# A STUDY ON ELECTROCHEMICAL MACHINING PERFORMANCE ANALYSIS OF SHAPE MEMORY ALLOY WITH ELECTROLYTE AND ELECTRODE

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**Abstract** - Nitinol shape memory alloy (SMA) is used in various industries such as medicine and aerospace. Micro-scale and complex shapes of SMA are often needed. Electrochemical machining is a non-contact method that has advantages regarding defects like thermal strain and micro burrs compared to other non-conventional machining methods, such as laser machining, electro-discharge machining, and etching. An insulated electrode is required for precise electrochemical machining. In this study, current density analysis was performed to determine the current density for three types of electrodes. The isolated electrodes had high current density in the same conditions. The workpiece was nitinol SMA. Square shapes were fabricated in electrochemical machining using a square electrode, a square electrode insulated on only the sides, and a square electrode insulated on the sides and center. The influence of the insulation layer on the applied current has been investigated. It is possible to obtain precise square shapes on SMA if the insulation layer controls the unnecessary current between the electrode and workpiece, which would be helpful in the medical and aerospace industries. The square electrode without an insulation layer creates inexact square shapes due to the unnecessary current. The side-insulated electrode creates precise square shapes. The most precise square shapes were found when the square electrode insulated on the sides and center was applied because the insulation layer concentrates the unnecessary current on the machining area and improves the removal rate.

**Index Terms** - Shape memory alloy (SMA), Micro machining shape, General electrode, Fillet electrode

## I. INTRODUCTION

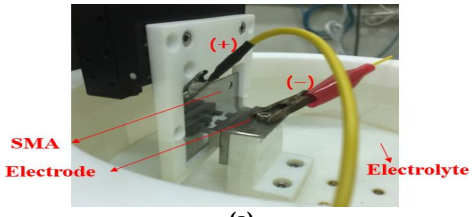
Nitinol shape memory alloy (SMA) is used in various industries, such as medicine and aerospace. SMA has a characteristic called the shape memory effect, which involves the recovery of deformed alloy to its original state through the application of temperature or stress. Micro-scale and complex shapes of SMA are often needed [1]. Non-traditional machining methods that have been researched for smart materials include laser machining, electro-discharge machining, MR fluid machining, etching, and electrochemical machining [2-3]. Electrochemical machining can be used without stressing or transmuting the material through non-contact machining between the tool and workpiece using metal dissolution by electrochemical reaction.

In electrochemical machining, the material and an electrode with a specific shape are placed in an electrolyte. Then, electrochemical dissolution of the material is generated by the electrode after current is applied to the material, which is connected to an anode (+), and to the tool electrode, which is connected to a cathode (-). An oxidization-deoxidization process occurs between the material and tool electrode. An insulated electrode is required for precise electrochemical machining. The influence of the insulation layer on the applied current has been investigated [4-5].

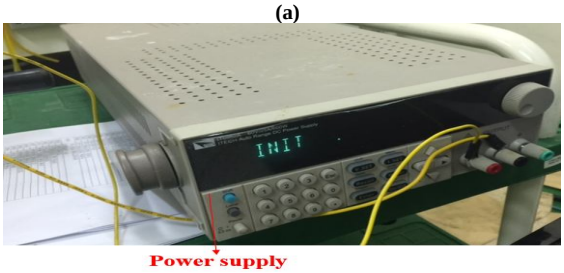
In this study, the processed shapes were compared with the ratio of the gap and the electrolytic solution, which is a factor influencing the shape memory alloy.In addition, the current flow was analyzed for general electrodes and fillet electrodes. Finally, machining shapes were fabricated in nitinol with electrochemical machining using the electrodes. It is possible to obtain precise square shapes on SMA using the general electrodes and fillet electrodes.[1-3].

## II. EXPERIMENTAL SETUP

Fig. 1 shows the experimental electrochemical machining system. The workpiece was SMA with 51% Ni and 49% Ti. A cathode made of still was used for the electrode. The anode was connected to the SMA, which was connected to a dedicated jig. A power supply supplies the current. Table. 1 shows the experiment conditions. Machining was performed by immersion in an electrolyte. The type of electrolyte was 0.2mol NaCl, 0.6mol NaCl, 1mol NaNO3and1.5mol NaNO3. Electrode gap was0.5mm. The constant current is employed in this experiment, and the current value is 30A.




**(a)**



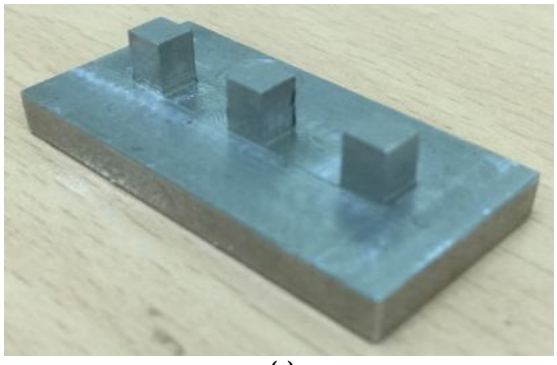

**(b)**

**Fig. 1 Experiment system**

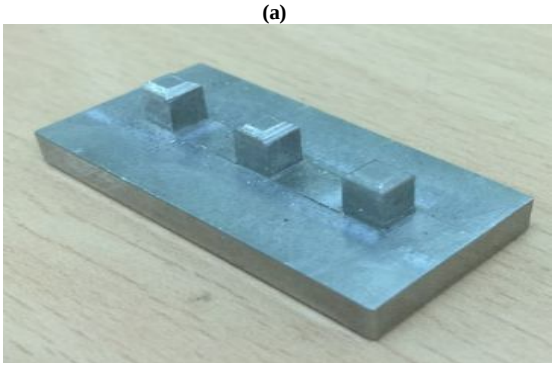
| Conditions | Value |
|---|---|
| Current | 30A |
| Electrolyte | 0.2mol NaCl, 0.6mol NaCl, 1mol NaNO3, 1.5mol NaNO3 |
| Electrode | General electrode, Fillet electrode |
| Electrode gap | 0.5mm |
| Workpiece | Shape memory alloy |

**Table 1. Experiment condition**

Fig. 2shows the electrodes used in the experiment. The electrodes type was general electrode andfillet electrode. The shape of electrodeswas square shape and the size of electrodes was 4mm x 4mm. A general electrode was an electrode of normal. The fillet electrode was filleted at the corners. By filleting, it is possible to adjust the processing shape by changing the current flow. It is possible to control the working shape by controlling the current flow.



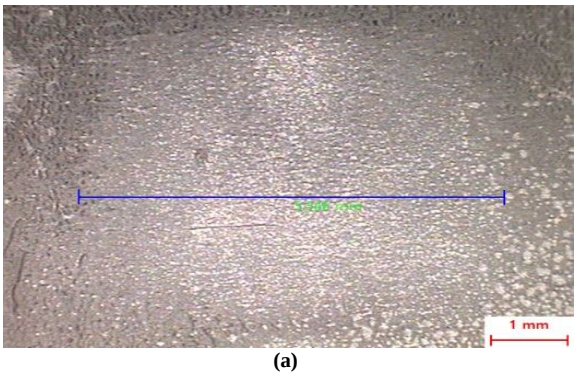
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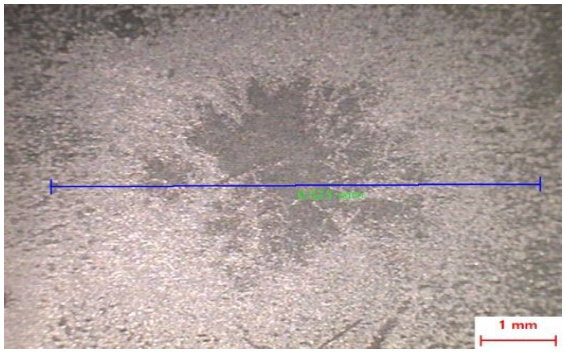
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**Fig. 2The type of electrodes**

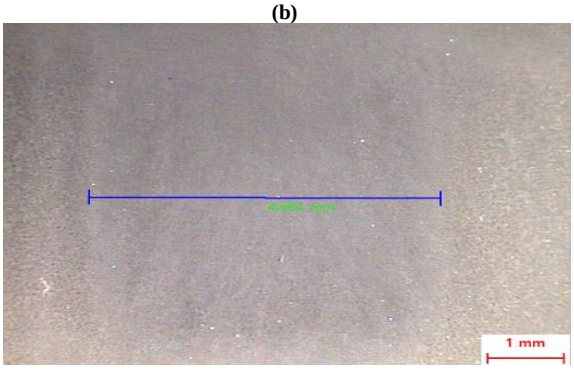
## III. RESULTS AND DISCUSSION



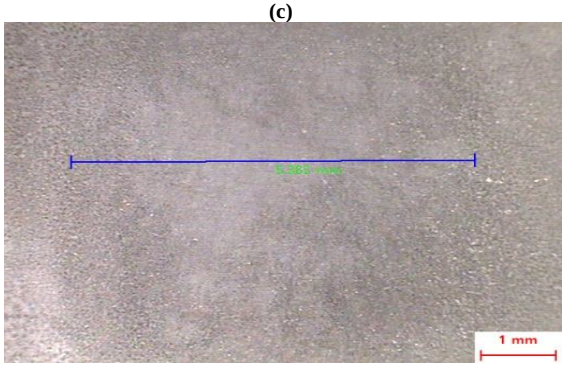

**(a)**




**(b)**




**(c)**




**(d)**

**Fig. 3Micrographics of SMA experiment according to electrolyte using general electrodes (x40)**

Fig. 3 shows micrographs of SMA experiment according to electrolyte using general electrodes. Fig. 3-(a)the machined shape from the0.2mol NaCl, (b) shows the results used 0.6mol NaCl, (c) shows the results used 1mol NaNO3, (d) shows the results used 1.5mol NaNO3. In case of thefig. 3-(a), the machined into a square shape, and the size of the shape is 5.546mm.In case of the fig. 3-(b), the machined into a non-square shape, and the size of the shape is 6.523 mm. in case of the used NaCl, the higher the electrolyte density, the more difficult it is to adjust the processing shape. Fig. 3-(c) shows the machined into a square shape, and the size of the shape is 4.604 mm.Fig. 3-(d) shows the machined into a square shape, and the size of the shape is 5.383 mm. in case of the used NaNO3, the shape of the machining is not clear.However, even if the density increases, the machined shape wasa square.

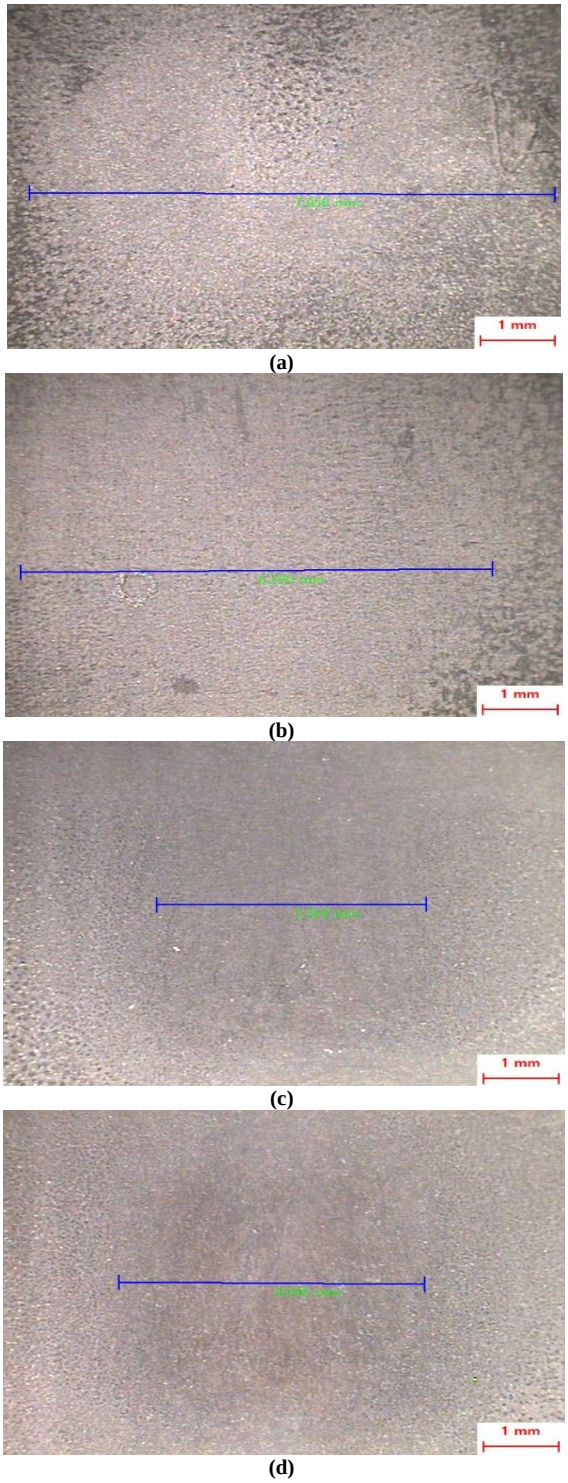
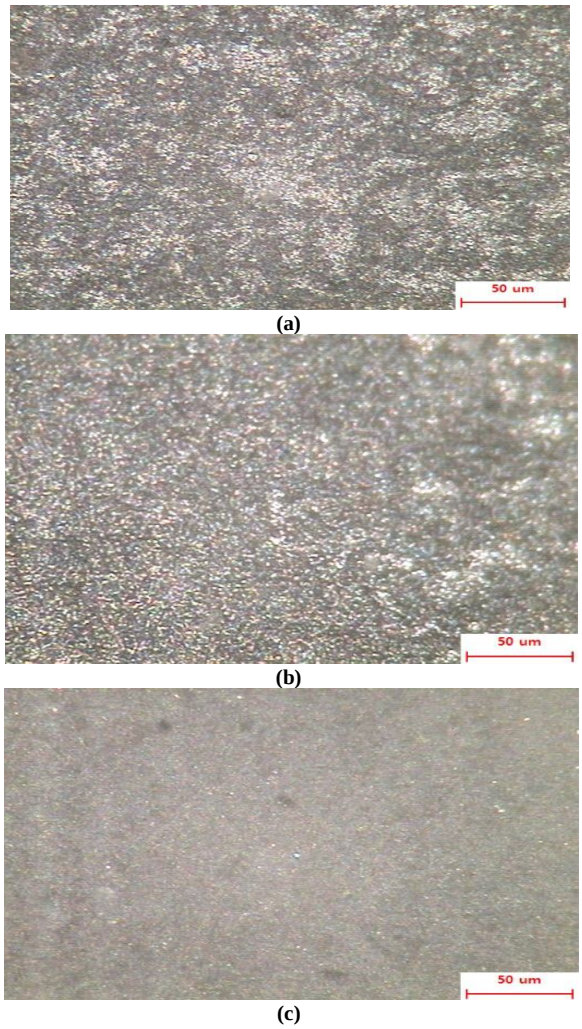
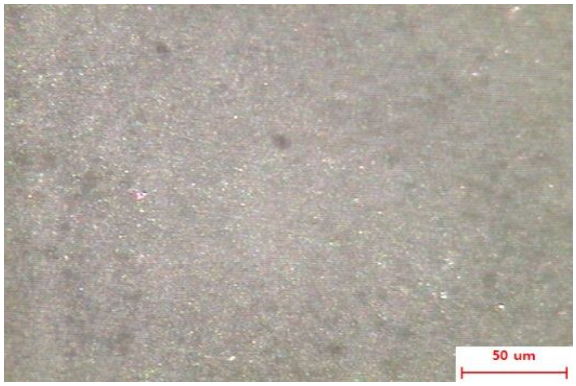



**Fig. 4Micrographics of SMA experiment according to electrolyteusing fillet electrodes (x40)**

Fig. 4 shows micrographs of SMA experiment according to electrolyte using fillet electrodes. Fig. 4-(a)the machined shape from the0.2mol NaCl, (b) shows the results used 0.6mol NaCl, (c) shows the results used 1mol NaNO3, (d) shows the results used 1.5mol NaNO3. In case of thefig. 4-(a), the machining area became large, and the size of the shape is 7.058 mm. Also in case of the fig. 4-(b), the machined into a non-square shape, and the machining area became large. Compared with Fig. 3, using a fillet electrode makes it more difficult to adjust the current. Fig. 4-(c) shows the machined into a square shape, and the size of the shape is 3.569 mm.Fig. 4-(d) shows the machined into a square shape, and the size of the shape is 4.048 mm.In case of the used NaNO3, the machined area is smaller than the using general electrode.

Fig.5 shows micrographs of SMA experiment according to electrolyte using general electrodes. Fig. 5-(a)the machined shape from the0.2mol NaCl, (b) shows the results used 0.6mol NaCl, (c) shows the results used 1mol NaNO3, (d) shows the results used 1.5mol NaNO3. In case of thefig. 5-(a), the surface condition is not good.It is possible to know that the surface condition is not smooth and the current flow is not good.In case of the fig. 5-(b), The surface condition is better than fig. 5-(a).However, it is understood that the state of the surface is not good in a certain region.in case of the used NaCl, the higher the electrolyte density, the more the machining is performed with stable current flow. Fig. 5-(c) shows the It can be seen that the surface condition is very smooth.Also, fig. 5-(d) shows the It can be seen that the surface condition is very smooth. in case of the used NaNO3, regardless of the concentration, the surface is smoothly machined.

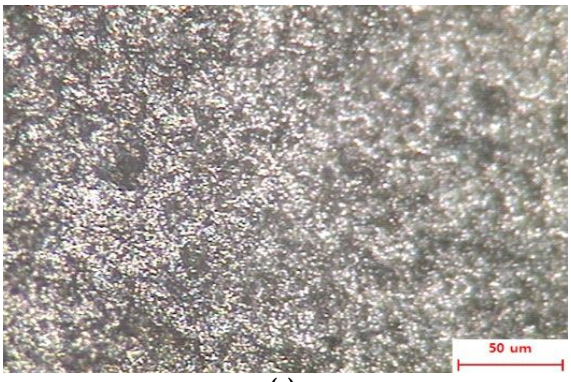




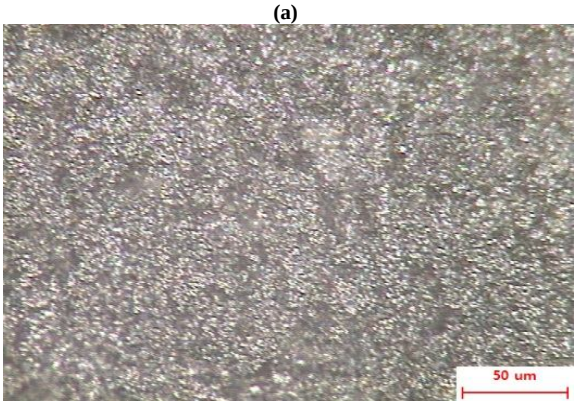

**(d)**

**Fig. 5Micrographics of SMA experiment according to electrolyteusing general electrodes (x1200)**

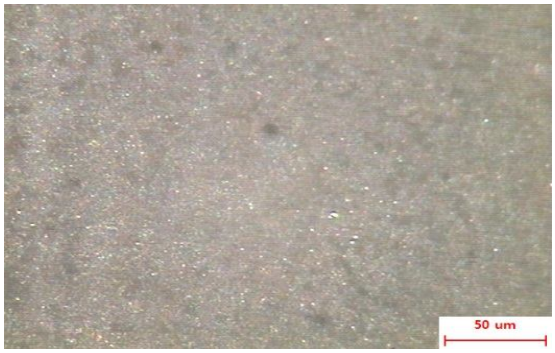
Fig.6 shows micrographs of SMA experiment according to electrolyte using fillet electrodes. Fig. 6-(a)the machined shape from the0.2mol NaCl, (b) shows the results used 0.6mol NaCl, (c) shows the results used 1mol NaNO3, (d) shows the results used 1.5mol NaNO3. In case of thefig. 6-(a), the surface condition is not good.However, the surface condition is smoother than in Fig 5-(a).In case of the fig. 6-(b), The state of the surface is smooth and constant.Due to the fillet, the direction of current has become widespread.As a result, the amount of current to be concentrated is reduced and machined irregularity. Fig. 6-(c) shows the It can be seen that the surface condition is very smooth.Also, fig. 6-(d) has the smoothest surface among the experiment.NaNO3is the optimum solution for smoothly processing shape memory alloys.



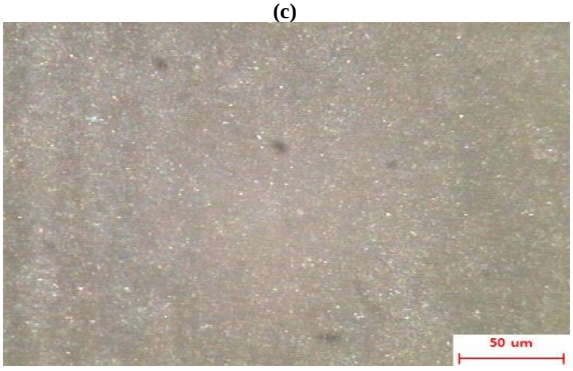

**(a)**




**(b)**



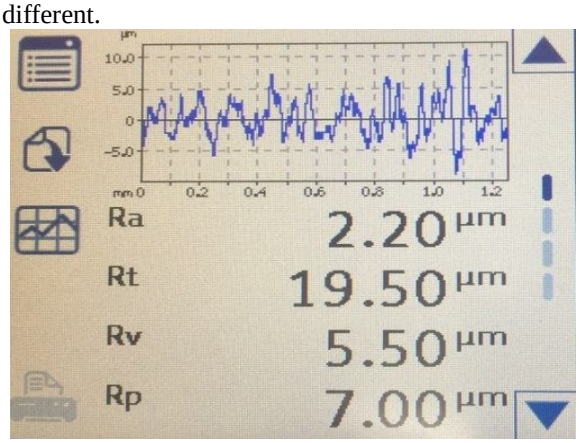

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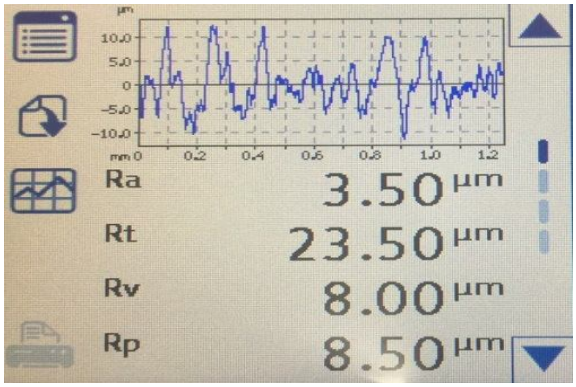

**(d)**

**Fig. 6Micrographics of SMA experiment according to electrolyteusing fillet electrodes (x1200)**

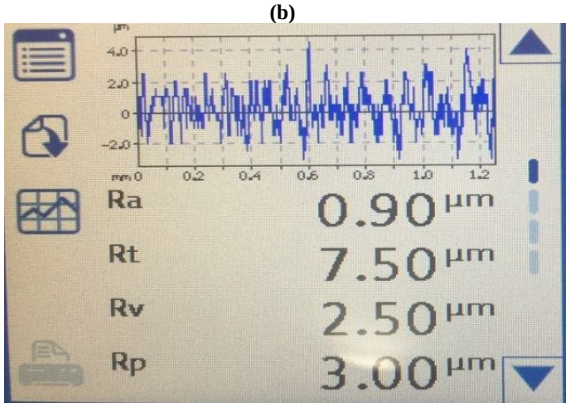
Fig. 7 shows the measurement of Contact surface roughness for machining area. Measurement was carried out for each electrode using a device of contact type surface roughness. Fig. 7-(a) was experiment results of 0.2mol NaCl using the general electrodes. The surface roughness value was 2.2 um. In case of the (b), experiment results of 0.2mol NaCl using the fillet electrodes. The surface roughness value was 3.5 um.Experiments using a fillet electrode as in showed not good surface condition Conclusion. Fig. 7-(c) was experiment results of 1.5mol NaNO3 using the general electrodes. The surface roughness value was 0.9 um. Fig. 7-(d) was experiment results of 1.5mol NaNO3 using the fillets electrodes. The surface roughness value was 0.6 um. Because of the experiment with NaNO3, the value of the surface roughness of the fillet electrode is better.Able to know that the tendency to process according to the electrolytic solution is different.



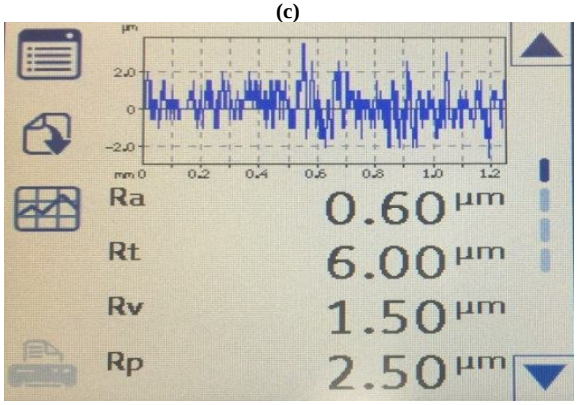

**(a)**




**(b)**




**(c)**




**(d)**

**Fig. 7Measurement of surface roughness for machining area.**

## CONCLUSION

Through this study, the analysis in machining shapes of shape memory alloy (SMA) according to electrolyte and electrodes. The type of electrolyte was 0.2mol NaCl, 0.6mol NaCl, 1mol NaNO3and1.5mol NaNO3. The electrodes type was general electrode andfillet electrode.

The results of experiment using general electrodes, in case of the used NaCl, the higher the electrolyte density, the more difficult it is to adjust the processing shape. Also, the higher the electrolyte density, the more the machining is performed with stable current flow.In case of the used NaNO3, the shape of the machining is not clear.However, even if the density increases, the machined shape wasa square. And regardless of the concentration, the surface is smoothly machined.

The results of experiment using fillet electrodes, in case of the used NaCl, using a fillet electrode makes it more difficult to adjust the current. Also, surface roughness gets worse and machining shape is not clear.Due to the fillet, the direction of current has become widespread. The amount of current to be concentrated is reduced and machined irregularity. But, NaNO3is the surface roughness of the fillet electrode is smooth.

Finally, the shape of the electrode can be changed to adjust the amount of current. Nacl was this machining speed is fast, the surface condition is not so good. NaNO3 was the machining speed is slow, it is suitable for obtaining a precise and smooth shape.In order to a shape memory alloy into a hole, NaCl having a high machining speed may be selected.Conversely, in order to process the shape, using the NaNO3 must be machined long.It is necessary to select an appropriate electrolyte for the shape memory alloy according to the intended use.

## ACKNOWLEDGEMENT

This research was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (No. 2015R1A2A1A15054116).

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