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Review of Wire-Cut EDM Process on Titanium alloy

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ABSTRACT
Wire electrical discharge machining (WEDM) is a specialized thermal machining process capable of accurately machining parts with varying hardness or complex shapes, which have sharp edges that are very difficult to be machined by the main stream machining processes. This practical technology of the WEDM process is based on the conventional EDM sparking phenomenon utilizing the widely accepted non-contact technique of material removal. Since the introduction of the process, WEDM has evolved from a simple means of making tools and dies to the best alternative of producing micro-scale parts with the highest degree of dimensional accuracy and surface finish quality. This paper reviews the vast array of research work carried out from the EDM process to the development of the WEDM. It reports on the WEDM research involving the optimization of the process parameters surveying the influence of the various factors affecting the machining performance and productivity on titanium alloy (Ti6Al4V).This paper reviews the effects of various WEDM process parameters such as pulse on time, pulse off time, servo voltage, peak current, dielectric flow rate, wire speed, wire tension on different process responseparameters such as material removal rate (MRR), surface roughness(Ra), Kerf (width of Cut), wire wear ratio (WWR) and surface integrity factors.

I. Introduction

Wire electrical discharge machining (WEDM) is a widely accepted non-traditional material removal process used to manufacture components with intricate shapes and profiles. It is considered as a unique adaptation of the conventional EDM process, which uses an electrode to initialize the sparking process.

WEDM was first introduced to the manufacturing industry in the late 1960s. The development of the process was the result of seeking a technique to replace the machined electrode used in EDM. In 1974, D.H. Dulebohn applied the optical-line follower system to automatically control the shape of the component to be machined by the WEDM process [1]. By 1975, its popularity was rapidly increasing, as the process and its capabilities were better understood by the industry [2]. It was only towards the end of the 1970s, when computer numerical control (CNC) system was initiated into WEDM that brought about a major evolution of the machining process. As a result, the broad capabilities of the WEDM process were extensively exploited for any through-hole machining owing to the wire, which has to pass through the part to be machined.

The first WEDM machine worked simply without any complication and wire choices were limited to copper and brass only. Several researches were done on early WEDM to modify its cutting speed and overall capabilities. In recent decades, many attempts were done on Wire EDM technology in order to satisfy various manufacturing requirements, especially in the precision mold and die industry. Wire EDM efficiency and productivity have been improved through progress in different aspects of WEDM such as quality, accuracy, precision and operation. The common applications of WEDM include the fabrication of the stamping and extrusion tools and dies, fixtures and gauges, prototypes, aircraft and medical parts, and grinding wheel form tools.

It can machine anything that is electrically conductive regardless of the hardness, from relatively common materials such as tool steel, aluminium, copper, and graphite, to exotic space-age alloys including hastalloy, inconel, titanium, carbide, polycrystalline diamond compacts and conductive ceramics. The wire does not touch the work piece, so there is no physical pressure imparted on the work piece compared to grinding wheels and milling cutters. The amount of clamping pressure required to hold small, thin and fragile parts is minimal, preventing damage or distortion to the work piece.

II. WEDM

WEDM is a thermo- electrical process in which material is removed by a series of sparks between work piece and wire electrode (tool). The part and wire are immersed in a dielectric (electrically non-conducting) fluid, usually deionized water, which also acts as a coolant and flushes the debris away. The material which is to be cut must be electrically conductive[3]. The Spark Theory on a wire EDM is basically the same as that of the vertical EDM process. In wire EDM, the conductive materials are machined with a series of electrical discharges (sparks) that are produced between an accurately positioned moving wire (the electrode) and the work piece. High frequency pulses of alternating or direct current is discharged from the wire to the work piece with a very small spark gap through an insulated dielectric fluid (water).

Many sparks can be observed at one time. This is because actual discharges can occur more than one hundred thousand times per second, with discharge sparks lasting in the range of 1/1,000,000 of a second or less. The volume of metal removed during this short period of spark discharge depends on the desired cutting speed and the surface finish required. The heat of each electrical spark, estimated at around 15,000° to 21,000° Fahrenheit, erodes away a tiny bit of material that is vaporized and melted from the work piece and some of the wire material is also eroded away. These particles (chips) are flushed away from the cut with a stream of de-ionized water through the top and bottom flushing nozzles. The water also prevents heat build-up in the work piece. Without this cooling, thermal expansion of the part would affect size and positional accuracy. Keep in mind that it is the ON and OFF time of the spark that is repeated over and over that removes material, not just the flow of electric current [4].

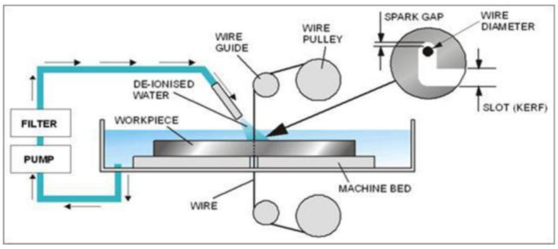

Fig 1: Schematic Diagram of WEDM System

A DC or AC servo system maintains a gap from 0.002 to 0.003" between the wire electrode and the work piece. The servo mechanism prevents the wire electrode from shorting out against the work piece and advances the machine as it cuts the desired shape. Because the wire never touches the work piece, wire EDM is a stress – free cutting operation. The wire electrode is usually a spool of brass, copper or brass and zinc wire from 0.001 to 0.014" thick. Sometimes molybdenum or tungsten wire is used. New wire is constantly fed into the gap; these accounts for the extreme accuracy and repeatability of wire EDM.

When sufficient voltage is applied, the fluid ionizes. Then a controlled spark precisely erodes a small section of work piece, causing it to melt and vaporize. These electrical pulses are repeated thousands of time per second. The pressurized cooling fluid, the dielectric, cools the vaporized metal and forces the resolidifies eroded particles from the gap. The dielectric fluid goes through a filter which removes the suspended solids. Resin removes suspended particles; filters remove suspended particles. To maintain machine and part accuracy, the dielectric fluid flows through a chiller to keep the liquid at constant temperature.

III. WEDM Process Parameters

The process parameters that can affect the quality of machining or cutting or drilling in Wire EDM process are shown through Ishikawa cause – effect diagram as shown in figure 2[5].

The major parameters are as follows:

Electrical parameters: Peak current, pulse on time, pulse off time, supply voltage and polarity.
Non – electrical parameters: wire speed; work feed rate, machining time, gain and rate of flushing.
Electrode based parameters: Material and size of wire.
Dielectric system: Type, viscosity and other flow characteristics.

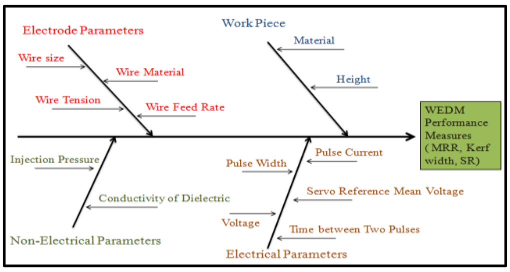

Fig 2: Ishikawa Cause and Effect Diagram for WEDM Process

The main goals of WEDM are to achieve a better stability and higher productivity. However, due to a large number of variables in WEDM, it is difficult to achieve the optimal performance of WEDM processes and the effective way of solving this problem is to establish the relationship between the response variables of the process and its controllable input parameters.

A. Process Parameters

1) Pulse on Time (Ton)

The pulse on time is referred as Ton and it represents the duration of time in micro seconds (μs). During the pulse on time, the voltage is applied in the gap between work piece and the electrode thereby producing discharge. Higher the pulse on time, higher will be the energy applied there by generating more amount of heat energy during this period.

Material removal ratedepends upon the amount of energy applied during the pulse on time. Material removal rate depends on longer or shorter pulse on time period. Longer pulse duration improves removal rate of debris from the machined area.

2) Pulse off Time (Toff)
The pulse off time is referred as Toff and it represents the duration of time between the two simultaneous sparks is also expressed in micro seconds. This is the time between discharges. Off time has no effect on discharge energy. Off time is the pause between discharges that allows the debris to solidify and be flushed away by the dielectric prior to the next discharge. With a lower value of Toff, there is more number of discharges in a given time, resulting in increase in the sparking efficiency. As a result, the cutting rate also increases. However, reducing off time, can overload the wire, causing wire breakage and instability of the cut by not allowing enough time to evacuate the debris before the next discharge [5].

3) Peak Current (Ip)
Peak current is the amount of power used in discharge machining and is measured in unit of amperage. During each pulse on-time, the current increases until it reaches a preset level, which is expressed as the peak current. In wire-EDM processes, peak current is the maximum amount of amperage is governed by the surface area of the cut. Higher amperage is used in roughing operations and in cavities or details with large surface areas. Higher currents will improve MRR, but reduce the surface roughness.

4) Servo Voltage (SV)
Servo voltage acts as the reference voltage to control the wire advances and retracts. And it is also called spark gap set voltage that reference for the actual gap between the work piece and the wire electrode used for cutting. If the mean machining voltage is higher than the set servo voltage level, the wire advances, and if it is lower, the wire retracts. When a smaller value is set, the mean gap becomes narrower, which leads to an increase in number of electric sparks, resulting in higher machining rate. However, the state of machining at the gap may become unstable, causing wire breakage [6].

5) Gap Voltage
Gap voltage or open circuit voltage specifies the supply voltage to be placed on the gap. Greater the gap voltage, greater will be the electric discharge. If the gap voltage increases, the peak current will also increase.The open gap voltage is the voltage read across the electrode and work piece space prior to the spark. In some WEDM machines both of these factors show machining voltage.

6) Dielectric flow rate
Dielectric flow rate is the rate at which the dielectric fluid is circulated. Flushing is important for efficient machining. Flushing pressure is produced from both the top and bottom nozzles. High flow rate of dielectric is necessary for machining with higher values of pulse power and also while cutting the work piece of more thickness. Low input pressure is used for thin work piece [7].

7) Wire Feed Rate
Wire feed is the rate at which the wire-electrode travels along the wire guide path and is fed continuously for sparking. In WEDM, wire electrode contributes 70% of the machining cost. Therefore, it is desirable to set low wire feed rate where stable machining with no wire breakage occurs. As the wire feed rate increases, the consumption of wire as well as cost of machining will increase. Low wire speed will cause wire breakage in high cutting speed.

8) Wire Tension
If the wire tension is high enough the wire stays straight otherwise wire drags behind. Within considerable range, anincrease in wire tension significantly increases the cuttingspeed and accuracy. The higher tension decreases the wirevibration amplitude and hence decreases the cut width so that the speed is higher for the same discharge energy. However, if the applied tension exceeds the tensile strength of the wire, itleads to wire breakage.

IV. LITERATURE BASED ON RESPONSE PARAMETERS

1. Material removal rate and cutting speed:
InWEDM the material erodes from the workpiece by a series of discrete sparks between the work and the tool electrode immersed in the liquid dielectric medium. These electrical discharges melt and vaporize minute amounts of the work material, which are then ejected and flushed away by the dielectric fluid.Lots of research tried to maximize the material removal rate and cutting speed by different approaches. Because these factors can help to increase, economic benefits in WEDM considerably. Almost both of these factors (material removal rate and cutting speed) determine same phenomena which is the machining rate.
MRR value normally obtained by the following equation

$$MRR = F \times Dw \times H \qquad \ldots\ldots\ldots 1$$

Where F is the machine feed rate [mm/min], Dwis wire diameter [mm] and H is piecework thickness [mm] and MRR is material removal rate [mm3 /min].
Rajurkar and Wang (1993) analyzed the wire rupture phenomena with a thermal model and experimental investigations. It was found that the material removal rate in WEDM increases initially with the decrease of pulse off time. However, at a very short pulse off time, the gap becomes unstable which leads to a reduction in the machining rate[8]. Manna and Bhattacharyya [20], carried out an experimental investigation to determine the parameters setting during the machining of aluminium-reinforced silicon carbide metal matrix composite (Al/SiC-MMC). Mathematical models relating to the machining performance such as MRR and Ra are established using the Gauss elimination method for the effective machining of Al/SiC-MMC [9]. Singh and Garg (2009) presented the effects of process parameters on material removal rate in WEDM, and it was found that, when pulse on time and peak current increase material removal rate also increase but with the increase of pulse off time and servo voltage, MRR decrease [10].Nithin et al.[11] used Taguchi's experimental design to obtaining the optimum machining parameters for the maximization of MRR and minimization of surface roughness separately in WEDM of brass material. They found that, the significant factors are pulse time and feed rate in both MRR and Surface finish. At higher values of feed rate and pulse duration increases the MRR and decreases the surface roughness.
The machining of titanium and its alloys is generally cumbersome owing to several inherent properties of the material. Titanium is very chemically reactive and therefore has a tendency to weld to the cutting tool during machining thus leading to premature tool failure.

Table 1
Chemical composition of Ti6Al4V (wt %)

C	Fe	Al	O	N	V	H	Ti
0-0.08	0.22	6.08	0-0.2	0.05	4.02	0-0.15	Balance

Titanium Properties:

Physical properties
High strength to weight ratio.
Low electrical (8.6 μm·m−1·K−1 (at 25 °C)).
Low thermal conductivity (21.9 W m−1·K−1).
Highly fatigue resistance.
It is non-ferromagnetic material.
Low density (4.506 g·cm−3).
High melting point (1668 °C, 3034 °F).
High Boiling point (3287 °C, 5949 °F).
Brinell hardness 716 MPa.
Ultimate tensile strength of about 434 MPa.

Chemical properties
Excellent resistance to corrosion.
Titanium readily reacts with oxygen at 1,200 °C (2,190 °F) in air, and at 610 °C (1,130 °F) in pure oxygen, forming titanium dioxide.
Capable of withstanding attack by dilute sulfuric and hydrochloric acids as well as chloride solutions, and most organic acids.
It burns in pure nitrogen gas, reacting at 800 °C (1,470 °F) to form titanium nitride.
DanialGhodsiyeh et al. [12,13] studied the effect of machining parameters including pulse on time, pulse off time, and peak current on surface roughness, sparking gap and material removal rate of titanium (Ti6Al4V). Stastical optimization model (a central composite design coupled with response surface methodology overcomes the limitations of classical methods and was successfully employed to obtain the optimum processing conditions while the interactions between process variables were demonstrated.Anish Kumar et al. [14] Parametric Effect on Wire Breakage Frequency and Surface Topography in WEDM of Pure Titanium and conclude that the effect of pulse on time on the wire breaking frequency indicating that the wire breakage frequency continuously increases with an increase in pulse on time. When the value of pulse on time is minimum then there is no wire breakage during the WEDM of pure titanium, but as the pulse on time increases, the probability of wire breakage starts increasing due to increase of discharge rate. Due to increase of pulse on time the rate of discharge energy increases which may significant affect wire breakage frequency.

2. Surface Roughness:
Lots of research tried to minimize the surface roughness by different approaches. Base on the theory surface roughness significantly affected by the pulse on time and peak current and the cutting speed and surface roughness have an inverse relationship. Surface roughness affects several functional attributes of parts, such as friction, wear and tear, light reflection, heat transmission, ability of distributing and holding a lubricant, coating etc. Therefore, the desired surface finish is usually specified and appropriate processes are required to maintain the quality. There are many different roughness parameters in use, but Ra is by far the most common. Other common parameters include Rz, Rq, Rv, Rp, Rt, Rku and Rskand is usually expressed in μm.
Scott et a. [15], presented a methodology to determine the optimal combination of control parameters such as discharge current, pulse duration,

pulse frequency, wire speed, wire tension and dielectric flow rate in WEDM of D2 tool steel. The performance measures were surface roughness and MRR. From the experimental results and ANOVA they found that discharge current, pulse duration and pulse frequency were significant control factors for both MRR and surface finish, where as wire speed, wire tension and dielectric flow rate were relatively insignificant.Ashan et al.[16], conducted experimental investigations toestablish relationships for surface finish with current and voltage. They concluded that the machined surface becomesrougher with increase in current and voltage.Anish Kumar et al. [17] Metallographic Analysis of Pure Titanium (Grade-2)Surface by Wire Electro Discharge Machining(WEDM) and conclude that SEM micrographs that WEDM surface produces the more irregular topography and defects included globules of debris, spherical particles, varying size craters, pockmarks and micro-cracks. The pulse on time and peak current are the most significant parameters which lead to deteriorate the surface texture. The residuals of copper, carbon and zinc were detected in the machined samples using EDX analysis. This may be due to the melting, evaporation and re-solidification of the brass wire electrode and are transferred to the work material.

3. Kerf width

It is the measure of the amount of the material that is wasted during machining. It can determine the dimensional accuracy of the finishing part and the internal corner radius of the product in WEDM operations. Kerf is one of the important performance measures in WEDM.

Sourav and Siba [18], applied response surface methodology to developed quadratic mathematical models to represent the behavior of WEDM process parameters for the processresponses such as MRR, surface roughness and kerf on D2tool steel. Grey relational analysis has been adopted for multi-objectiveoptimization.

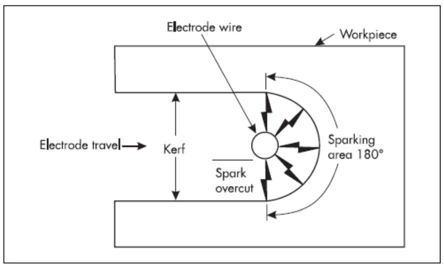

Fig 3: kerf width

Parasharet al. [19]investigate the effects of WEDM parameters on kerf width while machining

Stainless steel, it was found that pulse on time and dielectric flushing pressure are the most significant factors, while gap voltage, pulse off time and wire feed are the less significant factor on the kerf width. Tosun, N. et al. [20] presented an investigation on the level of importance of the machining parameters on the kerf width by using ANOVA. It was found that open circuit voltage and pulse duration were the highly effective parameters whereas wire speed and dielectric flushing pressure were less effective factors. According to this research open circuit voltage for controlling the kerf width was about three times more important than the second ranking factor (pulse duration).

4.Wire Wear Ratio

Some researches tried to minimize the wire wear ratio by different approaches. Because this factor can help to decrease the wire rupture phenomena considerably.

Wires wear ratio (WWR) value normally obtained by the following equation:

$$WWR = WWL/IWW \qquad \text{……..2}$$

Where WWL is the weight loss of wire after machining and IWW is the initial wire weight.

G. Ugrasen et al. [21]study outlines the electrode wear estimation in the wire EDM. EN-8 and EN-19 was machined using different process parameters. Electrode wear was measured using universal measuring machine. Estimation and comparison of electrode wear was done using multiple regression analysis and group method data handling technique. It was found that, each control factors are affecting the response variables to different extent. We have also seen that multiple regression analysis is a preferred tool for estimating electrode wear for EN-8 and EN-19 material. Comparing the electrode wear for EN-19 gave better result than EN-8. Tosun and Cogun [22]investigated the effects of different wire EDM parameters on wire wear ratio and it was found experimentally that the increasing pulse duration and open circuit voltage increase the WWR whereas the increasing wire speed and dielectric fluid pressure decrease it. Ramakrishnan and Karunamoorthy [23], identified that the pulse on time and ignition current intensity have influencedmore than the other parameters considered in their study onWWR.

5.Surface Integrity

During each electrical discharge, intense heat is generated, causing local melting or even evaporation of the workpiece material. With each discharge a crater is formed on the workpiece. Some of the molten material produced by the discharge is carried away by the dielectric circulation. The remaining melt resolidifies to workpiece. Four zones were identified considering microhardnesses and micrographs in all specimens after machining.

Outermost surface is debris or recast layer which cooled too quickly to escape the gap and were recast to the material. Next layer commonly called the white layer, has been heated to very high temperatures, taken to a molten state, and then rapidly cooled. This rapid heating and cooling process causes a very brittle surface, which is highly susceptible to thermal stress cracks. White layers have been suggested to have an untempered martensitic structure [24]. Below the white layer is an area which was heated and cooled more slowly. This created an annealed area, softer than the parent material.

Finally, come to the parent material and the thickness of white layer of WEDMed surfaces increases with the increase pulse duration and open circuit voltage. This layer is always present to some degree. It is found that the wire speed and dielectric flushing pressure have not a significant influencen the microstructure in applied conditions. However, in especially high pulse duration and open circuit voltage value, wire breakage caused of carbides in the workpiece decreases with increase wire speed and dielectric flushing pressure.

AmiteshGoswami at al.[25] studied Investigation of surface integrity, material removal rate and wire wear ratio forWEDM of Nimonic 80A. And conclude that Recast layer thickness tends to increase with increased current pulseduration and increased energy per spark. Recast layer thicknessincreases with decreasing pulse-off time. The depth of this topmelted zone depends on the pulse energy and duration. A higherpulse-on time setting leads to thicker recast layer. This indicatesthat recast layer thickness increases with an increasing peakdischargecurrent, pulse-on time and energy per spark and withdecreasing pulse-off time. Fig. 4 shows the recast layer ofthe machined sample of Nimonic 80 A.

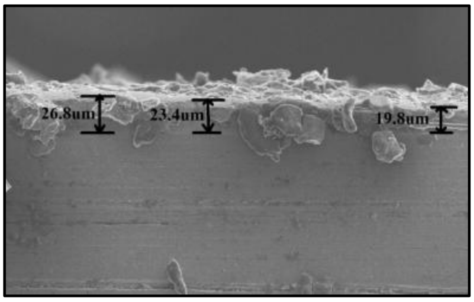

Fig 4: Recast layer of the machined sample

Kuriakose and Shunmugam [26] investigated the effects of different parameters on surface characteristics of Ti6Al4V. It is observed that more uniform surface characteristics are obtained withcoated wire electrode. Furthermore it was found that pulse off time is the most sensitive parameter that influences the formation of layer consisting of mixture of oxides. With a lower value of pulse of time, a considerable reduction in the formation of oxides can be obtained.

6. Wire lag and Wire EDM inaccuracy

WEDM is very useful wherever complex geometrywith tight tolerances needs to be generated. In this condition geometrical inaccuracies are completely unacceptable. Some researches tried to minimize the wire lag because geometrical inaccuracy can caused due to this phenomenon however still there is lack of information about this fact. More research about wire lag can help for improvement of accuracy in contour cutting with wire EDM.Several researchers have been of the opinion that the main forces acting along or upon the wire are forces from gas bubbles formed by the plasma of the erosion mechanism, hydraulic forces due to flushing, electrostatic force and electrodynamic force. However, the authors believe that there is little effect of electrodynamic force on the mechanical behavior of the wire. Instead, another force acts perpendicular to the wire, which is impact. During every individual spark discharge, the wire experiences an impact, which acts in the reverse direction of the discharge occurrence.

If the wire tension is high enough the wire stays straight otherwise wire drags behind as it shown in figure 5.

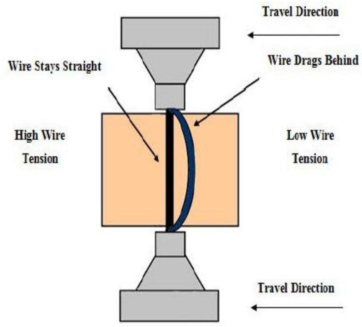

Fig 5: Relation between wire drag and wire tension

In Puri, A.B. and Bhattacharyya, B [27]The significant factors for geometrical inaccuracydue to wire lag (*g*) are pulse on time, pulse off timeand pulse peak current during rough cutting; andpulse peak voltage, wire tension, servo spark gap set voltage, wire tool offset and constant cutting speed during trim cutting. A single set of parametric combination can never produce the highest productivity (within the possible range) with the best surface finish and least geometrical inaccuracy due to wire lag. The experimental analysis further confirms that the difference between the offset values for the rough cut and the trim cut should be maintained as high as possible till the surface finish criterion permits. This will help in minimising the geometrical inaccuracy in the most effective way.

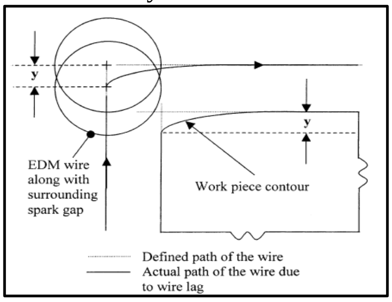

Fig 6: Illustration of the effect of wire lag on the work-piece contour in WEDM.

7. Dry and Near-Dry Wire Cut

There is a method in wire EDM which is conducted in a gas atmosphere without using dielectric liquid, this method called dry-WEDM. Recently, new method have introduced in WEDM which called Near-Dry Wire-Cut. In this method the liquid di-electric fluid is replaced by the minimum quantity of liquid with the gas mixture. Wang, T. et al. [28]Studied finishing cut with Dry-WEDM and it was found that dry-WEDM have some advantage like better straightness, lower surface roughness and shorter gap length and the main disadvantage of this method was poorer material removal rate in compare with conventional method.

Kunieda and Furudate [29] conducted studies in dry WEDM. It was found that in dry-WEDM, the vibration of the wire electrode is minimal due to the negligibly small process reaction force. In addition narrower gap distance and no corro- sion for work piece during machining are the other advantages of dry EDM. These characteristics can improve the accuracy and surface quality of workpiece during of finish cutting. The main drawbacks are lower material removal rate compared to conven- tional WEDM and streaks are more likely to be generated in this method. The drawbacks can be resolved by increasing the wire winding speed and decreasing the actual depth of cut.

C.C. Kao et al. [30] study the dry wire EDM of thin workpiece was proven to be possible. Effects of spark cycle (*T*) and spark on-time (*Ton*), air flow rate, workpiece thickness, and work-material type on the MRR for dry wire EDM of thin workpiece were investigated. Experimental results showed that not all thin work-materials could be machined using dry EDM. For example, thin porous carbon foam and carbon bipolar plate have failed to be machined using the dry EDM process. The high melting temperature of carbon is the likely cause. The research in dry EDM is continuing to improve the precision, MRR, and environment issues. The use of a mist of deionzied water has been investigated to reduce the smoke and fumes generated during dry EDM and help collecting the debris in solid particulate form.

8. Wire Properties and Influences on Wire EDM Performance

Wire electrical discharge machine should satisfy performance demands such as: high- speed cutting, resistant against wire rupture and accurate machining to improve the productivity and to achieve high quality in machining work pieces. Many factors have effect on the process of WEDM (cutting speed and work piece precision) including electrical parameters and electrode.

Higher angles of taper, thicker workpieces, automatic wire threading, and long periods of unattended operation, make choosing the optimum wire a much more critical factor in achieving a successful operation.

The wire used in WEDM should provide some features such as high electrical conductivity, sufficient tensile strength at high temperatures, low melting temperature and high heat conductivity in order to reach to high performance. The high electrical conductivity helps the wire transfers energy to work piece efficiently and minimize energy loss of sparking during machining. The wire with high tensile strength is a good heat resistance in high temperature and maintains straight under vibration and tension. The low melting temperature of wire improves the spark formation and decrease dielectric ionization time.The higher thermal conductivity of the electrode ensures a better spark discharge energy distribution during the EDM process.WEDM system core is wire which is used to receive a stable electrical discharge. So, the wire electrode is one of the important factors contributing the overall WEDM performance.

Wire rupture is a serious problem associated to WEDM process and wire electrode. This problem affects surface finish quality and accuracy, limits cutting speed and increases machining time.Wire EDM and work pieces requirements vary greatly, which can make selection of the correct wire an acute task. As a result, experimentation with wire types is necessary if optimum results are to be achieved. In fact, wire breakage poses a constant threat to WEDM productivity, but WEDM operators can avoid wire breakage and keep their operations running smoothly and efficiently with some knowledge about the wire-EDM process, wire rupture causes and the behavior of wire and work pieces materials when they are subject to the process.

The performance requirements for a wire electrode are summarized in Figure 7. The stable electric discharge leads to high-precision machining and higher cutting speed is achieved by high energy.

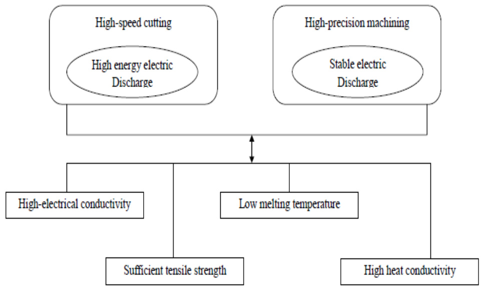

Fig 7:Wire Electrode Requirements

A variety of new materials and different types of wire are available to meet the desiredcharacteristics of wire electrode[31]. Recently, many different wire types have been developed with specific properties to give the user a variety of chances.

8.1 Wire Rupture Phenomenon

There are different factors leading to wire breakage such as high wire tension, thermal load, electrical discharge impact and poor flushing. When the developed stresses in wire are more that wire strength, the wire rupture will occur. The developed stresses in wire increase by changing in wire properties and characteristics, cross-section reduction and the increase in wire temperature.

High temperature, work piece varying thickness and process parameters influence the wire strength that affects the wire rupture. Wires rupture probability increases when the work piece thickness changes because the discharge energy changes rapidly. Also, the wire breakage increases when the height of work piece increases. Several researches were explored in this subject.

The excessive thermal load causes wire rupture because of huge heat production on wire electrode and increased wire temperature. The tensile strength of wire decreases when temperature increases. On the other word, the excessive thermal load that consists of internal

Joule heat reduces the wire tensile strength during machining. Several physical process parameters may increase the probability of wire rupture such asdischarge voltage, discharge current, duty factor, and coefficient of heat transfer, flushing, wire velocity and the electrical and thermal conductivity of the wire and work piece. If these parameters change, the temperature of wire will increase. Hence, the wire strength is influenced by maximum temperature and wire breakage happens. In fact, the wire rupture can be prevented by controlling above mentioned parameters.

V. Conclusion

WEDM is an advanced thermal machining process capable of accurately machining parts with complicated shapes, especially for the parts that are very difficult to be machined by traditional machining processes. 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. In addition, the development of newer and more exotic materials has challenged the viability of the WEDM process in the future manufacturing environment. Hence, continuous improvement needs to be made to the current WEDM traits in order to extend the machining capability and increase the machining productivity and efficiency.

More research can improve accuracy during WEDM machining specially in contour cutting.

In addition it seems that still there is lack of information about dry and near dry-WEDM. Moreover using optimization algorithms can develop the optimization process significantly while just genetic algorithm widely used for optimization of this process up to now and using other algorithm might enhance optimization.

Finally it seems that more researches can enhance the capabilities of WEDM process significantly to improve the machining productivity, accuracy and efficiency. Mathematical models have to be developed in order to reduce the inaccuracy caused by vibrational or static deflection of wire. To cope–up with the highly competitive and economical machining method, it is very much required that the WEDM process has to be improved enough in the today's modern manufacturing world.

REFERENCES

[1] E.C. Jameson, Description and development of electrical dis-charge machining (EDM), Electrical Discharge Machining, Society of Manufacturing Engineers, Dearbern, Michigan, 2001, pp. 16.

[2] G.F. Benedict, Electrical discharge machining (EDM), Non-Traditional Manufacturing Processes, Marcel Dekker, Inc, New York & Basel, 1987, pp. 231–232.

[3] SreenivasaRao M, Venkaiah N, Review on Wire-Cut EDM Process International Journal of Advanced Trends in Computer Science and Engineering, Vol.2, No.6, Pages : 12-17 (2013).

[4] Complete EDM handbook at http://www.reliableEDM.com.

[5] Sharanjit Singh*and ArvindBhardwaj "Review to EDM by Using Water and Powder-Mixed Dielectric Fluid " Journal of Minerals & Materials Characterization &

Engineering, Vol. 10, No.2, pp.199-230, 2011 jmmce.org.

[6] SreenivasaRao M, Venkaiah N "Review on Wire-Cut EDM Process" International Journal of Advanced Trends in Computer Science and Engineering, Vol.2, No.6, Pages: 12-17 (2013).

[7] MohdSyafiq Bin Dzulkapli "Study the Effect of Wire-EDM Parameters on Surface Roughness for Machining Die-Steel" Faculty of Manufacturing Engineering March 2008.

[8] Kozak, J., Rajukar, K. P. , Wang, S. Z. (1994) ''Material removal in WEDM of PCD blanks''Journal of Engineering for Industry. Vol. 116, No. 3, pp. 363-369.

[9] Manna, A, B. Bhattacharyya. (2006). Taguchi and Gauss elimination method: A dual response approach for parametric optimization of CNC wire cut EDM of PRAlSiCMMC. International Journal of AdvancedManufacturing Technology.28, pp. 67–75.

[10] Singh, H., Garg, R.(2009) ''Effects of process parameters on material removal rate in WEDM'', Journal of Achievements in Materials and Manufacturing Engineering Vol. 32:pp. 70-74.

[11] NithinAravind, R, S. Sowjanya, K.P. Yuvaraj, "Optimization of metal removal rate and surface roughness on Wire EDM using Taguchi method," presented in IEEE International Conference on Advances inEngineering Science and Management(ICAESM-2012), March 30,31,2012.

[12] DanialGhodsiyeh, AbolfazlGolshan, NavidHosseininezhad,MohammadhassanHashemzadeh and SinaGhodsiyeh, Optimising finishing process in WEDM of Titanium Alloy by Zinc Coated Brass Wire based on Response Surface Methodology, Indian Journal of technology, 5 (10) (2012), pp.3365-3377

[13] Danial Ghodsiyeh, Mohammadreja Askaripour Lahiji, Mahdi Ghanbari, Mostafa Rezazadeh Shirdar and AbolfazlGolshan, Optimizing material removal rate in WEDM titanium alloy using the Taguchi method, Research Journal of Applied Sciences, Engineering and Technology 4(17) (2012), pp. 3154-3161

[14] Anish Kumar, Vinod Kumar, Jatinder Kumar Parametric Effect on Wire Breakage Frequency and Surface Topography in WEDM of Pure Titanium in Journal of Mechanical Engineering and Technology Sept. 2013, Vol. 1 Iss. 2, PP. 51-56

[15] Scott Dan, SreedharBoyina, K.P. Rajurkar. (1991) " Analysis and optimization of parameter combinations in wire electrical discharge machining" International Journal of Production Research. 29:11, pp. 2189-2207.

[16] AshanAlikhan ,MuniraBt.Mohd Ali and NorhasmimahBt.MohdShaffiar. (2006). "Relationship of Surface Roughness with current and voltage during Wire EDM.Journal of applied Science" 6(10), pp. 2317-2320.

[17] Anish Kumar, Vinod Kumar, Jatinder Kumar Metallographic Analysis of Pure Titanium (Grade 2) Surface by Wire Electro Discharge Machining (WEDM) on Journal of Machinery Manufacturing and Automation Mar. 2013, Vol. 2 Iss. 1, PP. 1-5- 1.

[18] SauravDatta, SibaSankarMahapatra.(2010)"Modeling, simulation and parametric optimization of wire EDM process using response surface methodology coupled with grey-Taguchi technique" International Journal of Engineering, Science and Technology. Vol. 2, No. 5, pp. 162-183.

[19] Parashar V., A. Rehman, J.L. Bhagoria, (2012) ''Perfor- mance Measurement and Data Analysis of Material Remov- al Rate for Wire Cut Electro Discharge Machining Process'' Applied Mechanics and Materials Vols. 110-116. Pp. 1683-1690.

[20] Tosun ,N., Cogunb,C., Tosun,G. ,(2004). ''A study on kerf and material removal rate in wire electrical discharge ma- chining based on Taguchi method'', Journal of Materials Processing Technology Vol.152. pp: 316–322.

[21] G. Ugrasen, H.V. Ravindra, G.V. Naveen Prakash and D.L. Vinay"Comparative Study of Electrode Wear Estimation in Wire EDM using Multiple Regression Analysis and Group Method Data Handling Technique for EN-8 and EN-19 " Bonfring International Journal of Industrial Engineering and Management Science, Vol. 4, No. 2, May 2014.

[22] Tosun ,N., Cogunb,C., Tosun,G. ,(2004). ''A study on kerf and material removal rate in wire electrical discharge ma- chining based on Taguchi method'', Journal of Materials Processing Technology Vol.152. pp: 316–322.

[23] Ramakrishnan, R, L. Karunamoorthy. (2006) "Multi response optimization of wire EDM operations using robust design of experiments" International Journal of

Advanced Manufacturing Technology.29, pp. 105–112.

[24] J.C. Rebelo, A. Dias Morao, D. Kremer, J.L. Lebrun, “Influence of EDM pulse energy on the surface integrity of martensitic steel” J. Mater. Process. Technol. 84 (1998) 90–96.

[25] AmiteshGoswami, Jatinder Kumar “Investigation of surface integrity, material removal rate and wire wear ratio for WEDM of Nimonic 80A alloy using GRA and Taguchi method” Engineering Science and Technology, an International Journal xxx (2014) 1-12.

[26] Kuriakose, S., Shunmugam, M.S., (2005), ‘‘Multiobjective optimization of wire electro discharge machining process by Non-Dominated Sorting Genetic Algorithm”, Journal of Materials Processing Technology, Vol.170, pp.133–141.

[27] A.B. Puri, B. Bhattacharyya “An analysis and optimisation of the geometrical inaccuracy due to wire lag phenomenon in WEDM” International Journal of Machine Tools & Manufacture 43 (2003) 151–159.

[28] Wang, T., Zhang, X., Zhao, X., (2008) ‘‘Study on Dry WEDMed Surface Quality of Mould Steel’’ Key Engineer- ing Materials Vols. 375-376.pp 416-420.

[29] Furudate C., and Kunieda, M., (2001), ‘‘Fundamental study on dry-WEDM’’ Journal of the Japan Society for Precision Engineering.Vol 67, Issue 7, pp. 1180-1184.

[30] C.C. Kao, Jia Tao, Sangwon Lee, and Albert J. Shih “Dry Wire Electrical Discharge Machining Of Thin Workpiece”.

[31] DanialGhodsiyeh, AbolfazlGolshan, Jamal AzimiShirvanehdeh “Review on Current Research Trends in Wire Electrical Discharge Machining (WEDM)” Indian Journal of Science and Technology Vol: 6 Issue: 2 February 2013.