OPEN ACCESS

International Journal Of Modern Engineering Research (IJMER)

Improvement of Surface Roughness of Nickel Alloy Specimen by Removing Recast Layer In Wire Electric Discharge Machining

Taha Chowdry[1]

[1]*Department of Mechanical Engineering, Islamiah Institute of Technology/ Visvesvaraiah Technological University, India*

Abstract: *In this investigation, experimental work and computational work are combined to obtain improvement in the surface roughness of nickel alloy specimen, the machining is carried out by means of CNC wire electric discharge machining (WEDM). Brass wire is used as the tool electrode and nickel alloy (Inconel600) is used as the work piece material. The machining parameters such as Pulse-On time (T_{on}), Pulse-Off time (T_{off}), Peak Current (I_p), and Bed speed are considered as input parameters for this project. Surface roughness and Recast layer are considered the output parameters. The experiments with the pre-planned set of input parameters are designed based on Taguchi's orthogonal array. The surface roughness is measured using stylus type roughness tester and the thickness of the Recast layer is measured using Scanning Electron Microscope (SEM). The results obtained from the experiments are fed to the Minitab software and optimum input parameters for the desired output parameters are identified. The software uses the concept of analysis of variance (ANOVA) and indicates the nature of effect of input parameters on the output parameters and confirmation is done by validation experiments. Once the recast layer thickness is obtained Chemical Etching and abrasive blasting is performed in order to remove the recast layer and again the surface roughness is measured by using stylus type roughness tester. Finally from the obtained results it was found that there was significant improvement in the Surface roughness of the nickel alloy material. In addition using regression analysis this work is stimulated by computational method and the results are obtained.*

Keywords: *Analysis of variance (ANOVA), Recast layer, Scanning electron microscope (SEM), Surface roughness, Wire electric discharge machining (WEDM)*

I. INTRODUCTION

Industrial technology introduces a variety of superior materials, these materials have better mechanical characteristics such as higher toughness, higher strength, higher hardness etc. Processing these superior materials using traditional machining techniques is difficult. Therefore, nontraditional machining techniques such as wire electrical discharge machining (WEDM) can be applied. This work uses WEDM as the major process of machining materials. The machining technique enables handling these superior materials to fulfill various requirements. No direct contact occurs between electrode and work piece so no stress is created in the processed material. The work piece for processing can consist of any materials as long as the materials have good electrical conductivity. Therefore, WEDM applies widely for processing difficult to machine materials since it performs with superior machining characteristics.

WEDM process is a heat energy process, the processed part surface generates a heat-affected zone (HAZ) of Ni-based super alloy, this zone includes the recast layer structure and surface defects after removal. During the WEDM process, the melting and removal of material progresses between two polarities (electrode and work piece). Some materials experience a resolidification phenomenon. Mixing carbon elements of dielectric fluid, melting electrode, and melting work piece is easy during resolidification, therefore forming the recast structure after the processes. The recast structure has micro-cracks and discharge craters causing bad surface quality that are difficult to remove due to high cohesion and hardness characteristics compared to the base material. The recast structure greatly affects dye fatigue strength and shortens service life. Removing the damaged surface in a post-machining process greatly increases fabricating time and dye cost. Therefore, this study explores chemical etching and abrasive blasting to soften and destroy the recast structure for removing micro-crack and discharge craters. The introduction of the paper should explain the nature of the problem, previous work, purpose, and the contribution of the paper. The contents of each section may be provided to understand easily about the paper.

II. Experimental Methodology

2.1 Taguchi Method

The Robust design method, is pioneered by Dr. Genichi Taguchi, greatly improves engineering productivity. By consciously considering the noise factors (environmental variation during the product usage, manufacturing variation and component deterioration) and the cost of failure in the field, the robust design method helps to ensure customer satisfaction. Robust Design focuses on improving the fundamental function of the product or process. This technique helps to study effect of many factors (variables) on the desired quality characteristic. By studying the effect of individual factors on the result, the best factor combination can be determined. The standardized Taguchi-based experimental design used in this study is an L9 orthogonal array.

2.2 Signal to Noise ratio (S/N ratio)

In the Taguchi method, the term, signal represents the desirable value (mean) for the output characteristic and the term, noise represents the undesirable value (S.D) for the output characteristic. Therefore, the S/N ratio is the ratio of the mean to the S.D. S/N ratio is used to measure the quality characteristic deviating from the desired value. The S/N ratio is defined as smaller the better.

2.3 Chemical Etching

It is the process of using strong acid or mordant to cut into unprotected parts of the metal. In this study the recast layer from the substrate is removed by using an etchant. The etchant consists of sulfuric acid solution that includes nitric acid and sodium chloride. To ensure that all the recast has been removed, the substrate is wiped using a white cloth and if all the recast has been removed the cloth will not change in appearance or color.

2.4 Abrasive Blasting

Abrasive blasting uses a stream of fine grained abrasive mixed with air or some other carrier gas at high pressure. This stream is directed by means of suitably designed nozzle on the work surface to be finished. Metal removal occurs due to erosion caused by the abrasive particles impacting the work surface at high speed.

III. Results And Discussion

The machining experiments have been carried out on FANAUC RC C600 four axis CNC wire EDM, using Brass wire of diameter 0.25mm. Work piece dimensions – 10x10mm, Length 15mm. The experiments have been conducted under flushing dielectric conditions. Deionised water has been used as the dielectric fluid.

Figure 1. Fanauc RC C600 four axis CNC WEDM

In this research work, after conducting the experiments, response values are noted down and analysis is done. Taguchi analysis is conducted to determine the optimal parameters and ANOVA is also performed to estimate magnitude of factors effects on the responses. The response factors or output parameters considered in this project are Surface roughness and Recast layer.

3.1 Machining Data Analysis

The Surface roughness and Recast layer thickness obtained for the corresponding machining experiments are tabulated.Four factors are considered while performing the experiments, they are Pulse-on time, Pulse-off time, Current and Bed speed.

Depending on these factors the surface roughness as well as the recast layer may vary.The data obtained is fed to the Minitab software and the S/N ratio is obtained.Based on the S/N ratio Main effects plots are plotted.From the graphs, the optimum machining parameter values are choosen for conducting the verification experiment.

The response for the verification experiment is expected to be better than the previous designed experiments.Minimum Surface finish and minimum Recast layer thickness is expected from the verification experiment.The obtained result from the verification experiment produces minimum Surface finish and minimum. Recast layer thickness which can be further improved by using different recast layer removal techniques.The different recast layer removal techniques which is used to obtain improved surface finish used are chemical etching and abrasive blasting.

Table 1. Tabulation of surface roughness for different set of input parameters

Exp.no	Pulse on (µs) (A)	Pulse off (µs) (B)	Peak current (amps) (C)	Bed speed (microns/sec) (D)	Response – Ra (µm)	S/N ratio
1	5	20	1	50	1.823	-4.2521
2	5	25	2	75	1.523	-3.1975
3	5	30	3	100	1.928	-5.0021
4	6	20	2	100	1.623	-4.2064
5	6	25	3	50	1.973	-5.9025
6	6	30	1	75	1.541	-3.7561
7	7	20	3	75	1.029	-0.2483
8	7	25	1	100	0.978	0.1932
9	7	30	2	50	2.093	-5.9563

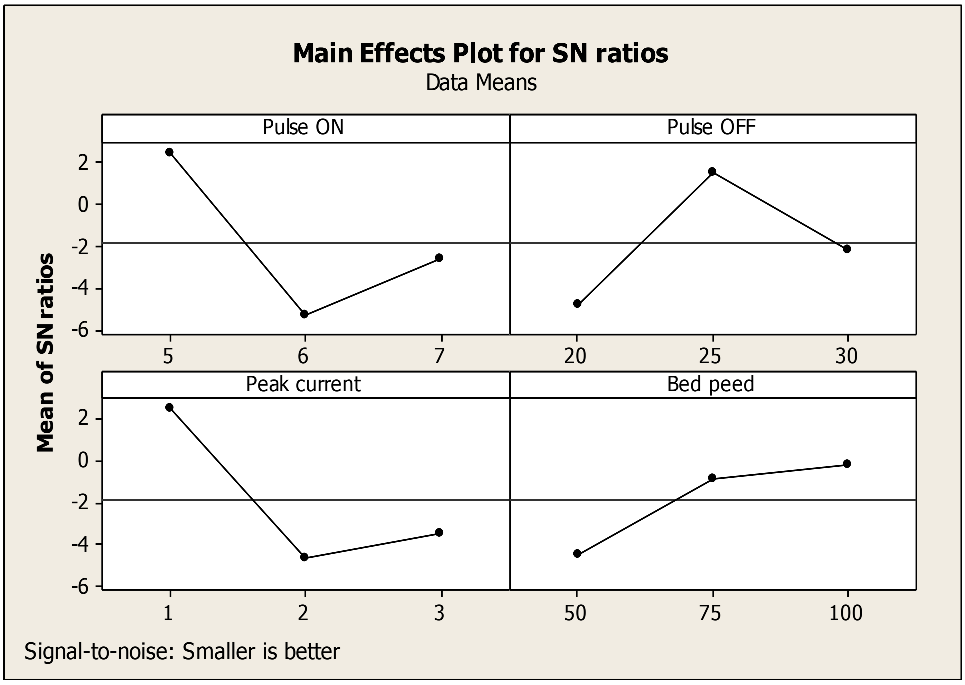

Figure 2.Main effects plot for S/N ratio (Surface Roughness)

Table 2. Response Table for Signal to Noise Ratio of Surface roughness

Level	Pulse ON (µs) (A)	Pulse OFF (µs) (B)	Peak current (amps) (C)	Bed speed (microns/sec) (D)
1	2.408	-4.8532	2.4772	-4.4776
2	-5.5323	-1.5094	-4.6185	-0.9126
3	-2.6697	-2.2413	-3.4435	-0.0194
Delta	7.732	6.3629	7.0957	4.2826
Rank	1	3	2	4

Based on the experiments, the optimum set of parameters is **A2 B1 C2 D1.** Figure 2 shows that Level 2 of A, Level 1 of B, Level 2 of C and Level 1 of D are having the smaller signal to noise ratio. Thus A2 B1 C2 D1 is the best combination i.e. Pulse-ON (6µs), Pulse-OFF (20 µs), Peak current (2 Amps) and Bed speed (50 µ/sec) produce minimum Surface roughness. From the main effects plot and Response table it is considered that the Pulse ON has more effect, Current and Pulse-OFF have lesser effect and Bed speed has least effect on the Surface roughness.

Table 3. Tabulation of Recast Layer for different set of input parameters

Exp.no	Pulse on (µs) (A)	Pulse off (µs) (B)	Peak Current (amps) (C)	Bed speed (microns/sec) (D)	Response–recast layer (µm)	S/N ratio
1	5	20	1	50	2.75	-8.7867
2	5	25	2	75	2.43	-7.7121
3	5	30	3	100	2.896	-9.2360
4	6	20	2	100	4.563	-13.1850
5	6	25	3	50	9.25	-19.3228
6	6	30	1	75	10.53	-20.4486
7	7	20	3	75	12.00	-21.5836
8	7	25	1	100	5.631	-15.0117
9	7	30	2	50	11.5	-21.2140

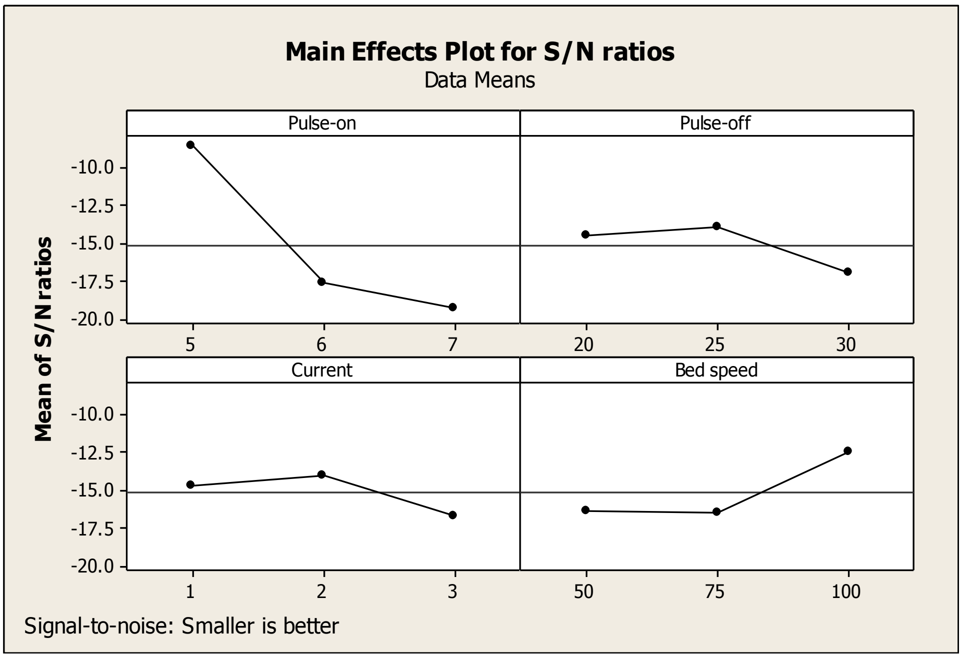

Figure 3. Main effects plot for S/N ratio (Recast Layer)

Table 4. Response Table for Signal to Noise Ratio of Recast Layer

Exp no	Pulse ON (µs) (A)	Pulse OFF (µs) (B)	Current (amps) (C)	Bed speed (microns/sec) (D)
1	-8.578	-14.518	-14.749	-16.441
2	-17.65	-14.016	-14.037	-16.581
3	-19.27	-16.966	-16.714	-12.478
Delta	10.692	2.951	2.677	4.104
Rank	1	3	4	2

Based on the experiments, the optimum set of parameters is **A3 B3 C3 D2.** Figure 3 shows that Level 3 of A, Level 3 of B, Level 3 of C and Level 2 of D are having smaller signal to noise ratio.Thus A3 B3 C3 D2 is the best combination i.e. Pulse-ON (7 µs), Pulse-OFF (30 µs),Current (3 Amps) and bed speed (75 µ/sec) produce the minimum recast layer. From the main effect plot and Response table it is considered that Pulse-ON time has more effect, Pulse-OFF and Bed speed have lesser effect and Current has least effect on the Recast layer.

3.2 Verification Experiment

The purpose of the verification experiment is to validate the conclusions drawn during the analysis phase. The verification experiment is performed by conducting a test with specific combination of parameters and values which are previously evaluated. In thisstudy, after determining the optimum values, a new experiment is designed and executedwith optimum values of the machining parameters. If the observed S/N ratios under theoptimum conditions are close to their respective predictions, then one can conclude thatthe predictive model is a good approximation of the reality.

Table 5. Optimized parameters to obtain minimum Surface roughness

Objective	Pulse ON (µs)	Pulse OFF (µs)	Peak current (amps)	Bed speed (microns/sec)	Obtained Surface roughness (before recast layer removal) (microns)	Obtained Surface roughness (after recast layer removal) (microns)
Minimizing Surface roughness	6	20	2	50	0.81	0.521

Table 6. Optimized parameters to obtain minimum Recast layer thickness

Objective	Pulse ON (µs)	Pulse OFF(µs)	Peak current (amps)	Bed speed (microns/sec)	Recast layer thickness (µm)
Minimizing Recast layer thickness	7	30	3	7	2.45

3.3 Analysis of Chemical Etching

The process of removing a layer of contamination on a metal or plastic surface through chemical erosion is called as chemical etching. Chemical etching of metals, also known as Chemical Milling, Photo-Chemical Machining, has been in existence for quite a long time, first being used for the production of metal 'frames' for holding electronic integrated circuit chips in place and allowing connection to be made to the external pins. Nowadays, it is used to create minute implantable surgical devices, micro machines and, most importantly, railway models.

Chemical milling or industrial etching is a manufacturing process of using baths of temperature-regulated etching chemicals to remove material to create an object with the desired shape. It was developed from armor-decorating and printing etching processes developed during the renaissance as alternatives to engraving on metal. The process essentially involves bathing the cutting areas in a corrosive chemical known as an etchant, which reacts with the material in the area to be cut and causes the solid material to be dissolved; inert substances known as maskants are used to etch specific areas of the material.

Table 6. Chemical etching performed for various experiments

Exp.no	Recast layer (µm)	Specimen dimension (initial) in mm Before etching	% of Chemical Composition/ 50ml of etchant	Time taken (mins)	Specimen dimension (final) in mm After etching
1	2.75	15.127	25 ml-HNO_3 20ml-H_2SO_4 6gms-NaCl	20	14.352
2	2.43	15.869	20 ml-HNO_3 10ml-H_2SO_4 4gms-NaCl	33	15.569
3	2.859	15.789	15 ml-HNO_3 15ml-H_2SO_4 4gms-NaCl	27	15.049
4	4.563	15.237	20 ml-HNO_3 15ml-H_2SO_4 6gms-NaCl	30	14.972
5	9.25	15.931	15 ml-HNO_3 10 ml-H_2SO_4 2gms-Nacl	45	15.775
6	10.53	15.128	25 ml-HNO_3 10ml-H_2SO_4 4gms-NaCl	30	14.892
7	12.00	15.193	20ml-HNO_3 15ml-H_2SO_4 2gms-NaCl	25	14.861
8	5.631	15.879	15 ml-HNO_3 20ml-H_2SO_4 2gms-NaCl	31	15.456

From table 6 it is found that higher concentration of etchant as in experiment 1 results in lesser time and more material removal rate and lower concentration of etchant as in experiment 5 results in more time and lesser material removal rate.

Table 7. Surface roughness values before and after recast later removal

**Chemical etching*
*** Chemical etching and Abrasive blasting*

Exp.no	Roughness (before recast layer removal) (microns)	Roughness (after recast layer removal by chemical etching) (microns)	Roughness (abrasive blasting performed on etched components) (microns)	Improvement in roughness (microns)
*1	1.823	1.612	-	0.211
**2	1.523	1.445	0.845	0.678
*3	1.928	1.622	-	0.306
**4	1.623	1.572	0.672	0.951
*5	1.973	1.501	-	0.469
**6	1.541	1.406	0.606	0.935
**7	1.029	0.991	0.705	0.324
**8	0.978	0.912	0.684	0.294

From table 7 it can be concluded that the surface roughness of the specimen is considerably improved after the Recast layer has been removed by etching method, further improvement is achived by using abrasive blasting once the recast layer is removed by chemical etching.

3.4 Regression Analysis

Regression analysis is a statistical tool for the investigation of relationships between variables. Usually, the investigator seeks to ascertain the casual effect of one variable upon another, for example the effect of a price increase upon demand, or the effect of changes in the money supply upon the inflation rate. To explore such issues, the investigator assembles data on the underlying variables of interest and employs regression to estimate the quantitative effect of the casual variables upon the variable that they influence.

The investigator also typically assesses the "statistical significance" of the estimated relationships, that is, the degree of confidence that the true relationship is close to the estimated relationship.

In this project, there are four control parameters which are independent variables.They are Pulse ON (Ton), Pulse OFF (Toff), Peak current (Ip) and Bed speed. Each of these factors has relationship with the Surface finish and Recast layer thickness of the work piece.

Table 8 Regression analysis :Experimental and Predicted values of surface roughness

Exp.no	Experimental Values(microns)	Predicted values(microns)	Deviation %
1	1.823	1.621	11.08
2	1.523	1.674	-9.91
3	1.928	1.727	10.42
4	1.623	1.168	28.03
5	1.973	1.858	5.82
6	1.541	1.617	-4.93
7	1.029	1.352	-31.38
8	0.978	1.111	-13.59
9	2.093	1.802	13.9

Exp.no	Experimental values (μm)	Predicted values (μm)	Deviation %
1	2.75	3.29	-19.63
2	2.43	3.36	-38.27
3	2.896	3.43	-18.43
4	4.563	4.2	7.955
5	9.25	9.475	-2.43
6	10.53	6.935	34.14
7	12.00	10.315	14.04
8	5.631	7.775	-38.07
9	11.5	13.05	-13.47

Table 9 Regression analysis : Experimental and Predicted values of Recast layer

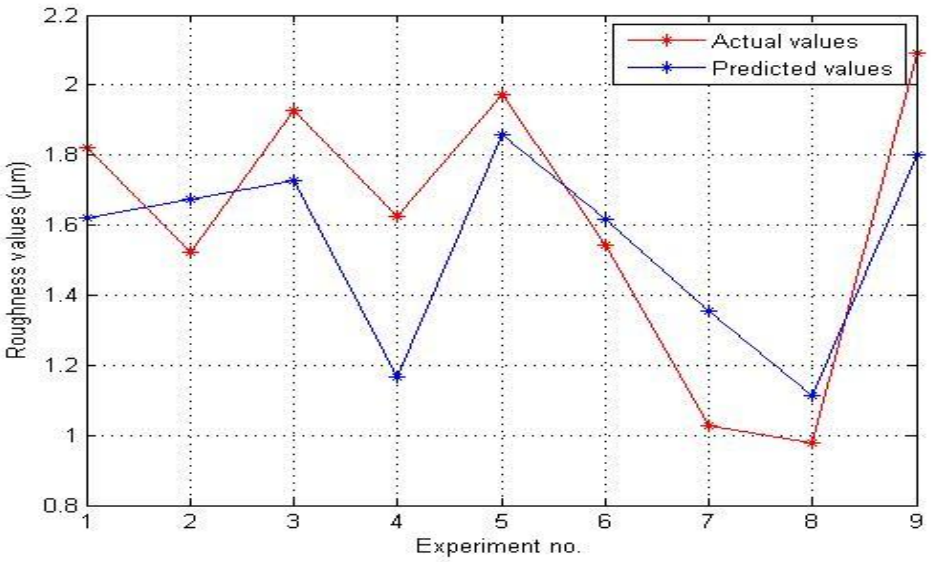

Fig 4.Comparison b/w Experimental and Predicted values of Surface roughness

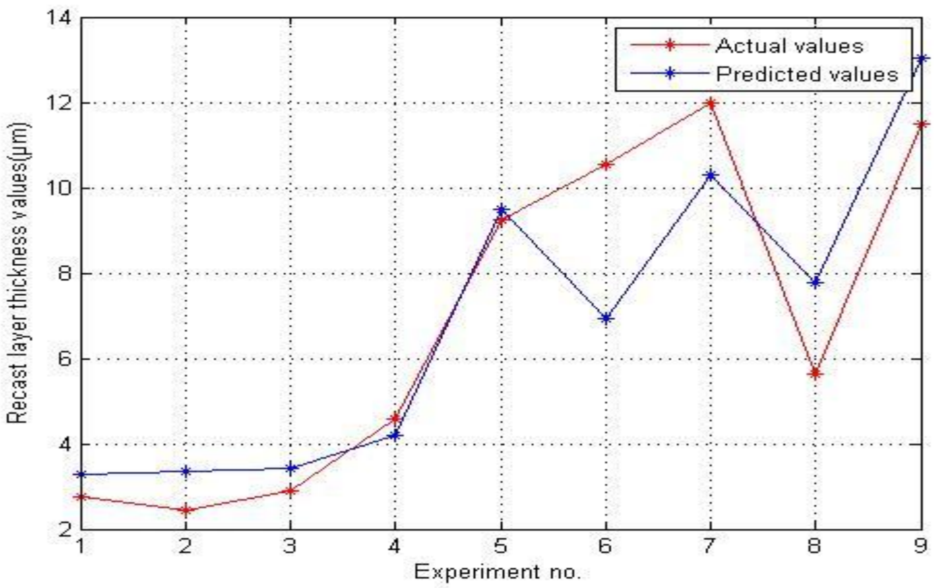

Fig 5.Comparison b/w Experimental and Predicted values of Recast layer

IV. Conclusion

From the results of machining experiments based on L9 orthogonal array and from the results of ANOVA analysis, it can be concluded that while machining the material Inconel-600 with FANUC RB C600 four axis CNC wire cut Electric Discharge Machine, the Pulse ON time has the major effect on Surface roughness and Recast layer thickness. The Pulse OFF time, Peak current and Bed speed have lesser effect on Surface roughness and Recast layer thickness

From the regression analysis results, it can be concluded that the prediction of results or responses with minimum errors are possible using regression analysis with MINITAB and MATLAB software.

REFRENCES

[1] P C Pandey and H S Shan, Modern machining processes, Tata McGraw-Hill Education, 1st edition, New Delhi 1980.
[2] P. K. Mishra, Non conventional machining, Hassan El-Hofy, Narosa Publishing House, New Delhi, 1997.
[3] Yan-Cherng Lin, Optimization of machining parameters in magnetic force assisted EDM based on Taguchi method, Journal of Materials Processing Techonology 2009, pp 3374-3383.

[4] Che-Chung Wang ,Recast layer removal after electric discharge machining via Taguchi analysis, Journal of Materials Processing Technology 2009, pp 4134-4140.
[5] D.K Aspinwall, Workpiece roughness and integrity after WEDM of Ti-6Al-4V and Inconel-718 using minimum damage generator technology, Journal of Material Processing Technology 2008, pp 187-190.
[6] Kung Ling Wu, Study on the characteristics of electric discharge machining using dielectric with surfactant, Journal of Material Processing Technology 2009, pp 3783-3789.
[7] R. Ramakrishnana, L. Karunamoorthy, Modeling and multi-response optimization of Inconel 718 on machining of CNC WEDM process, Journal of Materials Processing Technology, 2008, pp 343–349.
[8] H. Singh, R. Garg, Effects of process parameters on material removal rate in WEDM, Journal of Achievements in Materials and Manufacturing Engineering, Vol-32, Issue-1, 2009, pp 70-74.
[9] Danial Ghodsiyeh, Abolfazl Golshan, Optimizing Finishing process in WED-Machining of Titanium Alloy (Ti6Al4V) by Zinc Coated Brass Wire based on Response Surface Methodology, Indian Journal of Science and Technology, ISSN:0974-6846, Vol.5, Issue.10, 2012, pp 3365-3376.
[10] S. Sarkar, S. Mitra, I.K. Gomes and B. Bhattacharyya, Modeling and Optimization of Wire Electrical Discharge Machining In Single Pass Cutting Operation, Proceedings of the International Conference on Mechanical Engineering, Dhaka, Bangladesh,2005.
[11] S. S. Mahapatra, Amar patnaik, Optimization of Wire Electric Discharge Machining Process Parameters Using Genetic Algorithm, Indian Journal of Engineering and Material Sciences, Vol. 13, 2006, pp 494-502.
[12] A. B. Puri, B. Bhattacharyya, An Analysis and Optimisation of the Geometrical Inaccuracy Due to Wire Lag Phenomenon in WEDM, International Journal of Machine Tools & Manufacture, 2003, Vol. 2, pp 151-159.
[13] Nihat Tosun, The Effects of the Cutting Parameters on Performance of WEDM, KSME International Journal, vol.17, No.6, 2003, pp 816-824.
[14] M.S. Hewidy, T. A. El-Taweel, M. F. El-Safty, Modelling the machining parameters of wire electrical discharge machining of Inconel 601 using RSM, Journal of Materials Processing Technology, 2005, pp 328–336.
[15] S. Sivakiran, C. Bhaskar Reddy, C. Eswara Reddy, Effect Of Process Parameters on MRR in Wire Electrical Discharge Machining of En-31 Steel, International Journal of Engineering Research and Applications, ISSN: 2248-9622, Vol. 2, Issue. 6, 2012, pp 1221-1226.
[16] Atul Kumar, Dr. D. K. Singh, Performance Analysis of Wire Electric Discharge Machining, International Journal of Engineering Research & Technology, Vol. 1, Issue. 4, 2012.
[17] B J Ranganath, Thermal metal cutting process, New Delhi, India, I K International Publishing House Pvt. Ltd, 1st edition, 2008.
[18] Phadke. M. S. Quality Engineering Using Robust Design, Prentice-Hall, EnglewoodCliffs, NJ, 1989.
[19] Taguchi Genichi, Elsayed A Elsayed, Hsiang Thomas Quality Engineering In Production Systems, Mc Graw-Hill Book Company, New York, 1989.
[20] Pujari Srinivasa Rao, Dr. Koona Ramji, Prediction of Material removal rate for Aluminum BIS-24345 Alloy in wire-cut EDM, International Journal of Engineering Science and Technology, Vol. 2, 2010, pp 7729-7739.