis considered the effects of phase explosion, plasma shielding effects and energy accumulation under the pulse interval, and it includes heat transfer equations for multipulse laser ablation of the bronze-bonded diamond grinding wheel. The model was applied for numerical simulation of the heat transfer characteristics in the multipulse laser ablation of bronze and diamond. Next, experiments were conducted to analyse the topography of a bronze-bonded diamond grinding wheel after multipulse laser ablation. The theoretical analysis and experimental results showed that a multipulse laser can merge the truing and dressing on a bronze-bonded diamond grinding wheel. A comparative analysis showed that the numerical solution to the model is in good agreement with the experimental data. This study provides theoretical guidance for optimising the process parameters in the laser ablation of a bronze-bonded diamond grinding wheel.

© 2015 Elsevier B.V. All rights reserved.

1. Introduction

The essence of the technology of bronze-bonded diamond grinding wheel dressing using a pulsed laser is to irradiate a focused pulsed laser beam on a grinding wheel surface rotating at a fixed speed. Through the control of the laser process parameters (the laser energy density, pulse frequency, pulse width, and grinding wheel rotational speed), the selective removal of the grinding wheel surface bond using a laser can be achieved without causing thermal damage to the diamond abrasive. Therefore, the abrasive particles can be at the proper protrusion height above the bonding material, and chip space is formed around the abrasive particles, fulfilling the purpose of the grinding wheel dressing.

In the existing literature, researchers [1–7] have used a YAG ordinary laser pulse to sharpen materials such as resin, bronze-bonded diamond grinding wheels and resin bond CBN grinding wheels. A scanning electron microscope was used to observe the microstructure of the grinding wheel surface before and after the laser dressing, and the removal mechanism of various bond materials on the grinding wheel surface using a laser was analysed. Chen et al. [8–11] used a fibre laser to conduct an extensive dressing experiment study on a super-hard abrasive grinding wheel, and they observed the grinding wheel surface quality and topography after laser dressing. They confirmed that after laser dressing, the melted material on the grinding wheel surface blocked the crater, affecting the grinding wheel performance. At present, the physical process (phase explosion phenomenon, plasma shielding effect, the material energy accumulation factor under the pulse interval) and heat transfer research for multipulse laser ablation of bronze–diamond grinding wheels is rarely reported.

To address the above-mentioned problems, this paper presents a detailed analysis of phase explosion phenomena, plasma shielding effects and the material energy accumulation factor under the pulse interval for multipulse laser ablation of bronze-bonded diamond grinding wheels, and it derives heat transfer equations. Under the relevant conditions, the model was applied for numerical simulation of the heat transfer characteristics in the multipulse laser ablation of bronze and diamond, as well as to obtain the surface temperature field distributions of bronze and diamond. Experiments were conducted to measure the surface pit depth of the ablated bronze-bonded wheel using an ultra-depth three-dimensional microscope system. Additionally, the surface topography of the bronze-bonded diamond grinding wheel after multipulse laser ablation was observed. The theoretical analysis and experimental results showed that radial irradiation of a multipulse laser for conditioning of a bronze-bonded diamond grinding wheel can merge the truing and dressing, which provides theoretical guidance and process optimisation for research on multipulse laser ablation of that type of grinding wheel. The roughness decreased with increasing laser power, and the graphitisation temperature was reached after a short time at a laser power of 20 W. Furthermore, the combination of numerical simulation and experimentation demonstrated that the numerical solution to the

---

☆ Project supported by the National Science and Technology Major Project of the Ministry of Science and Technology of China (Grant No.2012ZX04003101).

* Corresponding author at: State Key Laboratory of Advanced Design and Manufacturing for Vehicle Body, Hunan University, Changsha, Hunan 410082, China.
E-mail address: hdgychen@163.com (S. Cai).

http://dx.doi.org/10.1016/j.diamond.2015.10.018
0925-9635/© 2015 Elsevier B.V. All rights reserved.

Nomenclature

T_{tc}	bronze thermodynamic critical temperature [K]
d	target thickness [m]
β	material absorption rate
b	adsorption coefficient
s	material energy accumulation factor under the pulse interval
a	number of laser pulses irradiated to the material
c_l	heat capacity of the liquid bond [J/(kg·K)]
p_l	density of the liquid bond [kg/m^3]
k_1	thermal conductivity [W/(m·K)]
I_0	maximum lase energy density [W/cm^2]
P	saturated vapour pressure [Pa]
c_s	viscosity coefficient [N.s/cm^2]
m_1	particle mass of the target material [kg]
Z	average charge [C]
n_i	ion number density [cm^{-3}]
v_0	incident frequency [Hz]
T_i	particle temperature [K]
k_b	Boltzmann's constant 1.38×10^{-23} J/K
h	Planck constant 6.6261×10^{-34} J·s
I_H	hydrogen ionisation potential [ev]
E_I	atomic ionisation potential [ev]
E	excited energy to be photoionised [ev]
T_l	target material gasification temperature
m	particle mass [kg]
D	diameter of the laser spot [μm]
r	radius of the ablative material [μm]
V_m	rotation speed of the grinding machine [r/min]

heat transfer model is in good agreement with the experimental values, thus verifying the correctness and feasibility of the model.

2. Physical process of laser ablation of a bronze-bonded diamond grinding wheel

In the actual laser ablation process, the laser beam is focused and then irradiated to the grinding wheel surface, resulting in the transition of four phases (solid, liquid, gas, and plasma) [12]. Fig. 1 schematically illustrates the laser ablation-driven grinding wheel dressing/truing process. The relative motions between the laser unit and the grinding wheel are also shown in Fig. 1. During the duration of a laser pulse, the laser beam is focused on a spot located on the outer most circumferential surface of the grinding wheel.

A compact Yb-doped fibre pulsed laser produced by IPG (Model: YLP-1/120/50/50-HC) was used. The fibre laser device has parameters of average power $Pavg = 5–50$ W, pulse recurrence frequency $f =$ 50–150 kHz, pulse width of 210 ns, and wavelength of 1064 nm, and the output laser energy approximately follows a Gaussian distribution. The laser beam is transmitted via a single-mode fibre to a laser ablation head that is fixed on a two-dimensional motorised displacement platform and has a standard isolator. Then, after it is focused by a biconvex lens with a 180 mm focal length inside the ablation head, it irradiates the grinding wheel surface vertically along the grinding wheel radial direction. The parameters for a compact Yb-doped fibre pulsed laser are shown in Table 1.

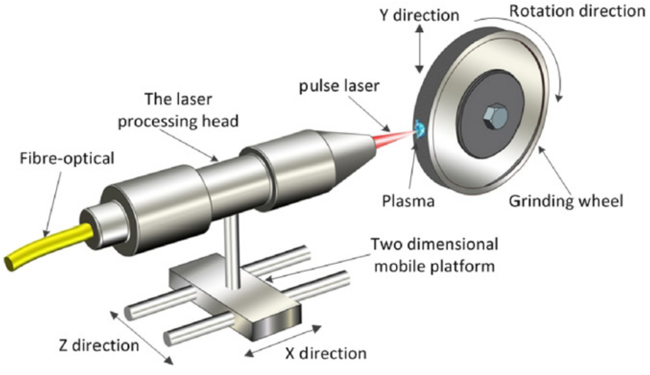

Fig. 1. Sketch of laser ablation.

Bronze bond is a mixed material mainly composed of copper powder (approximately 70%) and tin powder (approximately 25%). In addition, other metal powders, such as cobalt powder and nickel powder, in small quantities (5%), were added to alter its properties. The following is assumed: during the process, the bond is made of composite materials, i.e., two or more materials of differing properties that create a new material with new properties through physical or chemical methods.

Pulsed laser irradiation is a processing method based on a thermal effect, and the resulting thermal effect is determined by laser parameters such as laser energy density, pulse frequency, duty cycle, and peak power, as well as physical parameters of the bronze bond and abrasive particles [10].

Fig. 2(a) depicts the laser energy irradiating the grinding wheel surface. After energy deposition, the solid phase changes into the liquid phase. Fig. 2(b) shows the pulsed laser continuing to irradiate and generate increasing amounts of energy that are deposited on the irradiated surface, which leads to the melting of the bond and the gradual formation of a liquid layer. Due to the gradual increase of external pressure, there will be a phenomenon in which boiling does not occur even though the temperature is above the boiling point; this is called superheating [13]. During superheating, if the super-hot layer is irradiated by a high-power short-pulsed laser and its temperature reaches the bronze bond thermodynamic critical temperature $0.90T_{tc}$, a more violent phase explosion phenomenon will occur if there are disturbances at this time [14–18]. During the grinding wheel laser dressing process, the existence of a super-hot layer will lead to the occurrence of a phase explosion. The splash caused by the phase explosion during the laser dressing process is shown in Fig. 3.

When the laser continues to irradiate, the bronze bond reaches the evaporation temperature T_Q (under normal pressure). Fig. 2(c) depicts how the bond will experience a phase change to become vapour, and the evaporation effect occurs [19,20]. Under laser energy irradiation, the vapour-mixed particles have gained enormous energy, and their thermal motion has intensified. The particle kinetic energy increase exceeds the ionisation potential of the atoms of the bronze mixture. Through the three major mechanisms of photo ionisation, thermal ionisation, and collision ionisation, a hybrid plasma is formed, as shown in Fig. 4. After the plasma has formed, it will continue to absorb irradiated laser energy and effectively block the coupling of the laser irradiation energy and grinding wheel surface bond, resulting in a plasma shielding effect [21].

When the pulsed laser ceases to irradiate, the evaporation effect will continue due to the existence of a super-hot layer. During the

Table 1
The parameters for a compact Yb-doped fibre pulsed laser.

The parameter types	Symbol	The minimum value	Typical values	The maximum value	Unit
Working mode		Pulse			
Centre wavelength	λ	1055	1064	1070	nm
The average output power	P_m	50			W
The average power regulation scope		10		100	%
Launch bandwidth	$\Delta\lambda$		5	10	nm
The pulse width	$\Delta\tau$	190	200	220	ns
Pulse repetition rate	f	20		80	kHz

Download English Version:

https://daneshyari.com/en/article/701813

Download Persian Version:

https://daneshyari.com/article/701813

Daneshyari.com