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Micro Drilling Studies on Titanium Alloy Using Micro Electro Chemical Machining

[1]Ramesh, S., [2]Gobikrishnan, U., [3]Umanath, K.

[1]*Department of Mechanical Engineering, KCG College of Technology, Chennai, Tamilnadu, India.*
[2]*Department of Mechanical Engineering, SONA College of Technology, Salem, Tamilnadu, India.*
[3]*Department of Mechanical Engineering, Vel Tech High Tech Dr.Rangarajan Dr.Sankunthala Engineering College, Chennai, Tamilnadu, India.*

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ABSTRACT

The objective of this research is to drill holes in Titanium alloy using Micro Electro Chemical Machining (ECM). Based on these preliminary studies, experiments were conducted on Titanium Alloy. The optimum machining condition of Micro Electrochemical Machining for Titanium Alloy is determined in terms of Machining Voltage, Pulse on time, Machining Current, Electrolyte Concentration. In this experiment, we consider two electrodes named Stainless steel and Tungsten. In this experiments, We concluded that Stainless steel are most effective in the range of Machining Current at 4.2 amps, Voltage at 12v, Pulse on time8.33 m/s, Frequency60 Hz, Duty cycle=50 and then Electrolyte concentration 0.1mol/l. In this experimental, the electrolyte concentration was chosen as 0.1mol/l for values. Also, Scanning Electron Microscope(SEM) images were studied to check the performance in finished work piece.

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INTRODUCTION

Micro hole is one of the basic elements for micro devices or micro components. Several manufacturing processes are capable of meeting the requirements, in that aerospace components are a vital role in micro machining. However, electrochemical micro machining (EMM) is desired because of its advantages such as no tool wear, higher MRR, better surface finish and others. Performance of Micro ECM is planned to investigate through machining (making micro holes) of aerospace alloy disc. Material removal techniques have a pivotal role to play in component fabrication. Research on micromachining has been pursued by little researchers, international research in this area has been abridged.

Researchers have conducted many experiments in the Micro Electro Chemical Machining set up. Micro ECM is highlighting the major factors such as material removal Machining accuracy, power supply has been done (Bhattacharyya, B., 2004). Mohan and Shan investigated recent developments, new trends and the effect of factors influencing the quality of the holes produced by ECM processes. They found that for drilling cross holes and multiple holes of different shapes electrochemical hole drilling processes proves to be the better choice in comparison with other non-traditional hole drilling processes (Mohan Sen, H.S. Shan, 2005). Munda et al has investigated the influences of various machining parameters on the combined effect of micro-spark and stray-current machining, through Response Surface Methodology (RSM) approach (Munda, J., 2007). The effects of voltage, pulse duration, and pulse frequency on the localization distance for drilling a straight hole with a few micrometers in diameter using additional balance electrode and nanosecond pulses (Se Hyun Ahn, 2004).

The recent developments in EMM process and tool for the metal mask fabrication and they discussed about the merits and demerits of dry and wet etching and they found that wet etching process plays a vital role in industrial applications (Madhav Datta and Derek Harris, 1997). During micro machining operation Micro sparks will be occur that causes uncontrolled material removal which results in improper shape and low accuracy (Bhattacharyya, B., J. Munda, 2003). The principles of electrochemical micro fabrication processes, current distribution and different processes like electroplating, electro forming and chemical polishing are investigated (Datta, M., D. Landolt, 2000). The development of EMM process performs different operations such as mechanical machining unit, micro tooling system, electrical power and

Corresponding Author: Ramesh, S., Department of Mechanical Engineering, KCG College of Technology, Chennai, Tamilnadu, India.
E-mail: ramesh_1968in@yahoo.com

controlling system and controlled electrolyte flow system and provides major advantages in this paper (Bhattacharyya, B., 2002). The effect of electrochemical machining on the surface integrity of cast and wrought steels uses sodium nitrate as an electrolyte and found that the surface structure and surface finish of the material strongly depends on current density used during machining. Finally, they concluded that ECM at a low current density produce an inferior surface finish, but only a small further reduction in the fatigue strength (Strode and M.B. Bassett, 1966).

Several Researchers have developed the EMM set up to perform their basic and fundamental idea conducted on EMM by varying the process parameters such as Voltage, Current, Electrolyte concentration, Pulse on time and Pulse off time and their results discussed. In this paper, most studies focus in general and not much on specific applications like making holes in harder material such as Titanium Alloy material. Also increase the machining performance accuracy to achieve higher MRR and fewer overcoats.

II. Experimental Setup:

The developed EMM set-up which is used for machining is shown in Fig. 1. The EMM machine tool consists of mainly four sub-system such as Electrical power and drive system, Electrolyte supply and cleaning system, Tool and tool feed system, Work piece and work holding system.

The EMM Power supply has a voltage range of 0-20V and current rating of up to 30A average and 100A peak. The main power line has a 220V, single phase AC power supply, which is converted to a low voltage pulsed DC power by a step-down transformer and a Silicon controlled rectifier unit. Initially, the tool is moved in the forward direction to reach the work piece. And then electrolyte flow system is one of the important components in EMM. The electrolyte used in this process is HydroFlouric Acid**,** Hydrochloric Acid, Nitric Acid. The electrolyte is in the direction of the working zone with a average velocity with the help of pump. The electrolyte is then passed through a settle tank along with a filter, which remove the dirtied material from the electrolyte. Then the electrolyte solution is stored in the electrolyte chamber. After that a centrifugal pump is used to circulate the electrolyte solution through the machining gap. Two nozzles are mounted in the machining chamber, which are directed towards each other in the machining zone. The electrolyte passes throughout the nozzle with definite pressure without disturbing the tool and work piece position.

A. Experimental Preparation:

This study aims to find the influence of process parameters such as machining voltage in volts (V), electrolyte concentration in mole/litre (i.e gm/l), and machining current in Amps. And then in this paper, we are using two tool electrode named as Stainless Steel electrode and Tungsten electrode. The work piece used as Titanium Alloy (Grade5). The Thickness of the work piece as 0.2mm and 0.3mm. The experiments were conducted by varying the pulse frequency, Voltage, Duty cycle, and current. Then Pulse frequency as 40Hz,60Hz,80 Hz. Voltage as 18V,19V, 20V. Current as 4Amps,4.1Amps, 4.2Amps. Duty cycle as 50%,60%,70%. Hydrochloric acid, Hydrofluoric acid, Nitric acid is used as electrolyte in the same concentration of 0.1mol each (Sriharsha Srinivas Sundarram, 2008). In this paper there are two sets of experiments were too been done with an Tungsten electrode and Stainless steel electrode. Then both the electrode of same electrolyte concentration of Hydrochloric acid (3.6ml), Hydrofluoric acid (6.3ml), Nitric acid(2ml) are added in both the experiment sets. Digital micrometer is used to measure the electrode diameter .The material removal rate has been calculated using the time taken for penetrating the specimen thickness. The overcut is calculated by comparing the diameter of the tool electrode and the diameter of the machined hole.

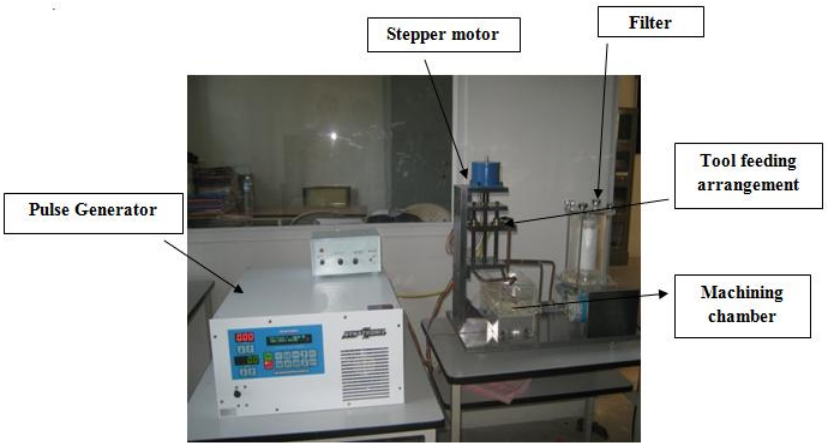

Fig. 1: EMM Power SupplyB. Experiments for Selecting Suitable Electrolyte Concentration.

From the study of literature survey (Sriharsha Srinivas Sundarram, 2008) different electrolytes at different level of concentrations have been used to find out the suitable electrolyte and its concentration to carry out the machining on Ti alloy.

Fig. 2: Work piece thickness =0.2 mm.

The electrolyte used in the above Fig. 2 is HCl (10ml) + HNO_3 (10 ml) + HF (10 ml) and after machining the specimen got eroded because of the random concentration applied for 0.2 mm thickness hence the following level of concentration (0.1 mol) have been used to get the good result and the concentration applied for 0.3 mm thickness is (HCl-3.6ml+HNo_3-6.3ml+HF-2ml).so to avoid this type of eroded material, we have to concentrate in the selection of molar concentration. Initially Electrolyte needs to have a high conductivity and low viscosity so that is able to flow easily in the narrow gap between the tool and the workpiece. And then electrolyte should be such that it is non-toxic, safe to use and does not erode the machine. Neutral salt solutions are commonly used as electrolytes. And then electrolyte should be cheap and readily available and should not exhibit large variations in its properties as the machining process.

First Set of Experiments:

ELECTRODE :STAINLESS STEEL (conical tip)
ELECTROLYTE SOLUTION: HF+HCl+HNO3 (0.1mol each)
WORKPIECE :TITANIUM ALLOY (Ti6Al4V)
WORKPIECE THICKNESS : 0.3mm

Table 1: First Set Of Experiment.

CURRENT (AMPS)	VOLTAGE (VOLTS)	FREQUENCY (HZ)	DUTY CYCLE (%)	PULSE		MACHINING TIME (MINS)	HOLE DIAMETER (micron)	OVER CUT (micron)	MRR (micron /sec)
				ON TIME (ms)	OFF TIME (ms)				
4	18	40	50	12.5	12.5	2.7	621.8	222.74	1.85
4	19	60	60	9.99	6.66	6	417.62	18.56	0.833
4	20	80	70	8.75	3.75	3.85	552.18	190.24	1.298
4.1	18	60	70	11.66	4.99	4.7	571.26	209.32	1.063
4.1	19	80	50	6.25	6.25	8.05	596.72	202.3	0.621
4.1	20	40	60	15	10	10	640.84	246.42	0.5
4.2	18	80	60	7.5	5	5.53	664.84	288.98	0.904
4.2	19	40	70	17.5	7.5	1.5	710.92	335.06	1.388
4.2	20	60	50	8.33	8.33	3.85	790.9	391.84	1.2987

Second Set of Experiments:

ELECTRODE : TUNGSTEN (flat tip)
ELECTROLYTE SOLUTION :HF+HCl+HNO3 (0.1mol each)
WORKPIECE :TITANIUM ALLOY (Ti6Al4V)
WORKPIECE THICKNESS : 0.3mm

Table 2: Second Set of Experiments.

CURRENT (AMPS)	VOLTAGE (VOLTS)	FREQUENCY (HZ)	DUTY CYCLE (%)	PULSE		MACHINING TIME (MINS)	HOLE DIAMETER (micron)	OVER CUT (micron)	MRR (micron /sec)
				ON TIME (ms)	OFF TIME (ms)				
4	18	40	50	12.5	12.5	25	841.64	442.58	2
4	19	60	60	9.99	6.66	16	860.84	461.78	3.75
4	20	80	70	8.75	3.75	5	668.2	306.26	10
4.1	18	60	70	11.66	4.993	5.2	756.36	394.42	9.615

4.1	19	80	50	6.25	6.25	4.7	881.64	487.22	10.6
4.1	20	40	60	15	10	6.05	974.52	580.1	8.264
4.2	18	80	60	7.5	5	6.68	672.84	296.98	7.485
4.2	19	40	70	17.5	7.5	8.52	876.84	500.98	5.868
4.2	20	60	50	8.33	8.33	3.54	886.28	487.22	14.12

RESULT AND DISCUSSION

To study the performance of EMM setup the most influential process parameters current, voltage, frequency and duty-cycle have been varied at three different levels and the process responses of machining rate and form accuracy (Radial overcut) are analyzed by plotting graphs on combined effects of "current + frequency + duty cycle" on performance parameters, keeping the major process parameter of applied voltage as constant.

The experiments have been conducted using Stainless Steel (with conical tip) and Tungsten (with flat tip) tool electrodes for the same parameter values to analyze the difference in performance among the two electrodes.

The graph of two different electrodes using various parameters as constant voltage as shown below:

A. Parameter-wise Comparison of Effect of Electrolytes on Machining Rate and Overcut:

Stainless steel tool electrode (conical tip) results: Machining voltage on metal removal rate:

Combined Effect of "Current + Frequency +Duty Cycle" On Metal Removal Rate at Constant Voltage of 20v – Stainless Steel

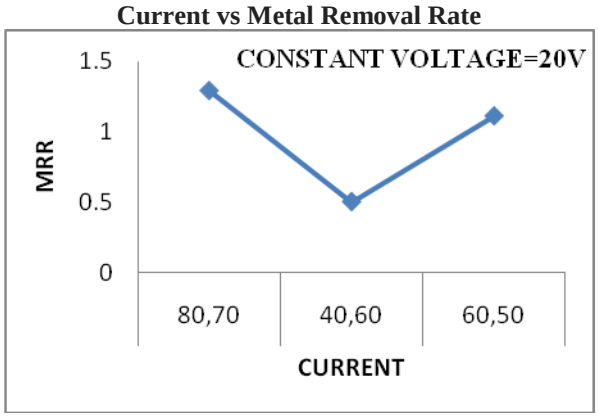

Fig. 3: Main effect plot of MRR for Current(20V).

Fig. 3shows that now at an higher voltage of 20V frequency plays a significant role in the machining rate comparing with pulse on –time. The MRR trend is directly proportional to the frequency in taking account the combined set of parameter values.

Stainless steel tool electrode (conical tip) results: Machining voltage on overcut:

Combined Effect Of "Current + Frequency +Duty Cycle" On **Overcut** at Constant Voltage Of 20v – Stainless Steel

Fig. 4 shows that the overcut increases as the process parameter values increases. But the effect is less severe here than 19V as both frequency and pulse on-time combination in on down trend and hence less severe effect on accuracy.

Tungsten Tool Electrode (flat tip) Results: Machining voltage on metal removal rate

Combined Effect of "Current + Frequency +Duty Cycle" On Metal Removal Rate At Constant Voltage Of 18v –Tungsten

The MRR shows an increasing trend initially and then a decreasing trend with increasing parameter values as it has crossed the optimum combination of parameter values. Though the current and frequency inputs increase the decrease in duty cycle has caused the machining rate to come down. This clearly shows the significance of duty cycle time on machining rate.

Tungsten Tool Electrode (flat tip) Results: machining voltage on overcut:

Combined Effect Of "Current + Frequency +Duty Cycle" on Overcut at Constant Voltage Of 18v- Tungsten

Fig. 6 shows that the overcut decreases as the combined process parameter values increases. The favourable down trend in overcut may be due to Increase in frequency and decrease in pulse on-time.

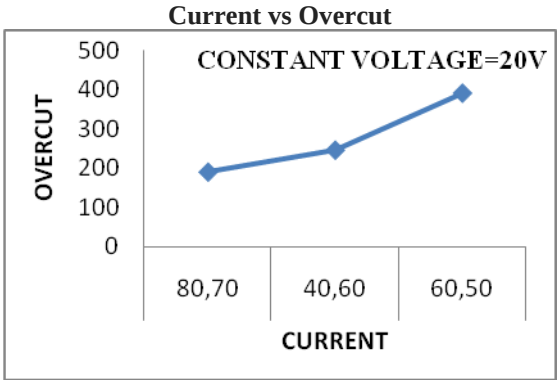

Fig. 4: Main effect plot of Overcut for Current (20V).

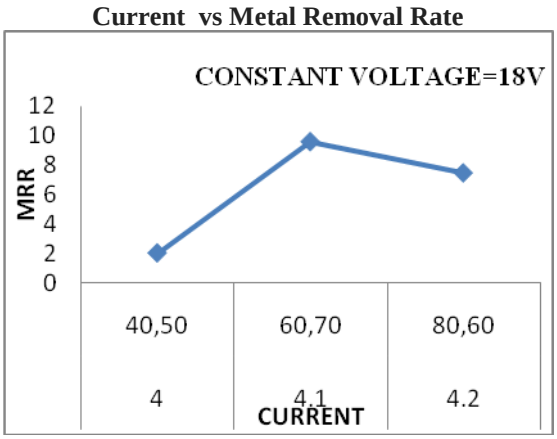

Fig. 5: Main effect plot of MRR for Current (18V).

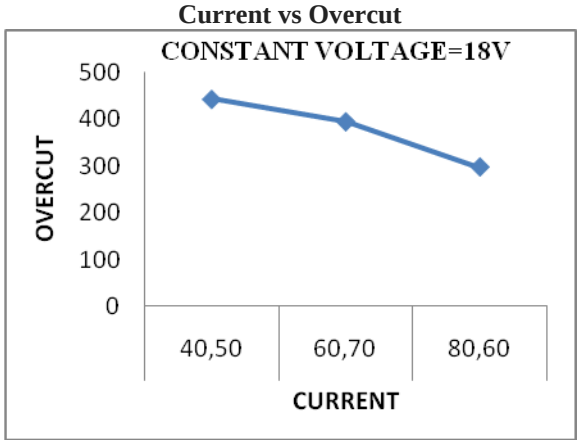

Fig. 6: Main effect plot of Overcut for Current (18V).

B. SEM Graphs:

The SEM pictures of the machined hole at entry and exit are shown in Fig.7 below. The overcut is observed due to the non localization of current in the inter electrode gap. This results in the formation of the inaccurate shape of machined micro-hole.

A SEM micrograph of micro hole machined by EMM at a particular parameteric combination i.e.Electrolyte Concentration of 0.1mol/lit,machining voltage of 20v,Pulse on time of 8.33ms ,frequency of power supply of 60Hz is shown.In this larger overcut has been observed.As machining voltage is more,which results in more current density and larger overcut is the consequent result.Again the relatively higher concentration of electrolyte also causes increases in the current density resulting in larger overcut.Current effect also increases with increases in machining voltage and the electrolyte concentration.It is clear from the SEM micrograph

that the shape of the hole is not circular.Due to the larger voltage and electrolyte concentration.

Fig. 9. shows that the SEM micrograph of a machined micro hole of stainless steel electrode of Sharp end electrode .The tool electrode tip shape plays important role in EMM. Different shape electrode tips shown in above Fig.9 are used for the experiments.

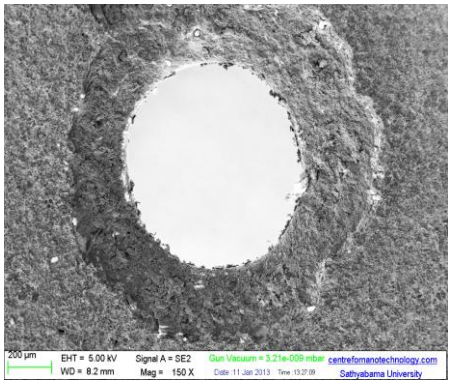

Fig.7: SEM picture view of entry side of the machined hole (machining voltage of 20V, machining current of 4.2A, electrolyte concentration 0.1 mole/l, pulse on-time 8.33 ms).

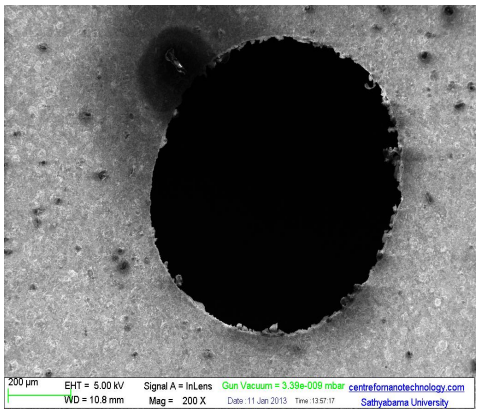

Fig. 8: SEM picture view of exit side of the machined hole (machining voltage of 20V, machining current of 4.2A, electrolyte concentration 0.1 mole/l, pulse on-time 8.33 ms).

C. Stainless Steel Electrode Used (Conical Tip):
SEM micrograph of the stainless steel tool electrode:

SHARP END

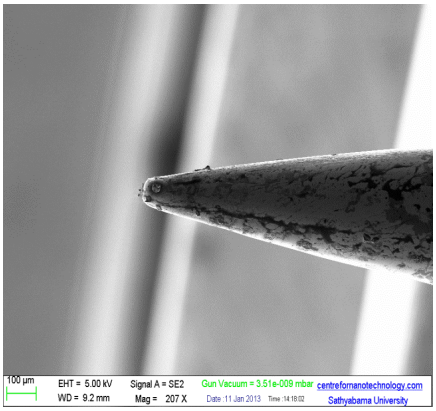

Fig. 9: Sharp End of Stainless Steel Electrode.

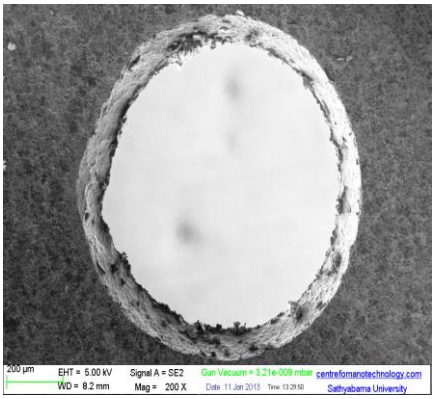

Fig. 10: SEM picture view of entry side of the machined hole (machining voltage of 18 V, machining current of 4.1A, electrolyte concentration 0.1 mole/l, pulse on-time 11.66 ms).

D. Tungsten Electrode Tool Used (Flat Tip):

A SEM micrograph of micro hole machined by EMM at a particular parameteric combination i.e.Electrolyte Concentration of 0.1mol/lit,machining voltage of 18v,Pulse on time of 11.66ms,frequency of power supply of 60 Hz is shown in the Fig.11.This condition of machining gives the appreciable amount of Metal Removal Rate as well as less overcut.It is clear from the micrograph that the hole is quite circular.Here the Pulse on time is more than off time.During machining,the micro tool feed rate is kept constant.In this case linear Metal Removal Rate is almost equal to the micro tool feed rate.so the chance of the tool touching work piece is less and also the tool does not get extra time to remove material from stray current region causes less overcut.SO at this parameteric condition ,the overcut of the machined hole produced by EMM is comparatively less resulting in an increase in accuracy and accurate shape generation.

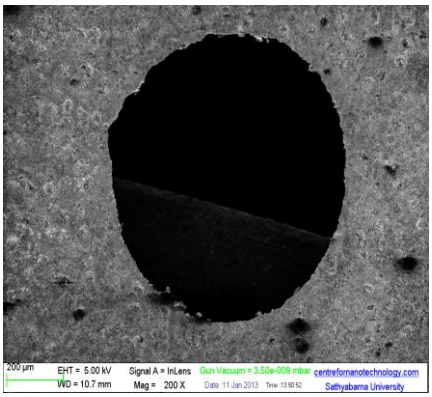

Fig. 11: SEM picture view of exit side of the machined hole (machining voltage of 18 V, machining current of 4.1A, electrolyte concentration 0.1 mole/l, pulse on-time 11.66 ms).

Fig. 11 shows that the shape of the machined hole matches with the profile of the electrode however, the effect of stray current is absorbed give to higher pulse on time. With the increasing pulse of time that machining time also increases

E. Tungsten Electrode Used (Flat Tip):
SEM micrograph of tungsten electrode (flat tip):

Fig. 12. Shows that the SEM micrograph of a machined micro hole of Tungsten electrode of Sharp end electrode and then tungsten electrode gives more overcut because corners are flat and while machining more overcut will occur

IV. Conclusion:

1. The actual micromachining capability of the developed EMM setup is also examined through experimentations considering the different predominant process parameters of EMM
2. Some of the predominant process parameters such as machining voltage and electrolyte concentration are successfully controlled with the help of developed unique EMM setup.
3. Machining voltage and electrolyte concentration were considered for the experimentations to study their influences on MRR and overcut
4. From the experiments conducted to investigate the performance of the EMM setup using two different electrodes (Stainless Steel, Tungsten) and variables, four different major process parameters at

three different levels the following conclusions have been made.

5. Titanium Alloy being hard to machine material requires acidic medium to carry out machining
6. The level of voltage and current required is also high compared to machining moderate materials.
7. The machining of performance using Stainless Steel tool electrode gives good accuracy comparing to Tungsten electrode.
8. Among the tool electrodes, Stainless Steel gives good results in terms of Metal Removal Rate & Overcut Performance.

END POINT

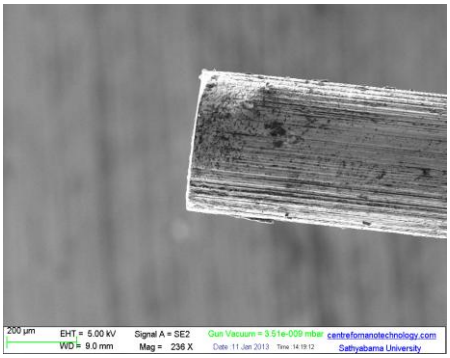

Fig. 12: End point of tungsten electrode.

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