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Comparing and Optimization of Material Removal Rate of Cryogenically Treated and Untreated Copper Tools Using EDM

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Abstract - Super alloys are advanced engineering materials, having high potential for aerospace and defence industries. Inconel 625, a nickel-chromium heat resistant alloy, finds its applications in the manufacturing of aerospace fasteners, gas turbine engineering and heat treatment equipment. In this study, electric discharge machining is used for making holes on inconel 625. Three control factors namely pulse current, pulse on time and flushing pressure having three levels each be taken into consideration and material removal rate (MRR) was taken as a response measure. Experiments were based on (L18 2^1x3^3) orthogonal array of Taguchi's methodology. Results analyzed showed that MRR increased as pulse current and tool electrode rotation increased. MRR was more for tool electrodes cryogenically treated than tool electrodes untreated.
***Keywords*: Advanced materials, EDM, Cryogenic treatment, Taguchi methodology, Optimization, MRR.**

I.INTRODUCTION

In the previous few decades the non traditional method of machining has become very popular. Electric Discharge Machining (EDM) is most popular among all non traditional machining methods. Electric Discharge Machining has its applications in aerospace, automotive, nuclear, medical and die mould production [1]. The machining of super alloys and the complex shapes can be easily produced using Electric Discharge Machining. Cryogenic treated tools play important role. Cryogenic treatment can be characterized by its application temperature, below 123^{o}K (-150^{o}C) or at about liquid nitrogen temperature (-196^{o}C). Cold treatment or sub-zero treatment includes below zero but higher temperatures than the cryogenic temperatures (down to about -80^{o}C) [2].The process has a wide range of applications from industrial tooling to improvement of musical signal transmission. Some of the benefits of cryogenic treatment include longer part life, less failure due to cracking, improved thermal properties, better electrical properties including less electrical resistance, reduced coefficient of friction, less creep and walk, improved flatness, and easier machining.

Hocheng and Guu (2001) [3] studied AISI D2 steel and concluded as the rotational speed increased, material removal rate also increases, due to easily removal of the debris. Surface roughness decreased due to increase in rotational speed.

Yan *et. al.* (2002) [4] studied the machining characteristics of 6061 Al composite by using rotary EDM. Material removal rate was affected by polarity and peak current that affects the electrode wear rate and relative wear rate. Newman and Ho (2003) [5] studied state of the art electrical discharge machining. This paper reviewed from the inception to the development of die-sinking EDM. MRR was improved by using multi-electrode discharging system. Delivering additional discharge simultaneously from a corresponding electrode connected serially. Newton *et. al.* (2009) [6] studied inconel 718 possessing high strength at elevated temperatures and resistance to oxidation and corrosion. Recast layer thickness increased with energy per spark, peak discharge current, and current pulse duration. Rupinder *et. al.* (2010) [7] advocated that cryoprocessing is a supplementary process to conventional heat treatment, involves deep freezing of materials at cryogenic temperatures to enhance the mechanical and physical properties. The execution of cryoprocessing on cutting tool materials increases wear resistance, hardness, and dimensional stability and reduces tool consumption and down time for the machine tool set up, thus leading to cost reductions. Flavio J. da *et. al.* (2006) [8] studied the effect of cryogenically treated (CT) AISI M2 grade high speed steel tools and reported complete transformation of retained austenite and no improvement in hardness value. A maximum of 44% improvement in tool life under Brandsma rapid facing test was observed. Improvement in tool life 65-343 % in case of twist drills was reported. Overall the CT had a favourable improvement on the life of tools tested. Firouzdor V. *et. al.* (2008) [9] studied the effect of deep cryogenic treatment on wear resistance and tool life of M2 HSS drill. An increase of 77% and 126% in tool life of cryogenic treated and cryogenic treated tempered drills was reported. Wear resistance improvement was attributed to the fine precipitates of carbides during CT. Vadivel and Rudramoorthy (2009) [10] analyzed the performance of cryogenic treated carbide tips. Cryogenic treatment changed the microstructure of the material which influenced the tool life. The untreated carbide inserts and treated carbide inserts were compared by turning nodular cast iron. The cryogenic treated coated carbide inserts gave better surface finish, less flank wear and less power consumption as compared to the untreated carbide inserts. The cryogenic treatment was done at -196oC and holds at soaking temperature for 10 to 60 hours, and was brought back slowly to ambient temperature.

The work specimen was heated to a temperature of 400oC and then brought back to ambient temperature. The SEM analysis showed that the wear resistance of cryogenically treated inserts is higher than un-cryogenically treated inserts due to the presence of the fine carbides. Akhbarizadeh *et. al.* (2009) [11] studied the effect of cryogenic treatment on the wear behavior of D6 Tool Steel. DCT has more chromium carbides compared to shallow cryogenic treatment (SCT) and also due to complete elimination of retained austenite in DCT specimen the wear resistance of DCT specimen was much higher. Also stabilized samples showed improvement in hardness after one week than the non stabilized samples.

Orthogonal Array

Orthogonal array is the foundation for designing an experiment with Taguchi methodology. Responses are obtained by orthogonal array via running the experiments. Orthogonal array divided into full level, two level, and three level classes. Each level has equal number of occurrence within each column [12].

TABLE 1 L18 ORTHOGONAL ARRAY

Run No.	**Noise Factor**	**Controllable Factors**		
	A	**B**	**C**	**D**
1	1	1	1	1
2	1	1	2	2
3	1	1	3	3
4	1	2	1	1
5	1	2	2	2
6	1	2	3	3
7	1	3	1	2
8	1	3	2	3
9	1	3	3	1
10	2	1	1	3
11	2	1	2	1
12	2	1	3	2
13	2	2	1	2
14	2	2	2	3
15	2	2	3	1
16	2	3	1	3
17	2	3	2	1
18	2	3	3	2

The standard form of orthogonal array is given in equation no. 1

LA (BC) …………

……………………………………………….. (1)

Where, A = number of experiments

B = number of levels

C = number of factors

In this particular study, L18 orthogonal array with one noise factor having two levels and three control factors with three levels each. Table 1 shows L18 orthogonal array (21×33).

II.DESIGN OF EXPERIMENTS

The design of experiments (DOE) technique is a powerful work tool which allows us to model and analyzed the influence of determined process variables over other specified variables, which are usually known as response variables.

The analysis is made on the basis of experimentation and the experiments are designed on the basis of Taguchi methodology. By proper designing this can be achieved by minimum number of experiments. The levels are decided on the basis of preliminary experiments [13]

For this particular study, Inconel 625 super alloy is selected as work material. Inconel 625 super alloy finds its applications in marine industries, aerospace industries, chemical processing and nuclear reactors. Two electrodes were used in this study one is simple copper electrode and second is cryogenically treated electrode. Table 2 shows plan of experiments.

TABLE 2 L 18 ($2^1 \times 3^3$) ORTHOGONAL ARRAY WITH VALUES OF LEVELS

Sr. No.	**Electrode Treatment**	**Pulse Current**	**Pulse on Time**	**Flushing Pressure**
1	U.T.	9	50	0.25
2	U.T.	9	75	0.50
3	U.T.	9	100	0.75
4	U.T.	12	50	0.25
5	U.T.	12	75	0.50
6	U.T.	12	100	0.75
7	U.T.	12	50	0.50
8	U.T.	15	75	0.75
9	U.T.	15	100	0.25
10	C.T.	9	50	0.75
11	C.T.	9	75	0.25
12	C.T.	9	100	0.50
13	C.T.	12	50	0.50
14	C.T.	12	75	0.75
15	C.T.	12	100	0.25
16	C.T.	15	50	0.75
17	C.T.	15	75	0.25
18	C.T.	15	100	0.50

U.T.-Untreated, C.T. - Cryogenically Treated

III.PROCEDURE

The experiments had been performed on the EDM machine Electra Puls PS 35. Spark erosion oil was used as the dielectric fluid.

Values of parameter like pulse current, pulse on time and flushing pressure is set according to design matrix. The values of various parameters which are held constant during the experimentation work is set. Spark button is then switched on. After machining time of 10 minutes spark automatically stops and machine head is moved upwards by control panel.

Fig. 1 Work piece material after experimentation with cryogenically treated tool electrode

Response Measures
Material removal rate (MRR)

Material removal rate is defined as the amount of material removed per unit time. The unit of the MRR is g/min and calculated by the formula given below:

$$MRR = \frac{(W_{wi} - W_{wf})}{t}$$

Where, W_{wi} = weight of the work material before machining in grams.
W_{wf} = weight of the work material after machining in grams
t = machining time in min.

Experimental Data

The experimentation results were obtained after performing experimentation and tabulated in Table 3. The material removal rate was calculated by measuring the initial and final weights of the material divided by machining time. Since each of the experimental runs were conducted twice, the mean material removal rate was calculated.

TABLE 3 EXPERIMENTAL DATA

Sr. No.	Electrode Treatment	Pulse Current	Pulse on Time	Flushing Pressure	MRR	S/N Ratio MRR
1	U.T.	9	50	0.25	0.08492	-21.4218
2	U.T.	9	75	0.50	0.09413	-20.5282
3	U.T.	9	100	0.75	0.08835	-21.0808
4	U.T.	12	50	0.25	0.14792	-16.6006
5	U.T.	12	75	0.50	0.15993	-15.9230
6	U.T.	12	100	0.75	0.17456	-15.1641
7	U.T.	12	50	0.50	0.14672	-16.6714
8	U.T.	15	75	0.75	0.18592	-14.6144
9	U.T.	15	100	0.25	0.22758	-12.8604
10	C.T.	9	50	0.75	0.30235	-10.3912
11	C.T.	9	75	0.25	0.21522	-13.3432
12	C.T.	9	100	0.50	0.23956	-12.4139
13	C.T.	12	50	0.50	0.32119	-9.86719
14	C.T.	12	75	0.75	0.25225	-11.9651
15	C.T.	12	100	0.25	0.17726	-15.0307
16	C.T.	15	50	0.75	0.25482	-11.8760
17	C.T.	15	75	0.25	0.26998	-11.3759
18	C.T.	15	100	0.50	0.33615	-9.47063

Subsequently, the signal to noise ratio for material removal rate had been calculated and has been shown in Table 5.1.

Analysis of Variance for S/N Ratio for MRR

The calculated values of sum of square, mean of square, F – value and P –value are shown in Table 4. The factor which is significant can be predicted from this table. Since the value for tool electrode treatment, pulse current is less than 0.05; the factors are significant at confidence level of 95.0%. While P – value for pulse ON time, and interaction between tool electrode treatment and pulse current is greater than 0.05, which implies that these parameters are not significant at confidence level of 95.0%.

TABLE 4 ANALYSIS OF VARIANCE FOR S/N RATIO FOR MRR

Input	Degree of Freedom	Sum of Squares	Mean sum of squares	F - value	P – value
Tool electrode treatment	1	134.103	134.103	40.98	0.032
Pulse Current	2	41.857	20.928	6.54	0.021
Pulse ON Time	2	0.195	0.194	0.04	0.963
Flushing Pressure	2	3.550	2.318	0.54	0.601
Tool Electrode Treatment * Pulse Current	2	27.595	13.798	4.22	0.056
Residual Error	8	26.182	26.182		
Total	17	234.526			

Response Table for Signal to Noise Ratio for MRR (Larger the Better)

Response table shows the ranking of the factor in the order of their significance. Table 5 shows the significance of each independent factor towards the performance measure, based on S/N ratios. The value of delta shows the contribution of particular variable towards the performance measure. Higher value of delta shows higher contribution of variable on the performance measure. The value of delta for tool electrode treatment is 5.46 which is highest among all variables, and hence been ranked as number 1. So pulse current makes highest contribution in material removal rate and is the most significant factor. The second largest value for delta is 3.65 which is for pulse current. So, pulse current is second largest significant factor. The rank of flushing pressure for significant factor is third as the value of delta is 0.96. The minimum significant factor is pulse ON time with value of delta 0.22. The order of significant factors for highest material removal rate, based upon the response table is tool electrode treatment, Pulse current, flushing pressure and pulse on time.

TABLE 5 RESPONSE TABLE FOR SIGNAL TO NOISE RATIO FOR MRR

Level	Tool Electrode Treatment	Pulse Current	Pulse On Time	Flushing Pressure
1	-17.21	-16.53	-14.41	-15.11
2	-11.75	-14.03	-14.62	-14.15
3		-12.88	-14.40	-14.18
Delta(Maximum - Minimum)	5.46	3.65	0.22	0.96
Rank	1	2	4	3

The optimal machining performance for MRR has been obtained at tool electrode treatment (level 2), pulse current (level 3), pulse ON time (level 3) and flushing pressure (level 3). Thus, the optimum parametric settings are A2B3C3D3.

IV.CONCLUSION

The various conclusions which have been observed from results and discussions are given below:

1. Analysis of Variance for S/N ratio for MRR showed that tool electrode treatment, pulse current, pulse on time and flushing pressure are significant.
2. Response table for S/N ratio for MRR revealed that tool electrode treatment makes highest contribution in material removal rate and is the most significant factor.
3. S/N ratio increased as pulse current, pulse ON time and tool flushing pressure.
4. Optimum parametric setting for higher MRR is A2B3C3D3.

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