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ELECTRIC DISCHARGE MACHINING OF COMPOSITES- A REVIEW

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ABSTRACT

In the recent time composite materials have been emerged out as one of the most favorable material for the industries like automobile, defense, and in aerospace. Among them metal matrix composites have shown the most optimal properties such as: hardness, strength, lightweight, corrosive resistance. But these metal matrix composites (MMCs) has shown problems during machining of these materials using conventional methods of machining. Hence, efforts have been made towards finding the number of alternative methods for machining of MMCs. Electric Discharge Machining (EDM) is one of the best choices. EDM is a non-traditional, thermoelectric machining process which uses the heat energy of spark in order to remove the material from the workpiece.

Keywords: *Electric Discharge Machining, Metal Matrix Composites, Surface Roughness, Metal Removal Rate*

INTRODUCTION

Over the last three decades or so, metal matrix composites have emerged as an important class of materials. The term metal matrix composites (MMCs) itself includes a wide range of microstructures. Metal matrix composites can be classified based on type and contribution of reinforcement. Fiber composite materials can be further classified into continuous fiber composite materials (multi- and monofilament) and short fibers or, rather, whisker composite materials.

MMC has found a lot of applications in various sectors, mainly in aerospace, defense and automobile industries. These materials have been considered for use in automobile brake rotors and various components in internal combustion engines. In comparison to conventional materials MMCs possess optimal properties for these applications, such as light weight and having greater wear resistance. Due to the highly abrasive nature of ceramic reinforcements, two main problems such as high tool wear and poor surface finish are encountered during the conventional machining of MMCs. As it is difficult to machine MMCs

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through conventional processes hence new or modified machining processes are required to process the MMCs.

EDM is widely used machining process among newly developed advanced machining processes (AMPs). The full advantage of EDM process can be taken for machining of MMCs which have a very high hardness due to reinforcement. Since EDM process does not have physical interaction between tool and workpiece to remove the unwanted material thus the hardness, strength or toughness of the workpiece does not affect the material removal rate (MRR).

This paper looks into various research work done on types of EDM processes on composites and discuss the experimental process used and findings and how they can be helpful in learning and development of WEDM process to cater the machining of MMCs.

ELECTRIC DISCHARGE MACHINING

EDM is a thermoelectric, non-traditional machining process in which heat energy of a spark is used to remove material from the workpiece. The workpiece and tool should be made of electrically conductive materials. A spark is produced between the two electrodes (tool and work piece) and its location is determined by the narrowest gap between the two, this is usually between 0.01 to 0.5 mm. Duration of each spark is very short. The entire cycle time is between 0.1 to 2000 µs. Temperatures of about 8000 to 12,000°C and heat fluxes up to 1017 W/m^2 are attained. There is no physical contact between the tool and work piece therefore there is no problem of mechanical stresses, chatter and vibrations [2].

EDM is a controlled metal removal process that uses electric spark erosion as means of material removal. In this process an electric spark is used as a cutting tool to cut (erode) the workpiece in order to produce the desired shape. In Fig.3 it can see the distribution of spark energy during EDM process. The metal removal process is performed by applying a pulsating (ON/OFF) voltage of high-frequency through the electrodes. This removes (erodes) very thin pieces of metal from the work piece at a controlled rate. During EDM, pulsed DC of 80-100 V at approximately 5 kHz is passed through the electrodes, this result in the intense electrical field at the location where surface irregularity provides the narrowest gap. Though the local temperature rise is rather high, still due to very small pulse on time the heat does not diffuse to other areas and thus almost no increment in bulk temperature takes place.

As thermal processing is required to be carried out in absence of oxygen so that the process can be controlled and the oxidation avoided. Hence, a dielectric fluid is used which should provide an oxygen free machining environment Further it should have enough strong dielectric resistance so that it does not easily breakdown electrically but at the same time ionize when electrons collide with its molecules. Generally kerosene and de-ionized water is used as dielectric fluid in EDM.

Electrode material should be such that it would not undergo much tool wear when it is impinged by positive ions. Thus the localized temperature rise has to be less by tailoring or properly choosing its properties so even when temperature increases, there would be less melting. The material should have high electrical conductivity, high thermal conductivity, higher density, and high melting point and should be cost effective. Graphite, copper, copper tungsten, tellurium copper and brass are the most commonly used tool electrode materials in EDM.

A servo system is used to maintain a pre-determined gap between tool and workpiece electrodes. There is a gap voltage sensor in power supply, which sends signals to the servo system. As soon as it senses the gap between the electrodes has been bridged by some electrically conductive material, a signal will be sent to the servo system to reverse its direction. The servo system will keep the tool reciprocating towards the workpiece until the dielectric fluid flushed the gap. If the dielectric flushing system is inefficient in cleaning the cutting gap, the machining cycle time will be long and vice-versa. The main requirements of the servo system are sensitivity for small movements and enough power to overcome weight of ram, electrode, flushing forces.

Wire edm process for machining of metal matrix composites

Wire Electric Discharge Machining (WEDM) uses a wire (about 0.05 to 0.30 mm) as an electrode and deionized water as dielectric. Within the past decade, the WEDM process is a competitive and economical option for fulfilling the machining requirements in modern manufacturing industries. Now a day's WEDM process is a commonly used for machining of materials from conventional materials to unconventional materials like Metal Matrix Composites, Ceramics composites, which have vast application in automobile, aircraft, railway sector, defenses, aerospace and etc.

Among the different material removal processes, WEDM is considered as an effective and economical tool in the machining of modern composite materials.

Gatto and Iuliano [4] selected two composites for their investigations roughing and finishing conditions. The materials selected were SiCAl alloy with 15% whiskers and with 20% particles reinforcement. The machined surfaces, their section and profiles were examined by scanning electron microscopy and energy dispersive semi-quantitative analyses of X-rays. Many conclusions were drawn from their experimental results. The machining rates (in mm/min.) were found to be equal for both composites. The roughness values of machined surfaces of the composite with 15% whisker reinforcement were less than the corresponding values of the composite with 20% particle reinforcement. Whereas the surface roughness values for the particle reinforced composite after WEDM and glass bead peening were found to be less the corresponding values of whisker reinforced composite. SiC reinforcements and Cu precipitates were not found in outer re-cast layer. The glass-bead peening resulted in disappearance of the layer without reinforcement. The thickness of the outer layer without reinforcement was found less than 5 µm under finishing conditions and for both of the composites. This paper specifically focused on the surface quality of the machined surface. One of the important aspect of this research was the effect of particle and whisker reinforcement on machining of the composite.

Patil and Brahmankar [5] investigated the performance of Al/SiCp composite with WEDM. Various control parameters such as pulse on-time, off-time, ignition pulse current, wire speed, wire tension, and flushing pressure on cutting speed and surface finish were studied in WEDM of Al/SiCp composite. They used Taguchi method for the experimental design. On the basis of the experimental results, mathematical models relating to the machining performance and machining parameters were developed. They also investigated the optimal settings for each performance measure. A comparative study on an unreinforced alloy revealed that the cutting speed in for the alloy was more than the composites but the surface finish in composites was better than in the unreinforced alloy.

Rozenek et al. [6] had done experiment on the effect of various machining parameters such as discharge current, pulse on time, pulse off time, and voltage on the machining feed rate and surface roughness for machining of metal matrix composites AlSi7Mg/SiC and AlSi7Mg/Al2O3. The feed rate and surface roughness increases with the increase in discharge energy. The outcome of the experiment showed that for the input parameters of 1.6 µs pulse on-time, 8 µs pulse off-time and 80 V gap voltage, the value of feed rate, and surface roughness parameters increases with increase in current. While in case of decreasing the voltage, the values of feed rate and surface roughness decreases little bit. Experimental observation shows that the maximum cutting speed of AlSi7Mg/Sic and AlSi7Mg/ Al2O3 composites are found approximately 3 times and 6.5 times lower than the cutting speed of aluminum alloy. The MRR is significantly affected by the type of the reinforcement. Therefore the research work is necessary in order to find out the influence of type of reinforcement on performance parameters.

Guo et al. [7] inspected into shaping particles reinforced material by wire-EDM with high travelling speed. His experiment was on 6061 alloy with 20% Al2O3 particle reinforcement. From his observation it was found that there was little influence of electrical parameters on the surface roughness. It resulted in coarse surface irrespective of high energy or low energy is used. The selection parameters (electrical) plays major role in determining the cutting rate. Use of low energy resulted in wire breaking due to blind feeding especially for low pulse duration and low machining voltage. It was noticed that at high pulse duration, high voltage, larger machining current, and at proper pulse interval high

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machining efficiency can be achieved. The research work is based on comparative experiments investigating machining mechanism and technique to shape the material with WEDM and also optimize the electrical parameters.

Yan et. al. [8] investigated WEDM machining of Al2O3p/6061Al composites. The experiments were done on 10 and 20 vol.% Al2O3 particles reinforced 6061Al alloys-based composites and 6061 Al as the matrix material itself. Machining parameters of pulse on-time were changed to investigate their effects on machining performance, including the cutting speed, the width of slit and surface roughness. Since the wire electrode breaks easily during the machining of composites, therefore there is an comprehensive investigation into the location of broken wire and the reason of wire breaking in this work. The cutting speed in the reinforced composites was found slower than in the 6061Al and both composite materials had similar cutting speed. And increasing the volume fraction of the reinforcing Al2O3 particles resulted in wire breakage. The MRR decrease by increasing the vol.% of the reinforcement material. The advancement of the Brass wire along the machining path was impeded by the protruding Al2O3 particles within the discharge gap, resulting the wire to split, therefore clear bandings were found on the machined surface when the 20 vol.% Al2O3P/6061Al composite was machined. These bandings were observed in low wire tension cutting conditions, but not found under high wire tension. On increasing the percentage of reinforcing Al2O3 particles the discharge craters of the wire surfaces were deepened and widened, which facilitated the wire breakage during machining. The largest craters were observed during the machining of 20 vol.% Al2O3P/6061Al composites due to abnormal arc discharge. A Very low wire tension, a high flushing rate and a high wire speed are required parameters to prevent wire breakage for machining these composite materials. This research work investigated the wire breakage mechanism, since wire breakage is a prominent problem in WEDM of MMCs. This study would be helpful in future for proper electrode design for this selective usage.

Ed drilling for metal matrix composites

R.Kumar et. al. [9.] tested on an Al6063 base composite material with Al2O3, SiC and graphite as reinforcement to study the effects of various input parameters namely Current, Duty factor, tool speed (in rpm) and flushing (kg/sq.cm) on MRR, Tool wear rate (TWR) and surface roughness. The experiments were conducted on a Z axis numerical control EDD process set-up. Cu electrodes of 7.5 mm diameter were used as tool electrode and commercial kerosene was used as the dielectric. The experiments gave these results; the magnitude of MRR increases with increase in current and pulse on time and also with increase in flushing pressure. The MRR first increase with the tool speed up to 500 rpm and then decreases slightly. The TWR increases with discharge current and it first increase with duty factor

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(the ratio of pulse duration to the pulse cycle time) up to 0.77 and then decreases. Similar effect of the tool rotation on TWR as the in case of MRR can be seen, it is maximum at 500 rpm. TWR increases with increase in flushing pressure since it would accelerate the debris removal from the machining zone. Surface roughness of the workpiece material increases with increasing discharge current and duty factor. The surface roughness is more at high rotation speeds. Surface roughness is less affected by flushing pressure and is lowest at the value of 0.63 kg/sq.cm.

Calignano et al. [10] did small-hole electro-drilling tests on Al2O3–TiC composite, Tubular these input perimeters peak current, pulse-on time and pulse-off time, with performance indicators being MRR, electrode wear rate, OC and surface roughness. The machining rate ranges from 5.7 to 44.2 mg/min and increases almost linearly with increasing pulse power and duty ratio. Electrode wear rate varies between 0.18 and 43.16 mg/min. The electrode consumption is very high for maximum values of peak current and high values of duty cycle. Minimum values of MRR, EW rate, and OC are obtained at minimum setting of pulse power (180W), where long drilling times are required but low tool wear and fine dimensional tolerances are achieved.

Singh et. al. [11] studied in detail about the z-axis numerical control electro discharge drilling. The also performed the experiment on the Al6063/10%SiC MMC specimen. The input parameters involved in the experiment were discharge current (3-15amp), arc on time (30-150µs) and tool speed (300-700rpm) and the output parameters were MRR and TWR. Due to increase in the discharge energy resulted in improvement of rate of melting and evaporation and the impulsive force of expanded dielectric fluid. The maximum thermal stocking is developed on the MMC. Hence, it leads to maximum MRR. Also increase in the arc on time resulted into increase in the MRR. Similarly tool speed also has a significant role in determining the MRR, upto a certain limit in the tool speed MRR increases but after crossing a certain limit it resulted into sudden loss in MRR. They also observed the effect on the tool wear rate (TWR), although TWR is dependent on the electrode material. TWR increases gradually with the increases in arc on time in the beginning, but then starts decreasing slowly. This is due to decrease in the spatial current density of discharge. But there was very little reduction in the TWR due to increase in tool speed.

Conclusions

[1] EDM process can be very helpful in machining of MMCs which are generally hard to machine through conventional methods, but we observe that the EDM process in its current state faces some problems in machining of MMCs. The machining rate and other qualitative parameters of EDM process are not affected by the matrix materials itself but by the reinforcements that are used in the composites.

[2] The cutting rates are generally not affected by the percentage of reinforcement in WEDM, but other factors such as surface roughness of the machined surfaces is more in the composites with more reinforcement.
[3] The electrical input parameters of the WEDM process also played significant role in the cutting of the Metal matrix composites. Even though these parameters didn't affect the surface roughness of the material, they affected the cutting rates and the wire breakage. The wire tends to break with increasing volume fraction of the reinforcement material also the cut area becomes narrower. The life of the tool wire is greatly affected by the reinforcement material and the fraction of reinforcement material used. The researches featured in this review looked into these characteristics, results of which would help in further research for the selection of tool wire material, the optimal input parameters for varying types of composites.
[4] Various studies on the effects of input parameters on the MRR and other qualitative factors are also done for ED Drilling process. It is an extremely cost effective method for producing fast and accurate holes into all sorts of conductive metals whether hard or soft, hence it can be very helpful in drilling of composites materials but as seen in WEDM process we here also the output parameters are affected by various input parameters. Therefore it becomes essential to determine the optimal input properties for different work piece materials; this can be seen in the studies done on the ED Drilling on composites materials.

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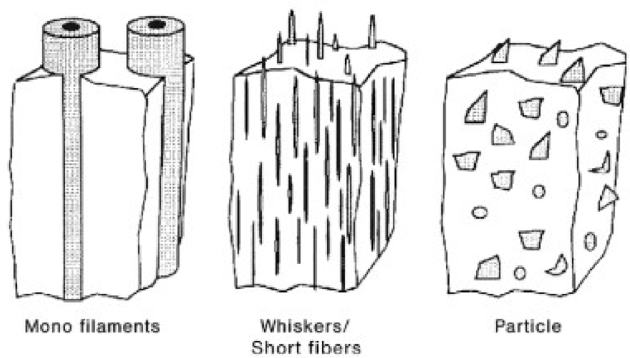

Figure 1: *Types of MMCs on the basis of reinforcement [1]*

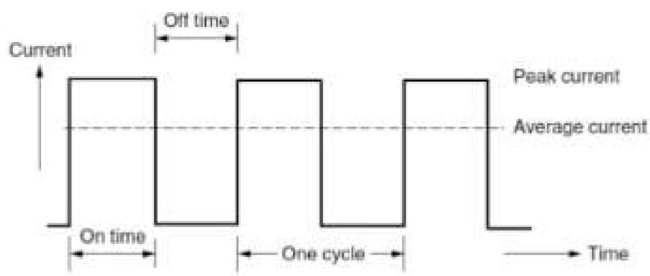

Figure 2: *Typical EDM pulse current train for controlled pulse generator [2]*

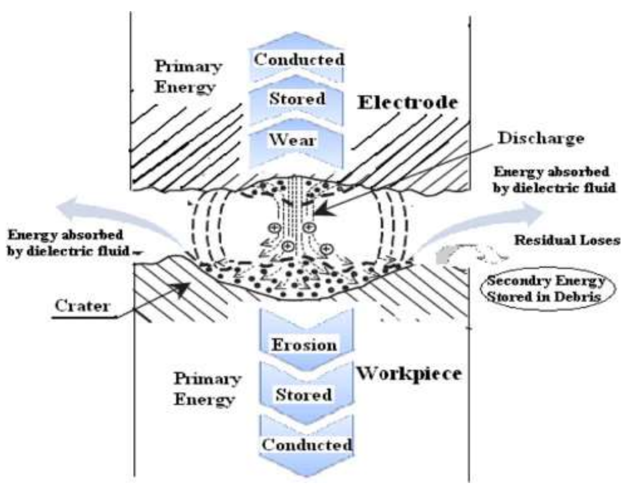

Figure 3: *Distribution of spark energy evolved during EDM [3].*