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Computer simulation of sub-micron-scale precision truing of a metal-bonded diamond grinding wheel

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Abstract

A new simulation mode of wheel profile generation was proposed in precision truing of a metal-bonded diamond grinding wheel by considering the mutual wear of grinding wheel and truer in sub-micron scale. The aim is to understand how truing parameters influence truing accuracy and truing efficiency, namely wheel profile flatness and truing number. In order to assure the sub-micron-scale accuracy of a trued wheel profile, dry electro-contact discharge was employed in arc envelope truing. First, an arc-shaped truing profile replicated on wheel profile was defined and analyzed theoretically and then identified by truing experiment; second, the micro-truing ratio describing the mutual wear of a grinding wheel and truer related to the depth of cut was investigated by micro-truing experiment; then the simulation mode of the truing grinding wheel was established by using dispersed profile coordinates of the grinding wheel and truer with reference to the micro-truing ratio; finally, simulation analysis was conducted to trace on-line formation of the trued wheel profile in truing process. It is confirmed that this simulation method is valid and applicable to visualize the sub-micron-scale truing process. It is also found that by decreasing the depth of cut or plunge truing number wheel profile flatness decreases but truing number increases. It is concluded that there exist minimum wheel profile flatness and minimum truing number in a truing process, which can be used to optimize truing parameters for efficient precision truing.

Keywords: Arc envelope truing; Diamond grinding wheel; Micro-truing ratio; Truing profile; Wheel profile flatness; Truing number

1. Introduction

A metal-bonded diamond grinding wheel is often employed to conduct precision form grinding, but it is very difficult to conduct sub-micron-scale precision truing of the wheel profile due to its high strength. Traditional single-point diamond truing is only valid for GC and WA grinding wheels, but it cannot true a super-abrasive grinding wheel because it is unable to produce sufficient grit protrusion [1,2]. Although a GC stick may be employed for truing of a diamond grinding wheel, it cannot assure high form accuracy of the grinding wheel due to rapid stick consumption. Therefore, a rotary GC cup truer has been used in truing of diamond grinding wheel by dissociated grits fell off from the grinding wheel surface [3], also called straight truing, which can assure truing efficiency and truing accuracy at the same time.

In order to true a metal-bonded diamond grinding wheel, dry electro-contact discharge was employed by applying an open-circuit voltage to the grinding wheel and rotary cup truer (electrode) for dressing and truing [4–6]. In dressing and truing, micro-pulse discharge occurs between the grinding wheel and truer until the conductive cut swarf derived from the truer (electrode) approaches the metal bond of the grinding wheel to some extent. It can remove metal bond in micron-scale without any damage to the grit cutting edges protruded from wheel surface [6].

For improving the truing accuracy further, a cone-shaped rotary truer was employed in truing, namely the central axis of truer is inclined by an angle, called arc envelope truing [7,8]. The profile accuracy of a truer

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Nomenclature

a	the depth of cut (μm)
$a(i)$	interaction height of profile coordinates of wheel and truer, namely $z_1(i)$ and $z_2(i)$
d_w	grinding wheel diameter (mm)
d_t	diameter of cone-shaped truer specializing a certain contact point (mm)
d_{t1}	inner diameter of cone-shaped truer (mm)
d_{t2}	outer diameter of cone-shaped truer (mm)
E_i	open-circuit voltage
N_p	the pass number of to-and-fro plunge truing, called plunge truing number
N_t	the pass number of to-and-fro traverse truing, called truing number
N_{tm}	minimum truing number
N^*_{tm}	minimum truing number for simulation
h_a	worn height of cone-shaped truer
h_w	total wheel removal height for profile (μm)
$h_t(m_0)$	worn height of truing profile (μm)
H_f	wheel profile flatness (μm)
H_{fm}	minimum wheel profile flatness (μm)
H^*_{fm}	minimum wheel profile flatness for simulation (μm)
H^*_{fo}	the overshoot value of minimum wheel profile flatness H^*_{fm}
H^*_{fo}	theoretical wheel profile flatness (μm)
k_m	the number of right and left dividing lines around the vertex point of truing profile
k_{m1}	outermost left coordinate number of truing profile interacted with grinding wheel
k_{m2}	outermost right coordinate number of truing profile interacted with grinding wheel
m	the number of dispersed wheel profile coordinates
m_0	the vertex coordinate number of truing profile
n_t	truer speed (rpm)
n_w	wheel speed (rpm)
P_f	wheel-axial orientation moving interval (mm)
v_f	work speed (mm/min)
$z_1(i)$	the coordinate of dispersed truing profile (μm)
$z_2(i)$	the coordinate of dispersed wheel profile (μm)
γ	micro-truing ratio
θ	the lean angle of cone-shaped truer (degree)
δ	the interval of dispersed coordinate
Δh_w	wheel removal height for profile after plunge truing for the depth of cut
$\Delta h_w(i)$	wheel removal height for dispersed coordinate after plunge truing

grinding wheel is 0.37–0.47 μm/10 mm [7,8]. However, it is very difficult to understand the formation of the sub-micron-scale profile of a diamond grinding wheel in truing process, especially truing time until truing accuracy limit, in connection with truing parameters. This is because it has not been clear how micron-scale and sub-micron-scale wears of grinding wheel and truer influence truing accuracy. Generally, it needs a lot of truing experiments and measurements, thus resulting in very high cost and very low efficiency in truing.

Until now, it has been mainly focused on simulation of wheel topography for formation of ground surface [9–11], but little work about simulation of wheel profile formation has been done in the truing process. For truing, it has been known that grinding quality is dominated by truer wears and there exists a good linear relationship between the volumetric wear of truer and the volumetric wheel removal [12], but truer wear and grinding wheel removal were observed only in the range of millimeter order; thus, it cannot be applicable to sub-micron-scale precision truing of a super-abrasive grinding wheel. Although geometrical analysis of wheel curve profile and ground surface was conducted to identify wheel alignment error and decrease wheel wear [13], it cannot describe on-line formation of wheel profile in sub-micron-scale precision truing. This is because the mutual wear between wheel and truer has not been considered.

In this paper, dry electro-contact discharge was employed to conduct sub-micron-scale form truing of a diamond grinding wheel [4–6]. In form truing, a cone-shaped truer was used for arc envelope truing [7,8]. Wheel profile formation was simulated on the computer in consideration of the truing profile replicated on wheel profile and their mutual wear mode derived from a micro-truing experiment. First, the truing profile used for simulation was analyzed theoretically and identified by experimental result. Second, wheel removal mode was established on the basis of micro-truing ratio describing the mutual wear of wheel and truer. Next, the formation mode of wheel profile was proposed by the use of dispersed profile coordinates and micro-truing ratio. Then, on-line formation of the trued wheel profile was investigated in connection with wheel profile flatness and truing number. Finally, minimum wheel profile flatness and minimum truing number were analyzed to optimize truing parameters for efficient precision truing.

2. Experimental procedure

Fig. 1 shows the scheme of arc envelope truing. In arc envelope truing, a rotary cone-shaped truer (electrode) was employed to envelope a wheel profile by grinding of truer. For the lean angle of the cone-shaped truer θ was designed as 10° according to the contact area between grinding wheel and truer [8]. The arc envelope truing includes X-axial plunge truing along with the depth of cut a, and Y-axial traverse truing along with moving interval P_f. After a number of passes for plunge truing, the wheel is driven