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A study on diamond grinding wheels with regular grain distribution using additive manufacturing (AM) technology

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ABSTRACT

In this paper, a metal bound diamond grinding wheel with a regular grain distribution was fabricated based on 3D printing technology, which provides a solution to the irregular grain distribution and complicated preparation processes of diamond grinding wheels for use in precise/ultraprecise grinding. A grinding wheel was designed in 3D with pro/E, and the data transformation to the stereo-lithography format was carried out. The fabrication of the diamond grinding wheel was achieved with Ni-Cr alloy and diamond by 3D printing and sintering layer by layer. Scanning Electron Microscopy (SEM), Energy Dispersive Spectrometry (EDS) and X-ray diffraction (XRD) were employed to characterize the grains and the micro-structures between the substrate and the Ni-Cr alloy in the diamond grinding wheel, suggesting the infiltration mechanism of Ni-Cr towards the diamond and steel substrate. Finally, the grinding performance was evaluated with an experiment. It was shown that the abrasion of the diamond grinding grains was normal, and no grains fell off the wheel.

1. Introduction

With the development of high-speed and precise grinding, ceramic and resin binding grinding wheels have been unable to meet the requirements of modern production in the past several years. Therefore, the demand for diamond grinding wheels is becoming higher and higher [1–3]. Metal-binding grinding wheels have been widely applied to ceramic, optical glass, hard alloy and other materials, but with challenging preparation, due to their excellent performance in holding force, binding, abrasion, molding, life span, and grinding press bearing together with high precision and efficiency [4–8].

For current diamond grinding tools, the distribution of diamond grains in the metal matrix is random with segregation and aggregation. This has caused the grinding artifacts to have poor surface morphologies, low grinding efficiency, and short lives. In the diamond-abundant regions, the concentration of grinding grains is higher so that the grinding is weak and easily blocked, lowering the grinding efficiency, while in the diamond rare region, the concentration of grinding grains is low so that the grains are not involved in the grinding, which leads to the fracture and dropping of the grinding wheel caused by the overload and higher impact forces. The problems caused by uneven distribution of diamond grains cannot be ignored because of the vicious cycle they create [7,8]. Previous studies have reported regular distribution of grains using different methods and shown that regular distribution of grains can improve surface roughness, life span of the wheel, and grinding efficiency. Nevertheless, some issues still exist: namely, the complicated manufacturing process and high cost. Also, a regular distribution of grains can be realized in one dimension, but is difficult to achieve in 3 dimensions. There is therefore an urgent need for a process to manufacture wheels with regularly distributed diamond grains at a low cost [9–17].

3D printing technology is a booming industry that is beginning to change the style of manufacturing and living [18,19]. It is believed that new technologies like 3D printing with the features of digitization, network, personality and customization will lead to the 3rd industrial revolution [20–26]. 3D printing technology works by dividing a CAD mold into several layers in the computer and sintering or bonding plastic, metal powder, or even biological tissues or cells in a 3D CAD plane with the printing instrument layer by layer to form a 3-dimensional object [27]. 3D printing technology shows great potential as a direction of advanced technological development. It is crucial to fabricate diamond wheels with regular distribution grains due to the progress of grinding technology and the demand for application. In the present paper, a 3D printing method to fabricate end face diamond wheels with regularly distributed grains has been developed. The analysis of the micro-structures between the two different phases (diamond grains and Ni based alloy, and Ni based alloy and steel substrate) together with tracking observations of the performance of the end face diamond wheel grains have suggested explanations for the abrasion, which provides the experimental basis for the fabrication of diamond grinding wheel with regular distribution grains. Manufacturing this type of product is virtually impossible by conventional methods [21–27].

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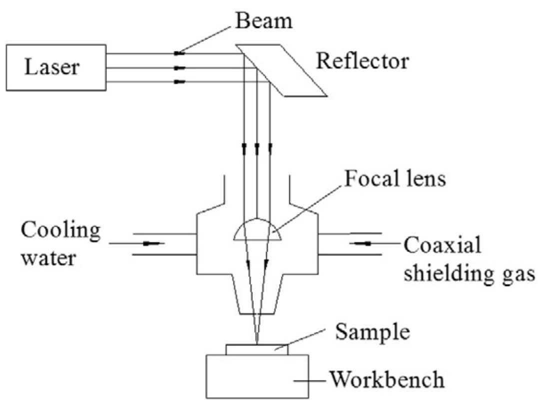

Fig. 1. Schematic of 3D printing instrument.

2. Instruments and methods

2.1. Materials and instruments

The grinding materials for the experiment were as follows: diamond, (size, 300–500 μm); metal binding powder (Ni_{75}-Cr_{18}-B_2-Si_5 alloy, self-made), with melting point 1000–1500 °C ; and substrate of AISI 1045 steel. The grinding wheel is a diamond wheel with an end face that is printed on the substrate ground and ultrasonically cleaned in acetone.

Instruments: TJ-HL-T5000 cross-flow CO_2 CNC laser machine. The initial laser mode is TEM00. The schematic for the 3D printing instrument is shown in Fig. 1.

The laser beam was originally a TEM00 (Transverse Electro – Magnetic) mold. In order to investigate the effects of 3D printing under different process parameters, the supplied energy density "ρ" was introduced in this paper.

$$\rho = P/bv$$

where ρ = supplied energy density (J/mm^2), P = laser power (W), b = width of laser spot (mm), and v = scanning speed (mm/s). The different results of laser printing under different process parameters were described by supplied energy density.

2.2. 3D model construction of diamond grinding wheel

A 3D model of a diamond grinding wheel was constructed using pro/E (Fig. 2). The model was divided into several layers by the software, allowing the cross-section image for each layer to be obtained. Multi-point data acquisition was then completed from the profile of the wheel together with the regular grains so that the printing route could be generated. This formed the 3D printing file (stereo-lithography, or STL).

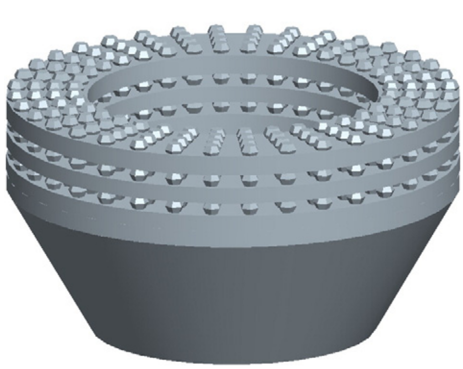

Fig. 2. Entity model of diamond grinding wheel.

2.3. 3D printing of the diamond grinding wheel

The STL file, which was generated from pro/E, was inputted into the 3D printer. The cross-section information of the grinding wheel was then transformed into a printing route by the printer. The 3D printing involved combined laser sintering and melting with laser fast scanning molding technology in order to obtain the target object. The preparation process for the diamond grinding wheel with regular distribution grains follows.

First, the mixture of Ni-Cr alloy powder and diamond grains was sprayed on the ASAI 1045-steel substrate uniformly by feeding devices.

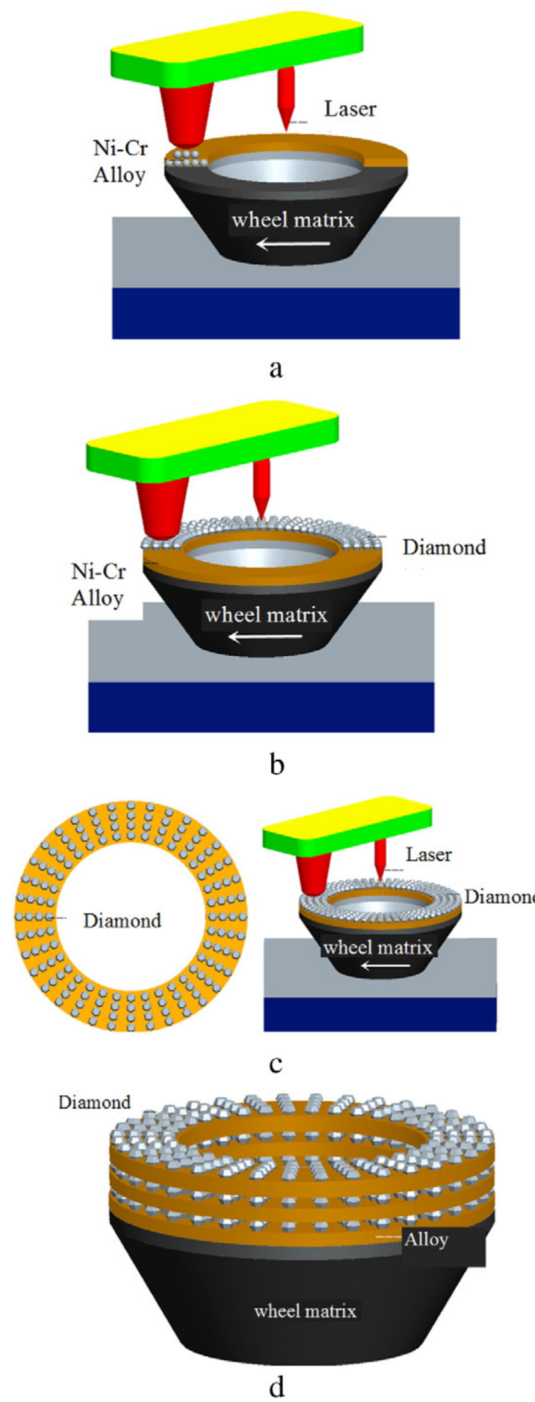

Fig. 3. 3D printing process of diamond grinding wheel with regularly distributed grains. a- Ni based binder 3D printer; b- Uniform spray of diamond grains; c- Regular distribution of grains; d- Diamond grinding wheel with regularly distributed grains.