International Journal of Technical Research and Applications e-ISSN: 2320-8163,
www.ijtra.com Volume 10, Issue 5 (SEPTEMBER-OCTOBER 2022), PP. 01-06

ELECTRICAL DISCHARGE MACHINING OF $Cu-Al_2O_3$ METAL MATRIX COMPOSITES

Chittaranjan Kumar[1], Adarsh Kumar[2],
[1]M.Tech.(Mechanical Engineering) Scholar, Mechanical Engineering department, Bansal Institute of Engineering & Technology Lucknow, Uttar Pradesh, India
[2]Assistant Professor, Mechanical Engineering department, Bansal Institute of Engineering & Technology Lucknow, Uttar Pradesh, India

***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-Al2O3 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.**

***Index Terms*—$Cu-Al_2O_3$, EDM, Taguchi analysis, grey relational analysis.**

I. 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.

II. 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 aluminium 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. proposed that the increase in reinforcement content in the matrix increases the wear resistance of the composite material. Eckert et al. 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. 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 found that the composites are compound materials which differ from alloys by the fact 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 shortcomings. Dasgupta found that aluminium alloy-based metal matrix composites (AMMCs) have been now proved themselves as a most acceptable wear resistant material especially for sliding wear applications.

Efe et al. proposed that copper is an excellent material for electrical applications whose efficiency can be enhanced by improving its mechanical properties. Motto et al. 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.

III. Experimental Work

A. Fabrication of composites:

Cu-Al2O3 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 Al2O3 powder 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 which 10 balls made up of chrome steel of sizes 10 mm. To achieve a homogenous distribution of the reinforcement in the mixture the blending machine was set up for 2 Lakh revolutions.

Fig 3.1: Ball Planetary Mill

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.

Fig 3.2: Electronic weighing machine

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 isostatic 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 1018 bar pressure. For this purpose, a stainless steel die of 25 mm 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.

Fig 3.3: Cold Uniaxial Pressing Machine

Sintering

Sintering operation was carried out in a horizontal tubular furnace (Make-Naskar and Co., Type- Vacuum and Control Atmosphere, Maximum temperature: 1600^{o}C, Cooling rate: 5^{o}C/min.) The samples were baked in a controlled atmosphere of argon at a pressure of 1 bar, temperature of 6200 C and a holding time of one hour. The aluminium 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 of 24 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.

Fig. 3.4: Horizontal Tubular Furnace Fig. 3.5: Samples after sintering

Quenching

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

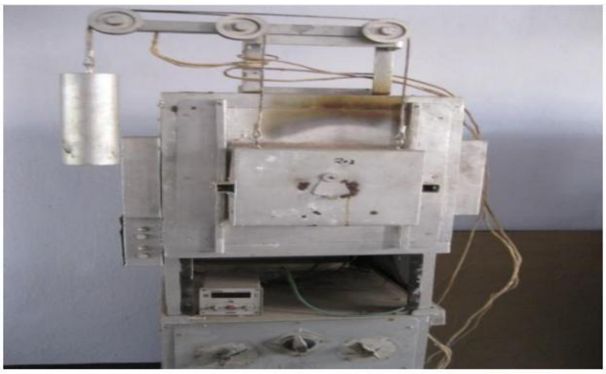

Fig. 3.6: Heat Treatment Furnace

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 shown in Fig.

All samples were aged at temperature of 2000C for span of eight hourand allowed to cool in it to room temperature.

Fig. 3.7: Closed Muffle Furnace

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 Production laboratory of Mechanical Engineering Department, NIT Rourkela, India which is shown in Fig. 3.8.

Fig 3.8: Electro discharge machine

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 which are shown in Table 3.1. Here, L9 orthogonal array has been chosen for experimentation which are presented in Table 3.2.

Table 3.1: Input factors and their levels

Factors	Units	Level 1	Level 2	Level 3
Current (Ip)	Amp	7	8	9
Voltage (V)	Volt	70	80	90
Pulse on time	Us	75	100	150

Table 3.2: Design of experiment

Sl. No.	Current (A)	Voltage	Pulse on time
1.	7	70	75
2.	7	80	100
3.	7	90	150
4.	8	70	100
5.	8	80	150
6.	8	90	75
7.	9	70	150
8.	9	80	75
9.	9	90	100

Taguchi Analysis:

Taguchi method is a statistical method developed by Dr. Genichi Taguchi to improve the quality of manufactured goods. Professional statisticians have welcomed the goals and improvements brought about by Taguchi methods, particularly by Taguchi's development of designs for studying variation in the output from targeted value. However, the method is criticized due to inability to solve multi-objective optimization proposals. In order to overcome this, utility theory, grey relation theory desirability function approaches have been reported and well documented in literature. These are widely being applied in combination with Taguchi method.

Hussain et al. suggested that productivity and quality are the two important aspects of machining process. Surface roughness and material removal rate greatly influence the performance of mechanical parts and the production cost. So, quality and productivity is to be monitored simultaneously at every stage and actions are to be taken in case of deviation from the target.

IV. Grey Relational analysis

The grey system theory was initiated by Deng in 1982. This method has been convinced as an advantageous methodology for approaching with incomplete, poor and uncertain information. To resolve the complex interrelationships among the multiple performance characteristics efficiently, the grey relational analysis can be implemented which is based on grey system theory. It also gives an effective solution to discrete data problem. With the employment of grey relational analysis, the relation between machining parameters and performance parameters can be procured.

The Experiments were conducted as per L9 orthogonal array, assigning various values of the levels to the process parameters. After conducting the experiment various output parameters such as material removal rate (MRR), tool wear rate (TWR) and Surface roughness have been calculated and the results are presented in the table given below.

Table 4.1 Experimental Results

Exp. No.	Current (A)	Voltage(V)	Pulse on time(us)	MRR(mm^3/min)	TWR(mm^3/min)	Surface Roughness(µm)
1	7	70	75	6.69	0.05	8.876
2	7	80	100	8.16	0.0678	7.027
3	7	90	150	11.27	0.0705	6.56
4	8	70	100	12.82	0.0369	6.89
5	8	80	150	15.27	0.0406	6.648
6	8	90	75	17.37	0.0256	8.534
7	9	70	150	16.89	0.0511	7.643
8	9	80	75	17.63	0.0364	10.376
9	9	90	100	21.23	0.0392	9.816

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.

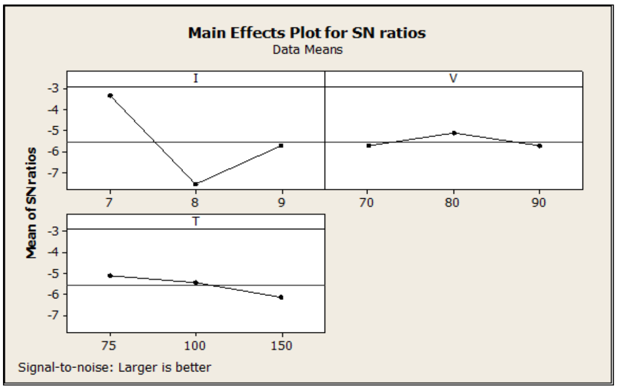

Fig 4.1: S/N Ratio graph for each parameter at different levels

Table 4.2: Response table for S/N Ratio

Level	I	V	T
1	-3.35888	-5.76783	-5.08325
2	-7.56041	-5.12591	-5.34325
3	-5.72846	-5.75402	-6.12536
Delta=max-min	4.20153	0.64192	1.04211
Rank	1	3	2

Table 4.2 shows response table for signal to noise ratio. This response table represents the effects of various input factors on Grey Relational Grade. The rank represents directly the level of effect of input based on the values of delta. Delta here represents the difference of maximum and minimum values and we calculated the value of delta for each input parameter. Here according to ranks, the effects of various input factors on Grey Relational Grade in sequence of its effect are current (I), followed by pulse on time (TON) and Voltage (V). From this analysis it can be concluded that the most influencial parameter is current (I), followed by pulse on time (TON) and Voltage (V).

The confirmation test for the optimal parameters with its levels was conducted to evaluate quality characteristics for EDM of copper composite material. Table 4.2. shows highest grey relational grade, indicating the initial process parameter set of A1B2C1 for the best multiple performance characteristics among the nine experiments. Table 4.3.shows the 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)

The response values obtained from the experiments are MRR = 8.16 mm³/min, TWR = 0.0678 mm³/min and the surface roughness is 7.027 µm. The comparison again shows the good agreement between the predicted and the experimental values.

Table 4.3: Comparison of actual and predicted values

	Optimal Process parameters	
	Predicted	Experiment
Level	A2B1C1	A2B1C1
MRR (mm^3/min)	8.172	8.16
TWR(mm^3/min)	0.06608	0.0678
Ra(µm)	7.052	7.027

V. 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-Al2O3 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.

VI. FUTURE SCOPE:

- Above mentioned work can be extended in further directions:
- For experimental analysis different material properties such as % Al2O3 and mesh size of powders can also be considered.
- Apart from EDM, ECM may be carried out in order to investigate the machinability 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 using 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] Yan M.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.