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On-machine precision form truing of arc-shaped diamond wheels

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ABSTRACT

In order to realize the efficient and precision truing of arc-shaped diamond wheel for precision grinding of spherical, aspherical and free-form surfaces, a novel on-machine precision form truing of resin and metal bonded arc-shaped diamond wheels is proposed utilizing rotary green silicon carbon (GC) rod. Through this on-machine rotary GC rod (ORGCR) mutual-wear truing, any required radius of wheel arc profile could be formed by programmed truing paths, meanwhile, the vertical direction position error of the wheel center could be corrected after truing. Firstly, the principle of ORGCR mutual-wear truing for arc-shaped diamond wheel was introduced, and new evaluation methods of truing performance and truing ratio were provided. Then the truing performance and truing ratio were observed for different grains and bond of arc-shaped diamond wheels, the effects of ORGCR mutual-wear truing parameters on profile radius and form accuracy of wheels were investigated. Finally, the convex aspherical surface of single crystal silicon was ground by trued arc-shaped diamond wheel. The experimental results showed that the resin and metal bonded diamond wheels could be efficiently and precisely trued with high truing ratio. The form error of wheel arc profile reached 2.5–6 μm/3 mm which decreased about 90% compared to pre-truing wheel. Besides, the diamond grains were well distributed on the wheel surface, and protruded out of the wheel bond after truing. The precision aspherical surface of single crystal silicon with the form accuracy PV of 507 nm and the average roughness Ra of 57.1 nm was achieved by parallel grinding with the trued D7 resin bonded wheel.

1. Introduction

The development of advanced optoelectronic and astronomical devices highly demands for optical components and molds with spherical, aspherical and free-form surfaces with high profile accuracy and excellent surface finish. Most of these components and molds have to be machined by abrasive processes with diamond wheels due to their hard-brittle materials property, such as ceramics, cements, optical glasses and crystalline materials, as expounded by Brinksmeier et al. (2010).

The arc-shaped diamond wheels with precision profile were usually adopted for ultra-precision grinding of spherical, aspherical and free-form surfaces. Saeki et al. (2001) investigated that the quality of aspherical opto-device surface ground by arc-shaped diamond wheels utilizing parallel grinding method was better than cross grinding method. Lin et al. (2014) applied arc-shaped diamond to grind BK7 glass with size of 430 × 430 × 27.5 mm using CNC envelope grinding on the surface grinder. Xie et al. (2010) demonstrated that CNC envelope grinding of free-form surface by arc-shaped diamond wheel permitted more grinding points around its torus-shaped working surface to take part in grinding process, and it decreased wears compared to a single grinding point when grinding large-size curve surface.

Considering these grinding process of spherical, aspherical and free-form surfaces with arc-shaped wheel, the form accuracy of the ground surface was mainly determined by the profile accuracy of wheels. To improve the accuracy of the wheel profile, Wegener et al. (2011) introduced abundant truing methods proposed for formed diamond wheels. Wang et al. (2009) developed a cup truer with a cyclical arc swing mechanism to true arc-shaped wheels, and the form error of the wheel profile was ±5 μm/17 mm after truing. Derkx et al. (2008) proposed a form crush dressing method to profile diamond grinding wheels, and the form crush dressing system concluded a lot of components, such as swiveling axis for truer, adjustment axis, motor housing, bearing housing and so on. Klocke et al. (2007) demonstrated that wire electro discharge (Wire-EDM) method which implemented on a conventional Wire-EDM machine was used to true and dress micro arc-shaped diamond wheels for grinding micro-arc array. Xie et al. (2010) showed that the fixed

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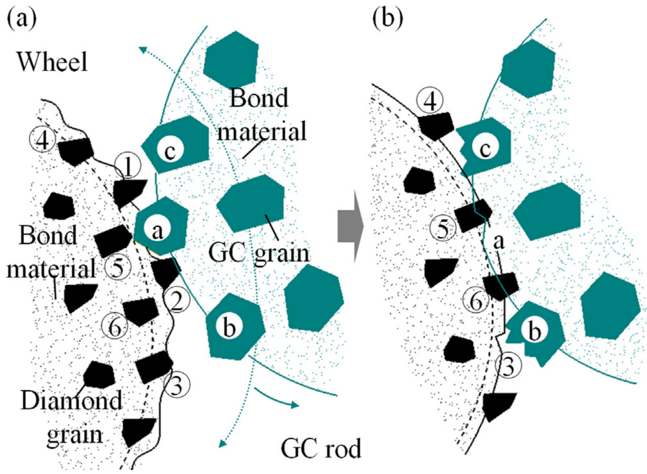

Fig. 1. ORGCR truing mechanism (a) initial truing (b) truing process.

green silicon carbon (GC) stick CNC mutual-wear truing without any complex accessory was applied to true #180 metal bonded diamond grinding wheel. After truing, the form accuracy of trued diamond wheel was 18.2 μm/10 mm. However, most of above truing methods need complicated attached devices, while the fixed GC stick CNC mutual-wear truing cannot confirm tool setting position of the wheel in the vertical direction after truing.

Based on the above, a novel on-machine precision truing of resin and metal bonded arc-shaped diamond wheels is proposed utilizing mutual-wear between diamond wheel and GC rod without any complex accessory. In this ORGCR mutual-wear truing, the workpiece spindle on the machine was applied to drive GC rod to remove the wheel bond along the circular interpolation paths, and then the arc profile was formed gradually, while the vertical direction position error of wheel center would also be corrected automatically after truing. Firstly, the principle of ORGCR mutual-wear truing was introduced, and new evaluation methods of truing performance and truing ratio were provided. Then the truing ratio and truing performance were observed for different grains and bond of arc-shaped diamond wheels. Next, the effects of ORGCR mutual-wear truing parameters on profile radius and form accuracy of wheels were investigated. Finally, the convex aspherical surface of single crystal silicon was ground by trued arc-shaped diamond wheel.

2. ORGCR mutual-wear truing of arc-shaped diamond wheel

Fig. 1 shows the ORGCR truing mechanism. In the truing process, the GC grains rub and remove the bond of diamond wheel, then the holding ability of the bond for some diamond grains is decreased so that the diamond grains like ①, ②, ③ fall off, and the diamond grains like ④, ⑤, ⑥ are protruded out of the wheel bond. Meantime, the similar removal mechanism emerges on the GC rod, the GC grain like ⓐ falls off, and the grains like ⓑ, ⓒ are protruded out of the GC rod bond. The only difference is the GC grains may be broken like ⓑ, ⓒ because of mutual-strike with the diamond grains.

Fig. 2 shows the ORGCR mutual-wear truing principle of arc-shaped diamond wheel. In ORGCR mutual-wear truing, the GC rod is driven by the workpiece spindle on the machine with the wheel speed n to true diamond wheel with the wheel speed N along the circular interpolation paths circularly with the feed rate v in CNC grinding system as shown in Fig. 2(a), then a arc-shaped wheel may be gradually formed with the depth of cut a_p through the CNC mutual-wear between the diamond wheel and GC rod dresser. Besides, the motion paths were designed to utilize more cylinder of GC rod to true the arc profile of diamond wheel as shown in Fig. 2(b). In the motion paths, when a circular interpolation path is completed, the diamond wheel is moved with the distance B along negative direction of Z axis, then the next circular interpolation movement is carried out, and keep the cycle going until the terminal of motion paths. After finishing the positive motion paths, the inverse movements are executed back to the beginning of motion paths. In short, the arc-shaped diamond wheel can be trued by rotary GC rod with circular interpolation paths and motion paths.

The radius of interpolation arc a is described as Exp. (1). Any radius of wheel arc profile can be obtained for different requirements by changing the radius of interpolation arc.

$$a = R + r \tag{1}$$

where R is the radius of GC rod which can be measured in truing process, and r is the expected radius of wheel arc profile, as shown in Fig. 2(a).

In the truing process, however, the radius of GC rod is decreased unavoidably because of the mutual-wear. According to Exp. (1), the actual radius of wheel arc profile would be increased and deviate from the expected radius largely in truing process if the radius of interpolation arc remain the same. Therefore the radius of interpolation arc need be compensated by the radius of GC rod measured in truing process to guarantee the radius of arc profile wheel to meet the expected radius as follows:

$$a_i = r + R_i \tag{2}$$

where a_i is the compensated radius of interpolation arc and R_i is the radius of GC rod measured in real-time.

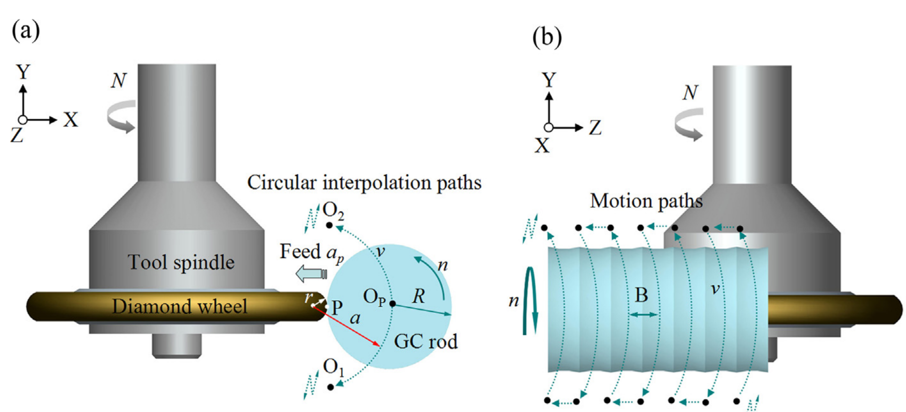

Fig. 2. ORGCR mutual-wear truing mode of arc-shaped diamond wheel: (a)truing mode (b)truing motion paths.