OPEN ACCESS

International Journal Of Modern Engineering Research (IJMER)

Experimental Study with Rotating Tool Electrode of EDM for Ni-Alloy

Sanjay Gaur[1], PK Bharti[2]

[1]*Director General of Aeronautical Quality Assurance, Ministry of Defence, New Delhi, India*

[2]*Head of Mechanical Department, Integral University, Lucknow, India*

***ABSTRACT*: *Conventional machining process has the limitation when desired surface finish and dimensional accuracy in geometry is required in difficult to machine aerospace materials especially for the cases of drilling holes. Non conventional advance machining processes (AMPs) are extensively used in the industry to machine for the complex geometrical dimension along with desired surface finish in hard materials. Electrical Discharge machining with modification for holding and rotating the electrode has been used in the present experiment for making holes in the Nimonic alloy. This paper investigate the influence of gap current, pulse on time, duty factor, tool electrode rpm and especially the polarity of the machine on Material Removal Rate (MRR) and surface roughness (R_a) for machining of Nimonic alloy. It is observed that with suitable control of input parameters of Electrical Discharge drilling (EDD), MRR and Ra both found to be improving together from 60 to 90 mg and 4.8 to 2.9 µm respectively which confirm the viability of using tool electrode rotation in EDM machining.*

Keywords: *Advance machining process, Average surface roughness, Material removal rate, Electrical discharge drilling*

I. INTRODUCTION

The ever increasing growth of aviation sector especially the fighter aircrafts has increased the demand for materials that have excellent mechanical and chemical characteristics along with high temperature resistance in comparison to originally employed various types of steels in aerospace applications. The developed materials, such as Ti-alloys, Nimonic super alloys, new ceramics, metal matrix composites, silicon infiltrated carbide (SiSiC), aluminium oxide,-titanium carbide etc. are usually employed in manufacturing of the components for aerospace application. Because these materials possess unique properties like high strength at elevated temperature, resistance to chemical degradation, wear resistance and low thermal conductivity etc. [1, 2]. However ability of these materials to retain their properties at elevated temperatures severely hampers its machinability. Such materials are referred as difficult-to-machine or advanced materials [3].

In conventional machining methods, the materials are removed from workpiece by shears which generate huge amount of heat at the interface of cutting edge of tool and workpiece [4, 5]. This results into the softening of cutting tools and reduces the strength of the cutting tool materials [6]. To address the difficulties faced in machining difficult to machine materials by conventional machining processes, researchers have developed many non-conventional machining processes which are used at increased rate in the industries. However its machining efficiency is very low in terms of material removal rate etc. These non-conventional machining processes are also known as AMP. Some of these AMPs are: Chemical Machining Processes, Ultrasonic Machining Processes, Electrical Discharge Machining, Beam Machining Processes, Electro Chemical Machining, and Jet Machining Processes etc.

In spite of all the efforts made to machine advanced material, still the challenges are not over especially for the machining of Ni-alloy and Ti-alloy. These alloys are extensively used in aeroengine because they are able to meet the characteristic requirements of aerospace materials such as high strength to weight ratio, high strength at elevated temperature, resistance to chemical degradation, high wear resistance and non corrosiveness etc. Ni-alloy specially nimonic alloy posses these aforesaid characteristics along with high resistance to mechanical and thermal fatigue, high resistance to mechanical and thermal shock and high resistance to creep and erosion at elevated temperature. Ni-alloy and Ti-alloy is used extensively in hotter section of aeroengine of aerospace vehicle in the form of turbine blades, compressor blades and liners etc as shown in Fig. 1 and Fig. 2.

Fig. 1 Photograph of a Turbine Blade

Fig. 2 Photograph of a Component used in Fuel System of aeroengine

Drilling of holes in difficult-to-cut aerospace materials specially nimonic alloy with desired surface finish and accurate geometry is beyond the capability of conventional machining such as drilling etc. In machining four basic factors are considered w. r. t. material, shape, size and quality of finish required etc. Problems of machining are associated with:-

- Frequent Tool failure due to poor heat conductivity.
- Difficult to machine because of their high hardness.
- Difficult to make intricate shapes in these materials.
- Difficult to make channel/cylindrical hole of miniature diameter in complex units
- Deformation of tool due high hardness.
- Poor surface finish and machining accuracy.
- Wear on the tool materials results from combination of dissolution /diffusion and attrition process.
- Localization of shear stress on cutting tool due to high dynamic shear strength.
- Notch formation at cutting tool due production of abrasive saw tooth.
- Rapid work hardening during machining especially in Ni-alloy.
- Abrasion based tool failure due to presence of abrasive carbides in Ni-alloys.
- Localization of temperature due to low thermal diffusivity.
- Welding of the work piece to the cutting tool edge resulting in poor surface finish.
- Reaction of the cutting tool with workpiece at elevated temperature, resulting in accelerated tool wear.

Non conventional machining methods are being used to machine the harder materials which have eased out the cutting difficulties to some extent. To overcome the problems of difficult to machine tough and high strength material by conventional machining, Advance machining methods are developed. Some of the of advance machining methods over conventional machining are:-

- Ease in Machining even with complex/intricate shapes and inaccessible areas
- Better surface integrity and high surface finishing.
- Precision & Ultra precision Machining (Micro & Nano Machining).
- Higher volumetric material removal rate
- With Adaptive control leading to unmanned and automated factories.
- Computer control of process result in better performance, higher reliability, better repeatability and higher accuracy.
- Drilling of holes with High Aspect ratio
- Material removal take places in the form of atoms/molecules or in group of these

In this paper authors have investigated the impact of the rotation of the tool electrode in Die sinking EDM on *MRR* and R_a of machined hole with the input parameters of current, pulse on time, duty factor and tool rpm. They have termed it as electrical discharge drilling (EDD) process. It is observed that both the parameters have improved while machining with rotating tool electrode EDM process.

II. LITERATURE REVIEW AND OBJECTIVE OF THE STUDY

Literature Review

Literature on research on EDM for last 10 years have been surveyed and found a very limited works related to EDD and particularly on high content nickel base superalloys. Jeswani [7] the first who was successful in drilling of small diameter holes between 0.19-0.71 mm in carbon steels using tool electrode of copper wires. Jain [8] used rotary EDM to drill precision blind holes in carbon steel and analyzed the effect of pulse time, tool electrode diameter and depth of penetration of precision blind hole drilling in high speed steel. Soni [9] used rotary EDM and sinking EDM both for drilling of holes in Ti-alloy with copper-tungsten electrode and compared the results of both machining. He reports that with rotary EDM, material removal rate (MRR) increases along with improvement in out of roundness in comparisons to hole made by sinking EDM. He supports his finding and credited the increase in *MRR* to improved flushing of eroded debris due to tool rotation. Mohan et al. [10] used hollow tubular electrode in rotary EDM and drilled holes in Al-SiC metal matrix composite and confirms improved *MRR*, R_a and low TEW. The author credited the improvement to improved flushing due to use of rotary EDM. Recently authors have reported for reduction in TEW by providing cooling effect on tool electrode. Suleiman et al. [11] conducted the experiments by providing cooling to tool electrode during machining of titanium alloy (Ti-6Al-4V) and reported for 27% reduction in TEW than that of sinking EDM. Kuppan et al. [12] has drilled holes in Inconel 718 with 99.9% tubular copper electrode. He finds that *MRR* increases with increase in peak current, duty factor, pulse on time and rpm of tool and substantially R_a also improves due to effective dielectric flushing. Addition of additives in dielectric a latest approach in EDM machining is also reported [13]. They have claimed that by using additives in dielectric, *MRR* and R_a both improves. And a latest journal reports for the use of water mixed dielectric in EDM to reduce the environmental hazards, which generates due to decomposition of dielectric [14]. Goswami et al. [15] studied the influence of machining parameters on cutting speed and MRR of Nimonic 80A using wire EDM. They have investigated that cutting speed (CS) and *MRR* increased with increase in pulse-on time and peak current. Yadav and Yadava [16] carried the parametric study on Electrical Discharge Drilling of Aerospace Nickel Alloy. They studied the effect of tool rotation on Average circularity (C_a) value on drilled hole by EDD process.

It is perceived from referred surveyed papers that *MRR* and R_a improve with rotary EDM due to effective flushing of eroded debris. However there is limited information available on Nimonic alloys with sinking EDM machine. Present authors have tried to highlight the issue related to *MRR* and R_a by controlling the input process parameter of EDM machine along with tool electrode rpm and to analyze the effects of selected input parameters for encouraging performance results.

Objectives of the Study

In the present experimental study, the main objective is to investigate the effect on machining performance of *MRR* and R_a with rotating tool electrode used in conventional Die sinking EDM on nimonic alloys aerospace material within the considered domain of selected input parameters.

III. EXPERIMENTAL PROCEDURE

3.1 Development of the Set-up

To conduct the experimental study an arrangement was made to rotate the tool electrode in the existing Die-sinking EDM machine with controlling of tool rpm as shown in Fig 3.

Fig. 3 Photograph of assembled setup on ZNC EDM machine

Since R_a requires a very precision machining and therefore all possible precautions were taken during manufacturing of the setup which was assembled on ZNC EDM machine. Prior to assembly on ZNC EDM machine, the setup was pre-tested with assembled tool electrode for the total indicating run out (TIR) by dial test indicator (DTI) and adjusted for maximum accuracy. An Electronic Automation Private Ltd (EAPL), India made portable digital tachometer (model: DT 200 1B) was used to measure and calibrate the tool rpm which was controlled by the variable speed controller.

3.2 Work piece and Tool Material

Ni-based superalloy of round bar 22 mm diameter is used as workpiece specimen. The chemical composition of the workpiece specimen is given in Table 1. The workpieces were sliced of 6 mm thickness disc by wire cut EDM machine. After measurement of MRR, the machined workpieces will be partitioned into two half to facilitate the accurate measurement of R_a.

Table 1. Composition of nickel alloy workpiece material (%)

Elements:	C	Al	Mn	Si	S	P	Cr	Fe	Ti	Ni
%age :	0.098	0.12	0.04	0.06	0.001	0.005	21.0	0.14	0.33	78

The tool electrode used was made of 99.9 % electrolytic copper having cylindrical diameter of 10 mm as shown in Fig 4.

Fig. 4 Photograph of tool electrode

The specification of dielectric fluid is given in Table 2 which has been used during EDM machining.

Table 2. Dielectric Specifications

Appearance	Bright and clear
Colour	0.0
Specific gravity @ 29.5 ° C	0.750 Min
Kinematic viscosity @ 40 ° C cSt	2.0-2.5
Flash point ° C	100 Min
Pour point ° C	< -3

3.3 Experimental condition

EDD process was performed using rotating tool electrode. The tool electrode was fed downwards under the control of servo system. The workpiece was connected to negative and tool was connected to positive terminal (referred as reverse polarity) of EDM machine power supply. All the experiments for desired output parameters of *MRR* and R_a were performed on reverse polarity.

3.4 Consideration of process parameters

Exhaustive pilot experiments were carried out to determine the range of input process parameters such as gap current, pulse on time, duty factor, and tool electrode rpm. Based on pilot experiments it was concluded to conduct the experiments in reverse polarity with constant pulse off time of 65 µs. The variation on *MRR* and R_a were observed by varying the input parameters one at a time, keeping other parameters constant known one parameter at a time (OPAT) study and ranges of input parameters were decided.

IV. RESULTS AND DISCUSSION

4.1 Average Surface Roughness

Effect of current

Figure 5 shows the variation of R_a with varying current at different duty factors. It is observed that on 800 rpm of tool electrode and at 60% duty factor, R_a increases by 31.03% (from 2.90 to 3.80 µm) with increasing of current from 16 to 24 A and similar trend is seen for all the considered duty factors at 800 rpm. This is due to reason that as the current increases, the intensity of the sparks increases. This lead to the increasing of higher energy of heat along with discharge power. This produces the large craters with appreciable depth at increased duty factor which has been observed in the form of higher Ra values on machined surface of work specimen.

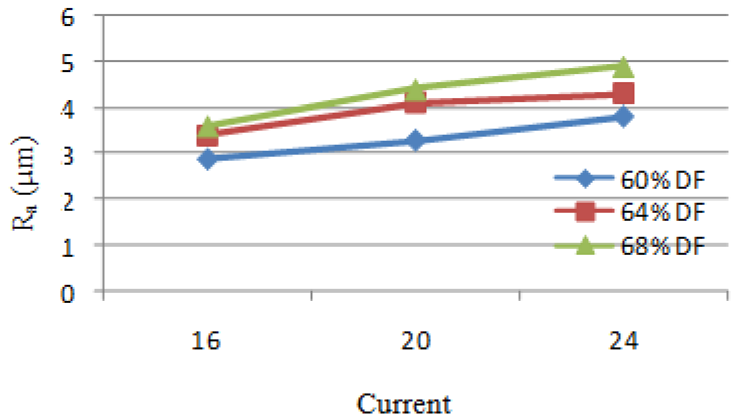

Fig. 5 Effect of current on R_a for different duty factor

Effect of Duty factor

Figure 6 shows the variation of R_a with duty factor at different tool rpm. It is observed that on 16 A current and at 800 rpm, R_a increases by 2.63 % (from 3.80 to 3.90 µm) with increasing of duty factor from 60 to 68%. The trend is found to be improving for all the considered rpm and the R_a values are found to be lower at increasing tool rpm. This is because of improved flushing of eroded debris from inter electrode gap (*IEG*) as a result the surface roughness improves along with increasing of tool rpm. The improvement of R_a at higher tool rpm is also due to the effect of improved melting of the materials from the machined surface at increased duty factor.

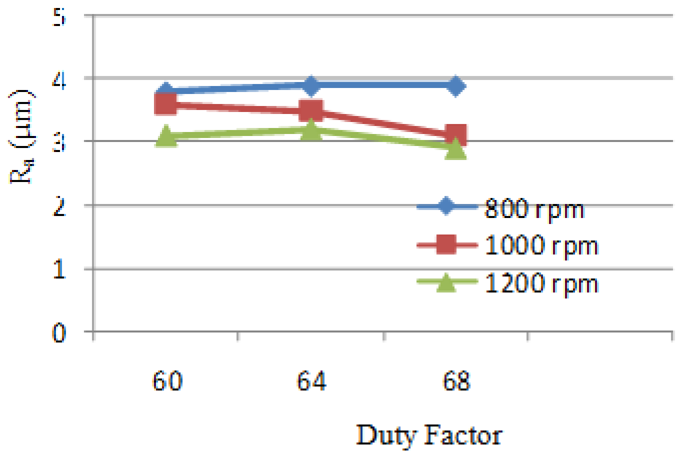

Fig. 6 Effect of duty factor on R_a for different tool rpm

Effect of Tool Rotation

Figure 7 shows the variation of R_a with tool rpm at different current and at 60% duty factor. It is observed that R_a almost improves or seems to be constant with the increase of tool rpm for all the current. It is noted that R_a has varied between 3 to 4 µm for all the current values. This is because of the effective melting of materials and improved flushing as a result of rotation of the tool electrode.

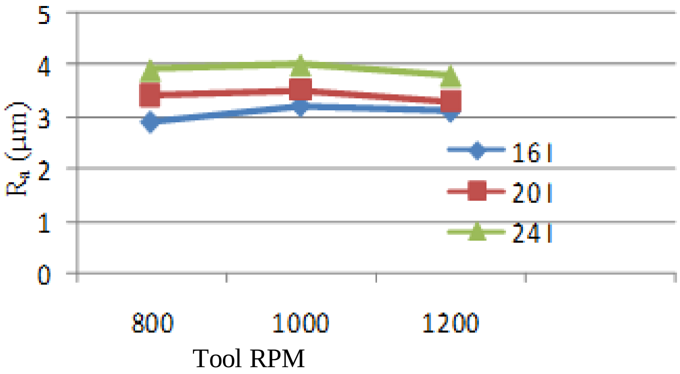

Fig. 7 Effect of tool rpm on R_a for different current

3.2 Material Removal Rate (MRR)

Effect of current

Figure 8 shows the variation of *MRR* with current at different duty factors and at 800 rpm. It is observed that at 60% duty factor, *MRR* increases by 14.56% (from 60.23 to 69.00 mg) with increasing of current from 16 to 24 A and increases by 20.98 % (from 73.21 to 88.57 mg) at 64% duty factor. The trend is found to be similar for 68% duty factor also. This is because of intensive heat generation with increasing of gap current and melting of the materials thereof.

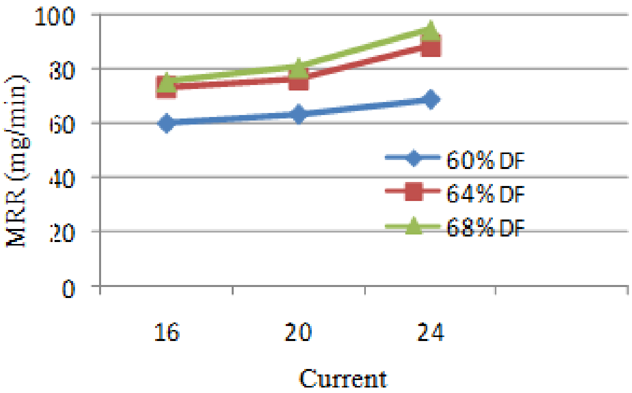

Fig. 8 Effect of gap current on MRR for different duty factor

Effect of Duty factor

Figure 9 shows the variation of *MRR* with duty factor at different tool rpm at 16 A current. It is observed that at 800 rpm, *MRR* increases by 16.31 % (from 60.00 to 69.79 mg) with increasing of duty factor from 60 to 68% and at 1200 rpm it has been increased by 5.15% (from 78.00 to 82.02 mg). This is also credited to the improved flushing of eroded debris from inter electrode gap (*IEG*) along with the increased heat energy due to the increased duty factor.

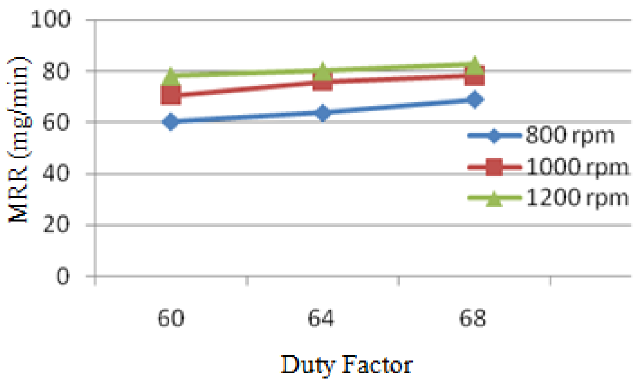

Fig. 9 Effect of duty factor on R_a for different tool rpm

Effect of Tool Rotation

Figure 10 shows the variation of *MRR* with tool rpm at different current and at 60% duty factor. It is observed that *MRR* increases with the increase of tool rpm for all the current. It is noted that at increased value of current (at 24 A), *MRR* has been found to be maximum which has varied from 74 to 81.23 mg. This is because of the effective melting of materials with increasing of current along with increasing of tool rpm. The increasing of tool rpm has certainly enhanced the flushing of eroded debris from the machined surface, as result *MRR* improved.

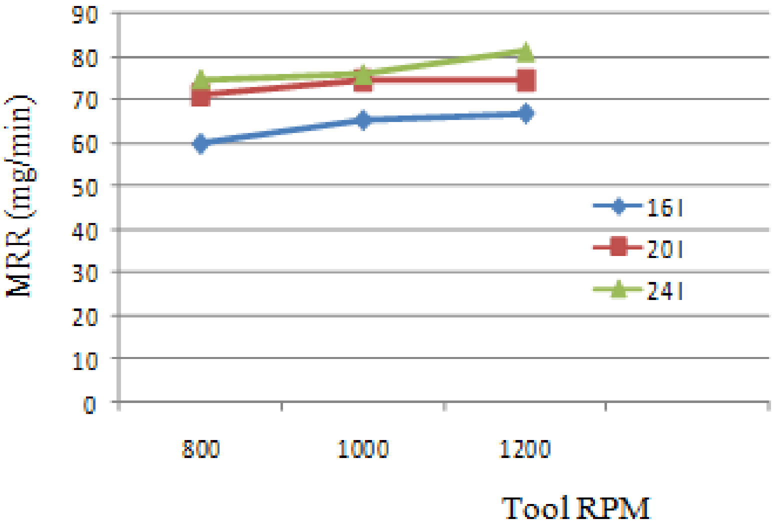

Fig. 10 Effect of tool rpm on R_a for different current

V. CONCLUSIONS

Following conclusions have been derived from the above study:

1. Materials have been developed to meet the challenges of ever increasing demand of high temperature resistance, light in weight along with enhanced strength materials, but the machining processes have to be developed for cheaper, reliable and easier machining processes.
2. The developed EDD process has been able to machine such difficult to cut materials with enhanced performances as this experimental study of nickel based super alloy confirms.
3. MRR has been increasing with the increasing of tool RPM and at the same time R_a has also been improved. The minimum MRR has found to be of 60 mg/min which is adequately enhanced. Also there has been an overall increase of 50% in MRR from 60 mg/min within the considered and controlled parameters of the present EDD process.
4. The observed R_a is found to be in between 3-4µm, which is very nominal for such superalloy materials, which can be further easily improved with light grade emery paper polishing.
5. Since the present experiment (EDD) has been very successful on high precipitation materials and hence authors confirm that future scope of EDD can be further explored for machining of ever developing such materials.

REFERENCES

[1]. Miller. S, Advanced materials means advanced engines. Interdisciplinary Science Review, 21 (2), 1996, 117-129.

[2]. Boyer. R. R, An overview on the use of titanium in the aerospace industry, Materials Science & engineering, A213, 1996. 103-104.

[3]. Ezugwu. E. O, Key improvement in the machining of difficult to-cut aerospace superalloys. International Journal of Machine Tools & Manufacturing, 45, 2005, 1353-1367.

[4]. Ezugwu. E. O, and Wang. Z. M., Titanium alloys and their machinability- A review. Journal of Materials Processing Technology, 68, 1997, 262-274.

[5]. Ezugwu. E.O, Bonney. J, and Yamane. Y, An overview of the machinability of aeroengine alloys. Journal of Material Processing Technology, 134, 2003, 233-253.

[6]. Kramer. B. M, On tool materials for high speed machining, Journal of Engineering for Industry, 109, 1987, 87-91.

[7]. Jeswani. M. L, Small hole drilling in EDM, International Journal of Machine tool Design and Research, 19, 1979, 165-169.

[8]. Jain. V. K, Analysis of electrical discharge drilling of a precision blind hole in HSS using bit type of tool, Microtechnic, 2, 1989, 34-40.

[9]. Soni, J.S., Machining of Titanium Alloy by Rotary EDM. Industrial products Finder, 1994, 253-260

[10]. Mohan. B, Rajadurai. A, and Satyanarayana. K.G, Electric discharge machining of Al-SiC metal matrix composites using rotary tube electrode, Journal of Materials Processing Technology, 153, 2002, 978-985.
[11]. Abdulkareem.Suleiman, Khan. Ahsan Ali, and Konneh. Mohammed, Cooling effect on electrode and process
[12]. parameters in EDM, Materials and Manufacturing Processes, 25, 2010, 462-466.
[13]. Kuppan. P, Rajadurai. A, and Narayanan. S, Influence of EDM process parameters in deep hole drilling of Inconel 718, International Journal of Advance Manufacturing Technology, 38, 2008, 74-84.
[14]. Kumar. anil, Maheshwari. Sachin, Sharma. Chitra, Beri. Naveen, Analysis of machining characteristics in
[15]. additive mixed electric discharge machining of nickel-based super alloy Inconel 718, Materials and
[16]. Manufacturing Processe,26, 2011, 1011-1018.
[17]. Liu. Younghong, Zhang. Yanzhen, Ji. Renjie, Cai. Baoping, Wang, Fei, Tian. Xiaojie, and Dong. Xin,
[18]. Experimental characterization of sinking electrical discharge machining using water in oil emulsion as
[19]. dielectric, Materials and Manufacturing Processe,28, 2013, 355-363.
[20]. Goswami. Amitesh, and Kumar. Jatinder, An Investigation into the Machining Characteristics of Nimonic 80A using CNC Wire-EDM, International Journal of Advanced Engineering Technology, III (I) 2012, 174-174.
[21]. Umacharan. Singh. yadav, and Vinod. Yadav, Parametric study on Electrical Discharge Drilling of Aerospace
[22]. Nickel Alloy, International Journal of Material and Manufacturing Processes, 29, 2014, 260-266.