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# Wire cut electrical discharge machining – A review

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## Abstract

An inventive machining technique called wire cut electrical discharge machining (WEDM) makes it possible to precisely produce components with sharp edges and high hardness that are otherwise exceedingly challenging to mill. The ultimate objective of process engineering for manufacturing (WEDM) is to optimise several process parameters analytically. several studies have examined various methods to achieve this aim. The results of a large body of previous research are ranked in this paper according to several different dimensions, including the influence of machining parameters, pulse classification, the effect of wire electrode parameter on machining criteria, thermal load on wire electrode, parametric optimisation, and adaptive systems. This report informs the reader, based on a literature assessment, of the best settings for several machining parameters. The planned study project's future scope is envisioned.

**Keywords:** Corner radius, Current, MRR, park gap, Thickness, WEDM.

## 1. Introduction

Frayed wires Wire Electrical Discharge Machining (WEDM) is an electro-thermal process that has shown great promise for machining conductive and otherwise challenging materials. Complex components like gears, cams, and dies and molds may be manufactured with ease because to its excellent process capabilities. Due to the existence of several process variables and a complicated stochastic process mechanism, selecting the best parametric combinations in WEDM to improve cutting efficiency and other dimensional accuracy features is difficult.

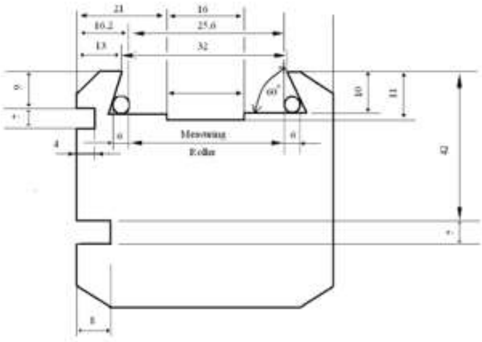

Fig. 1. Typical drawing of a clip tool for press work

Therefore, investigations are needed to provide a systematic method for determining the best parameter settings to maximise process criterion yield over a wide range of engineering material sizes and types. Fig.1 shows a typical drawing of a clip tool for press work that can be machined perfectly using WEDM.

Two Primary Focuses in the Study of WEDM

The current literature is broken down into 6 sections, each of which is examined in turn.

- The impact of adjusting machining settings
- Classification of pulses
- How wire electrode specifications affect machining requirements
- Thermal load on wire electrode
- Optimal Control Using Parameters
- Systemic flexibility

### *2.1.* Influence of machining parameters

The computer The parameters like specific energy, discharge current, discharge frequency, spark timings, dielectric fluids and their properties, thermo-physical properties and corner errors arising during machining by the earlier researchers are discussed. Liao and Yu [1] carried out an investigation to determine the specific discharge energy (SDE). The research claims that SDE doesn't vary for any particular medication. Quantitative relationships exist between material removal rate (MRR), MRR efficiency, and machining parameters. The findings may be used to adjust the machining parameters for various materials. Surface morphology after machining was studied by Han et al. [2]. Pulse energy is created using a discharge current, and its effects on the surface morphology are investigated over a range of pulse lengths. With 0.67 and 0.60 mJ of pulse energy, respectively, both short and long pulses produced surfaces with craters of comparable size. Researchers discovered that pulse energy and, in turn, discharge current, are crucial to the surface's shape.Sanchez et al. [3] examined corner faults in 50 and 100 mm thick AISI D2 steel wire electrical discharge machining (WEDM) utilising brass wire with a 0.25 mm diameter. Erroneous corner cutting may be caused by a number of variables, including guide wire friction, dielectric flushing, wire deformation, and work piece thickness. To address these issues, the authors suggest a series of trim cuts. To determine the optimal values for corner accuracy, Madhusudan et al. [4] derived mathematical correlations. For the purpose of MRR in PCD machining, Kozak et al. [5] analysed the impact of discharge frequency and discharge energy. By measuring the thermal tensions between the diamond grains and the cobalt phase, they were able to conclude that the frequency of the discharge reduces from 6.5 kHz to 4.5 kHz when the diamond grains are removed from the work piece.Williams and Rajurkar [6] modeled stochastically and analyzed the WEDM surface profiles to understand surface generating mechanism. They described the spark generation process using pulse ON time OFF timers. They concluded that machining current is the most important factor, rather than wire speed, wire tension, or dielectric flow rate. The authors conducted experiments on 38mm thick D2 steel with 0.25mm diameter wire at different current levels. Their observations revealed that at 4A current and 550mm/min cutting speed, higher currents generated larger craters and electrode material deposition on work piece. The authors suggested to compromise with surface quality for fast machining. Experimental results corroborated the theoretical model proposed by Spur and Schonbeck [7] for estimating the impact of thermophysical characteristics of material on machining criteria. Levy [8] conducted experiments by machining HC-HCr X210Cr12 steel and observed that the dielectric fluid, i.e. water is getting contaminated and causing trouble to environment and suggested measures to recycle the dielectric fluid. Tariq and Pandey [9] machined low carbon steel with copper and brass wires at low current densities with different dielectric fluids. Dielectric fluids such as tap water, distilled water, and a combination of 25% tap water, 75% distilled water are tested, and response surface equations for MRR, tool wear, and surface roughness are developed by statistically sound experimental design. The authors concluded that distilled water gives better MRR, surface finish and low electrode wear than other dielectrics.

Kumagai et al. [10] A new WEDM method for high aspect ratio hole machining was introduced. It used a composite electrode made of a wire enclosed in a dielectric pipe. The authors successfully machined holes of 0.7mm diameter, 150mm deep in carbon steel with 0.3mm dia. wire and saline water as dielectric and obtained best results. Banadeki and Murti [11] observed that the gap voltage, machining current, wire tension, wire velocity, dielectric pressure and conductivity are the parameters causing excessive wear and rupture of wire. The authors experimented with HC-HCr steel of 34 mm thick on ELCUT 234 machine with preset conditions of 60V gap voltage, 40N of wire tension, 3.5A of machining current, 1.5 m/min wire velocity, 1.1bar flushing pressure and 40mho of dielectric conductivity. The authors concluded that the critical values of these parameters depend on the work piece thickness and also mentioned that for other thicknesses, these values are to be studied and optimized.Two quantifiable results were the amount of metal removed and the roughness value of sintered carbides. As a function of dielectric electrical conductivity, Kim and Kruth [12] examined this. The metal removal rate increases as the space between the wire electrode and the work piece becomes smaller because the dielectric has a lower electrical conductivity. A wire electrode and a roughly machined piece of metal were compared and contrasted in detail. In order to reduce the electrical energy and offset value and provide a satisfactory surface equality without fracture, four finish-cuts were required. The scientists examined the metal removal rate and surface roughness value as two of the WEDM-cut sintered carbide's output qualities. As more solidified metal builds up on the eroded surface, as shown by the experiments, the amount of cobalt in carbides influences the rate of metal removal and degrades the surface quality. The metal removal rate rises as the distance between the wire electrode and the work piece decreases because the dielectric has a lower electrical conductivity. Kozak et al. [13] discovered that milling modifies the total electrical resistance between the work piece and wire electrode. The resistance was altered, leading to poor cutting quality and a detrimental effect on the material removal rate (MRR) and average surface roughness. By applying a conductive silver coating to the surface, the drop voltage in the work piece material is reduced and the amount of energy lost is also reduced. It has been shown that applying silver plating improves output and reduces resistance variations. Okada et al. [14] introduced an innovative method of evaluation that makes use of high-speed video cameras. Using image analysis, we can quantify the locations of sparks. The location of the spark may be affected by a number of variables; these are then examined. These variables consist of the wire running speed, the servo voltage, and the pulse interval duration, among others. It is also addressed if it is possible to measure the vibration of the wire. For ferromagnetic wires such as steel wire, Schacht et al. [15] have shown the significance of the wire's impedance because of the skin-effect and how this impedance varies with the frequency of the current signal. It is also shown that wire coatings are essential for avoiding a considerable slowdown in machining speed.

Using an experimental method, Cheng et al. [16] The convective heat transfer coefficient was found using WEDM. After a series of short circuit discharges, the wire's average temperature will have risen, thus an instrument is developed to record this increase in temperature. Additionally evaluated are the convection coefficient and the coolant flushing pressure. The cooling condition of the WEDM process is enhanced by raising the pressure from 0.1 to 0.8MPa, as the convective co-efficient improves by more than 20%. An online analysis technique for the ignition delay time's causation was created by Chega and Liao [17]. Autocorrelation function analysis and Fourier transform analysis used two separate mathematical procedures. The autocorrelation function was successfully employed to identify the arc and short circuit discharge in succession across a range of experimental settings.In order to achieve the required level of surface roughness on the machined components, Gokler [18] investigated the best combination of cutting and offset parameters for the wire electrical discharge machining process. Tosun et al. [19] looked at the impact of various machining settings on WEDM kerf and metal removal rate. Pulse width, open-circuit voltage, wire speed, and dielectric cleaning pressure were all studied experimentally. A Taguchi experimental design was used to establish the optimal settings for the controls of the machine tools. We use ANOVA to determine how significantly different machining parameters affect both the final cutting kerf and the MRR. The optimal machining settings were calculated using a signal-to-noise (S/N) analysis. Regression analysis is used to quantitatively describe the relationship between kerf and MRR and the machining parameters. Using well-established mathematical models, the optimum search for machining parameters is carried out, targeting

both a small kerf and a high MRR. Sanchez et al.[20] examined the differences in corner geometry between the roughing and finishing stages. The effects of a wide variety of variables, including work thickness, corner radius, and the number of trim cuts, are investigated. The authors concluded that an optimization strategy for corner accuracy must account for flaws induced by previous cuts.

### *2.2.* Pulse classification

Watanabe et al. [21] created a pulse classification statistical approach for offline process improvement. They described a method for classifying the discharge pulses. The machining efficiency and stability may be verified by analysing the pulse occurrence. The authors also mentioned a WEDM monitoring system that gave machining conditions quantitatively. Dekeyser et al. [22] built a multi discipline expert system based on pulse categorization and thermal modelling. Discerning and classifying different pulses and pulse lengths is the goal of an EDM pulse discrimination system. The experimental data is analyzed and the influence of machining parameters is predicted. We create a thermal model to foretell wire thermal overload and wire failure. The authors observed that the increase in wire velocity results in decrease of temperature and causes vibrations.

Wong et al. [23] investigated the material removal properties of 0.25µm. -positioning-resolution single RC pulse discharges. Using the identical RC pulse discharges, the authors machined SS (SUS 304) at low (10-20mJ) and high (50-700mJ) energies. Material removal effectiveness was found to be close to 1 for low energies and 0.15 for high energies, as noted by the authors. Further the authors calculated the specific energy and found it to be lower for machining with lower pulse energy than higher pulse energy. Juhr et al. [24] machined cemented carbide WC-TiC-Co using short discharge duration pulses to minimize the depth of thermal affected zone. The authors also modeled the thermal affected zone using ANSYS for the simulation of pulse wave forms. Scott et al.

[25] The spark on time, spark off time, MRR, and surface roughness value of metal-bonded diamond grinding wheels, sintered Nd-Fe-B magnets, and C-C bipolar plates were all examined. A regression analysis is performed on the process parameters in order to maximise the rate of material removal and improve surface smoothness. The voltage,

machining current, and kind of pulse-generating circuit all had a significant effect on the ultimate surface roughness, according to Liao et al. [26]. The authors used the Taguchi quality design approach

and for error analysis, ANOVA is done to discover the relevant parameters. The authors adopted DC pulse generating circuit and achieved 0.22µm surface roughness values with 5µs spark on time and suggested to carry out the machining at low wire tension, lower conductivity of dielectric fluid, lower spark off time for achieving good surface finish.

Yan and Lai [27] high-frequency, low-energy pulse regulation against electrolysis was accomplished by constructing a new, high-quality power supply that was thyristor-controlled and had a full-bridge circuit. The authors machined SKD11 steel and tungsten carbide with 0.25mm diameter wire at 170N wire tension, 5m/min wire speed and achieved 0.22 µm Ra surface roughness value. Yan and Chien [28] built a system to monitor and manage the WEDM production process using computer-aided pulse discrimination and control. Based on the features of the gap voltage wave shape, the system categorises the discharge pulses into 4 distinct classes. This system is helpful for real-time analysis of the connection between machine configuration and sensor parameters. Experiments were run on SKD 11 steel of varying thicknesses (5mm, 10mm, and 15mm) to validate the method created for studying and manipulating the impact of machining parameters such as pulse interval, machining feed rate, and work piece thickness on sparking frequency. The authors concluded that pulse frequency is to be increased with increase in work piece thickness.

Rajurkar and Wang [30] Following an examination of the various spark types and their impact on cutting speed and the quality of the machined surface, a WEDM sparking frequency monitor was suggested as a means of measuring the energy produced during the machining process. Yan developed a brand-new, superior power supply that was used in WEDM [31]. Transistors manage the power supply, which consists of two snubber circuits, a full-bridge circuit, and a pulse control circuit for high-frequency, very-low-energy, and anti-electrolysis pulse control. According to experimental findings, modifying the parallel capacitance to the sparking gap may reduce the discharge current's pulse length.

### *2.3.* Effect of wire electrode parameters on machining criteria

Some scholars provide summaries of their studies on the influences of wire speed, wire tension, fluctuations, amplitude of vibration, transport system, wire breakage reasons, metallurgical characteristics of wire, and coating on wires on various machining criteria. Puri and Bhattacharyya [32] evaluated the effects of wire lag on cutting speed, surface roughness, and geometrical correctness using an L27 orthogonal array based on the Taguchi approach. In

order to lessen wire tool vibration while milling 28mm thick hardened and annealed M2 type die steel, the authors developed a model. In order to examine the effects of wire fluctuation on the distribution of the discharge sites, Guo et al. [33] devised a computer simulation technique to study the vibration of wire electrode under the action of successive discharges. The authors conclude that changes to the machining parameters may affect the discharge energy by altering the vibration of the electrodes.

Puri and Bhattacharya [34] described the vibration behaviour of the wire and created wire-tool vibration equation to examine the impacts of wire vibration, affected by pulse discharges and wire tension. The authors hypothesised that as the height of the work piece increased, so too would the amplitude of the wire's vibration. For precise machining, the authors recommend using a greater wire tension and an appropriate density of spark discharges. Experiments on Silicon Nitrate Ceramics 10 mm thick were conducted by Tani et al. [35]. The authors observed extremely low machining rates and frequent wire breakage and identified the best machining settings.

Using a 70 m diameter wire in their transport system, Yan and Fang [36] designed a genetic algorithm based fuzzy logic control, which lowered wire breakage and wire vibration. Kinoshita et al. [37] analyzed the cutting process and discussed the micro short circuit phenomenon related to wire speed and feed rate on spark gap and tool feed rate. The authors developed a model, with which spark gap related to feed rate, wire tension and wire velocity can be calculated. Dauw et al. [38] conducted the experiments to analyze wire vibration and evaluated the effect of dielectric to dampen the vibrations. Kinoshita et al. [39] figured out how to measure the wire vibrating area and the corner radius, and came to the conclusion that corner machining benefited most from low wire tension. Ivano et al. [40] proposed an optical wire position sensor at the machining zone. This sensor will measure continuously the direction of wire position and controls it and also corner precision is improved. Luo [41] worked on wire rupture, and pointed out the need for higher wire tension to keep the same minimal bow error at increased cutting speeds. Quantitative conclusions on the impact of factors like load, material property, and geometrical parameter on wire strength are drawn. Rao [42] explained the wire rupture variations during machining of graphite and tungsten carbide. The research reveals that the wire wear is much higher for tungsten carbide than graphite. This may be due to the high melting temperature of tungsten carbide. Kruth et al.

[43] conducted studies with coated copper and molybdenum wires (0.1 mm in diameter) on pearlitic steel. The authors determined that an increase in coating thickness on the wire increased the cutting speed. Molybdenum–graphite coated wires showed better results than tungsten. The authors suggested phosphate coated wire for machining steel.

Dauw and Albert [44] described the evolution of WEDM in chronological order and their metallurgical aspects on machining parameters such as cutting speed, accuracy, cost, etc. The authors concluded that coated wires will increase the finish of the machined surfaces. Soft wires are preferred for taper cuts as they vibrate less. High tensile strength wires are useful for high precision cuts. Kozak, et al. [45] performed experiments on low conductive silicon nitrate material with silver coated wires and suggested use of silver coated wire for machining silicon nitrate material to achieve better cutting speed. Klocke et al. [46] testing the melting points and tensile strengths of ultra-thin tungsten wire and brass-coated steel wire of varying gauges. A special rig must be constructed so that 20 and 25 m wires may be used in a machine designed for 30 m wires.

In order to stabilize the wire electrode's form and location during WEDM-High Speed machining, Mingqi et al. [47] investigated the impacts of experimental analysis on the regularity of the wire electrode and provided various techniques. The present composite wires that Kruth et al. [48] are using contain many coatings and a high tensile core. The use of a core with a high tensile strength, the addition of a layer to shield the wire core from heat-induced deterioration, and the provision of a multipurpose superficial top coating are all taken into consideration. Prototype wire cutting results demonstrate a significant increase in accuracy, particularly in corner cutting, at a cutting rate that is on par with commercial reference wires. Citation: Yang et al. An electrostatic induction feeding mechanism was used to achieve micro-WEDM in order to reduce discharge energy and remove the impact of stray capacitance in circuits.

Using electrostatic induction feeding and air and oil as the working dielectrics, the micromachining characteristics of WEDM are examined. A 32.4-meter-wide microslit and a 100-meter-long, 3.8-meter-wide microbeam were successfully created by us. Moreover, moving the wire electrode over a 30 m thick Teflon sheet laid on a metal plate feeding electrode allowed for the successful non-contact feeding of electric current to the wire electrode.

Liao et al. [50] utilised a machine with a finished surface Ra0.7 m rougher for the best results. The conventional circuit, which requires just a small amount of power for ignition, is adapted for use in milling so that a satisfactory level of surface roughness may be achieved. The finishing process becomes more difficult when energy is increasingly decreased because of wire deflection and vibration. Yan and Shiu [51] constructed a controller and observer with a single degree of freedom to manage a direct drive motion system using permanent-magnet linear synchronous motors (PMLSM). Using an inverted model of the direct drive system, a new feed forward controller is proposed to remove tracking problems. The experimental findings show that the suggested controller can offer disturbance rejection and resilience while also achieving a high level of contouring accuracy (70,3 m).

### *2.4.* Thermal load on wire electrode

Hirmath and Mishra [52] built the first thermal model to measure the heating impact on the cable. The temperature profile of the wire and how it changes depending on the machining parameters are addressed. The authors expressed that the wire stability is less and rupture is frequent at higher input powers. The authors opined that at higher energy inputs, high temperature will occur in wire, deteriorating its ultimate tensile strength and causing rupture. Also MRR will not be steady. The authors concluded that a moderate power input is better for rough or faster cutting and also to compromise between wire tension and wire speed.

Banerjee et al. [53] used a simple finite element model to simulate the wire's temperature profile. Studies have standardized conditions including input power (50-300W), pulse on time (10-200s), wire speed (0.5-10m/min), and wire diameter (0.1-0.3mm). The authors found that more power input results in higher temperatures in some regions of the discharge channel, and found the same thing to be true of pulse on time. Researchers concluded that the influence of wire speed on temperature was minimal. The authors

hypothesised that a larger heat load and potential wire breakage would result from a decrease in wire diameter. For on-line regulation of the thermal load to avoid wire breakage, Rajurkar and Wang [54] reported on a WEDM sparking frequency monitor they created. A thermal model is also used to examine the phenomena of wire rupture. The machining rate and surface quality of a process, together with its overall control parameters, have been the subject of a thorough experimental examination. Using a multi-objective model, the link between surface quality and cutting speed under ideal
machine settings was found.

### *2.5.* Parametric optimization

Several ferrous materials are machined in this area. Nonferrous materials such as copper, brass, aluminum, graphite, tungsten carbide, and X210 Cr 12 steel in 17.3, 25, and 34mm thicknesses, as well as ceramics including sintered carbide, polycrystalline diamond, sailon, boron nitride, and silicon nitride, were also studied. The best surface quality and maximum MRR were achieved by the authors by determining the ideal machining settings. Hadda and Tehrani [29] used a Taguchi L18 array in their experimentation and turned AISI D3 steel using a wire electrical discharge. Regression analysis was used to find the ideal electrode rotation speed and spark on time for greatest material removal and least amount of surface roughness.

By carefully planning tests using the Taguchi approach, Kanlayasiri and Boonmung [55, 56] were able to determine the optimum values for the factors affecting surface finish while milling DC53 tool steel, 27 mm thick, with a wire diameter of 0.25 mm. Using a mathematical model for optimisation, the scientists were able to make accurate predictions about future surface roughness levels. The created model has shown a 30% maximum inaccuracy. A total of 54 precision turning tests were conducted by Mohammadi et al. [57]. The influence of input factors on output may be examined via ANOVA. Power, spark-on time, spark-off time, wire velocity, wire tension, wire speed, and rotation speed were examined to see how they affected the rate of material removal. As a means of determining the rate of material removal, the authors formulated a set of mathematical relationships. Turning operations on DIN X210 Cr 12 steel were completed by Haddad and Tehrani [58] using an L18 orthogonal array. To ascertain how the rate of material removal influences the roundness and roughness of a machined product's surface, the authors developed a mathematical model. The die's power, pulse off time, and rotation speed all significantly affect how quickly material is removed. Tarng et al. [59] used feed forward neural net work with the simulated annealing technique to maximise cutting performance. Work piece thickness, material, spark on/off duration, machining current, voltage, capacitance, and the ensuing surface roughness are all taken into account during optimisation. Ten and fifteen millimeter thick SUS 304 stainless steel was machined by the writers. The expected best settings are as follows:

Ra value of 16.1 m and a cutting speed of 1.63 mm/min for a 10 mm thick workpiece.

Workpiece thickness of 15 mm, Ra value of 1.65 m, and cutting speed of 1.65 mm/min.

Jesudas et al. [60] developed a mathematical model using Taguchi analysis to optimize the machining settings for a metal matrix composite made of bronze-alumina alloy. The design process adheres to the L9 orthogonal array. The speed of the best parameters is calculated using ANOVA. The spark frequency is monitored and adjusted in real time based on the on-line identification of the work piece's thickness, thanks to the adaptive control system established by Rajurkar and Wang [61]. Ten 40 mm thick samples of Sailon material were machined by Lok and Lee [62], who determined the material removal rate (MRR) to be 4.5-6.0 mm3/min under controlled circumstances. The authors observed that the machining rate of Sailon was much lower than that of SKD11 steel. It was also discovered that the rate at which material was removed rose with the first stages of a rise in the machining current before levelling out.

Kuriakose and Shunmugam [63] developed and carried out controlled tests (80V, 8-12A machining current, 4-8s pulse duration) on Ti6A14V material using 0.25mm diameter brass coated wire. It was discovered that oxides formed as a consequence of macro and micro level stresses, as well as the process's high temperature generation. From a metallurgical standpoint, the authors recommend using coated wire as the electrode since they found that non-uniform cooling and heating occurred when the duration between pulses was increased. Using a wire electrical discharge machining procedure, Calk and ayda [64] performed a controlled experiment to determine AISI D5 tool steel's machinability. Varying open circuit voltage, pulse length, wire speed, and dielectric fluid pressure were some of the experimental factors studied to learn more about surface roughness and metallurgical structure. Tests for recast, surface roughness, and micro cracking, as well as optical and scanning electron microscopy, revealed that wire speed and dielectric fluid pressure did not significantly affect the characteristics of the machined specimens. Using a 0.25 mm diameter wire and adjusting the duty factor, machining current, and wire speed, Kadam and Basu [65] conducted tests on 17.3 mm thick HC-HCr steel. Using regression analysis, the authors optimised cutting speed and surface roughness by establishing mathematical equations.

To evaluate the efficacy of the process parameters used, a number of nonferrous materials are machined. Rao et al. [66-69] formulated mathematical correlations. Using a data mining approach, Kuriakose et al. [70] machined a titanium alloy with a 40 mm thickness using a 0.25

mm diameter zinc-coated brass wire under preset machining conditions (80 volts, 8-16 amps, 8-10 metres per minute, and 1-1.2 kilopascals of wire tension). According to Kuriakose and Shunmugam [71], Cutting speed and surface quality are two areas where cutting parameters have inverse effects. The authors first use a multivariate regression model to determine the connection between the input and output variables, and then they use a non-dominated sorting genetic algorithm. Numerous factors were taken into consideration while analysing the cutting rate and surface quality. These variables included injection pressure, work piece height, wire speed, wire tension, and spark ON and OFF timings. The investigations on Ti6A14V Titanium alloy 60mm in thickness determined that 0.9735mm/min cutting speed and 3.2m surface roughness were optimal.

According to Hewidy et al. [72], the most crucial part of WEDM processes with Inconel 601 material is selecting the right machining settings. During WEDM machining of Inconel 601, the effects of peak current, duty factor, wire tension, and water pressure on the rate of metal removal, wear ratio, and surface roughness are thoroughly examined, and mathematical models explaining these effects are established. The parameters for evaluating MRR and surface roughness values were optimised by Prakash and Ranganath [73] via the machining of En8, En31, and HC-HCr materials, followed by an analysis of the results. In their trials, Kannan et al. [74] used 30 mm thick OHNS die steel. Taguchi's approach was used to design the experiments, which included two levels, seven parameters, and a L8 orthogonal array. Optimal settings, including minimal surface roughness and maximum cutting speed, were determined by ANOVA analysis of the experimental data. Mohammadi et al. [75] employed WEDM to precisely make cylindrical forms from hard, brittle materials. The experimental design made use of an L18 (2137) Taguchi standard orthogonal array. The optimal setting is determined by analyzing the signal-to-noise (S/N) ratio.

## *2.6.* Adaptive systems

Hana et al. [76] intended to replicate the motion of the wire electrode route in relation to the NC path during rough cutting using a WEDM. Results from experiments were compared to theoretical predictions and were found to agree. The authors suggested simulating the corner value, and a code to do so has been constructed (route). Levy [77] described the developments of WEDM machining performance since its introduction in 1969 to till date. By the use of controlled relaxation power supply in1974 to 3rd generation pulse controlled supply (1977) the performance has improved enormously. With the introduction of 4th generation power supply, 3-D cuts and taper cuts are enabled to perform and the cutting speed had increased by six fold.

Fujun et al. [78] have used the computer simulation technique to initiate the process of cutting. A mathematical model is developed using a motion equation of the machining system. Hang et al. [79] developed a method for identifying current that uses an adaptive control system fed by a strong servo without a feedback loop to determine erosion rate and discharge gap in real time. The authors believe that the developed method is helpful in quickly, precisely, and thoroughly identifying so that it can track the machining status in a clear and continuous manner, especially in cases when the work piece's thickness varies.

Snoeys et al. [80] developed the knowledge based system for WEDM. The authors developed an expert system for fault diagnostic and operator assistance. Using a metric representing the likelihood of a rupture, it was possible to keep tabs on and regulate the process. Kruth et al. [81] suggested a technological processor and processor planner for programming NC controlled machines. The processor is able to do unique computations such as tool path adjustments to increase geometrical accuracy while cutting narrow fillets and sharp edges. Die sinking electrical discharge machining (EDM) researchers Ho and Newman [82] summarised recent work on performance metrics, process variable optimisation, and spark process monitoring and control. The authors outlined the trends for future research. The following values for machine parameters such as wire tension, wire speed, wire diameter, wire material, and dielectric conductivity were derived after a study of the relevant literature:

| | |
|---|---|
| Gap voltage: | 80V |
| Wire diameter: | 0.25mm |
| Wire tension: | 80N |
| Wire speed: | 4.7 m/min |
| Dielectric conductivity: | 48 mho |
| Flushing pressure: | 1.5kN/mm$^2$ |
| Spark on time: | 5µs |

## Conclusions

- In the literature presented by the earlier investigators, the optimal parameters are available only for few sizes of work pieces and mostly ferrous, some of the non ferrous materials and ceramic materials. The data base is to be experimentally evaluated for commonly used aviation materials such as inconel, titanium for a wide range of thicknesses.
- The existing literature does not offer the details of cutting parameters for wire materials like tungsten and molybdenum in the diameter range of 0.03 – 0.1mm. There appears to be a lot of scope for more research to be done for evaluating the utility of thinner wires and improvement in the machining accuracy.
- Very little information is available on the effect of dielectric conductivity and dielectric materials. Some more research is to be carried out on the effect of conductivity of dielectric fluid as well as various dielectric materials.
- The affect of nano fluid presence in the dielectric is yet to be investigated.

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