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Surface Roughness and Material Removal Rate in Wire Electro Discharge Machining of Hard Materials: A Review

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***Abstract*: Wire cut EDM is now a days widely used machining process. It is widely used because it can machine very complex shape accurately. There is no contact in wire cut EDM between wire and work piece. Wire cut EDM works best for hard materials. There is thermal energy produced between wire and work piece. This heat is used to melt work piece material and material gets machined in this way. Erosion of material takes place because of this heat produced between work piece and moving wire. In this article author has discussed current trends in the field of wire cut electric discharge machining. Findings of reputed journal papers are discussed in this paper. Also author has discussed in this paper future possibilities in the field of machining using WEDM for machining of hard materials. The work concluded that there is need of time to perform extensive study with regard to effect of wire tension, flushing pressure, dielectric flow rate, different dielectric fluids, and wire consumption rate on Ra and MRR in WEDM.**

Keywords: WEDM, Surface Roughness, MRR, Titanium

I. INTRODUCTION

Wire electrical discharge machining is best suited for machining of hard materials where conventional machining does not perform best for fast machining and good surface finish. Wire cut machining has many applications in in aviation, atomic, car industry, tool and die industry. In wire cur EDM there is wire used which works as one of the electrodes. Second electrode is work piece which is electrically conductive metal. Generation of spark takes place between these two electrodes as current passes between them. This spark generates heat energy which melts work piece and this is how machining takes place. The sparks get generated between work piece and wire electrode due to voltage gap. There is generation of many successive sparks because of which work piece gets continuously eroded. This eroded metal gets flushed away by ionized water. Wire cut is now a days uses as advanced machining process because material removal rate is minimal which gives high surface finish. Thus, there is less wastage of material in wire cut EDM. Process parameters are optimized to enhance manufacturing capability. It was challenging area to machine harder materials so effective machining is a need now a days. Process parameter selection can be done to improve machining for this optimization of WEDM process can be a beneficial for having effective machining of hard materials.

II. LITERATURE REVIEW

This section presents the investigations done with regard to work material, input parameters, techniques used for analysis and specific conclusions.

Kumar et al., [1] done optimization of wire-cut EDM process parameter. He used Grey-based response surface methodology. He used a face centered cubic design for conducting experiments. The material used by him is high speed steel of M2 grade. The regression model is used. Process parameters selected are pulse-on time, pulse-off time, peak current, and wire feed. Material removal rate, surface roughness and Kerf width are optimized in his work. ANOVA is used for optimization. After optimization values of optimized responses like material removal rate (0.03137 g/min), surface roughness (1.79 lm) and Kerf width (0.19 mm) are generated. Optimal parameter values like pulse-on time 20 ls, pulse-off time 15 ls, current 2 A, and wire feed 50 mm/s are concluded.

Silambarasan et al., [2] did optimization of wire EDM using genetic algorithm. Metal used is Titanium grade 5 alloys. Process parameters selected which affects MRR and SR. Input process parameters selected are current, pulse on time, pulse off time, wire tension and dielectric flushing pressure. Process parameters optimization is done using three levels and L-18 orthogonal array. The genetic algorithm is used to find optimum parametercombination.

Kumari et al., [3] did optimization of wire EDM process parameters. Process parameters selected are pulse on time (Ton), pulse off time (Toff), peak current (Ip), spark voltage (Sv). Material selected is T-42 HSS with 10% cobalt material. Response parameter is material removal rate. Optimization is done by using statistical software MINITAB 18. Process parameters optimization is done using three levels and L-9 orthogonal array. After Taguchi analysis for MRR most significant factors are generated as rank 1 factor is Peak current (Ip) Rank 1 then Rank 2 factor is Pulse on time (Ton) and Rank 3 is Servo voltage (Sv) and Rank 4 is pulse off time (Toff).

Mahapatra and Patnaik et al., [4], optimized WEDM machining parameters. The methodology is beneficial to manufacturing industries, other areas as aerospace, automobile and tool making industries. The algorithm is used for optimization. Significant factors found are discharge current (A), pulse duration (B), dielectric flow rate (F).

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Kumar and singh et al., [5], used Taguchi method L9 array is selected to find the optimum values. Material selected is D3 steel. Wire Electric Discharge Machine (WEDM) process parameters are selected are peak current, gap voltage, duty cycle and pulse on time. Response parameters selected are material removal rate (MRR), electrode wear rate (EWR), radial overcut (ROC). Significant parameter is peak current that have influence on as material removal rate (MRR), electrode wear rate (EWR), radial overcut (ROC). WEDM is adequate process to machine Inconel with adequateMRR.

Bhaskar and Reddy et al.,[6] concluded wire Electric Discharge Machine (EDM) is widely used for the machining or micromachining of parts that have intricate shapes. Wire EDM has low machining speed as compared to conventional machining which is big advantage of wire EDM machine. The study of Wire EDM process is done to have an accurate and efficient machining operation with quality and at most best machining performance. This is done by optimizing the input parameters. Dimensional deviation increases with increasing the pulse off time initially after it decreases.

Singh et al., [7] did study of wire EDM for process parameter optimization. Material selected is EN 8 steel. Study is done to find best operating conditions for any manufacturing technique. Output parameter selected are dimensional deviation and input parameters selected are wire feed, pulse off time and servo voltage. Process parameters optimization is done using L-18 orthogonal array of taguchi method. MINITAB-17 software is used to find optimum values. Confirmation experiments are done for conforming the results. In the three parameters, servo voltage has the most influence on dimensional deviation and is followed by pulse off time, and wire feed in the order.

Kumar and singh et al., [8] In their study did optimization of wire EDM process parameters. Input parameters are pulse on time, pulse off time, open voltage, feed rate override, wire feed, servo voltage, wire tension and flushing pressure. Wire used is Brass wire and its thickness is 0.25mm diameter. Material used is Skd 61 alloy steel with 10mm thickness. Outputs parameters are material removal rate (MRR) and surface roughness. Taguchi L18 (21x37) orthogonal array is used for experimentation. Analysis is done for selection of an optimal value of WEDM parameters for machining of Skd 61 alloy to achieve better surface finish. Also the importance of the cutting parameters on the outputs is determined by using analysis of variance (ANOVA).

Srinivasa et al.,[9] selected material for study is Stainless Steel AISI 316. Machine selected is Wire-Cut EDM. The effect of machining parameters those are surface roughness (SR) and MRR (Material Removal Rate). brass wire of 0.25 mm diameter is used. Distilled water is used as dielectric fluid. Input parameters are Current, Pulse ON time and Wire feed rate with three levels of each. Similarly study is done for spark cut EDM. Electrodes used are copper rod of 12 mm diameter and 65 mm length. Input parameters are parameters Current, Voltage, and Pulse ON time with three levels of each. ANOVA & L-9 Orthogonal Array are used to optimize the output parameters Surface Roughness (SR) and MRR (Material Removal Rate).

Jaiswal et al., [10] did multi-response optimization of wire electrical discharge machining process. Input parameters are pulse-on-time, pulse-off- time, servo voltage and wire tension. The material selected is D3 die steelusing brass wire. The responses selected are cutting speed and surface roughness. Taguchi based DOE is used for design of experiment. The response parameters are optimized by using MOORA approach to obtain higher cutting speed and lower surface roughness. Higher cutting speed and lower surface roughness are obtained as a result.

Kumar et al., [11] is studied metal removal rate as a response parameter by using computational technique. For spark EDM material used for the work and for the electrode are EN-31 and copper electrode respectively. Input parameters used are electrode diameter, current and pulse rate. The models of experimental data are developed by using regression analysis. The parametric investigations have also been done by using central composite design. The material removal rate equation shows that the pulse rate is the main influencing factor, followed by current and electrode diameter in the operation model.

Kumara and Ravikumarb et al., [12] did optimization of the parameters of wire electric discharge machining (WEDM) process. Input parameters are Time On, Time Off, Wire Speed & Wire Feed. Three levels of these parameters are selected for optimization. Responses selected are Metal removal rate, surface roughness (Ra). Quadratic mathematical model (RSM) is used. Graphical representation is used for showing influence of the parameters on selected responses.

Pujari et al., [13] did study of wire EDM. It's been concluded in wire EDM surface roughness and kerf width are of crucial importance. Response parameters are surface roughness and kerf width of aluminum and mild steel. Taguchi method is used for process parameter optimization. The MRR is optimized with regression analysis. The parameters pulse on time, peak current and spark gap voltage have shown significant effect on both MRR and SR but at different levels.

Bobilli et al., [14] used multi response optimization technique based on Taguchi method. He coupled it with Grey rational Analysis. Study is done for wire EDM process. Material used is aluminum alloy. Results are Ton, IP, SV are significant variables togrey relational grade.

Gaikwad et al., [15], had done work on optimization of material removal rate for machining of electric discharge machining. Material used is NiTi alloys. Optimization is done by using Taguchi method. It is concluded by using ANOVA that in case of kerf width wire feed rate and spark on time have significant effect on Aluminium and Mild steel.

Rathore et al., [16] presented studied machining of Electric Discharge Machine. Study is done for high hardness of material. Based on the analysis it was found that work electrical conductivity, gap current and pulse on time are the significant parameters that affect the material removal rate.

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Sultan et al., [17] used Electric discharge machine for study. Response parameters are MRR, electrode wear rate and surface roughness. Optimization is done using response surface methodology. Material to machine is EN353 steel. It is concluded that the many work is done by using the various optimization techniques like Taguchi, RSM, GA, FEM etc., have been used in order to optimize the various parameters in Electrical Discharge Machining process (EDM).

Athisankar et al., [18] has concluded that the materials with much superior properties such as high strength, low weight and withstand the temperature are difficult to machine by conventional machining methods. Wire electric Discharge machine is commonly used to make a complex and micro shape. Based on the literature survey there is lot of research work is progressed in WEDM. But there is need to study the effect of WEDM in different alloys.

Sahu et al.,[19] concluded that that in recent time INCONEL has wide applications in aeronautical, aerospace industry and automobile engineering. It has favorable properties. Comparison of heat and non-heat treated tool is done for MRR, TWR,SR, kerf width. Then it is found that the heat treated tool is most significant as compared to non-heat.

Prakash et al., [20] did study on Wire Electrical Discharge Machining (WEDM). Variable are pulse on time, pulse off time, gap voltage and wire feed. Material used is fabricated Aluminium Matrix Composites (AMC- 413/B4C), using stircasting process. The experimentation is carried by using L27 orthogonal array by using Taguchi method. Analysis of variance (ANOVA) is used. Responses are maximum MRR and minimum SR was obtained by using the signal-to-noise (S/N) ratio. Most of the time the surface roughness is same for both heat treated and non-heat treated electrode.

Shastri et al., [21] concluded about titanium, stainless steel, high-strength temperature-resistant alloys, ceramics, refractories, fibre-reinforced composites, and superalloys has poor machinability and hence efficient machining is critical. This paper presents the application of socio-inspired optimization techniques, viz. CI and its variations as well as Multi-CI for solving real- life machining optimization problem of titanium alloy (Grade II) in MQL environment. The confirmation tests indicated that it is possible to decrease the surface roughness and increase material removal rate significantly by using the proposed statistical technique.

Nithyanandam et al., [22] concluded titanium is important material in many engineering fields. It has properties like high strength to weight ratio, superior corrosion resistance and thermal properties. It has application aerospace, biomedical and automotive field. They are said to be “difficult-to-Machine materials” as they possess poor thermal properties, poor machinability.

Snehaa et al., [23] has studied wire-cut electrical discharge machining process (WEDM). It is frequently used for making the complicated shapes. It is specially used for very hard materials and complecate work pieces. Since there is no physical contact between tool and work piece delicate sections and weak materials can be machined without any distortion. For having lower kerf width. Lower pulse on time, higher current and higherwire feed rate are suitableparameters.

Nourbakhsha et al., [24] used for study wire electro-discharge machining (WEDM). Material used is titanium alloy. Process parameters are pulse width, servo reference voltage, pulse current, and wire tension. Response parameters are cutting speed, wire rupture and surface integrity. A Taguchi L18 array is applied to design experimentation. Peak current and pulse width have significant effect on cutting speed and surfaceroughness.

Pramanik et al., [25] Geometrical errors as cylindricity, circularity and diametric errors of a feature (a hole) are investigated in this paper. Wire electrical discharge machining is used for study. Material studied is Ti6Al4V alloy. Input parameters are tension in wire, pulse on time, and flushing pressure. Pareto analysis of variance (ANOVA), Taguchi design of experiment (DoE), and traditional analysis are used for statistical analysis. Circularity, cylindricity, and diametral error were mostly influenced by wire tension and flushing pressure as the stability aswell as the wire electroderigidity depend on wire tension

Ahsan and Mazid et al., [26] presented literature review on optimization of machining parameters. Also problems related to machining of Ti-alloys and their effects were summarized. These alloys are some of the most difficult-to-machine materials therefore manufacturers using Ti-alloys for production are continuously facing challenge to reach the optimum cutting conditions for sustainability in manufacturing .

Vijay and Krishnaraj et al., [27] had done machining parameter optimization in end milling. Material used is Ti6Al4V. Input parameters are cutting speed, feed and depth. Depth of cut has the most significant effect on cutting force.

Garg et al., [28] has done study on wire electrical discharge machining. Identified process parameters that causes effect on the cutting speed and surface roughness. Material used is Titanium-62-4-2 (HSTR aerospace alloy). Also identifies optimal process parameter for simultaneous optimization of cutting speed and surface roughness. Surface roughness is effected by the main effects of TON, TOFF, IP, SV, WF and WT as well as interaction effects between TON and WT, IP and WF. Wire feed is a main effect which has little impact on surface roughness.

Magabe et al., [29] did research on wire electric discharge machining (wire-EDM) process. Material used is Ni55.8Ti shape memory alloy. The input parameters are spark gap voltage, pulse on-time, pulse off-time, and wire feed. Response parameters are metal removal rate (MRR) and mean roughness depth (Rz). Wire-EDM in machining of Ni55.8Ti at higher voltage, pulse-on time, and wire feed rate results in higher material removal rate means high productivity.

Jaber et al., [30] This paper presented study on EDM to improve the process performance. Responses are material removal rate, surface quality, and tool wear rate. Ton significantly affected the performance of the EDM process

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whilemachining the titanium and its alloys.

Sarkar et al., [31] studied wire electrical discharge machining (WEDM). Material is γ titanium aluminide. Optimum machining parameter combinations for obtaining higher cutting are selected. wire electrical discharge machining of γ titanium aluminide alloy has been carried out, and theoptimal combination of control parameters are determined.

Kumar et al., [32] studied wire-cut electrical discharge machining on Titanium Grade - 5 material . Taguchi grey relational analysis is used. Multiple performance characteristics of the output response variables are considered. The greyrelational analysis is used.

Ramprasad et al., [33] have studied parameter optimization on titanium alloy. Input parameters were peak current, pulse on time, pulse of time, and servo voltage. Output parameters are surface roughness and MRR. For both MRR and SR most significant parameters are peak current and pulse on time while pulse of time and servo voltage are less significant.

Vetrivel et al., [34] have studied machining parameters of wire electrical discharge machining (WEDM) on TITANIUM. Taguchi Method is used. It is most ideal and suitable for the parametric optimization of the Wire-Cut EDM process. Using the multiple performance characteristics MRR (Material Removal Rate) and Surface Roughness for machining the Titanium are optimized.

III. RESULTS AND DISCUSSION

The researchers performed investigation to study the effects of input parameters and tried to maximize material removal rate and minimize surface roughness value. The Taguchi approach and response surface methodology was used by the researchers for the design of experiments. It was observed that researchers have used Taguchi method, response surface methodology, genetic algorithm, MOORA (multi objective optimization on the basis of ratio analysis), artificial neural network model for analysis of WEDM process. Minitab or Design Expert software tool was used for design and
analysis of WEDM process. Pulse on time (Ton), pulse off time (Toff), peak current (Ip), spark voltage (Sv), wire feed, were commonly undertaken input parameters. Pulse on time is the main influencing factor, followed by current on material removal rate. Surface roughness is mainly influenced by pulse on time. Peak current and pulse on time were most significant parameters for both MRR and SR.

IV.DISCUSSION AND CONCLUSION

From the above literature survey, it was observed that the researchers have used various optimization techniques such as Taguchi method, response surface methodology, genetic algorithm, MOORA (multi objective optimization on the basis of ratio analysis), artificial neural network model for analysis and to optimize the various parameters in Wire EDM process. The Design of Experiment (DOE) analysis-based Optimization is the evolutionary algorithms which were used positively by the various investigators. Almost in all studies the main objective of the future work was to maximize the Material Removal Rate (MRR) and minimize the Surface Roughness (SR) value in WEDM.

V. FUTURE SCOPE

Study on influence of flushing pressure, dielectric flow rate, different advanced dielectric fluids on surface roughness and material removal rate is very limited. Therefore, it is need of time to perform extensive study on WEDM using wire tension, flushing pressure, dielectric flow rate, different dielectric fluids, and wire consumption rate and analyze its effect in Ra and MRR using RSM and ANN.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interests regarding the publication of this paper.

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