Experimental Investigation for Difficult-to-Machine Materials Using Micro-WEDM

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Abstract
Effect of various process parameters during machining in Wire Electric Machine (WEDM) has been reported by several researchers. Micro wire Electric Discharge Machine (μ-WEDM) operates on the same principle as that of EDM/WEDM, however the effect of process parameters viz. voltage, capacitance, wire tension, wire feed in context with micro-WEDM is yet to be established. Micro-WEDM differs in terms of energy supplied per pulse, wire size and axes resolutions. In this study two conventionally difficult-to-machine materials- Tungsten carbide and Titanium are selected for experimentation. The effect of voltage, capacitance, wire tension and wire feed on Material removal rate (MRR) and kerf width is investigated. An increase in voltage and/ or capacitance results in increase in discharge energy and which results into higher MRR. For better machining accuracy higher values of wire tension and wire feed are preferred.

Keywords
μ-WEDM, Kerf Width, MRR, Non-conventional Machining

I. Introduction

Some materials have high hardness, high strength, brittleness, toughness or low thermal conductivity. These characteristics make these materials difficult-to-machine conventionally. These materials, if machined by conventional methods, produce excessive tool wear, heat and cutting forces as well as inferior surface quality. This paper investigates Micro- Wire Electric Discharge machining of Tungsten carbide and Titanium using μ-WEDM. Micro-Wire Electric Discharge Machine has been used for accurate machining of small components which are difficult to manufacture using other conventional methods. In this process, there is no physical contact between the tool and the workpiece and hence is independent of the physical properties of workpiece material [1]. The process can only be employed for machining of electrically conductive workpieces. The material is removed in the form of craters by series of discrete sparks. The sparks occur between an electrode (tool) and a work piece in the presence of a dielectric fluid. A wire of less than 100μm diameter is used as tool in μ-WEDM.The wire travels along controlled path and can process complex 2-D and 3-D profiles. These features make μ-WEDM efficient, cost effective and popular [1-4]. Present work focuses on Micro-Wire Electric discharge machining of Titanium and Tungsten carbide. The effect of process parameters such as voltage, capacitance, wire tension and wire feed on output parameters viz; kerf width and MRR is studied.

μ-WEDM differs from macro-WEDM in many aspects viz; machines thinner work pieces, uses wire with smaller diameter with less tension.There are differences in type of pulse generator used, discharge energy applied per pulse, gap distance and axes resolutions [5]. Table 1 gives a comparison of Macro and micro WEDM. Due to the difference in the scale and therefore characteristics of the two machines, a need for separate analysis is therefore perceived.

MRR is observed as an important parameter that determines economy of production. Higher MRR indicates less time required for machining. Kerf width is the width of material removed during machining.

Table 1: Comparison between WEDM and Micro-WEDM [1, 2, 3, 4, 5,6]

Parameter	WEDM	Micro-WEDM
Workpiece thickness	>100 μm	<100 μm
Wire diameter	250 μm	20- 70 μm
Wire tension	1-2 Kg	100-200 gm
Pulse generator	Transistorized	Relaxation
Gap Voltage	30 to 60 V	80 to 110 V
Pulse on time	1-100 s	5-10 μs
Peak current	<3.5 A	In mA
Discharge energy per pulse	> 25 J.	$<10^{-6}$-10^{-7} J
Gap distance	100 μm	<10 μm
Resolution of X,Y,Z axes	1 μm	0.1 μm
Dielectric	De-ionized water	Hydro-carbon oil base dielectrics

Kerf width accounts wire diameter and the overcut produced during machining. The overcut is attributed to the vibration of wire [7] and heat dissipation in lateral direction. Kerf-width is an indicator of machining accuracy. In micro-WEDM machining accuracy is equally important and vital along with good rate of production. In order to improve the machining accuracy, it is important to investigate the kerf variation with respect to operating parameters. In this study MRR and Kerf-width are therefore selected as the performance parameters.

Previous researchers have investigated the effect of gap voltage and effect of capacitance on MRR as well as relative wear ratio (RWR) [8]. The comparison involved analyzing effect of capacitance on roughness. The study concluded that surface roughness increased with increase in the capacitance. An analytical model to evaluate MRR in micro-WEDM was proposed by Das and Joshi [9]. Mathai et al. emphasized importance of studying dependency of dimensional characteristics of microstructures on machining conditions. They proposed an empirical model that predicted accuracy of micro holes drilled using micro-EDM. Gap voltage, capacitance, pulse on time, aspect ratio and electrode rotation were the input parameters considered. Effect of these parameters on radial overcut was studied [6]. Experiments were carried out to investigate the effect of open voltage on MRR, slit width, thickness of the recast layer and surface finish. It was observed that the increase in open voltage leads to increase in MRR [10].

From the literature surveyed it can be inferred that the gap voltage and capacitance are important process parameters that dominate material removal rate and kerf width. Other important parameters are wire tension, wire feed, pulse on time, pulse off time, dielectric used, wire material and wire diameter.

II. Experimentation

Experiments were carried out on a high precision integrated multi process machine tool; Mikrotool machining center (DT-110) with Micro-WEDM attachment.

A. Materials

Tungsten carbide and Titanium (Grade-5) were selected for experimentation. Pilot runs were conducted using Electrolytic Copper in order to have clear knowledge of the effect of various process parameters. Tungsten carbide has high compressive strength, hardness, resistance to wear and corrosion. This material has important applications in tool and dies industry. Important aspects such as micro-cracks /surface integrity need to be considered while processing this material. Titanium has highest strength-to-density ratio than any other metal and is difficult –to-machine conventionally. The details of chemical composition of Tungsten Carbide and Titanium used in the experiments are enlisted in Table 2 and Table 3 respectively.

Table 2: Composition of Tungsten Carbide Specimen

% W	% Co	% Ni	% Cu	% Fe	% Ti
90.48	0.21	1.59	2.58	2.36	1.59

Table 3: Composition of Titanium Specimen

%C	%V	%Al	%Fe
0.067	4.55	6.80	0.20

B. Preparation of Test Specimens

The size of the test specimens were 65mm length, 15 mm width and 1mm thickness. The specimens were machined out of a metal block using WEDM (Ecocut, Electronica Machine). A Tungsten wire of 70 µm diameter is used as tool. 'Total EDM-3' oil was used as a dielectric. It has high flash point, high auto ignition temperature, less odour and low viscosity. The specimen surface was cleaned and contaminants were removed with acetone.

During pilot experiments it was observed that the range greater than 100 V was needed to machine Tungsten carbide and Titanium samples. This may be due to their properties. Ranges of the process parameters are shown in Table 4.

Table 4: Process parameters ranges

Parameters	Range
Voltage	120 - 140V (5 V)
Capacitance	10pF,0.1nF,1nF,10nF,0.1µF,0.4 µF
Wire Tension	10 - 50 % (10 %)
Feed	110 -190 % (20 %)

The trials were conducted by keeping three parameters constant and varying one parameter at a time. To cite an example, first trial was carried out by varying voltage from 120 to 140V at a step size of 5 V and maintaining capacitance 10 nF. Wire feed was kept constant at 25 % and wire tension was maintained at 35 %.Further trials were conducted similarly.

A micro-slit of 5mm length is made in the workpiece with a gap of 3mm between two consecutive slits. This gap prevented an error due to thermal deformation. Time required for machining each slit is recorded.

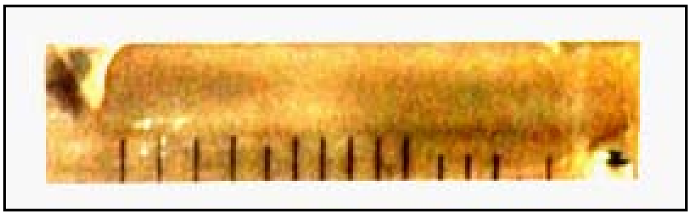
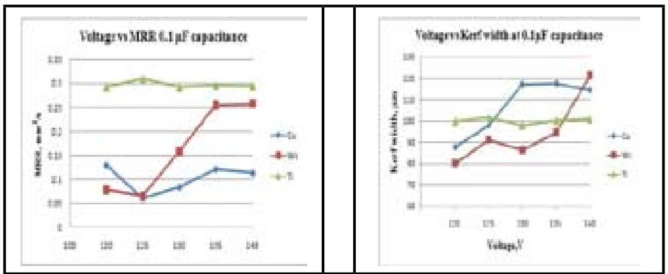


Fig. 1: Test Specimen After Machining

After completing the trials for a test specimen, the sample is cleaned using acetone to remove moisture and residual hydrocarbon particles in order to record microphotograph which results into estimation of kerf width. Kerf width of all slits on a single specimen was measured using a metallurgical microscope. Micro-photographs of kerf width were obtained and scaled using the microscope.

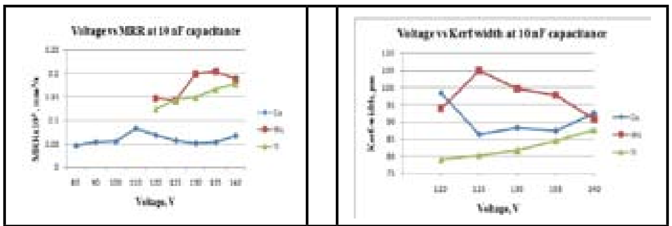
III. Results and Discussion

Fig. 2 and 3 represents the results obtained for kerf width and MRR for two different capacitances at varying voltage while tension and feed rate are held constant.



(a) (b)

Fig. 2: Effect of voltage on (a) MRR and (b) kerf width at 0.1µF capacitance at wire tension 35%, wire feed 25 %



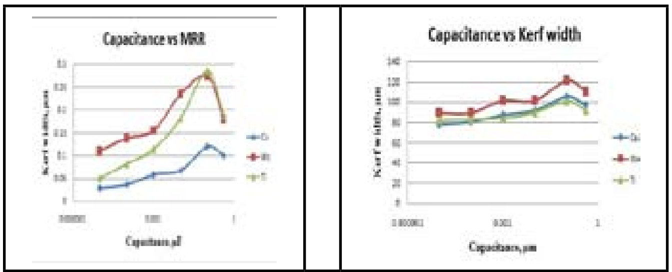
(a) (b)

Fig. 3: Effect of voltage on (a) MRR and (b) kerf width at 10 nF capacitance at wire tension 35%, wire feed 25 %

The graph illustrates as voltage increases MRR also increases for copper and tungsten while slight variation is observed for titanium for both the capacitance. This can be attributed towards increase in discharge energy which leads to increase in ionization effect resulting into increase in discharge channel width or spark gap. With increased spark gap, the molten metal can be easily flushed from the gap resulting into decrease in cutting time [8]. With longer duration of discharge, the electrons released from negative pole collide with the neutral particles which increase the Kerf width. A larger kerf width accelerates the MRR.

Micro-WEDM uses Relaxation type pulse generator. The relaxation generator works on the principle of charging and discharging of the capacitor. In this type of pulse generator, the maximum discharge energy per pulse can be obtained by E = ½ CV2 , where, C= Capacitance, V= Gap voltage [3]. The discharge energy supplied in the gap is therefore, governed by voltage and capacitance. With increase in the capacitance, energy supplied per pulse increases which enhances MRR. Higher current results into larger craters and increase in kerf width is observed; eventually increasing the MRR. This can be observed in fig. 4. and microphotographs shown in fig. 7.

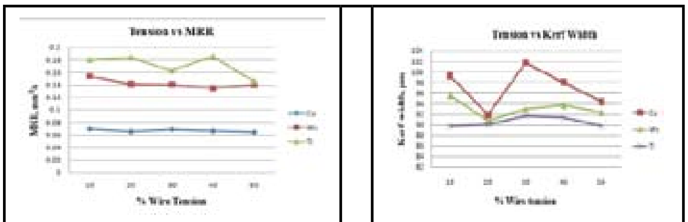
Wire tension is a non electrical parameter so it does not have much effect on MRR. This can be observed from fig. 5. But it is worth mentioning here that wire has to be under tension for effective machining.



(a) (b)

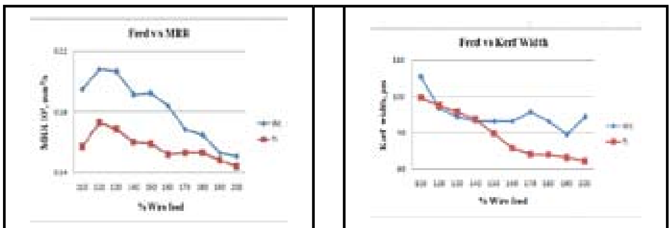
Fig. 4: Effect of capacitance on (a) MRR (b) kerf width at constant voltage 140 V, wire tension 35%, wire feed 25 %

If the wire is not having sufficient tension, wire lag will be observed. It can lead to frequent short circuits, thereby increasing cutting time. Wire tension is very important parameter as far as machining accuracy i.e. kerf width is concerned. Higher wire tension restrains lateral wire vibrations. This results in smaller kerf width, thereby improving the accuracy. This can be observed from Figure 6. Kerf width decreases with decrease in feed rate. Thus for better machining accuracy a higher wire feed is required. MRR decreases with decrease in feed rate.Few variations can be observed in above mentioned trend due to relaxation type of generator, which gives varying discharge energy during pulse on time. Another reason for these inconsistent results can be change in conductivity of the dielectric. Dielectric conductivity increases due to continuous usage as sediments of machining get deposited in the dielectric.



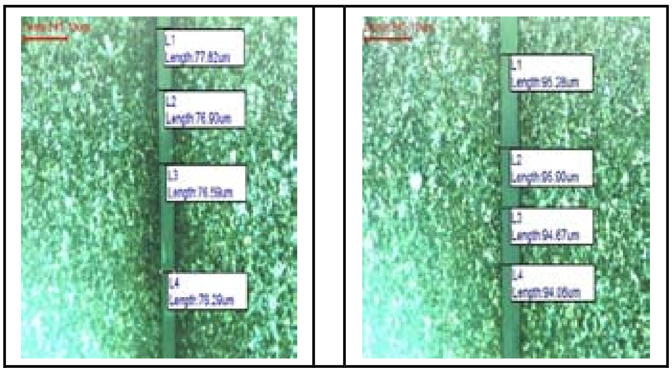
(a) (b)

Fig. 5: Effect of tension on (a) MRR (b) Kerf width at constant voltage 140 V, capacitance 10 nF, wire feed 25 %



(a) (b)

Fig. 6: Effect of feed on (a) kerf width (b)MRR at 10 nF capacitance, 140 V, wire tension 35 %, Wire feed 25 %



(a) (b)

Fig. 7: Microphotographs of kerf width for varying capacitance(a) At capacitance 10 pF and voltage 140V, Wire feed 25 %, wire tension 35 % (b) At capacitance 0.4 µF and voltage 140V, Wire feed 25 %, wire tension 35 %

IV. Conclusion

The following conclusions have been drawn from present study.

1. The energy supplied into the discharge gap is governed by voltage and capacitance. Hence, increase in either of the parameter results in increase in Material removal rate.
2. Kerf width increases with increase in capacitance keeping voltage constant. Thus for better machining accuracy lower capacitance is preferred.
3. There is no direct relation of tension with MRR however as tension increases kerf width decreases.
4. Kerf width decreases with decrease in feed rate. Thus for achieving better machining accuracy a higher feed is required. Decrease in MRR is observed with decrease in feed rate.

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