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Surface Texture and Elemental Characterization of High Aspect Ratio Blind Micro Holes on Different Materials in Micro EDM

Swapan Barman[a], Vijay[b], Nagahanumaiah[c], Asit Baran Puri[d]

[a,b,c] *CSIR-Central Mechanical Engineering Research Institute, M.G. Avenue, Durgapur-713209, India*
[d] *National Institute of Technology, Durgapur, M.G. Avenue, Durgapur-713209, India*

Abstract

Micro features machined through micro electrical discharge machining (micro EDM) are adversely affected by tool wear. Tool electrode and machined parts are deformed due to stochastic behaviour of discharge processes. Deposition of tool electrode material on workpiece deteriorates the surface quality of the micro part. Study of the surface quality of blind micro hole is very difficult in non-destructive method due to its miniature size. In this communication, attempts have been made to study the surface quality of high aspect ratio blind micro holes by opening the holes in destructive method. High aspect ratio blind micro holes were drilled in wear resistant high grade steel (block gauge material), zirconium based bulk metallic glass (BMG) Vit 1, titanium super alloy Ti-6Al-4V, oxygen free high thermal conductivity (OFHC) copper, Monel 400 and hard anodized aluminium alloy 6082 T6 in micro EDM by cylindrical tungsten (W) electrode and opened the holes axially through wire EDM (WEDM) to study the surface texture of the opened holes using 3D optical profilometry technique. Elemental analysis of materials of tips of tool electrode and surfaces of the opened micro holes were studied by using energy dispersive X-ray spectroscopy (EDS) technique in scanning electron microscope (SEM). Deformations of tool electrode and tool profile on the workpiece were also studied.

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Keywords : Micro EDM; Surface quality; Elemental characterization; 3D optical Profilometry, Energy dispersive X-ray spectroscopy

1. Introduction

In micro EDM, thermoelectric energy is generated in the spark gap between a tool electrode and a workpiece usually submerged in a dielectric fluid and material removal takes place through melting and evaporation by discharge pulses. Micro EDM process is focused on production of complicated and high aspect ratio micro features

* Corresponding author. Tel.: +91-9474112730; fax: +91-343-2548204.
E-mail address : sbarman@cmeri.res.in

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with improved surface quality and good repeatability of the process with advanced pulse generators and CNC systems reported by Pham et al. (2004). Presently micro EDM is widely used in industry for high precision machining of metals, metallic alloys, graphite and some ceramic materials regardless of their hardness communicated by Puertas et al. (2004). It has become one of the most reliable methods extensively used in micro mould making, production of dies, cavities and many complex 3D structures reported by Alting et al. (2000). Micro holes are the most basic features of micro manufacturing sectors for various applications like in circuit board of integrated circuit packages, fuel injection nozzles, spinneret holes, bio-medical filters and others found in article of Masuzawa (2000). But it is very difficult to study the surface quality of the micro holes irrespective of using high precision equipment and techniques in non-destructive method due to their miniature size. Surface metrology became very important in many branches of science and industry. Study of dimensional and surface nano metrology is becoming more common place in many applications and research environments as well as data treatments dealing with standardized rules. Therefore, surface characterization using advanced accurate and precise nano measuring techniques are important tools especially in production engineering, tribology, biotechnology and criminology using stylus or optical method for analysis of surface characteristics where each technique has its own specific applications reviewed by Ali (2012). Surface quality of micro holes is adversely affected by the deposition of tool electrode material on workpiece. Recast layer is formed due to deposition of molten metal from electrode to workpiece and vice versa. Destructive method to open the blind micro holes to study their metrological aspects has been widely acceptable. In this paper, an attempt was made to study the surface quality and elemental characterization of high aspect ratio (≅10) blind micro holes drilled by micro EDM by adopting destructive method.

High aspect ratio blind micro holes were machined on wear resistant high grade steel, BMG commonly known as Vitreloy 1 or Vit 1(Zr41.2,Ti13.8,Cu12.5,Ni10,Be22.5), titanium Ti-6Al-4V super alloy (composition Al5.5-6.75,C≤ 0.10,Fe≤0.50,H≤0.015,N≤0.05,O≤ 0.45,other<0.4,V3.5-4.5 and Ti balance), OFHC copper (composition Cu 99.95 minimum), Monel 400 (composition Ni 63% minimum, Cu 28-30%, Fe 2.5% maximum, Mn 2% maximum) and aluminium alloy 6082 T6 (composition Si0.7-1.3, Fe0.0-0.5,Cu0.0-0.1, Mn0.4-1.0,Mg0.6-1.2, Zn0.0-0.2,Ti0.0-0.1, Cr0.0-0.25, Al balance) by 300 µm diameter tungsten tool electrode. Holes were opened axially by WEDM. 2D and 3D surface texture characterization of surfaces of the opened holes was conducted by a high resolution (0.1Å) 3D optical surface profiler. Energy dispersive X-ray spectroscopy technique was used for the elemental analysis of the opened micro holes and tool electrodes after taking images in SEM. Tungsten was selected as tool electrode material as tungsten, tungsten carbide and its composites have a great influence in the production of cutting tools, dies and other special tools and components due to their high hardness, mechanical strength and wear resistance over a wide range of temperature reported by Mahdavinejad and Mahdavinejad (2005). 'EDM Oil 3' dielectric was preferred for its high dielectric strength, relatively high flash point and high auto ignition temperature. It has very low content of aromatic material, low volatility, low pour point facilitating outside storage, low viscosity ensuring easy evacuation of machined metal particles and exhibits good resistance to oxidation.

2. Details of Experimentation

2.1 Machine tool used for machining of micro holes

In this study, micro holes were drilled in a high precision, integrated multi-process machine tool (model : DT 110, manufacturer : Mikrotools, Singapore) with 0.1 µm read out. A pulse generator capable to switch to both the transistor type and the R-C type pulse generator energizes the machine. Machining accuracy is ± 1 µm per 100 mm travel and repeatability is 1 µm for all three axes. A full closed feedback control assures the accuracy in sub-micrometre level with vibration isolation maintained by four point heavy duty passive dampers.

2.2 Process parameters for machining

Blind micro holes for programed tool movement of 3.0 mm were drilled on each workpiece maintaining centre positions of the holes at same distance from the reference surfaces with new electrodes of 300 µm diameter for each hole. The process parameters used for machining of micro holes were given in Table 1. During machining, workpiece was connected to positive terminal and tool electrode to negative terminal of the power supply as it (direct polarity) gives higher material removal from workpiece, lower tool wear and better surface finish reported by

Lee and Li (2001). Higher capacitor value was chosen for faster operation and lower feed rate chosen for better control of the process to get micro holes with better surface finish. Lower threshold value was selected as it provides sensitivity in detecting short circuiting reported in programming manual (2006) of the machine. During machining for lateral section of micro hole by WEDM, wire diameter and overcut for WEDM were considered for setting of machining parameters for WEDM to open the holes.

Table 1. Process parameters for machining

Gap voltage	Discharge capacitance	Polarity	Threshold	Feed	Spindle speed	Retrieval feed
120 V	0.4 μF	Workpiece(+ve)	50%	4μm/s in Z-axis	3000 rpm	10 mm/minute

2.3 Measuring equipment used for collection of data

High resolution automated non-contact surface profiler (model: CCI Lite, manufacturer: Taylor-Hobson, UK) was used to scan the opened holes for 2D and areal surface texture characteristics. SEM (Hitachi, Japan, Model S-3000N) was used to obtain the images of the opened micro holes and tool electrodes for getting energy dispersive X-ray spectrograms to study the tool material deposition on workpiece and vice versa by elemental analysis. Marcel-Aubert, SA make optical microscope (model: MA-705-Z1) and Olympus, Japan make image analyzer (model: BX51M, camera: Olympus-E330) were used to take the images of the holes and tool electrodes. Nikon make profile projector (model V-12, least count 1 μm) was used to measure the depth of the opened micro holes.

3. Results and Discussion

3.1 Shape, size and surface texture characteristics of opened micro holes

2D (R_a) and 3D (S_a) surface texture analysis were carried out as per ISO 4287 and ISO 25178 by the 3D optical profiler with online software CCI Lite to scan the surfaces for collection of surface data and off line software Talymap Platinum was used for analysis of the data collected for computation of R_a and S_a. For R_a measurement, profiles were extracted parallel to the axis of the hole. For S_a measurement, surface area of the hole was used and form removal of the selected area was taken care off by the software. Measured depth of opened holes, arithmetic mean deviation of roughness profile R_a and arithmetic mean height of the surface S_a of the micro holes were tabulated in Table 2. 3D views of the opened holes revealed that the holes were tapered in shape and the bottoms were almost hemispherical and images of used tool electrodes showed that at the tip region, electrodes became almost hemispherical as observed in image analyzer and optical microscope shown in Fig.1. The depth of holes was smaller than the programed depth of tool electrode travel due to erosion of electrode during electrical discharge.

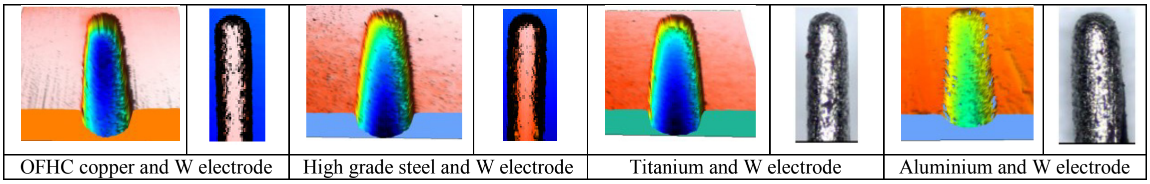


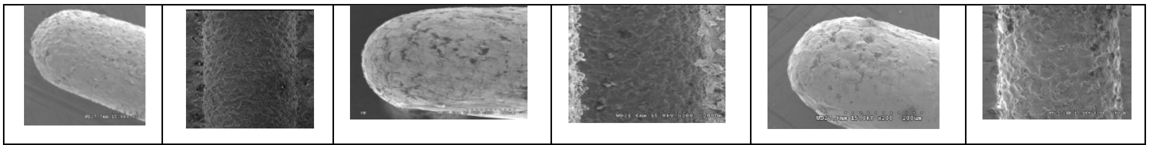
Fig.1. Images of opened micro holes and used electrodes taken in 3D optical profiler, image analyzer and optical microscope.

Table 2. Measured depth and 2D and 3D surface roughness of opened micro holes with their standard deviation (σ)

Workpiece material	Depth of opened micro holes in mm	Amplitude parameters R_a in μm (ISO 4287)	σ of R_a in μm	Height parameters S_a in μm (ISO 25178)	σ of S_a in μm
High grade steel	2.142	1.26893	0.00342	4.25147	0.00563
Bulk metallic glass	2.338	1.71839	0.00521	5.68251	0.00647
Titanium super alloy	2.106	1.17055	0.00276	3.80135	0.00398
OFHC copper	2.349	1.91952	0.00443	5.40483	0.00663
Monel 400	2.268	2.34537	0.00384	7.68502	0.00538
Aluminium alloy 6082 T6	2.434	3.68424	0.00572	10.2218	0.00738

3.2 Analysis by energy dispersive X-ray spectroscopy

The elemental analysis of the micro hole was studied by the analytical technique, energy dispersive X-ray spectroscopy (EDS or EDX or EDAX) from the entire scanned area of the micro holes and tip region of tools taken by SEM. EDS makes use of the X-ray spectrum emitted by a solid sample bombarded with a focused beam of electrons to obtain a localized chemical analysis. All elements from atomic number 4 (Be) to 92 (U) can be detected in principle. SEM images of some opened holes and tips of electrodes were shown in Fig. 2. The secondary electron image of the opened micro holes and electrodes and the corresponding X-ray spectra to identify the particular elements present in the selected scanned area were shown in Fig. 3 to Fig. 8 and their relative proportions by percentage of weight were tabulated in Table 3 to Table 8. The Y-axis showed the counts (number of X-rays received and processed by the detector) and the X-axis represented the energy level of those counts. EDS study clearly showed that the tool electrode element tungsten was deposited on the surfaces of the micro holes and the workpiece materials were deposited on the surface of the tool electrodes during machining. Several foreign elements including oxygen, sulphur, silicon etc. which were migrated from the dielectric fluid during the electrical discharge and handling were accumulated on the surface of the micro holes. Weight percentage of deposition of tool material tungsten on workpiece is higher in harder material and weight percentage of deposition of high electrical conductive metal from workpiece on tool electrode is higher.



W electrode and BMG workpiece	W electrode and Monel 400 workpiece	W electrode and Titanium workpiece

Fig. 2. SEM images of a portion of opened micro holes and tip of used tool electrodes

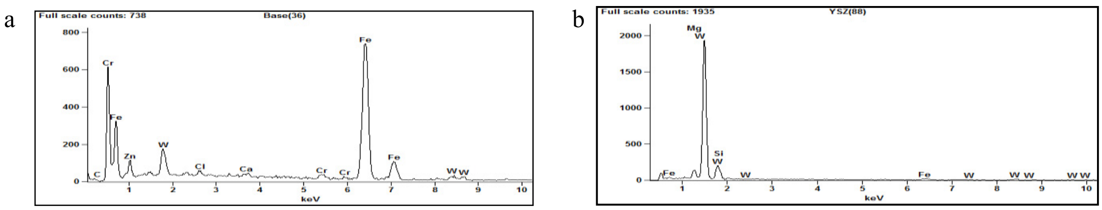


Fig. 3. EDS spectrograms of (a) opened micro hole drilled on high grade steel and (b) W tool electrode at tip region

Table 3. Weight percentage of elements present on opened hole drilled on high grade steel and W tool electrode at tip region

	Workpiece							Tool electrode			
Element Line	C K	Cl K	Ca K	Cr K	Fe K	Zn K	W L	W M	Fe K	Mg K	Si K
Weight %	5.01	0.99	0.65	1.75	75.36	3.82	12.43	92.62	6.06	0.94	0.38

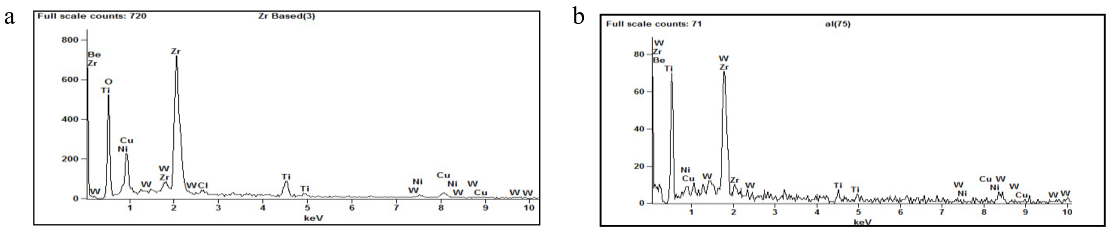


Fig. 4. EDS spectrograms of (a) opened micro hole drilled on BMG and (b) W tool electrode at tip region

Table 4. Weight percentage of elements present on opened hole drilled on BMG and W tool electrode at tip region

a b

	Workpiece								Tool electrode					
Element Line	Zr L	Be K	Ti K	Ni K	Cu K	Cl K	O K	W M	W M	Zr L	Ti K	Cu K	Be K	Ni K
Weight %	48.24	36.88	5.60	1.09	5.49	0.39	1.74	0.57	80.71	10.01	2.90	3.72	2.03	0.64

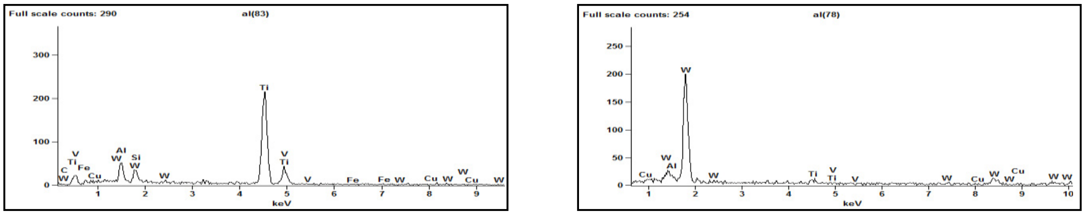


Fig. 5. EDS spectrograms of (a) opened micro hole drilled on titanium super alloy and (b) W tool electrode at tip region

Table 5. Weight percentage of elements present on opened hole drilled on titanium super alloy and W tool electrode at tip region

	Workpiece							Tool electrode						
Element Line	Ti K	Al K	V K	Fe K	C K	Si K	W M	W M	Ti K	Al K	V K	Cu K	C K	O K
Weight %	80.82	4.94	3.41	0.71	1.08	0.15	8.89	89.83	4.41	1.75	0.96	2.01	0.39	0.65

a

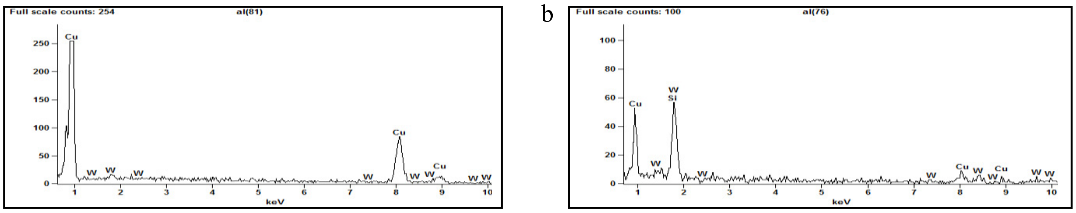


Fig. 6. EDS spectrograms of (a) opened micro hole drilled on OFHC copper and (b) W tool electrode at tip region

Table 6. Weight percentage of elements present on opened hole drilled on OFHC copper and W tool electrode at tip region

	Workpiece		Tool electrode		
Element Line	Cu K	W M	W M	Cu K	Si K
Weight %	97.76	2.24	74.19	24.99	0.82

a b

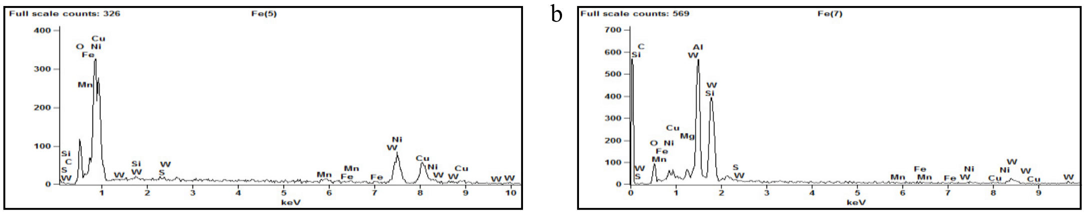


Fig. 7. EDS spectrograms of (a) opened micro hole drilled on Monel 400 and (b) W tool electrode at tip region

Table 7. Weight percentage of elements present on opened hole drilled on Monel 400 and W tool electrode at tip region

	Workpiece									Tool electrode						
Element Line	Cu K	Ni K	Fe K	Mn K	S K	Si K	O K	W M	W M	Cu K	Ni K	Al K	Mn K	Mg K	Si K	O K
Weight %	42.41	49.53	0.69	2.59	0.29	0.3	2.39	1.8	81.48	6.42	2.19	4.1	0.13	1.42	0.29	3.95

a b

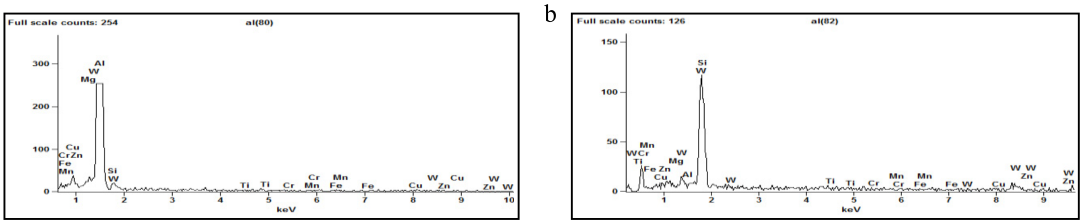


Fig. 8. EDS spectrograms of (a) opened micro hole drilled on aluminium alloy and (b) W tool electrode at tip region

Table 8. Weight percentage of elements present on opened hole drilled on aluminium alloy and W tool electrode at tip region

	Workpiece											Tool electrode		
Element Line	Al K	Cu K	Si K	Ti K	Fe K	Mn K	Mg K	Zn K	Cr K	O K	W M	W M	Al K	Cu K
Weight %	89.15	3.42	0.31	0.20	0.82	0.25	0.32	0.23	0.18	1.24	5.88	98.76	0.04	1.20

4. Conclusions

High aspect ratio blind micro holes were drilled in wear resistant high grade steel, BMG, titanium super alloy, OFHC copper, Monel 400 and aluminium alloy in micro EDM by cylindrical tungsten electrode and opened the holes axially through WEDM. Shapes of opened micro holes and used electrode, 2D and 3D surface texture characteristics of the opened holes and elemental characteristics of the opened holes and the tool electrode were studied. The following observations were made from the study :

a) The micro holes were tapered in shape and almost hemispherical at the bottom.
b) The depth of holes was smaller than the tool electrode travel due to erosion of electrode during discharge.
c) Tip region of the electrode took nearly hemispherical shape.
d) EDS study revealed that the tool electrode material was accumulated on the surface of the hole and vice versa along with the foreign materials from dielectric fluid during discharge and from the atmosphere / environment during handling.
e) Weight percentage of deposition of tool material tungsten on work piece is higher in harder material.
f) Weight percentage of deposition of high electrical conductive metal from work piece on tool electrode is higher.

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