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Electrical Discharge Machining of Cu-Al_2o_3 Metal Matrix Composites

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ABSTRACT

In today's scenario, MMCs are widely used in the manufacturing industries mainly in aerospace, automotive and electronics engineering due to its excellent mechanical and thermal properties as compared to conventional materials. But conventional machining process have been found difficulties in machining of these composites due to the due high tool wear, poor surface roughness, high machining cost etc. Hence, various researchers highlights the different advanced machining process such as electro discharge machining process, electro chemical machining process and electro or laser beam machining process in order to get effective machining for these composites. In this dissertation, EDM has been applied in order to machine Cu-Al_2O_3 metal matrix composite to obtain the high product quality with improved yield performance. Taguchi has been implemented to framework the layout of the experiment. The machining parameters such as current, voltage and pulse on time are taken whereas machining evaluation characteristics have been taken as material removal rate, tool wear rate and surface roughness. The work also adopted grey relation analysis to convert the aforesaid evaluation characteristics into a single response i.e. overall grey relation grade. Finally, Taguchi has been used to evaluate the optimal parametric combination.

INTRODUCTION

Composite material is a material composed of two or more physically and/or chemically distinct phases (matrix phase and reinforcing phase) and possessing bulk properties significantly different from those of any of the constituents. The composite normally has superior characteristics than those of each of the individual constituents. Most of the common materials (metals, alloys, doped ceramics and polymers mixed with additives) also have a small amount of scattered phases in their structures, however they are not considered as composite materials since their properties are similar to those of their base constituents (physical property of steel are similar to those of pure iron).Essential properties of composites materials include high stiffness and high strength ,low density , high temperature stability, high electrical and thermal conductivity, adjustable coefficient of thermal expansion, corrosion resistance, improved wear resistance etc.

Matrix Phase
The primary phase, having a continuous character,
Usually more ductile and less hard phase,
Holds the reinforcing phase and shares a load with it.

Reinforcing Phase
Second phase(or phases) is imbedded in the matrix in a discontinuous form,
Usually stronger than the matrix, therefore it is sometimes called reinforcing phase.

Types of metal matrix composites
Metal matrix composites are generally distinguished by characteristics of the reinforcement:
Particle reinforced MMCs,
Short fiber or whisker reinforced MMCs, and
Continuous fiber or layered MMCs.

The aspect ratio of the reinforcement is an important quantity, because the degree of load transfer from matrix to the reinforcement is directly proportional to the reinforcement aspect ratio. Thus, continuous fibers typically provide the highest degree of load transfer, because of very high aspect ratio, which results in a significant amount of strengthening along the fiber direction. Particle or short fiber reinforced metals have a much lower aspect ratio, so they exhibit lower strengths than their continuous fiber counterparts, although the properties of these composites are much more isotropic.

APPLICATIONS OF METAL MATRIX COMPOSITES

Space: The space shuttle uses boron/aluminum tubes to support its fuselage frame. In addition to decreasing the mass of the space shuttle by more than 145 kg, boron/aluminum also reduced the thermal insulation requirements because of its low thermal conductivity. The mast of the Hubble Telescope uses carbon-reinforced aluminum**.**

Military: Precision components of missile guidance systems demand dimensional stability- that is; the geometries of the components cannot change during use. Metal matrix composites such as SiC/aluminum composites satisfy this requirement because they have high micro yield strength. In addition, the volume fraction of SiC can be varied to have a coefficient of thermal expansion compatible with other parts of the system assembly.

Transportation: Metal matrix composites are finding use now in automotive engines that are lighter than their metal counter parts. Also, because of their high strength and low weight, metal matrix composites are the material of choice for gas turbine engines. MMCs are nowadays finding their use in automotive disc brakes. Early Lotus Elise models used aluminum MMC rotors, but they don’t possess better heat properties and Lotus has since switched back to cast-iron. Modern high-performance sport cars, such as those built by Porsche, use rotors made of carbon fiber within a silicon carbide matrix because of its high specific heat and thermal conductivity.

Processing of Metal Matrix Composites
Metal matrix composites can be processed using several methods .Few of them are described below:
Liquid state processes

Casting or liquid infiltration involves infiltration of a fibrous or particulate reinforcement preform by a liquid metal. Liquid phase infiltration of MMCs is not straightforward, mainly because of difficulties with wetting the ceramic reinforcement by the molten metal. When the infiltration of a liquid preform occurs readily, the reactions between the fibre and the molten metal may take place which significantly degrade the properties of the fibre. Fibre coatings applied prior to infiltration, which improve wetting and allow control of interfacial reactions, have been developed and are producing encouraging results. In this case the disadvantage is that the fibre coatings must not be exposed to air prior to infiltration because surface oxidation of the coating takes place.

Squeeze casting or pressure infiltration involves forcing a liquid metal into a fibrous or particulate perform. Pressure is applied until solidification is complete. By forcing the molten metal through small pores of the fibrous perform, this method obviates the requirement of good wet ability of the reinforcement by the molten metal. Composites fabricated by this method have the advantage of minimal reaction between the reinforcement and the molten metal because of the short processing time involved. Such composites are typically free from casting defects such as porosity or shrinkage cavities.

Electrical Discharge Machining

Electrical discharge machining (EDM) is a non-traditional concept of machining which has been widely used to produce dies and moulds. It is also used for finishing parts for aerospace and automotive industry and surgical components [1]. This technique has been developed in the late 1940s [2] where the process is based on removing material from a part by means of a series of repeated electrical discharges between tool called the electrode and the work piece in the presence of a dielectric fluid [3].

The electrode is moved toward the work piece until the gap is small enough so that the impressed voltage is great enough to ionize the dielectric [4]. Short duration discharges are generated in a liquid dielectric gap, which separates tool and work piece. The material is removed with the erosive effect of the electrical discharges from tool and work piece [5]. Materials of any hardness can be cut as long as the material can conduct electricity [6].

EDM techniques have developed in many areas. Trends on activities carried out by researchers depend on the interest of the researchers and the availability of the technology. In a book published in 1994, Rajurkar [7] has indicated some future trends activities in EDM: machining advanced materials, mirror surface finish using powder additives, ultrasonic-assisted EDM and control and automation.

IMPORTANT PARAMETERS OF EDM

Open-circuit Voltage: Open-circuit voltage specifies the voltage of applied pulses. It is not the voltage across the gap during electrical discharges.

Discharge Current: Current is measured in ampere per cycle. Discharge current is directly proportional to the Material removal rate.

Duty Factor: It is a percentage of the on-time relative to the total cycle time. This parameter is calculated by dividing the on-time by the total cycle time (on-time pulse off time).

On-time (pulse time ort_i): It is the duration of time for which the current is allowed to flow per cycle. Material removal is directly proportional to the amount of energy applied during this on-time. This energy is controlled by the peak current and the length of the on-time.

Off-time (pause time or t_0): It is the duration of time between the sparks (Ton). This time allows the molten material to solidify and to be washout of the arc gap. This parameter affects the speed and the stability of the cut. Thus, if the off-time is too short, it will cause unstable sparks.

Arcgap (orgap):It is the distance between the electrode and the part during the process of EDM. It may be called as spark gap.

Diameter of electrode (D): It is the electrode of Cu-tube there are two different sizes of diameter 4mm and 6mm in this experiment. This tool is used not only as an electrode but also for internal flushing.

Advantages of Electric Discharge Machining (EDM)
There are a lot of benefits when using electrical discharge machine (EDM) when machining. This is due to its capabilities and advantage. To summarize, these are the electric discharge machine (EDM) capabilities compare to other method:

Material of any hardness can be cut
High accuracy and good surface finish are possible
No cutting forces involved
Intricate-shaped cavities can be cut with modest tooling costs
Holes completed in one" pass"

Limitations of Electric Discharge Machining (EDM)
Few limitations of electrical discharge machining (EDM) are:
Limited to electrically conductive materials
Slow process, particularly if good surface finish and high accuracy are required
Dielectric vapour can be dangerous
Heat Affected Zone(HAZ)near cutting edges
Diesinking tool life is limited.

LITERATURE REVIEW

Rosso [8] discussed that metal matrix composites have a number of advantageous properties as compared to monolithic metals including higher specific strength, higher specific modulus, and resistance to elevated temperatures, better wear resistance and lower coefficients of thermal expansion. **Lindroos and Talvitie [9]**showed that in past two decades, metal matrix composites have been generating broad range of research fraternity in material science. Major of the applications and works have been demanding aluminum and other light matrices for purposes desiring high strength and accuracy along with light weight. **Clyne [10]** proposed that advantages in some attributes of MMCs such as no significant moisture absorption properties, non-inflammability, low electrical and thermal conductivities and resistance to most radiations.

Jianhua et al. [11] proposed that the increase in reinforcement content in the matrix increases the wear resistance of the composite material. **Eckert et al. [12]** gave the view that the main advantage of P/M over other methods, such as liquid and vapour state processing, is the relatively low processing temperature, which may avoid undesired interfacial reactions between matrix and reinforcement.

Procio et al. [13] found that the conventional powder metallurgy route for fabrication of involves proper blending or mixing of appropriate weight percentage of powders to obtain a homogenous mixture, cold uniaxial compaction for obtaining green sample, sintering at appropriate sintering temperature and finally heat treatment like ice quenching and ageing for enhancing various mechanical properties.

Berghezan [14] found that the composites are compound materials which differ from alloys by thefact that the individual components retain their characteristics but are so incorporated into the composite as to take advantage only of their attributes and not of their short comings. **Dasgupta [15]** found that aluminum alloy-based metal matrix composites (AMMCs) have been now proved themselves as a most acceptable wear resistant material especiall**y** for sliding wear applications.

Efeetal.**[16]**proposed that copper is an excellent material for electrical applications whose efficiency can be enhanced by improving its mechanical properties**. Mottoetal.[17]**

found that when alumina particles are dispersed in copper matrix, they exhibit unique characteristics, such as high thermal and electrical conductivity, as well as high strength and excellent resistance to annealing.

Gangadhar et al. [18] investigated the performance of Cr/Cu-based composite electrodes. The results showed that using such electrodes facilitated the formation of a modified surface layer on the work piece after EDM, with remarkable corrosion resistant properties. The optimal mixing ratio, appropriate pressure, and proper machining parameters (such as polarity, peak current, and pulse duration) were used to investigate the effect of the material removal rate (MRR), electrode wear rate (EWR), surface roughness, and thickness of the recast layer on the usability of these electrodes. According to the experimental results, a mixing ratio of Cu–0wt%Cr and a sinter pressure of 20 MPa obtained an excellent MRR.

Hassann et al. [19] found that owing to their lower density and better mechanical properties, nowadays, magnesium-based composites are becoming potential candidate materials for automotive and aerospace applications. Technology of magnesium-based composites is in the developing stage. Although magnesium is a relatively softer material, magnesium-based metal matrix composites are difficult to be machined.

Biing et al. [22] identified Open gap voltage and pulse-on time as significant influencing parameters on material removal rate in wire-cut EDM of aluminum composites. Increase in the Volume fraction of alumina reinforcement poses problems during machining. The interruption to machining is caused by the embedded alumina particles.

Mohan et al. [23] said that MRR, EWR, and surface roughness (SR) are considered for evaluating mach inability of aluminum silicon carbide composites. Pulse duration has an inverse effect on all response variables such as MRR, EWR, and SR.

Mahdavinejad [24] aimed to optimize electro discharge machining parameter for WC-Co work piece material and copper electrode using the neural model predictive control method. The testing results from ED machining of WC-Co confirms the capability of the system of predictive controller model based on neural network with 32.8% efficiency increasing in stock removal rate.

Saha and Choudhury [26] studied the process of dry EDM with tubular copper tool electrode and mild steel work piece. Experiments have been conducted using air and study the effect of gap Voltage, discharge current, pulse-on time, duty factor, air pressure and spindle speed on MRR, surface roughness (Ra) and TWR. Empirical models for MRR, Ra and TWR have then been developed by performing a designed experiment based on the central composite design of experiments.

Rebelo et al. [27] presented an experimental study on the effect of EDM parameters on material removal rate (MRR) and surface quality, when machining high strength copper-beryllium alloys. Processing parameters for rough, finishing and micro-finishing or polishing regimes were analyzed.

Patel et al. [28] presented an erosion model for anode material. The model accepts power rather than temperature as boundary condition at plasma/anode interface. A constant fraction of the total power supplied to the gap is transferred to the anode. The power supplied is assumed to produce a Gaussian-distributed heat flux on the area of anode which grows with time. Rapid melting of anodic material and subsequent resolidification of the material for longer durations of time is presented.

Yadav et al. [29]proposed that the high temperature gradients generated at the gap during EDM result in large localized thermal stresses in a small heat-affected zone leading to micro-cracks, decrease in strength and fatigue life and possibly catastrophic failure. A finite element model has been developed to estimate the temperature field and thermal stresses.

Allen et al. [30] presented the process simulation and residual stress analysis for the micro-EDM machining on molybdenum. Material removal is analyzed using a thermo-numerical model, which simulates a single spark discharge process. Using the numerical model, the effects of important EDM parameters such as the pulse duration on the crater dimension and the tool wear percentage are studied.

Lauwers et al. [31] presents a detailed investigation of the material removal mechanisms of some commercially available electrical conductive ceramic materials through analysis of the debris and the surface/sub-surface quality. ZrO2-based, Si3N4-based and Al2O3-based ceramic materials, with additions of electrical conductive phases like TiN and TiCN, have been studied. They pointed out that besides the typical EDM material removal mechanisms, such as melting/evaporation and spalling, other mechanisms can occur such as oxidation and dissolution of the base material.

Madhu et al. **[32]** proposed a model for predicting the material removal rate and depth of damaged layer during EDM. The transient heat conduction equation for the work piece which accounts for the heat absorption due to melting has been solved by Finite Element Method.

Simulations have been performed for a single spark in the form of pulses. The width of crater and the depth of penetration depend on spark-radius and the power intensity. It was found that MRR increases with power per spark and decreases with an increase in computational machining cycle time. It increases immediately after machining starts but soon reaches a steady state value.

Lin et al. [34] has reported that Electrical Discharge Energy on Machining of Cemented Tungsten Carbide using an electrolytic copper electrode. The machining parameters of EDM were varied to explore the effects of electrical discharge energy on the machining characteristics, such as MRR, EWR, and surface roughness. Moreover, the effects of the electrical discharge energy on heat-affected layers, surface cracks and machining debris were also determined. The experimental results show that the MRR increased with the density of the electrical discharge energy.

Kumaretal.[36]used Taguchi'sL27orthogonal array and conducted experiments to study the effect of various parameters like applied voltage, electrolyte concentration, feed rate and percentage reinforcement on maximizing the material removal rate and developed a mathematical model using the regression method.

Goswami [37] studied the effect of electrolyte concentration, supply voltage, depth of cut, and electrolyte flow rate on the evaluation of material removal rate (MRR), surface finish, and cutting forces during electrochemical grinding of Al2O3/Al inter penetrating phase composite using Taguchi based design.

Rao and Padmanabhan [38] employed Taguchi Methods, the Analysis of Variance (ANOVA),and regression analyses to find the optimal process parameter levels and to analyze the effect of these parameters on metal removal rate values in electro chemical machining of LM6 Al/5%SiC composites.

Objective of the Present Work

It has been revealed from the literature that less work has been carried out in machining of Cu- Al_2O_3 composite. Hence, this present dissertation comprises of two parts: First parts highlights the fabrication of Cu-Al_2O_3 by powder metallurgy technique and later part describes the machining of these composites in EDM. The study also used the grey relation analysis integrated with Taguchi technique in order to assess the favorable machining condition.

EXPERIMENTATION

Fabrication of composites:

Cu-Al_2O_3 has been fabricated by using powder metallurgy process. Following are the steps involved in powder metallurgy.

Mixing of Powders

Copper powders were mixed with alumina particles to form a mechanical mixture of Cu-alumina powder comprising 90% of Cu powder and 10% of Al_2O_3powder by weight to form a composite of 15 gram each. Blending of powders was accomplished in ball planetary mill (Model- PULVERISETTE-5, Make-FRITSCH, Germany) shown in Fig 3.1. It consisted of three cylindrical containers made up of chrome steel within which10 balls made up of chrome steel of sizes 10mm.To achieve a homogenous distribution of the reinforcement in the mixture the blending machine was set up for 2 Lakh revolutions

Weighing of samples
Mixing was followed by weighing the samples in an electronic weighing machine. Batch of nine samples were prepared keeping the weight of each of them as 10 grams.

Compaction of Powder
After carrying out the blending operation, pressing operation was performed at room temperature in a die punch arrangement made up of stainless steel at pressures which make the powders stick to each other. This process is called cold compaction. Cold iso static pressing was used for compacting the blended powders into a 'green compact form', with appropriate density. About 10 gm of the powder mixture was taken adopting a method of coning and quartering for compaction.

Cold uniaxial press
For each component, approximately 10 gm of powder was measured out and poured into the die cavity. The equipment used for this machine is cold uniaxial pressing machine (Make - SOILLAB, Type-Hydraulic, Maximum load: 20 tonne)as shown in Fig. 3.3.To fabricate the green circular test samples of 25 mm outer diameter a load of 5 ton was applied, which yielded 1018barpressure. For this purpose, a stainless steel die of 25mm internal diameter was used. To prevent the specimen from sticking on to the walls and to allow the powder to flow freely, acetone was applied to the walls of the die and punch as lubricant. The die body was split, with slight pressure applied to the green component and both sides of the die were pulled from the Component. The pressure on the component was then released completely, the top punch was removed and the component was ejected by downward movement of the floating die body.

Sintering
Sintering operation was carried out in a horizontal tubular furnace (Make-Naskar and Co., Type- Vacuum and Control Atmosphere, Maximum temperature: 1600ºC, Cooling rate: 5ºC/min.) The samples were baked in a controlled atmosphere of argon at a pressure of 1 bar, temperature of 620^0C and a holding time of one hour. The aluminum particle was always surrounded by an oxide layer. The oxide layer fragmented into small shell pieces disrupted in the copper matrix restrains the increment in strength and the movement of dislocation. Then furnace was left to cool to room temperature for a time period of24 hours. Then, the pallets were taken out of the furnace and kept in desiccators which contained concentrated H_2SO_4. The average thickness and diameter of pallets are 5 mm and 25 mm respectively.

Quenching
After sintering the samples were then solution heat treated in a heat treatment furnace(local made) as shown inFig.3.6. Quenching was carried out at a temperature of 500 ^{0}C for a span of one hour and then quenched in iced water.

Ageing
After quenching operation, there is initiation of natural ageing in the composites. In order to prevent it, all the quenched samples were artificially aged immediately after solution heat treatment. The ageing operation was carried out in a closed muffle furnace as showninFig.3.7.All samples were aged at temperature of 200^0C for span of eighth our and allowed to cool in it to room temperature.

SEM Analysis
The microstructures of samples are studied using a Scanning Electron Microscope (SEM) (JEOL JSM 6480 LV) shown in Figure 3.8:-

EDS Analysis
Energy dispersive X-ray spectroscopy analysis can be defined as a technique used for the chemical characterization of a sample. It depends on some source of X-ray excitation and a specimen. To encourage the emission of X-rays from a sample a very high energy beam of charged particles (such as electrons and protons) are directed on the sample. While at rest atoms present inside the sample contain electrons at the ground level. The incident beam may excite an electron present in an inner shell, ejecting it from the shell while creating a hole due to electron vacancy. An electron from an outer, higher-energy shell then fills this hole, and the difference in energy between the higher-energy shell and the lower energy shell may be released in the form of an X-ray.

In this analysis we take a small portion over individual particles (for e.g. alumina) and then determine the individual percentage of the different constituents present in the particles. For eg: Al-44%, O-56% or Cu-99%, Fe-1%. In the first instance we have projected X-rays onto the area shown by spectrum 2 it is basically black portion which consists mainly of copper and small traces of iron, aluminium and the analysis performed confirms the fact that the area consists of copper as the major element. Similarly we performed this analysis on the area depicted by grey colour. In this way we were able to predict the amount and composition of the various elements present in the given sample and the results were in conformity with the actual results.

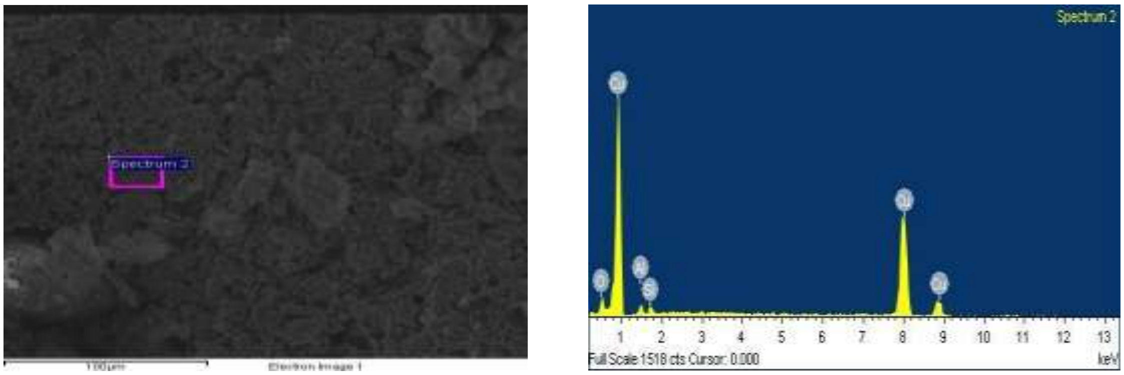

Fig 3.11: EDS Analysis performed by taking a point on the grey portion showing electron energy level against number of counts

Electro Discharge Machining

This thesis is aimed to evaluate the optimal machining condition in EDM of Cu-Al_2O_3 composites. Experimentation has been carried out on EDM machine (PS50 ZNC) installed at

Design of Experiment (DOE)

Design of Experiment consists of systematically layout for the each experimental run. Taguchi's orthogonal array design of experiment has been selected for the framework of DOE as it minimizes the experimental run which saves times and cost of the experimentation.

In this present study, three machining parameter have been varied into three different levels.

Integration of S/N ratio and Grey relational analysis

The terms Signal and Noise, are applied to the natural variation of the end product of the process with the Signal being represented by the process average and the Noise being represented by the standard deviation of that output.

These ratios are commonly used within the context of design of experiments in industry to find the best parameter setting for the process input variables; i.e., the level(s) which will optimize the process output variable.

The S/N ratio is a measure of the magnitude of a data set relative to the standard deviation. If the S/N is large, the magnitude of the signal is large relative to the "noise" as measured with the standard deviation. If S/N is large, then the signal is deemed to be significant – not just random variation.

From the results of S/N ratio analysis, it is found that voltage (V) at level 2, current and pulse on time at level 1 are the optimal operating conditions to perform EDM of the composite material.

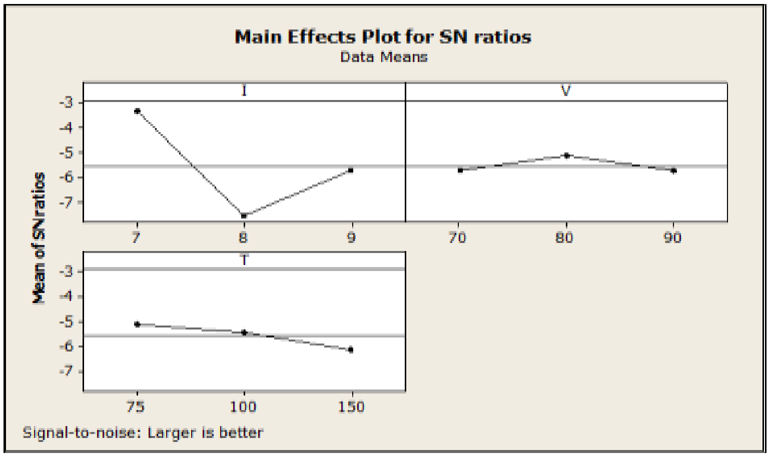

Fig 4.1: S/N Ratio Graph For Each Parameter At Different Levels

Confirmatory Results

The confirmation test for the optimal parameters with its levels was conducted to evaluate quality characteristics for EDM of copper composite material. Highest grey relational grade, indicating the initial process parameter set of A1B2C1 for the best multiple performance characteristics among the nine experiments. Comparison of the experimental results for the optimal conditions (A1B2C1) with predicted results for optimal (A1B2C1) EDM parameters. Here A-Current, B-Voltage, C-Pulse-on time

The predicted values were obtained by

Predicted Response = Average of A1 + Average of B2 + Average of C1 – 2 x Mean of response (Yij)

CONCLUSIONS

The larger the grey relational grade, the better is the multiple performance characteristics. After finding the grey relational grade for each experimental run S/N Ratio analysis was conducted to predict the most optimal setting. The optimal parameter combination was determined as A2 (voltage, 80 V),B1(pulse current, 7 A) and C1 (pulse on time, 75 µs).

Taguchi's Signal – to – Noise ratio and Grey Relational Analysis were applied in this work to improve the multi-response characteristics such as MRR (Material Removal Rate), TWR (Tool Wear Rate) and Surface Roughness of Cu-Al_2O_3 metal matrix composite during Electric discharge machining process. The conclusions of this work are summarized as follows:

The optimal parameters combination was determined as A2B1C1 i.e. pulse voltage at 80 V, pulse current at 7A, pulse ON time at 75µs.

The predicted results were checked with experimental results and a good agreement was found.

This work demonstrates the method of using Taguchi methods for optimizing the EDM parameters for multiple response characteristics.

FUTURE SCOPE

Above mentioned work can be extended in further directions:

For experimental analysis different material properties such as % Al_2O_3 and mesh size of powders can also be considered. Apart from EDM, ECM may be carried out in order to investigate the mach inability of these composites.

Mathematical model may be derived in terms of process parameters to optimize the process parameters in EDM of MMCs.

REFERENCES

[1]. Jameson E.C. (2001), Electrical Discharge Machining, first ed., Society of Manufacturing Engineers, Michigan.

[2]. Ho K.H., Newman S.T. (2003), State of the art electrical discharge machining (EDM), International Journal of Machine Tools and Manufacture, 43(5): 1287–1300.

[3]. Abbas N.M.,Solomon D.G.,Bahari M.Fuad(2007),A review on current research trends in electrical discharge machining, International Journal of Machine Tools and Manufacture, 47(3): 1214–1228.

[4]. Kumar S., Singh R, Singh T.P., Sethi B.L. (2009),Surface modification by electrical discharge machining: a review, Journal of Materials Processing Technology, 209(6): 3675–3687.

[5]. Jahan M.P., Wong Y.S., Rahman M.(2009),A study on the fine-finish die-sinking micro EDM of tungsten carbide sing different electrode materials, Journal of Materials Processing Technology, 209(7-8): 3956–3967.

[6]. Han F., Chen L., Yu D., Zhou X.(2007), Basic study on pulse generator for micro EDM, International Journal of Advanced Manufacturing Technology, 33(): 474–479.

[7]. YanM.T., Liu Y.T.(2009), Design analysis and experimental study of a high frequency power supply for finish cut of wire EDM, International Journal of Machine Tools and Manufacture, 49(7): 793–796.

[8]. Rosso M. (2006), Ceramic and metal matrix composites: Routes and properties. Journal of Materials Processing Technology, 175(6): 364-375.

[9]. Lindoors V.K. and Talvitie M.J.(1995),Recent advances in metal matrix composites. Journal of Materials Processing Technology, 53(6): 273-284.

[10]. Clyne T.W. (2003), Metal Matrix Composites: Matrices and Processing, Encyclopedia of Materials: Science and Technology, 58(4): 294-297.

[11]. Jianhua Zhu, Liu Lei, Shen Bin, Hu Wenbin (2007) the processing of metal matrix composites –an overview. Journal of Materials Processing Technology, 63(5): 339-353.

[12]. Slipenyuk A. Kuprin V.Milman Yu. Goncharuk V.Eckert J. (2006), Properties of P/M processed particle reinforced metal matrix composites specified by reinforcement concentration and matrix-to-reinforcement particle size ratio, Acta Materialia.

[13]. Rashed A. A., Holecek S., Prazak M. and Procio M. (1993), Powder metallurgy route in production of aluminium alloy matrix particulate composites. Journal de Physique, 73(5):435- 438.

[14]. BerghezanA.(1966),Non-ferrous Materials, Nucleus journal.

[15]. Dasgupta R. (2012), Aluminium alloy-based metal matrix composite: A potential material for wear resistant application. International Scholarly Research Network, 201(4): 335-337.

[16]. Celebi Efe G., Yener T., Altinsoy I., Ipek M., Zyetin S., Bindal C. (2011), J. Alloys Compd., 148(6): 6036–6042.

[17]. Motta M.S., Jena P.K., Brocchi E.A., Solorzano I.G. (2001), Material Science Engineering, 15(6): 175–177.