Chronological Advancement of Different Electrode Materials in Electric Discharge Machining (EDM) of Inconel 600

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Abstract—*Electric discharge machining (EDM) is one of most popular machining method to manufacture dies and press tools because of its capability to produce complicated shapes and machine very hard materials. Inconel600 (Nickel Chromium Alloy) is widely used in the industries. The objective of this research is to do a comparative study of Copper, Brass, and Copper-Tungsten (W 80 % & Cu 20 %), tool electrode in EDM of Inconel600 work-piece material. The effectiveness of the EDM process with Inconel600 is evaluated in terms of material removal rate, tool wear rate and surface roughness. Analysis of variance (ANOVA) was performed and the optimal levels for maximizing the responses were established. In case of material removal rate, electrode material and current are the significant parameters. In case of tool wear rate, electrode material is the only significant parameter. Current, pulse-on-time and voltage have insignificant effect on TWR. In case of surface roughness, electrode material and current are the significant parameter. Voltage, pulse-on-time has insignificant effect on SR.*

Keywords—Super Alloys, EDM, Optimization, MRR, TWR, SR, Taguchi Method

I. INTRODUCTION

Industries like aeronautics, automobiles, nuclear reactors, missiles etc. requires advance materials such as composites, ceramics and supper alloy which have high strength temperature resistant alloys, low density, high thermal conductivity, high strength to weight ratio higher strength, corrosion resistance, toughness and other properties [1]. Advance materials are an enlarge scale of engineering materials which provide improved technical properties such as good thermal conductivity, high hardness, high strength to weight ratio and wear resistance. Advanced materials can be classified into composites, ceramics and super alloys [2].

The composite materials provide many infinite possibilities for modern development and material science, totally depending on the application [3]. Ceramics are classified as inorganic and nonmetallic materials that are essential to our daily lifestyle. Super alloys are heat-resisting alloys based on nickel, nickel-iron, or cobalt that exhibit a combination of mechanical strength and resistance to surface degradation at higher temperature. Inconel super alloy series are classified as: Inconel600; Inconel601; Inconel625; Inconel718; Inconel722; Inconel903. Inconel600 has been taken as the working material for the present experiment study.

Electrical discharge machining (EDM) is a thermal process with a complex metal-removal mechanism, involving the formation of a plasma channel between the tool and work piece. It has proved especially valuable in the machining of super-tough, electrically conductive materials such as the new space-age alloys that are difficult to machine by conventional methods [4]. The word unconventional is used in sense that the metal like tungsten, hardened stainless steel tantalum, some high strength steel alloys etc. are such that they can‘t be machined by conventional method but require some special technique.

An unconventional machining process is a special type of machining process in which there is no direct contact between the tool and the work piece. Mechanical Processes, thermal process, electrochemical process, chemical process are different type of unconventional machining process.

II. LITERATURE REVIEW

In this chapter, some selected research papers have been discussed related to Electrical Discharge Machining. The studies carried out in these papers are mainly concerned with the EDM parameters such as tool material, current, voltage, pulse on time, etc. and how these affect the machining characteristics like MRR, SR, TWR, etc. SurajChoudharyet. al. [5] analyzes the MRR and SR with different electrodes on SS 316 with die-sinking EDM using Taguchi Technique. The author made use of copper, brass and graphite as electrodes. Assarzadehand Ghoreishi et.al. [6] Studied to improve process parameters in Electro-Discharge Machining (EDM) of tungsten carbide -cobalt composite grade K10 using cylindrical copper tool electrodes in planning machining mode based on statistical techniques.

S.Dhanabalan et al. [7] studied to optimize the multiple characteristics of electrical discharge machining (EDM) of Inconel718 using copper electrodes having different shapes via Taguchi method-based Gray analysis. C.D. Shah et. al. [8]investigate to optimize the process parameters during machining of Inconel600 by wire electrical discharge machining (WEDM) using response surface methodology (RSM). D. Sudhakaraet. al. [9] made an attempt to analysis the surface characteristics of Inconel 718 using Electrical discharge machining.Zahiruddinet. al. [10] conducted study on “Comparison of energy and removal efficiencies between micro and macro EDM”. It was found that Micro and macro EDM were similar. Manish Vishwakarmaet. al [11] studied the influence of input machining parameters on the material removal rate along with performance measurement analysis.

Priyaranjan Sharma et. al. [12] studied the optimization of multi response parameters of Inconel 600 on EDM using rotary brass hollow tubular electrode by Taguchi Method. Zhao et. al.[13] studied the electrical discharge machining of Ti6Al4V with a bundled electrode. Singh and Shukla et. al. [14] found that the Electrical Discharge Machining (EDM) process influences the material removal rate and other machining characteristics like crater geometry, relative wear ratio and surface roughness. Dinesh Kumar et. al [15] studied over cut during electric discharge machining of Hastelloy Steel with different electrodes using Taguchi Method. P.Janmaneeand

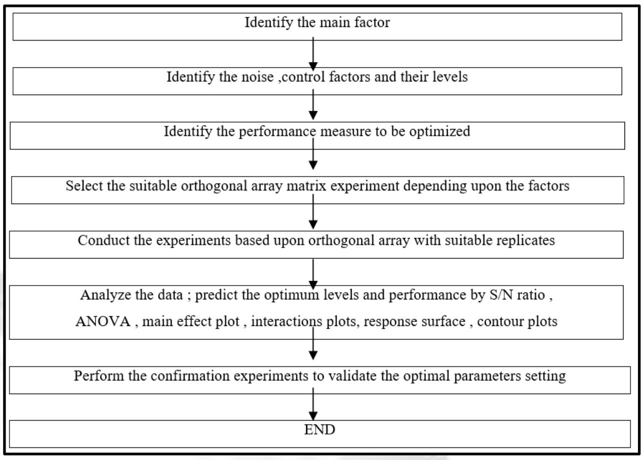
A. Muttamara et.al. [16] Studied the performance of different electrode materials on tungsten carbide work piece with EDM process .The electrodes materials were graphite, copper graphite, and copper-tungsten. S.H.Tomadi et al. [17] studied the influence of operating parameters of tungsten carbide on the machining characteristics such as surface quality, material removal rate and electrode wear. Study was carried out on the influence of the parameters such peak current, power supply voltage, pulse on time and pulse off time.

Bozdanaet. al. [18] conducted experimental study on Inconel718 and α+β type Ti-6Al-4V, with Brass and copper electrodes with tubular hollow shape. Metal removal rate (MRR), electrode wear rate (EWR) and surface characteristics were the output responses. H.S.Payal et al. [19] investigated that, experiment was conducted on EN-31tool steel with copper, brass and graphite as tool electrodes with kerosene oil as dielectric fluid. Kuppan et al. [20] evaluate the influence of EDM process parameters in deep hole drilling of Inconel 718 with electrolytic copper tube electrode of 3mm diameter with IPOL spark erosion 450 as dielectric.Valentincic et al. [21] offered a ‘Design Adaptation System for machining in tool making (DASMT)’ in order to avoid the knowledge gap between product and tool designers.The focus of the presented paper on the development of the Design Adaptation System for EDM (DAS-EDM).

III. DESIGN OF EXPERIMENTS

Design of Experiment (DoE) is a powerful approach to improve product design and performance characteristics, where it can be used to reduce cycle time required to develop new product or processes. DOE also provides a full insight of interaction between design elements therefore, it helps turn any standard design into a robust one. Taguchi techniques were developed by Genichi Taguchi and SeisoKonishi. The Taguchi method is used to minimize the number of the runs and time in order to minimize the various inputs. This is the effective approach to optimize the performance characteristics related to manufacturing processes Taguchi technique involves three stages for off line quality control which are System design, Parameter design and Tolerance design. The system design makes use of engineering and scientific information for producing a part. Parameters design obtains the optimum levels of process parameters. Tolerance design analyzes the optimum combination gives by parameters design.

A. *Steps in Taguchi’s Methodology*



IV. EXPERIMENTAL SETUP

For this experiment the whole work can be down by Electric Discharge Machine, model S 50ZNC (die-sinking type) with servo-head (constant gap) and positive polarity for electrode was used to conduct the experiments.Experiments were conducted with positive polarity of electrode. The major parts of EDM are dielectric reservoir, pump, circulation system, power generator, control unit, working tank with work holding device, X-y table accommodating the working table, the tool holder, servo system to feed the tool.

The work material selected for the present study is Inconel600 (ASTM B166), Nickel Chromium Alloy having hardness value of 75HRC and tensile strength of 655MPa. Melting range of work material lies between the ranges of 1354-1413 degree Celsius. The various performance measures or response variables which are studied in the EDM process are Material Removal Rate (MRR), Tool Wear Rate (TWR), Surface Roughness (SR).

V. MEASURING DEVICES & INSTRUMENTS

Material removal rate (MRR) and tool wear rate (TWR) has been obtained by measuring the weight of specimen before and after prescribed period of machining. For measurement of surface roughness each specimen has been evaluated from three different directions and the mean is taken as on reading.

VI. RESULTS & DISCUSSION

Results of the experiments are studied using the S/N ratio and ANOVA analysis. Based on the results on the S/N ratio and ANOVA analysis, optimal setting of the machining parameters for MRR, TWR and SR are obtained and verified.

A. *Analysis of the Signal to Noise (S/N) Ratio for Material Removal Rate (MRR)*

The terms signal represents the desire value (mean) and the noise represents the undesirable value (standard deviation for mean) for the output characteristics.

$$\frac{S}{N} = -10\log\left(\frac{1}{n}\sum_{i=0}^{n} 1/y_i^2\right) \qquad 6.1$$

$y_i = i^{th}$ response

B. Impact of Input Parameters

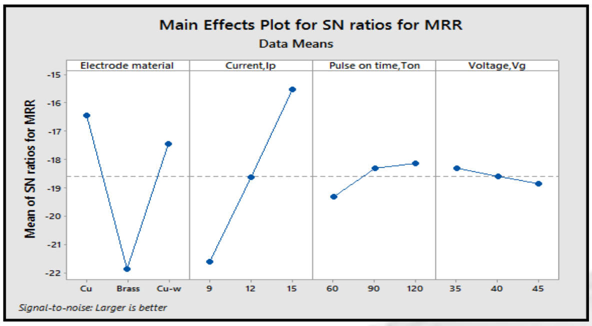


Fig.6.1:Impact of Input Parameters

From the Fig it is clear that MRR increase with increase in current level. Voltage has very less effect on MRR, only 35V shows little higher MRR. The Pulse on time shows that MRR is higher at 120µs and is lower at 60µs. The tool shows significant effect on MRR. Copper tool has highest MRR and Brass tool shows very MRR.

C. Analysis of the Signal to Noise (S/N) Ratio for Tool Wear Rate (TWR)

The term signal represents the desirable value (mean) and the noise represents the undesirable value (standard deviation from mean) for the output characteristic. The objective function in this work is to minimization of TWR, the ratio of signal-to-noise defined according to Taguchi method, Smaller is better is used.

$$S/N = -10\log\left(\frac{1}{r}\sum_{i=1}^{r} y_i^2\right) \quad 6.2$$

y =observation, response data, r =total number of repetitions in trail.

D. Impact of Input Parameters

Fig.6.2 shows that the most important parameter which effects the TWR is tool. Brass tool shows maximum TWR and Copper Tungsten tool shows very little TWR. Apart from Tool, Current also effects the TWR. The TWR increases with increase in current level. Pulse on time has very little effect on TWR. TWR decreases with increase in Pulse on time.

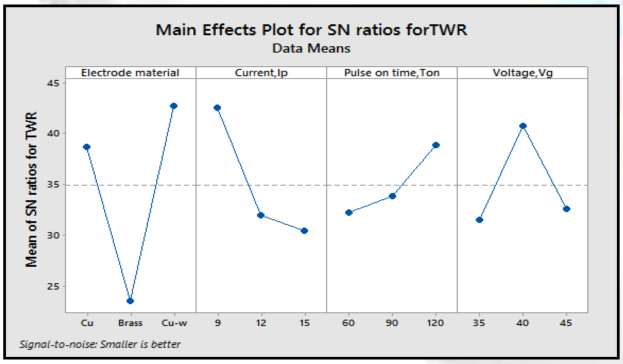


Fig.6.4:Impact of Input Parameters

E. Analysis of the Signal to Noise (S/N) Ratio for Surface Roughness (SR)

The term signal represents the desirable value (mean) and the noise represents the undesirable value (standard deviation from mean) for the output characteristic. The objective function in this work is to minimization of SR, the ratio of signal-to-noise defined according to Taguchi method, Smaller is better is used.

$$S/N = -10\log\left(\frac{1}{r}\sum_{i=1}^{r} y_i^2\right) \quad 6.3$$

y =observation, response data, r =total number of repetitions in trail, y =ith response.

F. Impact of Input Parameters on SR

The effect of input parameter of electrode material, pulse current, pulse on time and voltage on surface roughness has been demonstrated in Fig.5.8 Surface roughness increases with the increase of pulse current. The increase of surface roughness is due to the increase of spark energy, which causes the surface pits resulting from the removal of material to enlarge. With the increase of pulse on time in the machining of Inconel600 alloy using copper tools up to 90µs, surface roughness diminishes; and a further increase of pulse on time beyond 90µs results in the increase of surface roughness. Voltage has less effect on surface roughness.

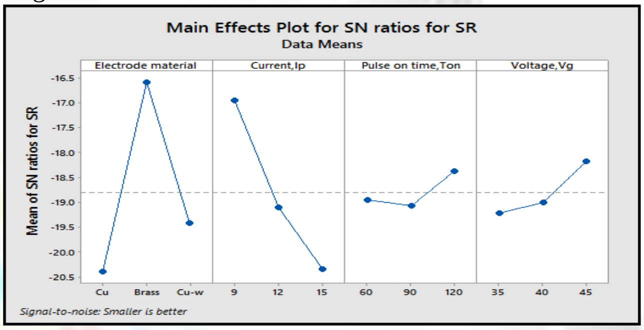


Fig. 6.3: Impact of Input Parameters on SR

VII. CONCLUSIONS

1) For material removal rate “Larger the better” approach has been used as it is desired that MRR should be maximum because larger MRR helps in reducing the cost of machining of work-pieces. The optimal settings obtained for MRR are copper electrode, peak current = 15A, pulse-on-time = 120 µs, and voltage = 35V (A1B3C3D1).
2) For tool wear rate “Smaller the better” approach has been used as it is desired that TWR should be minimum in order to achieve better quality products. TWR is mostly influenced by electrode material, pulse current and then voltage, and last is pulse-on-time. The optimal settings obtained for TWR are Copper-tungsten electrode material, pulse current = 9A, pulse-on-time = 120 µs, and voltage = 40V (A3B1C3D2).
3) For surface roughness “Smaller the better” approach has been used as it is desired that SR should be minimum in order to achieve better quality products. SR is mostly influenced by electrode material, pulse current, voltage, and last is pulse-on-time. The optimal settings obtained for SR are Brass electrode material, pulse current = 9A, pulse-on-time = 120 µs, and voltage = 45V (A2B1C3D3).

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