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Parametric optimization in machining on NIMONIC 75 alloy using Electrical Discharge Machining

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ABSTRACT

The increasing demands of machining of complex shape geometries and their high surface finish and has further strengthened the need of non-traditional machining processes. Among various process, EDM has been explored to large extent towing to surface finish and MRR are of crucial importance in the field of machining processes .Taguchi's optimization technique, in order to optimize the cutting parameters in EDM for super alloys. The objective of the effect of EDM parameters on MRR, Surface finish for machining NIMONIC75 alloy. In this present study super alloy is used as a work piece, copper or copper Alloy Like Brass used as a tool and distilled water is used as a dielectric fluid For experimentation, Taguchi's orthogonal array will be followed by ANOVA to identify the most significant factor .This would followed by developing empirical relation and optimization study. Nimonic75 (Nickel chromium base Alloys) is the most commonly used alloy. His basic chemical composition is Ni, Cr, Ti, C, Si, Cu, Fe, and Mn. Nimonic75 is significanty stronge than other commercially pure nimonic whilst still retaining the same stiffness and thermal properties. Nimonic75 extensively used in Gas-turbine engines Heat-treating equipment and fixtures Nuclear engineering aerospace, medical, marine and chemical processing.

Keyword— *NIMONIC 75, EDM, MRR, ANOVA, Taguchi's orthogonal, NTMP*

1. INTRODUCTION

The developments in manufacturing industries have led to the demands for advanced materials such as composites, ceramics and super alloy, having high hardness, toughness, and impact resistance. Challenges encountered during conventional machining of such materials are a complex shape, high precision, surface quality, and machining costs. Conventional machining processes include turning, milling, broaching, boring, slotting, grinding, shaping and many more. However, there arise difficulties in machining of advanced materials through conventional machining processes. The production of fine holes and intricate shape profile in thin and brittle jobs is very difficult by conventional methods.

The process of piercing, stamping, and extrusion does not work efficiently on brittle materials because of their limited plasticity. These materials may develop cracks, or may even crumble under such processes. The non-conventional machining processes are suggested for such situations. Electrical Discharge Machining (EDM) and its variants such as Wire Electrical Discharge Machining, Electrical Discharge Drilling, etc. Abrasive Jet Machining (AJM), Ultrasonic Machining (USM), Water Jet Machining (WJM) and Abrasive Water Jet Machining (AWJM) are some of the non-conventional machining processes

1.1 Ceramic

Ceramic are an inorganic non-metallic solid made by either metal or non-metal compounds that is the shaped and then hardened by heating to high temperatures. In general, they are hard, brittle and corrosion-resistant. Ceramics is divided into two classes: traditional and advanced. Traditional ceramics include clay products, cement; and silicate glass. and advanced ceramics consist of carbides (Sic), pure oxides (Al_2O_3), nitrides (Si_3N_4), non-silicate glasses and many others. Ceramic offers many advantages compared to other materials. There are harder and stiffer than steel; more heat and corrosion resistant than metals or polymers; less dense than most metals and their alloys.

The applications of ceramic materials are:
(a) Teeth of the human mouth
(b) Space shuttle tiles
(c) Glassware and windows
(d) Ceramic tiles, lenses and home electronics
(e) Spark plugs, pressure sensors, Thermistors, and vibration sensors

1.2 Composite
Composite is commonly defined as a combination of two or more distinct materials, each of which retains its own distinctive properties, to create a new material with properties that cannot be achieved by any of the components acting alone. Using this definition, it can be determined that a wide range of engineering materials falls into this category. High-performance rigid composites made from glass, graphite, Kevlar, boron or silicon carbide fibers in polymeric matrices have been studied extensively because of their application in aerospace and space vehicle technology. Based on the matrix material which forms the continuous phase, the composites are broadly classified in metal matrix (MMC), ceramic matrix composite (CMC) and polymer matrix (PMC) composites. Polymer matrix composites are much easier to fabricate than MMC and CMC.

1.3 Superalloys
A superalloys due to better multiple functional characteristics such as excellent mechanical strength, resistance to thermal creep deformation, good surface stability and resistance to corrosion or oxidation. Superalloys find a vast range of application in the aerospace, nuclear and chemical industries. Superalloys are difficult to machine by conventional machine process due to their high hardness and brittleness. This calls for non-conventional Machining processes.

1.4 Nimonic Alloy
Nimonic alloy is a group of nickel-chromium-cobalt based super-alloy that exhibit such as high resistance to corrosion, oxidation, carburization, pitting, corrosion cracking, and high-temperature strength. Commonly used Nimonic based alloys are Nimonic70, Nimonic75, Nimonic80A, Nimonic86, Nimonic 90, Nimonic105, Nimonic115, Nimonic706, Nimonic718, Nimonic 901.

Table 2: Properties of Nimonic75 alloy

Property	Metric
Density	8.37g/cm3
Melting Point	1340-1380 °C
Coefficient of Expansion	11 µm/m °C (20-100°C)
Tensile strength	750 MPa
Yield strength	275 MPa
Specific Heat	446 J/kg K
Thermal Conductivity	11.7 W/m K

1.4.1 Applications of Nimonic75
- Chemical Industrial Tube
- Gas turbine engines
- Aerospace fasteners
- Nuclear engineering
- Heat-treating equipment and fixtures
- Industrial furnaces

(a) Aerospace fasteners [20]

(b) Spray bars [14]

Fig. 1: Component made of Nimonic 75

1.5 Electrical discharge machining

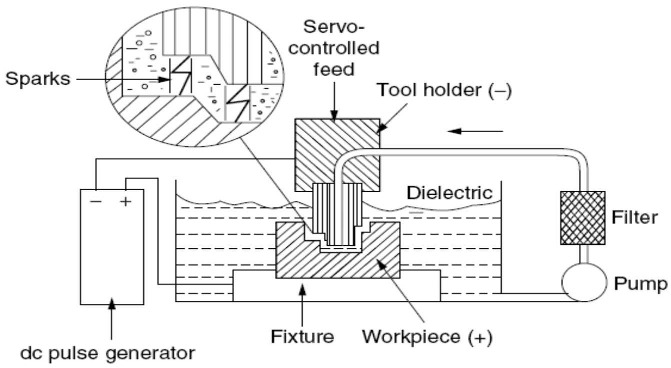

Fig. 2: Schematic diagram of the EDM system

Electrical Discharge Machining, a thermal material removal process in which electrical energy is used to generate an electrical spark and material removal mainly occurs due to localized heating, melting and vaporizing. Electro Discharge Machining (EDM) is an electro-thermal process, where electrical energy is used to generate electrical sparks and material removal mainly occurs due to the thermal energy of the spark.

In EDM, a potential difference is applied between the tool and workpiece. Both the tool and the work material are to be conductors of electricity. The tool and the work material are immersed in a dielectric fluid. Generally, kerosene or de-ionized water is used as the dielectric fluid for EDM. Generally, the tool is connected to the negative terminal of the generator and the workpiece is connected to the positive terminal.

1.6 Advantages of EDM process

The advantages of EDM process are:

- Complex shapes that would otherwise be difficult to produce with conventional cutting tools.
- By this process, materials of any hardness can be machined extremely hard material to very close tolerances.
- There is no direct contact between tool and workpiece. Therefore, delicate sections and weak materials can be machined without any distortion.
- A good surface finish can be obtained.
- Very fine holes can be easily drilled.
- One of the main advantages of this process is that thin and fragile/brittle components can be machined without distortion.
- Complex internal shapes can be machined.

2. DESIGN OF EXPERIMENT

Design of experiment techniques enables designers to determine simultaneously the individual and interactive effects of many factors that could affect the output results in any design. Physical process and computer simulation models are also conducted by design of experiment in which purposeful changes are made to the in variables of a system or process and the effects on response variables are measured. Designed Experiments are also powerful tools to achieve manufacturing cost savings by minimizing process variation and reducing rework, scrap, and the need for inspection. Factorial experimental designs investigate the effects of many different factors by varying them simultaneously instead of changing only one factor at a time. Factorial designs allow judgment of the sensitivity it to each factor and also to the combined effect of two or more factors. Experimental design methods have been successfully applied to several ballistic missile defence sensitivity studies to maximize the amount of information with a minimum number of computer simulation runs. In a highly competitive world of testing and evaluation, an efficient method for testing many factors is needed.

2.1 Taguchi technique

Taguchi constructed a special set of general designs for factorial experiments that covers many applications. They are orthogonal arrays with number of experiments, factors and levels for each special design orthogonal arrays. The use of these arrays helps to determine numbers of experiments needed for a given set of factors. When fixed number of levels for all factors is involved and the interaction are unimportant, standard orthogonal arrays will satisfy most experimental design needs. Taguchi method successfully resolves the difficulties in compacting experimental design by having the orthogonal arrays that represents the possible experimental condition and a standard procedure to analyze the experimental result The Taguchi method is a controlled approach for formative the "most excellent" combination of inputs to produce a product or service. The Taguchi technique was designed to decrease the variation in a process through robust design of experiments. The overall objective of the method was to reduce the engineering experimental time and cost stimulates the scheme and effort for product at low cost to the manufacturer. The Taguchi method was developed by Dr. Genichi Taguchi of Japan who maintained that variation. The mean and variance of a process performance characteristic are affected by different parameters to developed Taguchi approach to investigate that defines how well the process is functioning.

2.2 Taguchi methodology

The general steps involved in the Taguchi Methodology are as follows:

(a) Select Project: Identify a design optimization or production problem solving project. Define project clearly based on function you intend to improve. For complex systems/process, review subsystems/sub-processes and select activities responsible for the function. Lead if it's your own project, suggest DOE If it's someone else's.

(b) Plan Experiment: Conduct or arrange the planning/brainstorming session. If it's yours on project, you will benefit more if someone else facilitated the session. Determine: Evaluation criteria and establish a scheme to combine them, Control factors and their levels, Interaction Noise factors, Number of samples to be tested and Experiment resources and logistics.

(c) Designing experiments: Design experiment and describe trial conditions also:

- Determine the order of running the experiment
- Describe noise conditions fix testing samples if the design includes an outer array

(d) Conduct Experiments: Carry out experiments by selecting the trial condition in random order:

- Note readings, calculate and record averages if multiple readings of the same.
- Calculate OEC using the formula defined in the planning session.

(e) Analyze Results: Reduce observations (in case of multiple objectives) into results and perform analysis

2.3 Work material

In present study, plate of Nimonic 75, 8x (40x60x8mm). Nimonic 75 has tensile strength of 750 Mpa, compressive strength of 2200 Mpa and hardness value of 250-350 Hv. It has excellent oxidation and scaling resistance at temperatures up to 1340-1380°C, with an exceptional fatigue resistance, high corrosion resistance and high temperature strength.

Nimonic 75 also possesses high degree of formability and shows better weld-ability than nickel-chromium-cobalt- base alloys. Nimonic 75 is used in chemical processing, aerospace, turbine blade, discs, forgings, ring section, hot working, marine engineering, pollution-control equipment, and nuclear reactor applications.

Fig. 3: Work material Nimonic 75 plate

3. EXPERIMENTAL PROCEDURE

The experimentation was conducted to study the effect of various machining parameters on electrical discharge machining process which is based on L9 orthogonal array. Each experimental runs as per orthogonal array were repeated twice in order to reduce experimental error. Thus total experiments performed were 9X3 =27. CPC kerosene is used as Dielectric throughout the tests.

Following steps were followed in the cutting operation

(a) The tool was made vertical with the help of upper and lower guide block.

(b) The work piece was mounted in filter and lock on magnetic separate on the work table.

(c) We set reference point on the work piece for setting Work Co-ordinate System (WCS). The programming was done with the reference to the work co-ordinate system.

The reference point was defined by the ground edges of the work piece. Then after setting the wire electrode and the work piece the input process parameters viz. peak current (I_p), pulse-on-time (T_{on}) , Gap voltage(V) were set according to levels from the control panel of the machining and other parameters were kept constant throughout the experiments. A straight machining of 2mm depth was made on specimens of 8 x 40mm x 60mm x 8mm that is presented by the following figure 4 and figure 5.

Fig. 4: Plate material blank during machining on EDM machine

Fig. 5: Specimen cut by EDM machine after experimentation

Table 3: Experimental results of present work

S. no.	Gap voltage (V)	Pulse on time (μs)	Peak current (A)	Material removal rate (gm/min)			MRR average	Surface roughness (μm)			Average SR
				Trial 1	Trial 2	Trial 3		Trial 1	Trial2	Trial 3	
1	40	90	6	0.01989	0.02442	0.02634	0.02355	2.2	2.6	2.13	2.31
2	40	120	9	0.02631	0.03621	0.03931	0.03394	1.8	1.8	2.0	1.87
3	40	150	12	0.01295	0.02963	0.03600	0.02619	2.73	3.27	2.33	2.78
4	50	90	9	0.02270	0.03241	0.04578	0.03363	2.13	2.13	2.0	2.09
5	50	120	12	0.01518	0.02755	0.01956	0.02070	2.53	2.27	2.27	2.36
6	50	150	6	0.01036	0.02019	0.01140	0.01398	2.93	2.8	2.95	2.89
7	60	90	12	0.03375	0.04461	0.03399	0.03745	2.27	2.27	2.5	2.35
8	60	120	9	0.02406	0.02277	0.02542	0.02408	2.87	2.6	2.93	2.8
9	60	150	6	0.03809	0.03421	0.02960	0.03397	2.2	2.47	2.07	2.25

4. RESULTS

4.1 Material removal rate analysis using Taguchi experimental design

MRR of the work piece was measured as per procedure discussed earlier. The L9 orthogonal array experimental results for material removal rate along with their corresponding S/N ratio are given in following table response table for material removal rate based on larger the better characteristic of S/N ratios is given in table below. Along with delta value and ranking of each factor. It is clear from table below that peak current is having most significant impact on MRR followed by gap voltage and pulse on time is having least significant impact on MRR.

Table 4: Response Table for MRR

S no	Gap voltage	Pulse on time	Peak current	MRR (gm/min)	S/N ratio
1	40	90	6	0.02355	-32.5602
2	40	120	9	0.03394	-29.3858
3	40	150	12	0.02619	-31.6373
4	50	90	9	0.03363	-29.4655
5	50	120	12	0.0207	-33.6806
6	50	150	6	0.01398	-37.0899
7	60	90	12	0.03745	-28.5310
8	60	120	9	0.02408	-32.3669
9	60	150	6	0.03397	-29.3781

Table 5: Response Table for S/N Ratio for MRR

Level	Gap voltage	Pulse on time	Peak current
1	-31.19	-30.19	-34.01
2	-33.41	-31.81	-29.41
3	-30.09	-32.70	-31.28
Delta	3.32	2.52	4.60
Rank	2	3	1

4.2 Main effects plots for S/N Ratio of Metal Removal Rate (MRR)

The main effects plot for S/N ratio of Metal Removal Rate is shown in figure 6.

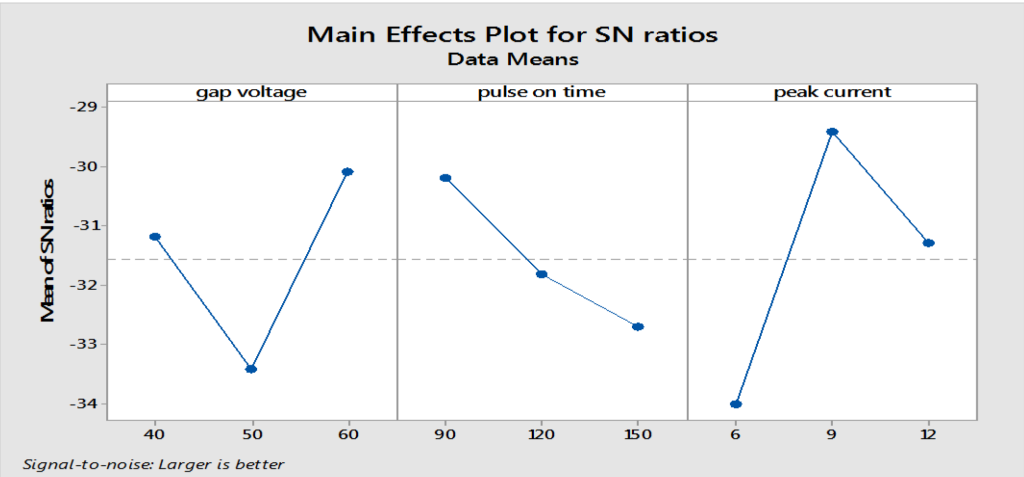

Fig. 6: Main effects plots for S/N Ratio of Metal Removal Rate (MRR) on Nimonic 75

From the above figure 6 in subplot 1, it is observed that when the value of voltage increases from 40V to 50V the value of MRR decrease and from 50V to 60Vthe value of MRR increases. The reason for this is being that at higher voltage rating the higher of energy per unit discharge is released causing more metal erosion and hence MRR increase. Maximum MRR obtained at voltage value of 60V The S/N ratio clearly shows that the value of MRR is more at 60V. In subplot 2, it is observed that when pulse on time increase from 90µs to 120µs the value of MRR also decrease higher rate and pulse on time increase from 120µs to 150µs the value of MRR also decrease. Subplot 3 shows that when the value of pick current increases from 6A to 9A MRR first increase but when further increase from 9A to 12A its decrease. Optimal value is 9A for higher MRR.

4.2.1 Contour plots for MRR

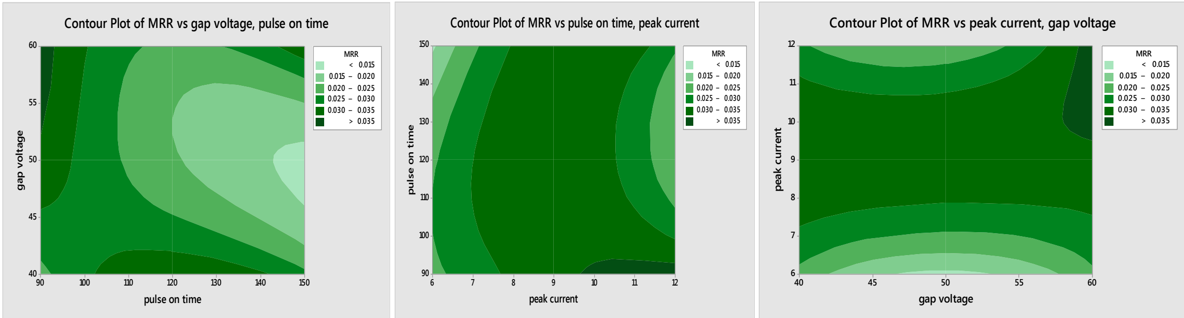

Fig. 7: Contour plot of Metal Removal Rate (MRR)

4.2.2 Surface plot for MRR

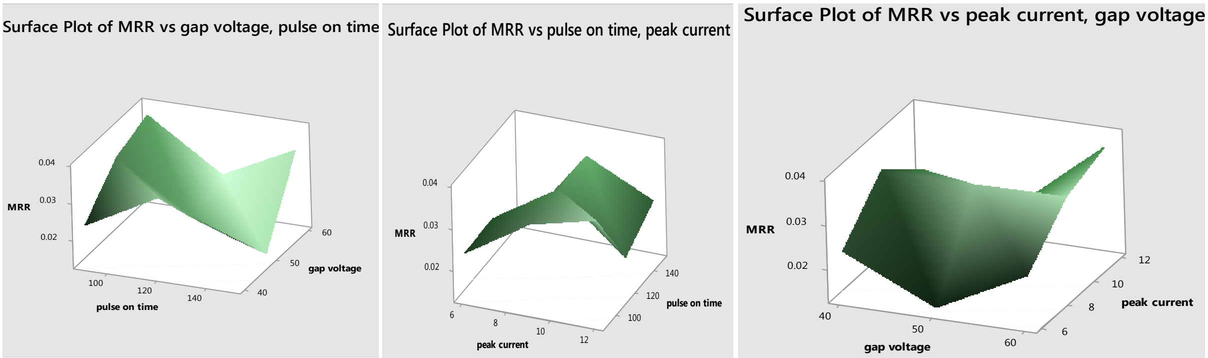

Fig. 8: Surface plot of Metal Removal Rate (MRR)

5. CONCLUSIONS AND FUTURE SCOPE

- When gap voltage increases from 50 to 60V MRR increases from 0.02 to 0.04 gm/min.
- On increasing pulse on time 100 to 120µs, MRR increases from 0.02 to 0.03 gm/min. But pulse on time increases from 120 to 140µs then MRR also decreases from 0.03 to 0.02gm/min.
- Peak current increases from 6 to 8 A then MRR also increases from 0.02 to 0.03 gm/min. But on increasing peak current from 8-11 A then MRR slightly increases from 0.03-0.035 gm/min while on increasing peak current from 11-12A the MRR deceases from 0.035-0.01gm/min.
- Peak current is having most significant effect on MRR as it followed by gap voltage and pulse on time having least effect.
- On increasing pulse on time 100-120µs, SR decreases from 2.5-2.0 µm but SR increases from 2-2.75 µm when pulse on time increases from 120-145µs.
- When gap voltage increases from 40-50V then SR increases from 2.5-3.5 µm but gap voltage increases from 50-55V SR also increases from 2.5-3.5 µm when gap voltage increases 50-60V SR decreases from 3.5-2.7 µm.
- When peak current increases from 6-9 A then SR decreases from 2.25-2.0 µm but when peak current increases 9-12 A then SR also increases from 2-2.5 µm.
- Peak current is having most significant effect on SR followed by pulse on time and gap voltage having.

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