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Machining of aluminium metal matrix composites with Electrical discharge machining - A Review

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Abstract

Electrical discharge machining (EDM) is the process of machining electrically conductive materials by using precisely controlled sparks that occur between an electrode and a workpiece in the presence of a dielectric fluid. Now a day's EDM process is commonly used for machining of metal matrix composites which have vast applications in automobile, aircraft, and railway sectors. Aluminium metal matrix composites are one of the important types of MMC because of their advanced properties like highest strength and light weight. Development of these lightweight materials has provided the automotive industry with numerous possibilities for vehicle weight reduction. In this paper we have discussed about EDM process, its parameters and role of EDM process in machining of aluminium based metal matrix composite materials (AMMC). The current research work going in this field was also discussed in this paper.

Selection and peer-review under responsibility of the conference committee members of the 4th International conference on Materials Processing and Characterization.

Keywords:EDM (Electrical discharge machining); metal matrix composites(MMC),aluminium metal matrix composite (AMMC)

1. Introduction

Electric discharge machining (EDM), sometimes colloquially also referred to as spark machining, spark eroding, burning, die sinking or wire erosion, is a manufacturing process whereby a desired shape is obtained using electrical discharges (sparks). Electric discharge machining provides an effective manufacturing technique that enables the production of parts made of special materials with complicated geometry which is difficult to produce by conventional machining processes. Controlling the process parameters to achieve the required dimensional accuracy and finish placed this machining operation in a prominent position. From that reason, electric discharge machining has found broad applications in industry. The absorbing interest for electric discharge machines has resulted great improvements in EDM technology. Nowadays, sophisticated electric discharge machines are available for most of machine shop applications.

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1.1 Working principle of electrical discharge machining

The working principle of EDM process as shown in figure 1 is based on the thermoelectric energy. This energy is created between a workpiece and an electrode submerged in a dielectric fluid with the passage of electric current. The workpiece and the electrode are separated by a specific small gap called spark gap. Pulsed arc discharges occur in this gap filled with an insulating medium, preferably a dielectric liquid like hydrocarbon oil or de- ionized water.

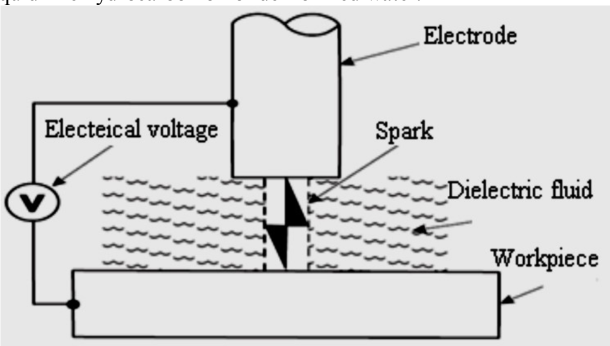

Figure 1: Schematic Diagram of EDM Process [1]

1.2 Process parameters

1.2.1 Electrical parameters

i. Pulse Duration (Ton): It is the duration of time measured in micro seconds. During this time period the current is allowed to through the electrode towards the work material within a short gap known as spark gap. Pulse duration is also known as pulse on time and the sparks are produced at certain frequency. Material removal rate depends on longer or shorter pulse on time period. Longer pulse duration improves removal rate of debris from the machined area which also effects on the wear behaviour of electrode.
ii. Pulse Interval (Toff): This parameter is to affect the speed and the stability of the cut. If the off-time is too short, it improves MRR but it will because more sparks to be unstable in the machining zone
iii. Electrode gap (spark gap): It is the distance between the electrode and the part during the process of EDM. An electro-mechanical and hydraulic systems are used to respond to average gap voltage. To obtain good performance and gap stability a suitable gap should be maintained. For the reaction speed, it must obtain a high speed so that it can respond to short circuits or even open gap circuits.
iv. Polarity: It may be positive or negative connected to tool electrode or work material. Polarity can affect processing speed, finish, wear and stability of the EDM operation. It has been proved that MRR is more when the tool electrodes are connected at positive polarity(+) than at negative terminal(-) .This may be due to transfer of energy during the charging process is more in this condition of machining.

1.2.2 Non electrical parameters

i. Rotation of Tool Electrode
It is the rotational effect of cylindrical (pin shaped) or disc shaped electrode tool measured in revolution/minute. The rotational movement of electrode is normal to the work surface and with increasing the speed, a centrifugal force is generated causes more debris to remove faster from the machining zone.
ii. Injection flushing
Flushing removes eroded particles from the gap for efficient cutting and improved surface finish of machined material. Flushing also enables fresh dielectric oil flow into the gap and cools both the electrode and the work piece.
iii. Tool Geometry
Tool geometry is concerned with the shape of the tool electrodes. The ratio of length /diameter of any shaped feature of material. In case of rotating disk electrode the ratio becomes thickness/diameter.
iv. Tool Material (Electrode)
Engineering materials having higher thermal conductivity and melting point are used as a tool material for EDM process of machining. Copper, graphite, copper-tungsten, silver tungsten, copper graphite and brass are used as a tool material (electrode) in EDM.

1.3 Types of EDM processes

1.3.1 Sinking EDM-The sinker EDM machining (Electrical Discharge Machining) process uses an electrically charged electrode that is configured to a specific geometry to burn the geometry of the electrode into a metal component. The sinker EDM process is commonly used in the production of dies and tools.

1.3.2 Wire EDM-Wire EDM machining (Electrical Discharge Machining) is an electro thermal production process in which a thin single-strand metal wire in conjunction with de-ionized water (used to conduct electricity) allows the wire to cut through metal by the use of heat from electrical sparks. Due to the inherent properties of the process, wire EDM can easily machine complex parts and precision components out of hard conductive materials.
1.3.3 Micro EDM-It is a well-known precise machining process that achieves micro structures of excellent quality for any conductive material. Micro-EDM is a newly developed method to produce micro-parts which in the range of 50 μm -100 μm. Micro-EDM is an efficient machining process for the fabrication of a micro-metal hole with various advantages resulting from its characteristics of non-contact and thermal process.
1.3.4 Powder Mixed EDM-Powder Mixed Electric Discharge Machining (PMEDM) has different mechanism from conventional EDM, which can improve the surface roughness and surface quality distinctly and to obtain nearly mirror surface effects. In this process different types of metal powders are added to dielectric to increase the metal removal rate and surface finish. It is a useful finish machining method and is researched and applied by many countries.
1.3.5 Dry EDM-Dry Electric Discharge machining (dry EDM) is a modification of the oil EDM process in which the liquid dielectric is replaced by a gaseous dielectric. High velocity gas flowing through the tool electrode into the inter-electrode gap substitutes the liquid dielectric. The flow of high velocity gas into the gap facilitates removal of debris and prevents excessive heating of the tool and work piece at the discharge spots.
1.3.6 Hybrid EDM- In hybrid machining process two non conventional machining processes are combined together. In hybrid EDM make use of the combined advantages and to reduce some negative effects the combined process produce better performance as compared to individual process machining. Now a day's electrical chemical machining is used with EDM for getting good surface finish. Many companies are developed hybrid model of water jet cutting and EDM.

2. Metal matrix composite materials

2.1 Metal matrix composite materials-A "composite" is when two or more different materials are combined together to create a superior and unique material. This is an extremely broad definition that holds true for all composites, however, more recently the term "composite" describes reinforced plastics. Metal matrix composites- Metal matrix composites (MMCs) are made of a continuous metallic matrix and one or more discontinuous reinforcing phases. The reinforcing phase may be in the form of fibers, whiskers or particles. The metal matrix composites have various advantages over other types of composites. Such as high strength, high modulus, high toughness and impact properties, Low sensitivity to changes in temperature or thermal shock, high surface durability and low sensitivity to surface flaws, high electrical conductivity. Metal matrix composites (MMC) are generating extensive interest in diverse fields like defense, aerospace, electronics and automotive industries. The mechanical properties of metal matrix composites are deeply influenced by the distribution of reinforcement particulates in the matrix and the morphology of secondary matrix.

2.2 Aluminium metal matrix composite materials-Aluminium metal matrix composite (AMMCs) refer to the class of light weight high performance aluminium centric material systems. The reinforcement in AMMCs could be in the form of continuous / discontinuous fibres, whisker or particulates, in volume fractions ranging from a few percent to 70%. Properties of AMMCs can be tailored to the demands of different industrial applications by suitable combination of matrix, reinforcement and processing routes. There are various types of AMMCs like Al/ SiC , Al/ Al 2 O 3 , Al. Ti C, etc. which are commonly used in automotive and defense. These AMMCs have greater demand because of their advanced properties like greater strength, improved stiffness, reduced density, improved high temperature properties, controlled thermal expansion coefficient, enhanced and tailored electrical properties, improved abrasion and wear resistance, control of mass ,improved damping capabilities. Development of lightweight materials has provided the automotive industry with numerous possibilities for vehicle weight reduction. Progress in this area depends on the development of materials, processing techniques, surface and heat treatments. Since fuel consumption relates directly to vehicle weight, reducing weight can improve the fuel usage and price-to-performance ratio. Aluminium matrix ceramic reinforcement composites have attracted increasing attention due to their combined properties such as high specific strength, high stiffness, low thermal expansion coefficient and superior dimensional stability at elevated temperatures as compared to the monolithic materials.

2. Research developments in EDM on AMMCs

Manish et al. found that [2] existing manufacturing industries are fronting challenges from these advanced nascent materials viz. nano material ,ceramics, super alloys, and metal matrix composites, that are hard and difficult to machine, requiring high accuracy, surface quality excellence which affects and increases machining cost.Electric Discharge Machining (EDM), a unconventional process, has a extensive applications in automotive, defense, aerospace and micro systems industries plays an outstanding role in the development of least cost products with more consistent quality assurance. Die sinking EDM, Wire electrical discharge machining (WEDM), Dry EDM, and Rotary disk electrode electrical discharge machining (RDEEDM) are some of the alternate methods of EDM. P. Cichosz and P. Karolczak discovered the results of electrical discharge machining [3] of aluminium matrix composites with particular attention given to thickness of the defected layer after machining. Influence of various machining parameters on the behavior of saffil fibres and matrix material in the affected zone was presented. Scanning micrographs and roughness measurements are used to analyze surface finish following machiningThe investigation showed that

ED machining process parameters affect the condition of surface layer in machined aluminium MMCs. Low current parameters resulted in a thin layer with a recast structure of increased hardness. Reinforcing fibres were generally left undamaged, some of them protruding from the surface.There is a need for working out optimized patterns of current density and frequency of sparks that would eliminate or reduce the extent of finishing operations necessary for removing the recast layer.Anil kumar et al. [4] found that additive mixed electrical discharge machining (AEDM) is a novel innovation for enhancing the capabilities of electrical discharge machining process in this direction.Despite the promising results, AEDM process is used in the industry at very slow pace. Fundamental issues of this new development, including machining mechanism, are still not well understood. These issues require furtherinvestigations before this process is well accepted by the industry. Mixing of additive powder in the dielectric medium of EDM plays a significant role in enhancing the process capabilities of EDM. Adding powder causes gap contamination. This gap contamination lowers dielectric strength and initiates the ignition process, which increases gap distance and increases the stability of the process. Additive powder characteristics (type, shape, size, concentrations, number of particles, and thermal properties) significantly affect process efficiency and surface characteristics of machined surfaces.There is a need to independently study the effect of various powder characteristics with important input process parameter on the phenomenon of surface modification and process capabilities.

According to Sushant dhar et al.[5] the aluminum matrix composites (AMC) are hard to machine due to the presence of hard and brittle ceramic reinforcements. Additionally, Researchers are turning to particulate-reinforced aluminum-metal matrix composites (AMCs) because of their relatively low cost and isotropic properties especially in those applications not requiring extreme loading or thermal conditions (e.g., automotive components).They evaluated the effect of current , pulse-on time and air gap voltage on metal removal rate (MRR), tool wear rate (TWR), radial over cut (ROC) on machining of Al-MMC with 20% SiC reinforcement.A quadratic mathematical model has also been developed for the same relating output and input quantities respectively. The MRR is found to increase in an almost linear fashion with increase in current for constant gap voltage and Pulse on time. MRR is also found to increase slightly with increase in Pulse duration clearly. And in agreement with the literature reported in TWR is also found to increase with increase in current as high current results in higher thermal loading on both electrodes (tool and work-piece) leading to higher amount of material being removed from either. It is found to first decrease and then increase with pulse duration. A similar trend is noticed with Gap Voltage. It is evident that an increase in current increases the Over Cut. An increase in pulse duration also increases the Over Cut due to the prolonged presence of sparks. An uncommon behavior is observed in the case of voltage gap. The influence of the most relevant parameters of Electrical Discharge Machining over material removal rate, electrode wear and machined surface quality of a hybrid metal matrix composite material (**Al/SiC)**has been carried out by Adrian losub et al.[6]. The material used in their study was aluminium matrix composite reinforced with 7 % SiC and 3.5 % graphite. They found that the hybrid SiC/Al composite material can be machined by EDM and a good surface quality can be obtained by controlling the machining conditions. Regarding the MRR output parameter, the most influential factors were current intensity, followed by its quadratic effect and pulse – off time. The material removal rate increases significantly when current intensity increases. The same tendency was observed when pulse – off time increases. They purposed an empirical model in order to optimise the processes. They found that in electrode wear parameter, the most influential factor is the current, followed by its quadratic effect and pulse – on time. For a low electrode wear, low values for intensity and for pulse – on time should be used.

P. Narender Singh et al. [7] found that the use of unconventional machining techniques in shaping aluminium metal matrix composites (Al-MMC) has generated considerable interest as the manufacturing of complicated die contours in these hard materials to a high degree of accuracy and surface finish is difficult.The objective of their work was to investigate the effect of current (*C*), Pulse ON-time (*P*) and flushing pressure (*F*) on metal removal rate (MRR), tool wear rate (TWR), taper (*T*), radial overcut (ROC), and surface roughness (SR) on machining as-cast Al-MMC with 10% SiC reinforcement.Analysis of variance (ANOVA) was performed and the optimal levels for maximizing the responses were established. Scanning electron microscope (SEM) analysis was done to study the surface characteristics. They found that MRR was found to be higher for larger current and pulse on time settings at the expense of tapercity, radial overcut and surface finish.TWR was found to be higher, larger than MRR, for larger current settings but it effects the dimensional accuracy also. Flushing pressure of the dielectric has considerable effect on the MRR and TWR. D Satishkumar et al.[8} found the effect of wire electrical discharge machining (WEDM) parameters such as pulse-on time (TON), pulse-off time (TOFF), gap voltage (V) and wire feed (F) on material removal rate (MRR) and surface roughness (Ra) in metal matrix composites (MMCs)consisting of aluminium alloy (Al6063) and silicon carbide(SiCp) where aluminium alloy Al6063 was reinforced with SiCp inthe form of particles with 5%, 10% and 15% volume fractions. The experiments were carried out as per design of experiments approach using L9 orthogonal array. The results were analysed using analysis of variance and response graphs. The results are also compared with the results obtained for unreinforced Al6063.It was found that the increase in volume percentage of SiC resulted in decreased MRR and increased Ra. This may be due to the presence of harder SiC particles in the MMCs. The SiC particles will enhance the thermal characteristics of aluminium, with consequent reduction in MRR. But MRR is found to increase with increase in pulse on time because of higher intensity of the spark in WEDM process.The results from this study will be useful for manufacturing engineers to select appropriate WEDM process parameters to machine MMCs of Al6063 reinforced with SiCp at various proportions.

Hung N.P. et al.[9]investigated the feasibility of applying electrical discharge machining (EDM)process forcast aluminum MMCs reinforced with silicon carbide particles (SiCp).It was found that the SiC particles shield and protect the aluminum matrix from being vaporized, thus reduce the metal removal rate. The un-melted SiC particles drop out from the MMC together with surrounding molten aluminum droplets. While some aluminum droplets are flushed away by the dielectric, others trap the loosened SiC particles then re-solidify onto the surface to form a re-cast layer (RCL). No crack was found in the RCL and the softened heat-affected zone (HAZ), which is below the RCL. The input power controls the metal removal rate and the RCL depth, but the current alone dominates the surface finish of an EDM'ed surface.K.M. Patel et al.[10] found that electric discharge machining (EDM) has been proven as an alternate process for machining complex and intricate shapes from the conductive ceramic composites. The performance and reliability of electrical discharge machined ceramic composite components are influenced by strength degradation due to EDM-induced damage.This paper presented a detailed investigation of machining characteristics, surface integrity and material removal mechanisms of advanced ceramic compositeAl2O3–SiCw–TiC with EDM. The surface and subsurface damages have also been assessed and characterized using scanning electron microscopy (SEM). The results provide valuable insight into the dependence of damage and the mechanisms of material removal on EDM conditions.

Biing Hwa Yan et al.[11] discovered that the alumina particle reinforced 6061 aluminum matrix composites (Al2O3p/6061Al) have excellent physical and chemical properties than those of a traditional metal; however, their poor machinability lead to worse surface quality and serious cutting tool wear.The experimental results indicate that the cutting speed (material removal rate), the surface roughness and the width of the slit of cutting test material significantly depend on volume fraction of reinforcement (Al2O3 particles).Test results revealed that in machining Al2O3p/6061Al composites a very low wire tension, a high flushing rate and a high wire speed are required to prevent wire breakage; an appropriate servo voltage, a short pulse-on time, and a short pulse-off time, which are normally associated with a high cutting speed, have little effect on the surface roughness.Biing Hwa Yan et al. [12] found the feasibility and optimization of a rotary EDM with ball burnishing for inspecting the machinability of Al2O3/6061Alcomposite using the Taguchi method.Three ZrO2 ballsattached as additional components behind the electrode tool offer immediate burnishing following EDM. They found that peak current and non – load voltage parameters significantly affect the machining rate for ball EDM process. Either a higher rotational speed of electrode tool, or 20 vol. % Al2O3 reinforced particles may increase the wear of the ZrO2 ball and generate a rougher surface roughness.

S. Singh [13]used the designs of experiments and grey relational analysis (GRA) approach to optimise parameters for electrical discharge machining process of 6061Al/Al2O3p/20P aluminium metal matrix composites.The process parameters included one noise factor, aspect ratio having two levels and five control factors, viz. pulse current, pulse ON time, duty cycle, gap voltage and tool electrode lift time with three levels each. The material removal rate, tool wear rate and surface roughness were selected as the evaluation criteria, in this study. Optimal combination of process parameters is determined by the grey relational grade (GRG) obtained through GRA for multiple performance characteristics. Analysis of variance for the GRG is also implemented. It is shown that through GRA, the optimization of the multiple performance characteristics can be greatly simplified. The results of ANOVA indicated that aspect ratio and pulse current were the most significant process parameters affecting the multiple performance measures followed by tool electrode lift time and pulse on time. Che Chung Wang et al. [14] optimized the blind-hole drilling of Al2O3/6061Al composite using rotary electro-discharging machining by using Taguchi methodology. Experimental results confirmed that the revised copper electrode with an eccentric through-hole has the optimum performance for machining from various aspects.Analysis of the Taguchi method reveals that the electrical group has a more significant effect than the non-electrical group on the machining characteristics.Furthermore, either the polarity or the peak current most prominently affects the MRR, SR or EWR amongst all of the parameters.

U. K. Vishwakarma et al.[15] developed the material removal rate (MRR) modeling using an axisymmetric model of Al-SiC composite during electrical discharge machining.FEA based model has been developed to analyze the temperature distribution and its effect on material removal rate. To validate the model, the predicted theoretical MRR is compared with the experimentally determined MRR values. A very good agreement between experimental and theoretical results has been obtained. It is evident from the analytical model that material removal in second discharge is more than single discharge, because of initial temperature and spark occurs on crater ridge .During the EDM there is very high temperature rise in the work piece but still it is not enough to melt thereinforced particle, so particles evacuates without melting. The model developed in present study can be further used to obtain residual stress distributions, thermal stress distributionmechanism of reinforcement particle bursting phenomenon. A very complex phenomenon occurs at the crater while material removal. They found that the follow-up publications will also consider the modeling of dielectric fluid, molten material and plasma channel at the discharge crater, using CFD tool.

Rabindra Behera et al. [16]investigated the distribution of SiC particulates in a stepped (3-step) cast LM6-SiCp metal matrix composites, which are reinforced by SiCp at different weight fraction i.e. 5, 7.5,10 & 12.5wt%.The mechanical properties such as hardness/micro hardness, tensile properties etc. and forgeability of stir cast MMCs examined at different step of the castings. The experimental results show that the mechanical properties and forgeability of cast MMCs are different at different step of castings. The morphology of cast MMCs indicates that the distribution of SiCp is not uniform throughout the casting and it changes on changing the thickness of the casting. The hardness of the MMCs is higher than the unreinforced matrix metal and the hardness of the cast composites increases linearly with increasing the weight fraction of SiCp. The tensile strength of the as cast composites increases on increasing the weight fraction of SiCp. But, the percentage of elongation decreases on increasing the percentage of SiCp in the matrix metal i.e.LM6.

They Yan – Cherng Lin[17] investigated the machining performance of conductive ceramics (Al2O3+ 30vol% TiC) using electrical discharge machining (EDM). The EDM machining parameters such as machining polarity, peak current, auxiliary current with high voltage, pulse duration, no load voltage, and servo reference voltage were chosen to explore the effects on material removal rate (MRR), electrode wear rate (EWR), and surface roughness (SR). The L18 orthogonal array based on the Taguchi experimental method was adopted to determine EDM machining characteristics systemically, and the experimental data were statistically analyzed by analysis of variance (ANOVA). Experimental results showed EDM is a feasible process to shape conductive ceramics, and relationships between machining characteristics and parameters were examined. Moreover, machining parameter optimal combination levels in machining conductive ceramics via EDM were also determined.

C. Velmurugan et al. [18] investigated the effect of parameters like Current(I), Pulse on time(T), Voltage(V) and Flushing pressure(P) on metal removal rate (MRR),tool wear rate(TWR) as well as surface roughness(SR) on the machining of hybrid Al6061 metal matrix composites reinforced with 10% SiC and 4%graphite particles. Composite was fabricated using stir casting process. A central composite rotatable design was selected for conducting experiments. Mathematical models were developed using the MINITAB R14 software. The method of least squares technique was used to calculate the regression coefficients and Analysis of Variance (ANOVA) technique was used to check the significance of the models developed. Scanning Electron Microscope (SEM) analysis was done to study the surface characteristics of the machined specimens and correlated with the models developed. They found that metal removal rate of the composite increases with increase in current, pulse on time and flushing pressure of the dielectric fluid while it decreases with increase in voltage. Tool wear rate of the developed composite increases with increase in current and voltage and it decreases with increase in pulse on time and flushing pressure of the dielectric fluid. They found that surface roughness of the composite during electric discharge machining increased with increase in current, pulse on time, voltage and flushing pressure. It was found that all the four machining parameters have significant effect on the response variables considered in the present study.

Rajesh Purohit et al.[19] reported the effect of input parameter viz. rotating speed of electrode, hole diameter and grain size of SiC on the output parameters i.e. the tool wear rate (TWR), metal removal rate (MRR) and radial over cut (ROC) obtained during electrode discharge machining of 7075Al-10 wt. % SiC composites. The hole diameter was varied from 0 to 6 mm and the electrode rotation speed was varied between 0 to 460 rpm. The three level full factorial design was used to study the effect of input parameters on the output variables.The results of the work can be used to select the suitable parameters while machining of Al alloy-SiC composite components for different applications.

3. Conclusion

In this paper a review was discussed related to use of EDM process for machining of aluminium metal matrix composites (AMMCs) .Presently EDM plays an important role in machining of composites like aluminium metal matrix composites (AMMCs) which has been discussed in this paper. For each and every method introduced in EDM process, the objectives are the same: to enhance the capability of machining performance, to get better output, and to have better working conditions. There is lot of work is going on developing EDM process to improve their machining capability related to aluminium based metal matrix composites as discussed in literature study. Various new optimization techniques are used by the researchers to find the best combination of process parameters of EDM process for machining AMMC like artificial neural network, grey relational analysis, genetic algorithm, etc. The EDM processes are combining with surface grinding, abrasive jet machining, and electro chemical machining to take advantages of hybrid machining process.

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