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RESEARCH ARTICLE

Dimensional Accuracy, Surface Roughness and Hardness Properties for Microplate Implants Manufacturing by EDM Die-Sinking Process

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ABSTRACT – The high cost of manufacturing microplate implants is a primary issue. This is because the production of microplate implants uses the micro-milling and wire-EDM process. Production costs can be reduced using one machining process, and die-sinking EDM is an alternative in the manufacturing of microplate implants. This paper investigates the capability of EDM die-sinking in manufacturing microplate implants. This paper also studies the reaction of electrode materials and pulse currents to the microplate's dimensional accuracy, surface roughness and hardness. The process of EDM die-sinking uses electrodes of graphite and copper with pulse current variance of 6, 9, and 13 A. The experiment results indicate that the process of EDM die-sinking success in manufacturing microplates on commercially pure titanium sheets. Decreasing the pulse current can improve dimensional accuracy, smoothen surface roughness and minimize the hardness decrease of the microplate. These results are better using the copper electrode compare with the graphite electrode. The best quality of the microplate is at 93.3% dimensional accuracy, 5.28 µm surface roughness, and a 12% decrease in hardness. The best quality microplates was achieved by using copper electrodes with a 6 A pulse current.

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1.0 INTRODUCTION

A microplate is a type of jaw implant that functions to connect fractured or broken jawbones [1]. The average microplate needed in several Yogyakarta hospitals reaches 35 plates per month [2]. The availability of microplates is fulfilled by imported products, which are relatively expensive. The high cost of microplates on the market is due to the manufacturing process, which uses two machining processes (in terms of the shape of the cutting surface), namely wire-EDM and micro-milling. To reduce the cost, manufacturing microplates with a single machining process is required. The single machining process for microplate manufacturing can use die-sinking EDM. This is because die-sinking EDM uses cutting-edge technology and is extremely precise [3]. Die-sinking EDM uses erosion together with a discharge of electricity in a bath of dielectric liquid between the electrode and the workpiece to cut materials [4]. Therefore, the quality of workpieces resulting from EDM die-sinking is influenced by several process parameters, such as voltage (V) [5], pulse current (I_p) [6], pulse on time (T_{on}) [7], pulse off time (T_{off}) [8], die electric [9] and material of electrode [10]. The influence of process parameters has been investigated using various methods and various materials.

In steel materials, the full factorial method has been applied to investigate the effect of electrode shape on electrode wear rate (EWR), material removal rate (MRR), and surface roughness (Ra) [11]. The electrodes existed in the shapes of diamond, square, triangle, and round. Their cross-sectional area was always 64 mm^2. The results demonstrate that the round electrodes' MRR was the highest, followed by those with square, triangular, and diamond shapes. Diamond shape has a peripheral length that is the longest compared to other shapes. This causes higher heat loss in the environment, so the MRR value is the lowest. The electrode with a round form experiences the least amount of EWR, followed by electrodes with square, triangular, and diamond shapes. Because there are no exposed sharp corners at the sparking tip, the effect of electrode form on Ra shown is minimal. The square, triangular, and diamond-shaped electrodes generate smoother surfaces than a round electrode. The square-shaped electrodes were used by Chandramouli and Eswaraiah to optimize the EDM parameters with the Taguchi method [12]. The optimization results show that T_{on} and I_p have an important effect on MRR and Ra, while T_{off} has the least influence. The optimum parameter combination to get the largest MRR uses I_p of 15 A, T_{on} of 50 µs, and T_{off} of 100 µs. The lowest surface roughness can result in 9 A for I_p, 200 µs for T_{on}, and 20 µs for T_{off}. The Taguchi method appears to be effective in optimizing EDM process parameters. The Taguchi method has other models, namely Taguchi–Grey Relational Analysis (TGRA) and Taguchi-Technique for Order Performance by Similarity to Ideal Solution (TOPSIS).

The taguchi-TGRA method has been used by Nguyen et al. to optimize High Chromium Machine Capability Tool Steels [13]. The optimization results show that the electrical parameters I_p (5 A), V (50 V), T_{on} (18 µs), and T_{off} (37 µs) work best together to increase surface performance. The I_p is shown to have an impact on performance metrics by the maximum max-min grade value. The Taguchi-grey-based optimum process parameter combination with a 4.1% standard

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deviation has improved surface performance metrics. Additionally, choosing the GR grade coefficient is an important step in the TGRA approach. Utilizing the EDM technique's optimal process parameter combination led to an improvement in surface morphology. The Taguchi-TOPSIS Method was used by Huu-Phan and Muthuramalingam to improve the performance of the vibration-assisted machining EDM for tool steel [14]. The results show that productivity and quality improved when the specimen and appropriate vibration were combined. Periodicity has a significant impact on choosing a TOPSIS-based quality measure. With 10.4% accuracy, the best process parameters were identified as I_p (4 A), T_{on} (12 µs), T_{off} (5.5 µs), and frequency (F = 512 Hz) among the selected factors and variables. In EDM, the use of low-frequency vibration on the workpiece can improve surface quality. Surface quality has been predicted by Khan et al. using Artificial Neural Network (ANN) [15]. The predictions demonstrate that the constructed neural network model is suitable for Ra estimation, where the inaccuracy is within the tolerable range. Ra initially rises as I_p grows up to 15 A. Ra is showing a declining trend with high I_p (>23 A). The Ra is discovered to grow with T_{on}, however, the declining tendency is noticeable for T_{on} longer than 280–350 µs.

In titanium alloys, Perumal et al. have adopted the Taguchi method to optimize and investigate the effect of EDM parameters [16]. The investigation was carried out on a circular workpiece. The EDM parameters investigated were I_p, T_{on} and electrode diameter. The outcome of the investigation expresses that T_{on} has a greater effect on MRR and EWR than electrode diameter and pulse current. MRR and EWR increase with increasing T_{on}, I_p, and electrode diameter. The optimum parameter uses I_p of 3.5A, T_{on} of 1024 µs, and an electrode diameter of 10 mm. This condition can produce MRR and EWR of 0.0029 and 0.0018 mm^3/min, respectively. The EDM process parameters have been optimized by Verma and Sahu using the full factorial method [17]. This research produces circular hole products in Ti6Al4V where MRR value increases with decreasing T_{on} value, and Ra value is smaller with increasing T_{on} value. MRR is not considerably affected by V while Ra is observed to be greatest at greater V, I_p, and T_{on}. The percentage contribution of V, I_p, T_{on}, and fluid pressure in the case of MRR is 6.32%, 64.08%, 20.46%, and 5.60%, respectively, while in the case of Ra, are 10.63%, 70.78%, 6.92%, and 6.35% respectively.

The full factorial method has been applied by Zainal et al. to study the effect of process parameters on dimensional accuracy (DA) [18]—analysis of the experimental results using ANOVA. The results of the investigation show that T_{on}, V, and I_p are significant parameters that influence DA. The resulting prediction is quite good according to the experimental results, with an R-squared DA value of 0.9085. The minimum DA is obtained using 150µs for T_{on}, 60V for V, 60µs for T_{off}, and 10A for I_p, while the maximum DA has resulted using 230µs for T_{on}, 30V for V, 60µs for T_{off}, and 12A for I_p. Khan et al. have used the full factorial method to study EWR in EDM die-sinking processes [19]. The electrode material used is graphite. The impact of the parameters of V, T_{on}, T_{off}, and I_p was also investigated. In addition, a mathematical model has been developed to predict the EWR. Using experimental data, a mathematical model based on the response surface approach was created. The model's fitness was confirmed by using RSM to implement an analysis of variance. The average error for the created model's accuracy was found to be 5.74%. The performance of EDM with respect to electrode wear during an EDM process on Ti-5Al-2.5Sn can be accurately predicted by these mathematical models. A combination of 15 A (I_p), 350 µs (T_{on}), 180 µs (T_{off}), and 95 V (V) resulted in negative tool wear. Additionally, the greatest negative EWR is produced when 75 V for *V*, 16.5 A for I_p, 350 µs for T_{on}, and 60 µs for T_{off} are combined.

Gugulothu has studied the effect of process parameters on MRR and Ra using the Taguchi method [20]. This research produces a hole product with a circular shape. The results of his study show that the interaction between the dielectric fluid and the I_p greatly influences the value of Ra. Dielectric fluid using drinking water will result in maximum MRR and reduce the Ra. T_{on} has a more significant effect than I_p for Ra, while I_p has a more significant effect than T_{on} for MRR. The maximum MRR of Ti-6Al-4V was 5.46 mm^3/min using drinking (dielectric fluid), 20 A (I_p), and 65 µs (T_{on}). The minimum Ra was 2.25 µm using deionized for dielectric fluid, 10 A for I_p, and 25 µs for T_{on}. Taguchi approach was utilized by Phan et al. to identify the best settings for the AlCrNi-coated electrodes [21]. The machinability of the micro EDM process can be improved by the AlCrNi-coated electrode. Among the selected factors, the ideal combination of 140V for V, 10 nF for capacitance, and 200 rpm for tool rotation might produce superior quality measurements. AlCrNi-coated electrodes were also applied by Huu et al. to improve the surface quality of micro-EDM processes [22]. The optimum parameter has been selected based on the input parameters 40 A for I_p, 55 V for V, and 1000 µs for T_{on}. The Ip has the greatest influence on all the input parameters in EDM with layered electrodes. The topography of the machined surface has been significantly upgraded to the lowest Ra. Both the quantity and size of microscopic fractures have decreased with the use of AlCrNi-coated electrodes.

Huu et al. have also applied a TiN-coated tungsten carbide electrode to investigate TWR [23]. It was found that capacitance has a more significant influence on the EDM process. The surface quality of the machine is improved by applying TiN coated to the tungsten carbide electrode. The tungsten carbide electrode used by Huu et al. for Multi-objective optimization of micro EDM [24]. Optimization using the Tagchi-TOPSIS method. Optimization shows that the EDM process using a voltage of 160V with a capacitance of 10 nF and an electrode speed of 400 rpm can produce better machinability. Tungsten carbide electrodes can produce fewer micro-cracks and void Ti6Al-4V. Carbon-coated WC electrodes have been used by Van et al. for the Development of AHP-embedded Deng's hybrid MCDM model in micro-EDM [25]. The results showed that Taguchi–Deng's method is the right solution for multi-target decisions in micro-EDM using the coated electrode. Carbon coating is the strongest impact on optimal efficiency, and V is the smallest. The machining quality under optimal conditions is improved by carbon coating on the electrode.

In pure titanium, Meena et al. have optimized the micro-EDM process parameters by Taguchi-TGRA [26]. The optimized parameters combine I_p, F, and T_{on}. The EDM performance investigated includes MRR, EWR and OC in making circular holes. The findings demonstrate that the best performance was produced with parameters of 125 kHz for F, 35 mA for I_p, and 1 μs for T_{on}. The best parameters produced were 0.006495 mm^3/min for MRR, 0.005959 mm^3/min for EWR, and 0.048 mm for OC. Among the three parameters, I_p has the most bearing on the micro-EDM machining of commercially pure titanium. TGRA can be used efficiently to optimize parameters simultaneously and get the desired outcomes. Results accuracy is based on effective parameter setting. Yan et al. have adopted the full factorial method to investigate the effect of urea solution in water as an EDM dielectric [27]. The investigation was carried out by fabricating circular holes. The investigation results showed that urea mixed with dielectric water caused a decrease in MRR and EWR. MRR and EWR increase with increasing I_p and T_{on}. The Ra deteriorated after the urea was applied to the dielectric, and I_p increased.

Many previous studies have shown that the investigation of the influence of process parameters was carried out in manufacturing circular, square, triangular and diamond holes. Additionally, the influence of parameters has also been studied in the manufacture of cardiovascular stents [28]. The influence of the parameters and optimum parameters shows the difference in results due to differences in the types of materials used and the shape of the products made. In other words, the material and product shape are different, so the optimum parameters are also different. Determining the process parameters for the fabrication of microplate implants will be difficult. This is because the investigation of the effect of EDM process parameters on pure titanium is still limited to making circular holes. This study aims to investigate the dimensional accuracy (DA), surface roughness (Ra) and hardness (Hv) of microplate implants that can be achieved by the EDM die-sinking process. The responses of electrode material and pulse current to dimensional accuracy, surface roughness, and hardness on the microplate were also investigated by the full factorial method.

2.0 MATERIALS AND METHOD

The microplates are made of commercially pure titanium (CP-Ti) with a purity of 99.8% (Nilaco, Japan). The CP-Ti workpiece used has a hardness of about 160 HV, with a thickness of 0.4 mm. The workpiece material is shaped like a rectangle, measuring 100×10×0.4 mm. Figure 1 shows the design of the microplates fabricated in this study. Copper and graphite are the materials used to make the electrodes for this study, and Figure 2 displays their geometry. The purity of copper and graphite used was 99.8% and 99.7%, respectively. Based on references, copper and graphite were chosen as electrode materials [15], [29]. The pulse current that has successfully carried out the EDM process on pure titanium is 10 A, based on reference [27]. However, the machine used in this study has limited current settings that are multiples of 3, and the maximum current is 13 A. Therefore, this study uses pulse current variations of 6, 9 and 13 A.

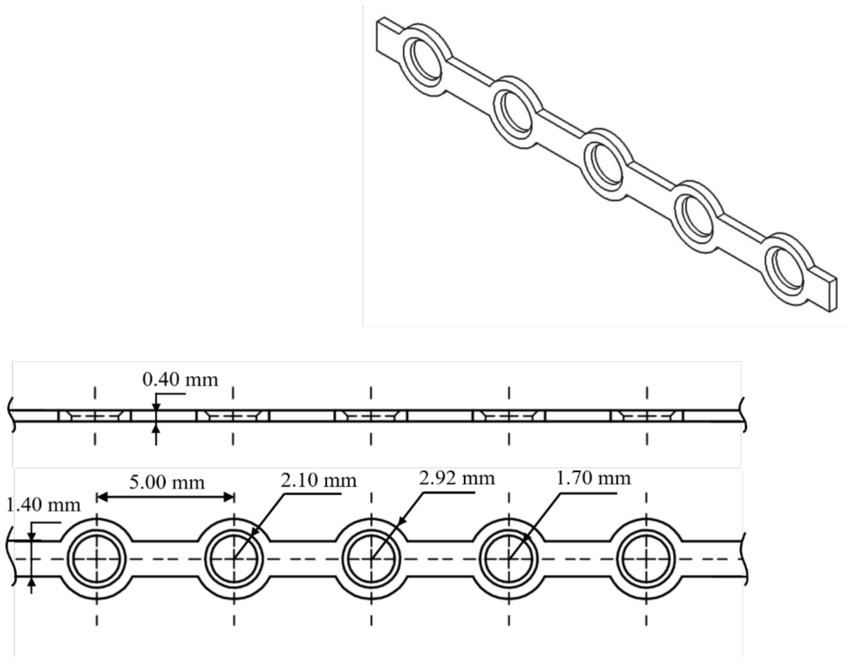

Figure 1. Shape of microplate implant

The experiment was carried out on a CNC EDM die-sinking Machine (JOEMARS AZ50, Taiwan). The schematic of the die-sinking EDM machine is illustrated in Figure 3. A fixture was used to clamp the workpiece and electrodes to the EDM. In the die-sinking EDM machine, a servo mechanism moves the electrode toward the workpiece while controlling this movement. The rinsing system is installed on the spindle for side and internal rinsing. The dielectric fluid utilized in this process is EDM oil Grade 30. The parameter settings are established, and machining is done until the electrode moves down by 0.5 mm. Table 1 displays the machining parameters used. After the machining process is complete, the electrodes and workpiece are unloaded and dried.

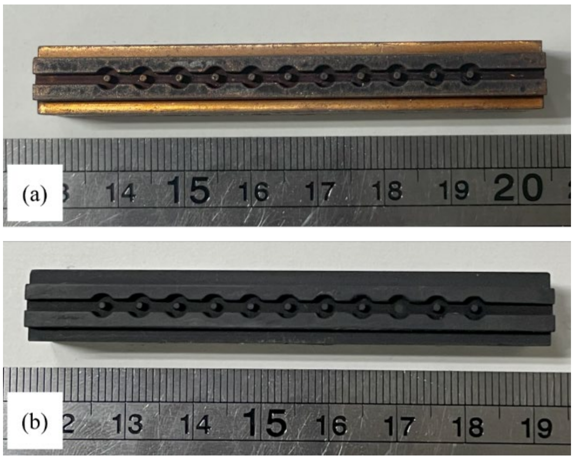

Figure 2. Electrode shapes for (a) copper and (b) graphite

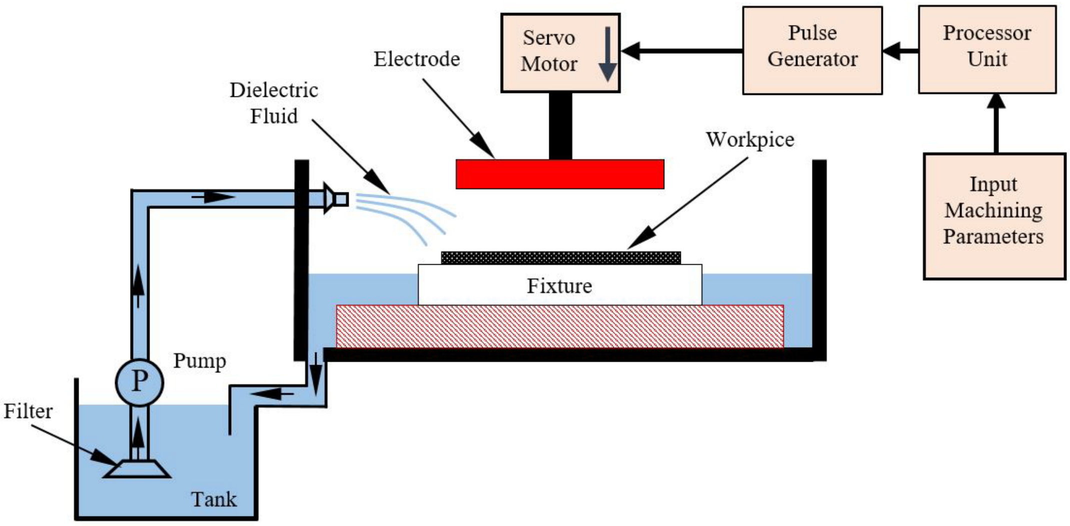

Figure 3. Schematic of die-sinking EDM machine

Table 1. Parameters for the machining process

Experiment	1	2	3	4	5	6
Electrode	Copper	Copper	Copper	Graphite	Graphite	Graphite
I_p (A)	6	9	13	6	9	13
T_{on} (μs)	28	28	28	28	28	28
T_{off} (μs)	29	29	29	29	29	29

Dimensional accuracy (DA) is calculated using Eq. (1) for the inner radius, Eq. (2) for the outer radius and Eq. (3) for the straight side [18].

$$DA_{ir} = (DH_E - DH_W)/DH_E \times 100\% \quad (1)$$

$$DA_{or} = (DW_w - DW_E)/DW_E \times 100\% \quad (2)$$

$$DA_{ss} = (LW_W - LW_E)/LW_E \times 100\% \quad (3)$$

where, DH_E is the inner diameter hole for the electrode (in mm), DH_W is the inner diameter hole for workpiece (mm), DW_E is the outer diameter hole for electrode (mm), DW_W is the outer diameter hole for workpiece (mm), LW_E is the width for electrode (mm) and LW_W is the width for workpiece (mm). The dimensions of the electrode and microplate were measured using a digital calliper (Mitutoyo, Japan). Measurement position for dimensional accuracy is shown in Figure 4.

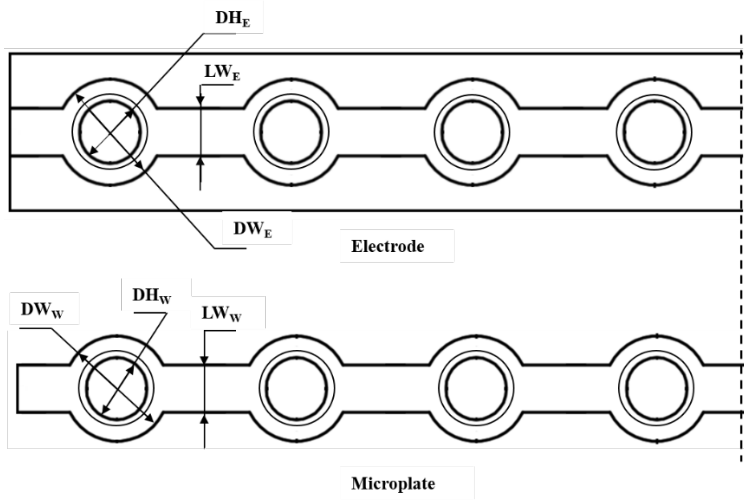

Figure 4. Measurement position for dimensional accuracy

An optical microscope made in Taiwan (Dino-lite AM2111) was used to examine the cutting surfaces. Observations were made on the cutting edge of the straight side. American-made roughness test (Fowler Surfcorder SE1700) was used to measure the surface roughness. The hardness of the microplate was measured by the Vickers micro-hardness test (BUEHLER) with 100 grams for load and 10 s for load time. Measurement was conducted at the cross-section of the outer radius, inner radius and straight side, as shown in Figure 5.

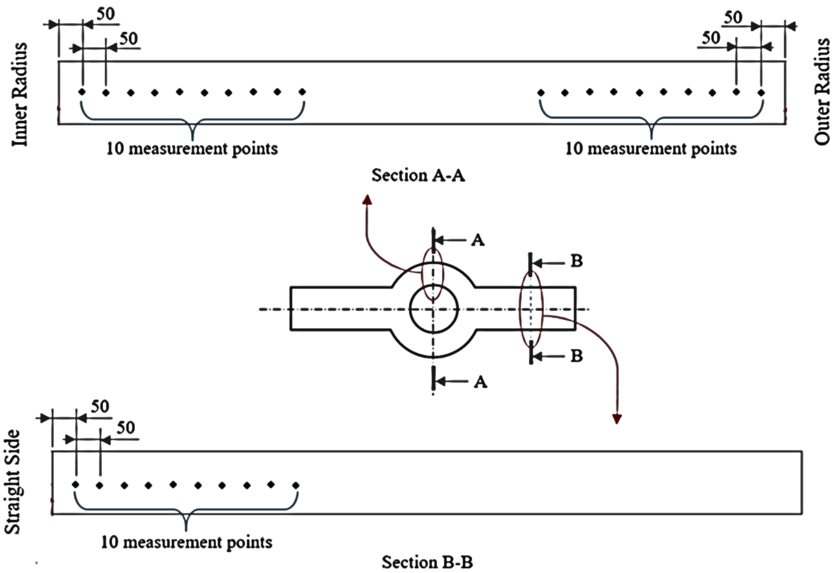

Figure 5. Position of hardness measurement

3.0 RESULTS AND DISCUSSION

3.1 Dimensional Accuracy

Figure 6 shows the microplate resulting from the EDM die-sinking process using copper and graphite electrodes. The resulting microplate implants using copper electrodes with a pulse current of 6 A in Figure 6(a), 9 A in Figure (b), and 13 A in Figure (c) look straight. This phenomenon also occurs in the similarity of microplate shape to graphite electrodes with pulse current of 6 A, 9 A and 13 A as in Figure 6(d), Figure 6(e), Figure 6(f) respectively.

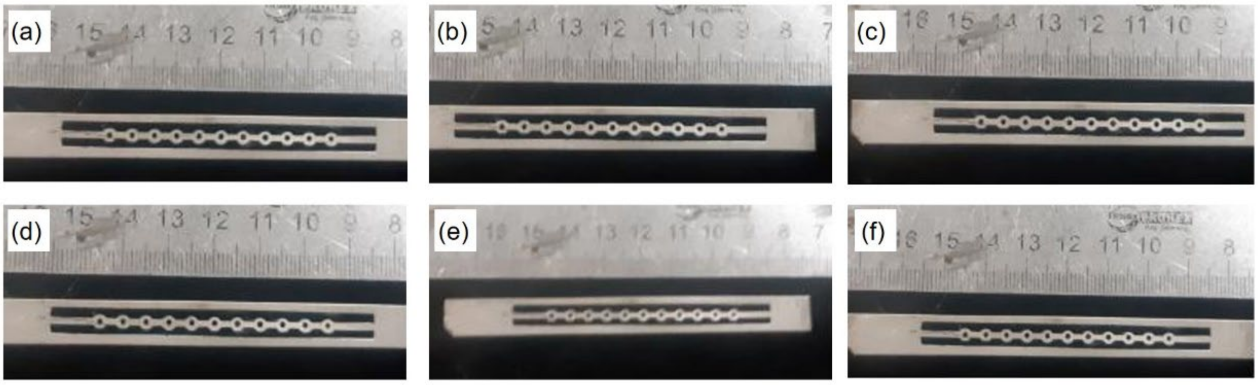

Figure 6. Microplate resulting from the EDM die-sinking process with (a) copper, 6 A, (b) copper, 9 A, (c) copper, 13 A, (d) graphite, 6 A, (e) graphite, 9 A, and (f) graphite, 13 A

The dimensional accuracy of the microplate resulting from the process of EDM die-sinking is presented in Figure 7. Dimensional accuracy resulting decreases when the pulse current increases. When utilizing a copper electrode and a 13-pulse current, dimensional accuracy is 86.8%. The dimensional accuracy produced by copper electrodes is lower than using graphite electrodes. It's because graphite electrodes have superior electrical characteristics to copper electrodes in terms of electrical resistance. Copper has an electrical resistivity of 1.724 x 10-8 Ωm, whereas graphite has a resistivity of 360 x 10-5 Ωm [10], [30]. The material may flow current more readily, as evidenced by the higher electrical resistivity. It indicates that the copper electrode's pulse current is less intense than that at the graphite electrode. Lesser sparks will result from the electrode's electrode receiving a lesser pulse current. The smaller sparks caused the crater to form shallower and shorter. This results in less material cutting and lower dimensional accuracy.

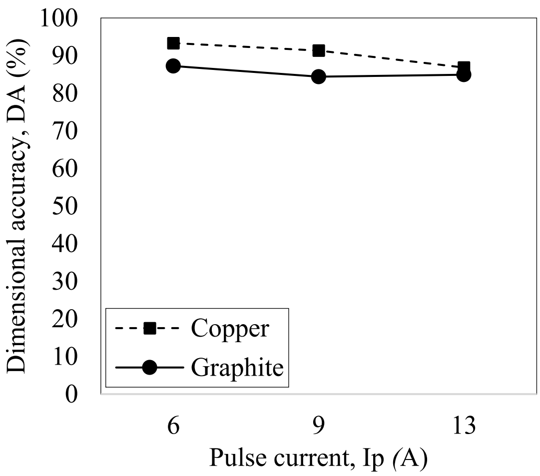

Figure 7. Relationship between the electrodes and the pulse currents to the dimensional accuracy of the microplate

3.2 *Surface Roughness*

Figure 8 shows the outcome of the observation of the microplate implant's cutting surface. The figure demonstrates how the resulting surface has a varied shape. In comparison to 9 A and 13 A pulse currents, the surface morphologies with 6A pulse current are more clearly visible at copper and graphite electrodes. Figure 9 displays the outcomes of a surface roughness tester's measurements of surface roughness. The image illustrates how surface roughness (*Ra*) is smaller at a 6 A pulse current than it is at 9 and 13 A. Compared to graphite, copper electrode has a smoother surface.

Figure 10 shows the impact of electrode material and pulse current on the cutting surface's roughness. The roughness of the cutting surface will increase with increasing pulse current. Compared to 6 A pulse current using graphite electrodes, the surface roughness of 1.78 µm is rougher when copper electrodes were used. When utilizing 13 A for pulse current, the surface roughness of 3.01 µm is rougher than using 9 A for pulse current. The increased surface roughness results from the increased pulse current, which increases the energy of initial spark. A bigger force will be produced on the workpiece surface due to the greater initial spark energy. It makes the crater that is created on the surface deeper and wider in both diameter and depth [28], [31], [32]. The profile height (Rz) on the surface roughness profile gives an indication of the crater depth. Rz is equal to 11.75 µm for 6 A, 24.08 µm for 9 A, and 49.41 µm for 13 A with copper electrode. Figure 5 illustrates how the deeper the crater, the rougher its surface will be. When applying a pulse current of 6A instead of 13A, the morphological surface is more uniform. These outcomes are in line with earlier research that have been published [6], [8], [17], [18], [28], [32]–[35].

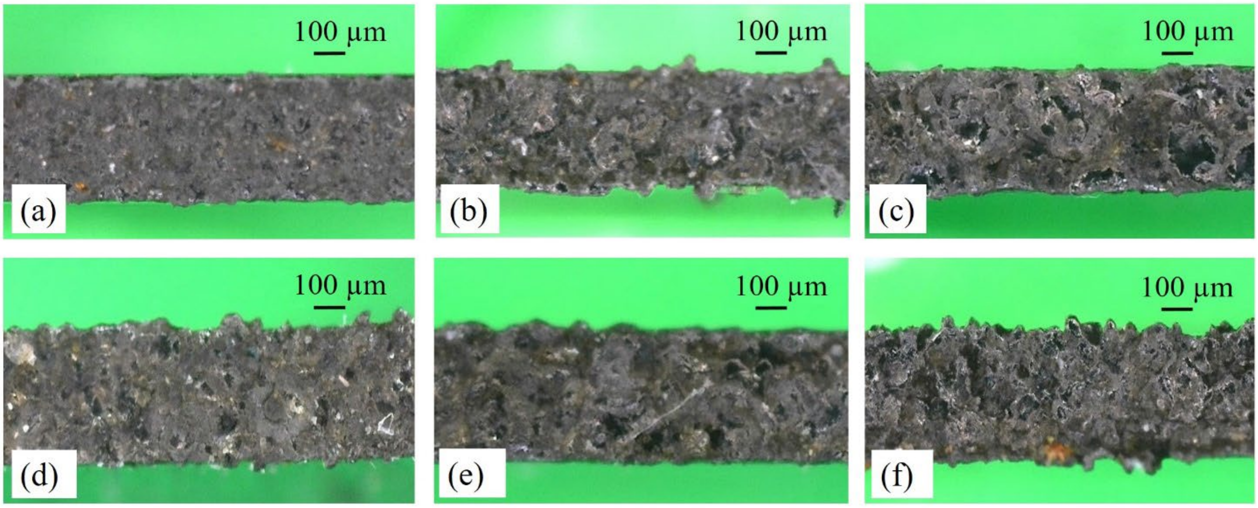

Figure 8. Surface morphologies when using (a) copper, 6 A, (b) copper, 9 A, (c) copper, 13 A, (d) graphite, 6 A, (e)graphite, 9 A, and (f) graphite, 13 A

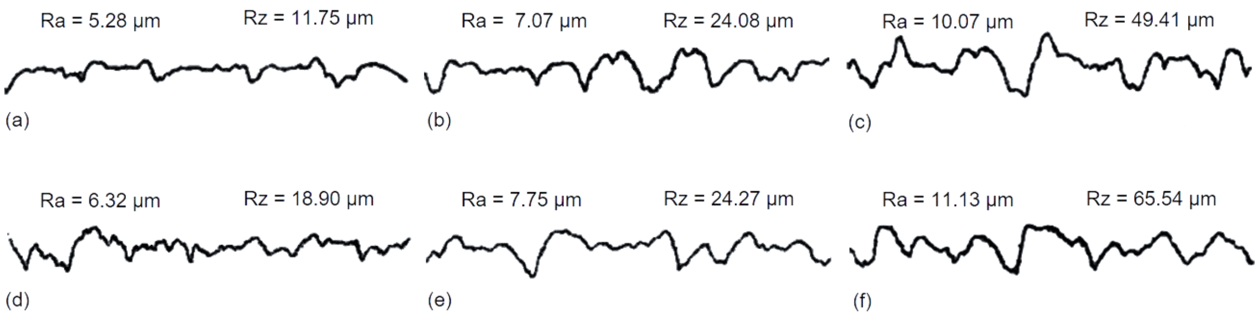

Figure 9. Profile of the Surface roughness when using (a) copper, 6 A, (b) copper, 9 A, (c) copper, 13 A, (d) graphite, 6 A, (e) graphite, 9 A, and (f) graphite, 13 A

With reference to Figure 10, it is clear that the electrode material has an impact on the surface roughness outcomes. The electrical characteristics of graphite and copper electrodes differ, which results in influence. With 6, 9, and 13 A for pulse currents on a copper electrode, the resulting surface roughness was 5.28, 7.07, and 10.07 µm, respectively. In comparison to the graphite electrode, it is smaller. Because material of graphite has a higher electrical resistance than copper, surface roughness is higher when employing graphite electrodes than copper electrodes. [10], [30]. According to the pulse current impact on surface roughness, the higher electrical resistance might lead to a deeper depth in the crater. Rz is 11.75 µm m with copper electrodes and 18.90 µm m with graphite electrodes while utilizing a 6 A pulse current. According to Figure 5, the deeper crater has a rougher surface morphology. Compared to graphite electrode, copper electrode produces a smoother surface morphology.

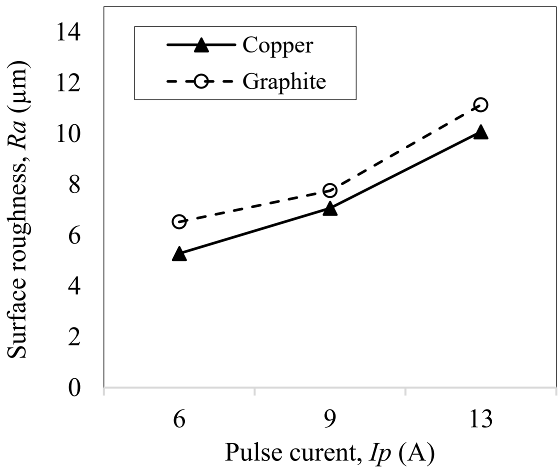

Figure 10. Relationship of electrode material and pulse current to surface roughness

3.3 Hardness

The EDM die-sinking process affects the workpiece hardness. The results of hardness measurements near the cutting surface at the outer radius, inner radius and straight sides are shown in Figures 11 and 12. Workpiece hardness on the outer radius, inner radius and straight sides after the EDM process appears below the initial hardness value. It decreases when using copper or graphite electrodes.

The EDM process can reduce the workpiece hardness because the cutting process uses sparks. Spark that contacts the workpiece cause increasing the workpiece temperature to the melting temperature. Simultaneously flowed dielectric fluid which can throw melted workpieces and cool the material. The process of heating and cooling the workpiece repeatedly using the pulse method causes the material to become soft such as the annealing effect of electro-pulsing [36], [37]. The decreasing hardness is related just not to the annealing effect induced by current of electric and the influence of the Joule heating, but also to the effect of purely electro-plastic of the electric pulses) [38]. Xie et al. suggested a model of flow stress by seeing the influence of elastoplasticity and modifying the classic model of Johnson-Cook [39]. The mathematical statement is stated as follows:

$$\sigma = (\gamma + b\varepsilon^k)\left[1 + cln\left(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_{ref}}\right)\right]\left[1 - \left(\frac{t - t_{rom}}{t_{melt} - t_{rom}}\right)^u\right]exp\left(dI\sqrt{F}\right) \quad (3)$$

where γ, b, k, c and u are the parameters similar to Ref. [39], ε is the equivalent of plastic strain, $\dot{\varepsilon}$ is the rate of plastic strain, $\dot{\varepsilon}_{ref}$ is the rate of reference plastic strain, t_{rom} is the room of temperature, t_{melt} is the temperature of material melting, d is a constant of the material constant, I for current, and F for the frequency of pulse.

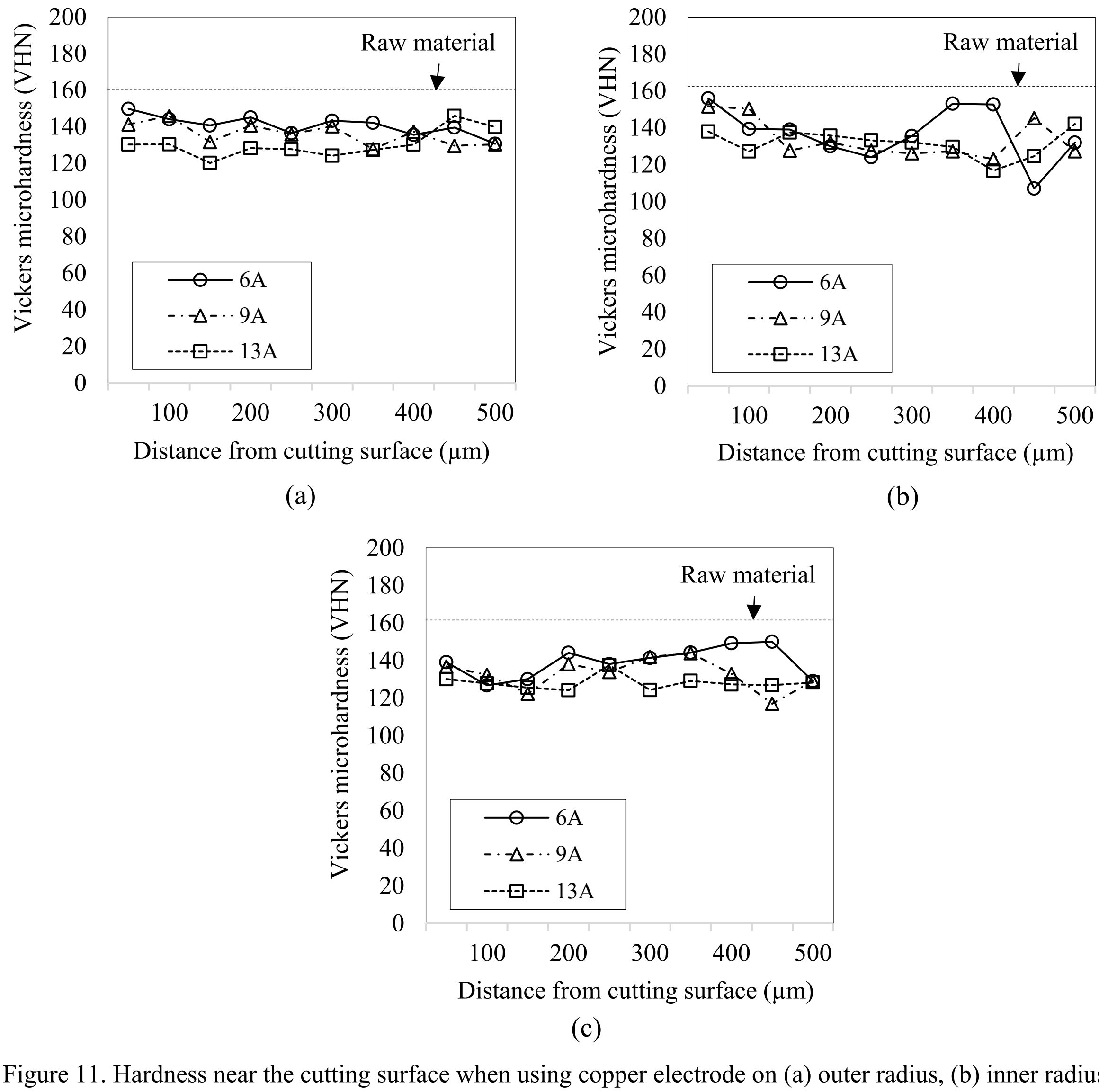

Figure 11. Hardness near the cutting surface when using copper electrode on (a) outer radius, (b) inner radius, and (c) straight sides

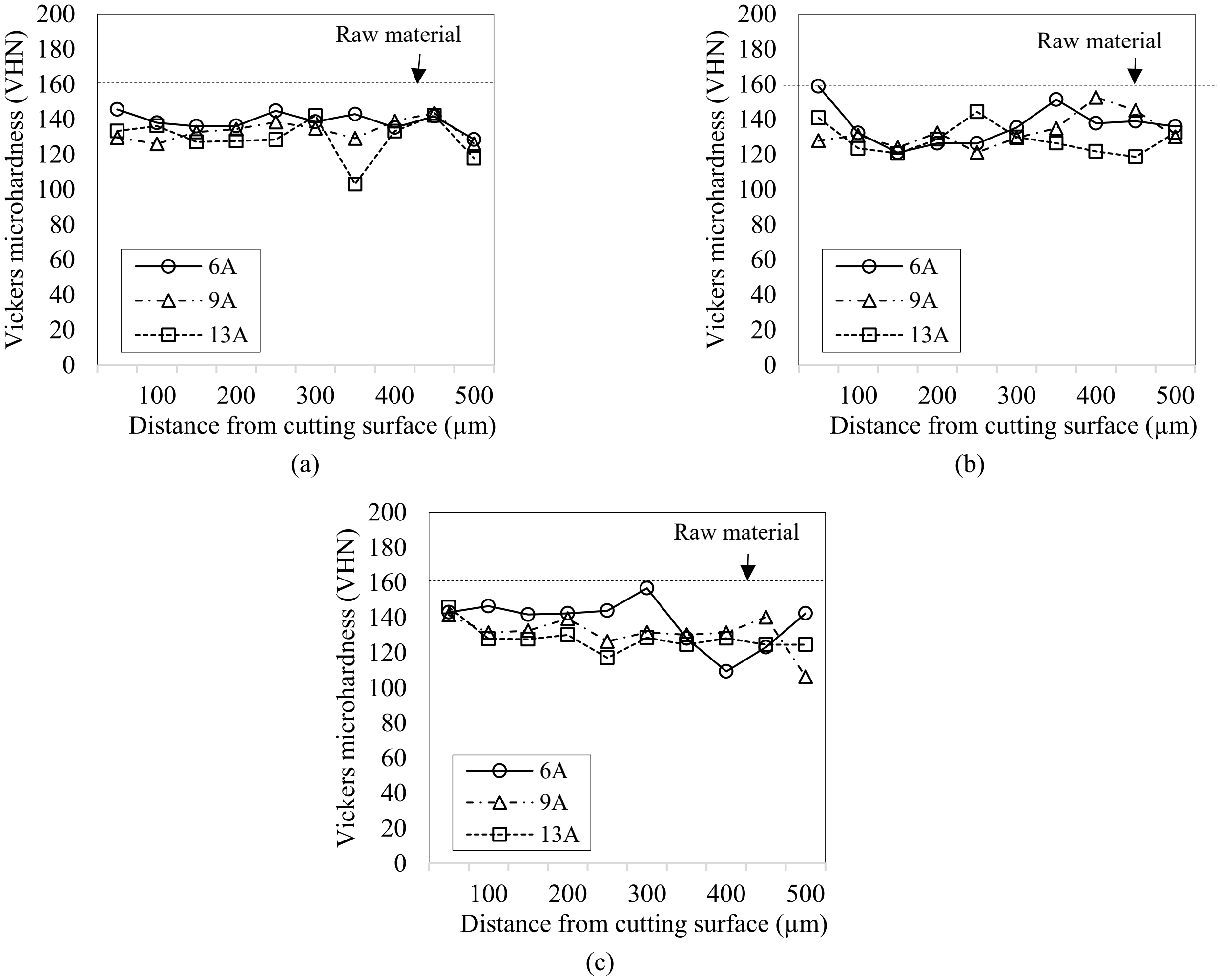

Figure 12. Hardness near the cutting surface when using graphite electrode on (a) outer radius, (b) inner radius, and (c) straight sides

Equation 3 shows that the last factor introduces the effect of electro-plastic, and $I\sqrt{f}$ is comparable to the current effectiveness. This means the current of electric direction to the movement of dislocation. Rising the effective current can expedite interactions between dislocations and electrons. It is advantageous for reducing flow stress. Therefore, with an increase in the pulse current, the hardness of the material decreases significantly, as shown in Figure 13. The decrease in material hardness occurs on the outer radius, inner radius and straight sides with graphite and copper electrodes. The greatest decrease in hardness occurs in the outer radius, inner radius and straight side when using a pulse current of 13 A with a copper electrode of 7%, 4% and 8%, respectively compared to a pulse current of 6 A. The hardness decreased by 7%, 6% and 7% on the outer radius, inner radius and straight side, respectively when using a pulse current of 13 A with a graphite electrode.

Referring to Figure 13, decreasing hardness when adopting electrodes from graphite material is bigger than the electrode from copper material. This is because graphite can absorb dielectric fluids. It causes the graphite to be capable of flowing larger currents than copper. A larger current will produce a larger spark. It causes the annealing effect generated by the current and the effect of the Joule heating to be greater [38], so that the decrease in hardness becomes large. Therefore, the decrease in workpiece hardness using electrodes from graphite is greater than the electrodes from copper. The average value of the workpiece hardness when using copper electrodes is about 1-3 VHN larger than graphite electrodes on all three sides. The average hardness of microplate implants that can be achieved by EDM die-sinking is around 137.6 VHN. This hardness is still below the starting materials.

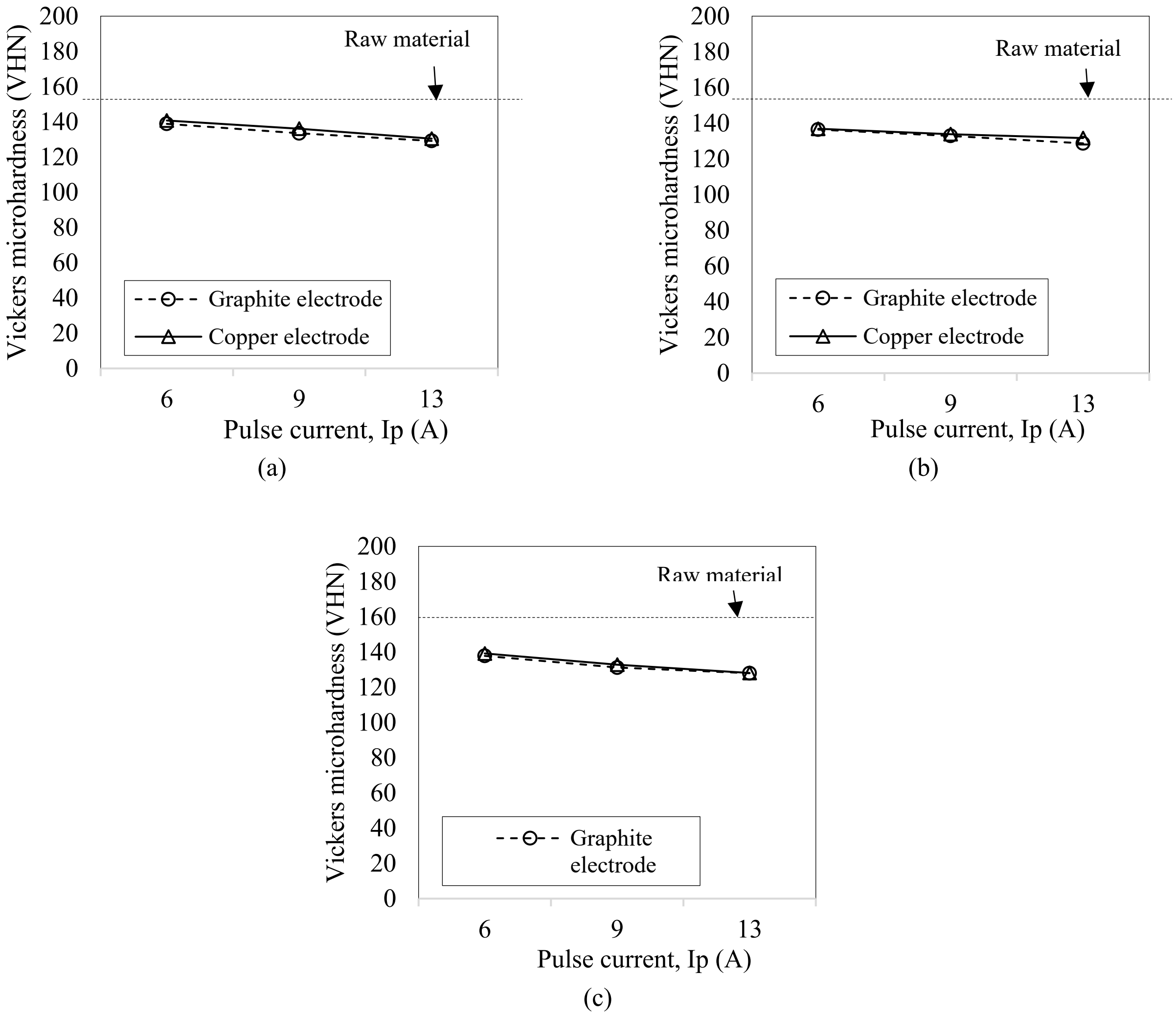

Figure 13. Average hardness near the cutting surface when using graphite electrodes on (a) outer radius, (b) inner radius and (c) straight side

4.0 CONCLUSIONS

EDM die sinking process successfully cut pure titanium sheets with microplate implant shape. The highest accuracy of the resulting microplate shape reaches 93.3% when using a copper electrode and 87.2% when using a graphite electrode. The highest accuracy can be achieved using a pulse current of 6A. The smoothest surface roughness is produced using a copper electrode with a pulse current of 6A. The resulting roughness reaches 5.28 µm; this is still rougher than the roughness of microplate implants on the market (about 2.50 µm).

Workpiece hardness decreases due to the EDM die-sinking process. The highest hardness of the resulting microplate implants was 137 HVN and 139 HVN with graphite and copper electrodes, respectively. This hardness is still below the microplate implants that are on the market, around 160-165VHN. In other words, a process of increasing the hardness of microplate implants is required if one is to apply them. The best quality of the microplate resulted when using a 6A pulse current with the copper electrode. Forthcoming research is expected to develop more parameters to minimize decreasing hardness in the manufacturing process of microplates adopting the process of EDM die-sinking.

5.0 ACKNOWLEDGEMENT

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