A Study on Performance Characteristics in WEDM

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Abstract- Wire-cut Electric discharge machining is a non conventional machining process. A lot of research work has been done on machining of different material in WEDM. There are many process parameters in WEDM such as pulse on time, pulse off, peak current, duty factor, servo reference voltage, wire tension, wire feed rate, dielectric pressure, table movements, work piece thickness, work piece material etc. which effect the performance parameters as surface finish, material removal rate, kerf width and electrode wear rate etc. This paper reviews the effect of process parameters on the performance characteristics such as surface integrity characteristics and roughness, material removal rate, kerf width and wire wear rate of WEDMed work piece and also can give an idea for the selection of the hard material such as nickel based super alloy, cobalt based super alloy, titanium based super alloy, iron super alloy on which rare amount of research work has been reported using WEDM.

Keywords: Wire electric discharge machining, SR, Kerf width, MRR, WWR, Super alloy.

I. INTRODUCTION

WEDM is a non-traditional machining process which is widely used in aerospace and automotive industries for machining hard materials with intricate shape [1]. Wire-cut electro discharge machining (WEDM) is the most extensively used cutting technique on the production floor for die-making, precision machining, the cutting/separation of sheet materials and for the manufacturing of prototypes [2]. WEDM cutting is characterized by high precision (≥ 0.01 mm), controlled and excellent surface quality of (Ra 0.15-2.8 µm), without creating internal stresses in the raw material. As wire never come in contact with work piece so no cutting force is required. Additionally, wire EDM is able to cut metals as thin as 0.004”or as thick as 300 mm. This is a special type of electric discharge machining that uses a small diameter wire as a cutting tool on the work. The wire is usually made of copper, brass or stratified copper, and diameters ranges between 0.05 to 0.3 mm [3]. Wire electrical discharge machining is a thermoelectric process which erodes material from the work piece by a series of discrete sparks created between the work piece and a wire electrode [4, 5]. Due to the very high thermal power concentration, the material removal mechanism is based on melting and evaporation [6]. A liquid dielectric medium is continuously passed in the narrow gap (0.025-0.05 mm) [3] provided between the wire and work piece [7, 8]. The basic condition for WEDM machining is work piece should be conductive.

The main goals of WEDM manufacturers and users are to achieve a better stability and higher productivity of the WEDM process, i.e. higher machining rate with desired accuracy and minimum surface damage. The main purpose of this paper is to study the performance characteristics of WEDM and give the idea for the selection of parameters. This study also can give an idea for selection of hard material to analyze the machining characteristics in WEDM which are using in aerospace industry.

II. WORKING PRINCIPLE

WEDM is a non-conventional thermo electric process in which work piece material is eroded due to continuous spark generation between the tool wire electrodes and work piece separated by steam of demonized water as dielectric fluid. Spark are created as wire electrodes under (-ve) charge is brought to within close proximity to a oppositely charged work piece in result electrical tension will be created due to strong electrical field formation between the electrodes and work piece. Due to this field action electron and free (+ ve) ion are accelerated, each with very high speed and rapidly form conductive channel. At this stage current start to flow and spark built up between electrodes and work piece resulting in infinity of collision between the particle and plasma zone is formed. Several hundred thousand of sparks (250000 sparks / sec) are produced as erosion takes place. These sparks are intensely hot and temperature reached at this zone approximates 8000-12000 ^{0}c or as high as 20000 ^{0}c. This high range of temperature results instantaneous melting of material around the periphery of wire electrodes and at the surface of work piece. Simultaneously due to vaporization of the electrodes and dielectric, gas bubbles are developed pressure increase regularly until it became very high. When the turn off period is start current is interrupted, sudden drop in temperature implodes the bubbles causing dynamic force to active which is the reasons of projecting this molten material out of the craters. These molten material particles are stripped

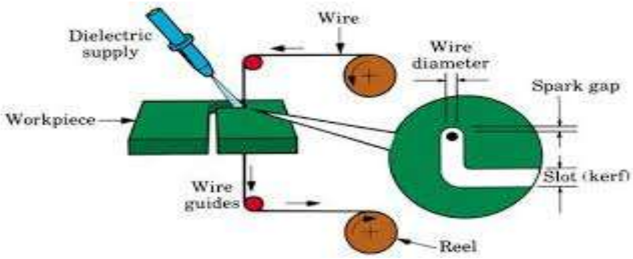

Fig. 1 Schematic Dig. of WEDM

from the gap by high pressure flushing of dielectric fluid. A sufficient amount of off time must be given to remove these particles from the gap for smoothly running of wire electrical discharge machining process.The gap between wire and work piece varies from 0.025 to 0.075 mm called as spark gape. If gap is too high, insulating liquid cannot be break through and there will be no spark created and if gap is too small, short circuit is easy to happen in result no spark discharging and process is stopped. So spark gape is closely maintained by state of the art servo control units that automatically maintain a constant gap between wire electrode and work piece.

III. Literature Review on Material Removal Rate

Material removal rates of wire electrical discharge machining can be calculated by using different formula which is following as:-

Material removal rate = $K_f \times T \times V_c \times \rho$
Material removal rate (mm^3) = $Vc \times b \times h$
Material removal rate = $Cs \times L$ (mm^2/min)
MRR (g/min) = wear wt. of workpiece/time of m/c
MRR = Mass before- Mass after/time × density

Where kf is the kerf width, t is the thickness of workpiece, Vc is the cutting rate, ρ is the density of worpiiece material, Cs is the cutting speed in mm/min and L is the thickness of the material in mm.

Lot of research work had been done by different researcher to increase the material removal rate of wire electrical discharge machining by using different approaches. Different work had been done by different researcher to increase the MRR of WEDM reviewed as:-

Matsuo and Oshima [9] investigated on the optimum carbide content and machining condition for WEDM of zirconia ceramics. It was found that the maximum machining rate can be obtained with about 28-30 vol% NbC or TiC content. There was no significant difference on the machining rates depending on offest although a slight decrease in machining rates with increase an offset was seen with higher pulse durations.

LOK and LEE [10] evolved the processing of two advanced (Sialon and AI203-TiC) ceramics using Wire-Cut Electrical Discharge Machining (EDM). It was found that the volumetric material removal rate (VMMR) for processing these ceramics materials were found to be very low as compared with cutting metals such as alloy steel SKD-II23.

Miller et al. [11] studied the effect of the spark cycle on material removal rate in wire electrical discharge machining of six advanced materials. Under the same EDM condition, the 316 stainless steel had higher MRR than the Fe-Cr-Al alloy. The carbon steel plate had relatively low MRR compared to the metal foams. This was likely due to better flushing conditions in the gap between the wire electrode and metal foam ligaments. Compared to grinding wheel II, wire EDM machining of grinding wheel I exhibits higher MRR under the same set of process parameters. The peak MRR for grinding wheel I and II was 27.0 and 23.5 mm3/min, respectively, comparable to that of the metal foams and higher than the carbon steel plate. The low electrical resistance and low melting temperature of the carbon–carbon material contribute to such high MRR. This corresponds to 231mm3/min MRR which was much higher than all the other materials investigated in this study.

Liao and Yub [12] studied on the specific discharge energy (SDE) defining as the real energy required to remove a unit volume of material was proposed. The material removal was increased but the efficiency of material removal was decreased with the increase of discharge on time.

Kozak et al. [13] studied on WEDM machining characteristics of silicon nitride Si3N4 composite one with 40% TiN and second with 37.5% TiN with a conductivity of 0.01s/cm has been investigated for different clamping positions. It was observed that actual MRR depends on the individual machining geometry and relative position of wire electrode with respect to clamping. A significant increase in MRR was observed due to silver coating.

Tosun et al. [14] studied on the effect and optimization of machining parameters on the kerf (cutting width) and material removal rate (MRR) in wire electrical discharge machining operations. The experimental studies were conducted under varying pulse duration, open circuit voltage, wire speed and dielectric flushing pressure. Open circuit voltage for controlling the MRR was about six times more important than the second ranking factor (pulse duration). Wire speed and dielectric flushing pressure were less effective factors.

Hewidy et al. [15] presented mathematical models for correlating the inter-relationships of various WEDM machining parameters of Inconel 601 material such as: peak current, duty factor, wire tension and water pressure on the metal removal rate, wear ratio and surface roughness. It was noted that an increase in the peak current leads to the increase of the volumetric metal removal rate. This increase was, however diminished after 7A. Increase in peak current higher over a certain limit, leads to arcing which decreases discharge number and the machining efficiency, and subsequently decreases in VMRR. The increasing of the water pressure decreases the tendency for arcing, and increases the metal removal rate.

Ozdemir and Ozek [16] carried out the investigation on machinbility of nodular cast iron by WEDM. The results of the experiment shown that machining voltage, current, and wire speed have an important effect on the high machining efficiency for nodular cast iron.

Mahapatra and Patnaik [17] studied on optimization of wire electrical discharge machining process parameters using taguchi method and it was found that factors like discharge current, pulse duration, and dielectric flow rate and their interactions have been found to play a significant role in rough cutting operations for maximizations of MRR.

Kung and Chiang [18] developed the mathematical models using RSM for the machinbility evaluation of aluminum oxide-based ceramic material (Al_2O_3 + TiC) in the WEDM. The results of sensitivity analysis showed that the pulse on time and the duty factor had significant effects on the value of MRR. The discharge energy increased with the increase in the peak current, resulting in the removal of more molten metal. When the peak current increased, the value of MRR was improved and the SR simultaneously increased. The wire speed did not have significant influence on MRR.

Lauwers et al. [19] investigated the Wire-EDM behaviour of various newly developed electro-conductive ZrO_2 ceramic matrix composites. The influence of the type and grain size of WC, TiC and TiCN from micro sized to nano sized grains of the second phase on the EDM material removal rate was experimentally studied. A higher cutting speed was obtained for the micro based ZrO_2–WC ceramic composites.

Haddada and Tehrani [20] investigated the effects of machining parameters on material removal rate (MRR) in cylindrical wire electrical discharge turning (CWEDT) process. It was noted that design factors, power and voltage should be fixed as high as possible and the pulse off time and spindle rotational speed factors, should be fixed as low as possible for increase the MRR.

Menzies and Koshy [21] studied on assessment of abrasion-assisted material removal in wire EDM. Experimental work has been validated the feasibility of an order of magnitude increase in material removal rates, by replacing the conventional wire with a fixed abrasive wire, which introduces abrasion in the working gap.

Janardhan and Samuel [22] given an insight into the wire electro discharge turning (WEDT) process, by analyzing the effect of machining parameters on material removal rate (MRR), using the pulse train data acquired at the spark gap. It was observed that the rotation of the workpiece has significant influence on the type of the discharges occurring at the spark gap. Preliminary experiments conducted to compare the WEDM and WEDT processes disclosed that MRR was less in WEDT and the number of arcs and arc regions were more in WEDT. MRR increased with decrease in pulse off time in both WEDT and WEDM.

An optimization work has been done by Huang and Liao. [23] to find out significant parameters using grey relational analysis and statically method and found that that the table feed rate had a significant influence on the metal removal rate out of table feed rate, pulse-on time, pulse-off time, wire tension, wire velocity and fluid pressure.

XIONG et al. [24] carried out the experimental investigation of WEDM of boron carbide engineering ceramics to increase the machining efficiency. It was observed that increase in pulse width and peak current increase the material removal rate which decreases firstly and increases later with pulse interval increasing.

Jangra et al. [25] proposed the graph theoretic approach (GTA) to evaluate the machinbility of tungsten carbide composite. It was noted that in case of work material low cobalt concentration and small grain size yields higher MRR while in machine tool, sub-factor combination of peak current 110A, pulse-on time 120μs, pulse-off time 40μs and servo voltage 40V produces maximum MRR. In case of cutting conditions, high conductivity and high flow rate of dielectric fluid results in high MRR.

Kuruvila and Ravindra [26] investigated the parametric influence and optimum process parameters of Wire-EDM of die steel (HDS) having the thickness of 40 mm using Taguchi's technique and Genetic algorithm. High MRR had been attained by adopting high spark intensity parameters, high bed-speed and medium flush rate.

Aliasa et al. [27] unveiled the influence of machine feed rate in wedm of titanium Ti-6Al-4V with constant current (6A) using brass wire. It was noted that with the increasing of machine feed rate, the MRR will increases simultaneously.

This result showed the same pattern with Somashekar et al. [28]. It was noticed that MRR increases with increase in feed rate. Theoretically, material erosion was influenced by the spark energy. As feed rate increase; MRR also increases till it reaches optimum. The MRR decreased with the decreasing of machine feed rate.

Ikram et al. [29] studied the effect of eight control factors on material removal rate (MRR), surface roughness and kerf in wire electrical discharge machining (WEDM) process for tool steel D2. The experimentation was performed under different cutting conditions of wire feed velocity, dielectric pressure, pulse on-time, pulse off-time, open voltage, wire tension and servo voltage by varying the material thickness. Taguchi's L18 orthogonal array was employed for experimental design. For MRR, the significant factors were pulse on-time, open voltage and servo voltage. In order to get the maximum material removal rate (MRR), the servo voltage and wire tension should be kept as 40volt, TW(g) 800, material thickness (M) 25.4mm, pulse off-time 25μ-sec and dielectric pressure 8Kg/cm2 while open voltage 110Volt, pulse on-time 5μ-sec and wire feed velocity at level 15mm/s.

Bobbili et al. [30] 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). It was noted that MRR increases when Ton was increased and decreases when Toff and SV were increased. MRR was directly proportional to the power supplied during this Ton. MRR decreased when SV was enhanced due to widening of discharge gap. The effects of wire feed, flushing pressure, and wire tension on MRR were found not to be significant.

An investigation has been made to combine ultrasonic vibration and wire electrical discharge turning by Mohammadia et al. [31]. Experimental results shown that wire vibration induced by ultrasonic action had a significant effect on material removal rate and evaluated the influence of four design factors: power, pulse off time, spindle rotational speed and ultrasonic vibration over material removal rate.

Rajyalakshmi and Ramaiah [32] investigated on wire cut electrical discharge machining (WEDM) of Inconel 825 to find out the significant factors that affect the material removal rates. It was shown that pulse on time is the major influencing factor (contributing 50.18% to performance measures) followed by pulse off time (contributing 14.19%), wire tension (contributing 11.79%), wire feed (contributing 4.29%), corner servo voltage (contributing 2.14%), spark gap voltage (contributing 2.06%), servo voltage (contributing 1.19%) and flushing pressure (contributing 0.87%).

IV. Literature Review on Kerf Width

The kerfs was measured using the Mitutoyo tools makers' microscope (x100), is expressed as sum of the wire diameter and twice of wire-work piece gap. The kerfs value is the average of five measurements made from the work piece with 20-mm increments along the cut length.

Tosun et al. [14] investigated the effect and optimization of machining parameters on the kerfs (cutting width) and material removal rate (MRR) in wire electrical discharge machining (WEDM) operations. The kerfs is calculated by summing up the wire diameter (ranges 0.05–0.4 mm) to 2 × "wire–work piece gap distance. Based on ANOVA method, the highly effective parameters on both the kerfs and the MRR were found as open circuit voltage and pulse duration whereas wire speed and dielectric flushing pressure were less effective factors. It was shown that open circuit voltage was about three times more important than the second ranking factor (pulse duration) for controlling the kerfs.

Optimization work has been done to find out the influence of parameters on performance parameters in rough cutting operation in WEDM using taguchi and genetic algorithms by Mahapatra and Patnaik [17] and found that factor wire speed was the most important factor among all factors whereas factor dielectric flow rates has least effect on kerfs width.

A modeling work on analysis of kerfs width in micro-WEDM has been done by Shichun et al. [33] in order to study the kerfs variations in micro-WEDM, the mathematical model of wire lateral vibration in machining process was established and its analytical solution was obtained. Evaluation of the spark distribution and wire vibration in wire EDM by high-speed observation had been done by Okada et al. [34] and give that the kerfs width significantly depends on the amplitude of wire vibration during machining.

Somashekar et al. [28] studied on material removal characteristics of micro-slot (kerfs) geometry in μ-WEDM on aluminum. Overcut increased with increase in capacitance. With increase in capacitance, large energy has been dissipated, which produces stronger sparks resulting in higher material erosion. As feed rate increases, there was less chance of dissipating heat to the surrounding hence more heat was generated at spark gap leading to higher material removal and higher overcut. With further increase in feed rate and capacitance, overcut starts decreasing. At higher levels of capacitance and voltage, spark energy per pulse was greater. It was found that overcut was high at higher levels of capacitance and feed rates.

A modeling and optimization work had been done for evaluation the effect of input parameters on kerfs width and material removal rates by Datta and Mahapatra [35] using RSM and grey relational analysis method and found that pulse duration was the most significant factor.

Huang and liao [23] applied the grey theory for optimization the parameters of WEDM. It was found that the table feed rate had a significant influence on the metal removal rate, whilst the gap width and surface roughness were mainly influenced by pulse on time.

Aliasa et al. [27] uncovered the influence of three different machine feed rates which were 2mm/min, 4mm/min and 6mm/min with constant current (6A) on kerfs width using WEDM of Titanium Ti-6Al-4V and shown that as the machine feed rate increases, the kerfs width decreases.

K. P. Somashekar et al. [28] does not recommend the usage of high feed rate since it caused higher inaccuracies in the kerfs width.

Nihat Tosun et al. [14] proved that open circuit voltage and pulse duration were highly effective parameters on both the kerfs and the MRR. It was found that open circuit voltage was about three times more important than the second ranking factor (pulse duration) for controlling the kerfs.

Mukherjee et al. [36] applied six most popular population-based non-traditional optimization algorithms, i.e. genetic algorithm, particle swarm optimization, sheep flock algorithm, ant colony optimization, artificial bee colony and biogeography-based optimization for single and multi-objective optimization of two WEDM processes to find out the optimal value of parameters for minimum kerfs width. The performance of these algorithms was compared and it was observed that biogeography-based optimization algorithm outperforms the others.

Shandilya et al. [37] evaluated the optimal process parameters during machining of SiCp/6061 Al metal matrix composite (MMC) by wire electrical discharge machining (WEDM) using response surface methodology (RSM) and ANOVA. It was proved that voltage and wire feed rate were highly significant parameters and pulse-off time was less significant. Pulse-on time has insignificant effect on kerfs.

Ikram et al. [29] investigated the effect and optimization of eight control factors on material removal rate (MRR), surface roughness and kerf in wire electrical discharge machining (WEDM) process for tool steel D2 and proved that pulse on-time, wire tension and open voltage were the significant factors for kerf width. Material thickness does not have significant effect in either case.

V. Literature Review on Wire Breakage or Wire Wear Rate

Dekeyser et al. [38] worked on thermal model to investigate the wire rupture phenomenon for improving performance in EDM wire cutting and proved that the thermal load on the wire seems to be a governing factor determining wire rupture. A thermal model to examine the effect of space concentration of successive discharges had been developed. The model reveals a relatively large variation of the temperature along the wire axis and proved that time and space concentration of discharges can cause wire rupture. The most important parameter governing the wire temperature appears to be the convective heat transfer coefficient h. Appropriate flushing conditions were important to avoid wire rupture. The influence of the thermal conductivity was negligible compared with the heat transfer by convection. The wire velocity influenced the temperature distribution however practical values were too small to significantly reduce the temperature.

Snoeys et al. [2] proposed an all-round solution to a number of problems, related to the wire-EDM process.The solution was based on the development of a knowledge-based system. It enables process monitoring and control, making use of a reliable rupture probability parameter.

Rajurkar and Wang [39] developed the new control strategy to monitor and control the sparking frequency at a constant level for avoiding wire rupture and improving productivity and proved that wire breakage phenomena is correlated with the sparking frequency.

Again Rajurkar and Wang [4] worked on WEDM sparking frequency monitor to detect the thermal load for on-line control to prevent the wire from rupture. The wire rupture phenomena were also analyzed with a thermal model. Liao et al. [40] worked to control the discharging frequency for the prevention of wire breakage by appropriate adjusting the table feed and pulse on time.

Yan and Liao [41] worked on adaptive control of the WEDM process using the fuzzy control strategy. The proportion of abnormal sparks (abnormal ratio) and the sparking frequency has been employed to monitor and evaluate the gap condition of the wire electrical discharge machining (WEDM) process on-line. The relationship was investigated between these two sensing parameters and wire breaking phenomenon. The abnormal ratio and the sparking frequency not only employed to monitor and evaluate the gap condition, they could also be used as control parameters for adaptive control of WEDM. A multivariable and three-region fuzzy controller was proposed to solve the ACO problems for WEDM.

Experimental results demonstrated that stable, optimal and high-speed machining can be achieved, while at the same time wire rupture can be prevented by employing the developed sparking frequency monitoring and control system. Y.F. Luo [42] carried out the investigation on rupture failure and mechanical strength of the electrode wire used in wire EDM instead of the spark characteristics or the temperature distribution. Material yielding and fracture were the causes for wire rupture, whilst a temperature increase aggravates the failure processes. A temperature rise reduced the work-hardening effect and thus causes early yielding rupture of the wire. In general, wire tension and spark pressure were the two major causes for wire rupture. A plane-stress model has been used to describe the stress distribution, and the solutions were given as Airy's functions. The yield strength was analyzed to reveal the influence of the loads and other parameters on wire yielding.

Ranganath et al. [43] worked on experimental and theoretical study of wire-EDM process. Wire erosion rate, which leads to wire failure was analyzed using experimental results obtained by machining mild steel, OHN steel and HCHCr steel work materials using bare brass and zinc coated brass wires. It was found that Wire failure occurs in wire-EDM process as a result of severity in wire wear rate, which was a function of discharge current and discharge time. For the same material removal rate, the wire wear rate was observed to be lower with zinc coated brass wire when compared to bare brass wire resulting in higher wire erosion rate.

Tosun and Cogun [44] investigated experimentally on wire wear rates during electrical discharge machining of AISI 4140 steel of thickness 10 mm. it has been found that the increasing pulse duration and open circuit voltage increase the WWR whereas the increasing wire speed will decrease it. Both wire speed and dielectric pressure were less effective on WWR.

Saha et al [45] proved that simple FEM modeling and optimization technique would make it easier to understand and prevent the wire breakage phenomena in WEDM. The results of the modeling and optimization showed that non uniform heating was the most important variable affecting the temperature and thermal strains and responsible for wire breakage. The modeling may lead to the development of a smart electro-discharge machining system with a sensor and feedback control to increase the cutting speed and minimize breakage.

Lautre and Manna [46] discussed about causes of wire failure or wear and remedies to avoid wire breakage of CNC-WEDM based on binary relational analysis and expert system. Higher value of pulse on time, peak current and no load voltage might be the cause of wire wear. Insufficient water column might be cause of wire break. The pressure of air in spark gap might be cause of wire breakage. Lower the pulse off time setting, larger the number of discharges in a given time resulting in increase of sparking efficiency. As a result cutting rate was increased and may cause of wire breakage. Higher setting value of water pressure with low wire tension may deflect the wire and it could be cause of wire breakage. Again use of very low dielectric conductivity during machining and the wire metal deposits on the work piece that might be cause of wire breakage.

Cheng et al. [47] determined experimentally that the convective coefficient inside the kerfs should be increased as high as possible in order to avoid the frequent wire’s breakage.

Cabanes et al. [48] proposed a methodology that guarantees an early detection of instability that can be used to avoid the detrimental effects associated to both unstable machining and wire breakage. In order to quantify the trend to instability of a given machining situation, a set of indicators related to discharge energy, ignition delay time and peak current has been defined. Wire breakage risk associated to each situation was evaluated comparing the evolution of those indicators with some previously defined threshold values.

Hana et al. [49] studied on thermo-mechanical analysis and optimal tension control of micro wire electrode to avoid wire breakage. Based on the coupled thermo-mechanical analysis, both the three-dimensional temperature and the stress distribution in the micro wire were determined. Optical tension control strategy has been developed which was effective on the improvement of the machining accuracy with the prevention of wire breakage for the micro WEDM.

Huang and Liao [23] studied on wire-EDM maintenance and fault-diagnosis expert system integrated with an artificial neural network to avoid wire breaking and unsatisfactory accuracy may still occur due to improper operations or inappropriate machine maintenance.

An optimization work has been done by Rao and Krishna [50] in the WEDM based on PCA and Taguchi's S/N ratio analysis to find out the optimal value of parameters to avoid the wire wear rates.

Nourbakhsha et al. [51] carried out the experimentally investigation on wire electro-discharge machining (WEDM) of titanium alloy and found that pulse width and time between two pulses were the most crucial machining parameters that affect wire breakage. On the other hand, wire mechanical tension (Wb) and injection pressure (INJ) were effective parameters in reduction of wire breakage when pulse width and time between two pulses were small and large enough respectively. Wire tension reduction and increase in injection pressure can decrease wire rupture possibility while machining. Experiments disclosed the frequency of wire rupture in machining of titanium was more than machining of D2 steel.

VI. Conclusions

a. MRR increase with increase in table feed, pulse width, peak current, open circuit voltage and capacitance.
b. MRR increase with decrease in pulse off time and spark gap.
c. Depth of craters depends upon discharge energy and peak current.
d. Pulses on time, wire tension, open circuit voltage are significant parameters which affect the Kerfs width.
e. High value of pulse on time, peak current and no load voltage are the main cause of wire wear rate.
f. New non-traditional technique of optimization can be used for optimization of parameter such as PSO, TELBO, ABC, ACO, GAS, ANN etc.
g. New advance super alloy of Nickel, Cobalt and Titanium such as Udimet L-605, Nimonic 105, Udimet D-979, Udimet 188, Nimonic 115, Titanium 6-2-4-2S etc can be used for analyzing the machining characteristic of these super alloy using WEDM.

VII. Future Work Summaries

a. Surface integrity and roughness will be analyse during machining of Nimonic-105 and Udimet-L605 using WEDM.
b. Material removal rate, Kerf Width and Dimensional Deviation will be found during machining of Nimonic-105 and Udimet-L605 using WEDM.

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