PROCESS PARAMETER OPTIMIZATION IN WIRE CUT EDM: A REVIEW

Govind S. Bagal[1], Ravindra L. Karvande[2], Mohammad Irfan[3]

[1] *M.E. Scholar, Mechanical Engineering Department, M.S.S'.S College of Engineering and Technology, Jalna, Maharashtra, India*
[2] *Associate Professor, Mechanical Engineering Department, M.S.S'.S College of Engineering and Technology, Jalna, Maharashtra, India*
[3] *Mechanical Engineering Department, M.S.S'.S College of Engineering and Technology, Jalna, Maharashtra, India*

ABSTRACT

This paper describes a comprehensive literature review of major published research work performed on the Wire-Cut Electrical-Discharge Machining which is one of the widely used unconventional machining process in the manufacturing industry. Regarding the optimization of process parameters a lot of research work has been reported, but in unconventional machining processes obtaining higher metal removal rate with better surface quality is still a difficult task. Based on the literature reviewed, further research scope is identified. The present literature reveals that there is a further scope to optimize the various process parameters as well as effect of heat treatment of the work-piece material should be taken into account in order to get better surface quality of machined surface, dimensional accuracy and higher metal removal rate in wire cut EDM process for minimizing the machining time, power consumption and manufacturing cost.

Keyword : - *Unconventional machining processes, wire cut-EDM, Surface roughness, Metal Removal Rate, Taguchi Method, Grey Relational Analysis etc.*

1. INTRODUCTION

Wire cut electrical discharge machining (WEDM) is widely used for machining chips free intricate shapes, narrow row slots and blind cavities etc. for example, sinking of dies for molding, die casting, press tools, plastic molding, wire drawing, compacting, cold heading, forging and extrusion [21]. Due to high dimensional accuracy and surface quality in machined surface it's application in aerospace, nuclear, and automotive industries, for machining difficult-to-machine materials is increasing tremendously. Wire cut EDM is used to machine any electrically conductive material irrespective of its hardness. Electric discharge machining, also known as spark erosion, electro erosion or spark machining is a process of metal removal based on the principal of erosion of metals by an interrupted electric spark discharge between the electrode tool (cathode) and the work piece (anode)[4].

The performance and accuracy of any machining process is based on choosing the proper combination of machining parameters. In WEDM, the improper selection of machining parameters lead to serious consequences like short-circuiting of wire and wire breakages, besides affecting the production rate and the quality of machined components[20]. In WEDM getting higher metal removal rate with minimum surface roughness value in machined surface is still a difficult task. Therefore an effort is taken to understand the effect of various process parameters, optimization techniques and methodology used for experimentation work carried out on the Wire- Cut EDM process by various researchers across the globe.

2. LITERATURE REVIEW

Literature review is undertaken to know the research work executed by researchers in the concern area of research. The reported information of research work is available in books, research papers published in National and International Journals, papers presented in conferences, the Post Graduate and Doctoral research work. The aim of this paper is to share exhaustive work carried out by various researchers in the area of wire-cut EDM operation and methodologies applied for the analysis of the operation. The detailed review related to the specified area is discussed herein as below.

Huang et al. [1] investigated the effect of control variables on the performance measures, such as white layer depth on the surface of machined work piece, gap width and surface roughness. They established Mathematical models relating machining parameters and performance by regression and non-linear programming using the Feasible-direction algorithm in order to obtain the optimal machining parameters.

Tarng et al. [2] has been applied simulated Annealing Algorithm to the ANN technique for modeling the process responses (SR and cutting velocity) and also to optimize the machining parameters they implemented a simple weighting method.

Tosun et. al. [3] has been established the mathematical model by using regression equation in order to understand the effect of process parameters on the kerf width and MRR. Also significant process parameters found out by ANOVA.

S. S. Mahapatra et al. [4] established the mathematical model by nonlinear regression analysis in order to understand the effect of control factors on output responses such as metal removal rate, surface finish and kerf width. Genetic algorithm is also applied for optimization of electrical discharge machining process.

M. Durairaja et al. [5] used Grey relational theory and Taguchi optimization (L9) technique, in order to optimize the cutting parameters in Wire EDM for SS304. The input parameters selected for optimization are gap voltage, wire feed, pulse on time, and pulse off time. Dielectric fluid pressure, wire speed, wire tension, resistance and cutting length are taken as fixed parameters. By the ANOVA they observed that the pulse on time has major influence on the surface roughness (μm) and kerf width (mm) in both the Taguchi optimization method and Grey relational analysis.

G. SELVAKUMAR1 et al. [6] Used Taguchi experimental design (L9 orthogonal array) method and considered pulse-on time, pulse-off time, peak current and wire tension as input parameters for wire electrical discharge machining (WEDM) of 5083 aluminum alloy. ANOVA test was performed to determine the level of significance of the parameters on the cutting speed and surface roughness. They found that, the CS was independent on wire tension and *R*a was independent on pulse-off time and wire tension. The additive model was used to model the process. The predictions of this model agreed very well with the experimental results. The process was optimized by Pareto-optimality approach and a technology table was proposed for optimum machining 5083 Al alloy in order to obtain higher productivity by maintaining the optimum surface finish.

Zahid A. Khana et al. [7] investigated the effect of the WEDM process parameters on the surface roughness average and the kerf width of the stainless steel (SS 304). By the Taguchi method and Grey relational analysis they found that, , the pulse ON time is the most significant controlled factor for the WEDM operation when the minimization of the both the surface roughness average and the kerf width are simultaneously considered.

G.Ugrasena et al. [8] optimized the process parameters in the wire EDM for HCHCr steel as a work material. By using Taguchi's L27 orthogonal array, process Parameters such as pulse-on, pulse-off, current and bed speed was varied. By ANOVA Analysis they determined that, the control factor 'Pulse -on' is having more effect on the response variables such as surface roughness, volumetric material removal rate and accuracy. By using optimized value of process parameters output values were improved from 3μm to 2μm for accuracy, and 2.105μm to 2.055μm for surface roughness, 11.899 mm3/min to 12.23132mm3/min for VMRR.

Ashish Goyal [9] investigated the effect of process parameters on material removal rate (MRR) and surface roughness (Ra) in wire electric discharge machining of Inconel 625 by cryogenic treated tool electrode. By using Taguchi L18 (21x35) orthogonal array of experimental design and Analysis of variance (ANOVA) found that pulse

on time, tool electrode and current intensity are the significant parameters. Cryogenic tool electrode provides better machining performance (maximum MRR and better surface roughness) as compared with normal tool electrode. The scanning electron microscopy (SEM) is used to identify the microstructure of the machined work piece.

B. Selva Babu et al. [10] investigated the effect of input machining parameters on the Metal removal rate (MRR) and surface finish for the Aluminum 6061 on wire cut EDM process. By using Taguchi's design for experimentation work and ANOVA analysis they found that, peak current and pulse on have significant effect on MRR an surface roughness whereas results shows that the most influencing parameter is the current for both MRR as well as the surface roughness.

Lalta Prasad et al. [11] used Taguchi method and genetic algorithm in order to evaluate the metal removal rate, and surface roughness while machining of with zinc- EN-42 spring steel in wire electrical discharge machining. For the research work they used zinc coated brass wire using distilled water as a dielectric medium and cryogenically treated zinc coated brass wire. They found the effect of of WS2 powder added in a dielectric medium reduced conductivity up to 10S/m which enhanced dielectric life. Because of the cryogenic treatment reduction in crystal vacancies takes place which improved the surface finish. Whereas cryogenically treated zinc-coated brass wire was used along with WS2 powder in dielectric fluid which increased MRR, because the electrical conductivity of wire increased, which shows significant improvement in the root mean square surface roughness. From the results, they observed that higher pulse on time shows better metal removal rate and lower pulse on time shows a better surface finish.

Ajay Kumar, et al. [12] investigated Optimum machining parameters for the D2 steel in WEDM operation. Taguchi L16 (orthogonal array) applied for experimental design with four process input control parameters, i.e. wire speed, flushing pressure, gap voltage, and current are selected in order to understand its effect upon MRR and SR. ANOVA and Signal to Noise ratio based analysis shows that MRR is influenced by these input parameters in the order of current followed by gap voltage, wire speed and flushing pressure.

Sahil Sharma et al. [13] investigated the influence of process parameters such as pulse on time, pulse off time, peak current, wire tension on the Metal removal rate (MRR), gap current(Ig), machining time(MT) while the machining of AISI D2 die steel of 13 mm diameter by using L9 orthogonal array. By using signal to noise ratio and ANOVA they found that, T_{off} has been the most significant factor for MRR, gap current and time taken for machining.

.

Jitendra Kumar et al. [14] considered fuzzy modeling as an option to conventional demonstration technology to obtain optimum results in WEDM for various machining parameters. The performance parameters of Pulse on time (Ton), Pulse off time (Toff), Discharge current (DC) and Wire feed rate (Wf) were analyzed byL9 Taguchi orthogonal array. They have developed Fuzzy model in MATLAB to predict fuzzy response parameters which showed 90% accuracy.

Veeresh Murthy et al. [15] has been used Taguchi Technique in order to optimize the Wire EDM Machining Parameters for Optimum Material Removal Rate and Surface Finish in an Aluminum 7075-T651 Alloy. ANOVA is also used to analyze the effect of each parameter on the machining characteristics namely (MRR and Ra) and predicted the optimal choice for each Wire EDM parameters namely Pulse on time (TON), Servo Voltage (SV) and Pulse off time (TOFF). By the experimental results WEDM parameters for higher MRR determined is TON=106, TOFF=40 and SV=15 and for lower Ra, TON=100, TOFF=40 and SV=15.

K.L.Uday et al. [16] predicted the angular error in wire-EDM taper cutting of AISI D2 tool steel by response surface methodology approach to reduce the experimental load on experiments were carried out. Author developed regression model for relating the responses to the process parameters and Separate analysis of variance (ANOVA) is used to analyze the effect of parameters and contribution of each parameter affecting the responses is calculated. From the Results they found that, part thickness and servo voltage are the most influencing variables reported in the carried out experimentation work..

Prashant Sinhaa et al. [17] A hybrid approach of Taguchi method (TM) and principal component analysis (PCA) multi-objective optimization (MOO)WEDM of AISI D3 tool steel to achieve better cut qualities within existing resources. The input parameters considered are pulse on time, pulse off time, peak current and servo voltage. Initially, single objective optimization has been performed using TM and then the signal-to-noise (S/N) ratios

obtained from TM have been further used in PCA for multi-objective optimization. From the considered work they found that, in single objective optimization using Taguchi method, servo voltage and pulse on time and peak current are the significant factors for material removal rate (MRR), while peak current and servo voltage are the significant for surface roughness. Multiple quality characteristics (MQC) has found improved by using hybrid approach of Taguchi method and principle component analysis(PCA) as compared to initial level of parameters.

Amitesh Goswami et al. [18] used Taguchi's design of experiments methodology for planning and designing the experiments in order to investigate the effect of machining parameters on the machining outputs (material removal rate and wire wear ratio) of Nimonic 80A in WEDM. SEM was performed on the machined samples to investigate the effect and microstructure of the samples after machining. Pulse-on time (Ton) and pulse-off time (Toff) have been found to be the most significant factors for MRR at 95% significance level, with percent contributions of 46% and 33% respectively. All of the input parameters investigated in the study have been found to be statistically significant for wire wear ratio. The recast layer has been observed to increase with increase in pulse-on time and peak current.

M M Dhobe et al. [19] investigated the effect of heat treatment and process parameters of Wire Electrical Discharge Machining (WEDM) like pulse on time (TON), pulse off time (TOFF), gap voltage (SV), peak current (IP) on surface roughness of tool steel AISI D2. From the experimental work they observed that, the surface roughness increases with increase in pulse on time (TON) and peak current (IP) whereas decreases with increase in number of tempering cycles after hardening for the same process parameters. This means double tempering after hardening reduces surface roughness compared to single tempering.

D. Sudhakara et al. [20] Determined the Optimum Surface Roughness in Wire Electric Discharge Machining of P/M Cold Worked Tool Steel (Vanadis-4E) by Taguchi Method. They considered pulse on time (ON), pulse off time (OFF), servo voltage (SV), peak current (IP), wire tension (WT) and water pressure (WP) as a process parameters in WEDM. By using L27 orthogonal array (OA) the signal- to- noice (S/N) ratio determined for surface roughness as per "the- smaller- the-better" approach. By ANOVA analysis they obtained the optimal value of process parameters as well as ranges of Optiimal process parameters in WEDM for the minimization of surface roughness. The optimal ranges found out for the process parameters pulse on time (ON), pulse off time (OFF), servo voltage (SV), peak current (IP), wire tension (WT) and water pressure (WP) are (108-12) μs , (47-63) μs, (11-13)Amperes, (18-68)Volts, (2-8) gms, (8-14) kg/cm^2 respectively.

3. SUMMARY OF LITERATURE REVIEW

Based on the available literature on wire cut EDM operation, following observations can be made.

a) Optimum level of process parameters can be found out by using Taguchi Method to get optimum value of each response variable such as material removal rate and surface roughness.

b) In WEDM MRR and Ra mostly influenced by pulse on time (Ton) and Peak Current (Ip).

c) Cryogenic treatment and heat treatment of material affects the metal removal rate and surface quality obtained in the wire cut EDM operations.

d) Multi-objective optimization and the optimal solution can be found out using Grey Relational Analysis and Principal Component Analysis.

e) From the literature review, various parameters are identified affecting the performance of Wire Cut EDM operation as follows:

1. Spark On Time
2. Spark Off Time
3. Peak Current
4. Spark Gap Set Voltage
5. Wire Feed
6.Servo Feed
7. Wire Tension
8.Dielectric Fluid Pressure
9.Type Of Wire Electrode
10. Type Of Dielectric Fluid
11.Wire Wear Ratio
12.Cutting Length
13. Bed Speed
14. Current Gap
15. Machining Time
16. Electrode Wear Rate
17. Work-Piece Material

4. CONCLUSION

The aim of the review is to highlight major research studies carried out on WEDM operation and various methodology used for the analysis. Many authors have focused on the process parameter optimization, materials of electrodes/tool-work-piece and dielectric medium. Most authors used Taguchi method for the designation of experiments in order to obtain optimum results. Some authors used grey relational analysis, response surface methodology, fuzzy modeling, mathematical modeling, Regression equations, Principal Component analysis and ANOVA has been applied to find most influencing parameters on the output response. Out of all the above research work very few authors have focused on the heat treatment of material used in WEDM. As heat treatment process relieve the residual stresses and changes the grain structure of metal which affects the metal removal rate and surface finish during machining processes. Therefore process parameters and heat treatment of materials can be taken into account while doing future work on Wire cut EDM operations.

5. REFERENCES

[1]. Huang, J.T., Liao, Y.S., Hsue, W.J., "Determination of finish cutting operation number and machining parameters setting in wire electrical discharge machining". J. Mater. Process Technol., 87 (1999) 69–81.
[2]. Tarng, Y.S., Ma, S.C., Chung, L.K., "Determination of optimal cutting parameters in wire electrical discharge machining", Int. J. Mach. Tools & Manufact., 35(12) (1995) 1693-1701,.
[3]. Tosun, N., Cogun, C. and Tosun, G., "A study on kerf and material removal rate in wire electrical discharge machining based on Taguchi method", Journal of Materials Processing Technology, 152 (2004) 316-322.
[4]. S. S. Mahapatra, Amar Patnaik, ''Optimization of wire electrical discharge machining (WEDM) process parameters using Taguchi method'', Int J Adv Manuf Technol (2007) 34:911–925 DOI 10.1007/s00170-006-0672-6.
[5]. M. Durairaja, D. Sudharsunb, N. Swamynathanb, "Analysis of Process Parameters in Wire EDM with Stainless Steel using Single Objective Taguchi Method and Multi Objective Grey Relational Grade", International Conference On Design And Manufacturing, IConDM 2013, Procedia Engineering 64 (2013) 868 – 877.
[6].G. Selvakumar1, G. Sornalatha2, S. Sarkar3, S. Mitra3,"Experimental investigation and multi-objective optimization of wire electrical discharge machining (WEDM) of 5083 aluminum alloy", Trans. Nonferrous Met. Soc.China 24(2014) 373_379.
[7]. Zahid A. Khana, Arshad N. Siddiqueea, Noor Zaman Khana , Urfi Khanb, G. A. Quadirc, "Multi response optimization of Wire electrical discharge machining process parameters using Taguchi based Grey Relational Analysis", 3rd International Conference on Materials Processing and Characterisation (ICMPC 2014), Procedia Materials Science 6 (2014) 1683 – 1695.
[8]. G.Ugrasena, H.V.Ravindrab, G.V.Naveen Prakashc, Y.N.Theertha Prasad, "Optimization of process parameters in wire EDM of HCHCr material using Taguchi's technique", 4th International Conference on Materials Processing and Characterization, Materials Today: Proceedings 2 (2015) 2443 – 2452.
[9]. Ashish Goyal, "Investigation of Material removal rate and Surface roughness during Wire electrical discharge machining (WEDM) machining of Inconel 625 super alloy by cryogenic treated tool electrode", Journal of King Saud University – Science, S1018-3647(17)30333-6.
[10]. B. Selva Babu , S. Sathiyaraj, Anantha Krishnan P. Ramesh, B.A. Afridi, K. Kristo Varghese, "Investigation of machining characteristics of aluminium 6061 by wire cut EDM process".
[11]. Lalta Prasad, Manish Upreti, Anshul Yadav, · Raj Vardhan Patel , Virendra Kumar, Anil Kumar, "Optimization of process parameters during WEDM of EN‑42 spring steel", Springer Nature Switzerland AG 2020.
[12]. Ajay Kumar, Vishal Jagota, Rashed Qayoom Shawl, Vishal Sharma, Kumar Sargam, Mohammad Shabaz, Mohd Tanveer Khan, Basharat Rabani , Smiley Gandhi , "Wire EDM process parameter optimization for D2 steel".
[13]. Sahil Sharma, Umesh Kumar Vates , Amit Bansal, "Parametric optimization in wire EDM of D2 tool steel using Taguchi method".
[14]. Jitendra Kumar, Tarun Soota, S.K. Rajput, " Experimental evaluation and modelling of wire-EDM process parameter for stainless steel AISI 630", Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2020.02.231..
[15]. Veeresh Murthy, **"**Optimization of Wire EDM Machining Parameters for Optimum Material Removal Rate and Surface Finish in an Aluminum 7075-T651 Alloy", NCRAEM - 2019 Conference Proceedings, International Journal of Engineering Research & Technology (IJERT) ISSN: 2278-0181.
[16]. K.L.Uday Kirana, P.Saratha, K.Saraswathamma, G.Chandra Mohan Reddy , "Prediction of angular error in wire-EDM taper cutting of AISI D2 tool steel by RSM approach", ICAMM_2016, Materials Today: Proceedings 5 (2018) 27043–27050.

[17]. PrashantSinhaa, Rajeev Kumar ,G.K.Singhb, DainThomasc, Tushar Srivastava, "Optimization of Wire EDM of AISI D3 Tool Steel using Orthogonal, Array with Principal Component Analysis", 4th International Conference on Materials Processing and Characterization, Materials Today: Proceedings 2 (2015) 2512 – 2521.
[18]. Amitesh Goswami, Jatinder Kumar, "Investigation of surface integrity, material removal rate and wire wear ratio for WEDM of Nimonic 80A alloy using GRA and Taguchi method Engineering Science and Technology", an International Journal Engineering Science and Technology, an International Journal 17 (2014) 173e184.
[19]. M M Dhobe, I K Chopde And C L Gogte, "Effect Of Heat Treatment And Process Parameters On Surface Roughness In Wire Electro Discharge Machining", International journal of mechanical engineering and robotic research, ISSN 2278 – 0149.
[20]. D. Sudhakara, G. Prasanthi, "Application of Taguchi Method for Determining Optimum Surface Roughness in Wire Electric Discharge Machining Of P/M Cold Worked Tool Steel (Vanadis-4e)", 12th Global Congress On Manufacturing And Management, Procedia Engineering 97 (2014), Pp. 1565–1576.
[21]. P.C. Sharma,A Textbook Of Production Technology (Manufacturing Processes), ISBN: 81-219-1114-1.