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ORIGINAL ARTICLE

Investigation of Optimum EDM Die Sinking Parameters in Micro Dimple Machining

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ABSTRACT – Micro dimple is a standard surface structure that is commonly used in micro-moulds, micro/nano-fluid devices, micromechanical systems, and bionic functional surfaces. These microstructure surfaces can be used for optical communication systems, micro sensors, flat panel display, light emitting diode applications and others. Many researchers have performed investigations on the parameters that help in manufacturing the micro dimple. However, there is still limited research on the certain parameters that will affect the micro dimple using EDM die sinking machine. EDM die sinking process involved a tool and workpiece material which immersed in a dielectric fluid medium and use the electrical spark discharges from electric pulse generation to remove the workpiece material. The actual performance of the surface integrity and form accuracy in micro dimple by EDM die sinking machine remains unclear. Therefore, this research attempts to investigate the effect of the dimple measurement such as diameter, depth and surface roughness (R_a) to the parameters which is surface roughness (R_z), sparking gap and type of electrode. By utilising the parameters, the lab experiment was conducted, and their surface integrity, effects in micro dimple behaviour were investigated. It was discovered that the higher surface roughness (Rz), the higher current produced thus erodes the material and caused the measurement of the dimple (diameter, depth and surface roughness (R_a)) differed from the expected size. Also the findings that the surface integrity was ununiformed due to the tool worn out occurred during the electric spark process causing high material rate removal. Other than that, the material electrode which has the high thermal conductivity and melting point resulted the best form accuracy of micro dimple.

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INTRODUCTION

Electrical Discharge Machining (EDM) is the most flexible and widely used modern machining method in manufacturing industries. EDM surface of the micro-edm is very crucial to produce a micro-component in the range of 50 μm to 100 μm. The functions of micro dimples on the surface of the material workpiece are to give a good impact on friction control and also wear resistance at the sliding surfaces. However, the surface is subjected to the crater surface and micro-cracks, thus it will affect the surface quality of the micro dimple. This phenomenon can be overcome by controlling the EDM parameters such as the sparking gap between electrode with the selected material, pitch and velocity. The current research aims to study parameters for machining micro dimples using EDM die sinking machine onto the aluminium material. The parameters that will be investigated are the sparking gap, surface roughness and types of the electrode (brass and copper).

Micro dimple is a surface structure that is usually used in micro molds, microfluid devices, micromechanical systems and others that meet the purpose requirements [1]. Micro dimples also required surface modification in order to achieve the desired properties. The uses of the surface texture of the micro dimple that can act as a control for friction and wear [2]. Dimple surfaces fabricated using the laser surface texturing display a considerable to reduce the coefficient of friction [3].

Electro discharge dies sinking machining (EDM) is an advanced machining process that uses the electric sparks generated by the dielectric fluid with the tools and materials to melt and withdraw the conductive materials [4-6]. The tool and the workpiece is no direct contact with each other, thus it can offer some benefits in terms of less tool wear and better surface finish. EDM is carried out by continuous discharge of the spark to remove the material which will melt and evaporate the workpiece material and will produce a very strong thermal impact during the process [7]. This process of heating and cooling will make the physical process complex. The choice of the electrode depends on the performance criteria required such as metal removal rate (MRR), surface roughness machining stability and also electrode manufacturing constraints. Normally an excellent electrical conductor will be chosen as the first choice in order to create the discharge. The tool's properties must have a high melting point and vaporising temperature as well as a high thermal diffusivity so that it can stabilise the geometrical shape of the electrode.

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METHODOLOGY

First of all, the Design of Experiment (DOE) will be carried out with the experiment's parameters, the surface roughness of the workpiece and also sparking gaps as shown in Table 1.

Table 1. Design of Experiment

Types of Electrode	Surface Roughness, R_z (µm)	Sparking Gap (mm)
Brass	8	0.1
		0.3
		0.5
	10	0.1
		0.3
		0.5
	12	0.1
		0.3
		0.5
Copper	8	0.1
		0.3
		0.5
	10	0.1
		0.3
		0.5
	12	0.1
		0.3
		0.5

Next, the tool electrode size was designed with a similar diameter and size for both the copper and bronze in order to obtain comparison results. Figure 1 below shows the design of the tools and workpiece with its dimensions by using drawing software. Besides that, Figure 1 shows the moth's eye shape of the micro dimple. From the process of dimple fabrication using EDM, the tools of 2 mm in diameter were used to machine the materials to form the micro dimple shape without touching the workpiece. The shape of the micro dimple is similar to the structure of a moth's eye.

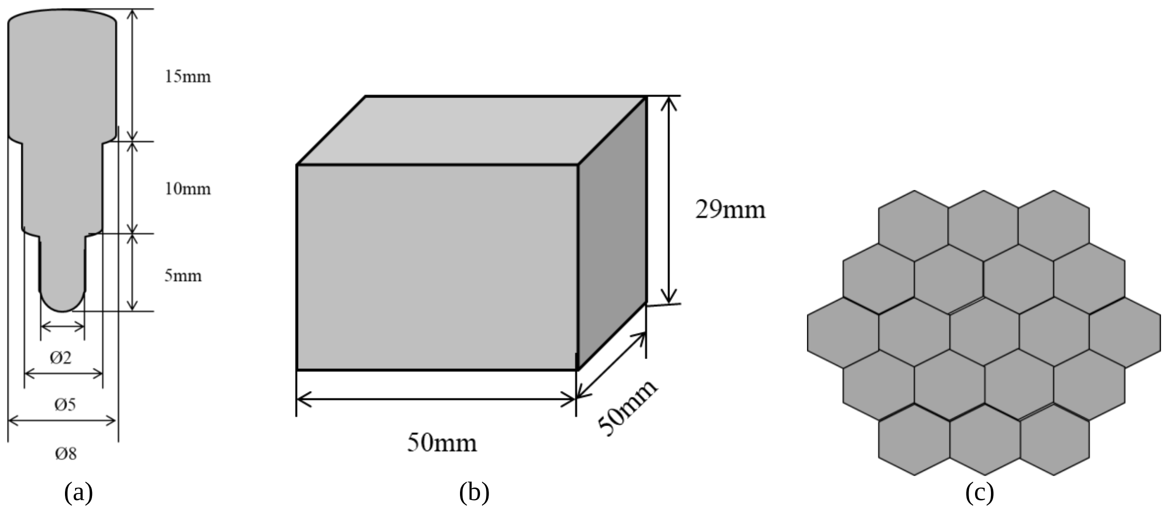

Figure 1. Schematic Diagram of the (a) Tool Electrode Design, (b) Workpiece, and (c) Micro dimple

Next, the tool electrode will be shaped into the desired shape using the turning machine. The materials will undergo facing milling process using a CNC machine. This process is used to control the dimensions within the identical and close tolerance, and at the same time to achieve a good surface finish.

Generally, the proposed EDM process consists of the potential difference between the tool and workpiece as shown in Figure 2. Both the tool and workpiece material are conductors of electricity so that the electric spark would occur in order to remove the excessive material. By following the set of the experiment design shown in Table 3.1, the process was carried out accordingly. The materials with the initial condition will be used as the first parameter, with the spark gap set to 0.1mm and the surface roughness at 8R_z.

After the process was completed, the specimens of the workpiece were removed and labeled with numbering to indicate the first set of the experiment using the bronze electrode. Figure 3 shows the output of the micro dimples at the workpiece with labeling. The steps were repeated until all sets of the experiments listed in Table 3.1 were completed.

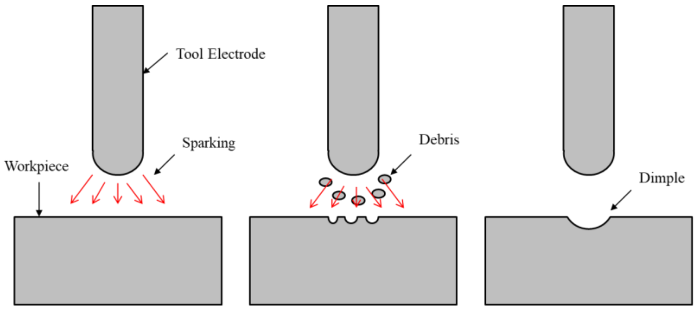

Figure 2. Setting up of Tool and Material and Process

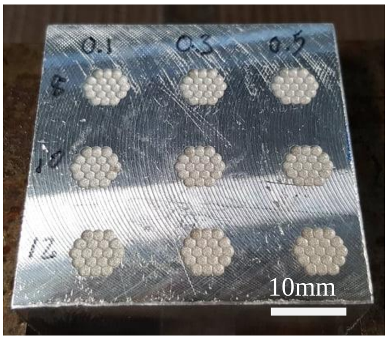

Figure 3. Micro Dimple with Labelling

Lastly, the results finding were evaluated using Analysis of Variance (ANOVA) and the graphical method. ANOVA was used to analyse whether the selected parameters had contributed to dimple measurement (diameter, depth and surface roughness, R_a); while the graphical method was used to determine the parameters that had contributed the most in affecting the formation of the micro dimple.

RESULTS AND DISCUSSION

The measurement of the geometrical of the sample was taken at the center of the circle to the other circles, (diameter, depth and surface roughness, R_a) using the 3D laser microscope (LEXT OLS5000). Figure 4 below shows the actual view of the micro dimple using EDM die sinking machine. Figure 4 shows the 9 sets of micro dimple's 3D topography using brass electrodes and the other 9 sets of micro dimple's structure using copper electrodes.

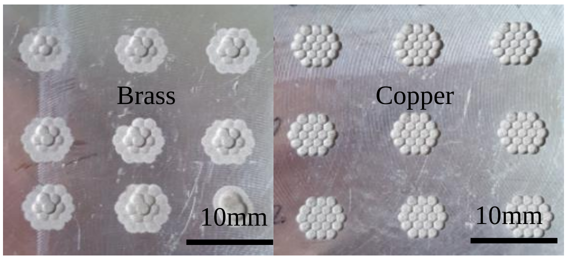

Figure 4. Actual View of Micro Dimple

The labeling of Figure 5 (b) below represents the numbering of the sequence of each micro dimple or each sample. It can be seen that the outer layer (Figure 5 (b)-h to (b)-s) of the micro dimple is not clearly seen as compared to the inner layer (Figure 5 (b)-a to (b)-g). This phenomenon occurred because brass has a low melting point, when high current is transmitted to produce more micro dimple, it eroded the material faster and caused the depth of the outer layer decrease. From Figure 5 (c-g) it can be seen that there was some undeformed surface occurred at the micro dimple due to the worn-out tool stuck into the surface when the sparking process occurred to remove the material. As for Figure 5 (i), the size of the micro dimple had changed due to the brass tool electrode having worn off.

Figure 6 (b) below represents the numbering of the sequence of each micro dimple or each sample. Figure 6 shows the inner (Figure 6 (b)-a to (b)-g) and outer layer (Figure 6 (b)-h to (b)-s) surfaces of the micro dimple were formed and measured at an average diameter of 1914 µm. This phenomenon occurred because the copper was an extremely good conductor of both heat and conductor, therefore during the sparking process to remove the material, it did not easily erode the electrode. Figure 6 (h-j), shows the uniform surfaces, these were due to the tool worn out that stuck into the surface during the sparking process to remove the material. The complete shape of the micro dimple shows that the copper electrode had the least wear-off condition than the brass electrode.

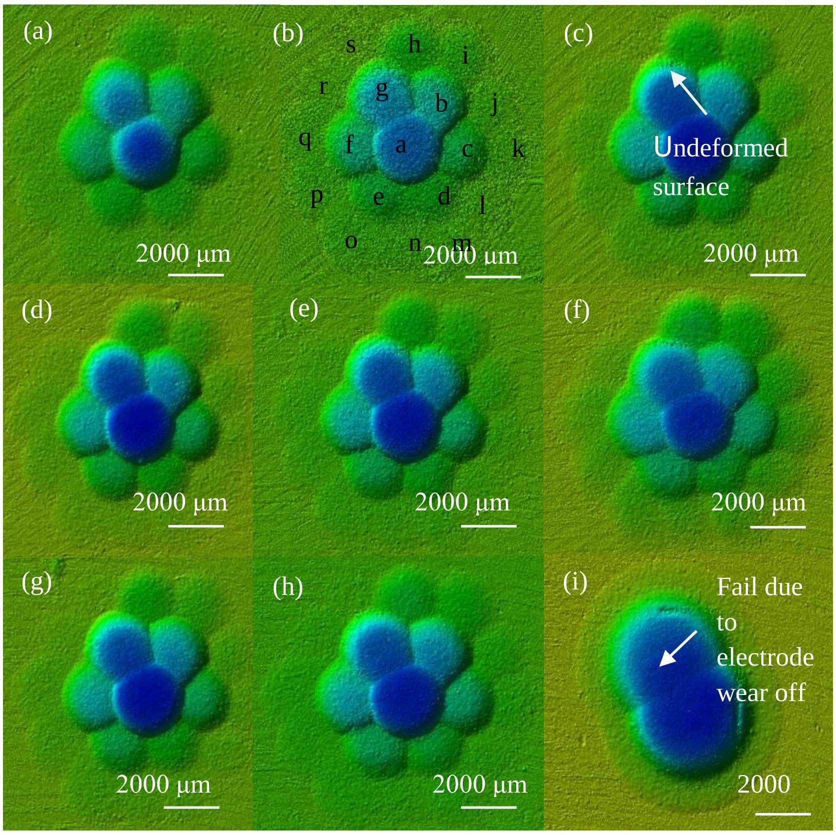

Figure 5. 3D Topography of Micro Dimple using Brass Electrode under 3D Laser Microscope

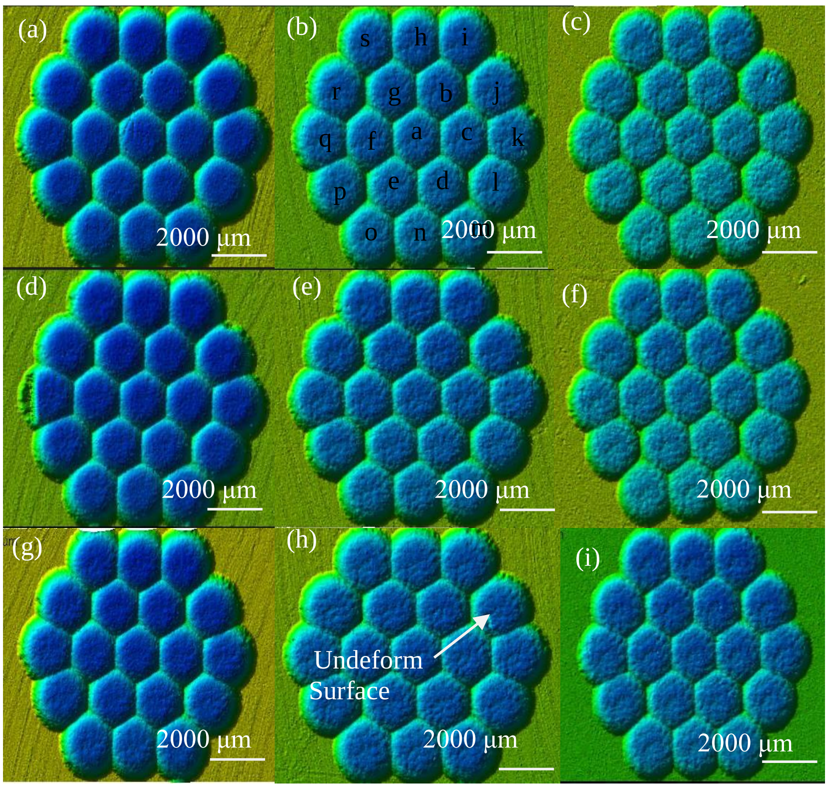

Figure 6. 3D Topography of Micro Dimple using Copper Electrode under 3D Laser Microscope

Analysis of Variance (AVOVA)

A two-way ANOVA was used to analyse the results. Three hypotheses were made and applied to both cases, which are shown below:

H_0: The means of the measurement variable are equal for different values of the surface roughness.
H_1: The means of the measurement variable are equal for different values of the sparking gap.
H_2: There is no interaction between surface roughness and sparking gap in the micro dimple effect.

By comparing the F-value to F-crit value (F critical), when F > F crit, then reject the hypotheses. Table 2 and Table 3 show the ANOVA results taken from the result of a set of experiments for case (i) and case (ii), respectively.

Case (i): Micro Dimple Analysis using Brass Electrode

Table 2. Summary of ANOVA for Case (i)

AVOVA		
Source of Variance	**F**	**F-Crit**
Sample	1.2090	3.4028
Coulums	158.3920	3.0087
Interaction	1.1099	2.5081

Case (ii): Micro Dimple Analysis using Copper Electrode

Table 3. Summary of ANOVA for Case (ii)

AVOVA		
Source of Variance	**F**	**F-Crit**
Sample	261.5768	3.4028
Coulums	4526.9108	3.0087
Interaction	109.9383	2.5081

By comparing the F-value and Fcrit-value, it can be seen that in case (i), the micro dimple was much influenced by sparking gap rather than the surface roughness (R_z) using the brass as tool electrode and did not show the interaction between two factors; while for case (ii), the micro dimple was much influenced by surface roughness (R_z) and sparking gap and it has shown an interaction between the two factors to the dimple measurement of the micro dimple. The worn-out tool rate was influenced by the surface roughness (R_z) and sparking gap.

Graphical Analysis

In graphical analysis, the data obtained will be taken to generate a bell curve and histogram graph, respectively. The average values of the dimple measurement for case (i) and case (ii) will be analysed in graphical method for a better illustration.

Bell Curve Graph (Depth Measurement with respect to Surface Roughness)

Figure 7 and Figure 8 below show the graphs of the depth with respect to the surface roughness such as 8R_z, 10R_z and 12R_z and without considering the sparking gap.

Case (i) Micro Dimple using Brass Electrode

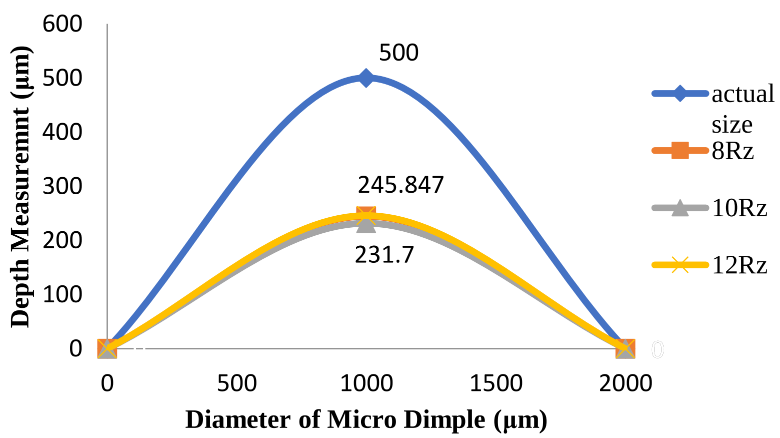

Figure 7. Depth Measurement with Respect to Surface Roughness (Brass Electrode)

Case (ii) Micro Dimple using Copper Electrode

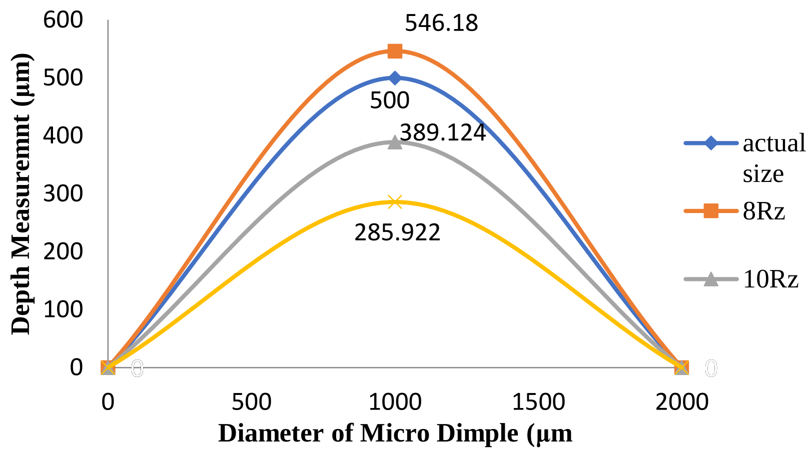

Figure 8. Depth Measurement with Respect to Surface Roughness (Copper Electrode)

Figure 7 shows the expected depth for the micro dimple to be 500µm as it is the setting in the EDM machine. The average depth measurement calculated for surface roughness were (8R_z, 10R_z and 12R_z) and without considering the sparking gap, the depth value were (244.397µm, 231.7 µm and 245.847 µm). The depth measurement for the micro dimple using brass electrode is not accurate but precise as the depth for the micro dimple in three different surface roughnesses; R_z has a similar output value. The difference between the three outputs is very small even it can be considered as negligible. The depth measurement was low because of the low conductive of brass, thus it was the least reaction with the material (aluminium) under the EDM electric spark to cut the material.

Figure 8 shows the expected depth for the micro dimple to be 500µm as it is the setting in the EDM machine. The average depth measurement calculated for surface roughness were (8R_z, 10R_z and 12R_z) and without considering the sparking gap, the depth value were (546.18µm, 389.124µm and 285.922µm). The measurement depth for the micro dimple using copper electrode was not accurate and not precise as the depth for the micro dimple in three different surface roughnesses, R_z had the different height of the micro dimple. The biggest difference between the expected and 12R_z was 214.078µm. This might be due to it being affected by the surface roughness, R_z of the EDM machine. The higher the surface roughness, R_z, the higher the current produced, thus it affected the erosion rate of the copper electrode and caused the depth decreasing.

Histogram Graph (Dimple Measurement with Respect to Surface Roughness and Sparking Gap)

Figure 9 and Figure 10 below show the graphs of the dimple measurement (diameter, depth, surface roughness, R_a) with respect to the surface roughness (8R_z, 10R_z and 12R_z) and sparking gap (0.1mm, 0.3mm and 0.5mm).

Case (i) Micro Dimple using Brass Electrode

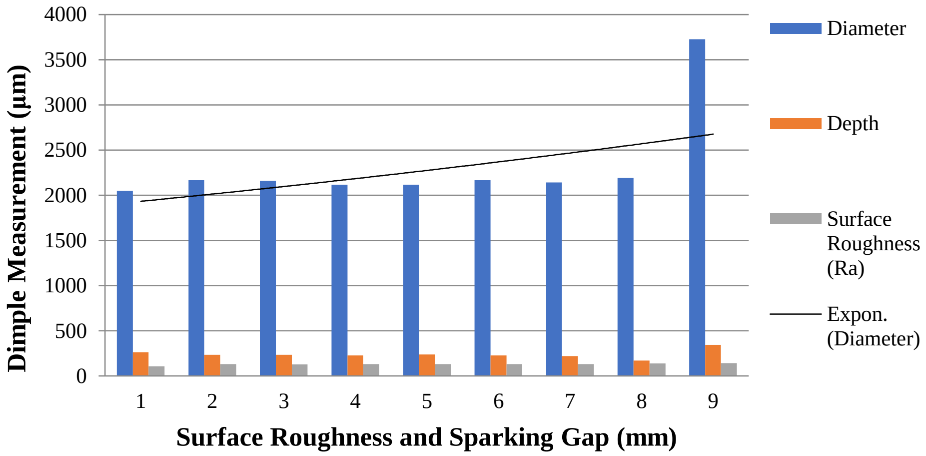

Figure 9. Dimple Measurement (Diameter, Depth and Surface Roughness, R_a) with Respect to Surface Roughness and Sparking Gap (Brass Electrode)

Case (ii) Micro Dimple using Copper Electrode

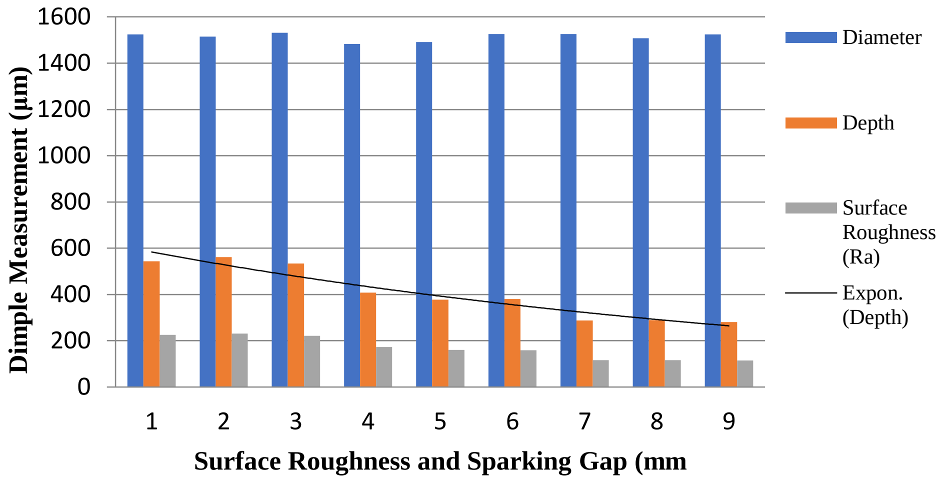

Figure 10. Dimple Measurement (Diameter, Depth and Surface Roughness, R_a) with Respect to Surface Roughness and Sparking Gap (Copper Electrode)

Figure 9 shows that the sample set of the micro dimple using brass electrode had the constant value for each categories of dimple measurements (diameter, depth and surface roughness, R_a) except for the last set. The outliers occurred at the last set of the sample due to the brass electrode worn off during the process of the continuous discharge of the spark to remove the material which melt and evaporated the workpiece material.

Figure 10 shows that the sample set of the micro dimple using copper electrode had the constant value for two categories of dimple measurements (diameter and surface roughness, R_a) except for the depth measurement. The differences in depth were due to the higher surface roughness, R_z, the higher the current produced, thus affecting the erosion rate of the copper electrode.

Tool Condition

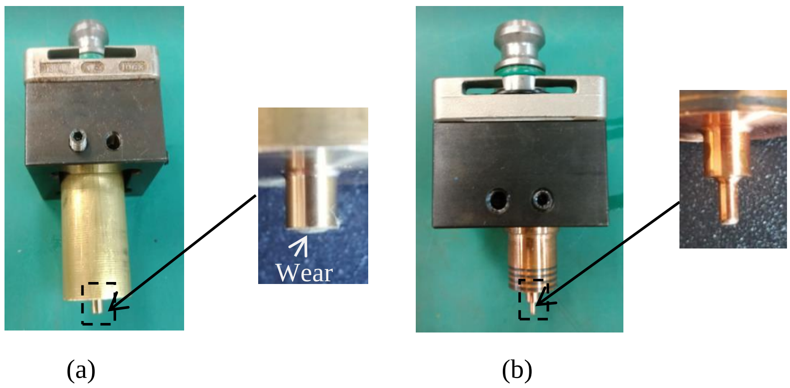

Figure 11. Tool Electrode Conditions (a) Magnified View of Brass Electrode (b) Magnified of Copper Electrode

Figure 11 shows the conditions of both electrodes. Figure 11 (a) is the brass electrode and it shows the obvious wear off as the tip of the electrode was used up during the process of the continuous discharge of the spark to remove the aluminium (Figure 11(b)). The electrical properties of brass is lower than copper. The melting point of brass is lower than copper which means that during the discharge of the spark to melt the material, it melt the brass electrode simultaneously.

CONCLUSION

By performing ANOVA and graphical analyses, the parameters of sparking gap, surface roughness (Rz) and type of electrode were investigated, and the interactions between the dimple measurements (diameter, depth and surface roughness R_a were studied. The mechanical property of tool electrode materials is important as it will affect the dimple measurement. The results were completely and successfully evaluated and analysed.

RECOMMENDATION

Some recommendations will be discussed as a reference for future research to improve the performance of the EDM dies sinking process for a micro dimple. Due to the limitation of EDM die sinking machine (Mitsubishi EA12D) used in the lab, it cannot choose the desired electrode material in the machine as it had been limited to a few of the material lists. Therefore, it was recommended to use the material that was already listed in the EDM die sinking machine. The following research can also be investigated with a similar sparking gap or surface roughness (R_z) but with different types of electrode materials which would lead to different dimple measurements of the micro dimple. Several data should be taken to obtain the average results to improve the data reliability.

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