Journal of Materials Processing Technology 210 (2010) 899–906

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

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

Grinding characteristics in high speed grinding of engineering ceramics with brazed diamond wheels

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ARTICLE INFO

Article history:
Received 20 June 2009
Received in revised form 2 February 2010
Accepted 2 February 2010

Keywords:
High speed grinding
Engineering ceramics
Brazed diamond wheels

ABSTRACT

An investigation was undertaken to explore the grinding characteristics and removal mechanisms in high speed grinding of three engineering ceramics—alumina, silicon nitride, and zirconia—by using brazed diamond wheels of two different grit sizes. The grinding forces and surface roughness were measured and the morphological features of ground workpiece surfaces were examined. The results indicate that material removal mechanisms are different for the three ceramics at high grinding speeds. For alumina, the removal is dominated by brittle fracture. For silicon nitride and zirconia, the ductile removal prevails in the grinding. For each of the three ceramics, grinding power per unit width is found to be nearly proportional to the rate of plowed surface area generated per unit time per unit width, indicating that the grinding energy expended is mainly associated with sliding and plowing.

1. Introduction

Engineering ceramics such as alumina, silicon carbide, silicon nitride, and zirconia are widely applied in modern manufacturing industries due to their excellent properties. However, it is very difficult to machine them owing to their great hardness and brittleness. Great efforts have been made in the efficient and economic machining of engineering ceramics over the several decades. High speed grinding is newly developed as a powerful technique for achieving good component quality combined with high productivity as compared to conventional speed grinding (Kopac and Krajnik, 2006; Jackson et al., 2001). The high wheel surface speed can reduce the undeformed chip thickness, thereby lowering grinding forces (Koenig and Ferlemann, 1991; Klocke et al., 1997). Until now, most studies for high speed grinding of ceramics have been carried out with electroplated diamond wheels (Hwang et al., 2000), and/or with resin bond diamond wheels (Huang et al., 2003; Huang and Yin, 2007; Huang and Liu, 2003; Xie et al., 2007). In the 1990s, the advent of brazed diamond wheels has opened up a new horizon, which shows many merits in bonding strength, grit protrusion and grinding efficiency (Chattopadhyay et al., 1991). Moreover, the brazed diamond wheels have great potentials to be used in high speed grinding. A few studies have been done on the machining performance of the brazed tools at the conventional machining speeds (Xu et al., 2004; Fu et al., 2004; Burkhard and Rehsteiner, 2002). In our recent study, an experiment was conducted to investigate the characteristics in grinding of alumina with a brazed diamond wheel at the grinding speed up to 80 m/s (Chen et al., 2009). However, no studies were found on the characteristics of grinding at higher grinding speeds with brazed diamond wheels.

The present paper is devoted to a systematic investigation on high speed grinding of three ceramics using two brazed diamond wheels of different grit sizes while grinding speed was up to 150 m/s. The grinding characteristics were assessed in terms of grinding forces, force ratio, surface roughness, surface morphology, and specific grinding energy. It is purposely to use coarse grit sizes in an attempt to elucidate if high quality grinding of ceramics can be achieved through raising grinding speeds. It is hoped this work will be of benefit to the application of brazed diamond wheels in high speed grinding of ceramics.

2. Experimental details

2.1. Brazed diamond wheels

Two brazed diamond wheels of different grit sizes were used in the experiments. The wheels fabricated by vacuum brazing process are shown in Fig. 1. The steel substrates, with diameter of 398 mm, hub width of 25 mm and rim width of 10 mm, were used to braze diamond grits. Synthetic diamond grits were used with the size of 500–600 μm (30/35 US mesh) and 250–300 μm (50/60 US mesh). Ni–Cr alloy powder was adopted as the brazing bond matrix. Before brazing, diamond grits were placed randomly on the surface of the rim, on which bond matrix was in the form of a paste. The brazing was conducted at the brazing temperature of 1045 °C and held for 8 min at vacuum atmosphere below 0.6 Pa in a heating fur-

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doi:10.1016/j.jmatprotec.2010.02.002

(a) 30/35 grit wheel (b) 50/60 grit wheel

Fig. 1. The photos of the brazed diamond wheels: (a) 30/35 grit wheel and (b) 50/60 grit wheel.

Table 1
Nominal properties of the ceramics used.

Ceramics	Density [kg/m^3]	Elastic modulus [GPa]	Hardness [GPa]	Fracture toughness [MPa m$^{1/2}$]
Alumina	3.85×10^3	390	18	4
Silicon nitride	3.6×10^3	311	16	8
Zirconia	5.7×10^3	200	12	8

nace. Before grinding, the wheels were balanced using a dynamic balancing instrument.

2.2. Specimens

The workpieces used in the experiments were three typical ceramics—alumina, silicon nitride and zirconia. Their mechanical properties at ambient temperature are listed in Table 1.

2.3. Grinding procedure

Surface grinding experiments were employed in the down grinding mode on a high speed grinder (BLOHM). The spindle is capable of running up to 8000 rpm. A 5% solution of a soluble water-based coolant was used as the grinding fluid in the grinding tests.

Grinding forces, F_h and F_v, were measured using a quartz piezo-electric type dynamometer (Kistler 9255B). Force signals were recorded by a personal computer via a data acquisition system (DAQCard-AI-16E-4), and then filtered by LabVIEW software with a cut-off frequency of 10 Hz. The ground surfaces cleaned with alcohol were examined by using an optical microscope equipped with a digital imaging system (Hirox KH-1000 HI-SCOPE) and a 3D laser scanning microscope (VK-9700). The surface roughness values were measured using a profilometer (Mahr XR20). The experimental setup is illustrated in Fig. 2.

Three main grinding parameters, peripheral wheel speed (V_s), the depth of cut (a_p), and workpiece velocity (V_w) were varied in the grinding tests, which are listed in Table 2. Under each set of parameters, the grinding process was repeated at least three times to obtain the average values of grinding forces.

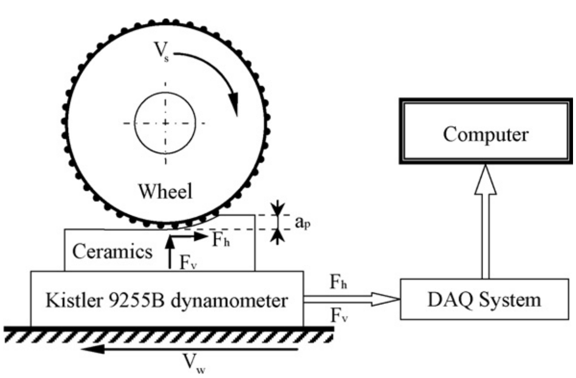

Fig. 2. Illustration of the experimental setup.

3. Results and discussion

3.1. Grinding force

Allowing for the shallow depths of cut in this work, the tangential and normal grinding forces (F_t and F_n) can be substituted by the horizontal and vertical forces measured from the dynamometer (F_h and F_v). Fig. 3 shows the tangential and normal grinding forces, F_t and F_n, obtained under different conditions for the grinding of three ceramics. It can be seen that the tangential and normal force components for all ceramics and wheels of both grit sizes decrease with the increasing of the peripheral wheel speed, which should be attributed to the reduction in the undeformed chip thickness at higher grinding speeds. The grinding forces at the speed of 150 m/s reduce about 30–75% as compared to the forces at the speed of 30 m/s. But the grinding forces are rather different for different ceramics. As is shown in Fig. 3, the forces for silicon nitride are the greatest, followed by zirconia, and the forces for alumina are the smallest, for a specific grinding condition. It is also noted that the magnitudes of the grinding forces are different for the two brazed diamond wheels of different grit sizes. In Fig. 3, it can be seen that the forces of the 30/35 grit wheel are lower than those of the 50/60 grit wheel under the same grinding conditions.

3.2. Grinding force ratio

The ratios of normal force to tangential force (F_n/F_t) for three ceramics are plotted versus the peripheral wheel speed in Fig. 4. It can be seen that the force ratio increases basically with the peripheral wheel speed. In addition, the force ratios for alumina, silicon nitride and zirconia ceramics are much different. The force ratio of zirconia grinding is the highest, which changes from 7 to 19. The values of force ratio in grinding of silicon nitride are in a range of 6–14. The lowest force ratio appears in grinding of alumina, which ranges from 5 to 10. This tendency also reflects the difficulty in the grinding of three ceramic materials. It can also be seen from Fig. 4

Table 2
Parameters of grinding experiments.

Peripheral wheel speed V_s (m/s)	Depth of cut a_p (μm)	Workpiece velocity V_w (m/min)
30, 90, 150	30	0.6
	10	12
	20	6
	40	3