International Journal of Modern Engineering Research (IJMER)
www.ijmer.com Vol. 3, Issue. 4, July - Aug. 2013 pp-2170-2176 ISSN: 2249-6645

Analysis of Machining Characteristics of Cryogenically Treated Die Steels Using EDM

Singh Jaspreet[1], Singh Mukhtiar[2], Singh Harpreet[3]
[1, 2, 3] *Lovely Professional University, Phagwara, Punjab.*

ABSTRACT: *The field of cryogenics was advanced during World War II when scientists found that metals frozen to low temperature showed more resistance to wear. Major advantages of these changes are to enhance the abrasion resistance hardness and fatigue resistance of the materials. To attain high accuracy in difficult to machine materials, the nonconventional machining has become the lifeline of any industry. One of the most important non-conventional machining methods is Electric discharge machining (EDM). In this research work, experimental investigations have been made to compare the machining characteristics of three die steel materials, before and after deep cryogenic treatment using EDM. The output parameters for study are material removal rate, tool wear and surface roughness. The results of study suggest that cryogenic treatment has a significant positive effect on the performance of work pieces, tool wear decreases and surface finish of the work piece after machining improves sharply for all three die steels. The best improvement in tool wear and surface roughness is reported by High Carbon High Chromium (HCHCr) followed by EN 8 and then by EN 31. It can be recommended that cryogenically treated die steels can be efficiently machined through EDM.*

KEYWORDS: *Austempered ductile iron (ADI), Electrical discharge machining (EDM), Surface modification, Surface finish*

I. INTRODUCTION

Electrical discharge machining (EDM) is a non-traditional machining method usually employed in production of die cavities via the erosive effect of electrical discharges between a tool electrode and a work-piece [3]. The advantage with EDM is its ability to machine complex cavities, small parts with sharp internal or external radii and fragile materials or work-pieces requiring the creation and modification of very thin walls. However, the occurrence of tool electrode wear is unavoidable and is a very critical issue since tool shape degeneration directly affects the final shape of die cavity. To improve the machining accuracy in the geometry of a work piece, methods to detect the tool electrode wear as well as to compensate the wear of the tool electrode are required [1]. The hard materials after Cryogenic processing makes changes to the crystal structure of materials. It is believed that cryogenically processing makes the crystal more perfect and therefore stronger. In Ferrous metals, it converts retained austenite to martensite and promotes the precipitation of very fine carbides.

Cryogenic processing will not itself harden metal like quenching and tempering. It is not a substitute for heat-treating. It is an addition to heat-treating. Most alloys will not show much of a change in hardness due to cryogenically processing. The abrasion resistance of the metal and the fatigue resistance will be increased substantially. Cryogenic Processing is not a coating. It affects the entire volume of the material. The change brought about by cryogenically processing is permanent. The EDM process on Cryogenic Processed material has actually altered the metallurgical structure and characteristics in this layer as it is formed by the unexpelled molten metal being rapidly cooled by the dielectric fluid during the flushing process and resolidifying in the cavity. This layer does include some expelled particles that have solidified and been re-deposited on the surface prior to being flushed out of the gap. This carbon enrichment occurs when the hydrocarbons of the electrode and dielectric fluid break down during the EDM process and impenetrate into the white layer while the material is essentially in its molten state. If this layer is too thick or is not removed by finer EDM finishes or polishing, the effects of this micro-cracking can cause premature failure of the part in some applications. Also, the existence of these micro-cracks lowers the corrosion and fatigue resistance of the material, so surface integrity should be the primary consideration when evaluating the performance of the EDM technique and the prime objective of EDM must be to establish the condition which suppresses this formation. The micro-cracks produced by EDM on Cryogenic Processed material are the result of thermal stresses created during the on-time phase of the EDM cycle. The depth of the micro-cracking is partially controlled by the EDM program and it goes without saying that as the spark intensity increases so does the depth. In the study, Taguchi quality design method was used to determine the significance of the machining parameters on the work piece removal rate [22]. The approach presented in this paper takes advantage the Taguchi method which forms a robust and practical methodology in tackling multiple response optimization problems. The paper also presents a case study to illustrate the potential of this powerful integrated approach for tackling multiple response optimization problems. The variance analysis is also an integral part of the study, which identifies the most critical and statistically significant parameters [4].

Different process parameters using Taguchi quality design. ANOVA and F-test to achieve a fine surface finish in EDM and found that the machining voltage, current type of pulse-generating circuit were identified as the significant parameters affecting the surface roughness in finishing process [23]. The test results were analyzed for the selection of an optimal combination of parameters for the proper machining.

II. PROBLEM FORMULATION

Most components made of hard alloys require high accuracy and complex machining. Therefore, the conventional method in machining of hard alloys is not suitable. Research on machining these using conventional machines mostly highlights chipping, stresses, cutting tool wear and thermal problem during machining which are caused by mechanical energy. Instead of conventional machining, EDM process is a potential machining method to eliminate such problems.

However, not much work has been reported in the investigation of effect of Deep Cryogenic Treated work piece while machining through EDM. In this research work, efforts have been made to study the effect of cryogenically treatment on the performance of EDM machining characteristics using Taguchi design approach to analyze the material removal rate (MRR), tool wear (TW) and surface roughness (SR).

III. EXPERIMENTAL PROCEDURES

The main objectives of the research work are:

1. To study the effect of deep cryogenically treatment on the die steels while using EDM.
2. Comparison of the machining parameters of three different types of die steels, before and after cryogenically treatment.
3. Analysis of input machining parameters using Taguchi experimental design technique.

3.1 Parameter selection

There are several parameters in EDM e.g. Polarity, Gap voltage, pulse on- time, pulse off-time, Duty factor, Peak current, Dielectric pressure, Dielectric temperature, Dielectric conductivity, Pulse Width, Pulse duration, Electrode gap, Pulse wave form, Spark frequency etc. can be varied during the machining process.

S.no.	Parameters	Range	Material
1	Current: (A)	6 Amps	L1
		8 Amps	L2
		10 Amps	L3
2	On time: (B)	20 µSec	L1
		50 µSec	L2
		100 µSec	L3
3	Duty factor: (C)	8 pos	L1
		10 pos	L2
4	Voltage: (D)	30 V	L1
		35 V	L2
		40 V	L3
5	Polarity	Straight	Electrode Negative

Table: 3.1 *Parameter selected for EDM process*

But for this experimental work, it has been proposed to choose following four parameters as only these could be easily monitored:

1. Peak current (1 to 60A)
2. Pulse on-time (1 to 2000 µSec.)
3. Duty factor (1 to 12 steps, each step corresponding to 8%)
4. Gap Voltage (1 to 100V)

Various levels of the above four input machining parameters were taken and further L_{18} orthogonal array of Taguchi experimental design was chosen to conduct the experiments. Parameter assignments of this array are shown in table 3.2.

Experiment	Duty Factor (Pos) (A)	Current (Amps) (B)	Voltage (V) (C)	Pulse on-time (D)
1	10	6	30	20
2	10	6	35	50
3	10	6	40	100
4	10	8	30	20
5	10	8	35	50
6	10	8	40	100
7	10	10	30	20
8	10	10	35	50
9	10	10	40	100
10	12	6	30	20
11	12	6	35	50
12	12	6	40	100
13	12	8	30	20
14	12	8	35	50
15	12	8	40	100
16	12	10	30	20
17	12	10	35	50
18	12	10	40	100

Table: 3.2 Orthogonal Array L18 Matrix

Table contains an orthogonal matrix of treatments by assigning the various levels of each parameter in the corresponding columns and rows of the matrix. After setting up the machine as per the experiments were conducted according to the treatment combination. The observed values of response/ output parameters are tabulated.

3.2 Response parameters

Output parameters are material Removal Rate (MRR) higher the better, Tool Wear (TW) lowers the better and Surface Roughness (SR) lower the better. The work piece used in the experiments is 3 Die Steel (2 samples of each, out of which one is cryogenically treated & other is non-cryogenically treated) High Carbon High Chromium (HCHCr), EN8 and EN31. Tool steels for hot work applications, designated as group 'EN, D3' steels in the AISI classification system, have the capacity to resist softening during long or repeated exposures to high temperatures needed to hot work or for die-casting other materials. The outstanding characteristics of these tool steels are high toughness and shock resistance. They have air hardening capability from relatively low austenitizing temperatures and minimum scaling tendency during air cooling.

1	Workpiece	HCHCr	Cryogenic Treated
		EN8	
		EN31	
2	Electrodes used	Copper electrode	14 mm in diameter
3	Dielectric used	EDM oil SEO 450	
4	Measuring Instruments	Surfcom	model 130A Resolution 0.001 µm

Table: 3.3 *E*xperimental details of materials used

IV. METHODOLOGY

Deep cryogenically treatment of die steels was done in a Cryogenic chamber. Liquid Nitrogen gas is used to perform the deep cryogenically treatment. Different set of parameters are used to perform the experiment on three different cryogenically treated die steels. Same set of parameters are used for non-cryogenically treated. Job material remains the same for all the cases. Performance of EDM is evaluated on the basis of Material Removal Rate (MRR), Tool Wear (TW) and Surface Roughness (SR).

The depth of cut is observed directly from the control panel, which is attached to the machine tool. Therefore, Material Removal Rate (MRR) for the EDM operation is calculated as *MRR (mm^3/min) = Depth of Cut (mm) × Area of Cut (mm)/ machining time (min).* Tool Wear (TW) for the EDM operation is calculated as *W (%) = (Initial weight- Final weight) × 100/ Initial weight*. The experiments were conducted at different combinations of input parameters. The results obtained in these experiments were optimized using Taguchi L18 orthogonal technique.

4.1 Deep cryogenically treatment of die steels

Deep cryogenically treatment of electrodes is done using 9-18-14 cycle. The temperature of cryogenically chamber is ramp down from atmospheric temperature to -184 °C in 9 hrs. The soaking period is 18 hrs. The temperature of cryogenically chamber is ramp up from -184 °C to atmospheric temperature in another 14 hrs. In this way 9-18-14 cycle is complete.

4.2 Taguchi experimental design and analysis

Taguchi method simplifies and standardizes the fractional design by introducing orthogonal array (OA) for constructing or laying out the design of experiments. It also suggests a standard method for the analysis of results. A factorial experiment with 4 parameters each at three levels would require (3^4=81) test runs whereas Taguchi L_{18} OA would require only 18 trial runs for providing same information. In the Taguchi method, the results of the experiments are analyzed to achieve one or more of the following objectives:

I. To establish the best or the optimum condition for a product and/or process.
II. To estimate the contribution of the individual variables and their interactions.
III. To estimate the response under the optimum conditions.

The optimum conditions are identified by studying the main effect of each of the parameters. The main effects indicate the general trend of influence of each parameter. The knowledge of the contribution of individual parameter plays an important role in deciding the nature of control to be established on a production process.

V. RESULTS AND DISCUSSION

5.1 Effect of cryogenic treatment on MRR

The standard procedure suggested by Taguchi is employed. The mean or the average values and S/N ratio of the response/quality characteristics for each parameter at different levels have been calculated from experimental data. For the graphical representation of the change in value of quality characteristic and that of S/N ratio with the variation in process parameters, the response curves have been plotted. These response curves have been used for examining the parametric effects on the response characteristics. ANOVA of the experimental data has been done to calculate the contribution of each factor in each response and to check the significance of the The third level of Pulse on-time (i.e.100µs) seems to be optimal as S/N ratio is higher. The main portion of material removal from work piece and electrode is due to occurrence of arcs. Since the MRR is contribution of discharges on total removed material is only due to the pulse train. model. Figure 5.1

indicates that increase in current results in improvement both in the average values and S/N ratio of MRR. Therefore, second level of current (i.e. 8 Amps) is optimal. The MRR will increase resulting into bigger crater on work surface and hence poor surface finish.

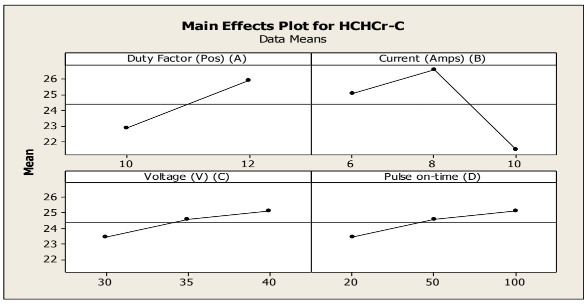

Fig 5.1: Work piece HCHCr (cryogenically treated)

Figure further suggest that second level of duty factor (i.e.12 pos) gives optimal results as regards to both average values and S/N ratio of MRR. As far as voltage is concerned, third level (i.e.40 V) is optimal as S/N ratio for this is highest.

Figure 5.2 indicates that increase in current results in improvement both in the average values and S/N ratio of MRR. Therefore, first level of current (i.e. 6 Amps) is optimal. The third level of Pulse on-time (i.e. 100 µs) seems to be optimal as S/N ratio is higher. First level of duty factor (i.e.10 pos) gives optimal results as regards to both average values and S/N ratio of MRR.

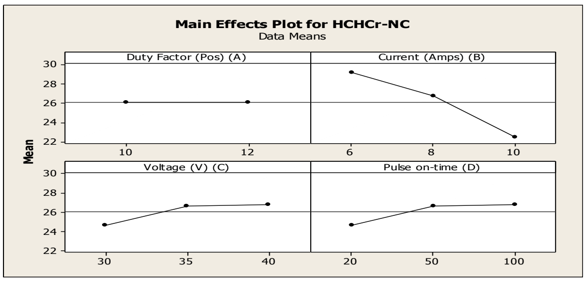

Fig 5.2: Work piece HCHCr (Non-cryogenically treated)

Voltage on third level (i.e.40 V) is optimal as S/N ratio for this is highest. Practically material removal rate is higher due to high spark energy. The first level of current (i.e. 6 Amps) is optimal. The third level of Pulse on-time (i.e. 50µs) seems to be optimal as S/N ratio is higher. Figure 5.3 further suggest that second level of duty factor (i.e.12 pos.) gives optimal results as regards to both average values and S/N ratio of MRR.

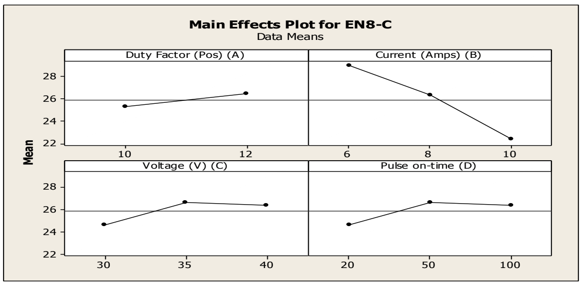

Fig 5.3: work piece EN 8 (cryogenically treated)

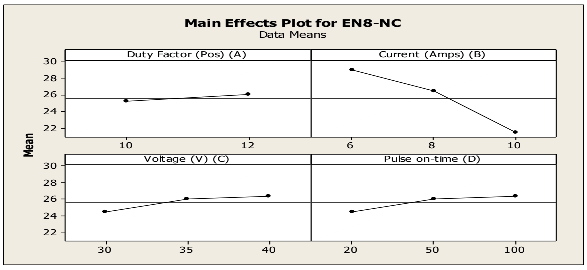

Fig 5.4: work piece EN 8 (Non-cryogenically treated)

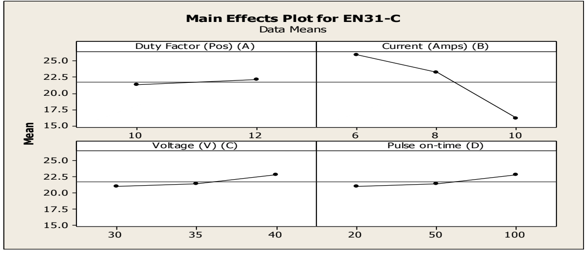

Fig 5.5: work piece EN 31 (cryogenically treated)

Similarly in figures 5.4-5.6 the maximum values are optimal values and representing the results for better MRR. The most favorable conditions (optimal settings) of process parameters in terms of mean response of characteristic have been established by analyzing response curves.

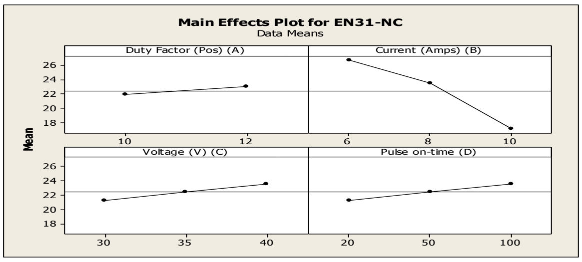

Fig 5.6: work piece EN 31 (Non-cryogenically treated)

5.2 Effect of cryogenic treatment on tool wear

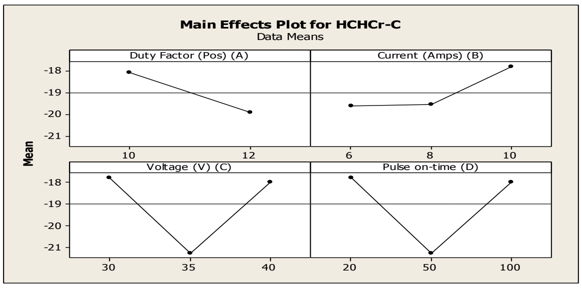

Fig 5.7: work piece HCHCr 8 (cryogenically treated)

It can be observed from figure 5.7 that high current increases the average value of TW. Third level of current (i.e.10 Amps) would be optimum as S/N ratio is maximum at this level.In case of Pulse on-time the second level (i.e.100 µs) would be optimal as it gives lowest average TW and highest S/N ratio. Figure further indicates that first level of duty factor (i.e.10 pos) is best as it gives maximum S/N ratio and lower average TW.

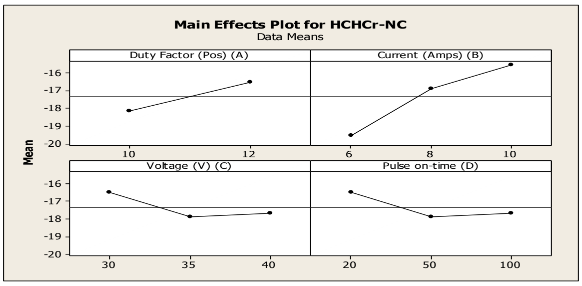

Fig 5.8: Work piece HCHCr (Non-cryogenically treated)

Figure 5.8 shows that first level of current (i.e.10 Amps) would be optimum as S/N ratio is maximum at this level. In case of Pulse on-time the third level (i.e. 20 µs) would be optimal as it gives lowest average TW and highest S/N ratio. The first level of duty factor (i.e. 12 pos.) is best as it gives maximum S/N ratio and lower average TW.

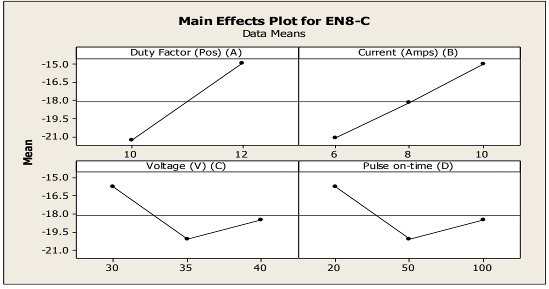

Fig 5.9: Work piece EN-8 (cryogenically treated)

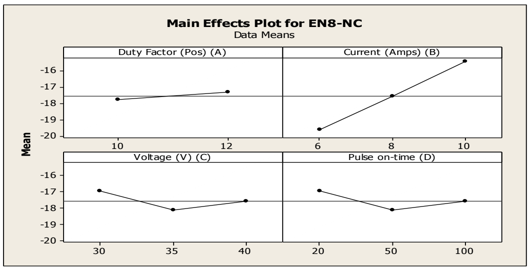

Fig 5.10: Workpiece EN-8(non-cryogenically treated)

It can be observed from figure 5.9 that first level of current (i.e.10 Amps) would be optimum as S/N ratio is maximum at this level. In case of Pulse on-time the second level (i.e.20µs) would be optimal as it gives lowest average TW and highest S/N ratio. Duty factor (i.e. 10 pos) is best as it gives maximum S/N ratio and lower average Tool wear.

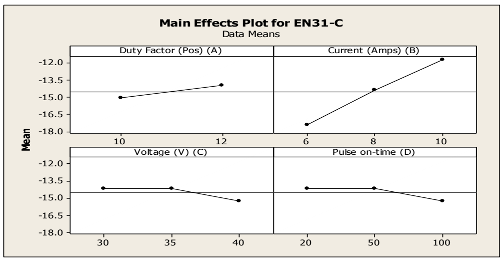

Fig 5.11: Work piece EN-31 (cryogenically treated)

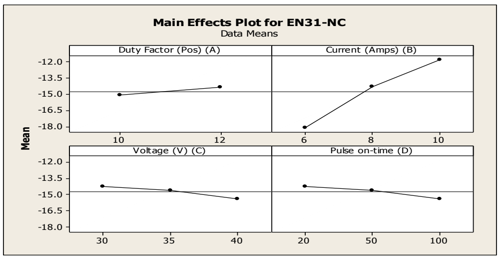

Fig 5.12: Work piece EN-31 (cryogenically treated)

Similarly in figures 5.10-5.12 the maximum values are optimal values and representing the results for less Tool Wear.

5.3 Effect of cryogenically treatment

From above main effect plots of MRR, TW and Ra, the optimum condition for them is concluded. After evaluating the optimal parameter settings, the next step of the Taguchi approach is to predict and verify the enhancement of quality characteristics using the optimal parametric combination. The estimated S/N ratio using the optimal level of the design parameters can be calculated: $\eta_{opt} = \eta_m + \sum_{i=1}^{o}(\bar{\eta}_i - \eta_m)$

Where $\eta_m$is the total mean S/N ratio $\bar{\eta}_i$is the mean S/N ratio at optimum level and **o** is the number of main design parameter that effect quality characteristic. Based on the above equation the estimated multi response signal to noise ratio can be obtained.

5.4 Comparison of results

Table5.1: Comparison of results

Electrode Material	Type of Electrode	Material Removal Rate	Tool Wear (%)	Surface Roughness (SR) (μm)
HCHCr	Cryogenically Treated	35.0917	0.05134	2.325
	Non Cryogenically Treated	31.0347	0.0784	7.7597
EN 8	Cryogenically Treated	37.1903	0.0385	1.6709
	Non Cryogenically Treated	30.907	0.0888	2.145
EN 31	Cryogenically Treated	15.0986	0.1758	1.1592
	Non Cryogenically Treated	13.8304	0.1499	2.3519

Table 5.2: Optimum combination of factors for the three response parameters

Electrode Material	Type of Electrode	Material Removal	Tool Wear	Surface Roughnes
HCHCr	Cryogenically Treated	A2 B2 C3 D3	A1 B3 C2 D2	A1 B3 C1 D1
	Non Cryogenically Treated	A2 B3 C3 D3	A1 B3 C2 D2	A1 B3 C1 D1
EN 8	Cryogenically Treated	A2 B3 C2 D2	A1 B3 C2 D2	A1 B3 C1 D1
	Non Cryogenically Treated	A2 B3 C3 D3	A1 B3 C2 D2	A1 B3 C1 D1
EN 31	Cryogenically Treated	A2 B3 C3 D3	A1 B3 C3 D3	A1 B3 C1 D1
	Non Cryogenically Treated	A2 B1 C3 D3	A1 B3 C3 D3	A1 B3 C1 D1

VI. CONCLUSIONS

1. Cryogenic treatment significantly affects the EDM machining parameters- tool wear decreases and surface finish of the work piece after machining improves sharply for all the three electrodes.
2. Some increment is also reported in Material Removal Rate (MRR) in all the three types of die steels after cryogenic treatment but in case of EN 31, it is comparatively less affected.
3. The best improvement in Tool Wear (56.64%) is reported by EN 8 followed by HCHCr (34.51%) and then EN 31 (14.39%).
4. The best improvement in surface finish (70.03%) is reported by HCHCr followed by EN 31 (50.71%) and then EN 8 (22.10%).
5. The optimum input parameters also get altered due to cryogenic treatment. It is observed that for the best value of surface roughness, pulse on-time undergoes a shift to the higher side for HCHCr; which may be an indication of strong crystal structure. Also, peak current undergoes a shift to higher side for the best values of tool wear for HCHCr which reflects the ability of tool electrode to withstand higher currents after cryogenic treatment.
6. Tool wear as well as surface finish of the work piece after machining are critical parameters in EDM. Since cryogenic treatment has a significant positive effect on both these parameters, it can be recommended that cryogenically treated die steels can be efficiently machined through EDM.

REFERENCES

[1]. Bannerjee, S., Prasad, B.V. S. S. S., Mishra, P. K. (1993), “A simple model to estimate the thermal loads on an EDM wire electrode”. Journal of Materials processing Technology, Vol.39, pp.305-317.

[2]. Daniels, A. C. M. and Philps, George. (1978), “An energy distribution strategy in fast cutting EDM”, Ann CIRP, Vol25 (2), pp. 521-525.

[3]. Dauw, D. F. and Albert, L. (1992), “About the evolution of tool wear performance in wire EDM “, Annals CIRP, Vol. 41(1), pp.221-225.

[4]. Dawei Luy and Jiju Antonyy, Optimization of multiple responses using a fuzzy-rule based inference system , int. j. prod. res., 2002, vol. 40, no. 7, 1613±1625, PP-33

[5]. Dhar A.R & Chhatopadhaya A.B, (2001), “The influence of cryogenic cooling on tool wear, dimensional accuracy and surface finish in turning AISI1040 and E4340 steels”, Wear, Vol. 249, n10-11, pp 932-942.

[6]. Fores F.H, Yu.K & Nishimura,T,(2004) “ Developing applications for Titanium”, Journal of Cost-Affordable Titanium, Vol. 14, pp 19-26.

[7]. Guo, Z. N., Lee, T. C., Yue, T. M., Lau, W. S. (1997), “A study of Ultrasonic-aided Wire Electrical Discharge Machining”, Journal of materials processing technology, Vol.63, pp.823-828.

[8]. Guo, Z. N., Lee, T. C., Yue, T. M., Lau, W. S. (1997), “Study on the machining mechanism of WEDM with Ultrasonic vibration of the wire”, Journal of materials processing technology, Vol.69, pp.212-221.

[9]. Guo, Z. N., Wang, X., Huang, Z. G., Yue, T. M. (2002), “Experimental investigation into shaping particle-reinforced material by WEDM”, Journal of Materials processing Technology, Vol.129, pp.56-59.

[10]. Han, Fujhu, Jiang, Jun., Dingwen, Yu. (2006), “Influence of machining parameters on surface roughness in finish cut of WEDM”, International Journal of Advance manufacturing Technology, Vol. 67, pp. 134-140.

[11]. Hargrove, S. Keith. And Ding, Duowen.(2006), “ Determining cutting parameters in wire EDM based on workpiece surface temperature distribution” International Journal of Advance manufacturing Technology, Vol. 154,pp. 24-27.

[12]. Huang, J. T. and Liao, Y. S., Hsue, W.J. (1999), “Determination of finish cutting operation number and machining parameters setting in wire electrical discharge machining”, Journal of materials processing technology, Vol.87, pp.69-81.

[13]. Huang, J. T. and Liao, Y. S. (2003), “Optimization of machining parameters of wire EDM based on Grey relational and statistical analysis”, International journal of production resources, Vol.41, No.8, pp.1707-1720.

[14]. Huang, Y. T., Zhu, Y. T., Liao, X. Z., Beyerlein, I. J.,Bouke, M. A., Mitchell, T. E. (2003), “Microstructure of cryogenic treated M2 tool steel” International Journal of Material Science Vol 339, pp. 241-244.

[15]. Juhr, H., Schulze, H. P., Wallenberg, G., Kunanz, K. (2004), “Improved cemented carbide properties after wire-EDM by pulse shaping”, Journal of materials processing technology, Vol.149, pp.178-183.

[16]. Kinoshita, N., Fukui, M., Gamo,G. (1976) , “Study on EDM with wire electrode: a gap phenomenon”, Annals CIRP, Vol.25 (1), pp.141-145.

[17]. Kinoshita, N., Fukui, M., Gamo, G. (1982) , “Control of wire EDM preventing from breaking”, Annals CIRP, Vol.31, pp.111-114.

[18]. Kuriakose, Shajan. And Shunmugam, M. S. (2005), “Multi-objective optimization of wire electro-discharge machining process by non-dominated sorting Genetic Algorithm”, Journal of materials processing technology, Vol.170, pp.133-141.