



Micro-electrical discharge machining characteristics of newly developed conductive SiC ceramic

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Abstract

An electrically conductive SiC ceramic was fabricated via hot-pressing a 72.6 wt% β -SiC, 7.6 wt% polysiloxane, 4.3 wt% phenol resin, and 15.5 wt% yttrium nitrate powder mixture. It was machined into 300- μ m-thick cylindrical specimens (YN-SiC) with diameters of 3 mm. The micro-electrical discharge machining characteristics such as the number of shorts, machining time, entrance clearance, material removal rate (MRR), and debris size of the conductive SiC ceramic were compared to those of SUS304. The number of shorts for SiC was smaller than that of SUS304 because of its low electrical conductivity. As the unit discharge energy increased, the debris size and its standard deviation for YN-SiC increased, while those of SUS304 decreased. The machining time for the SiC was longer than that of SUS304 because of the increase in the number of shorts at a small discharge energy. It was also found that the entrance clearance of the SiC was the smallest at a unit discharge energy of about 7 μ J. The MRR was inversely proportional to the machining time.

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1. Introduction

The use of ceramic materials has been increasing in industrial applications because of their high hardness, good mechanical strength, and resistance to oxidation. Their machining, however, is difficult, and is performed mostly by slow and expensive grinding processes. Electrical discharge machining (EDM) is a well-known process for producing complex structural parts from electrically conductive materials with high dimensional accuracy and a good surface finish. Some techniques have been developed over the years to apply EDM to ceramic materials [1–7].

The assisting electrode method (AEM) was proposed for machining an insulating material by EDM. Muttamara et al. successfully machined Si_3N_4 ceramics using AEM and

found that a carbon baked layer was a useful material for the assisting electrode [1]. Sabur et al. used an adhesive copper foil as an assisting electrode for the EDM of non-conductive ZrO_2 ceramics [2]. It was found that the material was removed mainly by spalling, with a small amount removed by melting and vaporization during the EDM process. Silver varnish is also used to create the starting layer for an AEM system [3]. It was found that the surface roughness of ceramics machined by micro-EDM was in the range of two to three times higher than that of steel machined under the same parameter set.

Lauwers et al. reported that the composition and grain size of electro-conductive phases such as WC, TiC, and TiCN significantly influenced the wire-EDM performance for ZrO_2 ceramic composites [4]. In general, finer microstructures for an electro-conductive phase produce a lower thermal conductivity and hence a higher cutting speed for materials where removal occurs by melting. In contrast, a higher cutting speed is

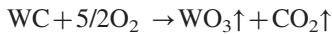
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Table 1
Machining conditions for experiments.

Electrode	Material	WC-Co 10%
	Diameter (μm)	300
	Length (μm)	20,000
Workpiece	Material	YN-SiC, SUS304
	Thickness (μm)	300
Dielectric fluid		Kerosene
Experimental condition	Voltage (V)	80, 100, 120
	Capacitance (pF)	1,000, 1,500, 2,000
	Resistance (es)	500
	Feed rate (μm/s)	1.0
	Spindle speed (rpm)	2,200

obtained for micro-based ZrO₂-WC ceramic composites due to the existence of chemical oxidation reactions [5]:



Lauwers et al. [6] investigated the EDM material removal mechanisms for three commercially available ceramic composites: ZrO₂-, Si₃N₄-, and Al₂O₃-based ceramic composites that contained TiN or TiCN as an electrically conductive phase. They pointed out that melting/evaporation and spalling were the main EDM material removal mechanisms, along with other mechanisms such as oxidation and decomposition. The EDM performance for Al₂O₃-TiCN and ZrO₂-TiN was also investigated, and it was found that the machining behaviors of both materials were similar to that of steel [7]. However, their surface roughness values were lower because of the higher amount of the electrically conductive secondary phase. The material removal and surface damage of Ti₃SiC₂ ceramics during EDM have also been investigated [8]. The material removal rate (MRR) for Ti₃SiC₂ ceramics increased with increasing discharge current, working voltage, and pulse duration. Microcracks in the surface and loose grains in the subsurface were observed in the ceramics as a result of thermal shock.

The previous works on the EDM of ceramic materials can be summarized as follows:

- (1) An electrically conductive baked layer or adhesive foil was used for the EDM of insulating materials.
- (2) Electrically conductive materials such as WC, TiC, and TiCN were incorporated into ceramic materials to make EDM feasible.
- (3) Electrically conductive Ti₃SiC₂ can be machined by conventional EDM.

In this research, the micro-EDM characteristics of a new electrodischarge-machinable SiC ceramic were investigated. Submicron-sized SiC was sintered with a yttrium nitrate additive to obtain a good electrical conductivity, as high as $3.3 \times 10^4 (\Omega\text{m})^{-1}$ [9]. The number of shorts, machining time, entrance clearance, and MRR of the new conductive ceramic were investigated and compared with those of SUS304.

2. Experimental procedure

2.1. Fabrication of SiC specimen

A powder mixture consisting of 72.6 wt% submicrometer β-SiC (Ultrafine, Betarundum, Ibiden Co. Ltd., Ogaki, Japan), 7.6 wt% polysiloxane (1036 kg/m³, GE Toshiba Silicones Co. Ltd., Tokyo, Japan), 4.3 wt% phenol resin (1090 kg/m³, Kangnam Chemical Co. Ltd., Seoul, Korea), and 15.5 wt% yttrium nitrate (Y(NO₃)₃·4H₂O, 99.99%, Sigma-Aldrich Co., St. Louis, MO) was mixed in ethanol by ball milling using SiC balls and a polypropylene jar for 24 h. After the powder mixture was milled, dried, and sieved using a 60 mesh screen, it was uniaxially pressed and heated at 200 °C for 2 h in air to cross-link the polysiloxane. The cross-linked specimen was heated at 1450 °C for 1 h and subsequently hot-pressed at 2050 °C for 6 h under a pressure of 40 MPa in a N₂ atmosphere. The hot pressed material was ground using a diamond grinder to manufacture cylindrical specimens with 3-mm diameters and 300-μm thicknesses. The specimen was called YN-SiC [9].

2.2. Material characteristics of YN-SiC

The electrical conductivity, Vicker's hardness, and fracture toughness of YN-SiC were $3.3 \times 10^4 (\Omega\text{m})^{-1}$, 24.2 GPa, and 4.9 MPa·m^{1/2}, respectively. The micro-EDM machining characteristics of YN-SiC were compared with those of SUS304. The electrical conductivity of SUS304 is $1.4 \times 10^6 (\Omega\text{m})^{-1}$, which is 42 times larger than that of YN-SiC.

The MRR was calculated using the following equation:

$$\text{MRR} = \frac{\pi}{12t_m} (D_{in}^2 + D_{IN} \cdot D_{OUT} + D_{OUT}^2) \times t \quad [\mu\text{m}^3/\text{sec}] \quad (1)$$

where t_m , D_{IN} , D_{OUT} , and t denote the machining time, entrance diameter, exit diameter, and thickness of the specimen, respectively.

2.3. Machining conditions

Machining experiments were conducted under the conditions of three different voltages (80, 100, 120 V), three

Table 2
Experimental conditions of each EDM run.

No. of runs	Voltage (V)	Capacitance (pF)	Resistance ((p	Unit discharge energy (μJ)
1	80	1000	500	3.2
2	80	1500	500	5
3	80	2000	500	7.2
4	100	1000	500	4.8
5	100	1500	500	7.5
6	100	2000	500	10.8
7	120	1000	500	6.4
8	120	1500	500	10
9	120	2000	500	14.4

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