A Literature Review on Surface Characterization of Electrical Discharge Machining

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Abstract-*In recent years, materials with unique metallurgical properties such as tool steel, tungsten carbide and its composites, titanium based alloy, nickel based alloy, stainless steel, hardened steel and other super alloys have been developed to meet the demand of extreme applications. While these materials are harder, tougher, less heat sensitive and/or more resistant to corrosion and fatigue; therefore these are difficult to machine. Since these materials possess excellent mechanical properties which can be useful in many important applications; the machining of same can open up opportunities of utilizing them comprehensively. EDM is one of the non-traditional machining processes which can be effectively employed to machine such materials..*

The key attention of scientists and researchers in the field of EDM is to explore the new ideas in order to improve the machining efficiency of the process. Many researches has been carried out to achieve the maximize MRR with good surface characteristics and lower TWR. This paper shows a literature study of the work relevant to the subject matter.

Keywords: *Electrical Discharge Machining, Surface Roughness, Surface Characteristics*

Introduction

EDM is one of the non-traditional machining processes which may be effectively employed to machine the materials which are recognized as difficult-to-machine. It has been widely employed to produce dies and molds, finished parts for aerospace and automotive industry and surgical components. During the EDM operation, the tool is moved towards the work-piece until the gap is small enough so that the impressed voltage is great enough to ionize the dielectric fluid in between the tool and the work-piece. As a result, short duration discharges are generated in the dielectric gap between tool and work-piece. The material is removed with the erosive effect of electrical discharges from the surface of the tool and the work-piece. EDM does not involve the direct contact between the tool and the work-piece;

thereby it can eliminate mechanical stresses and vibration problems in the course of machining. Materials with high index of hardness can be cut as long as the material can conduct electricity. A number of researchers have investigated to improve the machining performance of EDM in terms of MRR, TWR and surface integrity. So far as, the surface integrity of the machined work-piece is concerned, there are tremendous chances to improve it by incorporating the different mechanism. Surface integrity of the machined work-piece attributes the physical and mechanical properties of the material. It includes work hardness, surface roughness, surface structure, residual stresses, metallurgical transformations and micro structural changes which affect the operational aspect of the work piece material. Therefore, the surface integrity plays an important role in improving the physical and mechanical properties of the work-piece material.

Teimouri and Baseri (2012) investigated the effect of rotational electrode and external magnetic field on MRR and surface roughness of X210Cr12 cold work steel by using copper as electrode material. Experimental trials were divided into three discharge energy regimes as low (I_{av} 2.5A, T_{on} 50µs, T_{off} 25µs), middle (I_{av} 9A, T_{on} 100µs, T_{off} 75µs) and high (I_{av} 21A, T_{on} 200µs, T_{off} 150µs). The rotational speed of the electrode was varied as 0, 200, 500, 800, and 1000 RPM. Two magnetic poles with magnetic intensity (0.38 and 1.2 Tesla) were incorporated. In order to correlate the input parameters and output values, two mathematical models were also developed by the authors to predict the MRR and SR. Experimental results indicated that a rotary tool electrode applied a centrifugal force and whirl condition which could remove the debris from the machining gap and resulted in better flushing condition and hence the improved machining performance. Surface roughness was decreased by increasing the rotational speed due to better gap cleaning. Magnetic field could expel the debris from machining gap effectively. Consequently, the debris could not get re- melted and welded on the work-piece surface, thereby improved the surface quality.

Chattopadhyay and Verma (2007) reported the significance of input parameters affecting SR during rotary EDM with polarity reversed magnetic field. The materials were copper as electrode and EN-8 steel as work-piece. Taguchi method was adopted to construct the matrix of different levels of controllable factors. The respective parameters for level 1, 2 and 3 were: peak current 9, 18 and 36A;

pulse-on time 50, 100 and 200µs; off time 50, 100 and 200µs; magnetic field 123, 370

and 617 gauss; polarity reversal time 1 sec; electrode RPM 16, 32 and 48; and the flushing pressure 0.12, 0.25 and 0.35 bar. Experimental results confirmed that the effect of rotary EDM with polarity reversal magnetic field produced better surface finish and higher MRR, as compared to the machining without magnetic field. Variation of discharge-on time had significant effect on SR but little effect on MRR. Variation of induced magnetic field had significant effect on SR and MRR. The decrease in electrode rotation and induced magnetic field resulted in the higher MRR and better SR.

Teimouri and Baseri (2012) studied TWR and overcut in EDM with rotary tool and rotary magnetic field exactly around the machining gap. The materials were SPK cold work steel for work-piece and copper for electrode. Three energy regimes low, middle and high were taken. The rotational speed of the electrode was varied as 0, 200, 500, 800 and 1000 RPM. Two magnetic poles with magnetic intensity (0.38 and 1.2 Tesla) were employed. It was concluded that EWR increased by increasing the discharge energy, but, at high-energy regime, the paralytic carbon which was produced by deposition of dielectric fluid, acted as protective layer for electrode and therefore reduced the EWR. By increasing the rotational speed of electrode and applying the magnetic field, the EWR and overcut increased due to removal of debris from the machining gap effectively which removed the protective layer on the tip of electrode. When process was switched from low-energy regime to high, the overcut was increased due to increasing the size of discharge crater.

Lin et al. (2009) performed the optimization of machining parameters in magnetic force assisted EDM based on Taguchi method. Machining was accomplished on SKD 61 steel with straight polarity electrolytic copper in presence of commercial grade kerosene oil as dielectric fluid. The machining parameters were taken as: no-load voltage 120V, servo reference voltage 20V, auxiliary current with high voltage 0.4A, peak current 5, 10, 15 and 20A and pulse duration of 20, 70, 150, 350 and 460 µs with a duty factor of 50%. The machining characteristics such as MRR, EWR and surface roughness were adopted to assess the effects of different machining parameters. The optimal combination of machining parameters to maximize MRR of MFEDM were: negative electrode polarity, 20A peak current, 0.8A auxiliary current with high voltage, 460 µs pulse duration, 120V no-load voltage and 10V servo reference voltage. The optimal combination level of machining parameters with minimum SR were: positive machining polarity, 5A peak current, 1.2A auxiliary current with high voltage, 460µs pulse duration, 200V no-load voltage and 10V servo reference voltage. The S/N ratio correlated with MRR and SR for the optimal combination level of machining parameters was 9.76 and 12.48 dB higher than those obtained at the initial experimental conditions.

Shabgard et al. (2011) investigated the recast layer thickness, heat affected zone and surface roughness of AISI H13 tool steel. The electrode material was a forged commercial pure copper. Machining for 15 minutes was carried out at five pulse current as well as four pulse-on time settings. An ax-symmetric three- dimensional model for temperature distribution in the EDM process was developed using the finite element method to assess the surface integrity of H13. Both numerical and experimental results reported the increase in the white layer thickness and depth of HAZ with the increase in pulse-on time. The increase in pulse current resulted in a slight decrease in white layer thickness and depth of HAZ. The increase in both pulse- on time and pulse current resulted in a coarser surface roughness.

Zhang et al. (2011) investigated that the formation of recast layer using different dielectrics. The work was performed to acquire an overall knowledge of recast layer of EDM machined surface using water-in-oil (W/O) emulsion, kerosene and de-ionized water as dielectric. SEM, XRD, EDS and micro- hardness analysis were performed to compare the results in terms of recast layer. It was reported that recast layer created in W/O emulsion was bearing more surface roughness, thickness and micro-hardness compared with that of created in kerosene and de-ionized water. Both carbides and oxides were present in the recast layer formed in W/O emulsion, whereas only carbides were detected in the recast layer formed in kerosene. Because of higher super saturation of gases in the molten material, the recast layer formed in W/O emulsion had more micro-voids than that found in kerosene and de-ionized water.

Ahmet and Cayda (2004) investigated the machining characteristics and surface morphology of AISI D5 tool steel in wire-EDM. The machining parameters like pulse duration, wire speed, dielectric flushing pressure, open circuit voltage were considered. Some specimens were quenched and tempered and the other were cut in the size of 8x8 mm^2. It was concluded that the recast layer thickness increased with increase in pulse energy. The crack density in recast layer was directly proportional to the pulse duration and open circuit voltage. The penetration of cracks into the HAZ was observed depending upon the pulse energy. Surface roughness increased with increase in open circuit voltage and pulse duration. The influence of wire speed and dielectric flushing pressure on the surface roughness was not observed to be significant.

Mannan et al. (2013) studied the surface characterization of EDM machined surface of HSS. The test conditions were Cu electrode with negative polarity, kerosene as dielectric, side flushing, pulse current settings of 2, 5, 10, 15 and 20 A,
pulse-on time of 50, 200, 400, 800 and 1600 µs with duty factor of 0.5 and 85V open circuit voltage. The morphology of machined surfaces was examined with a metallurgical microscope and SEM/EDS analysis. It was observed that at low pulse current and low pulse-on time, the craters got little depth and the density of global appendages and pockmarks were low, whereas at higher pulse current and pulse-on time, the craters were deeper and global appendages were most evident.

Khan et al. (2013) investigated the effect of external magnetic field on surface roughness of SUS 304 stainless steel. Pulse current 2.5 and 6.5 A; duty factor 40, 46, 50 and 56%; pulse-on time 7 and 10.5 µs; and pulse-off time 10.5 and 8µs were taken as machining parameters. The external magnetic field was applied by fixing the six permanent magnets each of size 30x13x6mm around the electrode. It was concluded that by applying the external magnetic field to the conventional EDM at different peak currents, the surface roughness was measured as minimum. With further increase in the current and duty factor, the surface roughness increased.

Guu (2005) investigated the surface morphology of AISI D2 steel. The work- piece was heated up to 1030°C at a heating rate of 20°C/min for one hour and quenched, followed by tempering at 520°C for two hours. Kerosene as dielectric; copper electrode with negative polarity; pulse current 0.5, 1, 1.5A; pulse-on duration

3.2 and 6.4 µs; pulse-off duration 60 µs were taken as machining parameters. The machined specimens were studied by the atomic force microscopy. It was concluded that higher discharge energy lead to the poor surface characteristics. The atomic forcemicroscopy could be successfully applied for 3D image with a nanometer scale and evaluated the depth of the micro-cracks on the EDM surface.

Prihandana et al. (2011) investigated the effect of low-frequency vibrations on work-piece during the EDM process. The machining was accomplished by using copper as electrode and stainless steel (SS304) as work-piece material. The low- frequency vibrations were generated by using the shaker which was driven by a power amplifier. The experimental conditions were: discharge current 9A, no-load voltage 90V, electrode polarity positive, vibration amplitude 0.75, 1.00 µm and vibration frequency as 0, 300, 400 and 600 Hz. It was investigated that the application of low- frequency vibrations created a more frequent shortest distance between the electrode and work-piece. The MRR obtained with low vibrations as higher than the machining without vibrations, especially at a frequency of 600 Hz and amplitude of 0.75 µm. The resultant surface roughness and EWR measured without vibrations obtained higher than with low-frequency vibrations.

Srivastava and Pandey (2012) investigated the effect of process parameters on the performance of EDM with ultrasonic assisted cryogenically cooled electrode (UACEDM). In the experimental work, M2 grade high speed steel was machined with copper tool. The ultrasonic assisted EDM setup was composed of an ultrasonic vibration generator that was capable of producing ultrasonic waves with a maximum output power of 1200W and frequency of 20 kHz. The machining time was kept at 25 min. and kerosene was used as the dielectric medium. Four controllable variables were included as: discharge current from 3 to 7A, pulse-on time from 100 to 500µs, duty cycle from 0.24 to 0.88 and gap voltage from 50 to 70V respectively. It was concluded that the electrode wear ratio and surface roughness in UACEDM process significantly lowered and MRR observed at par with that of conventional EDM. The machined surfaces were abundance of cracks and the density of cracks increased with the discharge current.

Lee and Li (2001) studied the effect of EDM parameters on the machining characteristics of tungsten carbide. The machining parameters were studied as electrode material, electrode polarity, open circuit voltage, peak current, pulse duration, pulse interval and flushing pressure. Graphite, copper and copper tungsten were used as the electrode material. It was concluded that MRR increased with increasing the peak current. Highest MRR was achieved by using graphite electrode followed by copper tungsten and then copper. The negative electrode polarity resulted in higher MRR, lower relative wear ratio and better surface finish. The increase in the open circuit voltage reported a decrease in MRR whereas the relative wear ratio and surface roughness of machined surface increased. It was also investigated that with the increase in pulse duration, the MRR, relative wear ratio and surface roughness increased, while the increase in pulse interval reported a decrease in MRR. With the increase in flushing pressure, the MRR decreased gradually and became constant at high value of flushing pressure.

Jahan et al. (2009) investigated to achieve the fine surface finish in micro- EDM of tungsten carbide MG18 grade. The die-sinking micro-EDM at a depth of 5µm was conducted on 60x12.5x0.1mm work-pieces in presence of commercial total EDM3 oil. The elect rode material used was W, Cu-W and Ag-W of 500µm diameter with negative polarity. Other experimental conditions included as: discharge voltage 60, 80, 100, 120 and 140V and capacitance of 47 and 10pF. It was concluded that nano-surface could be produced by minimizing the discharge energy per pulse by means of low gap voltage and capacitance. Ag-W was the best choice for finishing of micro-EDM of WC of the three electrodes with higher MRR. However, for faster micro-EDM of WC, Cu-W performed well as it exhibited the highest MRR and relatively lower EWR. Ag-W provided better electrical and thermal properties compared to the other two electrodes.

Singh et al. (2011) studied the effect of composition of powder mixed dielectric fluid on the performance of EDM. The machining tests were conducted on ASTM A681 D3 die steel work-pieces using copper electrode with straight polarity. Aluminum oxide (Al_2O_3) powder with 100-300 mesh particle size and titanium carbide (TiC) powder with 325 average particle size were mixed into the DEF-92 EDM oil. The concentration of powder was varied from zero to 10 g/lit in steps of 2 g/lit by keeping the other machining parameters constant. The results revealed that the addition of an appropriate amount of powder into the dielectric fluid imparted a remarkable improvement in MRR and reduction in TWR. It was also observed that the machining became unstable at excessive powder concentrations due to occurrence of short circuits. MRR observed higher with TiC and TWR as higher with Al_2O_3 powder as an additive.

It is concluded from the literature study that research work accomplished in the field of EDM was bearing the common objective i.e., to enhance the machining performance of EDM and to develop techniques to machine new materials with better working conditions.

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