Journal of Manufacturing Processes 31 (2018) 96–102

Contents lists available at ScienceDirect

Journal of Manufacturing Processes

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

Technical Paper

Surface integrity of alumina machined by electrochemical discharge assisted diamond wire sawing

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ARTICLE INFO

Article history:
Received 2 June 2017
Received in revised form 1 October 2017
Accepted 7 November 2017

Keywords:
Surface integrity
Electrochemical discharge
Diamond wire sawing
Alumina

ABSTRACT

Alumina is difficult to cut due to its characteristics of high hardness, brittleness and electrical resistivity. Diamond wire sawing is one of the most widely used methods of cutting alumina. However, the material removal rate (MRR) needs to be improved with the increasing demand for alumina parts. In this paper, the MRR of alumina is increased through integrating electrochemical discharge with diamond wire sawing. The electrochemical discharge may bring variation to surface integrity and affect performance of the machined part. Therefore, this research focuses on a detailed investigation on surface integrity of alumina cut by electrochemical discharge assisted diamond wire sawing. Surface roughness, topography, recast layer, and elements of the machined surface are analyzed based on experimental results. The findings provide a valuable basis for the application of electrochemical discharge assisted diamond wire sawing.

1. Introduction

Alumina is a popular engineering ceramic which has advantages of high hardness, electrical resistivity, strength, wear resistance and low density. However, cutting alumina with conventional machining methods is difficult due to its hard and brittle characteristics. The wire electrical discharge machining method also does not work in cutting alumina because of its insulating property.

Several methods have been developed in cutting alumina. Abrasive water jet [1,2] is an efficient way but the angle of the machined surface is obvious and unavoidable. Plasma arc technique [3] was proposed but the recast layer of machined surface was thick and machining accuracy was low. Laser can only cut alumina with low thickness [4,5]. Assisted electrode method [6,7] relies on the unstable and uncontrollable carbon layer generated by the decomposition of kerosene. Electrochemical discharge machining (ECDM) was used to cut alumina but the material removal rate (MRR) was low [8]. Free abrasive wire cutting method was applied to cut monocrystalline silicon [9], but the MRR was low in cutting alumina. Compared with the above mentioned methods, diamond wire sawing [10,11] performs well on both machining efficiency and accuracy, but the MRR needs to be further increased with the increasing demand for alumina parts.

In this paper, the MRR of alumina is increased by integrating electrochemical discharge with diamond wire sawing. While, the surface integrity may be changed by electrochemical discharge. Singh et al. [12] analyzed the machinability of multi walled carbon nanotubes filled alumina composites by wire electrical discharge machining (EDM). A combined effect of spalling, melting and evaporation was found on the machined surfaces. Cracks and recast layer were also presented. Similar conclusions were drawn by Melk et al. [13] in their research on the material removal mechanisms by EDM of zirconia based composites. Vogeler et al. [14] studied the surface integrity of ZrO_2-TiN by wire EDM. The experimental results showed that the material was removed by melting, evaporation, and chemical decomposition. Different from EDM, the work material is removed by the heat from electrochemical discharges between tool and electrolyte instead of workpiece during ECDM. Much electrochemical discharge energy is transferred to the electrolyte, resulting in a decrease of energy applied to remove work material. Nevertheless, the work material can be removed in the form of melting and vaporization if the voltage is large enough and the workpiece is placed in the discharge zone [15]. In ECDM of insulating glass, micro cracks was found [16,17], and heat affected zone was observed [18,19]. The current research aims to analyze surface integrity of insulating alumina cut by electrochemical discharge assisted diamond wire sawing.

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https://doi.org/10.1016/j.jmapro.2017.11.008
1526-6125/

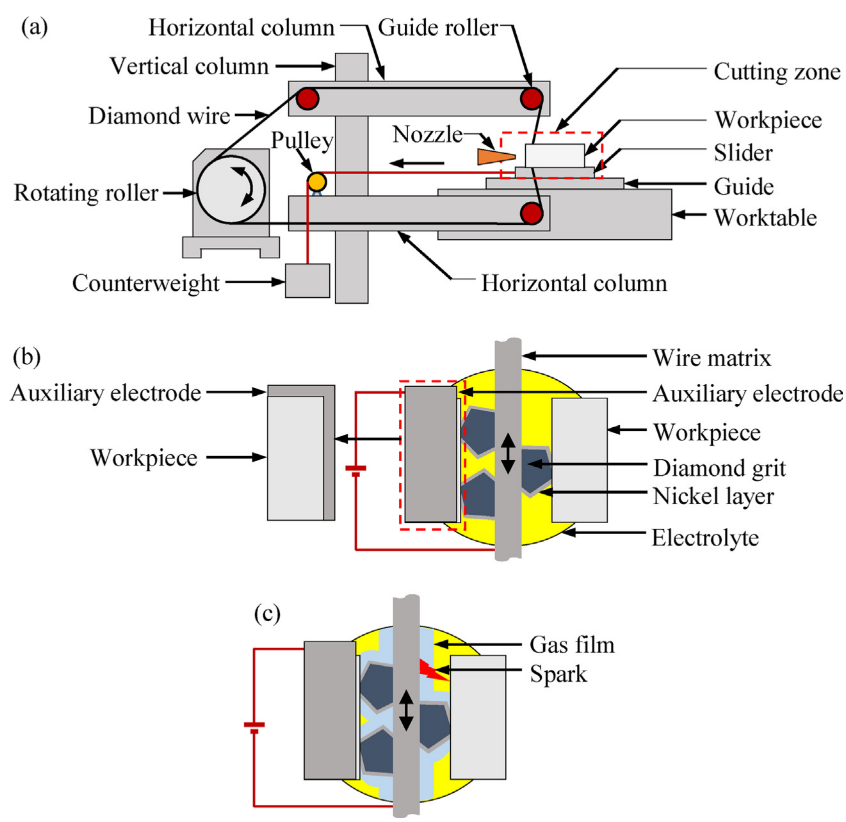

Fig. 1. Experimental setup and principle of the electrochemical discharge assisted diamond wire sawing: (a) cutting setup, (b) enlarged view of cutting zone without applying voltage, and (c) enlarged view of the cutting zone with applying voltage.

2. Experiments

2.1. Experimental setup

Fig. 1 shows the experimental setup and principle of electrochemical discharge assisted diamond wire sawing. In Fig. 1a, the diamond wire is driven by a rotating roller, and the workpiece is fixed on the slider which is installed on the guide. A counterweight pulls the slider and makes it moves forward with the removal of work material. With this feed mode, the workpiece feeds only when the work material is removed. The feed rate of the workpiece is not a process parameter, but a result of work material removal. A larger counterweight mass increases the deformation of diamond wire and the cutting force, which improves the cutting speed. The cutting speed is simply obtained by measuring the increase of the slit length per min. Fig. 1b shows the enlarged view of cutting zone without applying DC voltage. A right-angled stainless steel plate with thickness of 1.0 mm was used as the auxiliary electrode. The gap between the auxiliary electrode and the diamond wire was 1.0 mm. The diamond wire and the auxiliary electrode are connected to the negative and positive poles of the DC power, respectively. By using a nozzle, electrolyte is sprayed into the cutting slit to connect the diamond wire and auxiliary electrode and thus a circuit is generated. Fig. 1c shows the phenomenon in cutting slit as the voltage is applied. When the applying voltage is low, electrolysis occurs and hydrogen bubbles are generated close to the diamond wire. The number of hydrogen bubbles increases with the increasing voltage, and finally a gas film is formed around the diamond wire. The gas film isolates the diamond wire from the electrolyte, and so an open circuit is happened. Almost the entire voltage is exerted on the diamond wire and electrolyte. When the voltage exceeds the critical value [20], electrical discharge occurs and sparks are generated on surface of the diamond wire. The temperature of the electrical discharge sparks is so high that it can reduce the strength of the workpiece, which makes it easily to be removed by the constantly moving diamond wire.

Table 1
Characteristics of the alumina.

Density	Hardness	Melting point	Electrical resistivity	Thermal conductivity
3.9 g/cm^3	9 (Mohs)	2054 °C	10^{16} Ω/cm	35 W/m K

Table 2
Conditions of comparative experiment.

Conditions	Diamond wire sawing	Electrochemical discharge assisted diamond wire sawing
Diamond wire diameter	0.2 ± 0.01 mm	0.2 ± 0.01 mm
Workpiece thickness	5.0 mm	5.0 mm
Working liquid	Water	NaCl solution (20%)
Auxiliary electrode	–	Stainless steel plate
DC voltage	–	52 V
Wire speed	700 mm/s	700 mm/s
Counterweight mass	300 g	300 g
Machining time	5 min	5 min

2.2. MRR improvement

The MRR of diamond wire sawing with and without the assistance of electrochemical discharge was measured. Characteristics of the alumina are summarized in Table 1, and experimental conditions are shown in Table 2. The diamond wire used in this paper is commercially available. The wire core was steel and the diamond grits were fixed by an electroplated nickel layer. The grit size was