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WIRE ELECTRICAL DISCHARGE MACHINING FOR MICROFABRICATION

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ABSTRACT

This paper discusses the application of conventional wire electrical discharge machining (WEDM) for fabrication of miniaturized components using low pulse energy. The surface finish of the fabricated microparts was investigated for different level of discharge current at constant gap voltage and pulse-on time. Miniaturized gears of 3.58 mm outside diameter were fabricated from copper blank as an example. The fabricated microgears were inspected by using scanning electron microscope (SEM) (JSM-5600, JEOL, Japan) where higher accuracy and geometrical integrity were observed. The surface roughness of the microgear was measured by using surface profiler (Surftest SV-500, Mitutoyo, Japan). An average surface roughness (R_a) of 1.8 µm and dimensional accuracy of 1-2% were achieved.

Keywords: Micromachining, WEDM, surface finish.

1. INTRODUCTION

Microfabrication using focused ion beam (FIB), LIGA (Lithography, Electroplating, and Molding), and other lithography based techniques were complex, expensive, and time consuming. As a result researchers throughout the world were investigating micro electrical discharge machining (µEDM), micromilling, etc. for fabricating microparts with hard metals to use as a master tool for replication in second stage [1]. Because of less availability of microfabrication facilities, conventional EDM and WEDM were also used for microfabrication where sub-millimetre sized holes, slits, etc. were successfully produced [2, 3]. In WEDM a thin wire was used as an electrode and the relative motion between the wire electrode and workpiece was controlled by a computer numerical controlled (CNC) program to cut the workpiece into desired shapes. This process was economical to cut complex products and difficult-to-machine materials [4]. The surface produced by WEDM consisted of many craters caused by electrical spark. The higher the discharge energy the worse the surface finish was because of rippled surface, cracks, recast layer, etc. [5, 6]. The input parameters for WEDM included discharge current, gap voltage, pulse duration, pulse rate, polarity, etc. [7, 8]. Investigations have been carried out to improve the surface finish when fabricating macro-sized components [9, 10]. In relation to microfabrication, the relationship between WEDM parameters and the machining characteristics especially surface finish and accuracy required further investigation. The surface finish played a significant role in microfabrication as the tools were usually used as a master to replicate polymer microstructures [11, 12].

In this paper the conventional WEDM was applied for microfabrication with lower energy discharge. As the influence of pulse duration and gap voltage were less significant, the influence of discharge current was analyzed to achieve high surface finish. Then miniaturized components were fabricated with high surface finish and accuracy.

2. EXPERIMENT

At first experiments were performed on copper blank to identify the influence of discharge current on surface finish. Thin plates of 8 mm x 10 mm cross-sectional area were cut using the WEDM parameters as listed in Table 1. These parameters were selected based on literature review and preliminary experiments. A conventional CNC WEDM (FX10K, Mitsubishi, Japan) with de-ionized water dielectric fluid was used for these experiments. The surface roughness of the machined thin plates was investigated using surface profiler and scanning electron microscope (SEM) The measured surface roughness values are plotted against the discharge current as shown in Figure 1. Then using the optimized process parameters microgears were fabricated on copper blank which can be used as master microtool for the replication of polymer microparts. The WEDM parameters for this microfabrication were 1 A discharge current, 8 V gap voltage, 8 µs pulse-on time, and 5 µs pulse-off time. Other fixed parameters were remained the same as listed in Table 1.

The spur microgear of 3.58 mm diameter and 17 teeth with fillet radius of 70 µm was first designed in CATIA as shown in Figure 2. Then the microgear was fabricated on 6 mm thick copper blank by using the same WEDM machine. The average surface roughness (R_a) and the peak-to-valley height (R_t) of the fabricated microgears were measured using a surface profiler (Surftest SV-500, Mitutoyo, Japan). The surface texture was also investigated under scanning electron microscope (SEM) (JSM-5600, JEOL, Japan). The SEM micrograph of the fabricated microgear is shown in Figure 3. The measured surface roughness values were found to be 1.8 µm R_a and 7 µm R_t. The dimensional accuracy of the microgears was found to be within 1-2% of the designed outer diameter. The surface texture observed under SEM is shown in Figure 4.

Table1 1: Selected WEDM parameters for microfabrication

Parameters	Values/description
Discharge current (A)	1, 2, 3, 4
Pulse-on time (µs)	6
Pulse-off time (µs)	5
Gap voltage (V)	5
Feed rate (µm/s)	30
Dielectric fluid	De-ionized water
Wire electrode material	Brass
Wire electrode diameter (µm)	100
Wire electrode speed (µm/s)	200
Polarity	+ve workpiece

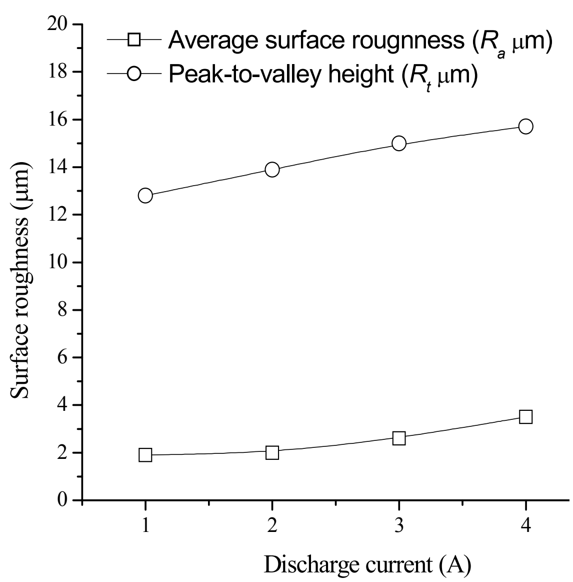

Fig. 1: Plot of discharge current and surface roughness at constant pulse-on time of 6 µs, pulse-off time of 5 µs and gap voltage of 5 V.

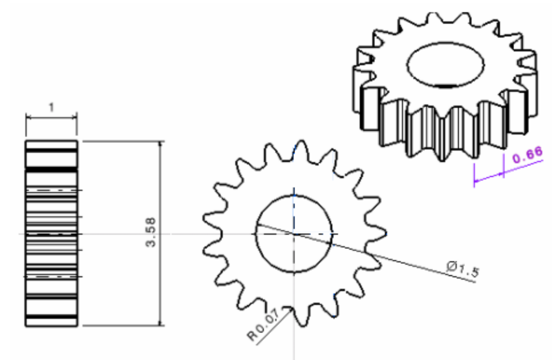

Fig 2: Design of miniaturized spur gear to be micro-machined by conventional WEDM

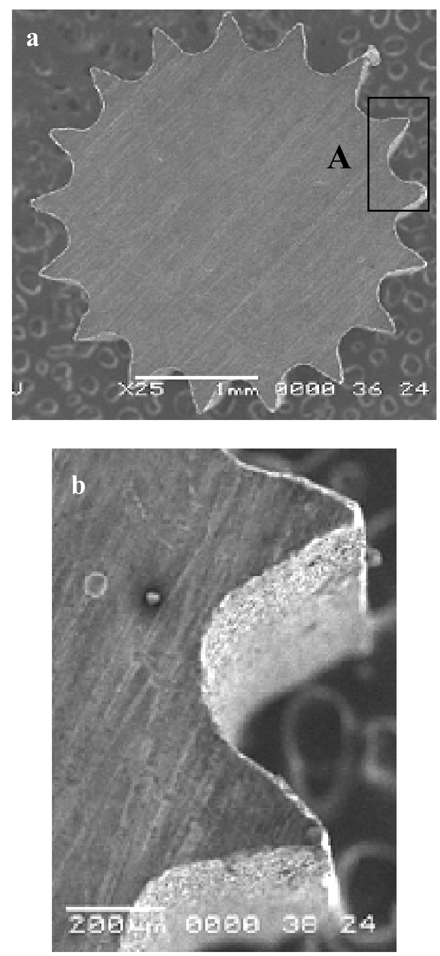

Fig 3: SEM image of miniaturized spur gear (a) top view of the gear, (b) zoom-in view of the teeth profile marked by window A. (Gear specification: Diameter 3.58 mm, pitch 0.66 mm, height 6 mm, and number teeth 17. Process parameters: 1 A discharge current, 8 V voltage gap, 8 µs pulse-on time, and 5 µs pulse-off time.)

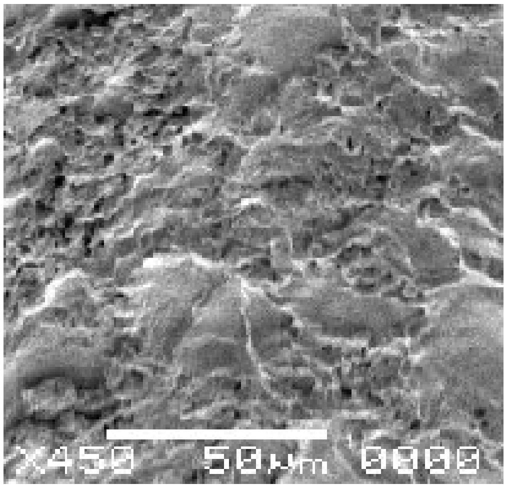

Fig 4: Surface texture of the microgear observed under SEM. (Surface roughness: 1.8 µm R_a and 7 µm R_t as measured by using surface profiler.)

3. RESULTS AND DISCUSSION

From the plot of discharge current and the measured surface roughness (Fig. 1) it was found that the both average roughness (R_a) and peak-to-valley height (R_t) were greatly affected by discharge current. The surface roughness increased with the increase of discharge current. The minimum value of discharge current (1 A) provided the best surface finish of 1.5 µm R_a and 8 µm R_t. Lower discharge current (less than 1 A) would produce better surface finish but the machining time was very long with lower material removal rate.

The longer pulse-on time did not change the energy level but prolonged the machining with more melting on the workpice. As a result longer pulse-on time produced smoother surface as it widened the periodicity of the surface ripple. The pulse-off time was set to a constant value of 5 µs for all experiments. This time was to wash away the debris and had no significant influence on surface finish. But if pulse-off time was set to a very low level, surface finish will be poorer because of short circuit with the wire electrode and debris. The high discharge current increased the spark size and creates deeper erosion crater on the surface of molten metal. At constant discharge current, if the pulse-on time decreased excessively, the EDM action struck deeper and worsening the surface finish. Higher gap voltage also increased the discharge energy and resulted higher material removal rate and poor surface finish.

Maximization of material removal rate (MRR) was an important issue in fabricating macro-sized parts. But in micromachining the MRR was always very low and considered less significant parameters. The main concern was the quality of the products such as the proper geometry, surface finish and the capability of the machine. Several miniaturized spur gears were machined with varying parameters in confirmation experiment. The investigation showed that the dimensional accuracy was 1-2%.

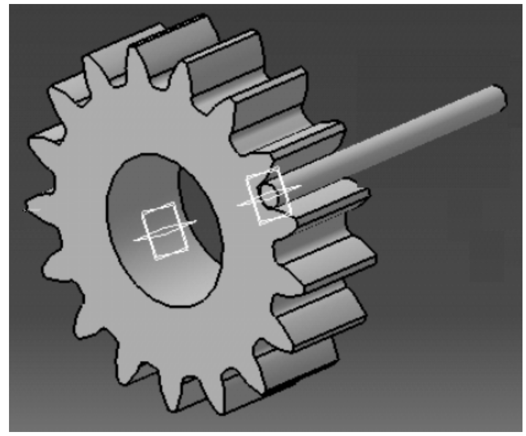

Fig 5: Wire electrode diameter should be smaller than gear fillet radius.

4. CONCLUSION

In this research, conventional WEDM was used for micro/meso fabrication. The influence of discharge current and pulse-on time were studied to achieve high surface finish. Using the optimized process parameters miniaturized spur gears were fabricated with 1-2% dimensional accuracy and about 1 µm R_a surface finish. The following conclusions can be made from this research.

1. Conventional WEDM can be used to machine miniaturized component with least cost compared to other method such as micro-WEDM, FIB, LIGA, etc. The minimum sizes of the component depend on diameter of the electrode wire. It is recommended to use wire electrode of smallest diameter and low energy discharge machining parameters to achieve high geometrical integrity and surface finish. The process was slower than conventional WEDM and faster than micro-WEDM.
2. In this research the smallest diameter of wire electrode was 100 µm. As a result, a fillet radius of 70 µm (larger than the wire electrode radius 50 µm) was selected to allow the easy movement of the wire electrode at the filleted corner as shown in Figure 5. So, considering a fillet radius of 70 µm, the smallest 17 toothed gears of 3.58 mm diameter was machined.
3. The surface texture of the gears had shallow craters and fewer irregularities (Fig. 4). The surface roughness of 1 µm R_a and 7 µm R_t were acceptable for MEMS applications. The surface craters and irregularities were deeper and larger for high discharge energy machining.
4. To estimate the dimensional accuracy several microgears were produced in confirmation experiments. The average dimensional variations were found to be 1-2%. The factors related to dimensional accuracies were measurement error, wire electrode vibration, and machine tolerance (25 µm).

5. ACKNOWLEDGMENT

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6. REFERENCES

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