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Trends in Wire Electrical Discharge Machining (WEDM): A Review

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ABSTRACT
The exponential growth of manufacturing industries and production and the increased need of accuracy and precision throws the spotlight on the nontraditional machining processes. The machining of metals and non-metals having special properties like high strength, high hardness and toughness is done by non- conventional machining methods. Wire electrical discharge machining is one of the earliest non-traditional machining processes. This machining process competes with conventional machining such as milling, broaching, grinding etc. However, its ability to cut extremely intricate and delicate shapes with utmost accuracy makes this process most suitable among all other processes. The otherwise hard to be machined materials like carbides, tungsten, zirconium etc. can be easily machined using this process. This paper reviews notable work done in the field of WEDM by various researchers.
Keywords - cutting speed, kerf width, material removal rate (MRR), parametric optimization, surface roughness (Ra), and wire electrical discharge machining (WEDM)

I. INTRODUCTION

Wire electrical discharge machining is a nontraditional widely accepted machining process used in tool & die industry, aerospace, surgical, automotive, nuclear industries because of its 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.

II. WEDM PROCESS

Wire electrical discharge machining (EDM) is a non-traditional machining process that uses electricity to cut any conductive material precisely and accurately with a thin, electrically charged copper or brass wire as an electrode. During the wire EDM process, the wire carries one side of an electrical charge and the workpiece carries the other side of the charge.

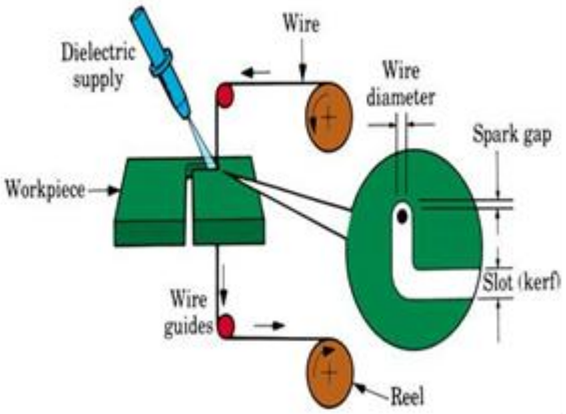

Fig: 1 Schematic diagram of WEDM process

When the wire gets close to the part, the attraction of electrical charges creates a controlled spark, melting and vaporizing microscopic particles of material. The spark also removes a miniscule chunk of the wire, so after the wire travels through the workpiece one time, the machine discards the used wire and automatically advances new wire. The process takes place quickly—hundreds of thousands of sparks per second—but the wire never touches the workpiece. Wire EDM machines use a dielectric solution of deionized water to continuously cool and flush the machining area while EDM is taking place.

In many cases the entire part is submerged in the dielectric fluid, while high-pressure upper and lower flushing nozzles clear out microscopic debris from the surrounding area of the wire during the cutting process. The fluid also acts as a non-conductive barrier, preventing the formation of electrically conductive channels in the machining area. When the wire gets close to the part, the intensity of the electric field overcomes the barrier and dielectric breakdown occurs, allowing current to flow between the wire and the workpiece, resulting in an electrical spark.

III. REVIEW OF WEDM RESEARCH WORK

This section presents the various notable research trends carried out in the field of WEDM.

Anmol Bhatia, Sanjay Kumar and Praveen Kumar [1] dealt with the optimization of surface roughness (SR) while machining High Carbon High Chromium steel on wire electrical discharge machine using Brass wire. Based on Taguchi Single Response optimization technique, the values of input parameters like peak current, pulse on time, pulse off time, wire tension were set such that the surface roughness obtained was minimum. After the experiments, it was found that surface roughness was affected maximum by pulse off time. The observed results were also validated using confirmation experiments. It was observed that the error between the experimental and predicted values for SR was 3.93%.

Shivkant Tilekar, Sankha Shuvra Das and P.K Patowari [2] investigated the effect of process parameters on surface roughness and kerf width of aluminum and mild steel using single response optimization technique. For experimentation, spark on time, spark off time, input current and wire feed rate were used as input parameters while many other parameters were taken as fixed parameters. By ANOVA method, the spark on time and input current were observed to have statistically significant effect on surface roughness of aluminum and mild steel respectively. In case of kerf width, wire feed rate and spark on time had maximum influence on aluminum and mild steel respectively.

Brajesh Kumar Lodhi and Sanjay Agarwal [3] have attempted to optimize the machining conditions for surface roughness(SR) in WEDM of AISI D3 steel based on (L_9 Orthogonal Array) Taguchi methodology. The effect of various machining parameter such as pulse-on time, pulse- off time, peak current and wire feed had been studied. It was identified that the pulse on time and current had influenced more than the other parameters considered in this study. The confirmation experiment had been conducted. Result showed that the errors associated with SR were only 3.042 %.

G. Selvakumar, G.Sornalatha et al[4] carried out experimental analysis for the selection of the most optimal machining parameter combination for wire electrical discharge machining (WEDM) of 5083 aluminum alloy based on the Taguchi experimental design (L9 orthogonal array) method. A series of experiments were performed by considering pulse-on time, pulse-off time, peak current and wire tension as input parameters while surface roughness (Ra) and cutting speed (CS) were considered responses. The optimal machining parameters setting for the maximum cutting speed and minimum surface roughness were found using Taguchi methodology. Then, additive model was employed for prediction of all (3^4) possible machining combinations. The process was optimized by Pareto-optimality approach and a technology table was proposed for optimum machining 5083 Al alloy. ANOVA revealed that the CS was independent on wire tension and Ra was independent on pulse-off time and wire tension. An optimum parameter combination for the minimum Ra and the maximum CS was obtained by the analysis of signal-to- noise (S/N) ratio.

R. Bagherian Azhiri & R. Teimouri et al [5] presented experimental study of dry WEDM of Al/SiC metal matrix composite where the liquid dielectric is replaced with gaseous medium to enhance the machining environment safety. Oxygen gas and brass wire were selected through a series of experiments as they guaranteed superior cutting velocity. The effect of pulse on time, pulse off time, gap voltage, discharge current, wire tension and wire feed were studied on cutting velocity(CV) and surface roughness(SR) using Taguchi’s orthogonal array. Relationship between process inputs and responses were correlated using, adaptive neuro-fuzzy inference system. At the end, a grey relational analysis had been used to maximize CV and minimize SR simultaneously. Also according to ANOVA, pulse on time and current were found to have significant effect on CV and SR.

Ashish Srivastava , Amit Rai Dixit et al [6] presented an experimental study on composite of Al2024 reinforced with SiC to investigate the effects of wire electric discharge machining(WEDM) for three levels of each parameters such as current ,pulse on time and reinforcement percentage on surface finish and Material Removal Rate(MRR). Response surface methodology (RSM) technique had been applied to optimize the machining parameters for minimum surface roughness and maximum MRR. The reinforcement percentages of SiC were taken as 2%, 4% and 6%. From the Scanning Electron Microscopy (SEM) images of machined samples it was observed that the surface finish that a non-conventional machining process gave was better than the surface finish we got from the conventional machining process. Results of experiments showed that surface roughness increased with the increase in pulse on time, peak current and reinforcement percentage while MRR increased with the increase in pulse on time, peak current and decreased with the increase in reinforcement percentage.

Adeel Ikram, Nadeem Ahmad Mufti et al [7] reported the effect and optimization of eight control factors on three response measures namely material removal rate (MRR), surface roughness and kerf using Taguchi's L18 orthogonal array. The workpiece used was tool steel D2. The control factors used were wire feed velocity, dielectric pressure, pulse on-time, pulse off-time, open voltage, wire tension and servo voltage by varying the material thickness. Analysis of variance (ANOVA) and signal-to- noise (S/N) ratio were used as statistical analyses to identify the significant control factors and to achieve optimum levels respectively. Additionally, linear regression and additive models were developed for surface roughness, kerf and material removal rate (MRR). Results of the confirmatory experiments were found to be in good agreement with those predicted. It had been found that pulse on-time is the most significant factor affecting the surface roughness, kerf and material removal rate.

Ravindranadh Bobbili, V. Madhu, and A. K Gogia et al [8] presented the influence of machining parameters on surface roughness (SR) and material removal rate (MRR) of high strength armor steel using wire cut electrical discharge machining (WEDM). Six different process parameters used in the experiment were: pulse-on time, pulse-off time, wire feed, flushing pressure, spark voltage, and wire tension. Taguchi's technique had been employed for experimental investigation. Results show that pulse-on time, pulse-off time, and spark voltage are significant variables to MRR and surface roughness (SR). By employing ANOVA optimum process parameter combinations for better MRR and SR were achieved. This technique is cost effective and time saving in evaluating the machining parameters without conducting large number of experiments. Relation between the process parameters and response characteristics was established by eventually developing mathematical models using regression analysis.

Kannachi Kanlayasiri and Prajak Jattakul et al [9] determined an optimal cutting condition of dimensional accuracy and surface roughness for finishing cut of wire- EDMed K460 tool steel. Box-Behnken design was used as the experimental strategy while multi response optimization was performed using the desirability function. The process variables investigated in this experiment included cutting speed, offset distance and peak current. According to the results, peak current and offset distance had significant effect on the dimension of the specimen and only the peak current affects the surface roughness. The optimization of the process variables on the dimension and surface roughness was simultaneously performed to find an optimal cutting condition. Using the optimal cutting condition, the dimension and the surface roughness of the cut specimens were still within the specified limits.

Farnaz Nourbakhsh, K. P. Rajurkar et al [10] presented an experimental investigation of wire electro-discharge machining (WEDM) of titanium alloy. The influence of zinc-coated brass wire on the performance of WEDM was compared with high-speed brass. The effect of seven process parameters including pulse width, servo reference voltage, pulse current, and wire tension was investigated on process performance parameters such as cutting speed, wire rupture and surface integrity. A Taguchi L18 design of experiment (DOE) has been applied. Results showed that the cutting speed increases with peak current and pulse interval. Surface roughness was found to increase with pulse width and decrease with pulse interval. The Analysis of Variance (ANOVA) also indicated that voltage, injection pressure, wire feed rate and wire tension have non-significant effect on the cutting speed. Compared with high-speed brass wire, zinc-coated brass wire resulted in higher cutting speed and smoother surface finish. Also, SEM photographs proved that uncoated wire produces a surface finish with more cracks, craters and melted drops. However, High speed brass wire resistance against wire rupture in tough conditions, high pulse width and low time between two pulses, is much more than zinc coated wire since tensile strength (130,000 PSI) of zinc coated wire is less than the high speed brass wire tensile strength. Scanning Electron Microscopic (SEM) examination of machined surfaces was performed to understand the effect of different wires on work piece material surface characteristics.

Uday A. Dabade [11] discussed the multi-objective optimization using Taguchi based GRA to improve the surface integrity on turned surface of Al/SiCp MMCs. Surface quality/integrity related parameters such as cutting forces, surface roughness, residual stresses and micro- hardness variation were selected as target responses. The optimum process parameters to improve the surface integrity on Al/SiCp composites were identified. Experiments on Al/SiCp composites of four different compositions are performed using L27 orthogonal array as per the Taguchi method. The GRA based best and worst machining conditions change with size and volume fraction of reinforcement in composites. The best optimized combination of machining conditions to enhance the surface quality/integrity on machined surfaces of Al/SiCp composite is use of 0.8 mm tool nose radius, wiper type insert geometry, 0.05 mm rev-1 feed rate, 40 m min-1 cutting speed and 0.2 mm depth of cut.

Chin-Chang Yeh & Kun-Ling Wu et al [12] implemented wire electrical discharge machining (WEDM) to process polycrystalline silicon ingot, and the influences on surface characteristics were examined. At first, two different dielectrics, pure water and pure water with sodium pyrophosphate powder, were experimented to compare their effects on cutting speed and surface roughness. In the experiment, pure water with sodium pyrophosphate powder had shown that it could enhance process efficiency and improve surface smoothness. From the preliminary experimental results, it could be found that the cutting speed of the phosphorous dielectric is 1.48 times faster than pure water. Phosphorous dielectric under high temperature would bring about the electrolysis effect. This reduces the surface roughness 12 % compared with pure water. The phosphorous dielectric could also effectively reduce the kerf loss. Then, the effects on cutting efficiency with different concentrations were examined. After setting the concentration, several experiments were conducted to find out how different currents and pulse-on times affect the cutting efficiency and surface roughness. The findings in this study prove that using phosphorous dielectric on WEDM could be applied onto polycrystalline silicon cutting. In addition, pure water with sodium pyrophosphate powder increases both working efficiency and improves infiltration of the phosphorous element on the surface. Based on the results, this study could be a future reference for industry and academic researchers on the solar cell process.

V.K. Saini, Zahid A. Khan et al [13] presented the investigation and optimization of WEDM parameters using Taguchi method. A set of experiments was undertaken to find the effects of various WEDM process parameters on surface roughness. Three process parameters chosen were Pulse on-time (Ton), Pulse off time (Toff) and Discharge current (or pulse current). The experiments were carried out as per design of experiments approach using L9 orthogonal array. Signal to Noise (S/N) ratios of the Surface Roughness (SR) for all experiments were calculated. The experimental results revealed that pulse on-time of 5 µs, pulse off-time of 3 µs and discharge current of 2A yielded the optimal i.e. minimum surface roughness. The level of importance of the machining parameters & their individual contributions on the surface roughness is determined by using ANOVA. Results showed that Pulse on-time (Ton) with a contribution of 48.38% had the greatest effect on the machining output characteristics. Parameter A i.e. Discharge current with a 45.38% share was the next most significant influence on the output parameters, followed by Parameter C i.e. machine's Pulse off-time, (Toff) 5.5%. Surface roughness at the best combination was 2.331 µm.

Kapil Kumar & Sanjay Agarwal et al [14] attempted to optimize the machining conditions for maximum material removal rate and maximum surface finish based on multi-objective genetic algorithm. Experiments, based on Taguchi's parameter design, were carried out to study the effect of various parameters, viz. pulse peak current, pulse-on time, pulse-off time, wire feed, wire tension and flushing pressure, on the material removal rate and surface finish. The workpiece used was made of high-speed steel (M2, SKH9) and zinc coated copper wire was used as wire electrode. It had been observed that a combination of factors for optimization of each performance measure was different. So, mathematical models were developed between machining parameters and responses like metal removal rate and surface finish by using nonlinear regression analysis. These mathematical models were then optimized by using multi-objective optimization technique based on Non-dominated Sorting Genetic Algorithm-II to obtain a Pareto-optimal solution set. The results of optimization indicated that the material removal rate and surface finish was influenced more by pulse peak current, pulse duration, pulse-off period and wire feed than by flushing pressure and wire tension. Results also indicated that the surface quality decreases as the MRR increases and they varied almost linearly. Out of 50 optimal solutions, the best parametric combination that yielded the highest possible MRR, while maintaining the specified surface finish requirement, i.e. 3.69 µm, were: pulse peak current030 A, pulse duration037 µs, pulse-off time050 µs, wire feed07 m/min, wire tension01260 g, flushing pressure02.1 kg/cm2.

Pragya Shandilya & P.K.Jain et al [15] optimized the process parameters during machining of SiCp/6061 Al metal matrix composite (MMC) by wire electrical discharge machining (WEDM) using response surface methodology (RSM). Four input process parameters of WEDM (namely servo voltage (V), pulse-on time (TON), pulse-off time (TOFF) and wire feed rate (WF)) were chosen as variables to study the process performance in terms of cutting width (kerf). In addition mathematical models were also developed for response parameter. Properties of the machined surface had been examined by the scanning electron microscopic (SEM). Input process parameters had been found to play a significant role in the minimization of kerf. ANOVA results showed that voltage and wire feed rate were highly significant parameters and pulse-off time was less significant. Pulse-on time had insignificant effect on kerf. For targeted value of kerf the optimized values of servo voltage was 70.06 V, pulse-on time was 2.81 micro seconds, pulse-off time was 7.79 micro seconds and wire feed rate was 8.90 m/min. SEM images of the cut surfaces 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 raised on the machined surface.

Sateesh Kumar Reddy K & Ramesh S et al [16] carried out parametric optimization of Wire electrical discharge machining of Composite material (Al+3%SiC) . They attempt to find the best affecting parameters for maximize material removal rate (MRR) and minimizing surface roughness (Ra). The Design of Experiment (DOE) and Analysis was conducted in Taguchi Method. The selected parameters to determine the larger MRR and smaller Ra were Voltage (A), Pulse on (B), Pulse off (C) and Current (D). The influence of parameters and optimization is performed using Taguchi Method and ANOVA was conducted with the help of General linear Method in Mini Tab 16 software respectively .The parameters like Voltage and Pulse off mostly affected on MRR .The increase in Voltage and Pulse off caused the MRR to increase and decreases respectively. The parameters like Pulse on and Voltage mostly affected Ra. The increase in Pulse on and Voltage caused the Ra to increase respectively. The error between the Taguchi analysis and Anova analysis was very minute for MRR and Ra that were 0.00 and 1.23 respectively. The hardness, Ra and MRR of material was increased when workpiece was machined using DM water as dielectric fluid. The hardness, Ra and MRR decreased when workpiece was machined using air as dielectric fluid.

Aniza Aliasa, Bulan Abdullaha et al [17] investigated the influence of feed rate on the performance of WEDM on Titanium Ti-Al-4V. Brass wire was employed as the electrode in this study. An attempt was made to determine the important machining parameters for performance of WEDM viz. Kerf width, MRR and Ra. The best combination of machining parameter viz. machine feed rate (4 mm/min), wire speed (8 m/min), wire tension (1.4kg) and voltage (60V) were identified. The main goal was to obtain the maximum MRR with the minimum kerf and surface roughness in setting the machining parameters. Machine feed rate has been found to play an important role in this experimental work. In finding how the output parameter varies with the variation in the input parameter, three set of experiments as shown in Table 1 have been studied. All experiments were performed in constant current (4A) mode.

IV. CONCLUSION

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.

WEDM is a well-established non- conventional material removal process capable of meeting the diverse machining requirements posed by the demanding metal cutting industries. The main objective of the WEDM process is to obtain the optimal parameters without making compromise with its performance measures. It has been commonly applied for the machining and micro-machining of parts with intricate shapes and varying hardness requiring high profile accuracy and tight dimensional tolerances. However the main disadvantage of the process is the relatively low machining speed, as compared to the other non- traditional machining processes such as the laser- cutting process, largely due to its thermal machining technique. Choosing optimal parametric conditions is vital for successful running of WEDM. The major input parameters of WEDM are pulse on time, pulse off time, peak current, gap voltage, wire feed, wire tension etc. and the response parameters are material removal rate (MRR), surface roughness, cutting speed, surface integrity, dimensional deviation etc. In the modern era of science and technology, the requirement of accurate and precise engineering products is successfully fulfilled by the wire electrical discharge machining (WEDM) process.

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REFERENCES

Journal Papers:

[1] Anmol Bhatia, Sanjay Kumar, Praveen Kumar, "*A Study to achieve minimum surface roughness in Wire EDM*", Procedia Materials Science 5(2014) 2560-2566.

[2] Shivkant Tilekar, Sankha Shuvra Das , P.K Patowari, " *Process Parameter Optimization of Wire EDM on Aluminum and Mild Steel using Taguchi Method*", Procedia Materials Science 5(2014) 2577-2584.

[3] Brajesh Kumar Lodhi, Sanjay Agarwal, "*Optimization of machining parameters in*

WEDM of AISI D3 Steel using Taguchi Technique", Procedia CIRP 14 (2014) 194 – 199.

[4] G. Selvakumar, G. Sornalatha, S. Sarkar, S. Mitra," *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.

[5] R. Bagherian Azhiri & R. Teimouri & M. Ghasemi Baboly & Z. Leseman," *Application of Taguchi, ANFIS and grey relational analysis for studying, modeling and optimization of wire EDM process while using gaseous media*", *International Journal of Advanced Manufacturing Technology (2014) 71*:279–295.

[6] Ashish Srivastava, Amit Rai Dixit, Sandeep Tiwari, "*Experimental Investigation of Wire EDM Process Parameteres on Aluminum Metal Matrix Composite Al2024/SiC*", *International Journal of Advance Research and Innovation, Volume 2*(2014)511-515.

[7] Adeel Ikram, Nadeem Ahmad Mufti, Muhammad Qaiser Saleem and Ahmed Raza Khan," *Parametric optimization for surface roughness, kerf and MRR in wire electrical discharge machining (WEDM) using Taguchi design of experiment*", *Journal of Mechanical Science and Technology 27 (7)* (2013) 2133-2141.

[8] Ravindranadh Bobbili, V. Madhu, and A. K Gogia, "*Effect of Wire-EDM Machining Parameters on Surface Roughness and Material Removal Rate of High Strength Armor Steel*", Materials and Manufacturing Processes, 28: 364–368, 2013.

[9] Kannachi Kanlayasiri and Prajak Jattakul, "*Simultaneous optimization of dimensional accuracy and surface roughness for finishing cut of wire-EDMed K460 tool steel*", Precision Engineering 37(2013) 556-561.

[10] Farnaz Nourbakhsh, K. P. Rajurkar, A. P. Malshe, Jian Cao, "*Wire electro-discharge machining of titanium alloy*", Procedia CIRP 5(2013) 13 – 18.

[11] Uday A. Dabade, "*Multi-objective Process Optimization to Improve Surface Integrity on Turned Surface of Al/SiCp Metal Matrix Composites Using Grey Relational Analysis*", Procedia CIRP 7 (2013) 299 – 304.

[12] Chin-Chang Yeh, Kun-Ling Wu, Jyh-Wei Lee, Biing-Hwa Yan, "*Study on surface characteristics using phosphorous dielectric on wire electrical discharge machining of polycrystalline silicon*", *International Journal of Advance Manufacturing Technology* (2013) 69:71–80

[13] V.K. Saini, Zahid A. Khan & Arshad Noor Siddiquee, "*Optimization of wire electrical discharge machining of composite material (AL6061/SICP) using Taguchi method*", *International Journal of Mechanical and Production Engineering (IJMPE) ISSN No.: 2315-4489, Vol-2, Iss-1*, 2013

[14] Kapil Kumar & Sanjay Agarwal, "*Multi-objective parametric optimization on machining with wire electric discharge machining*", *International Journal of Advance Manufacturing Technology* (2012) 62:617–633.

[15] Pragya Shandilya, P.K.Jain, N.K. Jain, "*Parametric optimization during wire electrical discharge machining using response surface methodology*", Procedia Engineering 38 (2012) 2371 – 2377.

[16] Sateesh Kumar Reddy K, Ramesh S, "*Parametric Optimization of Wire Electrical Discharge Machining of Composite Material*", *International Journal of Advanced Research in Computer Engineering & Technology Volume 1, Issue 3*, May2012, ISSN: 2278 – 1323.

[17] Aniza Alias, Bulan Abdullah, Norliana Mohd Abbas, "*WEDM: Influence of Machine feed rate in machining Titanium Ti-6Al-4V using brass wire and constant current (4A)*", Procedia Engineering 41 (2012) 1812 – 1817.