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ORIGINAL ARTICLE

Mechanical truing of V-shape diamond wheels for micro-structured surface grinding

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Abstract An on-machine mechanical truing method with rotary green silicon carbide (GC) roller to precision shape and prepare V-shape diamond wheels for microstructured surface grinding was proposed. The effects of truing parameters on trued wheel profile accuracy were investigated. The experimental results showed that the feed direction of GC roller had a remarkable effect on truing accuracy. The V-tip radius of trued wheel was reduced with the increase of the GC roller speed or the decrease of the grinding wheel speed, truing depth per pass, feed rate, and the grain size of GC roller. The V-shape diamond wheel with less than 18-μm V-tip radius and 0.6-μm run-out (center zone of wheel) was produced by parameter optimization. Finally, the V-groove array was ground on silicon nitride mold material by the trued diamond wheels. Although the V-tip of diamond wheel can be trued to less than 18 μm, the smallest corner radius, which was obtained in the first ground groove, was still bigger than 46 μm due to the unavoidable wear of diamond wheel in the grinding process of hard mold material.

Keywords Microstructured surfaces · V-shape diamond wheels · On-machine truing · GC roller · Truing accuracy · Precision grinding

1 Introduction

The precision elements with microstructured surface are becoming more and more important in advanced industrial technologies, especially in optical industry which needs high form accuracies and surface finishes, such as micropyramid array, blazed grating, and optical fiber splice. To achieve high quality of these microstructured surfaces, precision grinding with V-shape diamond wheels gives a promising alternative [1, 2]. It is, however, not easy to obtain satisfactory results because of the progressive wear and sharpness loss of these V-shape diamond wheels, especially in the V-tip of wheel [3]. Therefore, the truing process becomes essential for these wheels to acquire the required accuracy and efficiency.

In order to improve the accuracy and efficiency of truing, many on-machine truing methods for V-shape diamond wheels were presented, such as metal alloy block truing [4, 5], electrodischarge machining (EDM) truing [6–8], and electrocontact discharge mutual wear (ECDT) truing [9]. By metal alloy block truing, although the V-shape resin-bonded diamond wheels could be formed precisely, the experiment results shown that metal-bonded diamond wheel cannot be dressed by metal alloy blocks in an efficient way [5]. Considering the electrical conductivity of the metal bond, EDM is often suggested as a truing method for metal-bonded diamond wheels. Existing results have shown that the metal-bonded diamond wheels with high precise profile can be on-machine created efficiently by EDM truing [6–8]. The ECDT truing is able to form the V-shape diamond wheel with precise profile as well, which is based on both of electrodischarge removal and the mutual wear between the fixed electrode and the V-shape metal-bonded diamond wheel [9]. However, either the EDM truing or the ECDT truing, an expensive accessional pulsed power supply is necessary, which brings about the rise of truing cost.

In this paper, an on-machine mechanical truing method with rotary green silicon carbide (GC) roller to

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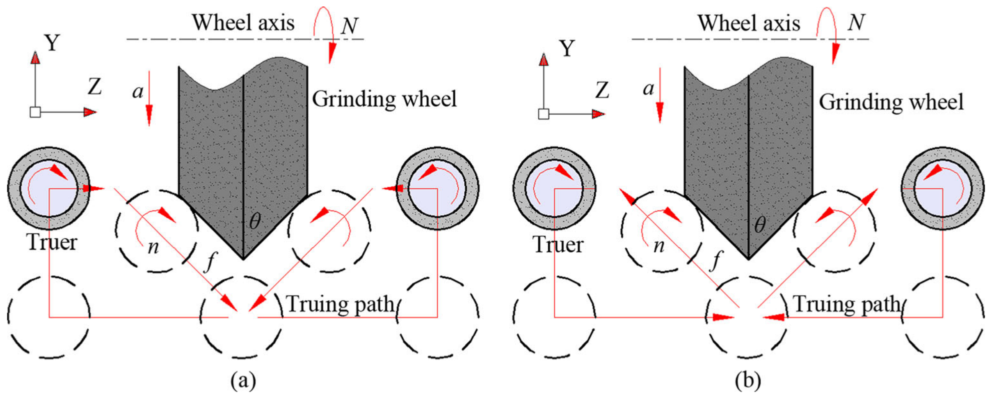


Fig. 1 Truing principle of V-shape diamond wheels. **a** Type 1 truing path. **b** Type 2 truing path

precision shape and prepare V-shape diamond wheels was proposed for microstructured surface grinding. The effects of truing parameters on trued wheel profile accuracy were investigated, and the morphology of trued diamond wheel was observed by a 3-D optical microscope. Furthermore, the V-groove array was ground on silicon nitride (Si_3N_4) mold material by these trued diamond wheels.

2 On-machine truing of V-shape diamond wheels

The truing method for V-shape diamond wheels, as shown in Fig. 1, is using a GC roller as the truer to generate the V-shape profile through programmed truing paths. The GC roller is placed on the machine table with its rotating axis perpendicular to the grinder spindle mounted the diamond grinding wheel. In truing process, the rotary diamond wheel is driven with the grinding wheel speed N to grind the rotary GC roller with the feed rate f, and then, the required wheel profile can be produced gradually with the truing depth per step a through the mutual wear between grinding wheel and GC roller. The angle of programmed truing paths is equal to the V-tip angle θ. Two types of truing paths can be adopted in this on-machine truing process. The only difference of these truing paths is the feed direction of GC roller: for type 1, the roller truing is from side of wheel to center, while in type 2, the roller is from center to side, as shown in Fig. 1.

3 Experimental setup and procedures

3.1 Truing experiments

Figure 2 shows the experimental setup of on-machine mechanical truing. The machining system used in this

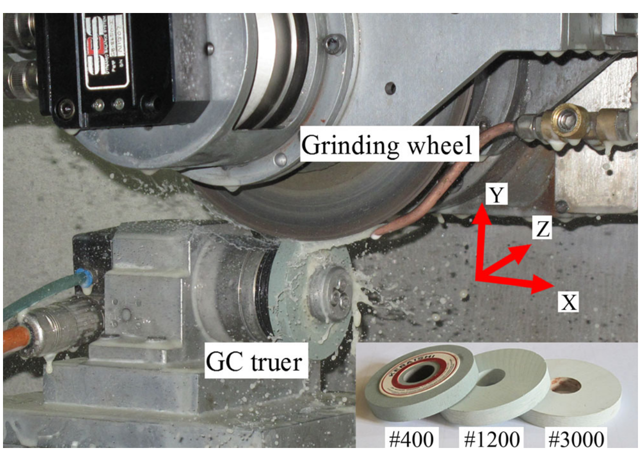


Fig. 2 Experimental setup of truing

Table 1 Details of truing experiment condition

Machine tool	MUGK7120X5 precision plane grinder (Hangzhou Machine Tool Group Co., Ltd.)
Diamond wheels	Metal-bonded 14E1 V-shape diamond wheel (120° profile angle), #400 (34-μm grain size), 125 %, dia. 200 mm (Fuji Die Co., Ltd.)
Truer	GC truer with 70-mm diameter and 10-mm thickness.
Truing spindle	Dr. Kaiser C58F3 (Dr. Kaiser Diamantwerkzeuge GmbH & Co. KG)
Balance system	SBS 4500 (Schmitt Industries, Inc.)
Coolant	Water-based emulsion

Table 2 The scheme of truing experiments

Experiment group no.	Grinding wheel speed (m/s)	Truer speed (m/s)	Truing depth per pass (μm)	Feed rate (mm/min)	Truer grit size
1	10.5; 13.6; 16.8; 19.9; 23.0; 26.2	9.4	50	0.3	#400
2	26.2	9.4; 12.6; 15.7; 18.8	50	1.0	#400
3	26.2	9.4	5; 10; 20; 30; 40; 50	1.0	#400
4	26.2	9.4	10	0.3; 0.5; 0.8; 1.0	#400
5	26.2	9.4	10	0.8	#400; #1200; #3000

experiment was a precision plane grinder MUGK7120X5. In order to resist the wear of diamond wheel in the subsequent grinding process of microstructures, a V-shape metal-bonded diamond grinding wheel with 125 % concentration and 200-mm diameter was adopted in this truing experiment. The GC roller with a diameter of 70 mm and a width of 10 mm was mounted on a precision truing spindle under the grinding wheel. The truing process was conducted following the Section 2, and the details of experiment condition and scheme are listed in Tables 1 and 2, respectively.

3.2 Grinding of microstructured surface

The experiments of subsequent grinding were also performed on the grinder MUGK7120X5. Within this work, the grinding performance of trued diamond wheel was evaluated via precision grinding of the V-groove array on Si_3N_4 ceramic. The width of each V-groove is 500 μm, and the included angle is 120°. The grinding conditions were given by the grinding wheel speed of 2500 rpm, feed rate of 0.3 mm/min, and grinding depth of 0.18 mm. Water-based emulsion was used as coolant.

3.3 Measurement of trued diamond wheel and ground microstructures

In truing experiments, the radial run-out of diamond wheel was in situ measured by Keyence LK-G5000 laser micrometer. The trued wheel profile was on-machine replicated on graphite block, and then, the replicated truing profile (V-tip radius) was evaluated by means of Talysurf PGI 1240 contact probe profilometer. Finally, the morphology of trued diamond wheel was observed off-line by Keyence HVX100 three-dimensional optical microscope. For ground microstructures, the profilometer and SEM were adopted to evaluate its form accuracy and morphology, respectively.

4 Results and discussions

4.1 The effect of truing type on truing accuracy

The effect of truing type on the radial run-out of different positions of diamond wheel is shown in Fig. 3.

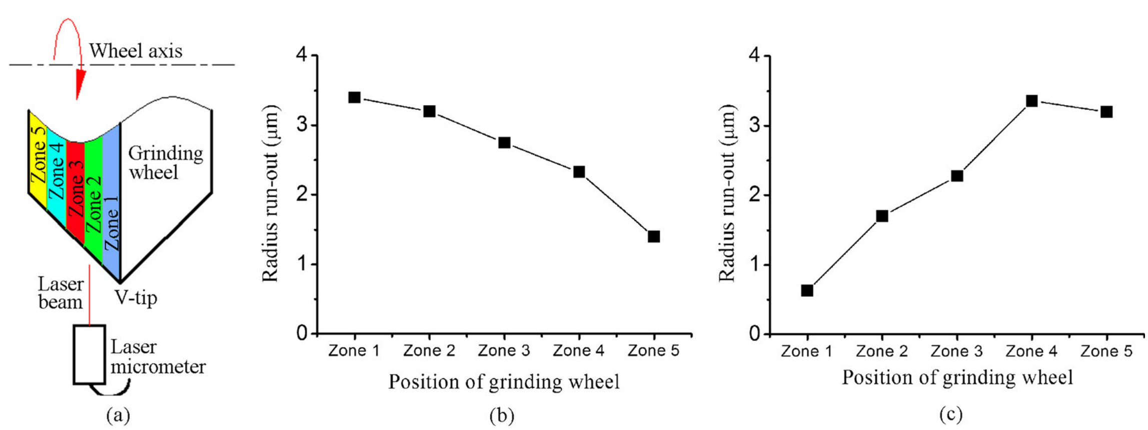


Fig. 3 The radial run-out of different positions of diamond wheel. **a** Measure method of diamond wheel. **b** Type 1 truing path. **c** Type 2 truing path

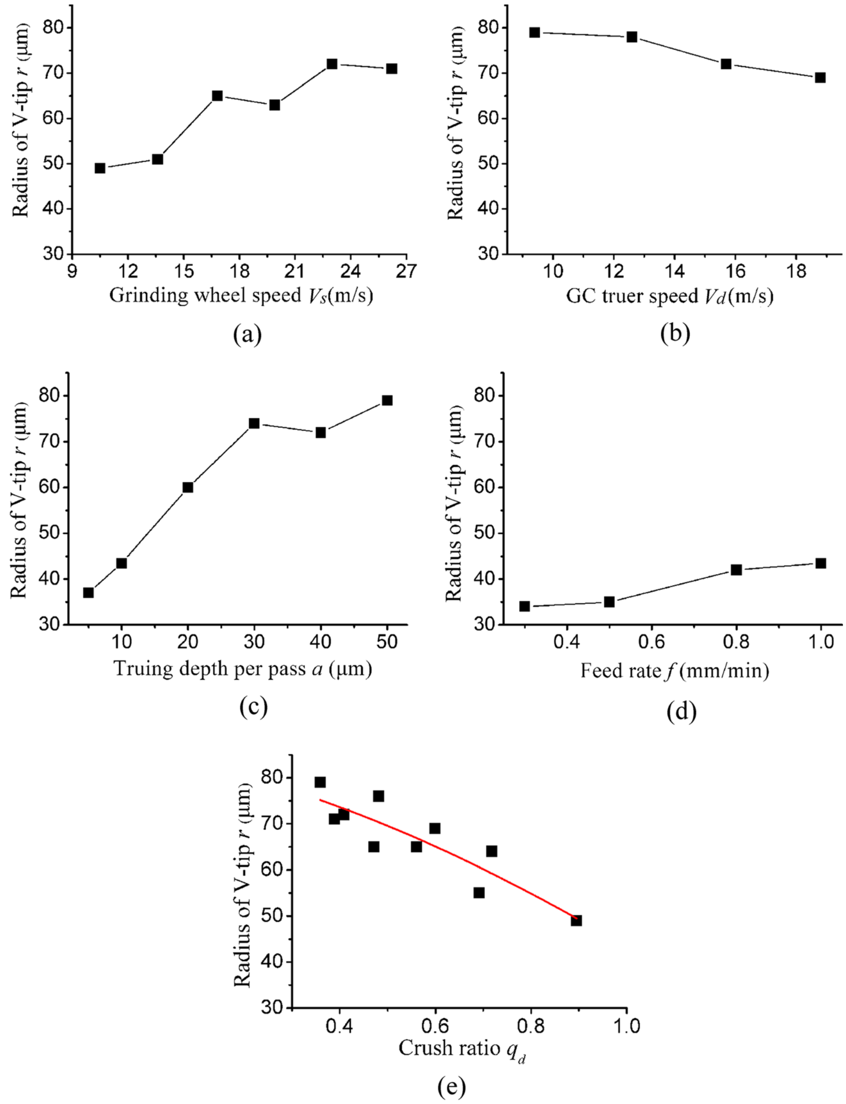


Fig. 4 The effect of truing parameters on truing accuracy. **a** Grinding wheel speed. **b** Truer rotation speed. **c** Truing depth per pass. **d** Feed rate. **e** Crush ratio

The smaller run-out could be obtained in the side zone of diamond wheel via type 1 truing, compared with the center zone of wheel. While the better run-out was achieved in the center zone of diamond wheel by type 2 truing path. This is due to the fact that the hardness of GC roller is much softer than that of high abrasive concentration diamond wheel. Less truing effect is achieved in the final truing zone of diamond wheel because of the wear of GC roller. Considering the limitation of microstructure size, the side zone of the diamond wheel usually does not play a role in microstructured surface grinding. Thus, the diamond wheel with smaller radial run-out in center zone would be more conducive to obtain better ground surface finish in subsequent microstructured surface grinding process. Besides, the V-tip measure results showed that the sharper V-tip of diamond wheel was obtained by type 2 truing path as well. Therefore, the type 2 path is more

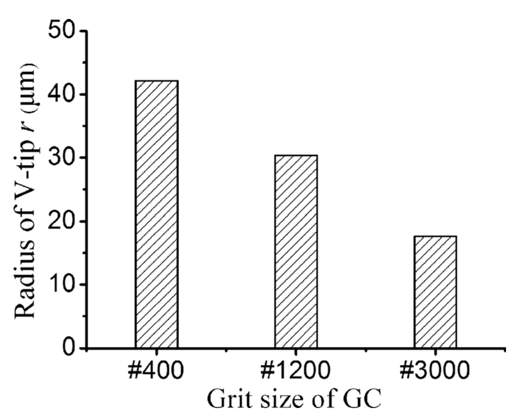


Fig. 5 The effect of GC roller granularity on V-tip radius

suitable to this GC mechanical truing of diamond wheel for microstructured surface grinding.

4.2 The effects of truing parameters on tip radius of V-shape diamond wheel

According to Table 2, a series of truing experiments (group nos. 1–4) were implemented in order to obtain the effect of truing parameters on truing accuracy. Figure 4 shows the V-tip radius of trued wheel versus truing variable such as grinding wheel speed, GC roller rotation speed, truing depth per pass, and feed rate. The average values of measure results were taken to increase reliability for obtaining the truing characteristic. The results indicated that the V-tip radius of trued wheel was reduced with the increase of the GC roller speed or the decrease of the other parameters, such as grinding wheel speed, truing depth per pass, and feed rate. Besides, the effect of crush ratio on the radius of V-tip is shown in Fig. 4e. It was determined that, for this cross-axis traverse truing of V-shape diamond wheel, an increase of crush ratio is beneficial to obtain the smaller radius of V-tip. This was caused by the decease of truing volume per truer rotation. Similar to the undeformed chip volume in the grinding process, the decease of truing volume per truer rotation would reduce the force in truing process, which is conductive to obtain sharper V-tip of diamond wheel.

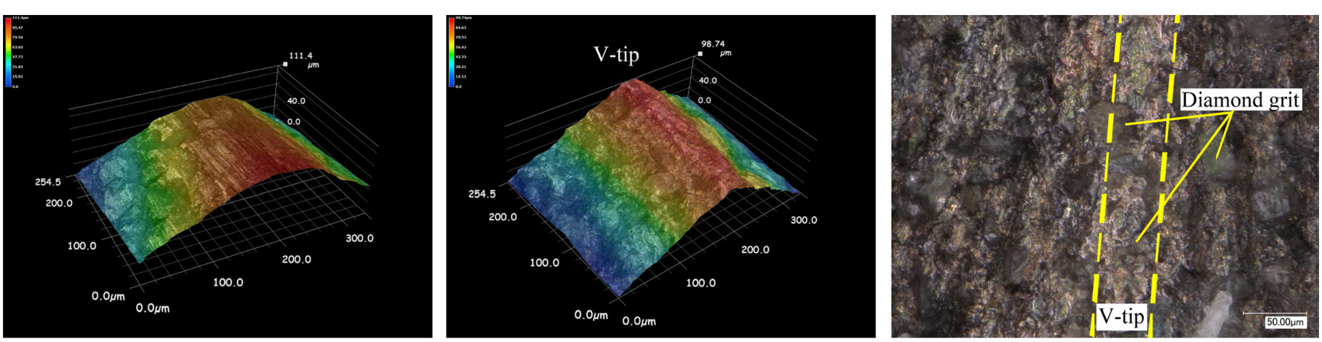
4.3 The effect of truer grit size on tip radius of V-shape diamond wheel

Figure 5 shows the effect of GC granularity on V-tip radius of wheel (the truing parameters as shown in group no. 5 of Table 2). The V-tip radius was reduced by the decrease of GC grain size. When the #400 GC roller was adopted in truing process, the V-tip radius of diamond wheel was about 40 μm. While the V-tip radius of 17.6 μm was obtained by using the #3000 GC roller. The truing time, however, was increased remarkably with the decrease of GC grain size from #400 to #3000. For example, the truing time by #400 GC roller was 1–2 h (original run-out of grinding wheel is more than 50 μm, and the trued run-out is about 5 μm) and that by #3000 GC roller was more than 4 h (original run-out of grinding wheel is about 10 μm, and the trued run-out is less than 5 μm).

Based on the experimental results, with #3000 GC roller, the most sharp V-shape diamond wheel with less than 18-μm V-tip radius and 0.6-μm run-out (zone 1) was produced when the truing parameters were conducted at the wheel grinding speed of 10.5 m/s (1000 rpm), the truer speed of 18.8 m/s (1800 rpm), the feed rate of 0.3 mm/min, and the truing depth per pass of 5 μm.

4.4 The surface morphology of trued V-shape wheels

For microstructured surface grinding, a satisfactory wheel not only need to have high profile accuracy, but also should have enough abrasive grains with cutting edges sticking out of the bond material. The surface morphology of V-shape wheel before and after truing is presented in Fig. 6. It can be found that a serious wear of V-tip of diamond wheel is observed in Fig. 6a. The diamond abrasive grains on the V-tip of wheel were nearly flattened or fall out. Compared with the surface morphology of worn diamond wheels, the V-tip of trued wheel was sharpened obviously, as shown in Fig. 6b. The surface morphology of trued V-shape wheels shows that many diamond grains were protruded from the metal bond on the trued wheel surface, even on the V-tip, as shown in Fig. 6c. Therefore, the radius of trued wheel was formed by both of the metal bond and the abrasive grain.



(a) 3D morphology of worn wheel (b) 3D morphology of trued wheel (c) Optical photo of trued wheel surface

Fig. 6 Surface morphology of V-shape diamond wheels. **a** 3-D morphology of worn wheel. **b** 3-D morphology of trued wheel. **c** Optical photo of trued wheel surface

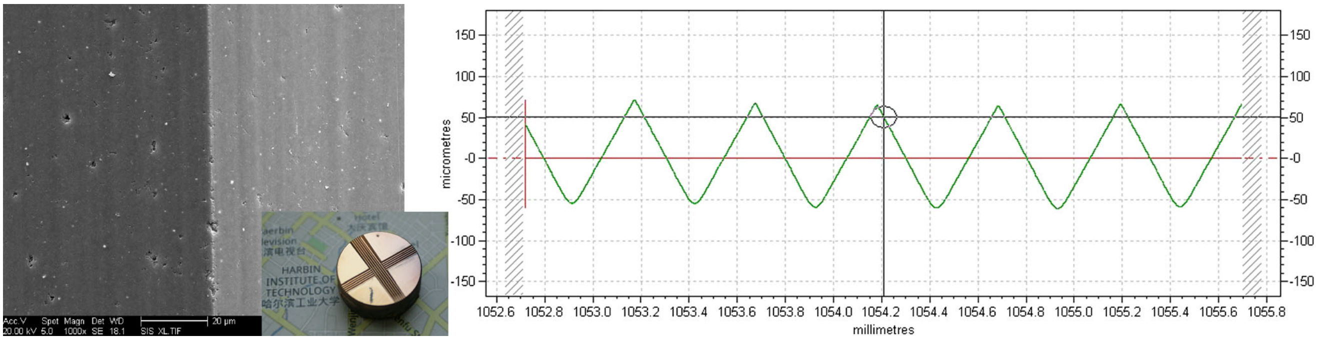


Fig. 7 The surface morphology and profile accuracy of ground microstructured surface

4.5 Microstructured surface grinding on ceramic mold

Figure 7 shows the SEM photo and profile of ground microstructured surface on Si_3N_4 ceramic mold by the trued V-shape diamond wheel. The SEM photo has shown that integrated microgroove array was obtained within ductile grinding. The measure results of V-grooves on Si_3N_4 have shown that the average edge radius was 4 μm and the average surface roughness of ground microstructured surface R_a was 112 nm.

Besides the edge radius and the surface roughness, the radius of included corner is one of the most concerned issues, which is depended on the tip radius of trued V-shape diamond wheel strictly. In this experiment, every included corner radius of grooves was measured, as shown in Fig. 8. It shows that the included corner radius enlarged with the increase of grinding distance. Although the V-tip of diamond wheel can be trued to less than 18 μm, the smallest corner radius, which was obtained in the first ground groove, was still bigger than 46 μm due to the unavoidable wear of diamond wheel in grinding process of hard mold material. For the reason of the ground radius is much more than the trued radius, it may be due to the weak grain holding capacity of metal bond on the V-tip. Compared with the plane, the diamond grain was easily pulled out from the sharp edge.

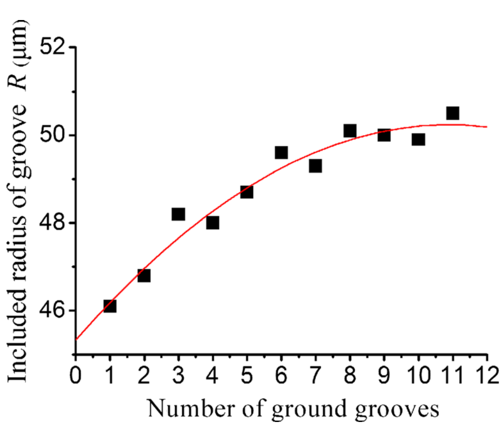


Fig. 8 The included radius of ground microstructured surface

Therefore, based on the Section 4.3, the #400 GC roller may be more suitable for truing in this case compared with the finer GC roller, because the truing time is longer and the trued wheel V-tip radius is sharp enough to the ground groove corner radius as well.

5 Conclusions

An on-machine mechanical truing method to precision shape and prepare V-shape diamond wheels was proposed for microstructured surface grinding. The conclusions are included as follows:

1. The truing direction of GC roller had an obvious effect on truing accuracy. The type 2 path is more suitable to the GC roller truing of V-shape diamond wheel for microstructured surface grinding.
2. The V-tip radius of trued wheel was reduced with the increase of the GC truer speed or the decrease of the grinding wheel speed, truing depth per pass, feed rate, and the grain size of GC roller.
3. After truing, the V-shape diamond wheel with less than 18-μm V-tip radius and 0.6-μm run-out (center zone of wheel) could be produced.
4. Although the V-tip of diamond wheel can be trued to less than 18 μm, the smallest corner radius, which was obtained in the first ground groove, was still bigger than 46 μm due to the unavoidable wear of diamond wheel in grinding process of hard mold material.

For future work, a full factorial design of experiments will be carried out to give more accuracy in the team of input parameters to provide the best truing accuracy.

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