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Optimizing the Machining Parameters of Micro-EDM for Inconel 718

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Abstract: This paper aims to study on the feasibility of micron size hole manufacturing using micro Electric Discharge Machining (Micro-EDM). Main and auxiliary unit of the micro-EDM machine tool and their functions are described in some detail. The technological and electrical parameters that are effective in Micro-EDM are stated explicitly. Geometry of the machined micro-holes and resolidified material around the hole entrance are observed. Several descriptive pictures, obtained by Scanning Electron Microscope (SEM) are included to understand the phenomena. EDM is an important process in the field of micro machining. However, a number of issues remain to be solved in order to successfully implement it an industrial environment. This study investigates the optimization of machining parameters for machining in micro EDM. Here, the overcut and the Metal Removal Rate (MRR) and Tool wear ratio are targeted. The study focuses on a specific combination of electrode and work piece material and proposes a typical method for micro EDM process optimization. The cutting of the Inconel 718 using Micro EDM with a brass electrode by using Taguchi methodology has been reported. The Taguchi method is used to formulate the experiment layout, to analyze the effect of each parameter on the machining characteristics and to predict the optimal choice for each EDM parameters like Discharge current, Pulse on time, Pulse off time. It found that these parameters have a significant influence on the machining characteristics such as Metal Removal Rate (MRR), Overcut and Tool wear ratio.

Key words: Micro EDM, micro holes, scanning electron microscope

INTRODUCTION

Rapid advances in technology require further development in the manufacturing of micro-parts and micro-electromechanical systems components. Increasing demand for micro-parts made micro-machining process more focused and investigated among the front-end of the technology in recent years. Micro-machining is the basic manufacturing technology of the miniaturized and smaller parts having size of millimeter down to submillimeter. EDM is considered to be one of the machining processes that may have high potential to manufacture small size components. It is a thermal process that utilizes spark discharges to erode a conductive material; the tool electrode is almost unloaded, because there is no physical contact between the tool electrode and the work piece. Therefore, the process works efficiently, particularly in the machining of difficult-to-cut materials. When the same process principles are applied to the micron size for micromachining, the process is called a micro-EDM.

The basic physical characteristics of the micro-EDM process is essentially similar to that of the conventional EDM process with the main difference being in the size of the tool used, the power supply of discharge energy and the resolution of the X-, Y- and Z-axes movement. EDM is widely used in tool room for machining of dies with fine details and for the production of unusually shaped and/or sized production work. Fuel injector valves, parts and components for medical devices, fiber optic connectors, micromachining, micro-mould making, stamping tools and micro electronics parts are the examples of miniaturized and smaller size parts produced by the micro-EDM technology.

There are many manufacturing techniques to drill micro holes and micro parts beside micro EDM. The recently developed methods are Wire Electric Discharge Grinding (WEDG), Micro- Electrochemical Machining (MECM), Laser-Beam Machining (LBM), Focused Ion Machining (FIM), Micro milling, Micro Ultrasonic Machining (MUSM), Electrochemical Discharge Machining (ECDM) and Micro punching. Performances of these methods are unique, because they have different machining mechanisms.

Growing popularity of micro EDM depends on its advantages including low set-up cost, high aspect ratio (depth/diameter ratio) of the holes, enhanced

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precision and large design freedom. In addition, EDM does not make direct contact between the tool electrode and work piece material, hence eliminating mechanical stress, chatter and vibration problems during machining. Therefore, replying on the above advantages, micro- EDM is very effective to machine any kind of holes such as small diameter holes down to μm and blind holes with 20 aspect ratio.

In spite of many studies on fast EDM hole drilling, the research on making of small-size holes on aerospace alloys is limited.

In EDM, the machining of conductive materials is performed by sequence of electrical discharges occurring in an electrically insulated gap between the tool electrode and work piece. During the discharge pulse, a high temperature plasma channel is formed in the gap causing evaporation and melting of the work piece. Debris of material is removed by the resulting explosion pressure, enabling the machining of the work piece. The characteristics of the electrical discharge pulses are linked with a set of machining parameters which control the energy and frequency of discharges and thus the power in the gap. Consequently, the chosen set of parameters affects the material removal rate MRR and overcut. However, in micro EDM a number of issues remain to be solved. For instance, the processing time is significantly higher. This study investigates the influence of various combination of machining parameters in micro EDM in an attempt to optimize the influence variables.

Characteristics of micro-EDM: The EDM process is based on the thermoelectric energy created between a work piece and an electrode submerged in a dielectric fluid. When the work piece and the electrode are separated by a specific small gap, the so-called 'spark gap', a pulsed discharge occurs which removes material from the work piece through melting and evaporation.

In recent years, numerous developments in EDM have focused on the production of micro-features. This has become possible due to the availability of the new CNC systems and advanced spark generators that have helped to improve machined surface quality. Also, the very small process forces and good repeatability of the process results have made micro-EDM the best means for achieving high aspect ratio micro-features.

Current micro-EDM technology used for manufacturing micro-features can be categorized into four different types:

- Micro-wire EDM, where a wire of diameter down to 0.02 mm is used to cut through a conductive workpiece
- Die-sinking micro-EDM, where an electrode with micro-features is employed to produced its mirror image in the work piece
- Micro-EDM drilling, where micro-electrodes are used to drill micro-holes in the work piece
- Micro-EDM milling, where micro-electrodes are employed to produce 3D cavities by adopting a movement strategy similar to that in conventional milling

Similar to macro-EDM, micro-EDM is also classified into several manufacturing configurations by simply scaling down the machining geometries. In general, micro-wire, die-sinking, milling and drilling EDM are the widely recognized methods. They can produce a feature size down to a few microns with possible aspect ratio of 100. In particular, Micro-Wire Electro-discharge Grinding (WEDG), firstly introduced by in 1985, is also regarded as an important micro- EDM configuration. This process is broadly used for forming very thin rods with high-aspect ratio which can be used as tool electrodes for micro-EDM drilling or milling. Moreover, it also allows shaping the tools into complex geometries which can be applied directly for fabricating 3D structures and die-sinking. An overview of the capabilities of these machining variants is listed in Table 1.

Table 1: Micro EDM capabilities

Micro EDM variant	Geometric complexity	Minimum feature size (μm)	Maximum aspect ratio	Surface quality
WEDM	3D	3	100	0.1-0.2
Die-sinking	3D	20	15	0.05-0.3
Milling	3D	20	10	0.2-1
Drilling	3D	5	25	0.05-0.3
WEDG	3D	5	30	0.5

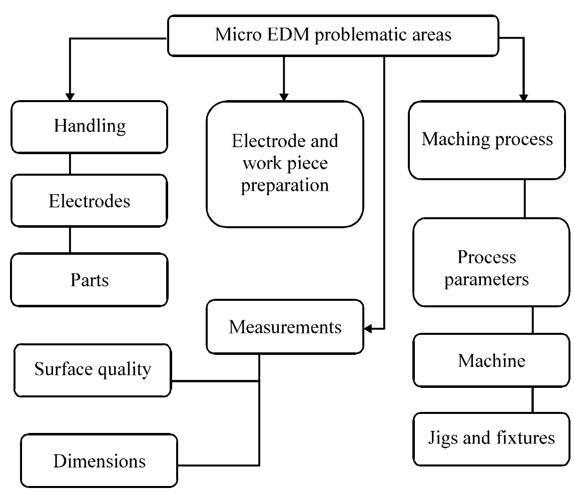

Fig. 1: Micro-EDM problematic areas

Micro-EDM issues: Figure 1 gives an overall view of the problems discussed. Special attention is paid to the different sources of errors directly affecting the accuracy of the EDM process and suggestions for machining strategies to reduce those errors are made.

Previous literature: Several studies on the manufacturing of micro holes are published in the literature.

Pham *et al.* (2005) in their study, they mainly focused on the various actors that affecting on the final accuracy in Micro EDM drilling. The main parameters size and position of the hole is discussed. Techniques for minimized the errors is proposed by Pham *et al.* (2004). This study is focused on the EDM process and Electrode wear problem and also the recent developments in the micro machining field (Cusanelli *et al.*, 2007). In this study, the holes are achieved from 0.05-1.8 mm in diameter for gasoline nozzles. The most important feature in this process positive tapered holes is obtained by mechanical setup (Liu *et al.*, 2009). In this study, the process capability of the micro EDM is discussed with the discharge pulse ratings that affecting the surface integrity and the machining geometry (Lajis *et al.*, 2009). The cutting of the Tungsten Carbide ceramic using Electro-discharge Machining (EDM) with a graphite electrode by using Taguchi methodology has been reported (Bigot *et al.*, 2005). The electrode wear ratio is taken into account by volumetric wear ratio. The suitable electrode wear compensation method is proposed. This study focuses the parameters optimization for rough and fine machining in micro EDM (Thillaivanan *et al.*, 2010). The machining parameters optimized based on Taguchi and the Artificial neural network.

Experimental procedure

Test piece and electrode materials: The test piece materials used in this study were common aerospace super alloys Inconel 718 (IN718) (Cullen and Freeman, 1965). Due to their specific thermal and physical properties these materials are preferred for aerospace applications. The chemical composition of IN718 are given in Table 2 and 3 show melting points and thermal conductive of base and electrode materials used in this study.

Experimental setup: The experiments were performed on test pieces of IN718 with predetermined dimensions using Sparkonics micro drilling machine (Fig. 2). The surface of the test pieces were ground prior to experiments.

The flat surfaces of two specimens were aligned in order to ensure that mating surfaces could be secured accurately using a specially designed and manufactured fixture. The holes were drilled in the test pieces one by one with varying the process parameters. Table 4 represents the Machining Conditions.

Measurement procedure: The drilling time for the each hole was recorded using an electronic timer. The test pieces were weighed before and after drilling using a digital precision scale.

Table 2: Chemical composition of IN718

Elements	Value	Elements	Value
Ni	50-55	Al	0.20-0.80
Cr	17-21	Si	0.35 max
Fe	Balanced	Mn	0.35 max
Nb (+Ta)	4.75-5.50	Cu	0.30 max
Mo	2.80-3.30	C	0.08 max
Co	1.00 max	B	0.06 max
Ti	0.65-1.15		

(wt. %)

Table 3: Properties of base and electrodes

	Melting point (°C)	Thermal conductivity (W/m[−]° K)
IN718	1336	11.4
Br	900-940	159.0

Table 4: Machining conditions

Discharge current (A)	25
Pulse on time (μsec)	10
Pulse off time (μsec)	10
Dielectric medium	Deionised water
Electrode	Brass, diameter 0.4 mm length 400 mm
Work piece	IN718
Technology	Blank/user

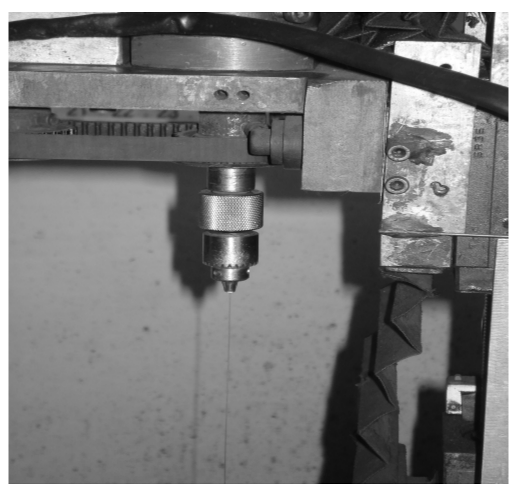

Fig. 2: Sparkonics micro-EDM machine, courtesy-covai EDM, Coimbatore

Micro-EDM issues: Miniaturization of the product requires a new approach to process design. Because so far micro-EDM has tended to be performed using conventional EDM machines modified to accommodate the micro-manufacturing requirements, a number of Material Removal Rate (MRR) for each experiment was calculated by the following formula:

$$\text{MRR}\,(\text{mg}\,\text{min}^{-1}) = \frac{\text{Intialweight} - \text{final weight}}{\text{Machining time}}$$

The Electrode wear ratio can be calculated by the following relations in percentage:

$$\text{EWR} = \frac{\text{Consumed electrode in length}}{\text{Machinedhole depth}} \times 100$$

The overcut shown in Fig. 4 were measured by using the Scanning Electron Microscope (SEM)

R1: Electrode radius
R2: Hole Radius
R2-R1: Overcut

RESEARCH METHODOLOGY

The purpose of the project is to evaluate the performance of the micro-EDM on Inconel 718. The Sparkonics micro-EDM machine is shown in Fig. 3. To achieve this objective proper experimental plan is necessary to achieve good results. This experiments consists of four main elements namely, research design and data analysis, variables, research procedure and instrumentation. Figure 5 shows the methodology for this experiment. Taguchi method using Minitab software was applied as a tool for data analysis. The confirmation test was also implemented in order to give the reliability of the micro-EDM results for Inconel 718.

Research design and data analysis: The experimental layout for the machining parameters using the L_9 Orthogonal array was used in this study. This array consists of three control parameters and three levels as shown in Table 5.

In the Taguchi method, most all of the observed values are calculated based on the 'the higher the better' and 'the smaller the better'. Thus in the study, the observed values of MRR, Overcut were set to maximum and minimum, respectively. Each experimental trial was performed with three simple replications at each set values.

Research design variable: The design variables are described into two main groups which are response parameters and machining parameters. Response parameters (machining characteristic @ dependent variable) include:

Table 5: Design scheme of experiment of parameters and levels

Control parameters	Levels: 1 Minimum	2 Intermediate	3 Maximum	Observed values
Discharge current (A)	10	15	20	Material removal rate (mg min^{-1})
Pulse on time (μsec)	10	10	10	Overcut (mm)
Pulse off time (μsec)	4	5	6	

Fig. 3: Sparkonics Micro-EDM machine, (Brass Electrode dia 0.4 mm), Courtesy- Covai EDM, Coimbatore

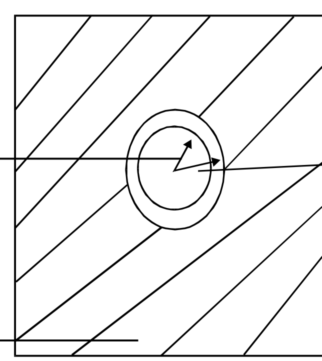

Fig. 4: Overcut measurements

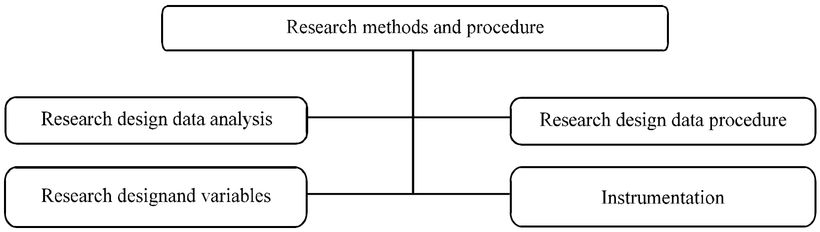

Fig. 5: Research methodology

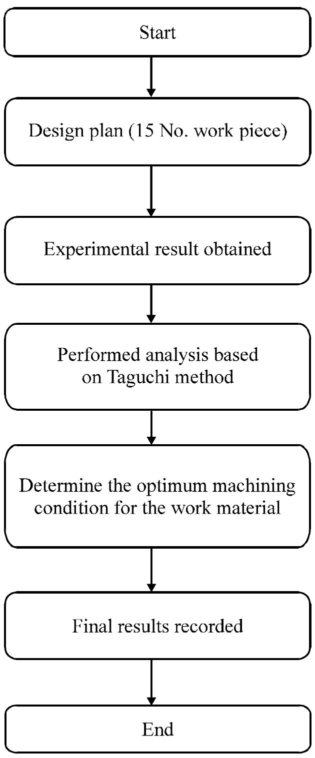

Fig. 6: Research procedure

Table 6: Set of experiments: L_9 Orthogonal array

No of experiment	Gap current	Pulse on time	Pulse off time
1	10	9.0	4
2	10	9.5	5
3	10	10.0	6
4	15	9.0	4
5	15	9.5	5
6	15	10.0	6
7	20	9.0	4
8	20	9.5	5
9	20	10.0	6

- Material removal rate, MRR
- Overcut
- Electrode Wear Ratio, EWR

Machining Parameters or also known as independent variables involves in this experiment:

- **Discharge current:** Which gives the highest electric current that can occur during the discharge (if no capacitor is used)
- **Pulse-on time:** Which is the duration of the impulse generated by the impulse generator
- **Pulse-off time:** Which is the time between two impulses

Machining parameters: As indicated machining parameters were deployed to obtain the optimized value.

- Discharge current
- Pulse on time
- Pulse off time

Output functions: In the proposed experimental procedure (Fig. 6), the main functions are Over cut, Material removal rate, Electrode Wear ratio was calculated. Digital images of the profiles from their profiles taken from SEM. The reduction of the electrode length due to the wear was measured on the machine. This was achieved by assessing the difference electrode tip and workpiece top surface. In this study, in order to facilitate computation the corner wear was considered as negligible. Set of experiments of L_9 Orthogonal array is presented in Table 6.

RESULTS AND DISCUSSION

In this study, In this project, the investigation of machining characteristics such as MRR. TWR, OC during micro hole in micro EDM on Inconel 718 using brass electrode with de-ionized water as dielectric medium. It can be concluded from this investigation that there is a great influence of using brass electrode for drilling performance characteristics in micro EDM during micro hole generation on Inconel 718.

From Fig. 7, discharge current 20 level 3, Pulse on time 9.5 level 2, Pulse off time 5 level 2.Gives the optimum conditions for reducing the MRR. From Fig. 8,

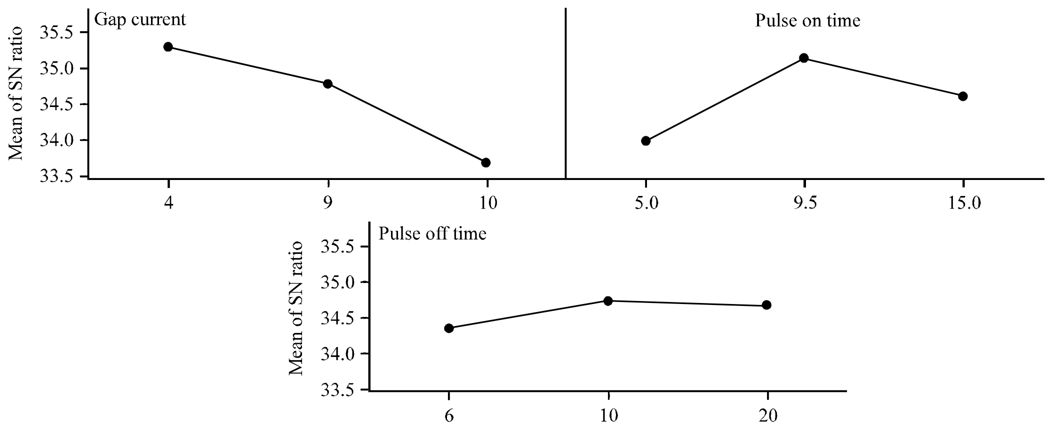

Fig. 7: SN ratio graph for MRR

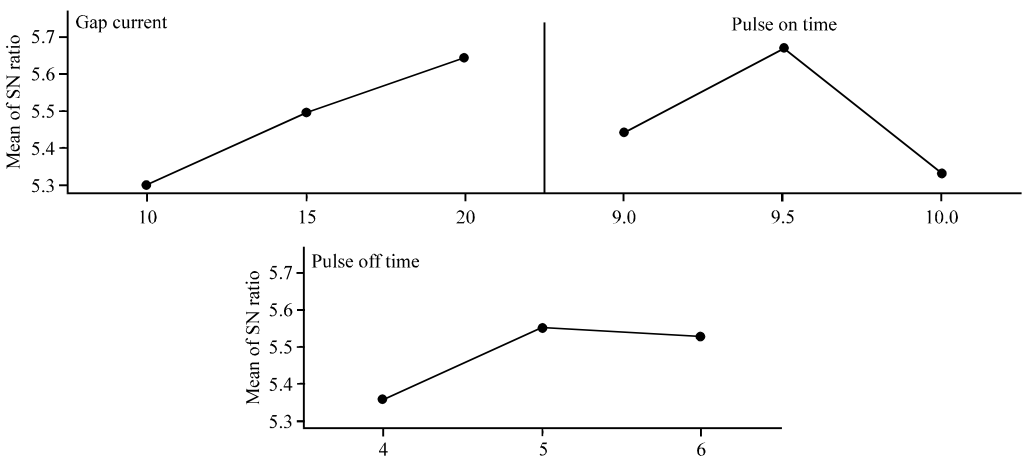

Fig. 8: SN ratio graph for TWR

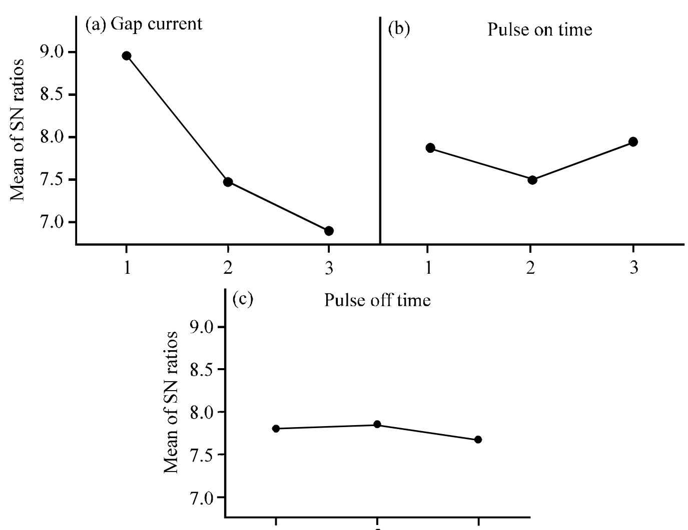

Fig. 9: SN ratio graph for OC

discharge current 20 level 3, Pulse on time 9.5 level 2, Pulse off time 6 level 3.Gives the optimum conditions for reducing the TWR. From Fig 9, discharge current 10 level 1, Pulse on time 10 level 3, Pulse off time 4 level 1. Gives the optimum conditions for reducing the Overcut.

REFERENCES

Bigot, S., A. Ivanov and K. Popov, 2005. A study of the micro EDM electrode wear. Proceedings of the 1st International Conference on Multi-Material Micro Manufacture 4M2005, Karlsruhe, Germany, June 29-July 1, 2005, Elsevier, Oxford.

Cullen, T.M. and J.W. Freeman, 1965. The Mechanical Properties of Inconel 718 Sheet Alloy at 800, 1000 and 1200°F. National Aeronautics and Space Administration, Washington, DC., USA., Pages: 47.

Cusanelli, G., M. Minello, F. Torchia, W. Ammann and P.E. Grize, 2007. Properties of micro-holes for nozzle by micro-EDM. Proceedings of 15th International Symposium Electromachining, April 23-27, 2007, Pittsburgh, PA, pp: 241-245.

Lajis, M.A., H.C.D.M. Radzi and A.K.M.N. Amin, 2009. The implementation of Taguchi method on EDM process of tungsten carbide. Eur. J. Sci. Res., 26: 609-617.

Liu, K., B. Lauwers and D. Reynaerts, 2009. Process capabilities of Micro-EDM and its applications. Int. J. Adv. Manuf. Technol., 47: 11-19.

Pham, D.T., S.S. Dimov, S. Bigot, A. Ivanov and K. Popov, 2004. Micro EDM-Recent developments and research issues. J. Mater. Process. Technol., 149: 50-57.

Pham, D.T., S.S. Dimov, S. Bigot, A. Ivanov and K. Popov, 2005. Micro-EDM Drilling: Accuracy Study. In: Advances in Integrated Design and Manufacturing in Mechanical Engineering, Bramley, A., D. Brissaud, D. Coutellier and C. McMahon (Eds.). Springer, Dordrecht, The Netherlands, ISBN-13: 9781402034817, pp: 281-294.

Thillaivanan, A., P. Asokan, K.N. Srinivasan and R. Saravanan, 2010. Optimization of operating parameters for EDM process based on the Taguchi method and artificial neural network. Int. J. Eng. Sci. Technol., 2: 6880-6888.