International Journal of Engineering, Applied Sciences and Management, Vol. 1, Issue 1 (2020) Paper ID:101I2020

AN OVERVIEW OF EDM ON SILICON CARBIDE (SIC)

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ABSTRACT:

Modern high performance materials especially ceramics find immense applications ranging from Aerospace to Automobiles, gas turbines to bearing, machining to mining etc. Because of their outstanding capabilities, these materials are difficult to be machined. Among them, Silicon Carbide (SiC) has excellent features which makes it an exciting candidate for machining applications. Due to its peculiar material removal mechanism, the electrical discharge machining (EDM) presents itself as a suitable candidate for the machining of SiC. This paper is a review of the research works that have gone into electrical discharge machining of the SiC.

KEYWORDS: Ceramics, *EDM, SiC*

INTRODUCTION:

Silicon carbide (SiC), the fourth hardest material in the world next only to diamond, boron nitride and boron carbide and with high oxidation, corrosion and thermal shock resistance, superior hardness, young's modulus, electrical resistance, chemical inertness, low density etc. is an excellent choice for usage in rigorous engineering applications like bearings, valves, rotors, cutting tools, etc. It is chemically and thermally stable even at raised temperatures and/ or pressures and with exceptional wear resistance it is used in refractory linings and heaters for furnaces. SiC is being used in a wide variety of fields such as industrial, automobile, defense, aerospace, biomedical, electrical and electronics fields. It finds applications as blanket material in nuclear reactors and also as neutron detectors which perform well even in hostile radiation fields . SiC is used in some challenging environment like military aircraft and combat vehicles, power generation, and petrochemical industries .

SiC's high-temperature high-power capabilities offer economically significant benefits to aircraft, spacecraft, power, automotive, communications, and energy production industries. Silicon carbide is deployed in the Si wafers' heat treatment. SiC is also applied in the making of the fishing rod guides, diesel particulate filters . Due to its remarkable irradiation endurance and chemical stability, SiC is utilised in flow channel inserts. In semiconductor industries, SiC is utilised in high temperature, high-frequency, and high-power device applications, due to its high thermal conductivity, high carrier mobility, and high chemical stability . A futuristic application of SiC is in the field of heavy duty quantum computing almost replacing diamond . Also the sintered Silicon Carbide is used to prepare space stationed reflectors operating at cryogenic temperatures . SiC devices lowers the power loss and achieve smaller power supply units and power conversion equipments .

In microelectronics applications, SiC is the popular choice for the micro electro-mechanical systems (MEMS) . Silicon Carbide wafers fixed on power modules minimizes the energy loss of devices thus resulting in high efficiency. Since the cooling requirements are non-essential, the miniaturization of the machining apparatus can be accomplished . Some distinct applications of SiC are down-hole instrumentation, aviation engine sensors & controls, gas turbine instrumentation and space exploration . SiC-based intricate semiconductors perform well even in adverse circumstances (i.e., temperatures up to 600 ^{o}C), where traditional Si-based electronics (limited to 350 ^{o}C) are unusable . SiC is also used in the construction of transparent armor and bullet-proof windows.

1.Electrical Discharge Machining (EDM) of Silicon Carbide

Electrical discharge machining (EDM) is an alternative manufacturing practice wherein matter is removed from a part of the work piece as a result of a sequence of repetitive electrical discharges between a tool electrode, and the work piece substance being shaped when it is immersed inside a dielectric solution. Nowadays, EDM has become a ultra-precision material processing technology for all types of conductive elements namely: metals, metallic alloys, graphite or even some ceramic materials, irrespective of any hardness [36].Among other processing methods available for SiC, the electrical discharge machining (EDM) presents itself as a suitable candidate due to its peculiar material removal mechanism.

SiC ceramics are electrically semi conductive with a broad bandgap. By doping N atoms into a SiC lattice, the ceramics' electrical conductivity can be enhanced and hence EDMed . In addition to the melting and vaporisation removal mechanism of EDM, the thermal crack arising out of the thermal stress due to the heat input from both arc plasma and Joule heat is found to be one of the primary mechanisms of the material removal in EDM of SiC .

Liew et al. studied the performances of Cu electrodes reinforced with CNF(carbon nano fiber) with different CNF contents in the EDM of reaction-bonded SiC and found that CNF addition to the electrode increased both the material removal rate (MRR) of work piece and wear rate of electrode

For the EDM of SiC, the various experimental results suggest that both the electrode wear and MRR readily improves with an increase in the duty cycle. The MRR is primarily influenced by current intensity and voltage, while the electrode wear is controlled by intensity, pulse time and flushing pressure. A hybrid machining process which combine ED milling and mechanical grinding to machine SiC ceramic was found to improve the MRR.

A novel machining method of SiC ceramic using end electric discharge (ED) milling was studied by Renjie et al.. In this process a turntable containing a few small cylindrical copper electrodes acts as the tool, and it can adequately process a huge surface area on SiC ceramic. The outcomes suggest the material removal mechanism as melting, evaporation and thermal spalling, relocation of tool electrode elements towards the work piece. The MRR improved and wear of electrode decreased with negative tool polarity, whereas the lower surface roughness can be attained with positive tool polarity under the same conditions.

Kim et al. developed electro-discharge-machinableSiC ceramics by hot pressing using a sintering additive such as yttrium nitrate. The specimen, when hot-pressed at 2050 ^{0}C for 6h under 40 MPa in nitrogen, showed an electrical conductivity as high as 3 x 10^4 $(\Omega m)^{-1}$ at room temperature thereby easily EDMed.. Silicon carbide (SiC) single crystals were EDMed by Kato et al. and confirmed that the EDM has caused no potential damage was effected within the SiCs in spite of high voltage and high temperature during EDM.

Luis et al. conducted a study on the significance of the most related EDM factors over MRR and electrode wear (EW) has been carried out. With a confidence level of 95%, they noticed that the MRR was affected by the intensity and voltage while EW was influenced by intensity, pulse time and flushing pressure.. Mahdavinejad et al. analyzed instability in ED machining of silicon carbide (SiC) due to heat generation in the work piece body. They found that the Joule heating due to the voltage drop in SiC body is a main factor in ED machining of this material. Therefore, some techniques as voltage injection are recommended for stable machining.

Zhao et al., investigated the influence of the crystal anisotropy on EDM performance and found that a slightly higher machining rate can be obtained when the cutting direction is along the c axis. Also, more fracture pits occurred on the machined surface when the cutting direction is along the c axis of SiC. Single crystal SiC possess a certain crystal orientation. And during EDM, when the direction of crack propagation is along crystal orientation, it was observed that the machining rate increases and as a result the machining efficiency increases. Crack propagation in any other direction reduces the machining rate.

1. Major areas of interest related with the EDM of silicon carbide

From the literature surveyed, some major areas of interest connected with theEDM of silicon carbide are as follows:

2.2 Shape and Geometry of Tool

Electrical discharge machining using foil electrode is a possible method for SiC processing. In this method a well tightened thin foil acts as the tool electrode. The merits of this method over wire EDM are that the foil thickness tinier than the wire diameter can be used, foil tension reduce vibrations, and larger current can be supplied because tool rupture is also minimised. It was observed that using a foil electrode with holes, cutting speed increased and tool wear decreased. This occurred because, the chip pocketing effect of holes improved flushing and cooling conditions, thereby the machining stability improved and the thermal load on the foil electrode decreased.

A unique method of SiC processing by EDM using a blade electrode was proposed by Zhao et al. The shaping process was achieved by using a reciprocating worktable, which moves the work piece against a tightened blade tool electrode. This resulted in decrease of the tool wear in length. However, the tool wear length was not uniform in the reciprocating direction. By controlling the work piece reciprocating speed, the tool wear shape could be improved, although it was difficult to make the tool wear length completely uniform. Also in a separate study Zhao et al. observed the the EDM behaviour of cutting SiC material and compared to those of cold tool steel. They informed that, the larger area moment of inertia of the foil, reduces its vibration. Also the cracking and fracturing in addition to melting and vaporizing contributed to the MRR . The authors also reported that, that EDM characteristics of SiC differ from those of steel. The EDM speed of SiC is higher and the tool wear ratio is lower compared to that of steel, although SiC has a higher thermal conductivity and melting point.

Another innovative use of tool geometry in the EDM of SiC was employing a steel toothed wheel as the tool electrode. This resulted in SiC with electrical resistivity of 500 Ωcm being machined by electrical discharge milling. The process is able to effectively machine a large surface area on SiC ceramics with high electrical resistivity, and effectively machine other advanced materials with high electrical resistivity such as polycrystalline diamond, and cubic born nitride.

As suggested by Liu et al., using a steel toothed wheel as tool electrode, the SiC ceramics with specific resistivity of 500 Ω cm can be easily machined by ED milling. The process shows high MRR.

A novel rotary tool electrode setup was designed for EDM coring of SiC ingot. EDM by electrostatic induction feeding method was applied to rough machining process. Also the multi-discharge EDM presented better surface integrity and machining efficiency due to the separate feeding of electricity.

A novel electrical discharge slicing process utilizing a running ultra-thin foil tool electrode is demonstrated for the slicing of SiC ingots. On the other hand, the large side surface area of the foil which causes difficulty in debris flushing, remains a problem to be solved in the future.

2.3Polarity of electrode

Negative polarity of tool electrode is more suitable for foil EDM of SiC with higher machining speed and lower tool wear ratio under short pulse duration. Long pulse duration is not suitable for EDM SiC due to a larger kerf width and lower machining speed. The MRR was higher when the work piece was positive due to larger discharge energy distribution into the anode in every single discharge. Also, increase in MRR was observed with increase in discharge current. Also, the kerf width was found to be independent of tool electrode polarity.

During the end electrical discharge (ED) milling, more tool electrode material can transfer to the work piece surface in case of positive tool polarity, when compared to negative tool polarity under the same conditions. Renjie et al. observed that under the same conditions, the lower surface roughness can be obtained with positive tool polarity, and the higher material removal rate, lower relative electrode wear ratio can be obtained with negative tool polarity. In order to get a better machined surface, positive polarity for the tool electrode should be used.

In ED-milling, exploiting the reverse polarity (a tool as an anode and dummy workpiece as a cathode) for the machining of silicon carbide ceramics with high electrical resistivity (500 Ωcm) showed high MRR, low TWR, and improved surface finish than that achieved with straight polarity.. For the EDM of silicon carbide, the most highly recommended electrode is electrolytic copper. Conversely, the use of negative polarity for the electrode is recommended for this material, as the machining process can therefore be carried out in a more stable way .

2.4Electrolyte/Dielectric

Renjie et al., suggests that using a water-based emulsion as the machining fluid, harmful gas is not generated during EDM and it shows a good working environmental practice. . The EDM of SiC in deionized water provided a higher machining rate than that in EDM oil. Twelve percent of oxygen was detected on the EDMedSiC surface in deionised water, indicating that oxidation effect is significant in the EDM of SiC in water, contributing to the higher EDM rate of SiC.. Luis et al. performed EDM on SiC using mineral oil (Oel-Held Dielektrikum IME 82) as dielectric fluid. It was found that the wear on the electrode tends to decrease, when the dielectric flushing pressure is increased for any value of intensity and pulse time.

2.5Assisting Electrode Method

Experiments by Zeller et al. shows that non-conductive sintered silicon carbide can be micro structured by EDM. The EDM process is enabled by a screen printed Assisting Electrode (AE) This method is based on a conductive material which is applied on top of the ceramic. The AE provides the required electrical conductivity of the work piece at the beginning of the machining process. Due to the high energy input during the discharges, the dielectric fluid is decomposed and a thin layer of carbonized products is deposited on the anodic work piece surface. This continually generated intrinsic AE provides electrical conductivity of the work piece and enables the process to continue after the applied AE has been penetrated. Therefore, usage of a carbonic dielectric fluid is a necessity for this process. The material removal of the ceramic work piece occurs due to the high energy input during the discharge process. .

Zeller et al studied the SiC specimens were coated using screen printing with a conductive carbon lacquer layer of ~ 25 µm of thickness to act as assisting electrode, promoting the first sparks between the electrode and the carbon coated SiC work piece

2.6Micro EDM (µ-EDM)

In µ-EDM operation, gap voltage, capacitance and threshold have significant effect on performance characteristics. It was observed that the high gap voltage, high capacitance and high threshold values gave higher MRR while performing µEDM of SiC. Whereas, low gap voltage, high capacitance and high threshold values resulted in low radial overcut. While, low gap voltage, high capacitance and low threshold values were needed for low tool wear rate. For a better surface finish, high gap voltage, low capacitance and low threshold values were required. µ-EDMed surface of SiC had high surface roughness which was mainly due to the presence of craters, debris and resolidified material, which arose from the improper flushing due to low gap between tool and work piece.

Li et al., studied the details in the gap area of micro EDM, and a sandwich work piece was made using two kinds of foils: stainless steel SUS304 and SiC. It was found that the behavior of bubble has strong influence on the exhaust of debris. With the increase of feed depth, the slower speed of bubble overflowing out of gap area leads to the lower effectiveness of debris exhaust. The debris accumulation in the gap area causes abnormal discharges. Discharges at the last stage of machining mostly occur between the tool and the mixture of debris and dielectric. Material migration phenomenon between tool electrode and work piece material in micro EDM of RB-SiC has been experimentally investigated. Material deposition rate is closely related to work piece surface roughness. The higher the roughness, the higher the deposition rate. Voltage strongly effects the deposition of tungsten tool material on the work piece. The lower the voltage is, the more significant the deposition rate is. [50]

Acknowledgement

I am deeply indebted to my guide and mentors Dr. M. Uthayakumar and Dr.S. Thirumalai Kumaran for their support and valuable suggestions during the preparation of this review paper. I also acknowledge the support of the management and staff of Amal Jyothi College of Engineering, Kanjirappally and last but not the least, the benevolent Almighty God.

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