Analysis & Optimization of Machining Parameters in ECM of Al/B4C Composites

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Abstract— In this thesis our work deals with the application of Taguchi method and Genetic algorithm in MATLAB 7.9.0 to compare which process parameters like machining voltage, electrolyte concentration, frequency will produce much impact on the response parameter like Surface Roughness, over cut and Material Removal Rate (MRR). This work discusses a methodology for the optimization of the machining parameters on drilling of LM6 Al/B4C composites using Electrochemical Micro Machining. In MINITAB 17 software Taguchi L27 orthogonal array was chosen for the experiment and also compare with optimized result which will we obtain from Genetic algorithm in MATLAB 7.9.0.

Key words: Optimization, ECM, Taguchi Method, Surface Roughness, Genetic Algorithm

I. Introduction

The process of metal removal by electro chemical dissolution was known as long back as 1780 AD but it is only over the last couple of decades that this method has been used to advantage. It is also known as contactless electrochemical forming process. The noteworthy feature of electrolysis is that electrical energy is used to produce a chemical reaction, therefore, the machining process based on this principle is known as Electrochemical machining (ECM). This process works on the principle of of Faraday's laws of electrolysis. Michael Faraday discovered that if the two electrodes are placed in a bath containing a conductive liquid and DC potential (5-25V) is applied across them, metal can be depleted from the anode and plated on the cathode. This principle was in use for long time. ECM is the reverse of the electroplating.

Since metallic materials can be processed regardless of their hardness, Electrochemical machining (ECM) is widely used for the machining of metal parts with complex shapes and made of difficult-to-cut metallic materials. Recently, many reports have been published on ECM applications in micro machining, which uses pulse power supply, electrolyte with lower concentration etc.

ECM can be thought of a controlled anodic dissolution at atomic level of the work piece that is electrically conductive by a shaped tool due to flow of high current at relatively low potential difference through an electrolyte which is quite often water based neutral salt solution. In ECM, Electrolyte is so chosen that there is no plating on tool and shape of tool remains unchanged. If the close gap (0.1 to 0.2mm) is maintained between tool and work, the machined surface takes the replica of tool shape.

Work piece and work holding system: Only electrically conductive material can be machined by this process, the chemical properties of anode (work) material largely govern the material removal rate (MRR). Work holding devices are made of electrically nonconductive materials having good thermal stability, and low moisture absorption properties, For Example, graphite fibres reinforced plastics, plastics, Perspex, etc., are the materials used for fabricating the work holding device.

A. Applications

1) ECM can be used to make disc for turbine rotor blades made up of HSTR alloys
2) ECM can be used for slotting very thin walled collets
3) ECM can be used for copying of internal and external surfaces, cutting of curvilinear slots, machining of intricate patterns, production of long curved profiles, machining of gears and chain sprockets, production of integrally bladed nozzle for use in diesel locomotives, production of satellite rings and connecting rods, machining of thin large diameter diaphragms.
4) ECM principle has be employed for performing a number of machining operations namely, turning, treplaning, broaching, grinding, fine hole drilling, die sinking, piercing, deburring, plunge cutting etc.
5) ECM can also be used to generate internal profile of internal cams.

B. Advantages

ECM offers impressive and long lasting advantages.

1) ECM can machine highly complicated and curved surfaces in a single pass.
2) A single tool can be used to machine a large number of pieces without any loss in its shape and size. Theoretically tool life is high
3) Machinability of the work material is independent of its physical and mechanical properties. The process is capable of machining metals and alloys irrespective of their strength and hardness
4) Machined surfaces are stress and burr free having good surface finish
5) It yields low scrap, almost automatic operation, low overall machining time, and reduced inventory expenses.
6) There is no thermal damage and burr free surface can be produced.

C. Disadvantages

1) High capital cost of equipment
2) Design and tooling system is complex
3) Hydrogen libration at the tool surface may cause hydrogen embrittlement of the surface.
4) Spark damage may become sometimes problematic
5) Fatigue properties of the machined surface may reduce as compared to conventional techniques (by 20%)
6) Nonconductive material cannot be machined.
7) Blind holes cannot be machined in solid block in one stage
8) Corrosion and rust of ECM machine can be hazard
9) Space and floor area requirement are also higher than for conventional machining methods. Some additional

problems related to machine tool requirements such as power supply, electrolyte handling and tool feed servo systems.

II. LITERATURE REVIEW

Bao Huaiqian et al. (2008) machined trilateral and square cavities and holes as well as a group of English alphabets on a stainless steel plate using pure water as an electrolyte.{1}

Neelesh K. Jain et al. Worked on optimization of different process parameters of different machining processes using genetic algorithms. Genetic algorithm is a kind of non-conventional optimization tool based on Metaheuristic search technique. To solve optimization and search problems, this technique utilizes the natural process of evolution. The three main operators in GA are reproduction, crossover and mutation. The process parameters are optimized as encoding them as genes by binary encoding. Jain et al. utilized this technique by encoding tool feed rate, electrolyte flow velocity as process parameters to binary form as genes in ECM to get geometrical accuracy and got improved geometrical accuracy.{2}

Chakradhar et al. (2011) has done the multi objective optimization of electrochemical machining of EN-31 steel by grey relational analysis. The process parameters considered are electrolyte concentration, feed rate and applied voltage and are optimized with considerations of multiple performance characteristics including material removal rate, over cut, cylindricity error and surface roughness. With the help of Analysis of variance (ANOVA) it was observed that feed rate is the significant process parameter that affects the ECM robustness.{3}

Senthil kumar et al. developed mathematical models for ECM based on response surface methodology (RSM) for Al/10%SiC composites. They have taken electrolyte flow rate, applied voltage, electrolyte concentration and tool feed rate as process parameters and material removal rate and surface roughness as responses. {4}

Kao et al. optimized the electrochemical polishing of stainless steel using grey relational analysis by taking surface roughness and passivation strength of electrolyte as responses. {5}

Munda et al. investigated the electrochemical micromachining through response surface methodology approach. They have taken MRR and ROC as two different objective measures and developed the mathematical models. {6}

Asoken et al. Developed multiple regression and Artificial Neural Network (ANN) models for optimizing the electrochemical process parameters like voltage, current, gap and feed rate.{7}

Rao et al. carried out modelling of the electrochemical machining process using fuzzy logics. Evolutionary algorithms were used for optimization of electrochemical machining process. {8}

Chakradhar et al. developed the multi-objective optimization models for electrochemical machining of EN31 steel using grey relational analysis by considering electrolyte concentration, feed rate and voltage as process parameters.{9}

Sharma et al. (2002) machined holes in Inconel super alloy that is used for turbine blades with acidified neutral salt electrolyte to minimize sludge formation in the Inter Electrode Gap (IEG). They obtained a good and uniform hole with an aspect ratio of 11.{11}

Lee et al. (2002) have applied two electrolytes, aqueous sodium nitrate and aqueous sodium chloride. The study reveals that the former electrolyte has better machinability than the latte. {12}

Mithu et al. (2011) have used less toxic and dilute electrolyte, 0.2 M HCl for micro holes fabrication. The acidic electrolyte allowed refreshing electrolyte in the machining area easily, due to the reason that acid electrolyte usually produced by-product much less than common salt electrolytes.{13}

Dhobe et al. (2011) have used sodium bromide electrolyte for machining of titanium, since simple chloride and nitrate electrolyte require higher potential difference to break down passive film. The use of sodium bromide improves the MRR and corrosion resistance. {14}

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N.K. Jain et al and V.K. Jain et al [1] have proposed the optimization of electro chemical machining process parameters using genetic algorithms. They have considered the three most important ECM process parameters namely tool feed rate, electrolyte flow velocity, and applied voltage with an objective to minimize geometrical inaccuracy subjected to temperature, choking, and passivity constraints using real-coded genetic algorithms.{19}

B.G. Acharya et al. V.K. Jain et al and J.L. Batra et al [2] have proposed a model for the multi-objective optimization of the ecm process. Their work describes the optimization of ECM process parameters by considering only one objective at a time from metal removal rate, geometrical accuracy, and total process cost. Some authors have worked on electrochemical discharge machine (ECDM) .{20}

III. TAGUCHI METHOD

Taguchi methods are statistical methods developed by Genichi Taguchi {5} to improve the quality of manufactured goods and more recently also applied to engineering, biotechnology, marketing and advertising. Professional statisticians have welcomed the goals and improvements brought about by Taguchi methods, particularly by Taguchi's development of designs for studying variation, but have criticized the inefficiency of some of Taguchi's proposals. The Taguchi method is a commonly adopted approach for optimizing design parameters. The method was originally proposed as a means of improving the quality of products through the application of statistical and engineering concepts. It is a method based on Orthogonal Array (OA) {8} experiments, which provides much-reduced variance for the experiment resulting is optimum setting of process control parameters. Orthogonal

Taguchi method is a powerful tool for the design of high quality systems. It provides simple, efficient and systematic approach to optimize designs for performance, quality and cost. Taguchi method is efficient method for designing process that operates consistently and optimally over a variety of conditions. To determine the best design it requires the use of a strategically designed experiment.Taguchi approach to design of experiments in easy to adopt and apply for users with limited knowledge of statistics, hence gained wide popularity in the engineering and scientific community. The desired cutting parameters are determined based on experience or by hand book.
Cutting parameters are reflected.
Steps of Taguchi method are as follows:

1) Identification of main function, side effects and failure mode.
2) Identification of noise factor, testing condition and quality characteristics.
3) Identification of the main function to be optimized.
4) Identification the control factor and their levels.
5) Selection of orthogonal array and matrix experiment.
6) Conducting the matrix experiment.
7) Analysing the data, prediction of the optimum level and performance.
8) Performing the verification experiment and planning the future action.

A. Orthogonal Arrays:

Taguchi has developed a system of tabulated designs (arrays) that allow for the maximum number of main effects to be estimated in an unbiased (orthogonal) manner, with a minimum number of runs in the experiment. Orthogonal arrays are used to systematically vary and test the different levels of each of the control factors. Commonly used OAs includes the L4, L9, L12, L18, and L27. The columns in the OA indicate the factor and its corresponding levels, and each row in the OA constitutes an experimental run which is performed at the given factor settings. Typically either 2 or 3 levels are chosen for each factor. Selecting the number of levels and quantities properly constitutes the bulk of the effort in planning robust design experiments. If there is an experiment having 3 factors which have three values, then total number of experiment is 27. Then results of all experiment will give 100% accurate results. In comparison to above method the Taguchi orthogonal array make list of nine experiments in a particular order which cover all factors. Those nine experiments will give 99.96% accurate result. By using this method number of experiments reduced to 9 instead of 27 with almost same accuracy.

B. Signal to Noise Ratio:

The S/N ratio developed by Dr. Taguchi is a performance measure to choose control levels that best cope with noise. The S/N ratio {7} takes both the mean and the variability into account. In its simplest form, the S/N ratio is the ratio of the mean (signal) to the standard deviation (noise). The S/N equation depends on the criterion for the quality characteristic to be optimized. There are three standard types of SN ratios depending on the desired performance response.

Smaller The Better (For Making The System Response As Small As Possible):

$$SN_S = -10 \log \left(\frac{1}{n}\sum_{i=1}^{n} Y_i^2\right)$$

Nominal The Best (For Reducing Variability Around A Target):

$$SN_T = 10 \log (Y^2/S^2)$$

Larger The Better (For Making The System Response As Large As Possible):

$$SN_L = -10\log \left(\frac{1}{n}\sum_{i=1}^{n} 1/Y_i^2\right)$$

"Where n is the number of observations, y is the observed data".

These SN ratios are derived from the quadratic loss function and are expressed in a decibel scale. Once all of the SN ratios have been computed for each run of an experiment, Taguchi advocates a graphical approach to analyze the data. In the graphical approach, the SN ratios are plotted for each factor against each of its levels. Finally, confirmation tests should be run at the "optimal" product settings to verify that the predicted performance is actually realized.

C. Genetic Algorithms

Genetic Algorithms (GAs) are general-purpose search algorithms that use the principles of natural genetics to evolve solutions of the problems. The basic idea is to maintain a population of knowledge structure that evolves over the time through a process of competition and controlled variation. Each structure in the population represents a candidate solution to the specific problem and has an associated fitness to determine which structures are used to form new ones in the process of competition.

The new individuals are created using genetic operators, such as crossover and mutation. GAs are robust and have great measure of success in search and optimization problems. As the name suggests, GA represents a new programming paradigm that tries to mimic the process of natural evolution, to solve the computing and optimization problems. In a GA,a population of chromosomes, which are

Usually strings of bits, is randomly selected. This population is transformed into a new population by a sort of natural selection based on the use of operators inspired by the natural genetic operators. The three operators defined by Holland are the reproduction, crossover, and mutation.

IV. PROBLEM IDENTIFICATION

Electrochemical Machining (ECM) is one of the non-traditional machining processes used to machine extremely hard materials that are difficult to machine cleanly using conventional methods. In optimization of machining operations thequantitative methods have been developed with considerations of a single objective only, minimization of cost or maximization of profit etc. For the process of single objective optimization several different techniques have been proposed, such as the differential calculus, regression analysis, linear programming, geometric, stochastic programming and computer simulation. While most hitherto researches are based on the single objective optimization, there have been some successful attempts also with the multi-objective optimization.

The optimization of process parameters is essential for the achievement of high responsiveness of production, which is the preliminary basis for survival in today's dynamic market conditions. Due to the complexity of the electrochemical machining process it is very difficult to determine the optimal machining parameters for improving the output quality. Optimal quality of the work piece in ECM can be generated through combinational control of various process parameters

The various process parameters in electrochemical machining are electrolyte concentration, voltage, feed rate,inter-electrode gap and electrolyte feed rate. The selection of proper process parameters for electrochemical machining process is crucial to have the efficient and high quality output. Due to the complexity of electrochemical machining process it is very difficult to determine optimal machining parameters for improving the output quality. To select the process parameters properly, several researchers developed mathematical models based on statistical regression techniques or neural computing to establish the relationship between the machining performance and the machining parameters. Particle swarm optimization algorithm has been used to optimize electrochemical machining parameters like tool feed rate, electrolyte flow velocity and the applied voltage in order to improve dimensional accuracy, material removal rate and machining cost.

Multi-objective optimization of current, voltage, feed rate and gap was done for improving material removal rate and surface roughness using multiple regression models and artificial neural networks.

Mathematical models were developed for correlating the influences of various machining parameters on number of experiments have to be performed and analyzed in order to build the mathematical models. Thus the required model building is very costly in terms of time and materials.

Electrochemical machining (ECM) uses a set of complex process to create a negative image of tool on workpiece by high rate anodic dissolution. This process is used to drill holes of variable cross section, removes defective surface layers to get improved surface finish. The tool in ECM, progressively advances towards workpiece maintaining an optimum working gap, typically in the order of one or several tenth of a milimeter.

V. EXPERIMENT AND DATA COLLECTION

A. *Experimental Setup:*

The optimization of process parameters is the key step in the Taguchi method. Twenty seven experimental runs (L27) based on the Orthogonal Array (OA) of Taguchi methods have been carried out. The multi-response optimization of the process parameters viz. MRR, Surface Roughness & Over cut has been performed for making a micro hole in the process of micro-ECM of LM6 Al/B4C composite. For analysisMRR, Surface Roughness &over cut, noted for every trial. MRR is Larger is better, Surface Roughness is smaller is better and Overcut is Smaller is better in this thesis. Electrochemical micro machining (EMM) characteristics (MRR and Overcut) as output responses for through micro – hole machining. MRR was derived as work piece removal weight over machining time. In Electrochemical micro machining Overcut of the micro hole has been closely related to the machining accuracy, hence it is the difference between the diameters of the tool electrode and machined micro hole. With the support of optical microscope the diameter of the machined micro– hole was measured.

MRR= (weight before machining – weight after machining) / machining time

ROC = (Hole diameter – Tool diameter) / 2

Surface is measured by using a SURTRONIC 3+ surface texture measuring instrument.

B. *Planning Phase Input Parameter & There Levels For ECM:*

Parameters of the setting	
Control factor	Symbol
Voltage (V)	Factor A
Electrolyte Concentration(g/l)	Factor B
Frequency (Hz)	Factor C

Table 1: ECM parameter of the setting

Level	Voltage (V)	Electrolyte Concentration(g/l)	Frequency (Hz)
1	6	20	10
2	8	25	30
3	10	30	50

Table 2: Selected input parameter

C. *Matlab Fitness Function-*

Weare using genetic algorithms for optimization of responses like material removal rate, surface roughness and over cut in electrochemical machining process by using the multiple linear regression equations fitness functions are formulated. MRR is a maximizing function, SR and ROC are minimizing functions. The objective functions are maximized and minimized by using GA toolbox in MATLAB software. The fitness function in MATLAB environment is as follows. Multiple linear regression models are developed using the experimental data in the form of-;

$$MRR = -0.166 + 0.0272X1 + 0.424X2 + 0.00776X3 \quad (1)$$

$$SR = 5.04 + 0.0153X1 - 0.648X2 - 0.0292X3 \quad (2)$$

$$ROC = 0.611 + 0.0265X1 - 0.249X2 + 0.00683X3 \quad (3)$$

VI. Result

A. *Result from the MINITAB.*

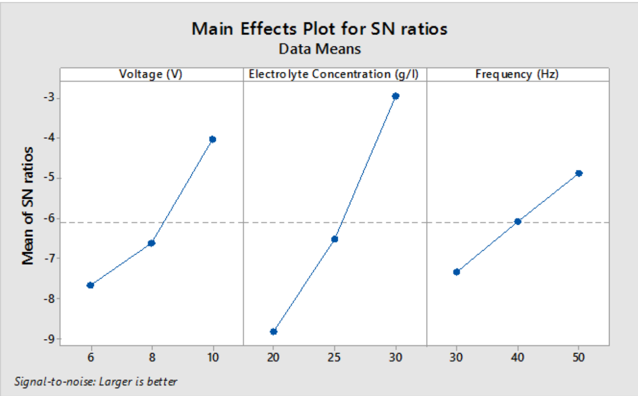

Fig. 1: Main effects plot for SN ratios (MRR)

Optimum Electrochemical micro machining parameters for MRR				
Level	Voltage (V)	Electrolyte Concentration (g/l)	Frequency (Hz)	MRR mg/min)
1	10	30	50	0.944

Table 3: Optimum Electrochemical micro machining parameters for MRR

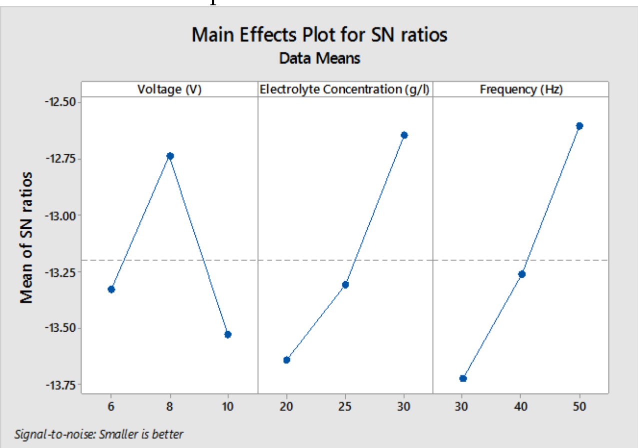

Fig. 2. Main effects plot for SN ratios (SR)

Optimum Electrochemical micro machining parameters for Surface Roughness				
Level	Voltage (V)	Electrolyte Concentration (g/l)	Frequency (Hz)	SR (µm)
1	8	30	50	3.598

Table 4: Optimum Electrochemical micro machining parameters for SR

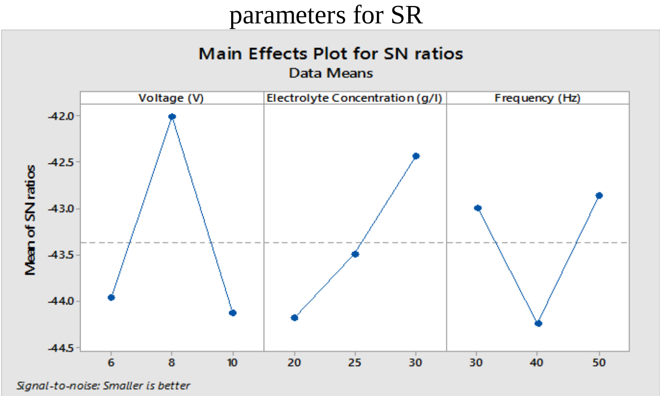

Fig. 1: Main effects plot for SN ratios (OC)

Optimum Electrochemical micro machining parameters for Overcut				
Level	Voltage (V)	Electrolyte Concentration (g/l)	Frequency (Hz)	Overcut (µm)
1	8	30	50	76.6

Table 5: Optimum Electrochemical micro machining parameters for Overcut

B. *Result from the Genetic algorithm using MATLAB*

Optimum Electrochemical micro machining parameters for MRR				
Level	Voltage (V)	Electrolyte Concentration (g/l)	Frequency (Hz)	MRR mg/min)
1	9.993	29.997	49.98	0.963

Table 6: Optimum Electrochemical micro machining parameters for MRR

Optimum Electrochemical micro machining parameters for Surface Roughness				
Level	Voltage (V)	Electrolyte Concentration (g/l)	Frequency (Hz)	Surface Roughness (µm)
1	6.50	29.999	49.999	3.219

Table 7: Optimum Electrochemical micro machining parameters for Surface Roughness

Optimum Electrochemical micro machining parameters for Overcut				
Level	Voltage (V)	Electrolyte Concentration (g/l)	Frequency (Hz)	Overcut (µm)
1	6.50	29.999	49.999	74.39

Table 8: Optimum Electrochemical micro machining parameters for Overcut

VII. Conclusion

1) In this work the effect of machining parameters Voltage, Electrolyte Concentration,Frequency are studied on MRR, SR & OC for ECM.
2) For surface roughness, our observation is based on smaller is better for s/n ratio.For MRRLarger is better for s/n ratio& for OC smaller is better for s/n ratio.
3) Summarizing all results I can state that if there are used correct cutting parameters then also machining of composite is economical and effective.

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