Comparative Experimental Study of Drilling Micro-EDM Without and With Ultrasonic Vibration on Inconel 718 Superalloy

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Abstract

Inconel 718 superalloy is extremely difficult-to-machine material due to its improved mechanical properties, such as work hardening nature and poor thermal conductivity. It is widely used in aerospace industries for making the engine parts, such as aircraft engine compressor disks, turbine blades and disks, casing, bearing rings etc. The high precise cooling holes are needed on these components because they work in an extreme temperature around 700 ºC. The drilling of cooling holes in this material by the conventional drilling processes is much difficult because it has high chemical affinity with many tool materials, high welding action of chips at the rake face, high strength at high temperature and work hardening nature. In consideration of all these problems, authors used self-developed drilling ultrasonic assisted micro-EDM (Drilling-UA-MEDM) setup to create microholes in this material. A comparative study regarding material removal rate (MRR), tool wear rate (TWR) and hole taper (T_a) has been studied due to Drilling-MEDM with and without application of ultrasonic vibration (UV). Comparative results show that the application of ultrasonic vibration in Drilling-MEDM increases MRR and decreases TWR and T_a. SEM observation of created microholes confirms that the assistance of ultrasonic vibration gives the microholes of good quality as well as good accuracy.

Keywords: Drilling ultrasonic assisted micro-EDM; Hole taper; Inconel 718 superalloy; Material removal rate; Tool wear rate.

1. INTRODUCTION

Nickel-based superalloys are very demanding in aerospace industries due to improved mechanical properties such as high strength, high toughness, strong corrosion resistance, excellent thermal fatigue properties and good thermal stability [1]. Inconel 718 is one of the important superalloy of this group and mostly used in aerospace, petroleum and nuclear energy applications. It has major application in aerospace and 50 % weight of a jet engine is made by using it [2]. These typical applications need high precision products in very close tolerances. Conventional machining methods are not capable to machine these alloys in acceptable surface finish and accurate geometry due to improved mechanical properties. When very small hole is produced by these machining methods, drill bit is easily broken and machining efficiency is become very low because of low heat conduction efficiency of these alloys [3].

Electrical discharge machining is suitable to machine any electrically conductive material because it does not make direct contact between the tool and workpiece and does not depend on mechanical properties of workpiece material such as young modulus of elasticity and hardness. It is only depend on electrical conductivity of the material. Basically, it is a thermoelectric process in which heat energy of a spark is used to remove material from the workpiece dipped in the dielectric which is used to flush out the debris particles [3, 4].

Hole size created by micro-EDM is in the micro range and the gap between the tool electrode and workpiece is narrow. Therefore, the material which is removed from workpiece and tool in the form of debris is started to collect at bottom side of hole as hole progresses which created arcing short circuiting etc. or even stop the continuation of machining. In the case of arcing, tool wears rapidly [5]. To overcome all these problems many researchers tried to develop alternative methods to assist the flushing conditions in micro-EDM, such as magnetic field assisted Micro-EDM, external electrical field assisted micro-EDM, carbon nanofibre assisted micro-EDM, vibration assisted micro-EDM, vibration and magnetic field assisted micro-EDM [6]. Among these, vibration assistance in micro-EDM is one of the important flushing methods. In micro-EDM vibration can be applied as low frequency vibration and ultrasonic vibration [7]. Tool rotation is another method which was used in EDM to improve the flushing conditions [8, 9].

In case of rotating tool, circulation of dielectric in inter electrode gap (IEG) increases by centrifugal and agitation effect generated by tool. Soni et al. [8] compared the performances of drilling (rotating tool) EDM to sinking (stationary tool) EDM. They have reported the enhancement in the material removal rate in case of rotating tool electrode due to enhancement in flushing as well as sparking efficiency. Yadav and Yadava [9] studied the effect of rotation of copper's tool electrode during making holes in nickel alloy workpiece. They have reported the improvement in circularity and surface finish of hole with increase in tool electrode RPM.

In recent years many researches are trying to introduce ultrasonic vibration during the machining of small hole by micro-EDM. Ultrasonic vibration provides high frequency alternating pressure variation in the inter electrode gap which improves the performance, effectiveness and stability of micro EDM. Huang et al. [10] have given ultrasonic vibration to tool electrode for fabricating the microholes in Nitinol. They found that the assistance of ultrasonic vibration increase the machining efficiency without significantly increase in the electrode wear due to strong stirring effect caused by ultrasonic vibration. Wansheng et al. [11] developed an ultrasonic vibration assisted micro-EDM setup and analyzed the effect of ultrasonic vibration on the EDM process during the machining of deep and small hole on titanium alloy. They found that holes

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with a diameter less than 0.2 mm and depth/diameter ratio more than 15 can be drilled with the help of developed setup. Hung et al. [12] used cylindrical and helical electrodes for machining of a high nickel alloy workpiece and ultrasonic vibration is provided to workpiece. They found that micro-EDM combined with ultrasonic vibration substantially reduces the EDM gap, taper and machining time for deep micro hole drilling. They also used helical electrode with ultrasonic vibration finishing to improve the surface quality and taper.

Gao et al. [13] provided ultrasonic vibration to workpiece in micro-EDM process and found that the efficiency and the aspect ratio of the hole are increased by the application of ultrasonic vibration in micro-EDM. Tong et al. [14] studied the effect of assisting workpiece vibration on the EDM performance of micro-structures and found that higher frequency vibration helps to acquire higher machining efficiency, and good machining effects can be obtained when the vibration amplitude is set nearly equal to the discharge gap. Mahardika et al. [15] have reported that the application of vibration on tool electrode in machining of polycrystalline diamond has significant effect up to 66.48% in increasing material removal rate without increasing surface roughness and tool electrode wear.

In this research, authors used a novel approach in which rotation is given to tool electrode and vibration is given to the workpiece. A comparative study regarding material removal rate (MRR), tool wear rate (TWR) and hole taper (T_a) has been studied on Inconel 718 superalloy without and with the application of ultrasonic vibration at constant and different tool RPM.

2. EXPERIMENTATION

Experiments have been performed on an innovative self-developed setup of Drilling-UA-MEDM with and without the ultrasonic vibration. It has developed with the help of two major subsystems: micro tool holding and rotating attachment and ultrasonic vibration unit.

2.1 Experimental Setup

Micro-EDM setup has been designed and developed by authors taking consideration of high precision micro tool holding arrangement, and tool rotation during micro-EDM machining. Two perpendicular aluminium alloy plates of adequate thickness are rigidly clamped each other for withstanding the weight and vibratory loads during the rotation of spindle, one of which is used for mounting DC motor and spindle housing assembly and second is used for installing the complete setup on the ram of EDM machine. A direct current (DC) motor of 0.24 HP and 3000 RPM is used for transmitting the rotation to the spindle. The shaft of DC motor is coupled with the spindle which is mounted on two high precision angular contact ball bearings in the spindle housing. These bearings share the axial loads arising during the rotation of spindle due to the servo movement. Micro-tool holder which can hold the tool of 200 µm diameter to 3 mm diameter is fixed by taper shank to the spindle The variable speed is given to the tool with the help of variac (0.24 HP DC drive). The variac has been calibrated using a digital tachometer (model: DT2001B) Electronic Automation Private Ltd (EAPL), India make. The complete setup has been installed on the ram of the ZNC 320 EDM machine by replacing the actual tool holder of ZNC EDM machine supplied by Ecoline Auto System Private Limited, New Delhi, India as shown in Fig. (1).

Two piezoelectric transducers of lead zirconate titanate of 50 mm × 20 mm × 6 mm are used for forming Bolt-clamped Langevin - type (sandwich) transducer. Both transducers are tightly clamped with the help of bolt to taper horn of 51.5 mm larger diameter and 21 mm smaller diameter. A workpiece holding arrangement is designed for holding the workpiece and tightly screwed on the horn. A frequency generator of resonance frequency 25 kHz ± 2% which has the provision to give the power supply within the range 0 to 250 W is designed and give the power supply to the transducers as shown in Fig. 1. The input given to the frequency generator is of 230 V 50 Hz AC which is converted to 25 kHz AC and finally it is converted to 25 kHz mechanical vibration with the help of transducers. A frequency counter and wattmeter are employed to show the reading of the frequency and power given to the transducers. The complete assembled vibration unit is clamped to the table of EDM machine as shown in Fig.1.

2.2 Experiment Materials

In this experimental study Inconel 718 superalloy is used as workpiece material. Workpiece specimens were prepared by wire-cut EDM machine of 25 mm × 20 mm × 1.05 mm size. Chemical composition of Inconel 718 workpiece is shown in Table 1. The material of tool electrode used in this study is tungsten carbide (WC) of 500 µm diameter. The composition of tool electrode is 94 % tungsten carbide (WC) and 6 % Cobalt (Co).

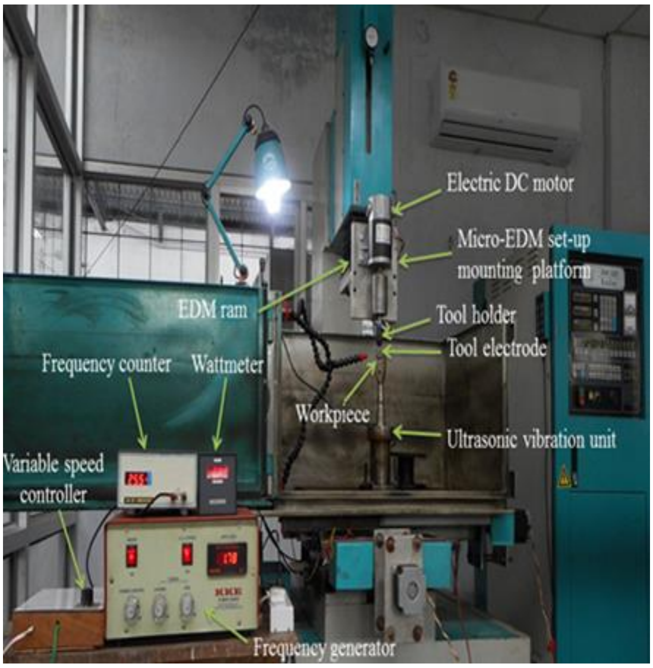

Fig. 1. Photographic view of developed Drilling ultrasonic assisted Micro-EDM setup

2.3 Experimental procedure

In the present experimentation comparative study between hole drilling micro-EDM without and with the application of ultrasonic vibration has been performed. The same setup can be successfully run for both of processes. The drilling micro-EDM (Drilling-MEDM) with ultrasonic vibration is also called Drilling-UA-MEDM and when the ultrasonic vibration is switched-off, it is called pure drilling micro-EDM. Vibration is produced by varying the ultrasonic power within the range of 0 W to 250 W at a fixed ultrasonic frequency of 25 kHz. As the ultrasonic power increases, the amplitude of vibration proportionally increases. MRR, TWR and T_a have been selected as response parameters. The input parameters and their values used in experimentation are shown in Table 2. In the present experiments 0 W ultrasonic power (U_P) is used for without ultrasonic vibration (UV) and 165 W for with ultrasonic vibration. Throughout the experimentations, 6 µs pulse on-time, and 10 µs pulse off-time were used as constant input parameters. MRR and TWR were represented in mm^3/min and T_a in degree. Weight before and after drilling was measured by micro-balance (make: CAE India Pvt. Ltd) to calculate the MRR and TWR. Top and bottom diameters was measured by optical measuring microscope (make: Sipcon Instrumentation Industries, India) to calculate the hole taper (T_a)

Table 1 Composition of Inconel 718

Element	Percentages
Nickel	50 – 55
Chromium	17 – 21
Copper	≤0.30
Niobium	4.75 – 5.50
Molybdenum	2.80 – 3.30
Titanium	0.65 – 1.15
Aluminum	0.20 – 0.80
Carbon	≤0.08
Boron	≤0.006
Silicon	≤0.35
Sulphur	≤0.015
Phosphorus	≤0.015
Cobalt	≤1.00
Manganese	≤0.35
Iron	Balance

Table 2 Machining conditions for comparative experimental study

	Drilling-MEDM	
Parameters	Without UV	With UV
Gap current (A)	2, 3, 4	2, 3, 4
Pulse on-time (µs)	6	6
Pulse off-time (µs)	10	10
Tool RPM	300, 600, 900	300, 600, 900
Ultrasonic power (W)	0	165
Workpiece material	Inconel 718	Inconel 718
Tool material	WC	WC
Dielectric	EDM oil	EDM oil
Polarity	Reverse	Reverse

3. RESULTS AND DISSCUSSION

3.1 Comparative study of MRR

The comparison of MRR of Drilling-MEDM process without and with the ultrasonic vibration (UV) is shown in Fig. 2 for different values of gap current and tool RPM. It is shown in Fig. 2 that MRR in case of UV assistance is higher for each case in comparison to Without UV. This is due to the better flushing of debris from the machining gap by the ultrasonic vibration. The ultrasonic vibration provides a high frequency alternating pressure variation in the inter electrode gap (IEG) which gives the pumping action. This high frequency pumping action improves the dielectric circulation by pushing the debris away and sucking fresh dielectric into the machining gap. Due to this short circuiting and probability of inactive pulses decreases so the discharge efficiency and erosion rate increases. The amplitude of piezoelectric transducers are controlled by ultrasonic power. Thus, as ultrasonic power increases amplitude of vibration also increases, resulting higher MRR.

It is shown in Fig. 2 (a) that the MRR with UV is 68.75 % 88.93 % and 66.38 % more than that without UV at 2, 3 and 4 A gap current respectively at 300 RPM of tool. At 3 A gap current, the percentage increment in MRR is found higher at the UV assistance. This is due to high material removal at 3 A gap current due to high discharge energy and better flushing of debris from IEG by ultrasonic vibration. But at 4 A current, all the molten material is not come out by flushing provided by UV due to very high material removal.

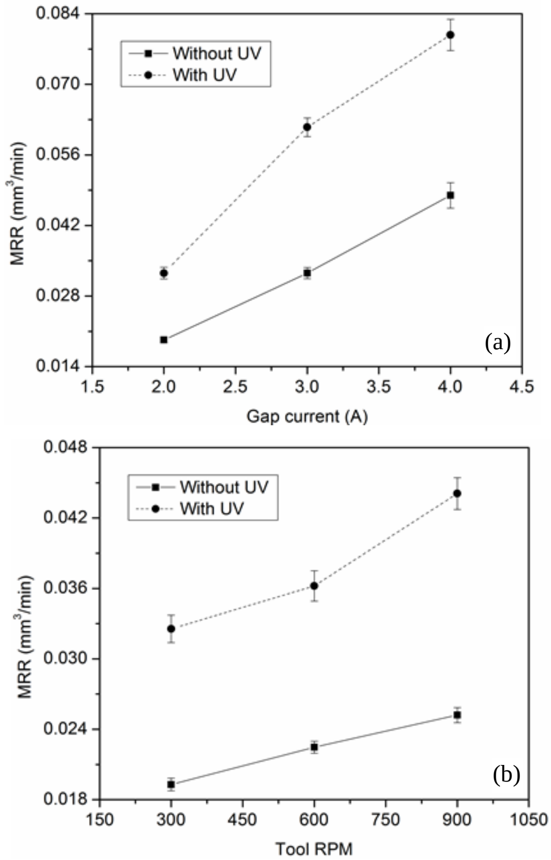

Fig. 2. Comparison of MRR of Drilling-MEDM without and with UV at different gap current and tool RPM

It is illustrated in Fig. 2 (b) that the MRR with UV is 68.75 % 61.19 % and 74.87 % more than that without UV at 300, 600 and 900 RPM of tool respectively at 2 A gap current. At 900 RPM of tool, the percentage increment in MRR is found higher at the UV assistance. In 600 to 900 range of tool RPM, MRR increase rapidly in case of UV due to increase in flushing and sparking efficiency by UV. Without the UV, MRR is slowdown in high RPM range due to decrease in sparking efficiency at high RPM. Thus, high percent increment in MRR is found at 900 RPM of tool.

3.2 Comparative study of TWR

Figure 3 show that TWR in case of Drilling-MEDM with UV is low in comparison to without UV. In Drilling-MEDM without UV, material is removed particle by particle from tool as well as workpiece, called debris, starts to sink to the bottom of IEG due to micro size hole. When the concentration of these particle exceed to a critical value, arcing is started between the tool and debris. During this arcing, tool bears high material wear. When the UV is applied, it increases pumping action to the workpiece which reduces the short-circuiting, arcing, and inactive pulses and improves the dielectric flushing. Thus, low TWR is found in case of UV assistance.

It is observed in Fig. 3 (a) that the TWR with UV is 14.06 %, 12.43 % and 23.86 % less than that without UV at 2 A, 3 A and 4 A gap current respectively at 300 RPM of tool. High percent

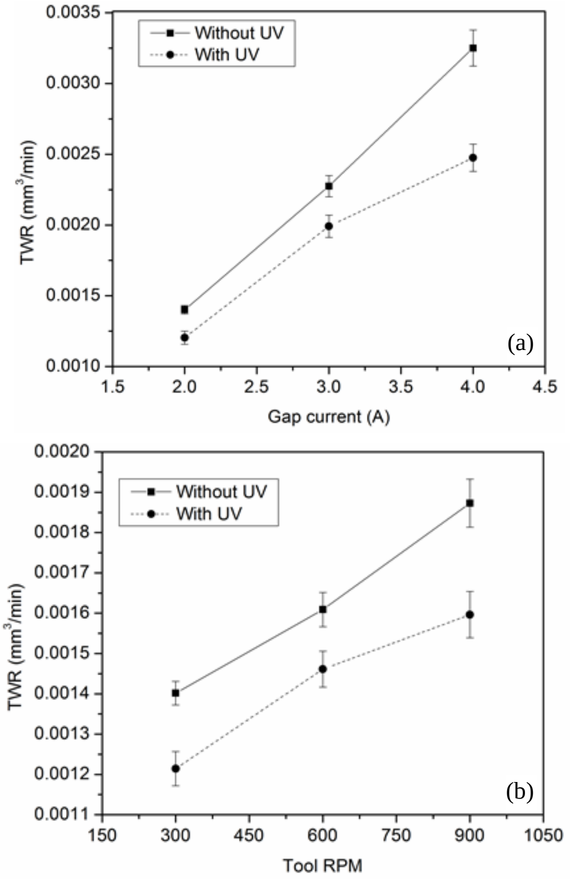

Fig. 3. Comparison of TWR of Drilling-MEDM without and with UV at different gap current and tool RPM

decrement in TWR is found at 4 A gap current. At high current, more material is removed from both tool as well as workpiece. Therefore, the collection of debris at bottom side of hole increases which increase the arcing phenomena. But, this is reduced by UV. Thus, high decrement is at 4 A gap current.

It is illustrated in Fig. 3 (b) that The TWR with UV is 14.06 % 9.19 % and 14.75 % less than that without UV at 300, 600 and 900 RPM of tool respectively at 2 A gap current. At 900 RPM of tool, the percentage decrement in TWR is found higher. At very high tool RPM, the debris are started to rotated with dielectric. But with the UV, better ejection is provided to rotating debris from IEG and decrement in secondary discharges.

3.3 Comparative study of hole taper (T_a)

The comparison of T_a of Drilling-MEDM process without and with the UV is shown in Fig. 4. T_a is due to the tool wear as well as secondary discharges (the discharge between tool and hole wall due to debris particles). UV assistance provides the better flushing of debris from the machining zone. It reduces secondary discharges, resulting low T_a in case of UV assistance.

It is shown in Fig. 4 (a) that the T_a with UV is 32.82 %, 27.89 % and 27.64 % less than that without UV at 2, 3 and 4 A gap current respectively at 300 RPM of tool. At low gag current (2 A), arcing and secondary discharges are already small in comparison to 3 and 4 A. UV also decreases them significantly. Therefore, high decrement is in T_a at low value of gap current.

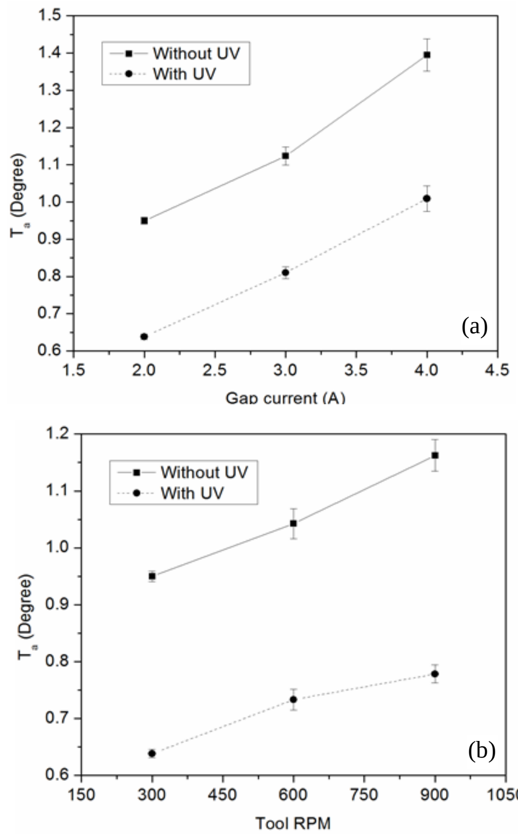

Fig. 4. Comparison of T_a of Drilling-MEDM without and with UV at different gap current and tool RPM

Figure 4 (b) shows that the T_a with UV is 32.82 %, 29.66 % and 33.06 % less than that without UV at 300, 600 and 900 RPM of tool respectively at 2 A gap current. At 900 RPM of tool, the percentage decrement in T_a is found higher at the UV assistance due to decrease in secondary discharge and arcing phenomena, and better ejection of rotating debris from IEG at high RPM by UV.

3.4 SEM micrographs comparison

Micrographs are taken at hole entry using scanning electron microscope (SEM) at 200X magnification as shown in Fig. 5. In pure Drilling-MEDM (when no UV applied), the material is recast at hole periphery as well edge of hole and large size of debris globules has been observed at the edge of hole. But, when UV is applied in Drilling-MEDM, they are almost diminished. Surface quality and circularity are also improved by the application of UV. This is due to pumping action provided by UV. Due to this, the material which is melted by the EDM action during the on-time, instantaneously remove from the IEG and very less molten material is re-solidified on the machined surface.

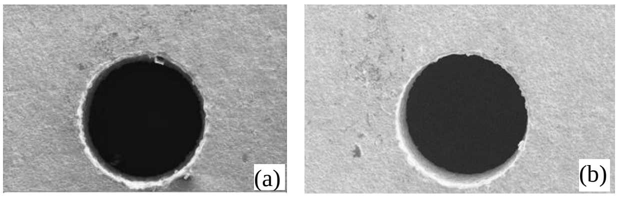

Fig. 5. SEM micrographs comparisons: (a) without UV (U_P = 0 W) and (b) with UV (U_P = 165 W) at I_g = 3 A, T_{on}= 6 μs, T_{off} = 10 μs and N=300 RPM

4 CONCLUSIONS

In the present experimental study, Drilling-MEDM setup has been run without and with ultrasonic vibration. The performance has been compared in the form of MRR, TWR and T_a. The following conclusions have been drawn from this study:

1. At moderate gap current (3 A) and high tool RPM (900), a high increment in MRR is found with assistance of UV in Drilling-MEDM. A significant increment of 88.93 % in MRR is found at 3 A gap current with UV assistance due to sufficient ejection of debris from IEG by the pumping action of vibrating workpiece.

2. Lower TWR is found in case of UV assistance in comparison to without UV. A significant decrement of 23.86 % is observed at high gap current (4 A) value due to reduction in arcing phenomena due to UV.

3. Hole taper (T_a) is also found lower with the application of UV in Drilling-MEDM. It decreases significantly by 33.06 % at high tool RPM (900 RPM) due to better ejection of rotating debris.

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