Electric Discharge Machining Method for various Metal Matrix Composite Materials

Mumtaz Rizwee, Sumit Swapnil Minz, Md. Orooj, Md. Zahid Hassnain , Mohammad Junaid Khan

Abstract: Among all the advanced Metal matrix composite (MMC) materials is among the important and beneficial materials for industry because of their characteristics such as high specific strength, high corrosive resistance, good wear resistance, light weight, and high thermal coefficient. It is very critical to do operation due to high hardness and reinforcement of the MMC by using conventional machining which is responsible for retard the development of MMC. Machining of MMC by using conventional machining process is a serious cause of higher Tool Wear Rate (TWR) because of abrasive properties of reinforcement particles. Machining of such materials can be done by using different type of non-convectional machining processes like that Laser beam machining (LBM) and water jet machining (WJM). But both processes are limited to linear machining only. This Articles represent a literature survey on Electric discharge machining (EDM) of reinforced MMC and different methodology used such as Analysis of variance (ANOVA), Response Surface Methodology (RSM), Taguchi methodology etc. which helps in optimizing the results. This review is analyzing the suitable process parameters and machining performance for machining of MMC and also reveals the research work area in which maximum research work can be done in future.

Keywords: MMC, Process Parameter, Machining Performance

I. INTRODUCTION

In nowadays use of high strength material and high temperature resistance material such as composites, metal matrix composite (MMC), ceramics etc increasing day by day because of their good mechanical, physical and electrical properties. but machining of these materials with the help of traditional machining process is quite cumbersome because of its high strength and hardness. Also the TWR is more for machining of such materials with the help of convectional machining processes. To machine these materials conventional method is less efficient. In the case of intricate shapes such as square-hole, blind-hole, step-hole, precise-hole conventional method do not give optimized performance. To overcome these difficulties the non convectional machining or non-traditional machining method has been developed. Of all the non-conventional process EDM is one of the best process to machine the high strength and electrical conductive materials. EDM techniques developed in about 1940s [1]. Electro discharge machining is generally used for making dies, punches and small hole drilling. It is extensively used to perform finish operation in aviation, automobile components and medical instruments. [2].The materials which is electrically conductive, EDM is extensively adopted irrespective of their shape, strength, hardness and toughness [3-5].

A. Principle of operation

Principle of EDM is based on the erosion of metal with the help of discharging spark. Electro discharge machining is also called as Electrical discharge machining or Sparks erosion machining [6].

In EDM, shaped tool which is also called electrode and work piece is connected to the D.C supply source and sink into the Dielectric fluid (electrically non- conductive) medium as represented below diagrammatically.

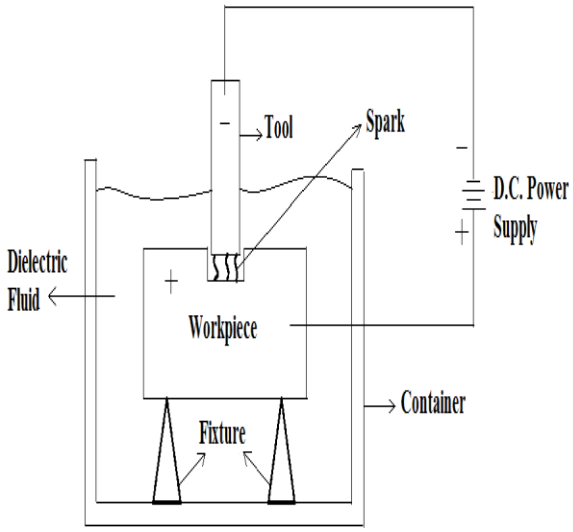

Fig. (a) Operational Diagram of EDM process

The fluid which are used as a dielectric medium are kerosene, demonized water, oil, white sprite, transfer oil etc. [7]. Vertical distance between the tool (electrode) and work-piece is called “spark gap” When the potential difference in this gap becomes sufficient high then the pulse discharge occurs which

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propagates from tool to the work piece through the ionized dielectric medium and small amount of metal is melted of the work piece which is drained by the de-ionized fluid and is removed from the work piece surface. This process is continued and ultimately the desired shape or profile is developed on the work piece surface [8-11]. The insulating effect of dielectric medium is used to avoid the electrolysis effect on the electrode at the time of machining. On applying sufficient voltage and maintaining the required gap between electrode and Workpiece leads to ionization the dielectric fluid [12]. In EDM, channel of plasma is generated between cathode and anode by the thermal energy [13] at a temperature ranges about 8000 to 12000 ^{o}C [14]. When the frequency of direct pulsating current reached at a rate approximately 15,000 - 30,000 [15] breakdown of the plasma channel occurs which assist in flushing out debris particles from the machining zone by dielectric fluid. In EDM because of no actual contact between tool and work-piece, hence it is from mechanical stresses, vibrations and chatter problems. [2].

II. Types of Electro Discharge Machining Process

A . Sinking EDM

In sinking Electro Discharge Machining process current carrying specific shaped electrode (tool) is used to machine the replication shape into work piece materials or components. Removal of debris is done by the help of dielectric fluid. In manufacturing of Dies and Tools this method is widely used [16-17].

B. Wire EDM

In this method, wearing of materials takes place between work-piece and wire electrode from the machining surface by the sequence of discontinuous discharge. In this method copper wire is used as a electrode of about 0.1 to 0.3 mm diameter and the work piece is mounted on the computer numerical control work table [18]. Generally the gap between the work piece and wire is 0.025 to 0.05 mm which is constantly maintains with the help of microprocessor. This process is generally used in die and tool making industry, electronics industry, automotive industry, in the field of medicine etc. [19].

C. Micro – EDM

This method is used for machining micro shaft, micro holes as small as 5µm in diameter as well as for the machining of three dimensional complex micro cavities. This process is generally used for machining very precise hole unlike mechanical drilling which produces hole minimum up to 70µm diameter [2]. There are four type of micro EDM (µEDM) like as die sinking µEDM, micro wire EDM, µEDM milling and µEDM drilling. In micro wire EDM, a wire less than 0.02 mm diameter is used to cut the work piece. Its electrode (tool) having micro features, is used to cut its replication shape in the work piece. To drill the micro holes a narrow electrode having diameter about 5 to 10µm is used. In µEDM milling, diameter about 5 to 10µm narrow electrode is used to generate three dimensional cavity by following the movement strategy as like the convectional milling [20].

D. Powder mixed EDM

In this method a suitable materials powder is mixed in the dielectric fluid of the sinking EDM process. on applying the required voltage, the additive fills up the spark gap and from 25 – 50 to 50 – 150 µm gap distance setup is increased between the work piece and tool [21]. In these process different types of metal powder is used with dielectric medium like that Alumina, SiC, Cr, Cu etc to increase the Material removal rate (MRR) [16-17]. In the sparking zone powder particles arranged themselves like a array due to this a chain formation take place which assist in removing the gap between the tool and the work piece due to this early explosion take place.

E. Dry EDM

In this technique thin walled tube like tool is used through which a high intensity gas or air is fed. The objective of the gas to flush out the eroded particles and cool the inter electrode gap. This techniques is used to minimize the pollution which take place because the use of dielectric fluid which produce vapours at the time of machining.

III. Different Parameters of EDM Process

In electro discharge machining process there are two types of process parameters. The first one is process parameter and second one is machining performance.

Process parameter:
Electrical parameter

- Peak voltage
- Peak current
- Pulse duration
- Gap voltage
- Pulse interval
- Polarity

Non-electrical:

- Flushing
- Tool rotation
- Workpiece rotation

A. Effect of Electrical Parameter

Pulse duration (T-ON): pulse duration is a time in which current is flow from tool (electrode) to work piece through spark gap. This time is measured in microsecond. Pulse on time is the name of pulse duration. MRR is the function of amount of energy which propagates during ***T-ON*** [22]. Longer or shorter ***T-ON*** affects the MRR. Longer the ***T-ON*** increases the removal of eroded particles from the machining zone which also affect the TWR. In EDM process, erosion of material takes place from the tool and Workpiece because of melting and vaporization process and the amount of melting and vaporization is depends upon the ***T-ON*** i.e. longer ***T-ON***, more the amount of melting and vaporization and vice versa [23]. But some research work shows that optimum pulse on time is required for higher performance measures. Always ***T-ON*** only not increase the MRR, a suitable peak current is also required with pulse on time to improve MRR.

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If we keep the peak current and duty factor constant and increases the ***T-ON*** then MRR decreases [24]. This is due to the fact that by increasing the pulse on time the plasma channel expands and due to this expansion, the density of plasma channel becomes lesser on the work piece surface and hence MRR decreases.

Pulse interval [T-OFF]: T-OFF (Pulse off time) means the time in which spark is not propagated from tool to work piece through spark gap. If the T-OFF is too short then the MRR increases but it because of more spark machining surface becomes unstable. Kansal et al. [25] research implies that on increasing interval MRR decreases. Saha et al. [26] shows the result that if the pulse interval time is small then MRR is low and by increasing the T-OFF MRR increases. Experiments shows that MRR decreases slowly on increasing T-OFF because for small T-OFF probability of arching is more because dielectric have no more time to recover its dielectric strength for short interval time. O.A. Abu Zeid reported in his experiments that MRR is not too much sensitive for pulse interval [27].

Electrode gap (Spark Gap): For good machining there should be proper gap is maintained between tool and work piece. The constant gap is maintained between tool and work piece by servomechanism automatically.gap width between tool and work piece can't be measured directly but it can be guessed by the average gap voltage [28].

Polarity: Tool or work material may be either connected with the positive terminal or negative terminal but if we take tool as a negative terminal and work piece as a positive terminal then the MRR becomes more in compassion to the reverse connection i.e. tool as positive and work piece as negative. This is due to the fact that in this condition (tool consider as negative and work piece as positive) energy transfer during charging is more in respect to other condition (tool consider as positive and work piece as negative) [29]. Hence negative polarity is more suitable with respect to positive polarity. Investigators concluded this because when MRR depends on anode potential drop then it provides better surface finish and MRR. Researcher implies that MRR of work piece is lower with positive polarity because the formation of recast layer [30].

B. Effect of Non Electrical Parameter

In electro discharge machining there are also some non electrical parameter such as flushing of dielectric fluid, aspect ratio and rotation of tool electrode. Non electrical parameters also affect the performance parameter.

Flushing of dielectric: Function of flushing is to remove the debris from machining zone. Flushing is done with the help of dielectric fluid which is also used for cool down the tool and work piece. Dielectric fluid also used for quenching the spark. The property which required for dielectric fluid is high dielectric strength and quick recovery after breakdown [31]. Dielectric fluid work as a conducting medium when ionized. The dielectric fluid which is generally used is hydrocarbon compounds and ionized water. Mostly as a dielectric fluid kerosene is used. The pressurized dielectric fluids are usable for draining out worn out particles from the machining zone and cool down the tool and work piece [32]. It was investigated by Chen et al. [33] when we used 16 distilled water as a flushing medium then MRR becomes more and TWR becomes less.

Rotation of Tool Electrode: Stationary as well as rotatory both type tools can be used for electro discharge machining process. Rotatory electrode (Tool) removes more material from the machining zone because of centrifugal action. The rotational movement of the electrode is perpendicular to the work piece surface. Soni and Chakraverti [34] in their research compare the use of rotatory tool and stationary tool and their result implies that the use of rotatory tool enhance the MRR, lessen the TWR and improve sparking efficiency in comparison to the stationary tool.

Tool Geometry: Tool geometry means shape of the electrode i.e. square, rectangle or circular. Shape of the electrode also affects the performance measure o f the electro discharge machining. Because shape affects the aspect ratio. Aspect ratio is defined as the length / diameter for any shape of electrode and it becomes thickness/ diameter for rotating disc electrode. Singh et al. [35] investigate in their experiment that shape of the electrode affect the TWR i.e. lowers the aspect ratio higher the TWR. Hence on increasing the size of the electrode improve the machining performance.

C. Machining performance

MRR, TWR, Surface Roughness (SR), radial over cut (ROC), tapper (T) are the machining performance of the electro discharge machining process. These all are also known as Performance Measure or Machining Responses or Process responses.

IV. OVERVIEW OF SINKING EDM OF MMC MATERIALS

Karthikeyan et al. in 1997 researched on EDM of aluminum silicon carbide by using mathematical modeling [36]. They reported the effect of current, pulse duration and percentage volume (vol. %) of SiC particles on the MRR, TWR and SR. They developed a mathematical modeling to compare the theoretical data with the experimental data within the operating region. The investigation reported that performance measures greatly affected by the current, pulse on time and percent volume of silicon carbide in the metal matrix composite material. The MRR increases with the increase in current and decreases by increasing of percentage volume of SiC particles in the material.

Tool wear ratio also increases with the increase in percentage volume of SiC particles in the material and current but it reduces with increased in pulse duration. SR increased with the increase of all the three performance parameters i.e. percentage volume of SiC in the material, current and pulse duration. The research revealed the optimum value of all the three process parameters which give the maximum MRR and minimum TWR and SR which is generally required for machining. Muller and Monaghan had done their research on machinability of reinforced SiC particles Aluminum metal matrix composite using different non-traditional machining processes such as EDM (spark erosion machining), Laser cutting and Abrasive water jet machining [37].

The main motive of this research work is to compare the surface quality such as SR, surface topology and sub-surface with the help of different non- convectional machining processes.

The research also revealed the effect of SiC reinforcement on machining operation by performing comparative test on aluminum alloy. The EDM process is effective for the machining of SiC aluminum MMC. The machining leads to crater which depends upon the discharge energy i.e. when discharge energy is more than crater size becomes more. The result implies that relatively small amount of sub-surface damage also found on the machined surface.

P. Narender Singh et al. had researched on the optimization of machining parameters for machining of Al- 10 % silicon carbides particles (SiC) by EDM process by using Gray relational analysis (GRA) [38]. Multi responses characteristics optimized by using orthogonal array and GRA in EDM of Al–10% SiC composite. Gray relational method converts multi responses variable into a single response variable (gray relational grade) and hence simplify the optimized procedures. This research work mainly aimed on parameters optimization by using gray theory. Sushant Dhar et al. investigated the mathematical analysis of cast Al – 4Cu – 6Si alloy with 10 weight percent (wt. %) SiC composite [39]. The main motive of the research was to valuate the influence of T-ON, current and gap voltage on the MRR, radial over cut and TWR. The mathematical model is used to imply the optimal condition which is suitable for EDM of Al – 4Cu – 6Si alloy – 10 wt. % SiC composite. In this research linear programming mathematical model is used to find the optimal condition for optimum machining responses i.e. maximum MRR and minimum TWR and ROC. All the three machining responses increased in non-linear fashion due to increase of current. Effect of MRR and ROC were increased on increasing of pulse duration and also the effect of gap voltage was very less on all the three responses.A. Mouangue Naniminia et al. revealed in their research the EDM of Al6061 alloy and 30 vol. % Al2O3 reinforced Aluminum metal matrix composite (AMMC) material and the effect of process parameter such as peak current, T-ON, T-OFF and their effect on machining responses like that MRR and TWR) [40]. When the peak current is very low then MRR of both (Al6061 alloy and 30 vol. % Al2O3 AMMC) material almost equal but when peak current reached upto 15 A at that position MRR of Al6061 alloy becomes three times more than the 30 vol. % Al2O3 AMMC. When the pulse on time increases then MRR of both materials increase in non- linear fashion but in between both MRR of Al6061 alloy is higher than 30 vol. % Al2O3 AMMC and when T-OFF decreases then the MRR of both the material decreases in non-linear fashion but in between both MRR of 30 vol. % Al2O3 AMMC is becomes more lower than the Al6061 alloy.

The TWR of Al6061 alloy is higher at low peak current and more when the peak current start to decrease but TWR of 30 vol. % Al2O3 AMMC is lower at low peak current and slightly decreases on increasing peak current upto certain value and after that on increasing peak current TWR becomes nearly constant. At low T-ON, TWR of Al6061 alloy is more as compared to 30 vol. % Al2O3 AMMC and when pulse on time becomes 12 µs then TWR of both Al6061 and 30 vol. % Al2O3 AMMC becomes lower. On increasing T-OFF TWR of Al6061 remains nearly constant but TWR of 30 vol. % Al2O3 AMMC is lower at low T-OFF and increases on increasing T-OFF. Effect of process parameters on the machining response also shown in 3D-graph.

Rajesh Kumar Bhuyan et al. reported the effect of process parameter such as T-ON, T-OFF, peak current and flushing pressure on machining responses such as MMR, TWR and SR on the EDM of 12 wt. % SiC particles reinforced AMMC [41]. RSM is used to develop the mathematical model to correlate the process parameter with performance measures. ANOVA technique is used to audit the significance of model and also used to compare the experimental data with the predicted data to analyze the effectiveness of the expected method and then morphological study of surface is performed after machining with the help of Field Emission Scanning Electron Microscope (FESEM) and make the relation with the model. It is observed that peak current is the most significant parameter among all the parameter and peak current increases linearly with the MMR, TWR and SR. MRR and SR increases with increase in T-ON and flushing pressure but TWR decreases with increase in T-ON and flushing pressure. R. K. Garg et al. present a review paper on EDM and wire Electric discharge machining (WEDM) of MMC materials [42]. They implies that the maximum research work has been done on the optimization of process parameter and improvement of machining performance of EDM by using maximum SiC particles reinforced MMC materials. Chicosz and Karokzak researched on the EDM of Al/Si/Mg- Al2O3 MMC [43]. They investigated the effect of current on the surface layer formation on the machined surface. In the investigation they observed that the current density and frequency of spark improved the machining responses. Akshay Dvivedi et al. has done their investigation on the spark erosion machining of Al6063 SiC metal MMC and revealed the optimum process parameter for optimum machining responses [44]. In their experiment optimum process setting was established for the maximum MRR with sufficient TWR and satisfactory dimensional accuracy. On increasing the value of process parameter beyond the optimum setting value decreases the MRR and increases in TWR. The experiment revealed that for maximum value of pulse current, T-ON, T-OFF, up to the maximum set value, the MRR increased. The effect of Pulse current (IP) is more on the MRR with respect to other process parameter. The flush pressure and gap voltage are also responsible for achieving high MRR. Adrian et al. had been researched on the effect of process parameter on the performance measures of electro discharge micro drilling of Al/SiC hybrid composite [45]. They consider T-OFF, T-ON, peak current a process parameter, and MRR, TWR and surface quality as a machining performance in their investigation. The research revealed that peak current is most influential parameter among all parameters for the MRR, TWR and surface quality. They also used Regression analysis for establishing the mathematical model for the MRR and TWR. Jadam et. al. has been done their experiment on EDM of Inconel 718 super alloy by using triangular shape copper tool electrode [46].

They examine three process variables like that peak discharge current, T-ON and gap voltage and their effect on the EDM work surface in terms of surface crack density. They used XRD (X-ray diffraction) test to compare the metallurgy of the machined EDMed (Electro discharge machined) surface with respect to received Inconel 718. EDAX analysis is used to compare the result of this experiment. Shrivastava, P. K., & Dubey, A. K research shows the effect of electro discharge abrasive grinding (EDAG) on copper-iron-graphite MMC. They considered process measures as average surface roughness (ASR) in their research work [47]. The Regression and Artificial neural network (ANN) modeling have been used to produce the predictive models for ASR and also compare both the models with each other to predict proper ASR.

Hassan et. al. have done their research work in the formation of MMC-Electrode for EDM process by using Rapid Prototype technology and by these technology they reduce the cost of production of the electrode [48]. They generally take mixed copper powder with Al_2O_3 powder as MMC materials for the formation of Electrode for EDM. Takahata, K., & Gianchandani, Y. B. have done their research work for the fabrication of Micro- electro- mechanical system (MEMS) by using micro electrode discharge machining (uEDM) and their modified form [49]. Abdulwahid et. al. shows in their research the effect of mechanical mold vibration on EDM parameter during machining of Aluminium- alumina composite [50]. The research reported that mechanical mold vibration increases the mechanical and physical properties of aluminium alumina composite such as hardness increased, porosity and grain size decreased, MRR and TWR increased and SR decreased. They used RSM to determine the optimum process parameter to achieve higher MRR and lower TWR. Mohan et. al. have done their experiment on electro discharge machining of Al-Sic metal matrix composite using rotatory tube electrode [51]. they consider three process measures such as MRR, EWR and SR and process parameters are peak current, polarity, volume fraction of Sic reinforced particles, hole diameter of tube electrodes, pulse duration and speed of electrode rotation. Result shows that increase in % of Sic reduces the MRR and increased the TWR, with the positive polarity of the electrodes MRR, TWR, SR becomes more, peak current also shows beneficial effect on TWR, MRR and SR by increasing rotational speed of the electrode and reducing the hole diameter of the electrode MRR increases and TWR and SR decreases. Genetic algorithm is used to find the optimum machining parameters for higher MRR and lower TWR and SR. Singh et. al. research work objectives were to show the effect of process parameter such as current (C), T-ON, and flushing pressure force (F) on the process measures such as MRR, TWR, taper (T), ROC and SR on machining of cast Al- MMC with 10 % SiC reinforced particles [52]. They used ELEKTRA PLUS EDM having jet type flushing and for Dielectric fluid kerosene has been used. ANOVA approach is used to optimize the process responses. Scanning electron microscope (SEM) is used for study of machined surface characteristics. Mohan et. al. investigated the effect of process parameter of EDM such as current, polarity, electrode material, T-ON and rotation of electrode on the process responses such as TWR, MRR and SR on the machining of Al-MMC with 20 to 25 percent reinforced Sic particles [53]. Result shows that MRR increases with increases in discharge current and decreases with increase in T-ON for any specific current. Increase in percentage fraction volume of Sic particles develop the positive effect on TWR and SR and negative effect on MRR. With the Increase in the speed of rotating electrode gives positive effect on TWR and MRR and better surface finish with respect to stationary electrode. Dhar et. al. research work evaluates the effect of T-ON, Current (C) and gap voltage (V) on the TWR, MRR, ROC with EDM of cast Al-4Cu-6Si alloy with 10% SiC reinforced particles [54]. They used PS LEADER ZNC EDM with a cylindrical shape brass electrode having diameter 30 mm. Non- linear mathematical model is used to establish the relationship among the machining parameter and also performed ANOVA approach to verify the adequacy of the developed mathematical model.Singh et. al. research work showed the optimization of multi machining responses such as MRR, TWR, taper (T), ROC, SR of the process parameter by using GRA on EDM of Al- composite with 10 % Sic reinforced particles [55]. They also used orthogonal array (OA) with GRA to enhance the multi machining responses. Their research work implies that how the multi machining responses are optimized by using GRA.

Habib in their research work used RSM approach to develop a mathematical model to correlating the EDM process parameter by using relevant experimental data [56]. They also used ANOVA approach for the adequacy of the above proposed model. Dvivedi et. al. research work showed the effect of T-ON, T-OFF, IP, flushing pressure and gap control setting on MRR and TWR on EDM of cast Al 6063 – SiC MMC by using one-factor-at-a- time approach [57]. To obtain most favorable process parameter they used Taguchi Technique. The result showed that MMR increases on increasing IP and T-ON upto a certain range and then start to decrease. The effect of IP is more on MRR as compared to other process parameter. Kumar et. al. have done their research work to optimize the Abrasive mixed Electric discharge machining (AEDM) with multiple performance characterctics by using orthogonal array with GRA [58]. The input parameter considered are concentration of silicon abrasive powder in dielectric fluid, T-ON, peak current and duty factor and their effect on machining performance such as MRR and SR. The research also reveals the effect of dielectric fluid mixed with abrasive particles on the performance electrode. Gopalakannan & Senthilvelan et. al. have been done their research on electro discharge machining of metal matrix nano composite (MMNC) of Al 7075 reinforced with 1.5 wt. % SiC nano particles by using copper electrode [59]. They used novel ultrasonic cavitation method for making MMNC. Due to uniform distribution of SiC nano particles with aluminium metal matrix they used FESEM and SEM. ANOVA approach is used to investigate the effect of process parameter and also mathematical model used to formulate and determine the machining characteristics of EDM.

Result shows that among all the input parameter IP is the important factors which affect the output parameters such as MRR, EWR and SR. Through the experiment they developed optimum input parameters which increase the MRR, lowers the EWR and SR. Senthilkumar & Omprakash investigate the effect of current (C), T-ON and flushing pressure (P) on MRR and TWR during electro discharge machining of sintered Al- MMC with 5% and 2.5 % reinforcement TiC particles [60].For dielectric fluid kerosene has been used and copper as a tool electrode for drilling of specimen. An L18 orthogonal array is used to conduct the experiment and ANOVA approach is used to check the affirmation of the experimental plan. The research work also implies the effect of TiC particles on the MRR, TWR and EWR. Gopalakannan et. al. investigated on the optimization of process parameter and their effect on machining performance during the EDM of Aluminium 7075 MMC reinforced with 10 wt % of B4C particles which is made by stir casting method [61]. They consider T-ON, T-OFF, gap voltage and IP as a process parameter and MRR, EWR and SR as a machining performance. ANOVA is used to investigate the effect of process parameter on the machining performance. The result provides significant process parameters which improve the MRR and minimize the EWR and SR. Ponappa et al. research work investigate the outcomes of EDM parameters such as taper and surface finish of microwave- sintered magnesium nano composites (reinforces with 0.8 and 1.2 w % of nano alumina) [62]. Taguchi methodology is used to determine the effect of EDM process parameter and also this parameter is optimized to achieve hole accuracy and SR. ANOVA approach is used to determine the major factor which affect the hole accuracy and SR. The result reveals that T-ON and servo speed significant response variable for achieving hole accuracy and SR. SEM micrographs are used to see the changes in micro structure and the effect of nano particle reinforcement in drilled hole. Chattopadhyay et. al. investigate the rotatory electro discharge machining of EN – 8 steel with copper tool [63]. Linear regression analysis is used to predict the output parameter applying logarithmic data transformation of non linear equation by developing Empirical model. They consider three input parameter such as peak current, T-ON and rotational speed of the electrode to determine the output parameter such as MRR, EWR and SR. Taguchi analysis and ANOVA approach is used to determine the significance of input parameter and their contribution in improving the output parameter. The research also investigates the maximizing of MRR, minimizing the TWR and improving the SR and all is not achieved by the single set of input parameter. The result implies that peak current and T-ON play a major role for improving MRR and TWR and peak current and rotational speed of the electrode keep significant effect on SR. Gopalakannan & Senthilvelan research investigates the electro discharge machining of metal matrix nano composites (MMNC) of Al 7075 reinforced with 0.5 wt % SiC particles is made by ultrasonic cavitation process [64]. Scanning electron micrograph is used to see the uniform distribution of nano SiC particles on Al 7075 metal matrix. ANOVA approach is used to know the effect of process parameter on the machining performance and also mathematical model is employed to formulate the input parameter to determine the machining characterctics.

Aliakbari & Baseri research work determine the optimal setting of the process parameter on rotatory EDM process [65]. In machining parameter three parameter such as peak current, T-ON and rotation speed of the electrode with three kind of tools are considered. Taguchi method is used to show the effect of input parameter on the MRR, EWR , SR and overcut. Taguchi methodology also used to optimize the input parameter to obtain higher MRR, lower EWR, SR and overcut. Ramulu et. al. investigation reveal the effect of electro discharge machining of 15 vol % SiC particles reinforced A356 Al on SR and other machining performance under the fatigue and monotonic loading condition [66]. They compared the EDM machined surface with the same material polished surface. Tensile test has been performed with both i.e. EDM machined surface and polished surface to see the effect of EDM processing on monotonic properties. Fatigue test of high cyclic constant stress has conducted on the polished material and EDM material and Factograph approach is used to see the mechanism of fatigue fracture. Result reveals the SR is high and surface becomes soft below the recast layer in EDM process. Because of higher MRR fatigue strength is reduced in greater extent in EDM process. Seo et. al. research work on drilled by EDM of 15-35 vol % SiC reinforced particles in Al359 MMC to estimate the machinability and work piece quality [67]. The research work show the effect of EDM method on machining performance and work piece quality including MRR, material removal mechanism, EWR and also drilled hole quality such as surface texture and roundness by using profilometer, coordinate measuring machine (CMM) and SEM. The experimental result implies that the MRR rises with rise in peak current and T-ON up to a optimum level and after that keeps on lowering. Due to higher peak current and T-ON, greater the tool wear and higher the mean diameter error. By increasing the percentage volume of SiC particles in Aluminium MMC, MRR increases and TWR found to be decreases. SEM and EDX- ray examination were used to inspect the EDM machined surface and melted SiC particles. Lee & Li research work investigates the influence of the operating parameters of EDM and their effect on machining characteristics during the electro EDM like that MRR, TWR and surface finish of tungsten carbide [68]. They consider Copper tungsten as a suitable tool material for machining of tungsten carbide. For high MMR, low TWR and good surface finish, tool is taken as negative terminal and work-piece as positive terminal. Because of high melting point and hardness of tungsten carbide open circuit voltage is required. The flushing pressures in the experiment maintain about 50 kpa. The research reveals that optimum machining characterctics can't be obtain by a single set of operating parameter. The result implies that higher the discharge current faster the machining time, faster the MRR and higher the SR. Their research gives the optimum value of operating parameter at which optimum machining characteristics can be achieved. Rangajanardhaa & Rao research work objectives were to optimize the SR during EDM process by considering various input parameter simultaneously [69].

The experiment is performed on materials such as Ti6Al4V, HE15, 15CDV6 and M-250. In the experiment, SR is measured by varying the peak current and voltage. They used artificial neural network to optimize the input parameter. For optimizing the weighting factor of network genetic algorithm concept is used. When experimental and network model result are compared it shows the developed model is under tolerance of agreeable error. To see the relative effect of factor (type of work material) on performance measures, sensitive analysis is used. Shehata et. al. in their investigation compare the effect of kerosene oil and paraffin oil on EDM of Al/SiC MMC [70]. The experiment shows that MMR, TWR and SR are higher when paraffin oil is used as a dielectric fluid in comparisons to kerosene oil. Energy dispersion analysis of X- rays (EDX) is used which shows the formation of carbide (Al4C3) and calcium (Ca) layer on the work piece and tool surface when paraffin and kerosene is used as a dielectric fluid. Their research work explained that the formation of both said layer reduce the MMR, TWR and SR because both carbide and calcium particles having higher melting point with respect to base metal and also retard the discharge process of electrode if as a dielectric fluid kerosene is taken. Kibria et al. depicts the effect of pure demonized water and Boron carbide mixed demonized water and kerosene dielectrics on the machining responses on machining of Ti – 6Al - 4V alloy by using EDM [71]. The outcome shows that the B4C contains kerosene has not great effect on EDM, but B4C contains demonized water shows the excellent effect and increased the MRR. TWR is higher in pure demonized water and B4C containing demonized water as compared to kerosene dielectric fluid. Syed and Palaniyandi has revealed in their experiment on the effect of Aluminium metal powder contains distilled water on machining responses in spark erosion machining process [72]. The result of the experiment investigates that when Aluminium metal powder is present in distilled water the MRR increases, surface finish improves and reduces white layer thickness. Ojha et al. in their research revealed that the influence of Nickel powder contains dielectric fluid on the machining performance such as MRR and TWR in spark erosion machining process [73]. The research implies that the kerosene containing micro suspended nickel powder increases the MRR but it shows no more effective effect on the TWR.Prabu et. al. experiment show the effect of EDM process by the use of graphite particles mixed with dielectric fluid during the machining of Al-TIB_2 MMC [74]. Insulation strength of dielectric fluid decreases with the addition of conductive graphite powder and also spark gap gets maximized. Graphite mixed dielectric fluid also assists to concentrate the discharge energy into the narrow region and as result of this, discharge frequency and discharge energy increases. They conducted their research work by using ELEKTRA PULS EDM machine. The main aim of their research work was to find out the optimum process parameter (such as current, T-ON, flushing pressure and vibration) increases MRR and decrease TWR.Shankar et. al. in have compared the effect of plain dielectric fluid and silicon carbide particles mixed dielectric fluid of EDM process during the machining of stir- casted 6061Al/Al $_2O_{3P}$/20P MMC [75]. They used copper as a electrode material. Lenth's method has been used to analyze the results of both the process and to finds out the optimum process parameter. The result reveals that the silicon carbide particles size, concentration and IP is the most effective parameters which affect the surface characteristics.

Kansal et al. investigates the effect of powder containing dielectric fluid on the process parameter and machining responses of Al- 10 % SiC MMC in EDM [76]. The main aim of their investigation was to establish the optimum process parameter by the experiment. They have used RSM model to make the experimental design. Aluminium powder is used as a mixing powder in dielectric fluid. The relationship was setup between process parameter (such as concentration of aluminium powder, peak current and T-ON) and machining performance (such as MRR and SR). According to the investigation it was revealed that among all the process parameters which is important for machining performance and in the experiment process parameter were also optimized for high machining rate and low SR.

The result of the experiment had been compared with the EDM of the same composites materials but without using aluminium powder in the dielectric medium and had revealed the importance of aluminium powder in the dielectric fluid. Agrawal et. al. investigated the effect of Powder mixed-EDM process on the copper- iron- graphite MMC [77]. In their experiment they consider the process measures are TWR and MRR. They used RSM for TWR and MRR and also used GRA, RSM and genetic algorithm for the multi objective optimization of TWR and MRR.

V. Comparative Analysis of Electro Discharge Machining Method for Different MMC Materials

On the survey of research work we see that various research work conducted by using different MMC materials such as SiC/Al, SiC/Al-Cu-Si, Al2O3, Cu-graphite and TiC/A which has been represented in percentage by using Pie – Chart shown in figure (b)

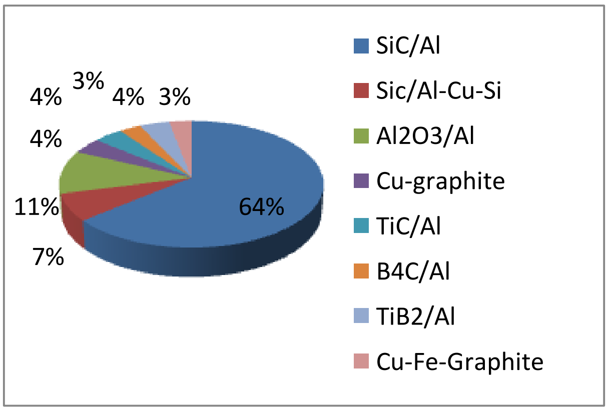

Fig. (b) Research work conducted on different MMC by EDM process.

On the survey of research work we see that various research work conducted by using different EDM tool materials such as Brass, Copper, Graphite, MMC Electrode, Cu- tungsten which has been represented in percentage by using Pie – Chart shown in figure 3.

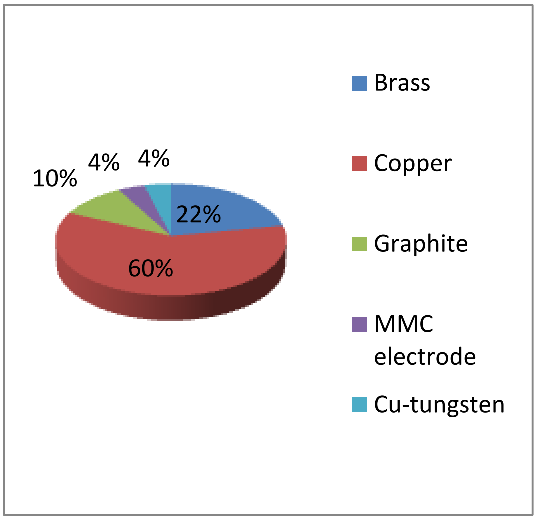

Fig. (c) Research work conducted by using different tool in EDM of MMC

On the review of research work we see that various research work conducted by using different dielectric fluid in EDM such as Kerosene, Deionised water, Powder mixed dielectric which has been represented in percentage by using Pie – Chart shown in figure (d)

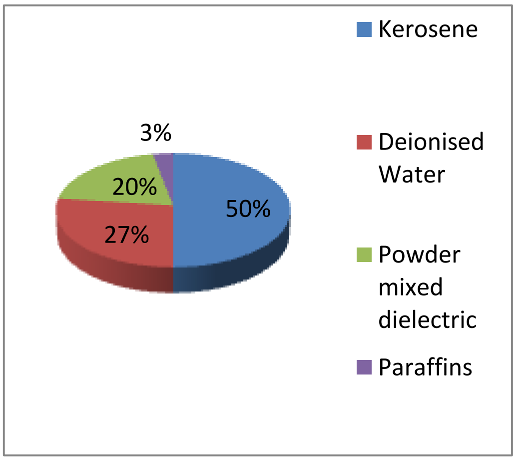

Fig.(d) Research work conducted by using different dielectric fluid in EDM

Table I. Comparison of Different Methodology for EDM Optimization

References	Method/ Technique	Used Material	Advantage	Research Gap
[41, 52, 54, 59-64]	Analysis of Variance (ANOVA)	12 weight % silicon carbide particles reinforced aluminium, 10 % silicon carbide particle reinforced aluminium, Al(aluminium)-4Cu(copper)-6Si(silicon) alloy with 10 % silicon carbide reinforced particle, Aluminium 7075 reinforced with 1.5 weight % silicon carbide particle, Aluminium with 5 % and 2.5 % reinforced titanium carbide particles, Aluminium 7075reinforced with 10 weight %of boron carbide particles, magnesium reinforced with 0.8 and 1.2 weight % alumina, EN -8 steel, aluminium 7075 reinforced with 0.5 weight % silicon carbide	To audit the significance of model and compare the experimental data with the predicted data to analyze the effectiveness of the method. To optimize the process responses such as MRR, TWR, taper, ROC, SR. To verify the adequacy of the developed mathematical model. To determine the effect and significance of input parameter (peak current, T-ON, gap voltage, T-OFF) on machining responses (MRR, TWR, SR).	They can also use artificial neural network (ANN) analysis to compare the experimental data with predicted data to analyze the effectiveness of the process.
[41, 50, 56, 76, 77].	RSM	12 weight % silicon carbide particles reinforced aluminium, aluminium alumina composite, aluminium reinforced with 10 % silicon carbide, copper- iron-graphite.	To developed a mathematical model for correlating the process parameter with machining responses and determine the optimum process parameter to achieve maximum MRR and minimum TWR.	They can also use genetic algorithm to improve the methodology.

			For multi objective optimization of TWR and MRR.	
[45, 47]	Regression Analysis	Aluminium silicon carbide, copper- iron- graphite	To established the mathematical model for the MRR and TWR. To produce a predictive models for average SR.	They can also use RSM for developed a mathematical model for the MRR and TWR.
[47, 69]	Artificial Neural Network (ANN)	Copper- iron- graphite, Ti6Al4V, HE 15, 15CDV6, M-250	To produce the predictive models for average SR. For obtained optimal input parameter such as peak current and voltage.	They can also use the genetic algorithm to produce the predicted model for average SR.
[51, 69, 77]	Genetic Algorithm	Aluminium silicon carbide, Ti6Al4V, HE 15, 15CDV6, M-250, copper- iron- graphite.	Determine the optimum machining parameters such as peak current, polarity, volume fraction of silicon carbide reinforced particle, pulse duration, speed of electrode rotation, hole diameter of tube electrodes. For optimization of the multi objective characteristics of TWR and MRR.	They can also use hybrid technique for optimized the machining parameter.
[54]	Non linear Mathematical Model	Al-4Cu-6Si alloy with 10 % SiC reinforced particles	Established the relationship among the machining parameter.	They can also use RSM methodology to establish the relation among the machining parameter.
[57, 62, 63].	Taguchi Technique	Aluminium 6063 silicon carbide, magnesium reinforced with 0.8 and 1.2 weight % alumina, EN -8 steel.	Determine the, effect of process parameter and optimal value of process parameters (machining parameters).	They can also use Genetic Algorithm to determine the optimal process parameter.
[39]	Linear Programming Mathematical Model	Al-4Cu-6Si alloy with 10 weight %SiC composite	To developed the optimal condition for optimum machining responses.	They can also use RSM analysis to optimize the machining responses.
[38, 58, 77]	Orthogonal Array and GRA	Aluminium 10 % silicon carbides, EN- 24 tool steel, copper- iron- graphite.	For optimizing the multi responses (objectives) characteristics of TWR and MRR.	They can also use RSM analysis to optimize the multi responses.
[75]	Lenth's Method	6061Al(aluminium)/ Al_2O_3 (aluminium oxide)/ 20p	Analyzing the process and find out the optimum process parameter such as particle size and their concentration in dielectric fluid, pulse current.	They can also use ANN technique to optimize the process parameter.

VI. RESEARCH TREND

In future, more research has been done by using different tool materials such as tungsten copper, tellurium copper, Zinc and Tin alloy, cast iron, silver tungsten alloy, aluminium alloy (by reverse polarity), and steel (by reverse polarity) in EDM of MMC materials.

In future also more investigation can be done by using mixed fluid such as Benzene and Kerosene, Xylene and Kerosene and Toulene and Kerosene as a dielectric medium in EDM of MMC materials.

Modified genetic algorithm and Particle Swarm optimization methods can be used for improving process parameter.

Some research can be done by using different MMC materials such as aluminium graphite, copper graphite, titanium silicon carbide, cobalt silicon carbide, supper alloy tungsten, titanium boron carbide, steel boron nitride etc. metal matrix composite.

VII. CONCLUSIONS

In this article, the review of EDM method for different metal matrix composite materials has been presented. Researchers have been investigated different methodology to determine the effect of process parameters on machining performance and also find out the optimal process parameter for getting optimal machining performance during electric discharge machining of different MMC.

Genetic algorithm find out the optimum machining parameters like that peak current, polarity, T-ON , gap voltage, T-OFF, speed of electrode rotation for optimum machining performance such as MRR, TWR, SR, taper, radial overcut.

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