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Electrical Discharge Machining of Al_2O_3 and Si_3N_4 Ceramics; A Research

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Abstract—Ceramic materials which have high hardness and brittleness cannot be machined by traditional machining process because of their low efficiency and feasibility. But in non-traditional machining process, it overcomes these limitations proving it to be very useful in manufacturing process. In this review paper we are discussing about electrical discharge machining (EDM) process on Al_2O_3 and Si_3N_4 ceramic materials which are machine able. EDM parameters like material removal rate (MRR), tool wear rate (TWR), surface finish are discussed. EDM is very much suitable for ceramic materials because of its high surface finish, accuracy and efficiency.

I. INTRODUCTION

Ceramics, metal and polymers are mostly used for industrial applications based on the requirement. These materials having their specific advantage and limitations. The high temperature, wear and chemical reaction related issue are comes in the metals and polymers. Ceramics materials is suitable for higher temperature, wear and chemical resistance. However, ceramic material offered the great hardness, strength, higher temperature resistance, high strength to weight ratio and biocompatibility [1]. Due to its extra ordinary properties of ceramic materials widely applied in the various types of applications such as cutting tool, biomedical, electrical, sanitary, aerospace industries, suitable for mechanical components and also suitable to resist the mechanical loads [2]–[6]. Moreover, ceramics is highly demanded material in medical field for implant of dental, acetabular cups, femoral head, hip replacement, bone fillers and scaffold for tissue engineering [7].The ceramic material divided in to two categories such as conductive and non-conductive material. The alumina, silicon, zirconium with nitride and boron, silicon with carbide etc. are the generally used ceramics.

II. METHODOLOGY

Manufacturing process are the steps through which raw materials are converted into a final product where the customers can consume. Machining is part of manufacturing process, it is a process of removing excess materials from the workpiece material to obtain the desired shape and size. The process is classified into two types:

1. Conventional machining process
2. Un-Conventional machining process

Conventional machining process uses mechanical energy for metal removal, it involves direct contact between the tool and the workpiece. Tool life is less due to the wear of the tool resulting from its direct contact with the workpiece metal. The cutting tool must be harder than the workpiece material. Machining is characterized by macroscopic chip formation by shear deformation. Difficult to obtain high accuracy and surface finish. Metal removal rate is limited by mechanical properties of the workpiece material. This process may require a semi-skilled or unskilled labour. Low capital cost and easy setup of equipment's.

Whereas in Un-Conventional machining process utilizes different energy sources like mechanical, electrical, chemical, and thermal sources. There is no physical contact between the cutting tool and workpiece. Tool life is more as there is no contact. Cutting tool need not be harder than the workpiece material. Machining is mostly characterized by microscopic chip formation. It results in high accuracy and surface finish. It can remove materials with much ease even with difficult to cut materials.

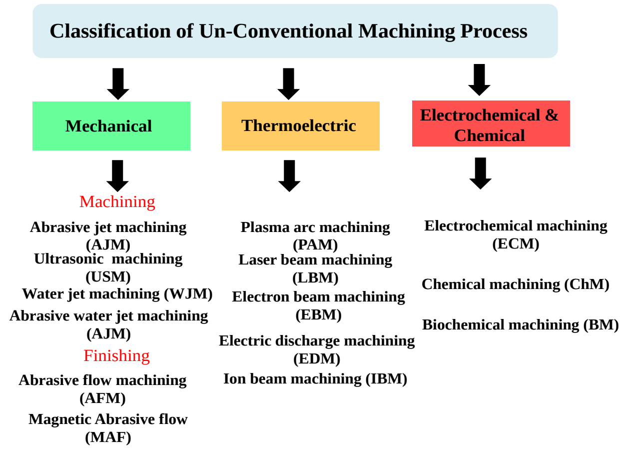

Figure 1. Classifications of Un-conventional machining processes[8].

It requires skilled operator. High capital cost and complex setup required. The different types of Un-conventional machining processes are shown in Figure 1. [9]–[12].

From the aforementioned unconventional machining processes are suitable for different types of material and their

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machining depends on the requirement. In this paper we have selected the ceramics material and their machining.

Moreover, all the unconventional machining processes are not capable to machining the all types of material. In case of ceramics EDM is the most suitable un-conventional machining process.

III. PRINCIPLE OF EDM

EDM process is a controlled metal removal based on the principle of erosive effects of electrical discharges taking place between two electrically conducting materials immersed in a dielectric fluid. One of the conducting materials is tool and another one is workpiece. The shape of the tool is similar to that of the desired shape of the workpiece to be obtained. The tool and the workpiece are separated by a dielectric fluid and connected to dc power supply to create potential difference between the tool and workpiece. When there is sufficient potential difference, the dielectric fluid in the gap gets ionized under the pulsed application of the direct current, then enabling a spark discharge to pass erosion caused by the electric spark. The amount of material removed is very small, and is flushed away with the continuously flowing fluid. The downward movement of the tool will produce the desired shape on the workpiece [7][13]. Many attempts have been made by the researches to find the suitable method of machining. Some researchers say 50% is EDM process, 31% for laser beam machining process, 10% for electrochemical machining process, and remaining 9% is for photochemical machining process. As there is non-contact in EDM process, extremely hard materials can be easily machined with close tolerances, thin and small sized workpieces can be easily machined, fine holes can be easily drilled, capable of producing any geometric shape, can produce parts without any distortion, burred, or including residual stress, high accuracy, and surface finish.

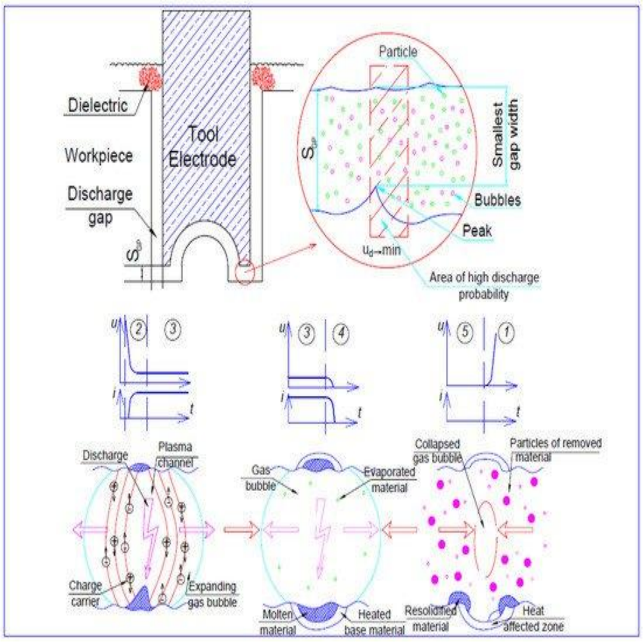

Figure 2. Machining principles of EDM [13]

This process is widely used in aerospace applications to produce turbine blades, nozzle holes and other parts[14]. The machining principle are shown in Figure.2.

IV.EDM MACHINING OF Al2O3

The machining of ceramic material required high amount of energy to remove the material by melting and vaporization from the surface. During the machining of ceramic material thermal stress are occurs. There are different types of ceramics material and they having their individual electrical resistance. The selection of the pulse frequency is depend on the electrical resistance of that particular material. [15], [16].

Aluminium oxide has a strong inter atomic bonding, resist to strong acid and alkali attack. There is no reaction to any type of gases and reagent except hydrochloric acid, phosphorus and wet fluorine. It is a complex ceramic and has high electrical resistivity, to machine by electrical discharge machining of Al_2O_3 is quite difficult because of this**.** Stability of aluminium is disturbed by physical and thermal properties during traditional machining process, so EDM is best for ceramic materials[14], [17]–[21].

The selection of input parameters play an important role to remove the material from the surface it depends on the mechanical and physical properties of the material. During the EDM machining of (Al_2O_3 + TiC) apart from evaporation and oxidation sometimes thermal spalling, material removed from the deep layer that is responsible for high surface roughness. The variation in thermal and electrical conductivity is responsible for uneven melting and thermal spalling[22], [23].

V.EDM MACHINING OF SI3N4& RESULTS

Silicon nitride is a non-conducting and as extreme mechanical properties which leads to difficulty in machining. Direct nitration of a compacted silicon powder alleged to chemically bonded silicon nitride which is very hard to achieve high density because there is a difficulty in completing the reaction. So a conductive element has to be induced into the material matrix if we have to machine a silicon nitride on EDM [24].

Si_3N_4-Tin it finds its usage in reinforced environment like convoluted moulds and heat exchanges which is in the metal forming, wear opposing components etc., it's composition is 55% tin, 40% $si_3 n_4$, and 5% of additives like al_2o_3 and y_2o_3. It has a very high material removal rate 100uj to 110uj because of the addition of tin which is a catalyst in EDM process [7], [25]–[27].

EDM applied on Si_3N_4-Tin and Alumina Toughened Zirconia and observed that Si_3N_4-Tin is provides double MRR and machining depth with compare to Alumina Toughened Zirconia [28]. RC circuit is highly recommended for control the spark in EDM [29]. In this work compared various types of ceramics such as; ZrO_2, Al_2O_3, Si_3N_4 and SiC by manipulate the polarity, voltage and capacitance. Moreover, voltage is the effective parameters that directly effects on the MRR [30], [31]

VI. CONCLUSIONS

1. The review paper shows that Un-conventional machining process is most suitable when compared to Conventional machining process. Electrical discharge machining process is suitable for ceramic materials.

2. Ceramic materials like Si_3N_4 and Al_2O_3 should add some catalyst as there is a difference in its physical, mechanical, thermal, and chemical properties.

3. There is no stress induced in the workpieces and the workpiece has a high accuracy, surface finish and precision.

4. EDM process is more suitable for Al_2O_3 materials compare to Si_3N_4.

5. High consumption of current, excessive tool wear occurs during machining of ceramics, hence additional cost for the tool.

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