

Study and Analysis of Recast Layer Formation during Wire Electro Discharge Machining Process

Bhosale Sachin ¹, Shelge Shrinivas ², Bhagwat Vishal³

Assistant Professor, Dept. of Mechanical Engineering, V.P.'s College of Engineering, Baramati, Maharashtra, India¹

Assistant Professor, Dept. of Mechanical Engineering, V.P.'s College of Engineering, Baramati, Maharashtra, India²

Assistant Professor, Dept. of Mechanical Engineering, V.P.'s College of Engineering, Baramati, Maharashtra, India³

ABSTRACT: Wire-electrical discharge machining (WEDM) is a non-traditional machining process in which a pulsed voltage difference between a wire electrode and a conductive workpiece initiates sparks which erode workpiece material. Removing material in such a way is often advantageous when the workpiece material would be difficult to machine with traditional machine tools due to high strength, hardness, toughness, etc. This process has been used in commercial machine tools for nearly half a century. It is well known that the EDM process has a detrimental impact on the surface integrity of machined surfaces. Each spark melts a small portion of the workpiece. A portion of this molten material is ejected and flushed away. The remaining material re-solidifies to form a surface layer known as the recast layer. This layer can contain an altered microstructure, tensile stresses, microcracks, impurities which can lead to premature part failure when put to service. Surface integrity effects are dependent upon both the wire-EDM process parameters and the chemical composition of the workpiece. Experimentation has been done using Taguchi's L9 orthogonal array. Each experiment was conducted under different combinations of pulse on time, pulse off time and Wire feed. The optimum machining parameter combination was obtained by using the analysis of signal-to-noise (S/N) ratio, analysis of means and analysis of variance (ANOVA) in Minitab 15 software. The analysis of variance (ANOVA) was carried out to study the effect of process parameters on process performance

KEYWORDS: WEDM, Recast Layer, micro-hardness, Taguchi method, Design of Experiment.

I. INTRODUCTION

Wire EDM Machining (also known as Spark EDM) is an electro thermal production process in which a thin single-strand metal wire (usually brass) in conjunction with de-ionized water (used to conduct electricity) allows the wire to cut through metal by the use of heat from electrical sparks. A thin single-strand metal wire, usually brass, is fed through the work piece, submerged in a tank of dielectric fluid, typically deionizer water. Wire-cut EDM is typically used to cut plates as thick as 300mm and to make punches, tools, and dies from hard metals that are difficult to machine with other methods. The effects of various wire-EDM parameters on the machined workpiece as it has been long established that electrical discharges impact the surface integrity of the workpiece [14, 15]. It has been well established that increasing the current pulse duration increases the surface roughness of the machined surface [5, 6]. Recast layer depth has also been shown to increase with current pulse duration. Surface crack density also tends to increase with increased current pulse durations [3]. Reducing the voltage off-time has been shown to minimize the formation of an oxide layer in Ti-6Al-4V [4]. In micro-wire-EDM, it has been found that a high table feed rate will contribute to a diminished gap, and consequently an increased short ratio. Others contend that there is an effect on surface roughness [2]. In trim cutting, a low table feed rate can effectively remove surface peaks and can also have a significant effect on the removal thickness of previously imparted recast layer [5]. It has been found that gap width increases with the energy per spark [5], as well as surface roughness and recast layer [5, 3]. Surfaces machined with both short and long current pulse durations had almost identical surface roughness as long as the energies per spark were equal to one another. However, a comparison

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

of the morphologies revealed great deference between the two cases. Over the ranges examined, short current pulse durations created craters by vaporization, while long current pulse durations generated craters through melting.

II. MATERIAL SELECTION

Much work has been devoted to the study of surface integrity in wire-EDM of common steel alloys, particularly tool and die steels. However, little research has been reported on the effects of wire-EDM on high nickel content superalloys. Specifically, no significant literature has been found by the author relating to surface integrity of MDN 250. Maraging is a 18% nickel, cobalt strengthened steel (C-type), with excellent mechanical properties, workability and heat treatment characteristics. Typical applications for maraging include missile and rocket motor cases, landing and takeoff gear, munitions, aerospace, extrusion tooling, die casting, high Performance shafting, gears and fasteners. Spectroscopic analysis was done to find the chemical composition of material. The limiting chemical composition of MDN 250 is listed in Table 1.

Table1. Chemical composition of MDN 250

C	Mn	Si	P	S	Ni	Co	Mo	Ti	Al	Cr	Cu	.Fe
0.03 max	0.10 max	0.10 max	0.010 max	0.010 max	17- 19	7.00- 8.50	4.60- 5.20	0.30- 0.50	0.05- 0.15	0.50 max	0.50 max	Bal

III. EXPERIMENTATION

Experiments were conducted to find the available parameters and the range over which they could be varied. An experiment was designed and conducted to test the effect of each variable. The measured output, recast layer thickness and Micro hardness were analyzed. Through these experiments, the major contributing factors could be identified. All of the wire-EDM cuts were made on **Electronica Spreintcut 734** Wire-EDM machine. This machine is capable of CNC motion in two-axes and with the appropriate wire guides can accept wire from a diameter of 100 μm to 300 μm . For actual Experimentation Brass wire with diameter of 0.25mm is used. The machine has a reservoir of water, which acts both as a dielectric and as a flushing medium for the swarf. The machine controls the conductivity of the water by de-ionizing it with a resin tank. A chiller maintains the water at a constant temperature. While the parameters and their levels selected for the work given in Table 2. The two material Strips of size 100mm x 25mm x 8 mm were used as workpiece material. Small cuts of 5mm x 5mm x 8mm along the length of work piece were taken on CNC WEDM and for the same CNC Program were feed to machine. The design of experimentation is used for actual Practice; The Parameters values are selected from available machine (Electronica Sprintcut 734) parameter range.

Table 2. Parameters and their levels selected for work

Symbol	Levels Parameters	unit	Level 1	Level 2	Level 3
A	Pulse on time (Ton)	μs	120	115	125
B	Pulse off time (Toff)	μs	60	55	50
C	Wire Feed	m/min	2	3	4

The experiments were planned and conducted as per Taguchi's standard orthogonal array L-9. The selected output for these experiments is the recast layer thickness to measure the Recast layer thickness; all the cut specimens are pre-processed by cleaning them in acetone and in sodium hydroxide solution. Then small specimens are put in the SEM to

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

get photograph on PC. Due to the variable nature of the recast layers observed, an average must be taken. The best results were obtained when an average recast layer thickness was calculated by measuring the area of the recast material and dividing by the length of the measurement. The average values of Recast layer thickness were measured and tabulated in Table 3.

Table.3 Experimental design using L9 orthogonal array for Response as Avg. RL Thickness of MDN 250.

RUN/ Experiment No	Parameters			Observed Avg.gap current	Response
	T _{on} (μs)	T _{off} (μs)	W _f (m/min)		Avg RL thickness(μm)
1	120	60	2	2	11
2	120	55	3	3.5	20
3	120	50	4	5	16
4	115	60	3	2	11
5	115	55	4	2.5	17
6	115	50	2	3	10.5
7	125	60	4	4	21
8	125	55	2	4.5	20
9	125	50	3	5	14

IV. MICRO HARDNESS EXPERIMENTS

Micro Vickers hardness tester (model HV 10009, Sr. No 75/2014) Manufactured by ACME ENGINEERS, Dhayri, Pune, India, is used for Micro hardness testing of all cut specimens. The term micro-hardness test usually refers to static indentations made with loads not exceeding 1 kgf. The load value of 0.5N for dwell of 10 sec was used on the Vickers micro hardness indenter in present study. Fig. 1 shows a sample indentation of a diamond indenter. Vickers hardness is also sometimes called Diamond Pyramid Hardness (DPH) owing to the shape of the indenter. The test samples should have a smooth surface and be held perpendicular to the indenter. All things being equal, a lighter indenter load will require a smoother surface for a satisfactory test. Indentation is done on each and every cut specimen and results as Micro hardness are tabulated as shown in Table 4.

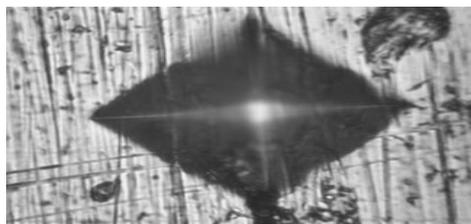


Fig. 1 Sample indentation

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

Table.4. Experimental design using L9 orthogonal array for Response as Micro hardness of MDN 250

RUN/ Experiment No	Parameters			Observed Avg.gap current	Response
	T _{on} (μs)	T _{off} (μs)	W _f (m/min)		Micro Hardness (VH)
1	120	60	2	2	187.6
2	120	55	3	3.5	183.9
3	120	50	4	5	110
4	115	60	3	2	233.6
5	115	55	4	2.5	217.5
6	115	50	2	3	231.4
7	125	60	4	4	224.3
8	125	55	2	4.5	235.1
9	125	50	3	5	237.4

It can be seen from the table that for a RL thickness & Micro hardness is maximum followed by T_{on}, W_f and T_{off}. Hence in the same order rank is given to the control factors.

V. RESULT ANALYSIS

The observed RL thickness & Micro hardness is entered as a response for this analysis. The results generated by the MINITAB 15 in terms of S/N ratio are used to draw the conclusions. The Table 5 indicates the S/N ratio for nine experimental runs with factor level set for each trial as per MINITAB 15 software.

Table 6.1 S/N ratio given by MINITAB for RL thickness & Micro hardness as a response

RUN/ Specimen No	Parameters			Response		S/N ratio
	T _{on} (μs)	T _{off} (μs)	W _f (m/min)	Avg RL thickness(μm)	Micro Hardness (VH)	
1	120	60	2	11	187.6	-1.72922
2	120	55	3	20	183.9	-1.15582
3	120	50	4	16	110	-0.68447
4	115	60	3	11	233.6	-2.40859
5	115	55	4	17	217.5	-1.38842
6	115	50	2	10.5	231.4	-2.26378
7	125	60	4	21	224.3	-1.42138
8	125	55	2	20	235.1	-1.74792
9	125	50	3	14	237.4	-1.72335

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

The result shows that the Minimum RL thickness i.e. $12\mu\text{m}$ is obtained at $115\mu\text{s}$ T_{on} , $60T_{\text{off}}$, 2m/min W_f . This is the optimum conditions in which the experiments performed.

5.1 Effect of pulse on time, wire feed and pulse off time on the Recast Layer

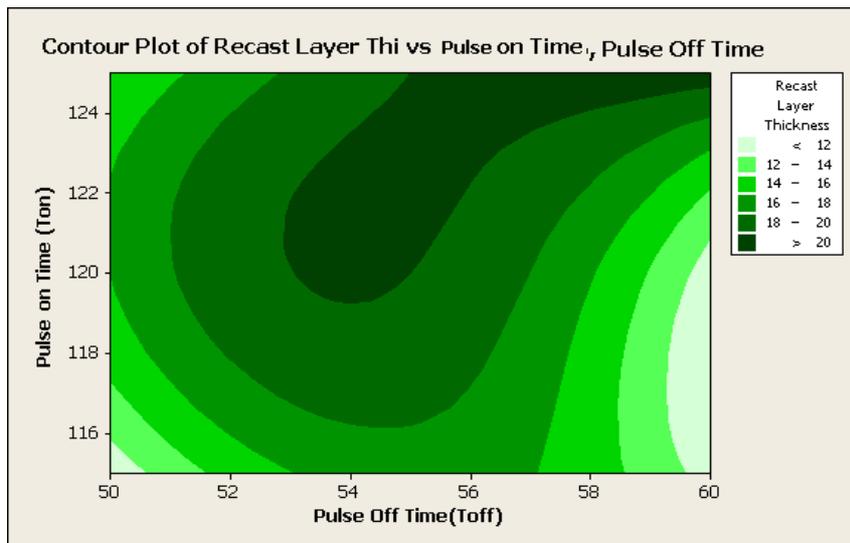


Fig.2 Contour Plots for RL v/s Pulse on time, pulse off time

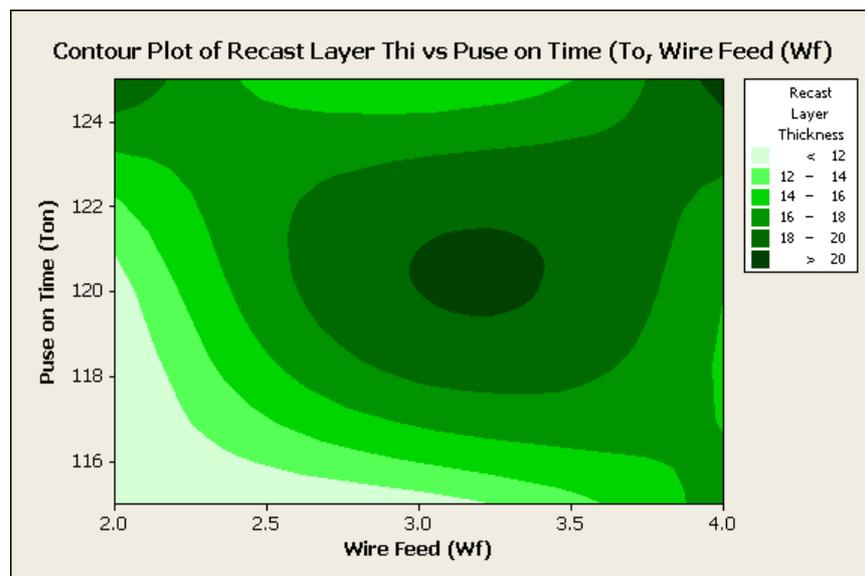


Fig.3 Contour Plots for RL v/s Pulse on time, Wire Feed

Contour plots are useful to determine output Values at intermediate input parameter levels. Fig 2 & Fig. 3 shows the effect of each parameter at various intermediate levels. It shows effect of two parameters on the RL at intermediate levels. The result shows that the Minimum RL thickness i.e. $12\mu\text{m}$ is obtained at $115\mu\text{s}$ T_{on} , $60T_{\text{off}}$, 2m/min W_f . This is the optimum conditions in which the experiments performed.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

5.2 Effect of pulse on time, wire feed and pulse off time on the microhardness

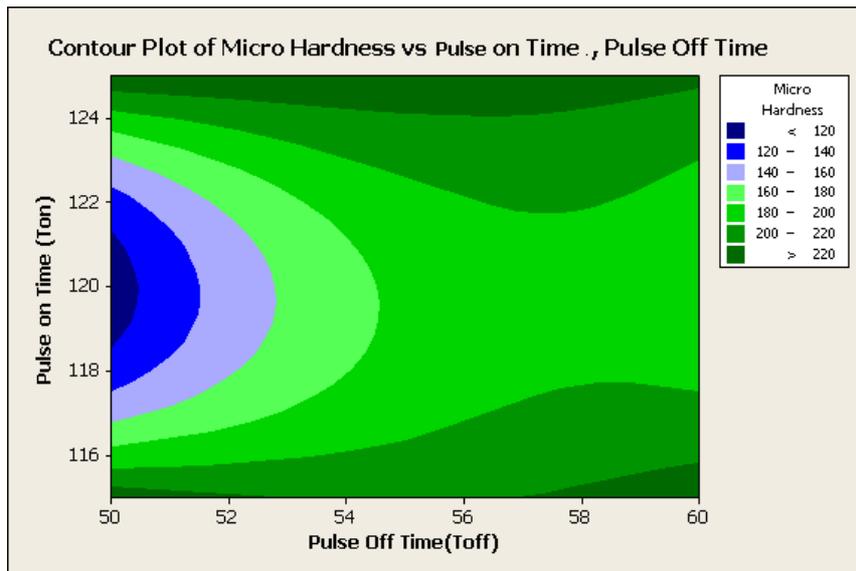


Fig.4 Contour Plots for Micro Hardness v/s Pulse on time, pulse off time

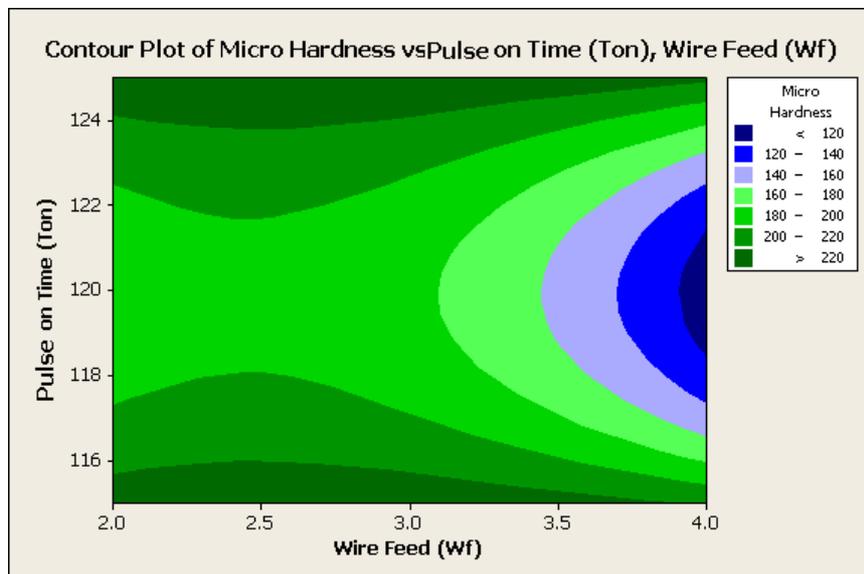


Fig.5 Contour Plots for Micro Hardness v/s Pulse on time, Wire Feed

Fig. 4 & Fig. 5 shows the effect of each parameter at various intermediate levels. It shows effect of two parameters on the micro hardness at intermediate levels. The result shows that the Minimum micro hardness i.e. ≤ 120 HV is obtained at $120 \mu s$ T_{on} , $50 T_{off}$, 4 m/min W_f . This is the optimum conditions in which the experiments performed.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

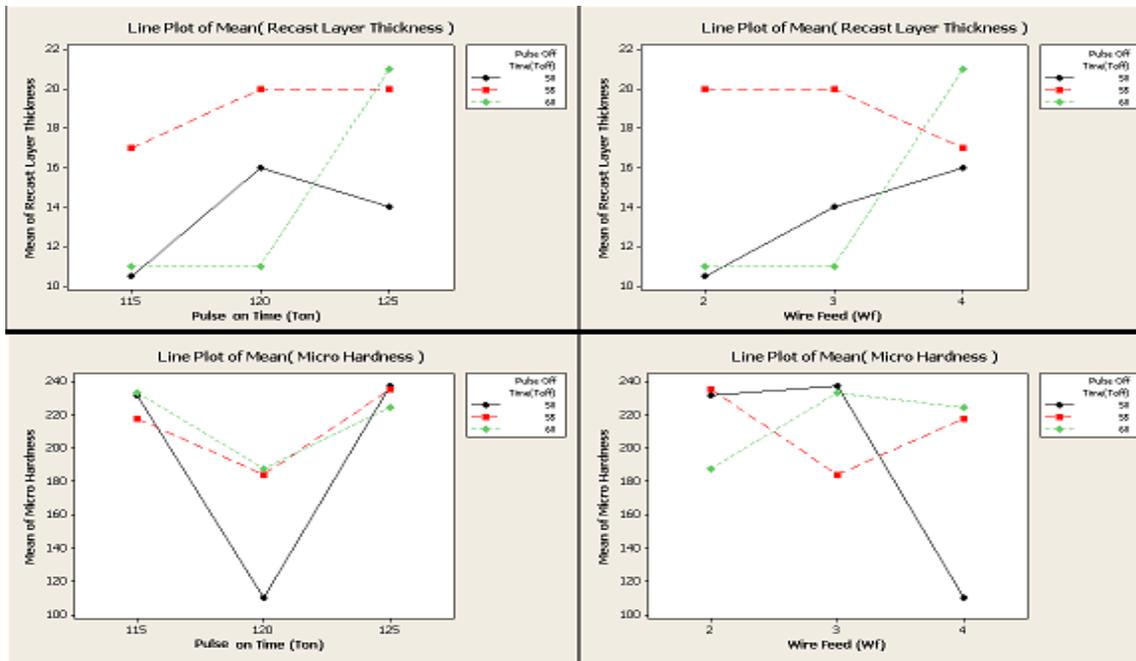


Fig.6 Line Plot for Means of RL & Micro hardness vs T_{on} , W_f , T_{off}

From the line plots obtained from Minitab software it is found that as Pulse on time and Wire feed increase Recast layer thickness and micro hardness increases.

VI. CONCLUSION

An extensive experimental study has been conducted to investigate the effect of the machining parameters on machining characteristics in WEDM on MDN 250. The machining parameters are the pulse duration (T_{on}), pulse interval (T_{off}), Wire Feed (W_f). While, the machining characteristics are the recast layer (RL) and Micro hardness.

The following conclusion was drawn from the study.

1. Pulse on time (ON) was appeared to be the main effect for all two responses investigated in this study. This means that, ON is the most significant and dominant factor than other factors in affecting the surface integrity such as RL & Micro hardness. Thus, in order to minimize RL when machining MDN 250, one can employ low pulse on time 115 μ s, pulse off time 60 μ s & wire feed of 2 m/min.
2. The results images obtained in SEM in this investigation also reveals that RL normally caused by different process parameters causes surface integrity like uneven fusing structure, globules of debris, shallow craters, pockmarks and voids. These effects become more evident when ON increased.
3. From the experimental results, the most significant factor for RL was pulse on, wire feed and then pulse off. It is observed that thickness of RL rapidly increased when pulse on increased while pulse off decreased. This happened due the molten materials builds up and resolidified on the machined surface during cooling period. Recast layer also contributed to the micro hardness increment during machining MDN 250.
4. From the micro hardness for cut specimens were observed as having increased values from that of Base metal's Micro hardness value, thus it is clear that as RL is present after machining it consist altered microstructure which results in increased Micro hardness.

ACKNOWLEDGEMENT

Research sponsored by BCUD, Savitribai Phule Pune University under Research Grant Scheme in academic year 2013-15

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

REFERENCES

- [1] Thomas R. Newton, Shreyes N. Melkote, Thomas R. Watkins, Rosa M. Trejo, Laura Reister "Investigation of the effect of process parameters on the formation and characteristics of Recast layer in wire-EDM of Inconel 718", Materials Science and Engineering A 513-514 (2009) 208-215.
- [2] Y. Liao, J. Huang, and H. Su, "A study on the machining-parameters optimization of wire electrical discharge machining", Journal of Materials Processing Technology, 71:487-493, 1997.
- [3] A. Hascalyk and U.C. "Experimental study of wire electrical discharge machining of AISI D5 tool steel", Journal of Materials Processing Technology, 148:362-367, 2004.
- [4] S. Kuriakose and M. Shunmugam, "Characteristics of wire-electro discharge machined Ti6Al4V surface", Materials Letters, 58:2231-2237, 2004.
- [5] J. Huang, Y. Liao, and W. Hsue, "Determination of finish-cutting operation number and machining-parameters setting in wire-electrical discharge machining", Journal of Materials Processing Technology, 87:69-81, 1999.
- [6] B. Yan, H. Tsai, F. Huang, and L. Lee, "Examination of wire electrical discharge machining of AL2O3/6061Al composites", International Journal of Machine Tools & Manufacture, 45:251-259, 2005.
- [7] Danial Ghodsiyeh, Abolfazl Golshan, Jamal Azimi Shirvanehdeh, "Review on Current Research Trends in Wire Electrical Discharge Machining (WEDM)", Indian Journal of Science and Technology, Vol: 6 Issue: 2 February 2013 ISSN:0974-6846.
- [8] Kumar Anish, Dr. Kumar Vinod, Dr. Kumar Jatinder, "A review on effect of WEDM performance, recast layer and wire accuracy", First National Conference on Advances in Mechanical Engineering (NCAME-2011), 20TH - 21st May 2011, UIET, Punjab University, Chandigarh.
- [9] Rajeev Kumar and Shankar Singh gives "Current Research Trends in Wire Electrical Discharge Machining: An Overview" in International Journal on Emerging Technologies 3(1): 33-40(2012)
- [10] C.D. Shah, J.R. Mevada and B.C. Khatri, "Optimization of Process Parameter of WEDM By Response Surface Methodology on Inconel-600" International Journal of Emerging Technology and Advanced Engineering, Volume 3, Issue 4, April 2013.
- [11] S. Jeelani and M. Collins, "Effect of electric discharge machining on the fatigue life of Inconel 718. International Journal of Fatigue", 10(2):121-125, 1988.
- [12] R. Williams and K. Rajurkar, "Study of wire electrical discharge machined surface characteristics. Journal of Materials Processing Technology", 28:127-138, 1991.
- [13] J. Kruth and P. Bley, "Measuring residual stress caused by Wire EDM of tool steel", International Journal of Electrical Machining, 5:23-28, 2000.
- [14] Warren, Y. Guo, and M. Weaver, "The influence of machining induced residual stress and phase transformation on the measurement of subsurface mechanical behaviour using nanoindentation", Surface Coatings & Technology, 200:3459-3467, 2006.
- [15] Brinksmeier, E., Koning, W., Leskover P and Tonshoff H. K., "Residual Stress Measurement and Causes in Machining Process", Ann. of CIRP, Vol. 31, No. 2, pp. 491-510, 1982.
- [16] C. Wilkins, "EDM wire covers all the angles", Cutting Tool Engineering, pages 40-45, April 1996.
- [17] A. Schoth, R. Forster, and W. Menz, "Micro wire EDM for high aspect ratio 3D microstructuring of ceramics and metals", Microsystem Technologies, 11:250-253, 2005.
- [18] Tapan Bagachi, "Taguchi Methods Explained: Practical Steps to Robust Design", Prentice-Hall India Ltd., 1992.
- [19] Phillip J. Ross, "Taguchi technique for quality engineering" McGraw-Hill publication.
- [20] Rodge M. K, Sarpate S. S and Sharma S. B "Investigation on Process Response and parameters in Wire Electrical Discharge Machining of Inconel 625", International Journal of Mechanical Engineering and Technology, ISSN 0976-6340, volume 4, Issue 1, January-February (2013), pp.54-56.