International Journal of Machine Tools & Manufacture 88 (2015) 118–130

Contents lists available at ScienceDirect

International Journal of Machine Tools & Manufacture

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

Study on micro-topographical removals of diamond grain and metal bond in dry electro-contact discharge dressing of coarse diamond grinding wheel

Y.J. Lu, J. Xie*, X.H. Si

School of Mechanical and Automotive Engineering, South China University of Technology, Guangzhou 510640, China

ARTICLE INFO

Article history:
Received 3 May 2014
Received in revised form
22 September 2014
Accepted 23 September 2014

Keywords:
Grinding
Diamond grinding wheel
Electro-contact discharge dressing
Grain protrusion topography

ABSTRACT

A coarse diamond grinding wheel is able to perform smooth surface grinding with high and rigid grain protrusion, but it is very difficult to dress it. Hence, the dry electro-contact discharge (ECD) is proposed to dress #46 diamond grinding wheel for dry grinding of carbide alloy. The objective is to understand micro-topographical removals of diamond grain and metal bond for self-optimizing dressing. First, the pulse power and direct-current (DC) power were employed to perform dry ECD dressing in contrast to mechanical dressing; then the micro-topographies of diamond grains and metal bond were recognized and extracted from measured wheel surface, respectively; finally, the relationship between impulse discharge parameters and micro-topographical removals was investigated with regard to grain cutting parameters, dry grinding temperature and ground surface. It is shown that the dry ECD dressing along with spark discharge removal may enhance the dressing efficiency by about 10 times and dressing ratio by about 34 times against the mechanical dressing along with cutting removal. It averagely increases grain protrusion height by 12% and grain top angle by 23%, leading to a decrease 37% in grinding temperature and a decrease 46% in surface roughness. Compared with the DC-25V power along with arc discharges, the Pulse-25V power removes the metal bond at 0.241 mm^3/min by utilizing discharge energy by 73% and diamond grain at 0.013 mm^3/min through surface graphitization, respectively, leading to high and uniform grain protrusion. It is confirmed that the impulse discharge parameters are likely to control the microscopic grain protrusion topography for efficient dressing according to their relations to the micro-removal of metal bond.

1. Introduction

The hard and brittle materials such as ceramic, silicon, optical glass and carbide alloy have been widely applied in the components of automotive manufacturing, electronics, aerospace and precision optics, etc. It is known that a superabrasive diamond grinding wheel was an alternative to the machining of hard and brittle materials. Generally, superfine diamond grinding wheels were employed to perform a smooth surface grinding [1,2], but they led to poor grinding efficiency due to the limited height of grain protrusion and the rapid fall-off of superfine grains.

It was reported that the critical cutting depth of optical glass was enhanced from 60 nm to 160 nm when the grain rake angle was changed from $-35°$ to $-90°$ using a single-point diamond tool of #46 grain [3]. In #60 coarse diamond grinding of Si wafer, the ductile-mode cutting was conducted by the cutting edge of single diamond grain when the cutting depth was less than 73 nm [4]. This means that the ductile-mode grinding may be performed by controlling coarse diamond grain topography along with suitable grinding conditions.

Hence, a coarser diamond grinding wheel had been considered to improve both grinding efficiency and surface quality. For example, a #140 diamond grinding wheel was able to perform a super-smooth axial-feed grinding [5]. Furthermore, the 150-μm diamond grinding of BK7 optical glass may make the ground surface roughness be less than 50 nm [6]. A truncated #60 coarse diamond grinding wheel with large grain top angle and valid grain number may realize a mirror finish grinding of SiC ceramics in a macroscopic size [7].

However, it is very difficult to dress the metal-bonded coarse diamond grinding wheel. In the recent decades, many non-conventional dressing technologies, such as ELID (electrolytic in-process dressing) [8], WEDD (wire electrical discharge dressing) [9] and laser dressing [10], have been used to dress metal-bonded diamond grinding wheel. However, they needed complex control system, expensive equipment and generated pollution emissions.

* Corresponding author.
E-mail address: jinxie@scut.edu.cn (J. Xie).

http://dx.doi.org/10.1016/j.ijmachtools.2014.09.008

Nomenclature

a	depth of cut (μm)
B	the width of diamond wheel (mm)
D	the diameter of diamond wheel (mm)
d_e	impulse removal diameter (μm)
d_g	nominal diameter of grain (μm)
E	open-circuit voltage (V)
E_d	discharge voltage (V)
h_{br}	bond removal height (μm)
h_e	impulse removal height (μm)
h_g	grain protrusion height (μm)
h_{gr}	grain removal height (μm)
h_{pulse}	the predicted removal height of metal bond (μm)
h_{wheel}	wheel removal height (μm)
h_y	removal height of grain micro-topography (μm)
I_d	discharge current (A)
I_e	impulse peak current (A)
m_e	impulse removal volume (mm^3)
n	maximum discharge frequency (s^{-1})
N	the grid point number of grain micro-topography
n_g	grain number
N_{pulse}	the number of impulse dischargecraters
n_{spark}	spark discharge frequency (s^{-1})
R_a	surface roughness (μm)
S_g	grain area (μm^2)
S_m	metal bond area (μm^2)
S_{xz}	the projected area of grain topography on XOZ plane (μm^2)
T	dressing time (min)
t_d	discharge time (μs)
T_h	hole temperature (°C)
T_{on}	actual contact discharge time (min)
T_s	grinding temperature (°C)
T_s^v	surface temperature (°C)
V_E	dresser/electrode removal volume (mm^3)
v_f	feed speed of wheel (mm/min)
V_{gr}	grain removal volume (mm^3)
V_{pulse}	the predicted removal volume of metal bond (mm^3)
V_{tbr}	total bond removal volume (mm^3)
V_{tgr}	total grain removal volume (mm^3)
v_w	wheel speed (m/s)
V_{wheel}	wheel removal volume (mm^3)
W_d	discharge energy rate (J/s)
W_e	impulse discharge energy (J)
α_g	grain top angle (°)
γ	dressing ratio
γ_g	grain rake angle (°)
ε_g	grain relief angle (°)
η	dressing efficiency (mm^3/min)
τ_e	impulse discharge duration (μs)
ω	effective spark discharge ratio

Hence, the dry electro-contact discharge (ECD) dressing was developed along with ecological pollution-free and easy operation [11,12], but it was not applied to coarse diamond grinding wheel.

It was reported that increasing valid grain number, negative grain rake angle and grain top angle can improve the ground surface quality [7,13], but there is no way to monitor these microscopic grain cutting parameters during dressing. Although the impulse discharge parameters were related to impulse removal crater sizes of metal bond for valid dressing [14], the grain cutting parameters were not investigated. Moreover, the grain protrusion topography can be measured and evaluated [7], but it has not yet been clear how the micro-topographies of diamond grain and metal bond are removed during dressing.

It was found that the grain surface graphitization (temperature > 700 °C) occurred under the concentrated electrical discharge [15]. Through Raman spectra testing, the diamond–graphite phase transformation was produced during the micro-EDM of PCD [16]. A graphite layer thickness of about 0.5 μm on fine diamond grain surface after wire electrical discharge dressing was measured by HRTEM analysis [17]. However, the actual micro-removal of diamond grain has not yet been quantitatively reported.

In this paper, the dry ECD dressing of metal-bonded #46 coarse diamond grinding wheel is proposed using pulse and direct-current power supplies, respectively. The dressed wheel surface topography was characterized using measured 3D information by white light interferometer (WLI). The objective is to understand

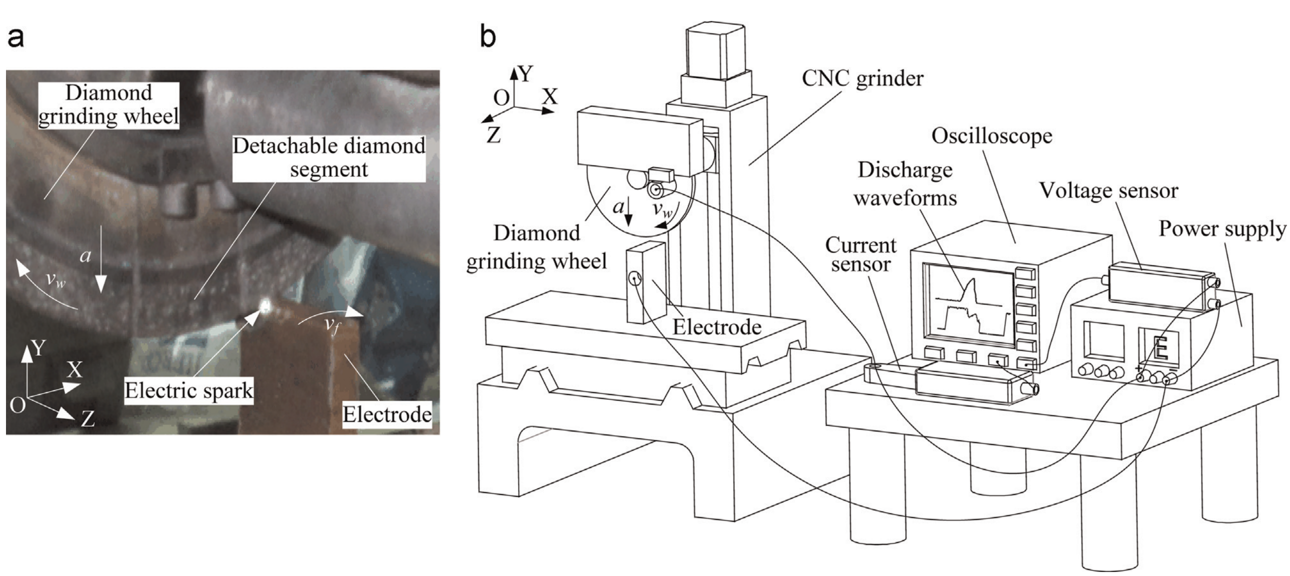

Fig. 1. Dry ECD dressing experimental setup: (a) dressing scene and (b) on-line discharge waveforms monitoring.