EXPERIMENTAL STUDY OF PEAK DISCHARGE CURRENT ON ELECTRICAL DISCHARGE MACHINING PERFORMANCE OF NIMONIC 80A SUPER ALLOYS

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Abstract: *Machinability assessment of Nimonic 80A was carried out during Electro-Discharge Machining (EDM) using Copper tool electrode. In this work, machinability was evaluated in regards of material removal efficiency, tool wear rate along with surface roughness, and surface crack density observed at the machined specimen. Morphological features of the machined surface were studied. Effects of peak discharge current on machining performance features were analyzed through graphical representation of the experimental data. Significant carbon migration onto the EDMed surface was induced due to pyrolysis of the dielectric media during spark discharge.*

Keywords:EDM, MRR,SCD,TWR,WEDM

Introduction

The Nimonic 80A superalloy is a wrought nickel based alloy (min. 69 % Ni) containing chromium (min 18 %), with minor additions of carbon (0.10% max), cobalt (2% max) and iron (3% max), as well as major alloying elements of Manganese (1% max), aluminum (1 to 1.8 %) and titanium (1.8 to 2.7 %) [1]. The density of Nimonic 80A is 8.19 g/cm^3 and melting range is 1320-1365 ° C. Nimonic is nickel based super alloy widely used in automobile parts, aerospace and defense industries. This alloy exhibits excellent properties including high temperature stability, high corrosion resistance and high wear resistance. However, execution of conventional machining is experienced very difficult for Nimonic super alloy due to its rapid work-hardening tendency, excessive tool wear, evolution of high cutting temperature, high cutting force and finally disappointing surface finish of the end product. In contrast to traditional machining, non-conventional machining like Electro-Discharge Machining (EDM) seems comparatively more advantageous for this alloy. However, poor thermal conductivity of this alloy limits performance of the EDM process offering less material removal rate (MRR) and dissatisfactory surface finish.

Litarature Review

Goswami and Kumar analyzed and optimized the machining characteristics of trim cut WEDM on Nimonic 80A. They used ANOVA to find out the relative significance of input parameters such as Pulse-On-Time, Pulse-Off-Time, Peak-Current and Wire-Offset to predict material removal rate, Surface roughness and Wire wear ratio. Taguchi's method of design of experiment is used to optimize the output parameters. It was found that Pulse-On-Time was the major factor affecting the surface roughness and MRR and Wire offset mainly affected the Wire wear ratio. The optimised condition found are pulse on time: 0.6 µs, pulse off time: 14 µs, peak current: 90A, wire offset: 0.10 mm. Trim cut produced higher values of surface finish and corner accuracy [2].

Loua et al. proposed silicon-boronising of the Nimonic 90 alloy to achieve high corrosion and erosion resistance properties. A multi-layer coating was formed when silicon-boronising paste was used to modify the surface. The micro hardness was found to be increased by 3 times and wear resistance increased by 2.5-5 times as compared to the base metal [3].

Goswami and Kumar investigated machining characteristics of wire electrical discharge machining of Nimonic 80A such as material removal rate and wire wear ratio. And also various surface integrity features such as recast layer and surface topography. Orthogonal arrays along with Taguchi's Method were used to determine the major factor that affects the machining characteristics without the need of much experimentation. Signal to Noise ratio is then obtained using the Minitab software to optimize MRR and WWR. It was concluded that pulse on time and pulse off time are the vital factors for MRR. With the increase in pulse on time and peak current recast layer thickness also increased [4].

Bharadwaj and Sharma investigated the effects of process parameters on machining of Nimonic 80A in WEDM. Pulse on time, pulse of time and spark gap voltage were selected as the process parameters. These parameters are then arranged in an L9 orthogonal array. Analysis of variance is then done to find out the relative signification of each parameter on the machining characteristics selected i.e. Material removal rate. Finally Taguchi's design of experiment method is used to optimize the output. Pulse off time and Pulse on time were concuded to be the most vital parameters affects the MRR. Parameters with decreasing order of effect on the MRR are pulse off time, pulse on time and spark gap voltage having percentages contributions of 46.64%, 46.23% and 0.39% respectively. Optimal parameter setting obtained is pulse on time: 122µs, pulse off time: 35µs and spark gap voltage: 50s [5].

Unune et al. studied the machining of Nickel based Nimonic 80A super alloy by abrasive assorted electrical discharge diamond surface grinding machine. Fussy logic based artificial intelligence technique was used to predict the surface roughness and material removal rate. The results obtained pretty much comply with the experimental data with an accuracy of 93.89%. The input parameters taken are wheeling RPM, abrasive concentration, pulse on time and pulse current. Increasing wheel RPM resulted in increase in MRR and decrease in surface roughness. MRR increases as abrasive concentration is added up to 4 g/L thereafter it lessens. Surface roughness significantly reduced with increase in abrasive concentration from 0 to 8 g/L. Increase in pulse on time and pulse current resulted in increase in MRR however surface finish is deteriorated [6].

Mandal et al. proposed mathematical models that were developed for performance measures such as surface roughness of work piece, spark gap between electrodes and wire wear ratio and compared against the experimental data to find conformance with very high accuracy. Important process parameters were taken are discharge current, discharge voltage, and the pulse duration of discharge current. Desirability function was used to predict the optimum values of operating conditions. Also it was found that multicut strategy can be used where surface integrity is of primary importance owing to the improved surface roughness and minimized recast layer thickness of the job [7].

Mandal et al. suggested two in-process strategy i.e. single cut or rough cut for shaping and multi-cut or finish cut for finishing and two post-process strategies i.e. grinding and etching-grinding for elimination of this white layer. They concluded: multi-cut strategy significantly improved surface texture and micro-hardness but it could not completely remove micro-voids and tool wire deposition. Grinding proved to be very efficient in reducing the recast layer thickness and induced compressive stresses. However this process faces some challenges due to the high hardness of the white layer. Therefore etching prior to grinding improves the effectiveness of this process by softening the recast layer. Etching-grinding improved the surface integrity and produced a smooth surface and was able to maintain the machined surface elemental composition with that of the base metal [8].

Swain et al. proposed the machining perfoemance of Nimonic 75 using TiAlN nano coated tool and uncoated tool. Input parameters selected were cutting speed and feed rate and the output parameters were surface roughness, burr formation, geometry of slot and tool wear. It was found that flank wear and chipping were the dominant form of tool wear. Feed rate of 6 mm/min and cutting speed of 13 m/min was found to be the optimum machining conditions. They concluded that surface integrity and was wear of tool significantly improved using TiAlN coated tool against uncoated tool [9]

Objectives

- In the present investigation, effects of the peak discharge current were studied on EDM performance of Nimonic80A super alloys.
- EDM performance was assessed in purview of rate material removal, rate of tool wear and surface integrity (morphology and topography) of the machined surface of workpiece.
- Elemental analysis was carried out to investigate aspects of material migration onto the machined surface of workpiece during EDM operation.

Experimental Details

Nimonic 80A square flat plates $(50 \times 50 \times 50) mm^3$ were used as workpiece material. The properties and chemical composition of Nimonic80A could be found in [1]. EDM experiments were performed on Die-sinking EDM setup (Fig. 1) with a copper tool electrode of 20mm diameter. Conventional EDM oil was used as dielectric media. Experiments were conducted by varying peak discharge current as 15A, 25A, 35A, and 45A (Table 1). Aside from peak discharge current, fixed values of remaining process factors were provided in Table 2. Taguchi based design of experiment has been articulated in Table 3. After EDM, specimens of required dimensions were cut using Wire-Electro Discharge Machine (WEDM). Material Removal Rate (MRR), Tool Wear Rate (TWR), and surface roughness were measured for each experimental run. Surface roughness was measured by surface roughness tester. Morphological features of the EDMed surface were observed through Scanning Electron Microscope.

Table 1. Machining parameters of the Experiment

Parameters	Unit	Notation	Levels of variation			
			1	2	3	4
Peak current (I_P)	[A]	A	15	25	35	45

Table 2. Process factors kept at constant values

Parameters	**Unit**	**Value**
Gap voltage	[V]	230
Pulse on time	[µs]	2000
Pulse off time	[µs]	500
Polarity of electrode	-	(workpiece positive)
Electrodes gap	[µm]	50
Depth of cut	[mm]	0.50

Table 3. Design of experiment

Sl. No.	DOE	Weight Measurements				Machining time In minute
	A	Weight of workpiece before machining in gram	Weight of workpiece after machining in gram	Weight of tool before machining in gram	Weight of tool after machining in gram	
1	1	97.700	96.730	144.860	144.830	26.24
2	2	102.380	100.900	144.920	144.890	6.23
3	3	100.900	99.500	144.890	144.870	2.59
4	4	99.500	97.720	144.870	144.860	2.46

Results and Discussion

Morphology of the machined surface as observed under scanning electron microscope, exhibited presence of cracker mark, mark of uneven material deposition, globule of debris, Pockmark and surface cracks in abundance (Fig. 3). Pockmark (or chimney) is formed when entrapped gas is released from the machined surface. Surface cracking takes place due to evolution of huge thermal stress developed during machining process. The significance of crack has been observed due to induced thermal stress when exceeds ultimate tensile strength. The effect of peak discharge current on white layer thickness is shown in Fig. 4. It was found that the thickness of white layer increases with increase in peak current. The discharge energy per spark increases with peak discharge current. Thus, more energy input leads to higher material removal. Additionally, the dielectric fluid becomes increasingly inefficient to flush out the eroded material completely; remaining material gets solidified on the work surface forming 'recast layer' or 'white layer'. Effect of peak discharge current on material removal rate was presented in Fig. 5. It was found that with increase in peak discharge current, MRR got increased due to increased energy input. Increased energy input also increased evaporation of electrode material which further resulted in significant weight loss of the tool electrode. This weight loss was correlated with Tool Wear Rate (TWR). Hence, increase in peak discharge current resulted in increased TWR (Fig. 6).

With increase in peak discharge current, MRR was increased; however, dielectric media appeared increasingly inefficient to flush away entire debris. Debris thus got accumulated in an increasing extent with increased peak current. This contributed towards deterioration of surface finish. Therefore, surface roughness was found assuming an average increasing trend with respect to increased peak current (Fig. 7).

It was found that with increase in peak current, surface crack density showed an average decreasing trend. It is to be noted that due to insufficient flashing of the dielectric media, some debris gets accumulated over the machine surface which forms white layer or recast layer upon resolidification. Thickness of the white layer is increased with increase in peak discharge current due to high material removal rate. On the other hand, increased peak current and thereby increased energy input induces huge thermal stress at the machined surface. Therefore, it is expected that intense cracking may take place with increased peak current. However, the intensity of surface cracking being relatively less as compared to the rate of growth of white layer; crack density is reduced with increased peak current (Fig. 8).

Figure 1. Experimental setup

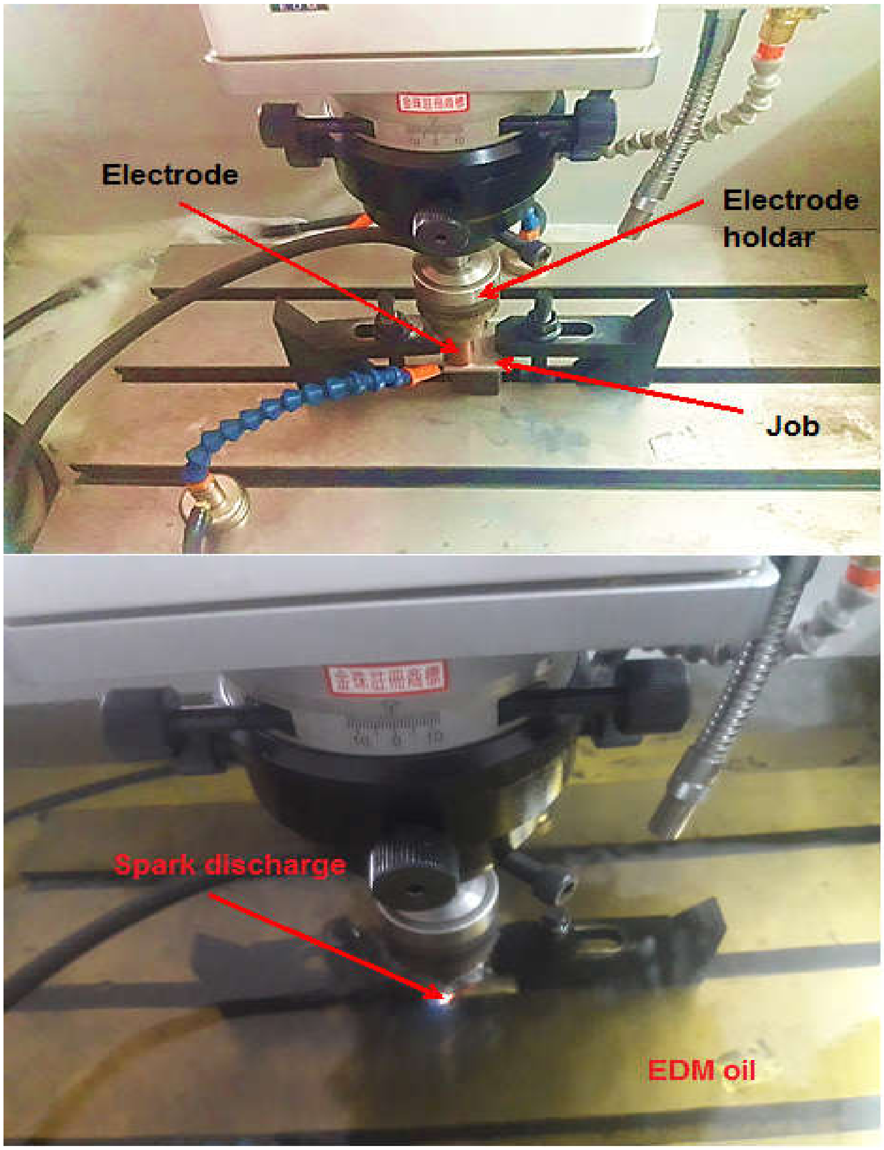


Figure 2. EDMed Work piece

Figure 3.Surface morphology of the EDMed specimen at Ip=45A

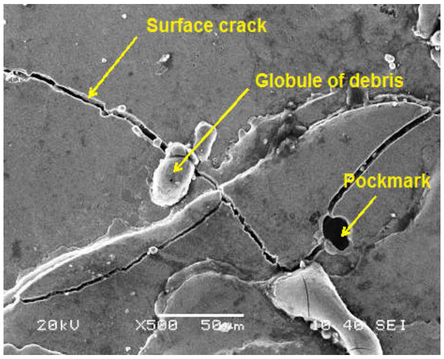


Figure 4. SEM micrographs of the EDMed specimens exhibiting effect of Pick Current (15A and 45A) on WLT

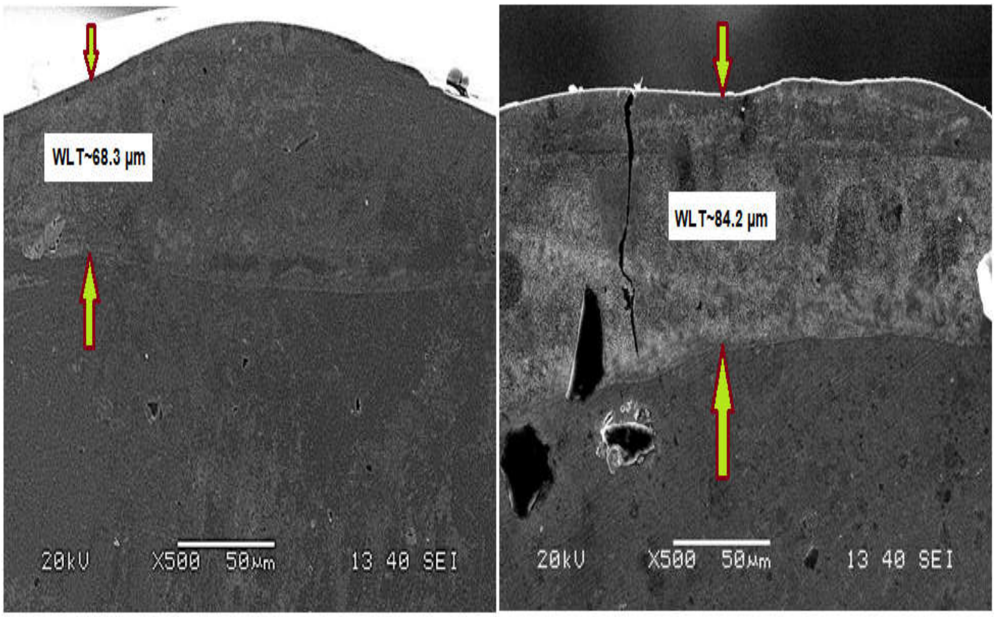


Figure 5. Effect of peak discharge current on MRR

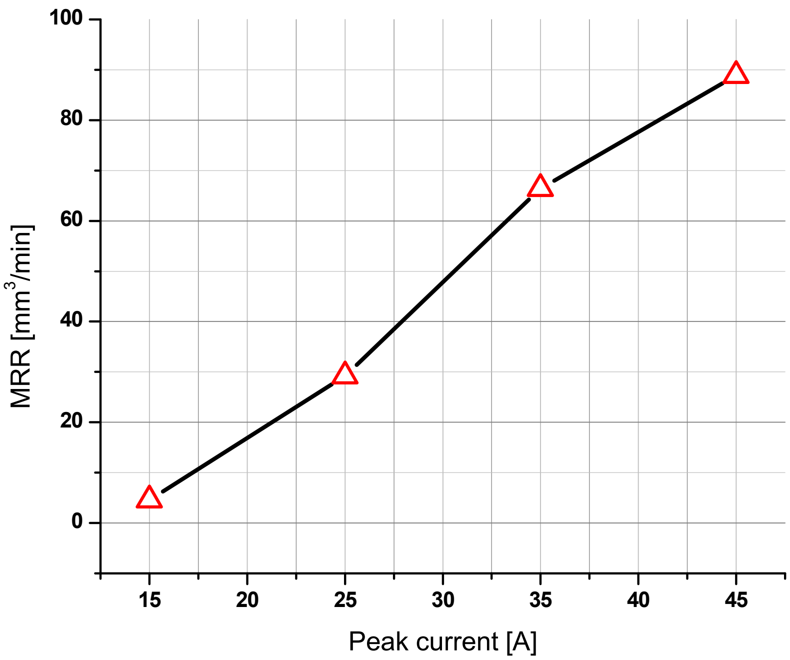


Figure 6. Effect of peak current on tool wear rate

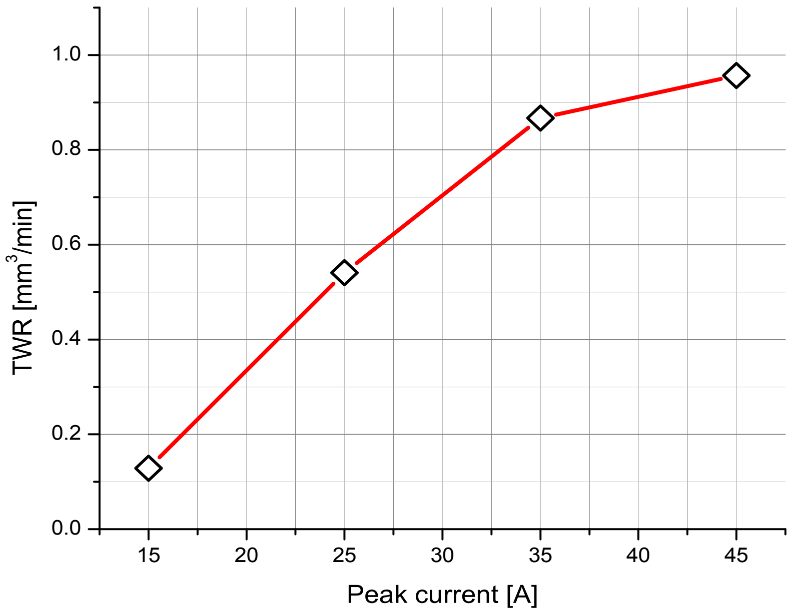


Figure 7. Effect of peak discharge current on SR

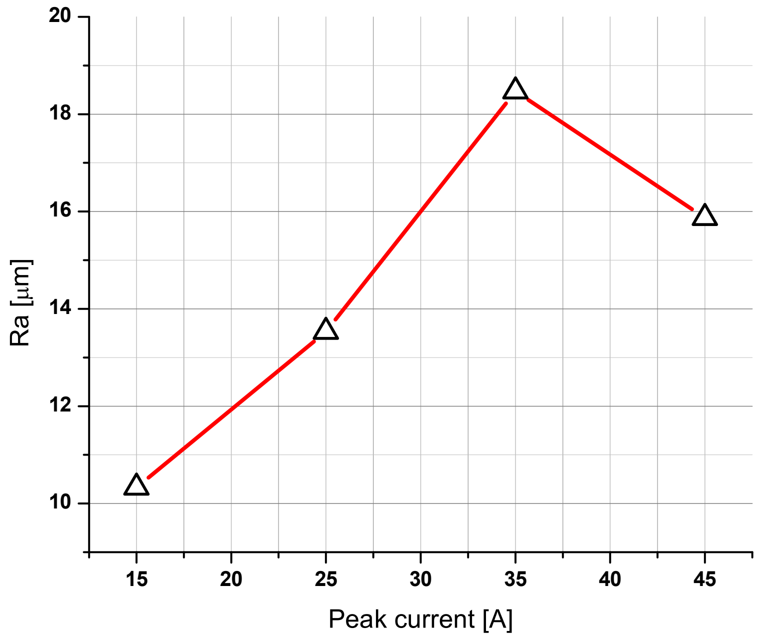
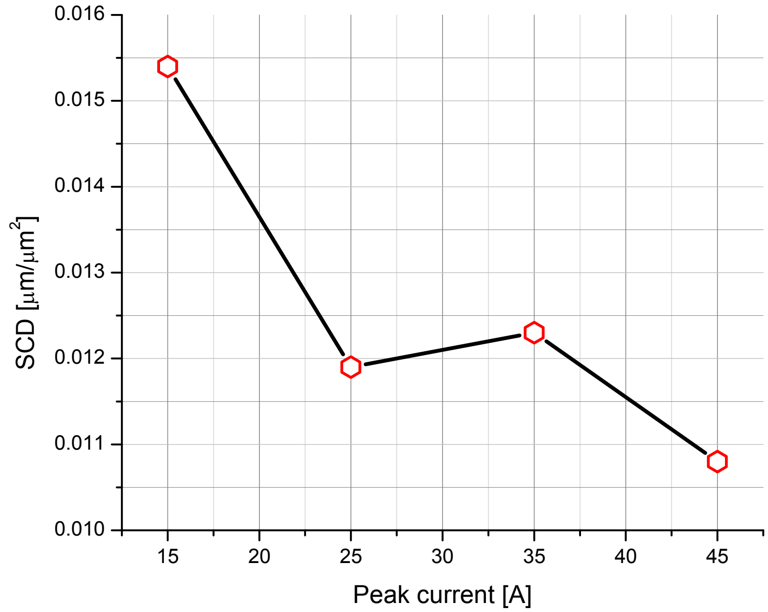


Figure 8. Effect of peak discharge current on SRD



Conclusions

- The machined surface of Nimonic 80A exhibited poor surface morphology characterized by crater, uneven material deposition, globules of debris, pockmark (or chimney) and surface cracks.
- Pyrolysis of EDM oil (dielectric media) resulted in significant carbon migration which further contributed towards formation of carbides at the machined surface. This in turn was expected to improve mechanical properties (hardness) of the machined specimen.
- Increases the peak discharge current resulted into lower rate of material removal, superior surface finish, cracks of higher intensity and thicker white layer. Extremity of surface cracking is found more at higher energy input.
- High energy input resulted in relatively less carbon enrichment onto the machined surface of workpiece.

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