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Review Article

Review of Research Trends: Process Parametric Optimization of Wire Electrical Discharge Machining (WEDM)

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Abstract

The wire cut EDM is one of the most important machining process for technologists in the field of moulds, dies and in precision manufacturing .The wire electrical discharge machining producing parts with in very short period , the demand over the time increases extensively .So that an extensive research work has been carried out to optimize the parameters of the process by eliminating trial and error cost for the selection of parameters during machining of materials, for getting optimum responses like best surface finish, metal removal rate, with good dimensional accuracy and with retaining the physical and chemical properties of parent material.The present paper mainly explores the review of the research work carried out by various research workers with various methodologies and how the output parameters of the WEDM like surface finish , metal removal rate, dimensional accuracy and HAZ were affected by the input process parameters like on time, off time, voltage, wire tension, wire feed, dielectric pressure. current, etc.

Keywords: *Wire electrical discharge machining, Review of the research trends, Optimization of parameters, MRR, Surface roughness, Dimensional deviation, etc..*

1. Introduction

Wire electrical discharge machining is a nontraditional widely accepted machining process used in tool & die industry, aerospace, surgical, automotive, nuclear industries because of it's capability to cut materials having intricate profiles, very hard materials which are difficult to cut by conventional machining process. The wire electrical discharge machining is similar to that of electrical discharge machining (EDM) process, in which there is no contact between tool and work piece. Because of the invention of Wire electrical discharge machining (WEDM) process, it evolved as best machining process for producing complicate parts with very good surface finish and dimensional accuracy.

2. WEDM Process

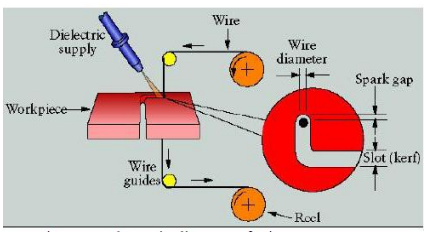

Fig.1 Schematic diagram of the wire electric discharge Machine(WEDM)

The material removal mechanism of WEDM is very similar to the conventional EDM process involving the erosion effect produced by the electric discharges. In WEDM, material is eroded from the work piece by a series of discrete sparks occurring between the work piece and the wire separated by a stream of dielectric fluid, which is continuously fed to the machining zone. However, today's WEDM process is commonly conducted on work piece that are totally submerged in tank filled with dielectric fluid. Such a submerged method of WEDM promotes temperature stabilization and efficient flushing especially in cases where the work piece has varying thickness. The WEDM process makes use of electrical energy generating a channel of plasma between the cathode and anode and turns it into thermal energy at the temperature in the range of 8000c-12,000c or as high as 20,000c initializing a substantial amount of heating and melting of material on the surface of each pole.

3. Review of The WEDM Research Work

(Speeding et al, 1997) performed experimental study on AISI 420 steel to optimize the process parameters in combinations by modeling the process using ANN and characterized the WEDM machined surface by time series technique. (Speeding et al, 1997) attempted to optimize the process parameters in combinations by modeling the process using ANN and RSM. A RSM model used on central composite rotatable experimental design, and 4-16-3 size BPNN has been used. They worked with the pulse

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width, time between two pulses, wire mechanical tension and injection point as process parameters and cutting speed, surface roughness and surface waviness are output responses. From the results , both of the models were predicted the process performance such as cutting speed, surface roughness and surface waviness within a reasonable large range of input parameters factor level and the ANN model found to be fit the data better and higher predictive capability to Ra and cutting speed. (Gokler et al, 2000) conducted experiments on Sodic Mark XI A500 EDW WEDM as machine tool and 1040, 2379 and 2378 steels as work piece materials in order to investigate the effect of cutting and offset parameters on surface roughness in WEDM process. From the results it was concluded that, the offset parameters does not affect the surface roughness and same result with cutting parameters .If the thickness of the work piece increases, the average feed rate decreases. (Tusan et al, 2003) carried out experiments on Sodic A320/EX21 WEDM machine tool with 0.25 mm brass wire as tool electrode and AISI 4140 steel as work piece material. They studied the effect of cutting parameters on the size of erosion craters (diameter and depth) on wire electrode. When the increase in pulse duration and open circuit voltage increase the wire wear ratio, where as the increase in wire speed and dielectric fluid pressure decrease the WWR. The WWR is always accompanied by high MRR and high Ra values. Based on ANOVA and F-test, open circuit voltage and pulse duration has more influence on WWR .(Tusan et al, 2003) used AISI 4140 steel as work piece material and Sodic A320/EX21 WEDM as machine tool conducted experiments to study the variations of cutting parameters with pulse on time, open circuit voltage, wire speed and dielectric fluid pressure. The responses considered in this study were surface roughness and cutting speed. From the results it was found that the cutting speed and surface roughness were increases with increase in pulse on time, open circuit voltage and dielectric fluid pressure. Mathematical relationships between cutting parameters and cutting performances were developed by regression analysis method. The developed model was used in estimating performance characteristics. Based on ANOVA method, the open circuit voltage, pulse duration and wire speed were more effective on cutting speed. Whereas the dielectric fluid pressure was insignificant. In case of surface roughness, the open circuit voltage and pulse duration were more effective, where as fluid pressure and wire speed were ineffective. (Tusan et al, 2004) carried out experiments on Sodic A320/EX21 WEDM machine tool with 0.25mm brass wire as electrode and AISI 4140 steel as work piece material. They investigated the effect and optimization of machining parameters on the kerf (cutting width) and metal removal rate in WEDM process. The WEDM parameters were pulse duration, open circuit voltage , wire speed and dielectric flushing pressure. The experiments were designed as per Taguchi's L_{18} orthogonal array and the level of importance of parameters on cutting kerf and MRR were determined by ANOVA. Based on ANOVA method, the open circuit voltage and pulse duration affected more on both kerf and the MRR, where as wire speed and dielectric flushing pressure were effective factors. From the results it was concluded that open circuit voltage was about 3 times more important than the pulse duration for controlling kerf, where as open circuit voltage for controlling the MRR was about six times more important than pulse duration. (Hascalyk et al, 2004) conducted experiments by using Sodic A320D/EX21 WEDM machine and AISI D5 as work piece. They considered input parameters as open circuit voltage, wire speed, pulse duration and dielectric fluid pressure and explore their effect on the surface roughness and metallurgical structure. From the results it was concluded that the surface structure is composed of four zones by considering micro hardness and micro graphs. Outer most layer is recast layer and next is white layer .Below this there is annealed area soften than parent material and finally parent material is present. The thickness of HAZ (or) white layer depends upon magnitude of energy impinged on the surface .The density of cracks in white layer increases with increase pulse duration and open circuit voltage. The surface roughness increased when the pulse duration and open circuit voltage were increased. The cutting specimens were harder than the original material because of white layer, while the HAZ is soften in quenched and tempered specimens because of over tempered Martensite. (Tani et al, 2004) conducted experiments on Si_3N_4 insulating ceramics by wire cut electrical discharge machine (WEDM). In the WEDM machining of thick work pieces of $Si3N_4$ insulating ceramics, wire breakage is the main problem. Using a carbonized layer as the assisting electrode, a ceramic plate of 100 mm thickness could be cut under high discharge current condition. The accuracy of the straightness and roundness of the obtained cylinder shape were about 12 and 17 µm. In case of thin ceramic plate hollowed out of Si_3N_4, wraps at the end of the product owing to appear it's residual stress. However, the amount of wrap has been improved to about one fourth by changing the machining path with consideration to heat influence. (Shanmugam et al, 2004) carried out experiments on Ti6Al4V with Robofil 310, 5-Axis CNC WEDM as machine tool. The process parameters of the WEDM process were time between two pulses, pulse duration, servo voltage, servo speed variation, wire speed, wire tension and injection pressure. The experiments were planned as per Taguchi's L18 orthogonal array. The machining was performed with zinc coated and uncoated brass wire of 0.25mm diameter. Taguchi's and ANOVA methods have been effectively employed to find out the influence of process parameters. For uniform surface characteristics the coated wires were preferred over than the uncoated wires. The time between two pulses was the most sensitive parameter that influences the formation of layer consisting of mixture of layers. (Sarkar et al, 2005) conducted experiments on ELECTRA SUPERCUT 734, SERIES-200 CNC WEDM machine using γ-titanium Aluminide alloy as work piece material and then created a model they predict the cutting speed , surface finish and dimensional deviation as the function of different WEDM parameters. Both surface roughness and dimensional deviation is independent of pulse off time . So that pulse off time can be varied as per requirement to achieve the

better stability and accuracy without affecting the dimensional deviation and surface finish significantly. They determined the optimal process parameters by applying constrained optimization technique in which one performance characteristic was optimized considering other as constraints. (Taweel et al, 2005) uses an ELEKTTA MAXICUT434 CNC WEDM as machine tool and INCONEL-601 as work piece , developed a mathematical model for correlating interrelationship of WEDM process parameters such as peak current, duty factor, wire tension, water pressure and responses MRR,WR and SR uses RSM approach. From the results it was concluded that , the volumetric MRR increase with increase of peak current value and water pressure. But with further increase in peak current, the decrease in VMRR. The WR increase with increase in peak current. The surface roughness increased with the increase in peak current and decreased with the increase of duty factor and wire tension. (Yan et al, 2005) adopted WEDM for machining Al_2O_3p/6061Al composite material. The machining parameters like pulse on time, wire tension, flushing pressure, wire speed and responses were cutting speed, width of slit, surface roughness, breakage of wire, location of wire broken. The metal removal rate (cutting speed), surface roughness and width of the slit cutting significantly depend on the volume fraction of reinforcement (Al_2O_3 particles). The results reveals that while machining Al_2O_3p/6061 Al composites a very low wire tension, a high flushing rate and high wire speed were required to avoid wire breakage. An appropriate servo voltage, a short pulse on time are associated with a cutting speed and have little effect on the roughness. (Lin et al, 2005) Used MS-300 CNC WEDM to machine shape memory alloys of Fe-30Mn-6Si and Fe-30Mn-6Si-5Cr. Pulse on time, pulse off time ,gap voltage, current and flushing pressure as process parameters and recast layer thickness, hardness were output responses .From the results it was concluded that , the recast layer of Fe-30Mn-6Si is much thicker than that of Fe-30Mn-6Si-5cr after WEDM. The hardness of outer surface was reached 550 Hv for both Fe-30Mn-6Si and Fe-30Mn-6Si-5Cr.(Ramakrishna et al, 2006) performed experiments on heat treated tool steel by 5-Axis Robofil-290P CNC Wire EDM with 0.25mm zinc coated brass wire. They determined optimal process setting by optimization of multiple response signal-to- noise (MRSN) ratio, which is the logarithmic transformation of sum of the weighted normalized quality loss of individual response variable by considering three response characteristics MRR,SR,WWR.(Mahapatra et al, 2006) carried out experimental studies on Robofil100 WEDM with D2-Tool Steel. They find relationship between control factors and responses like metal removal rate and surface finish by using non-linear regression analysis.GA was employed to optimize the WEDM process with multiple objectives. (Munna et al, 2006) attempted to optimize the process parameters of Super Cut -734 CNC Wire cut EDM machine with Al/Sic MMC as work piece material. The process parameters of the WEDM process were pulse on time, pulse off time ,peak current, wire feed rate, wire tension, spark gap set voltage and output responses were metal removal rate ,gap current, surface roughness and spark gap(gap width).The experiments were planned as per Taguchi's L_{18} orthogonal array design. ANOVA and analysis and F-test were used to determine the significant machining parameters affecting the machining performance. Mathematical models relating to the machining performance were established using Gauss elimination method. The open gap voltage and pulse on time were most significant parameters for controlling the metal removal rate. Wire tension and wire feed rate were most significant parameters for surface roughness, Wire tension and spark gap set voltage are the most significant parameters for controlling spark gap. The open gap voltage and gap current are the most significant parameters for controlling gap current. (Sarkar et al, 2006) were attempted to optimize the process parameters of the Wire electrical discharge machining of γ-Titanium Aluminide through ANN (Feed forward back propagation neural network model). The process is carried out with Electra Super Cut 734 series200 CNC Wire cut EDM machine. The process parameters were pulse on time, pulse off time, peak current, servo reference voltage, wire tension, dielectric flow rate and response parameters were cutting speed, surface roughness and wire off set. By using feed forward 6-15-3 BPNN, WEDM process model was developed. That ANN model was used to predict the process performance for all possible combinations of 15625. Out of 15625, 27 optimum combinations were selected and act as technological guidelines for effective machining of the alloy. From this process, it was observed that the surface quality decreases as the cutting speed increases and they vary almost linearly up to a surface roughness value of 2.44 µm and a cutting speed of 2065 mm/min. Beyond this value of cutting speed , surface roughness deteriorates drastically. (Chiang et al, 2006) conducted experiments on Al2O3 particle reinforced material (6061 Alloy) with FANUC water spray wire cut electrical discharge machine. The process parameters of the WEDM are on time, off time, arc on time, arc off time, servo voltage, wire feed, water flow and output response are cutting removal rate, surface roughness. The experiments were planned as per Taguchi's L_{18} orthogonal array design. The process parameters were optimized by using grey relational analysis approach. From the results it was concluded that on time, off time, time discharge and voltage have greater influence on the performance characteristics. (Han et al, 2007) performed experiments on a WEDM machine EU64 developed by Makino milling machine for Alloy steel [Cr12] with machining parameters of pulse duration, discharge current, sustained pulse time, pulse interval time, polarity effect, dielectric to be find out it's influence on surface roughness. from the results it was found that surface roughness can be improved by decreasing both pulse duration and discharge current. When the pulse energy per discharge is constant, short pulses and long pulses will produce the same surface roughness but dissimilar surface morphology and MRR is also different. The short pulse duration with a high peak value can produce better surface roughness, which a long pulse cannot do. It also found that reverse polarity machining with appropriate pulse energy can improve the

surface roughness somewhat better compared with normal polarity in finish machining. (Kanlayasiri et al, 2007) started investigation of the effects of machining parameters on surface roughness of WEDM machining of DC53cold die steel with Sodic model A280. The machining variables included were pulse on time, pulse peak current, pulse off time and wire tension. The variables effecting on the surface roughness were identified by ANOVA technique. The assumptions of ANOVA were tested by residual analysis. From the results it showed that pulse on time and pulse peak current were significantly affected the surface roughness .The surface roughness of the test specimen became larger when these two variables increases. A mathematical model was developed by multiple regression method predicted accuracy within the experimental region. The maximum prediction error of the model was less than 7% and the average percentage error of prediction was less than 3%. (Kanlayasiri et al, 2007) used a Sodic A320 WEDM with ire electrode of 0.25mm diameter and DC53 was used as work piece material. He studied the effect of WEDM machining parameters pulse on time, pulse off time, pulse peak current, wire tension and surface roughness as response. The ANOVA technique was applied to find out the effect of process parameters on surface roughness. The ANOVA results were examined through residual analysis. Results from ANOVA showed that the surface roughness increased with the increase of pulse on time and pulse peak current. (Mahapatra et al, 2007) conducted experiments on D2 tool steel as work piece material with Robofil100 5 axis CNC WEDM machine. The control factors of WEDM machine were discharge current, pulse duration, pulse frequency, wire speed, wire tension, di-electric fluid rate and output responses were MRR,SF and cutting width(kerf).The experiments were planned as per Taguchi L27 orthogonal array .By using this Taguchi method ,significant parameters were identified to maximization of MRR , minimization of SR and cutting width. A nonlinear regression model developed a mathematical model to optimize 3 parameters in combinations. Genetic algorithm was used to obtain machining parameters for multi objective optimization by using several combinations of the weight. (Bamberg et al, 2008) carried out experiments on WEDM as machine tool and Gallium -doped germanium as work piece material with the aim to investigate the surface roughness and subsurface damage. The experiments were conducted with a wire of brass (100µm, 200 µm) and molybdenum (50µm, 75µm and 100µm) and varied process parameters of voltage and capacitance for each wire type. The maximum slicing rate 4.07 mm2 /min for the 200µm brass is achieved using 68.8nF capacitor at a voltage of 159V.The maximum surface roughness was obtained for 50, 75 and 100µm molybdenum wire are 3.31,3.48 and 3.54 Ra. The surface contamination was measures by using X-ray energy dispersive spectrometer. At higher discharge energy levels, cracks originate at machined surface. The length of cracks increased as increase in discharge energy causes more sub surface damage in the form of micro cracks. (Ramakrishna et al, 2008) carried out experiments using 5 Axis Robofil 290P WEDM machine with INCONEL-718 metal, developed ANN model and multi response optimization technique to predict and select the best using cutting parameters of WEDM process. The experiments were planned as per L_9 OA. The experiments were conducted under cutting conditions of pulse on time, delay time, wire feed speed and ignition current. It was found that the pulse on time, delay time and ignition current were influenced more than wire feed speed on the performance characteristics considered in this study. An MRR was improved with increase of pulse on time and ignition current. But with higher pulse on time and ignition current, the quality of the work specimen adversely effected. (Yuan et al, 2008) developed a multi-objective optimization based on Gaussian process regression (GPR) to optimize the higher speed wire cut EDM process, by considering process parameters of mean current, on-time, off-time as input features and MRR and SR as output responses. WEDM-HS is optimized with the reliability maximum MRR and minimum SR objective. Model performance of the GPR, BPNN, SVR and RVM is compared based on the experimental results on the data set of WEDM-HS process. The GPR models have the advantage over the other models in terms of model accuracy and feature scaling and probabilistic variance. The experimental optimization and optimal solutions show that the coefficient parameters decrease the predictive variance of solutions and acquire higher degree reliability solutions, which were validated cutting experimental results. (Parameswararao et al, 2009) conducted experiments on Graphite work piece with ELCUT 234CNC WEDM. The process parameters were discharge current, Gap Voltage, wire tension, wire speed and output responses were cutting speed, spark gap and MRR. The thickness of the work piece varies from 5mm to 80mm.From the results it was concluded that with increase in thickness, the required current also increases. As the thickness of the work piece increases, the cutting speed decreases rapidly and spark gap increases. But beyond 60 mm thickness, the rate of variation of spark gap was low. The MRR was increased with increase in thickness due to the increase in cutting speed and spark gap. (Garg et al, 2009) the effects of various process parameters of WEDM like pulse on time (TON), pulse off time (TOFF), gap voltage (SV), peak current (IP), wire feed (WF) and wire tension (WT) have been investigated to reveal their impact on material removal rate of hot die steel (H-11) using one variable at a time approach. The optimal set of process parameters has also been predicted to maximize the material removal rate. (Routara et al, 2009) in this study a multi response optimization method using Taguchi's robust design approach was proposed for WEDM operations. Experimentation was planned as per Taguchi's L_9 orthogonal array. Each experiment has been performed under different cutting conditions of gap current (I), gap voltage (V), wire feed rate (W) and duty factor (D). Two responses MRR and SR have been considered for each experiment. The machining parameters are optimized with the multi response characteristics of the material removal rate and surface roughness, using the grey relational analysis. Multi response S/N (MRSN) ratio was applied to measure the performance characteristics deviating from

the actual value. Analysis of variance (ANOVA) is employed to identify the level of importance of the machining parameters on the multiple performance characteristics considered. Finally experimental confirmation was carried out to identify the effectiveness of this proposed method. (Onur Guven et al, 2010) carried out experimental studies on AISI 4340 steel as work piece and ACUTEX WEDM as machine tool with CuZn37 sun cut brass wire with 0.25mm diameter. They used two neural network techniques i.e. BPN and GRNN to determine and compare the parameters of WEDM with the features of surface roughness .From the results it was concluded that BPN and GRNN's can model the WEDM with reasonable accuracy. But BPN has better learning ability for WEDM process than GRNN. At the same time BPN has better generalization ability for WEDM than GRNN. (Chen et al, 2010) worked with WEDM (W-430F) on pure Titanium material. They analyzed the variation of cutting velocity and surface finish depending upon the WEDM process parameters during machining of pure titanium. A method of integrating BPNN and simulated annealing approach (SAA) was used to determine an optimal parameter setting of the WEDM process. -The experiments were conducted as per Taguchi's L9 orthogonal array table. The experimental results from WEDM were utilized to train BPNN to predicting the cutting velocity and roughness average (Ra) and roughness maximum (Rt) properties and then SAA was also applied to find out an optimal setting. The BPNN was successfully utilized to predict cutting velocity, Ra and Rt during manufacturing of pure tungsten after being trained and its prediction models yield smaller SME after training .Through ANOVA, the pulse on time is most significant controlled factor when cutting speed, roughness average and roughness maximum were considered simultaneously. (Muthukumar et al, 2010) carried out experiments on Incoloy800 super alloy with 4 Axis Electronica Ecocut CNC WEDM, the electrode used was 0.25mm diameter brass wire. The process parameters considered were gap voltage, pulse on time, pulse off time and wire feed and output responses were MRR, SR and kerf. They investigated the multi response optimization of WEDM process for machining Incoloy800 super alloy using combination of Grey relational analysis and Taguchi's method. The ANOVA and necessary optimization tests were conducted to validate experimental results. From results , optimal process parameter were base grey relational analysis include a 50V voltage, 10µs pulse on time and 8mm/min wire feed rate. It was also concluded that the Grey Taguchi's method is most ideal and suitable for parametric optimization of WEDM process, when using multiple performance characteristics. The mathematical relation between process parameters and output responses establishes a mathematical model used in estimating the MRR, SR and kerf width without conducting experiments. (Saurav Datta et al, 2010) conducted experiments on D2 Tool steel with Robofil100 high precision CNC WEDM. The process parameters were discharge current, pulse on time, pulse frequency, wire speed, wire tension and dielectric flow rate and responses were MRR, surface roughness and kerf. The experiments were conducted based on Taguchi's L_{27} orthogonal array and used in optimization of process parameters in combinations. Grey relational analysis has been used to convert this multi objective optimization into an equivalent single objective function. Response surface method has been found efficient for prediction of process responses for various combinations of factor setting. Grey based Taguchi technique has been utilized to evaluate optimal parameter combination to achieve maximum MRR, minimum roughness and minimum width of cut. (Lin et al 2010) worked with FUNUC CNC W1-CNC Wire electrical discharge machine on magnesium alloy AZ31B. and carried out experiments to optimize the process of multiple quality characteristics for wire electrical discharge machining of magnesium alloy parts via Taguchi method -based gray analysis. The process parameters of the WEDM were wire feed rate, pulse on time, pulse off time, no load voltage, servo voltage, wire tension and response characteristics were MRR, and SR. The modified algorithms adopted here was successfully used for both determining the optimum setting of machine parameters and for combining multiple quality characteristics in to one integrated value called gray relational grade. The optimum machine parameter setting were clearly improved multiple quality characteristics of the machined work piece compared to quality levels achieved for initial machine parameter settings. The MRR changed from 41.10 to 113.57 mm^2 /min and surface roughness on the work piece changes from 2.69 to 3.13µm Ra. (Daud et al, 2010) carried out experiments on two pieces of extruded AZ61 Magnesium alloy. The Mg alloy was composed of 6% of Al and 1% Zinc , as major alloying elements .The Two specimens were prepared by wire -EDM cut by HITACHI H-CUT 203 M20 EDM machine and smooth specimens and investigated the effect WEDM cutting process surface quality and fatigue strength of AZ61 Mg alloy. The average surface roughness Ra and maximum surface roughness R_{max} for WEDM sample were higher compared to the carefully polished specimen. The maximum surface roughness value for wire EDM was 2.09 µm . The fatigue strength of the EDM as cut sample decreases as compared to that of the smooth sample. The fatigue limit for the smooth specimen was found to be 150 Mpa in comparison, the fatigue limit of the EDM as cut sample is higher at 130 Mpa. The fatigue crack initiates from a cutting pit for wire EDM cutting specimen and propagates to final failure but there was no cutting pit observed on the fracture surface of the smooth specimen. The size of the pit on specimen in WEDM as cut, depends on pulse on time, pulse off time, peak current and voltage. The increase in pulse on time, the larger the craters or pits and results in the faster the cut and results in rough surface. (Rao et al, 2010) conducted experiments on OHNS with Elektra ELPULSE-30 CNC WEDM machine tool. The process parameters considered hare were pulse on time ,pulse off time, peak current, servo feed and responses MRR and SR. Mathematical models have been developed based on RSM approach for correlating combined effects of pulse on time , pulse off time, peal current and servo feed setting on machining speed and surface roughness. The optimum process parameters were

found using a non-traditional optimization technique namely, particle Swarm Optimization(PSO).(Islam et al, 2010) conducted experiments with FANUC ROBOCUT wire-cut EDM equipped with digital servo technology on MS1040 with aim to increase dimensional accuracy Subsequently optimize the input parameters like Discharge current, Pulse duration, Pulse gap frequency, Wire speed, Wire tension, Dielectric flow rate. Three techniques—traditional analysis, the Taguchi method, and Pareto ANOVA analysis—are employed to determine the effects of six major controllable machining parameters. From the results it was concluded that the dimensional accuracy achievable in wire-cut electrical discharge machining is not as high as anticipated and its precision level is far less than CNC end milling. Of the six input parameters considered, wire tension showed the greatest overall affect on three dimensional accuracy characteristics, therefore, its value should be chosen carefully. The problem of erosion of the corner shapes caused by the wire lag phenomenon remains; consequently requires more research and their practical applications. (Po-Huai-Yu et al, 2011) worked with WEDM on polycrystalline silicon (poly silicon) with conventional- pulse voltage supply and the auxiliary-pulse voltage mode to avoid delay in electrical discharge during pulse on time. The experimental results shown that, auxiliary - pulse voltage mode would increase machining speed, reduce machining groove width and obtain better surface finish. (Satish et al, 2011) performed experiments using a 4-axis Electronica CNC Eco cut Wire Cut EDM machine on unreinforced Al6063, Al6063/SiCp and MMC by using L_9 OA design. The process parameters were pulse on time, pulse off time, gap voltage and wire feed. From the results it was concluded that the increase in volume percentage of SiCp resulted in decreased MRR and increased surface roughness. (Rong et al, 2011) analyze the variation of MRR, roughness and corner deviation on a pure tungsten by WEDM machine of CW-430F with BPNN to predict MRR, surface roughness and corner deviation properties and BPNN is trained by results of L18 Taguchi's technique orthogonal array design. Simultaneously, RSM and SAA methods were individually applied to search for an optimal setting. From the result it was concluded that when the pulse on time increases, the discharge energy becomes more intense , the metal removal rate was increased and the brass wire of cutting tool accelerates the depletion , generates a large built up layer and so that produces rougher surfaces. When the wire tension increases, the corner deviation was decreased. The experimental data was validated through BPNN and RSM in order to verify the quality of the algorithm. By comparison, the percentage of residuals via a trained BPNN were less than the predictions from the regression models derived by the RSM approach and BPP/SAA approach produced better quality than the RSM method for confirmation results of the optimization of process parameters. (kamal Jangra et al, 2011) worked with 5-Axis Electronica Sprint cut (ELPLUS-40) Wire EDM with WC-CO composite material. They studied the effect of taper angle, peak current, pulse on time, pulse off time, wire tension and dielectric flow rate on MRR & SR during machining. For optimization GRA along with Taguchi method was used. The optimal predicted values for MRR and SR were 2.52 mm/min and 0.88µm. By ANOVA on experimental results, taper angle , pulse on time, pulse off time were found the most significantly affecting MRR and SR under 95% C.I. . In case of GRA, gray relational grade was used as a performance index to determine optimal set of parameters for multiple machining characteristics. The optimal set predicted for multiple machining characteristics will be closer to the optimal set predicted for single characteristic with larger weight. (Saha et al, 2011) carried out experiments on WC-CO composite with Electronica 4-Axis CNC WEDM as machine tool. The process parameters of the WEDM process were feed rate, pulse on time , pulse off time , peak current setting, capacitance, average gap voltage and output responses were cutting speed and surface roughness. The experiments were planned as per Taguchi's L_{32} orthogonal array design. A Neuro-Genetic technique (Combination of Residual Base Function Network (BPNN) and Non Dominated Sorting Algorithm (NSGA-II)) were used for optimization of multi objective process parameters. From experimental results, the value of cutting speed and kerf width of 0.615mm/min and 032mm. After optimization using RBFN based NSGA-II, the cutting speed was increased by 34.9% and the for the same kerf width. (Guo et al, 2011) attempted to find out the surface integrity of powder metallurgical Tool steel(ASP2023) by main cut and finish trim cuts in WEDM with oil and water as dielectric fluids. From the results, compared to main cut, average roughness is significantly reduced by rough trim cut in oil, while it only slightly reduced in water. Finish trim cut produces very smooth surfaces in both dielectric fluids. But the smooth surface in oil trim is much smoother .A highly non-uniform while layer produced in main cuts in oil and water were characteristics by two layer structure i.e. a thick top porous layer and a thin solid layer at the bottom. The water dielectric produces more porosity in white layer that that oil. The porous white may be formed by the gas bubbles produced during EDM, while the solid white layer is a re-solidified material from the molten metal. The thickness of HAZ in main cut, rough cut and finish trim cut in oil was 30µm, 20µm , 5µm respectively. For water dielectric, the HAZ thickness was 27µm, 17µm , 7µm respectively. It was clear from above values, finish trim cut was essential to reduce the depth of HAZ. Form considering all reviews, oil was a better dielectric than water. (Amitesh et al, 2012) conducted experiments on NIMONIC 80A with CNC WIREEDM with aim of to investigate the machining characteristics of cutting speed (CS) and material removal rate (MRR). The process parameters are pulse-on-time (Ton) and peak current (IP), pulse-off-time (Toff) and spark gap set voltage (SV). From the results it is concluded that cutting speed (CS) and material removal rate (MRR), both increases with increase in pulse-on-time (Ton) and peak current(IP), while decreases with increase in pulse-off-time (Toff) and spark gap set voltage (SV). (Garg et al, 2012) carried out experiments on Al-5%ZrO2 Particulate Reinforced Metal Matrix Composite with Wire EDM Robofil-290 for OPTIMIZATION of process PARAMETRs such as

dielectric conductivity, pulse width, time between pulses, maximum feed rate, servo control mean reference voltage, short pulse time, wire feed rate, wire mechanical tension and dielectric injection pressure. The performance measures are spark gap and material removal rate. The experiments are planned as per Taguchi L_{36} mixed orthogonal array (21 X 38). From the results it concluded that the optimum value of maximum material removal rate is more while using diffused wire as compared to brass wire electrode whereas the optimum value of minimum spark gap is less while using brass wire electrode as compared to diffused wire electrode .The optimal machining conditions for maximum material removal rate are pulse width of 1.2 μs, time between pulses of 5 μs, servo control mean reference voltage of 20 volts, short pulse time of 0.6 μs, wire feed rate of 4 m/min and wire mechanical tension of 0.5 daN and the optimal machining conditions for minimum spark gap are pulse width of 0.6 μs, time between pulses of 21 μs, servo control mean reference voltage of 20 volts, short pulse time of 0.2 μs, wire feed rate of 4 m/min and wire mechanical tension of 1.5 daN. (Anish Kumar et.al 2012) conducted experiments with four-axis CNC type WEDM (Electronica Sprint cut 734) on pure titanium (grade-2) material with aim to model the surface roughness variable with RSM. The input parameters are i.e. pulse on time, pulse off time, peak current, spark gap voltage, wire feed and wire tension. The experiments are planned as per Box-Behnken design method. Multi-response optimization through desirability is used to optimize the surface roughness and ANOVA has been applied to identify the significance of developed model. The most significant parameters with respect to the response variables are found to be pulse on time, pulse off time, peak current and spark gap voltage according to the ANOVA and F-test analysis. The wire feed and wire tension found to be insignificant to the output process parameters. (Muthuraman et al, 2012) used Sodick AQ 427 WEDM machine as machine tool and WC-Co, Tungsten and Carbide are hard wear resistant materials are work piece materials. the main aim of the this work is to derive best operating inputs in order to attain best output. The input parameters are on time, off time, wire feed, wire tension, ignition current and dielectric pressure and output performances are material removal rate (MRR) and surface roughness (Ra). The experiments were planned and conducted as per Taguchi L_{32} orthogonal array .Anova was used to optimize the material removal rate (MRR) and surface roughness (Ra). (Pragya Shandilya et al, 2012) conducted experiment s with ECOCUT WEDM machine from Electronica India Pvt. Ltd on Aluminum (6061) based MMC using response surface methodology (RSM). . The main aim of this work is to optimize the process parameters during machining. The input process parameters are servo voltage (V), pulse-on time (TON), pulse-off time (TOFF) and wire feed rate (WF) and output response is cutting width (kerf). To study the effect of process parameters on cutting width, analysis of variance (ANOVA) is conducted. ANOVA results show that voltage and wire feed rate are highly significant parameters and pulse-off time is less significant. Pulse-on time has insignificant effect on kerf. SEM images of the cut surfaces have revealed that the fine surface finish was obtained when machining was done at a combination of lower levels of input process parameters. When machining was done at combination of higher levels of input process parameters, craters and black patches arise on the machined surface. (Sivakiran et al, 2012) carried out experiments with CONCORD DK7720C four axis CNC Wire-cut electrical discharge machining (WEDM) on EN-31 tool steel. The input process parameters of these process is Pulse on, Pulse off, Bed speed and Current and output response is metal removal Rate (MRR).The experiments are planned as per Taguchi's L_{16} (4*4) Orthogonal Array (OA). The relationship between input parameters and Output parameter (MRR) is developed by means of linear regression. From the results it is concluded that the current, pulse on, Bed speed and pulse off are the most effecting parameters. (Swati et.al (2012) carried out experiments on High Speed Steel (HSS) with ELEKTRA WIRE CUT Electric Discharge Machine comprises of a Machine Tool, a Power Supply Unit (ELPULS) and a Dielectric Unit. The weighted principal component (WPC) method is applied to optimize the multiple responses of WEDM processes. The input parameters of the process are Pulse on time (Ton), Pulse off time (Toff), Upper Flush and wire feed. The output response of this process MRR & less WWR. The experiments are planned as per L9 Array. From the results is concluded that the Ton is a most significant factor, UF is also a effective parameter and Toff & WF less effective. (Maneesh et.al, 2012) conducted experiments on AISI D3 material with Ezeecut Plus Wire cut EDM as machine tool. The main intension of the work is to examine the effects of input machining parameters such as the are wire feed rate, pulse ON time and gap voltage, on the work piece surface roughness. From the results it is concluded that there is decrease in surface roughness with increase in wire feed rate because of formation of small crater over machined surface. This is because of less time available for spark concentration. There is increase in material removal rate with pulse duration at all gap voltage settings. The machined work-piece surface roughness increases steadily with increasing pulse duration. On increase in pulse on time, gap voltage first slowly decreases then slowly increases. And for a fixed value of pulse on time, gap voltage should be higher for better surface finish. (Atul Kumar et al, 2012) carried out experiments on SKD 61alloy with five axis CNC Wire cut EDM (CHMER- CW64GS) as machine tool. The main aim of the machining process is to find out the optimal process parameters of the machining process. The Pulse On time, Pulse Off time, Open voltage, Feed Rate override, Wire feed Servo voltage, Wire tension and Flushing pressure. The output responses are cutting speed, Surface roughness and dimensional deviation. The experiments are planned and conducted as per Taguchi's L_{18} Orthogonal array. From the results it is concluded that the cutting speed increases with the increase in pulse on time and decreases with increase in pulse off time and open voltage. The effects of feed rate override, wire feed, servo voltage, wire tension and fluid pressure on cutting speed are not very significant. (U. KÖKLÜ et al, 2012) carried out experiments on Al 7475-T7 351 with Wire

Electrical Discharging Machining as machine tool. The main aim of this work is to find the effect of cutting parameters on the kerf and surface roughness during Wire Electrical Discharging Machining process. The factors selected for the optimization are the pulse on time, table feed rate and the wire speed, each of the factors in three different levels. The experiments were carried out according to Taguchi's L_{27} orthogonal array design matrix. From the results it is concluded that the increase of the pulse on time, wire speed and decrease of table feed rate increase both the kerf and the surface roughness. (Yigit Kazancoglu et al, 2012) carried out experiments on work piece AISI 4340 with WEDM machining set-up with the aim to find out the Optimization of the Surface Roughness in a Wire-Electrical-Discharge Machining Process. The input parameters of the process are open voltage, pulse duration, wire speed, flushing pressure and output response is surface roughness. A back-propagation neural network (BPNN) was developed to predict the surface roughness. An analysis of variance (ANOVA) was used to determine the significant parameter affecting the surface roughness (Ra). Finally, the Taguchi approach was applied to determine the optimum levels of machining parameters. From the results it is concluded that The optimum parameter combination for the minimum surface roughness was obtained by using the Taguchi design method with an analysis of the S/N ratio and the obtained results indicate that the BPN model agreed well with the Taguchi analysis.(Tyagi et al, 2012) carried out experiments with CNC WEDM as machine tool on AISI 316L stainless steel work piece. The main operating process parameters of the WEDM are pulse on time (Ton), pulse off time (Toff), peak current (IP), and Spark gap set voltage (SV). The output response of this process is surface roughness. The experiments were planned as per Taguchi L9 orthogonal array. The experimental results demonstrate that the Ton is the main parameter among the four controllable factors (Ton, Toff, IP and SV) that influence the surface roughness in machining of AISI 316L stainless steel. Kamal Jangra et al, 2012) conducted experiments on Tungston carbide with a 5-axis sprint cut (epulse-40) WEDM with the aim to study on un machined surface area named as surface projection, in die cutting after rough cut in WEDM. As part of this machining process discharge current (Ip), pulse-on time (Ton), pulse-off time (Toff), servo voltage (SV), dielectric flow rate (DFR), wire feed rate (WF) and wire tension (WT) are considered as input parameters. From the results is conclude that un machined surface area named as surface projection has been observed on die surface after first or rough cut in WEDM process. These surface projections are function of wire electrode diameter and discharge energy across the electrodes. Increasing discharge energy results in increase in un machined surface area on work surface. Also high discharge energy with low pulse-off time results in deep heat affected zone and deteriorated surface projections with more re-deposited eroded work material around the region. To eliminate these surface projections after rough cut from small and complex intricate geometries, trim cutting operation on WEDM is best option. In trim cut, discharge energy and wire offset value plays a significant role in minimizing the surface projections. (Harsha kumar et al, 2012) conducted experiments on H11 die tool steel with CNC WEDM with aim to find the MRR and SR. A Taguchi design of experiment (DOE) approach with L_{27} Orthogonal Array employed to conduct this experiment. The input machining process Parameters are Pulse On Time , Pulse Off Time , Flushing Pressure, Wire Tension , Servo Voltage and Wire Feed Rate. From the results is concluded that MRR increased by increasing Pulse on Time, flushing pressure and reduces with increasing Pulse OFF Time. Increasing Pulse ON Time also increase Surface Roughness. Material Thickness has little effect on MRR but it has significant effect over surface finish. Increasing Thickness reduces Surface Roughness and increase surface finish.(Sivakiran et al, 2012) conducted experiments on EN31 steel with Wire Electrical Discharge Machine with the aim to find out the effect of machining parameters on MRR. Taguchi's L16 (4*4) Orthogonal Array (OA) designs have been used on EN-31 tool steel to achieve maximum metal removal rate. from the results it is concluded that the better Parameter setting is Pulse on 24μs, pulse off 6 μs, Bed speed 35 μm/s and Current to obtain maximum metal removal rate. The order strength of parameters are found from response table is current, pulse on, Bed speed and pulse off. Regression analysis is used to predict the MRR with 6.77% error. (Jaganathan et al, 2012), attempted to optimize the process parameters of WEDM process on EN31 Alloy steel. Applied voltage, pulse width, pulse interval and speed were considered as input parameters and MRR and SR were considered as output responses. The design of experiments (DOE) is done in Taguchi L_{27} orthogonal array (OA). Factors like Voltage, Pulse width and Speed have been found to play a significant role for MRR and surface roughness. (Rajesh Kumar et al, 2013), this research outlines the Taguchi's Parameters Design Approach which is applied to optimize machining parameters of dimensional accuracy in wire cut electric discharge machining (WEDM). Analysis of variance (ANOVA) is used to study the effect of process parameters on machining process. Work piece is of special tool steel, EN 24 and Wire Cut Electric Discharge Machine is machine tool. The machining parameters investigated are pulse on time(Ton) , pulse off time (Toff),Spark gap voltage(SV) and gap current(IP).

Conclusions

From all the literature review, Wire cut EDM has resulted as the most efficient and accuracy machining process. The Wire cut EDM machining process can machine any material irrespective of their hardness and they can produce any intricate shape. The modeling and optimization of various machining parameters of Wire cut EDM improved in precision machining of work materials.The wire cut EDM worked with metals, alloys, composites and ceramics and literature is discussed from last 15 years.

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