541 Electrical Discharge Machining with Ultrasonic Assistance

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Abstract: In ultrasonic assisted EDM, the role of the acoustic wave and cavitation phenomena is to improve the flushing and material removal from the surface craters. The main objective of this investigation is to study the effects of ultrasonic assistance on electrical discharge machining process performance while machining materials such as titanium alloy, tungsten carbide and stainless steel. The effect of current, pulse-on time, and pulse frequency on material removal rate and surface roughness has been studied. It has been found that the optimal improvement takes place at the resonance of discharge and ultrasonic frequencies.

Key words: EDM, Ultrasonic vibrations, Material removal rate, Surface roughness, Titanium Alloy, Tungsten Carbide

1. INTRODUCTION

Manufacturing industry continues to face challenges in machining advanced difficult-to-machine materials (tough super alloys, ceramics, and composites), meeting stringent design requirements (high precision, complex shapes, and high surface quality), and reducing production costs. Many traditional (such as high speed cutting, hard machining and dry cutting) and nontraditional (such as electrical discharge and electro-chemical) machining processes are being employed to address these challenges. Additionally, hybrid machining processes which combine two or more processes (or some of their unique features) are also being employed to solve these problems [1]. These hybrid machining processes use the various combinations of mechanical, thermal, and electro-chemical/chemical actions to exploit the inherent benefits of constituent processes or their working principle and avoid or reduce their individual disadvantages or improve the performance.

One of the hybrid machining processes, called ultrasonic-assisted electro discharge machining (USEDM) integrates the vibratory action of the tool electrode at ultrasonic frequency with electro-erosion of EDM. EDM process removes material in a closely controlled manner from electrically conductive materials immersed in a dielectric liquid. A minute volume of material is removed from the workpiece and the tool electrodes by the thermal action of each discharge. When a voltage (about 80V) is applied

between the tool and the workpiece, an electric field is generated along the path of least resistance between the tool and workpiece. This continues until the electric field is broken and current flow is initiated. At this stage, the electrons and the ions migrate towards the anode and cathode respectively at a high current density, forming a plasma column, initiating the melting and vaporization of the workpiece. When the voltage is no longer applied to the gap, current stops flowing and the molten metal is ejected from the workpiece and a crater is formed on the workpiece as well as on the tool electrode. A portion of molten but not ejected material redeposits on the surface at the end of the cycle. For an effective electric discharge during the subsequent cycle, the narrow interelectrode gap must be thoroughly cleaned by the flushing dielectric fluid. A small portion of conductive debris remaining in the gap increases the electrical conductivity of the dielectric and therefore, harmful arcing takes place resulting in unstable machining, lower productivity and surface damage. Hence, it is essential to seek means to generate favorable conditions at the gap in a very short time (in μsec) between the two cycles.

Application of ultrasonic vibrations to EDM tool electrode is one of the methods to improve the gap conditions and therefore, machinability. The process conditions scheme (PCS) of USEDMD is shown in Figure 1. The diagram shows the mechanism of interaction, energy transfer carrier, and working media as three sides of a triangle. This diagram is

applicable to most of the traditional and nontraditional processes. For USED, the interaction mechanisms are ultrasonic and electric discharge; energy carriers are ion, electron and plasma; and the working media is dielectric (hydrocarbon oil in most cases).

Although the first combined ultrasonic and electroerosion machine was produced in 1959 by an Italian firm [2], the process is becoming more important now due its application potential to advanced materials. Limited research reported in the literature indicates that this combined machining process improves the machinability of materials like ceramics and steel [3,4]. It has been observed that the vibrating movement of the tool electrode/workpiece improves the slurry

were also observed [5]. It is recognized that the role of the acoustic wave and cavitation phenomena is to improve the flushing and material removal from the surface crater.

In order to enhance the knowledge base of the USED process from the view point of its interaction with advanced materials (such as Titanium and Tungsten alloys) and the effect of EDM parameters (such as pulse current and pulse times and polarity) on process performance, a comprehensive experimental study is required. This paper reports recent experimental results and analysis conducted on a specially modified commercial level die-sinking EDM for USED investigations. The second section describes the experimental set up and experimental conditions. The experimental results and their analysis are given in the third section. The last section summarizes this paper.

Fig. 1 The PCS scheme for USED

circulation, by pushing the debris away and sucking fresh dielectric, providing ideal conditions for effective discharges, resulting in higher removal rate. Also the alternate motion of the tool electrode/workpiece with a high frequency due to ultrasonic motion creates more turbulence and cavitation, which results in a better ejection of the molten metal from craters [5]. In steel, with ultrasonic assistance, EDM process has shown an increase of 10% to 400% in material removal rate when compared to EDM process, where as in ceramics the increase is about 200% [6]. However, in both the cases, application of vibrations did not have any affect on surface roughness, accuracy, residual stress and micro hardness [5]. In most of the previous works, abrasive slurry was used as a dielectric fluid [3,4]. Some beneficial actions like thinner heat affected layer and smaller micro cracks

2. EXPERIMENTAL SET-UP

Fig. 2 Experimental setup of USED

An ultrasonic assembly was clamped (using a fixture) on a Mitsubishi M35K die-sinking NC EDM (Figure 2). These ultrasonic generator, which has a power of 1 KW and a frequency of 20 KHz, produces voltage pulses. These voltage pulses are transformed into mechanical vibrations by a piezo electric transducer to produce an ultrasonic wave. A booster and horn further amplifies the ultrasonic wave. In ultrasonic assisted EDM process, the horn acts as a tool-electrode or as a workpiece-electrode depending upon the polarity. The horn with a negative polarity acts as a workpiece for

Titanium and as a tool for Tungsten carbide. Dielectric oil (US1) flushes the gap between the tool and workpiece.

Investigations were mainly focused on Titanium alloy and Tungsten Carbide. Titanium alloy (Ti-6Al-4V) is an alpha + beta alloy and Tungsten Carbide (73% W, 27% Co) are generally regarded as mechanically difficult to machine materials. Stainless Steel (316 L) was used as a base material for comparing the output parameters. Tool electrodes of graphite and copper with a diameter of 38.1 mm were used for Titanium and Tungsten carbide & Steel respectively. Tables 1, 2 and 3 shows input parameters for various materials. For Steel three levels of parameters (lower, medium and high values) correspond to finishing, semi-finishing and rough machining stages.

One of the main objectives of the present investigation is to study the relationship between EDM pulse frequency and ultrasonic frequency. The experiments were designed at different EDM pulse frequency values ranging from 10 KHz to 40 KHz, therefore the pulse on-time and duty factor values were chosen accordingly. Based on the results of the machining experiments with Stainless Steel, the levels of the parameters were reduced for experiments with Titanium alloy and Tungsten Carbide. Material removal rate and surface roughness were the output parameters.

Material Removal Rate (MRR) was measured by the difference of weight of the workpiece before and after machining using a Sartorius E-12005 precision scale having a maximum capacity of 1210 g and a precision of 0.001 mg. The surface roughness was measured by a Surtronic 3+ skid and stylus type profilometer having an accuracy of 0.01 μm from Rank Taylor Hobson Co.

Table 1 Input parameters for Stainless Steel.

Input Parameters	
Pulse Current (A)	12, 25, 51
Pulse On-Time (μsec)	12.8, 25.6, 51.2
Duty Factor	0.25, 0.5, 0.8

Table 2 Input parameters for Tungsten Carbide.

Input Parameters	
Pulse Current (A)	12, 25
Pulse On-Time (μsec)	12.8, 25.6
Duty Factor	0.25, 0.5

Table 3 Input parameters for Titanium alloy.

Input Parameters	
Pulse Current (A)	12, 25
Pulse On-Time (μsec)	16
Duty Factor	0.25, 0.5

3. RESULTS AND ANALYSIS

Fig. 3 Variation of MRR with Pulse Current (On-Time = 25.6 μsec and Off-Time = 76.8 μsec ; Material: Stainless Steel)

The effect of current on material removal rate (MRR) for Steel is shown in the Figure 3. It is found that MRR is significantly higher, ranging from 10% to 350% in ultrasonic assisted EDM process. Also material removal rate increases linearly with the current. The high frequency action of the working end of the electrode pumps the debris away and sucks the fresh dielectric in the interelectrode gap, thus increasing the discharge efficiency, which results in a higher material removal rate. This confirms the conclusion

related to improved sparking efficiency and average pulse energy reported in [7].

Fig. 4 Variation of MRR with On-Time(Off-Time values are 25.6 μ sec (5,6), 76.8 μ sec (3,4), and 153.6 μ sec (1,2); Pulse Current = 12 A (1,2), 25 A (3,4), 51 A (5,6); Material: Stainless Steel)

Figure 4, shows the effect of pulse on-time and off-time on MRR. In EDM, the generated crater size (material removal) increases with current and pulse on-time. However, for the same pulse on-time, the material removal rate decreases with increase in pulse off-time. From the Figure 4, in EDM process, it can be observed that MRR decreases for some values of pulse on-time, but this is not repeated in US assisted EDM process because of the improved conditions for removing molten material from the crater.

The effect of ultrasonic assistance becomes clear, when the coefficient of ultrasonic efficiency K is used. In Figures 5 and 6, coefficient K is defined as the ratio between material removal rate of US assisted EDM process to the material removal rate of EDM process. Figures 5 and 6 show that effect of ultrasonic assistance is significantly higher at lower current values. EDM finishing operations are time-consuming because of the necessity to use low current values (for better finish). Therefore, this observation about a higher beneficial effect of ultrasonic assistance at lower current is very significant for EDM finishing stage. These experimental results also show that EDM pulse frequency is the most significant factor in improving material removal rate. Figures 5 and 6 indicate that when the EDM pulse frequency matches the ultrasonic frequency, the value of K is maximum. It

confirms the Lhiaubet's conclusion [8], that synchronization of electrical discharge frequency and pulse pressure field generated by ultrasonic frequency leads to an increase in material removal rate; thereby increasing the machining efficiency.

Fig. 5 Relationship between Coefficient K and Pulse Frequency (Material: Stainless Steel)

Fig. 6 Relationship between Current and K (1:On-Time = 51.2 μ sec, Off-Time = 153.6 μ sec; 2:On-Time = 25.6 μ sec, Off-Time = 76.8 μ sec; 3:On-Time = 12.8 μ sec, Off-Time = 38.4 μ sec; Material: Stainless Steel)

It seems that there is no significant change in surface roughness between US assisted EDM process and EDM process (Figure 7). The surface roughness initially increases with current and beyond 25 A almost remains same. The ultrasonic assistance improves the material removal rate due to higher discharge efficiency. The improved gap conditions due to ultrasonic assistance also lead to uniform distribution of discharges in space and time. Therefore, the surface roughness remains the same.

Fig. 7 Variation of Surface roughness with Current (Material: Stainless Steel)

Figure 8 show that material removal rate is higher in ultrasonic assisted EDM process, by a range of 70% to 450% in Titanium alloy and 130 % to 400% in Tungsten carbide. Similar to steel, MRR increases linearly with the current.

Fig. 8 Variation of Current with Material removal rate (Titanium alloy: On-Time = 16 μ sec, Off-Time = 35.2 μ sec), (Tungsten Carbide: On-Time = 12.5 μ sec, Off-Time = 38.4 μ sec).

Figures 9 and 10 show that the value of K is low for lower current values whereas as in Steel it is higher for lower current values, when the pulse frequency matches the ultrasonic frequency. In Steel the K value is in the range of 2 to 20 (Figure 5) where as for Titanium alloy and Tungsten Carbide it is between 1.5 to 6. One of the reasons for lower K value in Tungsten Carbide is difficulty in removing Tungsten Carbide particles from Cobalt matrix, which has a higher melting temperature. Even though ultrasonic assistance helps in removing molten

material from the crater, the Tungsten Carbide phase is not fully melted, thus decreasing the effect of ultrasonic vibrations and therefore lower K values are obtained. In Titanium alloy, the formation of oxide layer on the surface results in lower K values.

Fig. 9 Relationship between K and Frequency (Material: Titanium alloy)

Fig. 10 Relationship between K and Frequency (Material: Tungsten Carbide)

Figure 11 shows that there is no significant change in surface roughness between EDM and USED process. The slight increase in surface roughness in US assisted EDM process may be due to the removal of more molten material, because of ultrasonic vibrations, which leads to deeper craters.

Usually electrical discharge machining of Tungsten Carbide results in a high tool wear rate. Figure 12 show that the application of ultrasonic vibrations slightly increases the tool wear rate by a range of 10% to 20%, when compared to EDM, As USED improves the MRR from the workpiece electrode a similar phenomena, though at a lower scale, also takes

place at the tool electrode. Therefore, more material is removed from the tool surface.

Fig. 11 Variation of Surface roughness with Current (Material: Titanium alloy and Tungsten Carbide)

Fig. 12 Variation of TWR with Pulse Frequency (Pulse Current = 25 A; Material: Tungsten Carbide)

4. SUMMARY

The ultrasonic vibrations of tool/workpiece electrode have been used as a means to improve the EDM process performance in machining difficult-to-cut materials. The paper reports machinability results of ultrasonic assisted EDM (USEDMM) of Titanium and Tungsten alloys using a specially designed and assembled USEDMM system. It was found that ultrasonic assistance significantly increases the EDM performance. It was also observed that the optimal improvement is obtained at the resonance of ultrasonic and pulse frequencies.

5. ACKNOWLEDGEMENTS

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