Experimental Investigation of Process Parameters on Inconel 925 for EDM Process by using Taguchi Method

Vishal Kumar Jaiswal[1] Amitesh Paul[2] Vikas Yadav[3] Vijay Singh[4]
[1,3,4]PG Student (M.Tech)
[1,2,3,4]Department of Mechanical Engineering
[1,3,4]Sri Satya Sai College of Engineering, RKDF University, Bhopal [2]RKDF University, Bhopal

Abstract— By means of the improvement and growths in new mechanisms, low weight- high strength, high hardness and temperature resistant materials have been advanced for distinctive applications which include aerospace, medical, automobile and more. In the machining of hard and metal matrix composite materials, outdated manufacturing processes are being more and more changed by more non-traditional machining processes which include Electrical Discharge Machining (EDM). The work piece material designated in this experiment is Inconel 925 taking into interpretation its wide usage in industrial applications. In today's world stainless steel provides to nearly half of the world's production and consumption for industrial determinations. In this experiment the input variable factors are voltage, current and pulse on time. As we know that Taguchi method is functional to produce an L9 orthogonal array of input variables by means of the Design of Experiments (DOE). So, Taguchi method is used to analysis the output data. The consequence of the compliant parameters stated overhead upon machining characteristics such as Material Removal Rate (MRR) and Tool Wear Rate (TWR) is considered and examined. In this we are focused on to analysis minimum TWR and maximum MRR based on control factors and response parameters.

Key words: EDM, Electric Discharge Machining, Unconventional Manufacturing Process, TWR, MRR, Inconel 925

I. INTRODUCTION

A. *Electrical discharge machining*

As we know that the basic EDM process is actually pretty modest technique. An electrical spark is produced between an electrode and a workpiece material. We can see that the spark is visible indication of the flow of electricity. This electric spark produces near about extreme heat with temperatures getting 8000 to 12000 degrees Celsius, that can be melting nearly everything. The spark is actual sensibly organized and confined so that it only affects the material's surface. The EDM process typically does not affect the heat treat below the surface. [1] With wire EDM the spark continuously takes place in the dielectric of deionized water. The conductivity of the water is cautiously controlled formation an outstanding environment for the EDM method. The water behaves as a coolant and flushes gone the eroded metal elements.

The main apprehension is the optimization of the method parameters for refining the output characteristics, i.e., maximize the material removal rate (MRR) and concurrently diminish the tool wear rate (TWR) and the surface roughness (CLA value). A number of attempts to model the process have been stated in the literature by applying analytical, numerical or empirical methods.

EDM process is used to formed the desired shape with the help of electrical discharge operations. Material removal process has completed due to current discharge between two electrodes. Dielectric liquid and electric voltage play very important role in this operation. As we know that electrical discharge machining operations stated under non-conventional machining techniques. It is typically used for machining operations on hard metals and for complex operations, which are nearly difficult with outdated techniques [2].

The EDM process is eliminating undesirable material in the form of debris and produce shape according of the tool surface as of a workpiece piece via an electrical discharge trapped between tool and work piece i.e. (cathode and work piece) in occurrence of dielectric fluid. In these machining procedure tool is committed to negative so it called cathode (polarized electrical device) and work piece is called the anode, because, it is attached to positive. Dielectric fluids are kerosene, transformer oil, distilled water, may be filled.

B. *Die-sinking EDM process*

This process was originated by two Russian scientists, B. R. Butinzky and N. I. Lazarenko in 1943 to catch the ways of checking the erosion of tungsten electrical contacts due to sparking. Numerous times, they were unsuccessful in this assignment but they establish that the erosion was more precisely controlled if the electrodes were immersed in a dielectric fluid [3]. This led them to develop an EDM machine used for working difficult-to-machine materials such as tungsten.

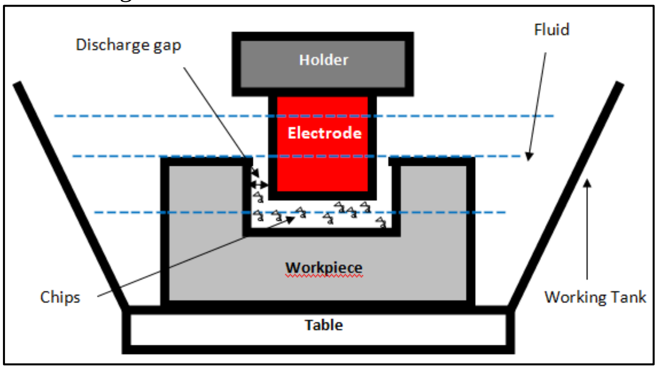

Fig. 1: Mechanism of Die-Sinker EDM

In this process two electrodes are fitted on their places on the machine parts which is work bench and the tool holder. Both the electrodes must be the electrically conductive. After that both the electrodes are immersed in an insulating liquid dielectric with the help of the pump. The dielectric is the EDM oil/ kerosene / transformer oil. Then set the machining parameters on the CNC controller for machining on the work piece to get required shape and the size.

C. Wire EDM process

The wire-cut types of machine founded in the 1960s for the determination of manufacture tools (dies) from hardened steel. In this process the tool electrode in form of wire. So, it is clear that due to this erosion of material causes. To avoid the erosion of material from the wire causing it to break, the wire is wound between two reels so that the dynamic part of the wire is constantly changeable [3].

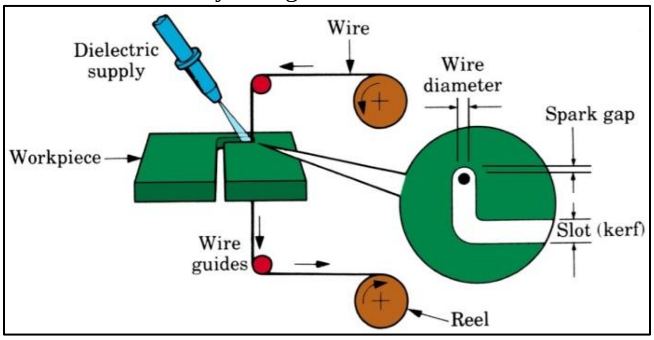

Fig. 2: Mechanism of Wire EDM

The wire cut EDM process also called electric discharge wire cutting process. It is used for the producing two or three dimensional complex shapes using an electro thermal mechanism for eroding the material from a thin single stranded by guide metal wire surrounded by deionized water which is used to the conduct electricity.

D. Dielectric Fluid

It is used as a coolant, flushing medium and also a catalyst conductor. It plays very important roles in EDM process. The requirements are:

1) The dielectric should have compulsory and constant dielectric strength to serve as insulation between tools and the work, till the breakdown voltage is reached.
2) It must be de-ionizing speedily afterwards the spark ejection has taken place.
3) It must need small viscosity and a polite moistening ability to provide effective cooling mechanism and remove the swerve particles from the machining gap.
4) It should flush out of the element produce during the spark out of the gap. This is the most important purpose of the dielectric fluid. Insufficient flushing can result in arcing decreasing the life of the electrode and increasing of the machining time.
5) It should be chemically in neutral, so as not to attack to the tool, job and the movable table or the tank.
6) Its flash point should be high so that there are no fire threats.
7) It should not release any toxic vapours.
8) It should sustain these properties with temperature variation, contamination by working residuals and products of the decomposition.
9) It should be economical and easily available in nature [4].

II. CURRENT RESEARCH DETERMINATIONS

Rao, P. Srinivasa et al.[5] have studied that have an effect on by means of design four factors such as current, servo control, duty cycle and open circuit voltage over the outputs on the MRR, TWR, SR and hardness on the die-sinker EDM process of machining AISI 304 SS. They have been hired the DOE technique with mixed degree layout and to analyze for appearing a minimal quantity of runs. They finished that for higher the MRR, the current, servo and duty cycle should be fixed as high levels and 95% confidence level with descending order in case of the TWR with equal elements.

S. H. Tomadi et al.[6] analyzed that impact of machining settings of the tungsten carbide on the outputs such as TWR, MRR and Surface finish. Confirmation check finished to assess errors between the predicted values and to experimental runs in terms of machining characteristics. They were found out copper tungsten tool use for better surface finishing of work piece. They were using full factorial DOE, to optimization and discovered out with greater pulse off time lesser tool wear of the tungsten carbide and with current, voltage and pulse on time increment with tool wear increased.

Zhao Wansheng et al.[7] have studied about surface machining process by EDM. Shows the consists of a series of discharge craters, and explain that there is no screw-like trail left on the hole's inside wall that would be formed by ordinary drilling. This can change the field of distribution condition when fluid or gas flows through the small hole. As there is no macroscopic force, it is easy to machine a half hole by using EDM.

Ulas Çaydas et al.[8] analyzed that the EW and WLT in die-sinking EDM process were modelled and analyzed through response surface methodology (RSM). A valuable central composite rotatable design (CCRD) in RSM consisting of three variables. Pulse on time, pulse off-time and pulse current have been employed to carry out the experimental study have a look at. Analysis of variance (ANOVA) was applied to study. Their predicted values match the experimental values reasonably nicely, with R2 of 0.99 for EW and R2 of 0.97 for WLT. Pulse current was found the most essential factor effecting the both EW and WLT, even as pulse off-time has no enormous impact on both responses.

H. Shen et al. [9] have studied in micro EDM, they defined about the discharge gap that is very small, and the dimensions of the electrode is just too small to use internal and/or outside flushing to dispose of debris. In their paper, a new method the usage of planetary movement of the electrode is proposed to lessen the particles concentration and enhance precision. The planetary movement of electrode provides extra area for particles elimination. Therefore, the material removal rate increases and the electrode wear reduce. This method has been confirmed through machining of micro holes with excessive element ratio and blind noncircular micro holes.

G. Appa Rao et al. [10] have studied the effect of normal heat treatment on the microstructure and mechanical properties of hot isostatically pressed superalloy inconel 718. In this, Inconel 718 was analyzed processed through powder metallurgy (P/M) hot isostatic pressing (HIP) route. In this study, they have led to better study of the property and structure relationships in HIP + heat treated analysis on alloy 718 and suggest that the standard heat treatment approved for wrought IN 718 is not convenient for HIPed alloy and has to be modified to realize optimum properties.

The stress rupture life and ductility of the alloy have also made better marginally after heat treatment and has got the minimum expected life for wrought heat treated

IN 718, however, the rupture ductility was found to be much less than the specified value. This suggest that the recommended heat treatment for wrought alloy is not suitable for HIP processed alloy and has to be modified to realize optimum properties.

P. Kuppan et al. [11] shows the experimental analysis of small deep hole drilling of Inconel 718 using the EDM process. The parameters such as peak current, pulse on-time, duty factor and electrode speed were selected to study the machining components characteristics. In these experiments, they were prepared using central composite design (CCD) method. The output feedbacks measured were material removal rate (MRR) and depth averaged surface roughness (DASR). The process parameters are enhanced for the maximum MRR with the specified surface roughness value 3 µm and 3.5 µm using desirability function approach. The optimized parameters are fairly in good compliance with the experimental values. For Inconel 718, the outcome of pulse on-time is irrelevant on MRR but strongly effect the DASR. Hence to achieve better surface finish low value of pulse on-time to be selected.

T.A. Spedding et al. [12] analyzed the response surface methodology and artificial neural networks models. It have been developed for the wire EDM process, experiments showing that both of the models are able to predict the process performance, such as cutting speed, surface roughness, surface waviness within a reasonable large range of input factor levels. In the investigating area, the ANN model is found to fit the data better and have higher predictive capability to Ra and the cutting speed. From the results presented in this paper it can be concluded that these techniques can be extended to processes exhibiting similar stochastic character and complexity.

K. Salonitis et al. [13] studied about theoretical thermal model. It has been proposed for the simulation of the die-sinking EDM process. A number of experiments were conducted in order for the effect of the current and the discharge duration in the MRR and the average surface roughness to be studied. The MRR and average surface roughness can be decided with an average deviation of 8.2 % and 6.1 %, respectively. The deviations are attributed to the assumptions posed during the development of the model, i.e., the overlook of the recast layer's formation and the idea that the idling time is insignificant in comparison with the discharge duration.

III. MATERIAL USED

A. Inconel 925 (Workpiece)

In this study and analyze all the effects of machining variables like pulse on time, discharge current and voltage on the output results such as during machining, MRR of the INCONEL 925 work piece by using copper tool material with TWR data.

Table No. 1 Chemical Composition of INCONEL 925

Element	Required Weight %	Actual Weight %
Carbon	0.03 max	---
Nickel	42.0-46.0	42.95
Chromium	19.5 – 22.5	20.13
Molybdenum	2.5-3.5	2.68
Copper	1.5-3.0	1.54
Manganese	1.0 max.	---
Silicon	0.5 max.	---
Aluminum	0.1-0.5	---
Titanium	1.9-2.4	2.12
Iron	22 min.	Balance

Many conventional and non-conventional methods for machining Inconel 925 are available. Inconel 925 is a non-stabilized austenitic stainless steel [14] with low carbon content.

Table No. 2 Physical & Mechanical Properties

Density	8.05 gm/cm^3
Specific Heat	450 J/kg-°K
Electrical Resistivity	1.17 µΩ m
Modulus of Elasticity	190 GPa
Melting Range	1311–1366°C
Thermal Conductivity 212°F (100°C)	12.9 W/m-°K
Yield Strength	810 MPa
Ultimate Tensile Strength	1210 MPa
Hardness	

Alloy 925 is an phase hardenable nickel based alloy that covers chromium and iron. Its configuration offers a high level of strength and corrosion resistance. Frequently available as Inconel 925, alloy 925, it is known for a number of dissimilar unique properties together with:

1) Safety in oxidizing and reducing atmosphere
2) Resistance to chloride ion stress-corrosion cracking
3) Excellent resistance to opposing and crack corrosion

Many diverse industries depend on Alloy 925 for a number of uses including:

1) Valves, hangers, packers, and tubulars for sour gas production
2) Marine fasteners and pump shafts

B. Electrode (Tool)

To obtain the better accuracy, the electrode must be design with the nearby tolerance. Over cut and under cut is the major problem in the EDM process. It can enhance by lamination of tool by insulating material.

The tool material used in the Electro Discharge Machining can be of a variety of metals such as copper, brass, aluminum alloys, silver alloys etc. The material used in this experiment is copper. The tool electrode is in the shape of a cylinder form having a diameter of 18mm.

Fig 3: Copper electrode for EDM process

The MRR is the rate at which material gets removed from work material surface. Electric discharge as spark is created between the tool and workpiece during the machining process. Every spark forms a minute crater and thus erosion of material is caused. The MRR is specified as the ratio of variation in workpiece weight before and multiplication of after machining to the density of the material and the machining time.

$$MRR = \frac{W_i - W_f}{\rho t}$$

IV. METHODOLOGY

A. *Taguchi Method*

As we know that, from 1960, Taguchi method has been used for improvement and quality achievement of Japanese products for good response. Adopting Taguchi's robust design methodology job can be manufactured rapidly and at the least cost. During 1980 many Japanese companies began to feel that the old methods of ensuring the quality were not correct as a comparison with Japanese methods [15].

B. *Selection of levels and control factors*

All these three process parameters with three levels are selected as the control parameters so that the levels are appropriately distant. Hence they beset wider range. These process parameter and their ranges are analyzed using literature, books, and experience of machine operators.

C. *Selection of orthogonal array*

As we know that Orthogonal Arrays (generally referred to Taguchi Methods) are usually engaged in the industrial experiments to study the consequence of several control factors. The Taguchi technique has been used to generate a scheme of arranged the designs (arrays) which allow the maximum number of major conclusions to be predictable in an uncategorized way, with least number of the iterations in the experiment. The orthogonal arrays are generally used to follow the system systematically vary and test different levels of each of the control factors.

Generally, in orthogonal arrays include the L4, L9, L12, L18, and L27 experiments. The columns in the orthogonal arrays show factor and its corresponding the levels, and each row in orthogonal arrays established an experimental which is acted at the given factor settings. Typically, either 2 or 3 levels are selected for each the factor. To selecting the number of levels and quantities properly of constitutes the bulk of the effort in planning robust design experiments [16].

Table No. 3 Standard L9 (3^3) O.A.

S.NO	Level		
	1	2	3
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

D. *ANOVA Approach & Signal to Noise Ratio*

Evaluation of Variance (ANOVA) is likewise called statistical technique that's used to analyze variations between two or more ways. It can appearance peculiar that the method is referred to as "analysis of Variance" in the region of "evaluation of Means." As we are able to see, the name is suitable due to the fact assumptions about manner are made with the aid of evaluating variance [17].

Well, there are so many different possible ways in the S/N ratios equation, mostly these three of them are noticed standard and are usually suitable for this situation given below:

1) Biggest-is-best quality characteristic
2) Smallest-is-best quality characteristic and
3) Nominal-is-best quality characteristic

1) Smaller the better (for making the system response such as small as possible):

$$\text{SNs} = -10\ log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^{\,2}\right)$$

2) Nominal the best (for reducing variability around the target):

$$SN_T = 10\log\left(\frac{y^2}{s^2}\right)$$

3) Larger the better (for making the system response such as large as possible):

$$SN_L = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^{\,2}}\right)$$

V. RESULT & DISCUSSION

In this chapter we will discuss the results obtained and along with that find out the influential parameters that affect the MRR and TWR.

In this conclusion, there are following major factors are reviewed:

A. *Selected Input Data*

Table No. 4 Control Factors And Levels.

Levels	Voltage V(v)	Current I (A)	Pulse on Time T_{on} (μsec)
1	50	9	300
2	60	13	400
3	70	17	500

B. *Effect of Control factor on MRR & TWR*

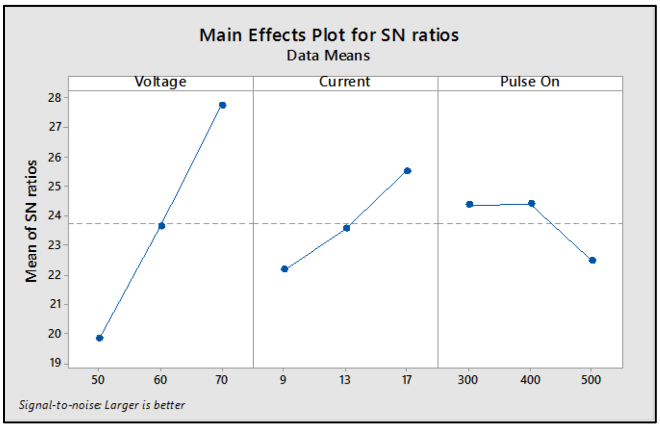

Fig. 4: Main effect plot for SN Ratios MRR

All calculation and optimized values obtained By using MINITAB 18 software.

Table No. 5 Confirmation table for MRR

Optimal Machining Parameters		
	Predicted values	Experimental Values
Level	A3B3C2	A1B3C3
MRR (gm/min)	31.429	32.795
S/N Ratio	30.1983	30.3162

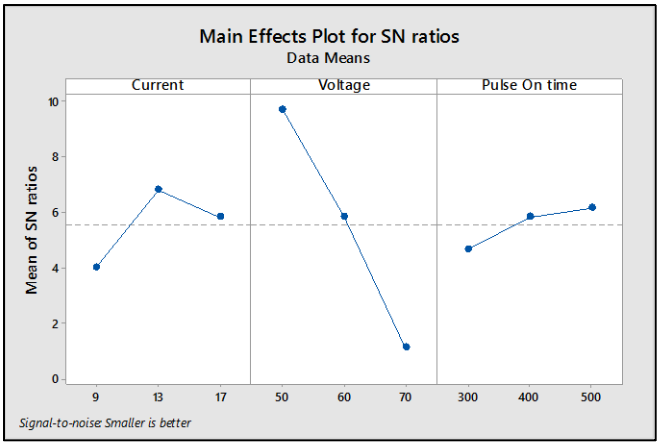

Fig. 5: Main effect plot for SN Ratios TWR

Table No. 6 Confirmation table for TWR		
Optimal Machining Parameters		
	Predicted values	Experimental Values
Level	A1B3C1	A2B1C2
TWR (gm/min)	0.246433	0.223
S/N Ratio	11.5814	13.0339

C. Bar chart for MMR & TWR

Figure 6 shows the three dimensional bar chart plot of MRR against different input variable. It indicates the variation of MRR at different level, MRR is highest in this plot at experiment.

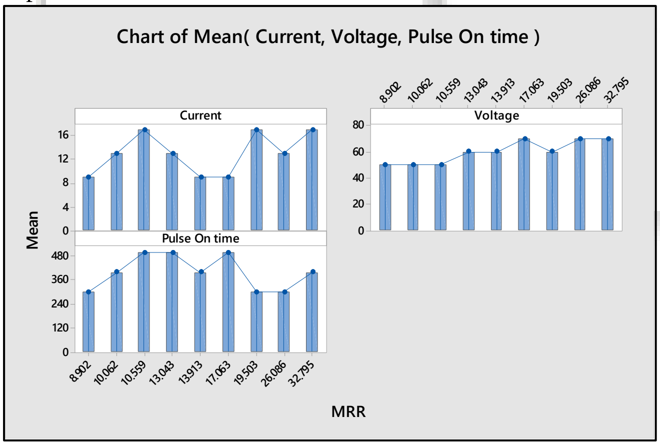

Fig. 6: Bar chart of Mean for MRR

Figure 7 shows the three dimensional bar chart plot of TWR against different input variable. It indicates the variation of TWR at different level, TWR is lowest in this plot at experiment.

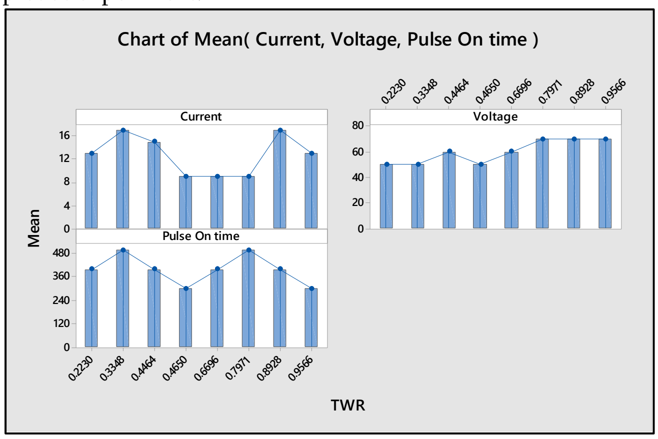

Fig. 7: Bar chart of Mean for TWR

D. Scope for Future Work

- Innovative technology in the EDM is unceasingly progressing to make this procedure further appropriate for the Machining. In the field of manufacturing additional attention is on the optimization of the method by dropping the number of Electrode.
- The mathematical model can be advanced different workpiece and electrode materials for EDM.
- Results like roundness, circularity, cylindricity, machining cost etc. are to be dignified in additional research.
- The standard optimization procedure can be developed and the optimal results are to be validated.

REFERENCES

[1] K. Salonitis, A. Stournaras, P. Stavropoulos & G. Chryssolouris "Thermal modeling of the material removal rate and surface roughness for die-sinking EDM" Int J Adv Manuf Technol (2009) 40:316–323.
[2] Sushil Kumar Choudhary (2014) Current Advanced Research Development of Electric Discharge Machining (EDM), International Journal of Research in Advent Technology, Vol.2, No.3 (E-ISSN: 2321-9637) pg. 273-274
[3] Jameson, E. C. (2001). Electrical Discharge Machining. SME. ISBN 978-0-87263-521-0. p. 8, pp 12-17
[4] Murphy, E. J.; Morgan, S. O. "The Dielectric Properties of Insulating Materials". Retrieved October 2, 2012.
[5] Rao P. Srinivasa, Reddy Sidda B., Kumar JS and Reddy KVK, Fuzzy modelling for electrical discharge machining of AISI 304 stainless steel, Journal of Applied Sciences Research, 6(11) (2010): pp. 1687-1700.
[6] Tomadi SH, Hassan MA, Hamedon Z, Daud R, Khalid AG. Analysis of the influence of EDM parameters on surface quality, material removal rate and electrode wear of tungsten carbide. In Proceedings of the International MultiConference of Engineers and Computer Scientists 2009 Mar 18 (Vol. 2, pp. 18-20).
[7] Zhao Wansheng, Wang Zhenlong , Di Shichun, Chi Guanxin, Wei Hongyu "Ultrasonic and electric discharge machining to deep and small hole on titanium alloy." Journal of Materials Processing Technology 120 (2002) 101-106.
[8] Ulas Çaydas & Ahmet Hasçalik, "Modeling and analysis of electrode wear and white layer thickness in die-sinking EDM process through response surface methodology", Int J Adv Manuf Technol (2008) 38:1148–1156.
[9] Z.Y. Yu, K. P. Rajurkar and H. Shen, "High Aspect Ratio and Complex Shaped Blind Micro Holes by Micro EDM" University of Nebraska-Lincoln, USA 2002.
[10] G. Appa Rao, Mahendra Kumar, M. Srinivas, D.S. Sarma "Effect of standard heat treatment on the microstructure and mechanical 2003.
[11] P. Kuppan & A. Rajadurai & S. Narayanan, "Influence of EDM process parameters in deep hole drilling of Inconel 718" Int J Adv Manuf Technol (2008) 38:74–84.properties of hot isostatically pressed superalloy

inconel 718.” Materials Science and Engineering A355 (2003) 114/125.
[12] T.A. Spedding and Z.Q. Wang “Study on modeling of wire EDM process” Journal of Materials Processing Technology 69 (1997) ! 8- 28
[13] K. Salonitis, A. Stournaras, P. Stavropoulos & G. Chryssolouris, “Thermal modelling of the material removal rate and surface roughness for die-sinking EDM" Int J Adv Manuf Technol (2009) 40:316–323.
[14] Kiyoko Takeda, Haruhiko Kajimura, Mitsuo Miyahara, Current Assignee "Sumitomo Metal Industries Ltd" p.1 (2002-12-12)
[15] Rosa, Jorge Luiz; Robin, Alain; Silva, M. B.; Baldan, Carlos Alberto; Peres, Mauro Pedro. "Electro deposition of copper on titanium wires: Taguchi experimental design approach". Journal of Materials Processing Technology. 209: 1181–1188.
[16] C. L. Lin, J. L. Lin and T. C. Ko "Optimisation of the EDM Process Based on the Orthogonal Array with Fuzzy Logic and Grey Relational Analysis Method". Int J Adv Manuf Technol (2002) 19:271–277.
[17] Gelman, Andrew (2005). "Analysis of variance? Why it is more important than ever". The Annals of Statistics. 33: 1–53.