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Electrical Discharge Machining Characteristics of Aluminium Metal Matrix Composites - 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 the work piece in the presence of a dielectric fluid. Aluminium Metal Matrix Composites (AMMC's) are new generation engineering materials that possess superior physical and mechanical properties compared to non-reinforced alloys. This makes them attractive for wider range of applications in automotive, aerospace and defense industries. These materials have desirable qualities such as high strength to weight ratio, high toughness and low value of coefficient of thermal stability. It is very difficult to cut the complex shapes by using Conventional Machining. High tool wear and high cost of tooling is also a limitation in Conventional Machining, Unconventional Machining offers an alternative solution to this problem. This paper presents a review of research work done on AMMC's on EDM, Wire EDM, Powder Mixed EDM, EDM in Water, Micro EDM. The paper also discusses the future trends of research work in the same area.***

Keywords: Electrical Discharge Machining, Metal Matrix Composites, Pulse ON time, Pulse OFF time, Metal Removal Rate, Tool Wear Rate.

1. Introduction

Metal Matrix Composites (MMCs) are new generation engineering materials that possess superior physical and mechanical properties compared to non-reinforced alloys. This makes them attractive for wider range of applications in automotive, aerospace and defense industries. The reinforcements in MMCs are very hard and abrasive in nature. Thus, they pose a limitation to their economic conventional machining. Production of complex shapes in such materials by traditional methods is also difficult. In view of high tool wear and high cost of tooling with conventional machining, unconventional material removal processes offers an attractive alternative.

Among the many unconventional processing techniques, EDM has proved itself to be one among the effective tool in shaping such difficult-to-machine materials. Electrical discharge machining is used to make dies, punches and moulds. This process can be employed to make complicated profiles on difficult to machine materials and is best suitable for finishing automotive, aircraft and surgerical components. Current, pulse on-time, pulse off time, gap voltage, feed and flushing pressure are widely used as a machining parameter. Metal removal rate, tool wear rate, taper, radial overcut and surface roughness are considered as the important responses.

This paper reviews about the research work done on AMMC's in following types of EDM:

- General EDM
- Wire EDM
- Powder Mixed EDM
- Water EDM
- Micro-EDM

2. Research Work in EDM of AMMC Materials

Electrical Discharge Machining (EDM) is the most widely-used non-traditional machining process, mainly to produce injection molds and dies, for mass production of very common objects. It can also produce finished parts, such as cutting tools and items with complex shapes. EDM is used in a large number of industrial areas such as automotive industry, electronics, domestic appliances, machines, packaging, telecommunications, watches, aeronautic, toys, surgical instruments. The history of EDM itself begins in 1943, with the invention of its principle by Russian Scientists Boris and Natalya Lazarenko in Moscow. The Lazarenko's developed during the war the first EDM machines, which were very useful to erode hard metals such as tungsten or tungsten carbide. The "Lazarenko circuit" remained the standard EDM generator for years.

In the 1950's, progress was made on understanding the erosion phenomenon. It is also during this period that industries produced the first EDM machines. Swiss industries were involved very early in this market, and still remain leaders nowadays. Agie was founded in 1954, and Les Ateliers des Charmilles produced their first machine in 1955. Due to the poor quality of electronic components, the performances of the machines were limited at this time.

Yan et al. [29] experimented WEDM by using Al6061/Al_2O_3 of 20 vol.% into the locations of broken wire and the reason for wire breaking in machining. Results indicated that the cutting speed (MRR), the surface roughness and the width of the slit of cutting test material depends on volume fraction of reinforcement and also that in machining Al6061/Al_2O_3 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.

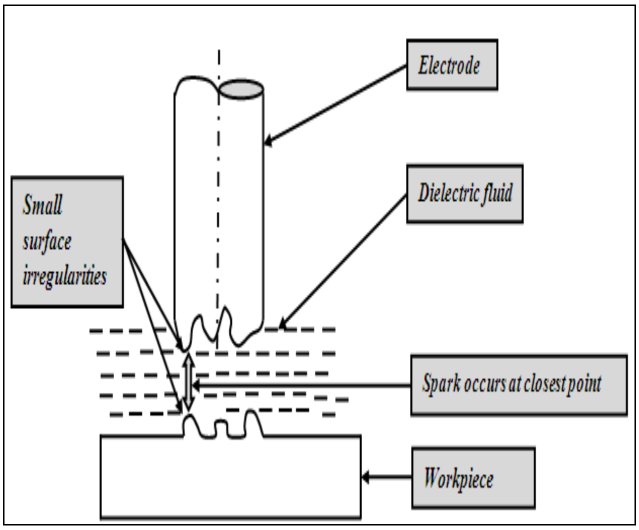

Figure1: Working Principle of EDM

The principle of EDM is to use the eroding effect of controlled electric spark discharges on the electrodes. Thus, it is a Thermal Erosion Process. The sparks are created in a dielectric liquid, generally water or oil, between the workpiece and an electrode, which can be considered as the cutting tool. There is no mechanical contact between the electrodes during the whole process. Since erosion is produced by electrical discharges, both electrode and workpiece have to be electrically conductive. Thus, the machining process consists in successively removing small volumes of workpiece material, molten or vaporized during a discharge. Since from the inception of EDM there were various types of workpiece materials had machined whereas on Aluminium MMC's it was first done by Hung et al. [1] experimented on the Aluminium Metal Matrix Composite with reinforced with SiC_p which is used to shield and protect the Al. matrix from being vaporized to reduce the Metal Removal Rate (MRR) on EDM process. With surrounding molten Al. droplets un-melted SiC particles dropout from the MMC but some Al. droplets are flushed away by the dielectric by trapping the loosened SiC particles it re-solidifies on to the surface to for a Recast Layer. Below the Recast layer it is known to be softened Heat Affected Zone (HAZ) and no crack would found in the recast layer. The input power controls the MRR and the recast layer depth but the current alone dominates the surface finish of an Electric Discharge Machined surface.

Hocheng et al. [2] has done experiment on Aluminium Metal Matrix with SiC a defined the correlation between major machining parameters, electrical current and on-time and crater size produced by a single spark for the representative material. Their results shows the predicted proportionality based on heat conduction model with comparison of common steels in material removal rate.

Yan et al. [3] conducted experiments on characteristics of Al6061/Al_2O_3 using Rotary EDM with a tube electrode considering parameters as peak currents, pulse durations, volume fraction of Al_2O_3 reinforced particles, flushing methods, flushing pressures and electrode rotations. They also developed the semi-empirical expressions for EDM-drilling to summarize the effect of machining characteristics i.e., metal removal rate, electrode wear rate and surface roughness. It is confirmed to have significant affects on the MRR, EWR and SR due to the peak currents of EDM-drilling and volume fraction of Al_2O_3 and there will be minor affects on the MRR, EWR and SR in comparison of flushing pressure and the electrode rotation speed.

Karthikeyan et al. [4] developed a mathematical models to optimize EDM process parameters MRR, TWR and the Surface Roughness (CLA value) by considering input parameters as current, pulse duration and the percent volume fraction of SiC (25µm size) present in LM25 Al. matrix. They conducted experiments by choosing three level full factorial design and mathematical models with linear, quadratic and interactive effects of the parameters chosen were developed. It was found that MRR would decrease with an increase in the percent volume of SiC, while the TWR and the surface roughness increases with increase of SiC percent.

Wang and Yan [5] experimented on Al6061/Al_2O_3 composite using rotary EDM by using Taguchi methodology to optimize the blind hole drilling of composite. The experimental results shows that the revised copper electrode with an eccentric through hole has the optimum performance for machining from various aspects.MRR, EWR and SR verifies this optimization of the machining technique.

Narendara singh et al. [6] investigated the EDM of Al. MMC with 10% SiC by selecting current, pulse on time, flushing pressure as machining parameters. The response to be studied for this study was MRR, TWR, SR and radial overcut. They reported the effect of each machining parameter on the responses.

Hwa et al. [7] conducted a feasibility study of Rotary EDM with ball burnishing for Al_2O_3/Al6061 composite to find out machinability of composite using Taguchi method. Machining rate, surface roughness and improvement of SR are considered for optimizing machining technique. The analysis of results supports practical technique for applying Rotary EDM with ball burnishing in machining the composite.

Ramulu et al. [8] investigated on 15 vol% SiC particulate reinforced with A356 Al. their effects on EDM machining under monotonic and fatigue loading conditions for surface quality and subsurface conditions which are compared with the same material after careful surface polishing and tensile tests, high cycle constant stress amplitude fatigue tests were conducted on polished material. Fractographic analysis is performed to study the mechanisms of fatigue fracture. Results shows that EDM sparking was found to increase SR and cause slight subsurface softening in the microstructure below the outer recast layer and fatigue strength is reduced by EDM with greater degradation resulting from higher MRR.

Mohan et al. [9] conducted experiments on Al6065/SiC composite on EDM using brass electrode shown that increase in volume percentage of SiC resulted decrease in MRR and increasing EWR and pulse duration had a inverse effect on machining parameters. Also, decrease in hole diameter by increasing speed of the rotating tube electrode results in increasing MRR and decrease in EWR and SR. By comparing the electrode hole diameter and rotational speed it has major effect on MRR, EWR and SR and optimized the machining parameters using Genetic Algorithm.

Singh et al. [10] evaluates the effect of current, pulse on time and flushing pressure on MRR, TWR, Radial Over Cut (ROC) and SR on machining as cast Al. with 10% SiC_p reinforcement and to conduct experiments L_{27} orthogonal array used for machining parameters at three levels each. Experiments were performed in a random order with three successive trials. ANOVA was performed by using optimizing tool as Grey Relational Analysis.

Seo et al. [11] made an observation in the functionally graded 15-35 vol% SiC_p/Al. composites and said that the MRR increased with increasing current and pulse on time to the optimal points and began to decrease drastically thereafter. There will be greater tool wear and the larger average diameter error due to high peak current and pulse on time.

Sushant Dhar et al. [12] found that due to the presence of hard and brittle ceramic reinforcements it is hard to machine AMMC's. Due to their low cost and isotropic properties researchers are considering the particulate reinforced AMMC's where there is no need of extreme loading or thermal conditions. They investigated the effect of current, pulse on time, air gap voltage on MRR, TWR and ROC on machining of AMMC with 20% SiC reinforcement. ANOVA had performed and graphs are plotted. Experimental results show that MRR is found to increase in linear fashion with increase in current for constant gap voltage and pulse on time and also increases slightly with increase in pulse duration clearly. TWR is also found to increase with in current as high current results in higher thermal loading on both electrodes leads to high amount of material removed from both. It is found to first decrease and then increase in pulse duration and gap voltage. It shows that increase in current increases the overcut.

Dvivedi et al. [13] conducted experiment on machinability of Al6063/SiC_p MMC which is developed using melt stir squeeze quench casting to obtain optimal setting of process parameters. Their work is related to the influence of process parameters on performance measures and parameter optimization, the process variable affecting MRR according to relative importance are current, pulse off setting, flushing pressure, pulse on and gap control setting.

Cichosz and Karolczak [14] investigated the EDM process parameters on AMMC's on a thickness of the defected layer after machining will affect the condition of surface layer and reinforcing fibres were generally left undamaged and they said that there is a need for working out optimized patterns of current density and frequency of sparks which would eliminate/reduce the extent of finishing operations which are necessary for removing the Recast Layer.

Ahmed et al. [15] explores the possibility of machining using EDM machining by varying various machining parameters. Results indicated that AMMC's can be effectively EDM machined at low peak current at certain ON time and OFF time.

Adrian et al. [16] studied the EDM characteristics of Al-Si-7Cu-Mg-SiC MMC. They investigated the effect of tool diameter and pulse on time on tool wear and MRR. They observed that increase in electrode diameter increase the MRR and reduce the TWR. TWR more when increasing the pulse on time whereas increase in pulse on time increase MRR.

K.M. Patel et al. [17] found that the EDM has been proven as alternate process for machining complex and intricate shapes from the conductive ceramic composites. They investigated the machining characteristics, surface integrity and material mechanisms of advanced ceramic composite Al_2O_3-SiC_w-TiC with EDM. The surface and subsurface damages have also been assessed and characterized using Scanning Electron Microscopy (SEM).

Karthikeyan et al. [18] conducted studies on aluminum alloy-silicon carbide composites by using new combination of vortex method and pressure die casting technique. They used copper electrode in an EDM. The MRR and SR of the work piece increases with an increase in the current. The MRR decreases with increase in the percent weight of silicon carbide. The surface finish of the machined work piece improves with percent weight of silicon carbide.

Iosub et al. [19] studied the influence of the process parameters of EDM Machining over MRR, electrode wear and machined surface quality of a hybrid metal matrix composite material (Al/7%SiC/3.5%graphite). The hybrid composite was machined using brass tools with Ø = 3.97 mm. Different pulse on-times (T_{on}), pulse off time (T_{off}) and peak current values (I_p) was used for each electrode. For the experiments, a full factorial design was used. Regression analysis was applied for developing a mathematical model.

Senthilkumar et al. [20] conducted experiment on the effect of current, pulse on time and flushing pressure on MRR, TWR during electrical discharge machining of as-sintered AMMC with 5% and 2.5% TiC reinforcement. An L_{18} orthogonal array, for the three machining parameters at three levels each, was opted to conduct the experiments. They made an attempt to study the effect of TiC particle addition on the EWR, a new parameter taking into consideration both MRR and TWR. SEM analysis was conducted to study the recast layer evolved during the EDM machining process.

Nanimina et al. [21] evaluates effect of EDM process parameters on 30% Al_2O_3 reinforced aluminum metal matrix composite. A high value of peak current and On time increase rapidly MRR of Al6061 rather than AMMC while it decreases with increasing of Off time. Tool wears more at low peak current and On time than Off time.

S.Singh [22] investigated the Aluminium metal matrix composite Al6061/Al_2O_3 of 20% wt. to optimize the parameters of EDM by using design of experiments and Grey Relational Analysis (GRA). The process parameters included one noise factor, aspect ratio having two levels and five control factors such as pulse current, pulse on time, duty cycle, gap voltage and tool electrode lift time with three levels each. The MRR, TWR and SR were selected as the evaluation criteria, in this study. Optimal combination of process parameters is determined by the grey relational grade obtained through GRA for multiple performance characteristics. ANOVA for the grey relational grade 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.

Prabu et al. [23] conducted EDM studies on Al/TiB_2 with low frequency vibrating tool. The results shown that MRR and surface cracks of the work piece increases with an increase in current. The increase in reinforcement ratio decreases the MRR and surface cracks.

Senthil et al. [24] proposed a multi criteria optimization technique to optimize the EDM parameter in machining of Al/Cu/TiB_2 in-situ MMC's. Discharge current, pulse on time and pulse off time are considered as machining parameter and MRR, TWR and SR as response parameters. The Result analysis shows that the optimized results are good agreement with confirmation run.

N.Radhika et al. [25] conducted experiment on Multi objective optimization of process parameters of Al/Si/10Mg/9wt.% Al_2O_3/3wt. %graphite in EDM for obtaining minimum SR, minimum TWR and maximum MRR. Peak Current, flushing pressure and pulse on time are selected as machining parameters. Experiments were conducted by selecting different operating levels for the three parameters according to Taguchi's Design of Experiments and the multi-objective optimization was performed using GRA to determine the optimal solution. The Grey Relation Grade values were then analyzed using ANOVA to determine the most contributing input parameter. Experiment result shown that peak current was found to be the most dominant parameter with contribution of 61.36%.The obtained optimal level of process parameters was found to lead to good surface finish, reduced TWR and better MRR in the EDM of Al hybrid composites.

3. Wire EDM on Composites

Wire Electric Discharge Machining (WEDM) is one of the greatest innovations affecting the tooling and machining industry. This process has brought to industry dramatic improvements in accuracy, quality, productivity and earnings. Before Wire EDM, costly processes were often used to produce finished parts. Now with the aid of a Computer and Wire EDM machines, extremely complicated shapes can be cut automatically, precisely and economically, even in materials as hard as carbide.

In 1969, the Swiss firm Agie produced the world's first Wire EDM machine. These machines are equipped with automatic wire threading and can cut over 20 times faster than the beginning machines. During the wire EDM process, the wire carries one side of an electrical charge and the workpiece carries the other side of the charge. When the wire gets close to the part, the attraction of electrical charges creates a controlled spark, melting and vaporizing microscopic particles of material. The spark also removes a miniscule chunk of the wire, so after the wire travels through the workpiece one time, the machine discards the used wire and automatically advances new wire. The process takes place quickly—hundreds of thousands of sparks per second but the wire never touches the workpiece.

This section presents the various notable research trends carried out in the field of Wire EDM of AMMC's.

Gatto and luliano [26] performed tests on WEDM on Al Alloy/SiC with 15% whiskers and 30% particles reinforcement under one roughing and two finishing conditions. Some roughed and some finished surfaces were glass bead peened. During the machining of both composites the machined surfaces their sections and profiles were examined by SEM to understand the reinforcement and the behavior of the matrix.

Rozenek et al. [27] conducted experiment on AlSi7Mg/SiC and AlSi7Mg/Al_20_3 to investigate the effect of machining parameters on the machining feed rate and surface roughness of WEDM. The machining feed rate of WEDM cutting composites significantly depends on the kind of reinforcement. The maximum cutting speed of AlSi7Mg/SiC and AlSi7Mg/Al_2O_3 are approx. 3 times and 6.5 times lower than the cutting speed of Al alloy.

Samy et al. [28] developed a mathematical modeling for WEDM of Al-SiC composites. They optimized WEDM characteristics such as MRR, cutting speed and the SR was developed. The process parameters considered are the average machining voltage, pulse frequency, workpiece height, kerf size and the percentage volume fraction of SiC present in the Aluminium Matrix.

Yan et al. [29] experimented WEDM by using Al6061/Al_2O_3 of 20 vol.% into the locations of broken wire and the reason for wire breaking in machining. Results indicated that the cutting speed (MRR), the surface roughness and the width of the slit of cutting test material depends on volume fraction of reinforcement and also that in machining Al6061/Al_2O_3 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.

Manna and Bhattacharya [30] investigated the parameter setting during the machining of Aluminium reinforced silicon carbide AMMC and the Taguchi method was used to optimize the CNC wire cut EDM parameters and L_{18} orthogonal array was used. From experimental results and through ANOVA and F-test values, the significant factors are determined for each machining performance criteria, such as the MRR, SR, gap current and spark gap (gap width). Mathematical models relating to the machining performance are established using the Gauss elimination method for the effective machining of Al/SiC MMC.

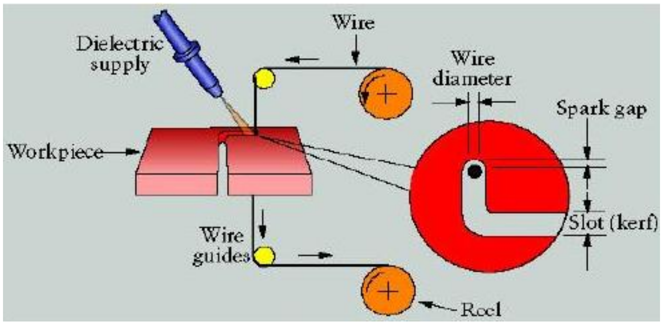

Figure 2: Schematic Diagram of Wire EDM

Patil and Brahmankar [31] performed experiments on performance of Al/SiCp composites with WEDM using Taguchi method. Based on experimental results, mathematical models relating the machining performance and machining parameters were developed. Optimal settings for each performance measure have also been investigated. A comparative study on unreinforced alloy revealed the effect of reinforcement. Cutting speed for unreinforced alloy was found higher compared to composites but whereas surface finish in composites was found superior compared to the unreinforced alloy. Wire breakage posed limitations on the cutting speed of composite.

Ganpatrao et al. [32] studied about the determination of MRR of WEDM of Metal Matrix Composites using Dimensional analysis. They proposed Semi-empirical model of MRR in WEDM based on thermo physical properties of the workpiece and pulse on time, average gap voltage. An empirical model based on response surface method was developed.

Satishkumar et al. [33] investigated the effect of WEDM machining parameters such as pulse-on time, pulse-off time, gap voltage and wire feed on MRR and SR in AMMCs consisting of aluminum alloy (Al6063) and SiCp. The Al6063 is reinforced with SiCp in the form of particles with 5%, 10% and 15% volume fractions. The experiments were carried out as per design of experiments approach using L_9 orthogonal array. There results were analyzed using ANOVA and response graphs. The results were also compared with the results obtained for unreinforced Al6063. From the study, it was found that different combinations of WEDM process parameters are required to achieve higher MRR and lower surface roughness for Al6063 and composites. Generally, it was found that the increase in volume percentage of SiC resulted in decreased MRR and increased SR. Regression equations were developed based on the experimental data for the prediction of output parameters for Al6063 and composites.

Pragya Shandilya et al. [34] optimized the process parameters during machining of SiCp/6061 Aluminium MMC by wire electrical discharge machining (WEDM) using Response Surface Methodology (RSM). Four input process parameters of WEDM namely servo voltage (V), pulse-on time (Ton), pulse-off time (Toff) and wire feed rate were chosen as variables to study the process performance in terms of cutting width (kerf). In addition mathematical models were also developed for response parameter. Properties of the machined surface had been examined by the Scanning Electron Microscopic (SEM). Input process parameters had been found to play a significant role in the minimization of kerf. ANOVA results showed that voltage and wire feed rate were highly significant parameters and pulse-off time was less significant. Pulse-on time had insignificant effect on kerf. For targeted value of kerf the optimized values of servo voltage was 70.06 V, pulse-on time was 2.81 µs, pulse-off time was 7.79 µs and wire feed rate was 8.90 m/min. SEM images of the cut surfaces revealed that the fine surface finish was obtained when machining was done at a combination of lower levels of input process parameters.

Rajaneesh N. Marigoudar et al. [35] emphasized in their work on behavior of zinc aluminium alloy reinforced with silicon carbide particles when machined with wire electric discharge machining process (WEDM). The workpiece material used was ZA43 reinforced with SiCp. MMC was fabricated by liquid metallurgy technique. MMC with three different reinforcement percentages 5%, 10% and 15% were casted in the form of cylindrical specimen. The fabricated cylindrical specimens were machined i.e. sliced in transverse direction. Machining was carried-out by varying applied current of (2, 4 and 6amp.), pulse on time (4, 8 and 16µs) and pulse off time (5, 7 and 9µs) while other parameters such as voltage, dielectric flushing pressure, wire tension etc. were maintained constant. It was observed that there was a reduction in the material removal rate and increase in surface roughness for increasing reinforcement percentage in the composite. Material removal rate decreased with increase in reinforcement content in MMC. For same value of current and pulse on time, MMC with 5% SiC took less time and with 15% SiC took more time to slice the bar. It was thus concluded that to get higher material removal rate, higher currents and higher value of pulse on time had to be used for machining The quantity of SiC in MMC was also influencing parameter on surface roughness. Higher the quantity of SiC, higher will be the surface roughness .It was also observed that applied current and pulse on time increased the material removal rate whereas pulse off time had less effect on it.

Sanjeev KR. Garg et al. [36] experimentally investigated the machining characteristics and the effect of wire EDM process parameters during machining of newly developed Al/ZrO_2 Particulate Reinforced Metal Matrix Composite Material (PRMMC). Central Composite Design (CCD) of Response Surface Methodology (RSM) considering full factorial approach had been used to design the experiments. The input parameters considered for optimization were pulse width, time between pulses, servo control mean reference voltage, short pulse time, wire feed rate and wire tension. The response measures considered were cutting velocity and surface roughness. The multi optimization results obtained by initial parameters setting, response surface methodology and grey relational techniques had been compared and validated by confirmation experiments. The comparison of performance characteristics using different wire electrode was also carried out. It was found that diffused wire electrode provided better performance results related to cutting velocity, surface roughness breakage as compared to brass wire electrode. The optimal machining conditions for multi-objective optimization were pulse width=1.14 s, time between pulses=4.61µs, short pulse time=0.7 µs, servo control mean reference voltage=50 volts, wire feed rate=11.1 m/min and wire tension=0.43 daN. The value of performance measures obtained were cutting velocity=8.234 mm/ min and surface roughness =1.803µm. The values of the performance measures proved that the newly developed MMC could be effectively machined by wire EDM.

Uday A. Dabade et al. [37] discussed the Multi-Objective Optimization using Taguchi based GRA to improve the surface integrity on turned surface of Al/SiCp MMCs. Surface quality/integrity related parameters such as cutting forces, surface roughness, residual stresses and micro hardness variation were selected as target responses. The optimum process parameters to improve the surface integrity on Al/SiCp composites were identified. Experiments on Al/SiCp composites of four different compositions are performed using L_{27} orthogonal array as per the Taguchi method. The GRA based best and worst machining conditions change with size and volume fraction of reinforcement in composites. The best optimized combination of machining conditions to enhance the surface quality/integrity on machined surfaces of Al/SiCp composite is use of 0.8 mm tool nose radius, wiper type insert geometry, 0.05 mm/rev feed rate, 40 m/min cutting speed and 0.2 mm depth of cut.

Ganpatrao et al. [38] studied effect of Al_2O_3 particulate reinforced Aluminium matrix composites on WEDM. The effect of combination of reinforcement, current, pulse on time, pulse off time, servo reference voltage, maximum feed speed, wire speed, flushing pressure and wire tension on cutting speed, surface finish and kerf width was determined by Taguchi orthogonal array. The optimum machining parameter combinations were obtained for surface finish, cutting speed and kerf width separately.

Lal et al. [39] conducted experimental study on WEDM of Al7075/SiC/Al_2O_3 hybrid composite fabricated by inert gas assisted electromagnetic stir casting process. The objective of the paper was to investigate the effect of WEDM process parameters like discharge duration, pulse interval time, discharge current and the wire drum speed on the kerf width while machining newly developed hybrid metal matrix composite Al7075/7.5%SiC/7.5% Al_2O_3. The discharge current has most significance on kerf than discharge duration.

Ashish Srivastava et al. [40] presented an experimental study on composite of Al2024 reinforced with SiC to investigate the effects of Wire Electric Discharge Machining (WEDM) for three levels of each parameter such as current, pulse on time and reinforcement percentage on surface finish and Material Removal Rate (MRR). Response surface methodology (RSM) technique had been applied to optimize the machining parameters for minimum surface roughness and maximum MRR. The reinforcement percentages of SiC were taken as 2%, 4% and 6%. From the Scanning Electron Microscopy (SEM) images of machined samples it was observed that the surface finish that a nonconventional machining process gave was better than the surface finish we got from the conventional machining process. Results of experiments showed that surface roughness increased with the increase in pulse on time, peak current and reinforcement percentage while MRR increased with the increase in pulse on time, peak current and decreased with the increase in reinforcement percentage.

Anand Sharma et al. [41] experimentally investigated the impact of process parameters namely pulse on time, pulse off time, peak current and servo voltage on cutting rate using WEDM on Al6063/$ZrSiO_4$ 5% of wt. metal matrix composite. An experimental plan of the Box-Behnken based on the Response Surface Methodology (RSM) was applied to perform the experimentation work. The mathematical relationships between WEDM input process parameters and response parameter are established to determine optimal values of cutting rate mathematically. The ANOVA and F-test are performed to obtain statistically significant process parameters. The generated optimal process conditions have been verified by conducting confirmation experiments and predicted results were found to be in good agreement with experimental findings. It was found experimentally that increasing the pulse on time and peak current, the cutting rate increased, whereas increasing the pulse off time and servo voltage decreased the cutting rate. Surface topography of the machined surface showed that large size craters and cracks were formed on the surface when pulse on time was increased to a high level and pulse off time was kept at a lower level.

4. Powder Mixed EDM on Composites

The major problem to use EDM for large scale production is its low machining rate and poor surface finish. Many advances have come in the field of EDM to overcome these difficulties. One of those advancements is powder mixed EDM (PMEDM). Even though, the principle of PMEDM is not completely understood, the results of the experiments done by many researchers have shown significant improvement in material removal rate (MRR) and surface quality. Among the powder materials, aluminum produced better MRR and good surface finish compared to other materials like Cr, Cu and SiC. This was attributed to the increased spark gap due to aluminum's high electrical conductivity and low density. Kerosene or some commercial EDM oil was widely used as the dielectric medium in PMEDM. However, the Multi objective optimization of PMEDM process was performed by Kansal et al. [42]. They carried out an experimental study of the machining parameters in Powder Mixed Electric Discharge Machining (PMEDM) of Al/10%SiCp metal matrix composites and observed that MRR increased considerably with an increase in peak current for any value of pulse duration. The SR increased with increase in peak current and pulse duration. Composites and observed that MRR increased considerably with an increase in peak current for any value of pulse duration. The SR increased with increase in peak current and pulse duration.

Singh et al. [43] reported the work on EDM with SiC abrasive powder-mixed dielectric, a hybrid process. The machining of Al6061/Al_2O_3p 20% of wt. work specimens has been carried out with copper electrode. An L_{18} orthogonal array was employed for the optimization of the performance measures such as MRR and SR. The effects of seven control factors (three levels each) and a noise factor (two level), and one two-variable interactions on the responses were quantitatively evaluated by the Length's method. Analyzed results indicate that the process effectively improves the MRR and reduces the surface roughness, in comparison with the conventional EDM.

Gangadharudu et al. [44] made an attempt to fabricate and machine Al/Al_2O_3 MMC using EDM by adding Aluminium powder in kerosene as dielectric fluid. Results showed an increase in MRR and decrease in Surface Roughness compared to those for conventional EDM. Semi empirical models for MRR and SR based on machining parameters and important thermo physical properties were established using a hybrid approach of dimensional and regression analysis. A multi response optimization was also performed using principal component analysis-based grey technique to determine optimum settings of process parameters for maximum MRR and minimum SR within the experimental range. The recommended setting of process parameters for the proposed process has been found to be powder concentration =4 g/l, peak current (I) =3 A, pulse on time (Ton) =150 ms and duty cycle =85%.

5. Water EDM on Composites

Water EDM is in which the dielectric fluid is used as deionised water. Using deionised water as the dielectric results in lower machining time as opposed to other fluids. However, Mwangi J.W et al. [45] investigated the effect of using oil and deionised water as the dielectric fluids as well as the effect of introducing low frequency vibration in EDM machining of Aluminium Silicon Carbide (AlSiC) MMC. Experiments were carried out on AlSiC (AMC225XE) material using Sarix-100 high precision micro-erosion machine. A series of experiments were carried out with and without workpiece vibrations. For the experiments with vibrations a vibration frequency of 900Hz was used. The result of this study indicates that the introduction of vibration raises the material removal rate but results to an inferior surface quality.

6. Micro EDM on Composites

In recent years, numerous developments in EDM have focused on the production of micro-features. This has become possible due to the availability of new CNC systems and advanced spark generators that have helped to improve machined surface quality. Also, the very small process forces and good repeatability of the process results have made micro-EDM the best means for achieving high-aspect-ratio micro-features.

Current micro-EDM technology used for manufacturing micro-features can be categorised into four different types:

- Micro-wire EDM, where a wire of diameter down to 0.02mm is used to cut through a conductive workpiece.
- Die-sinking micro-EDM, where an electrode with micro-features is employed to produce its mirror image in the workpiece.
- Micro-EDM drilling, where micro-electrodes (of diameters down to 5–10 m) are used to 'drill' micro-holes in the workpiece.
- Micro-EDM milling, where micro-electrodes (of diameters down to 5–10 m) are employed to produce 3D cavities by adopting a movement strategy similar to that in conventional milling.

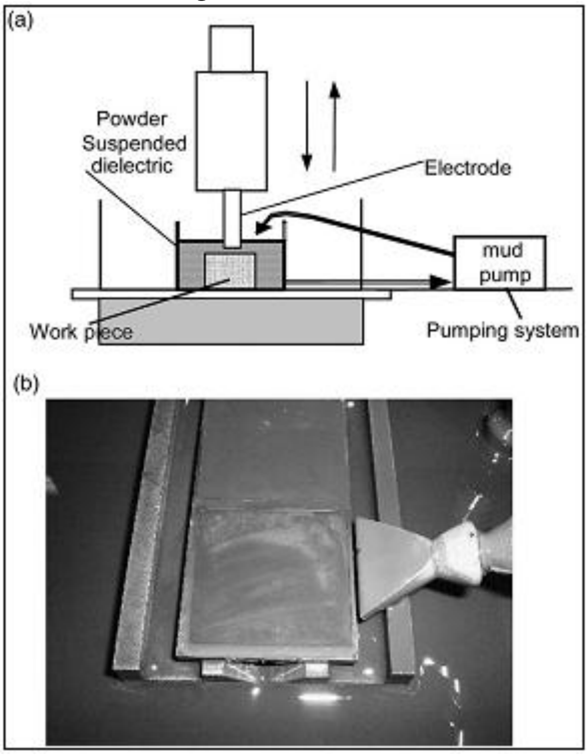

Figure 3: (a) Circulation system schematic view (b) Machined sample with silicon powder suspended on dielectric.

Zhao et al. [46] machined SiCp/Al using micro-EDM. First, a Φ40μm × 4.1mm micro tool electrode of which the aspect ratio is up to 100 was made; and then, through experiment, the impact of open-circuit voltage and electrode material on processing speed and electrode wear was analyzed; finally, 28μm wide micro slits, micro square platform of 34μm long on each side and other micro three-dimensional structure were machined. Research and experimental results show that the use of appropriate micro-machining parameters and reasonable processing methods can improve processing performance to better achieve the micro-EDM of SiCp /Al.

7. Conclusion

A Review research work on Aluminium Metal Matrix Composites on Electric Discharge Machining is presented in this paper. Majority of the research was focused on increasing the metal removal rate and improving the surface finish. The research work of the last 20 yrs has been discussed and the following conclusions are drawn:

1) Most of the work has been done on Aluminium MMC's reinforced with Silicon Carbide (SiC) particulate and on Alumina (Al2O3), due to their reinforcement in Aluminium composites for its excellent combination of physical properties, availability and low cost of the particulate.
2) Much less work has been done on Aluminium MMC's reinforced with Si3N4, ZrB2, B4C, SiO2, B, AlN, BN, due to their rare utilization and cost. Aluminium Composites reinforced with those particulates may also be considered as future scope.
3) Mostly, the work has been carried out on AMMC's using EDM and Wire EDM, less work has been done on other types of EDM.
4) Review revealed that, Water EDM resulted in the high MRR but it shows the poor Surface quality.
5) Micro EDM and Powder Mixed EDM indicates the improvement in the MRR and good surface finish compared to other types. More work could be done on Micro EDM and Powder Mixed EDM in future and there is enormous scope for research work in this area.

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