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Electrochemical Discharge Machining Process

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ABSTRACT

Electrochemical discharge machining process is evolving as a promising micromachining process. The experimental investigations in the present work substantiate this trend. In the present work, *in situ*, synchronised, transient temperature and current measurements have been carried out. The need for the transient measurements arose due to the time-varying nature of the discharge formation and time varying circuit current. Synchronised and transient measurements revealed the discrete nature of the process. It also helped in formulating the basic mechanism for the discharge formation and the material removal in the process. Temperature profile on workpiece and in electrochemical discharge machining cell is experimentally measured using pyrometer, and two varieties of *K*-type thermocouples. Surface topography of the discharge-affected zones on the workpiece has been carried out using scanning electron microscope. Measurements and surface topographical studies reveal the potential use of this process for machining in micron regime. With careful experimental set-up design, suitable supply voltage and its polarity, the process can be applied for both micromachining and micro-deposition. It can be extended for machining and or deposition of wide range of materials.

Keywords: Electrochemical discharge machining, micromachining, surface topography, temperature profile, transient measurements, electrochemical machining, ECM, EDM, spark-assisted chemical engraving, electrochemical spark machining

1. INTRODUCTION

Electrochemical discharge machining (ECDM) is an advanced hybrid machining process comprising the techniques of electrochemical machining (ECM) and electro discharge machining (EDM). The process is also referred as electrochemical spark machining (ECSM) process. The process is important since it can support a variety of materials including metals, ceramics, composites, alumina, glass, etc. The process has possible potential usage in the following areas:

- Micro-fabrication of miniature machine tools for micromachining
- Micro-fabrication of array of holes in SU-8 material (high aspect ratio, polymer, dielectric photoresist material) to fabricate micro-filters needed in micro-EDM process
- Micro-seam welding of copper plates and foils
- Fabrication of miniature components
- Heat treatment.

Hence, electrochemical processes are being reconsidered for the micro-fabrication purposes. The study presents the use of ECDM for the micromachining purposes.

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2. LITERATURE SURVEY

Kulkarni and Jain[1] have highlighted some of the current trends and techniques used for micro-fabrication of parts using electrochemical processes (ECM, EDM, ECDM/ECSM, etc). Micro-fabrication of the parts can be achieved by combing micromachining and micro-deposition processes in various sequences. Schuster[2], *et al*. at the Fritz Haber Institute of the Max Planck Society, Berlin, have developed a simple ECM procedure to fabricate 3-D micro-structures. To obtain the delicate copper prism in the middle of the hole-cavity with a cross section area of 5 μm x 10 μm x 12 μm, sitting on a pedestal 15 μm x 15 μm x 10 μm, the tool electrode of platinum wire (10 μm dia) was used. Machining operation was performed using pulse voltage of 1.6 V, pulse current in the range of 0.02 - 0.03 A, pulse-on time of 50 ns, and frequency of 2 MHz. The complete machining time for the structure was 30 min.

An electrochemical micromachining (EMM) experimental set-up has been developed[3] for carrying out in depth research for achieving a satisfactory control of EMM process parameters to meet micromachining requirements. EMM can be effectively used for high precision machining operations, that is, for accuracies of the order of 1 μm on 50 μm. Some industrial applications of EMM have also been reported such as surface finishing of print brands, nozzle plate for ink-jet printer head, deburring, and for production of high accuracy holes. The typical application is the production of high aspect ratio holes and large-scale production of micro-holes in turbine blades for generating cooling effect.

The EDM is one of the most extensively used advanced material removal processes. Its unique feature of using thermal energy to machine electrically conductive parts regardless of their hardness, has been its distinctive advantage in the manufacture of mould, die, automotive, aerospace, and surgical components. Ho[4], *et al*. have published a paper on the state-of-the-art EDM. A range of EDM applications are highlighted for metals, ceramics, and modern composite materials together with the development of hybrid machining processes.

Use of electrochemical spark (ECS) for machining of nonconductive materials such as ceramics[5-9], glass[10-12], composites[13], and alumina[14,15] has been successfully carried out. Kulkarni[16,17], *et al*. have successfully explained the ECS process investigating the basic discharge mechanism by experimental measurements. A novel technology for micromachining of glass, called spark-assisted chemical engraving (SACE) using ECS[18] is presented. This technology is based on electrochemical discharge phenomena. Beyond a critical voltage, electrical discharges occur through the gas film around the electrode and the glass machining is possible. *In situ* measurements have been performed by Wuthrich[19], *et al*. while performing the micromachining on glass using ECSM. Machining speeds of the order of 30 μm/s have been achieved with the developed tool holder. Simultaneous scanning of the substrate surface while performing the close-loop machining is possible in this process.

The research is being done on the feasibility of using ECSM for fused deposition of metal on to metal[20,21]. In the present work, the machining aspects of the ECS process for micromachining have been studied.

3. EXPERIMENTAL

As mentioned, ECDM is an extension of the ECM process. The electrolyte cell is similar to that used in ECM. In ECDM, anode is made up of inert material while cathode normally is made of copper. Dilute hydrochloric acid (HCl) is generally used as the electrolyte. When a voltage is applied to the cell in proper polarity, i.e., positive terminal to anode and negative terminal to cathode, reduction of electrolyte with liberation of hydrogen gas takes place at the cathode tip. This is similar to the ECM process. When the applied voltage is increased beyond a threshold value, hydrogen gas bubbles evolve in large number at the tip of the cathode and grow in size. Discharge occurs at the tip of the cathode. Machining takes place on the workpiece surface kept near the cathode tip where discharge occurs. *In situ*, synchronised, transient temperature and current measurements were performed. The experimental procedure and the set-up schematic are explained[22]. Figure 1 shows the photograph of

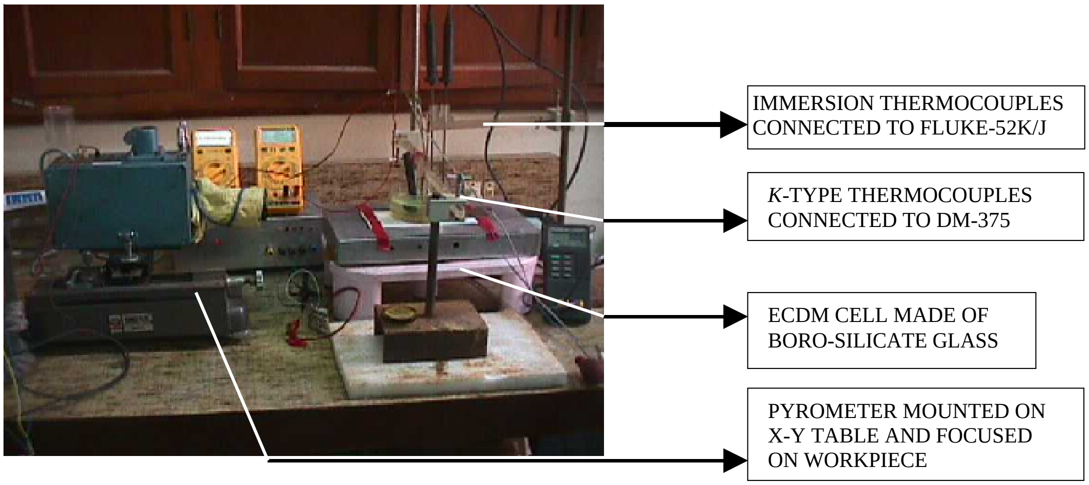


Figure 1. Photograph of the experimental set-up.

the experimental set-up. The temperature and current-sensing methodology, use of particular measuring equipment are highlighted.

- Experiments are performed with graphite anode, 2 mm thick copper wire as cathode, and copper workpiece in 2.5 cm x 2.5 cm dimensions with 0.6 mm thickness. The working voltage is 155 V. Hydrochloric acid with 5 per cent concentration is used as electrolyte. Workpiece and cathode separation is of the order of 600 μm.

- To sense the high, transient temperature of localized zone on the workpiece surface where discharge strikes, a pyrometer is used. Pyrometer model D-7441, Kohelberg, with a sensing temperature range of 815-1700 ^{o}C measures the temperature in a non-intrusive way. The pyrometer has been suitably modified for transient temperature measurements. Its Response time was experimentally determined using a step change in temperature and its suitability for this process has been established.

- To measure the temperature on the workpiece surface at the locations of 4 mm and 6 mm away from the discharge-affected zone, *K*-type thermocouples fabricated with smaller bead diameter to ensure smaller thermal mass, and hence faster response to measure the temperature on the workpiece surface are used. Wires are wrapped in a sheath for better stability.

- To measure the temperature in the cell, immersion thermocouples provided with a special coating to withstand the harsh environment are used. These are placed at 16 mm and 26 mm from the discharge location in the ECDM cell.

- Current transients are measured using resistive shunt method. 1Ω resistor is connected in series with the cathode for this purpose.

- Discharge-affected region is examined using SEM.

- Pyrometer temperature transients and current transients are measured and stored using KIKUSUI 60 MHz, 4-channel digital storage oscilloscope. Study of transient temperature and current in synchronisation is the unique feature of the present study. A digital camera (Sony 10X Digital Mavica, MVC-FD7) is used for photographs of these stored waveforms. The *K*-type thermocouple output voltages are recorded using two digital multimeters (DM-375). A standard conversion chart is used to convert the voltage readings to temperature readings. Immersion thermocouples readings are displayed on a digital thermometer (Fluke-52 K/J).

4. RESULTS AND DISCUSSION

Figure 2 gives the photograph of the display of the stored waveforms and shows the representative values of current and the resulting temperature transients for copper workpiece. The upper waveform represents the current transient and the lower waveform the ensuing temperature transient at the discharge-affected zone on the workpiece. Here, two current pulses are seen with a temperature pulse occurring in between. Each current pulse represents the distinct formation of the discharge at the tip of the cathode. With the arrival of the first current pulse of about 8 A, the temperature of the copper workpiece in the localised region increases to 865 °C due the bombardment of the electrons on the workpiece due to discharge formation[22]. The temperature soon reduces to 815 °C after 2.8 ms. It reduces further, below 815 °C showing a steep fall. After about 14 ms, the second current pulse of about 10 A arrives showing that the next discharge has happened. This will heat up the workpiece again. Because of the chosen time scale of the oscilloscope, the next temperature pulse cannot be seen here. It is to be noted that the pyrometer's minimum sensing temperature is 815 °C. Temperatures below 815 °C are not sensed and once the temperature reading is above that value, the pyrometer gives a sharp pulse as seen in Fig. 2. It is observed while carrying the experiments that sometimes the temperature attained at the discharge-affected zone is of the order of the boiling temperature of workpiece material[16].

Experiments have been also performed on brass, tantalum, and silicon as workpiece materials[17] with the same copper tool. Similar trends for transient current and ensuing transient temperatures were observed for these materials. In case of silicon as workpiece material, frequent breakage and cracking of workpiece was taking place as the discharge was striking the surface. Hence, it was felt that the process is not suitable for silicon in particular.

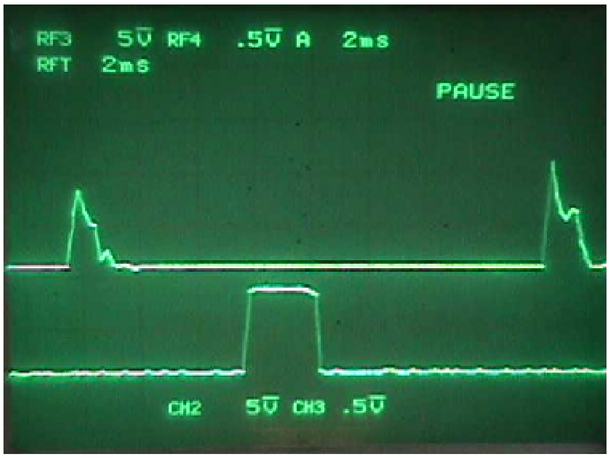
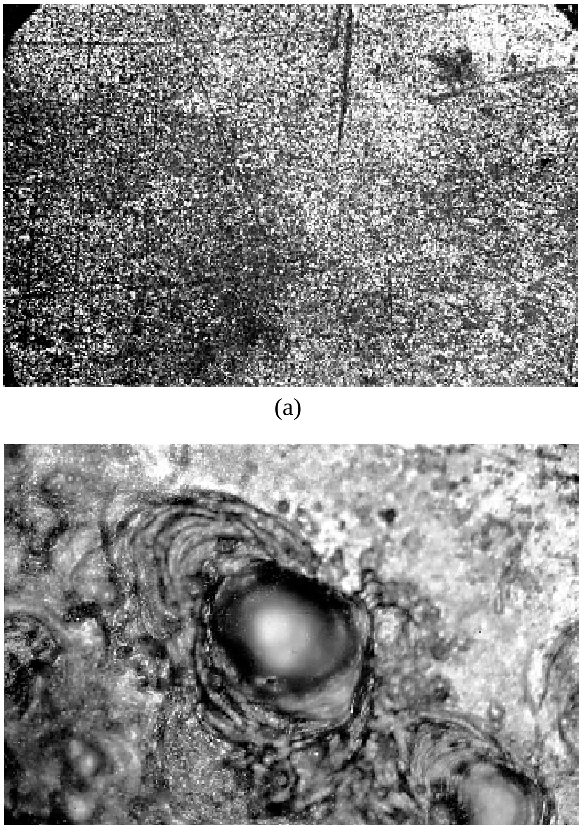


Figure 2. Synchronised time-varying current (upper waveform) and temperature (lower waveform) for copper workpiece[16].

Figure 3 shows the surface topography of the SEM scanned samples. In Fig. 3(a), the copper workpiece surface of an untreated workpiece is shown for comparison. Figure 3(b) shows a magnified (200X) view of the discharge-affected zone. The surface clearly shows ring pattern formed by melting and solidification due to quenching of the workpiece surface. The inner shining round spot of 60 μm dia is due to the removal of metal from the workpiece surface.

As the study aimed to understand and formulate the basic mechanism for the discharge formation



(a)

(b)

Figure 3. Surface topography of workpiece using SEM[17]: (a) Untreated workpiece, no discharge, and (b) material removed from the inner core of dia 60 mm.

and the material removal in the process, the parametric study such as prediction of the hole diameter as a function of tool diameter, optimisation were not addressed.

Figure 4 gives the experimentally measured temperature profile using three types of temperature sensors mentioned in Section 2. As can be seen from the graph, temperature is highest at the position where discharge strikes. It is around 865 °C as noted by the pyrometer. It drastically decreases away from discharge location and becomes around 200 °C at 4 mm and 50 °C at 6 mm away from the discharge location. These three readings are shown in black solid circles. The two readings shown by black rectangle represent the temperature readings in the electrolyte, 16 mm and 26 mm away from the discharge location, respectively. These are recorded by the immersion thermocouples as mentioned earlier.

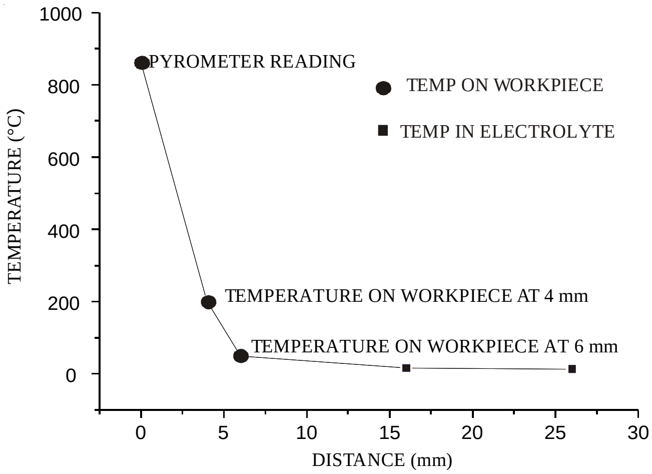


Figure 4. Experimentally measured temperature profile in ECDM.

5. CONCLUSIONS

Based on the study, the following conclusions are drawn:

- Transient and synchronised measurements were successfully performed for the first time in studying the ECDM process.
- The discharge in ECDM is a discrete phenomenon. Synchronised study of the process revealed that the discharge temperature rise is due to the bombardment of the electrons generated during the discharge process. At times, the temperature rise at the discharge-affected zone is of the order of the boiling temperature of workpiece material. Machining, and hence, the material removal takes place.
- Geometry of the discharge-striking zone, and hence, the machining can be performed in the micron region using this process. The dimensions can be further reduced by reducing the geometry of the cathode tip, and by careful design of the process and its parameters. Close-loop control of the process can be achieved.
- Prediction of hole dia as a function of tool dia and the area of machining over the number of discharges striking the workpiece can be carried out in the subsequent research of the process.
- Hence, it is a potential candidate for micro-fabrication.

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