Optimization of Wear Parameters of MAO Coated Aluminum Based on Taguchi Method

Mehmet Erbil ÖZCAN[1], Latif ÖZLER[2], and İsmail Hakkı ŞANLITÜRK[3]

Abstract— Micro arc oxidation (MAO) coating method is the process of coating with hard, abrasion and corrosion resistant surface by immersing the substrate in an electrolytic liquid by the effect of electrochemical reaction through the plasma discharge.

In the first step, the samples are coated aluminum oxide in the solution of potassium hydroxide, sodium aluminate and sodium phosphate. In the second step, coating is performed by adding 0,8 gr/lt Ti particles in the same solution. For both solutions, the frequency, voltage and processing time varied as 100-350 Hz, 450-550V, 10-30 min, respectively. After the coating process, measurements are carried out for analyzing the impact of experimental parameters (voltage, frequency and processing time) and Ti addition. Afterwards wear tests are applied on coated samples on block-on-disc abrasion test unit. The weights of the samples were recorded after 500, 1000 and 1500 m wear distance with 10^{-5} g sensitive scales.

After these experiments and tests, Taguchi method, a way to optimize the parameters which cannot be controlled during experiment. Various methods are used to determine the factor levels in this technique. The algorithm which will be used to solve multi-response problem by using orthogonal arrays were explained. Consequently in this study, coatings and wear tests described above were carried out and variance analysis were performed by using ANOVA. The relevance of the results has been checked.

Keywords— taguchi method, MAO, coating, AA7075

I. Introduction

ONE of the main purposes of scientists is to decrease the losses caused by the corrosion, abrasion and fatigue of metals and metal alloys used in many different areas by improving corrosion, abrasion and fatigue resistance properties by means of using different methods. The losses due to corrosion and abrasion around the world constitute the %3-5 of national income on average. Today, a significant portion of the studies carried out to eliminate these losses and to improve the properties of the materials against the corrosion and abrasion are mainly composed of the surface coating operations. Although there are many coating methods for this purpose, MAO method has been getting much more used particularly after the 2000s [1-8]. The coating with MAO is mainly based on the coating of the substrate material with an abrasion and corrosion resistant, hard layer by immersing into the electrolytic liquid by means of the plasma discharges obtained by the influence of electrochemical reactions [9].

The most important advantage of MAO coating method is to reduce the friction and abrasion with an investment cost lower than other coating methods [10]. Having this advantage, this coating method is used in many areas especially like the manufacturing, motor, hydraulics, textile, automotive and aerospace industries. The main objective of this widespread usage is the formation of high temperature, abrasion, corrosion resistant, hard surface oxide layer. Moreover, in the MAO coating method, the composition of the oxide layer can be modified by adding different chemicals into the electrolyte solution [11]. This coating modifications can be used in the isolated areas owing to the dielectric properties and in the architectural areas through the ability of being produced with different colors [12]. Being an environmentally friendly coating method, the MAO method makes it possible to coat the surface of the materials such as Mg, Ti and Al having different mechanical and physical structural properties [10-13].

Considering the former carried out studies, there are so many coating applications with the micro-arc oxidation method on different substrate materials. These studies have generally focused on the Al_2O_3 and TiO_2 coatings in the solutions at different concentrations. After doing those in this study, coatings and wear tests described above were carried out and variance analysis were performed by using ANOVA. The relevance of the results has been checked.

Fig. 1. Micro-arc Oxidataion Process[14]

Mehmet Erbil ÖZCAN[1] is with the Mechanical Engineering Department, Firat University, Elazig, 23119 Turkey, (Phone: +905425199988, e-mail: meozcan@firat.edu.tr).

Latif ÖZLER[2], is with the Mechanical Engineering Department, Firat University, Elazig, 23119 Turkey, (e-mail: lozler@firat.edu.tr).

İsmail Hakkı ŞANLITÜRK[3] is with the Mechanical Engineering Department, Firat University, Elazig, 23119 Turkey, (e-mail: ihsanliturk@firat.edu.tr).

This study has been financially supported by FUBAP MF-13.04 Fırat University

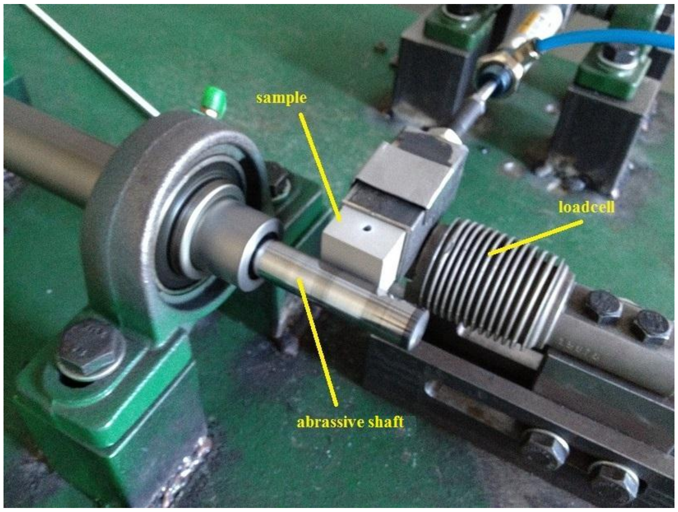

Fig. 2. Experimental setup

II. Materials and Methods

In the first step, the samples were coated aluminum oxide in the solution of potassium hydroxide, sodium aluminate and sodium phosphate. In the second step, coating was performed by adding 0,8 gr/l Ti particles in the same solution. For both solutions, the frequency, voltage and processing time was varied. After the coating process, measurements were carried out for worn mass weight with 10^{-5} gr sensitive scales. Table I shows experiment conditions.

TABLE I
EXPERIMENTAL CONDITIONS

Coating time (min)	10, 20, 30
Frequency (Hz)	100, 350
Voltage (V)	450, 500, 550
Ti addition	None (0), Added (1)
Wear distance (m)	500, 1000, 1500

Wear tests were conducted on a block-on-disc wear equipment with diamond abrasive, which can be seen in Fig. 1. Surface speed and pushing force that applied onto specimen was 50m/min and 19.62N (2kgf), respectively.

Normally, the full-factorial design would require 108 experimental runs in this study. Taguchi method, a powerful tool for parameter design of performance characteristics [15], to determine optimal coating parameters for minimum wear was used in this study. Taguchi method proposes to acquire the characteristic data by using orthogonal arrays, and to analyze the performance measure from the data to decide the optimal process parameters [16-18]. Five coating parameters were used as control factors (Table I). According to the Taguchi quality design concept, a L_{18} orthogonal arrays table with 18 rows (corresponding to the number of experiments) was chosen for the experiments (Table II).

TABLE II
EXPERIMENTAL DESIGN

Exp No	Ti Add.	Freq. (Hz)	Coating time (min)	Voltage (V)	Wear dist. (m)	Wear Amount (gr)
1	0	100	10	450	500	0.00120
2	0	100	20	500	1000	0.00129
3	0	100	30	550	1500	0.00225
4	0	350	10	450	1000	0.00376
5	0	350	20	500	1500	0.00333
6	0	350	30	550	500	0.00041
7	0	350	10	500	500	0.00112
8	0	100	20	550	1000	0.00206
9	0	350	30	450	1500	0.00249
10	1	100	10	550	1500	0.00231
11	1	100	20	450	500	0.00104
12	1	100	30	500	1000	0.00107
13	1	350	10	500	1500	0.00156
14	1	350	20	550	500	0.00055
15	1	350	30	450	1000	0.00161
16	1	100	10	550	1000	0.00086
17	1	350	20	450	1500	0.00216
18	1	100	30	500	500	0.00049

After the experiments, one-way ANOVA analysis was run for each parameter in order to see whether the results are statistically significant or not. IBM SPSS ver.21 was used to run the ANOVA analyzes with $\alpha = 0.05$, and Tukey HSD post-hoc test.

III. Results and Discussion

Main effect plot of the wear amount has been shown in Fig.2, and table of main effect data has been given in Table 3. According to data given in Table 3, parameter set of $A_2B_1C_3D_3E_1$ is selected for obtaining optimal value of the wear amount. It can be seen that from the Table 3, wear amount has been affected most by the wear distance. Following factors affecting the wear amount after wear distance are Ti addition, voltage (V), frequency (Hz) and coating time (min).

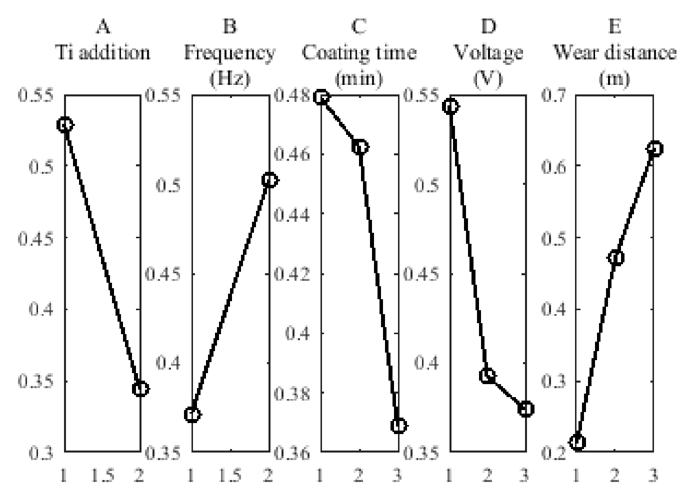

Fig. 3. Main effect plot of wear amount

TABLE III
MAIN EFFECTS TABLE OF WEAR AMOUNT (SMALLER THE BETTER)

Level	A	B	C	D	E
1	0,529255	0,371454	0,479167	0,54344	0,213209
2	0,344267	0,502069	0,462323	0,39273	0,472074
3	NaN	NaN	0,368794	0,374113	0,625
Δ	0,184988	0,130615	0,110372	0,169326	0,411791
Rank	2	4	5	3	1

It can be said that Ti addition affects the wear amount values, because ANOVA(F=6.544, p=0.012) has been determined by ANOVA. Since there is only two groups for Ti addition ("None", "Added"), post-hoc tests hasn't been performed.

Significance of frequencies have been calculated as ANOVA(F=5.773, p=0.018). Selected values for frequency as 100 and 350 Hz resulted statistically significant difference on wear amount, and can be kept as this in future studies.

There has been a statistically significant difference between coating times as determined by ANOVA(F=3.206, p=0.045). Tukey HSD revealed that there is no statistically significant difference between 10 and 20 minutes (p=0.932), and 20 and 30 minutes (p=0.87). But there is a statistically significant difference between 10 and 30 minutes (p=0.044). This means making 20 minute or bigger intervals as, for example, 10, 30 and 50 minutes, rather than 10 minute intervals would be resulted better in terms of variance of the wear amount.

Calculation for Voltage has been resulted ANOVA(F=0.602, p=0.550). There is no statistically significant difference in voltage groups for wear amount. It can be said that the voltage would not included in the experiments, or intervals should be selected bigger than 50 V.

ANOVA(F=57.346, p≈0.000) has been determined for the wear distance. This means there is statistically significant difference in groups of the wear distance. Tukey test revealed that there is statistically significant different wear amount as significance values for 500, 1000 and 1500m almost equal to zero.

IV. CONCLUSION

A conclusion section is not required. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

Addition of the Ti particles into the solution has been resulted the wear amount to decrease. In this study 0,8 gr/l of particles were used. Because it changes the wear amount, density of the Ti particles in a solution can be added as a parameter for future studies. The coating time may be selected as 10, 30 and 50 minutes. The voltage can be kept constant or varied as 300, 500 and 700 V.

Required time for experiments has been lowered, and optimum parameters for coating process has been obtained by Taguchi method. Conclusions has been made with the help of ANOVA.

In future studies, this type of experimental studies can be divided into two stages. In first stage, design of experiments can be conducted with Taguchi method, then results can be interpreted with ANOVA. Parameters and intervals of them can be fine-tuned in first stage. Full factorial tests can be run in second stage. Thus deeper understanding can be built on experimental values.

REFERENCES

[1] Z. C. Shao, Q. F. Zhang, M. Wang and L. Yang, "Preparation of Black Coating on AM50 Alloys by Microarc Oxidation (MAO)", Materials and Manufacturing Processes, Volume 29, Issue 9, 1095-1100,(2014). https://doi.org/10.1080/10426914.2014.921695

[2] Khokhryakov E.V., Butyagin P.I., Mamaev A.I., "Protective Coatings-Formation by Microarc Oxidation, Modern Technique and Technologies", Material Science, Chapter 6, Pages: 143-145 (2002)

[3] Wen L., "Corrosion Evaluation of Microarc Oxidation Coatings Formed on 2024 Aluminium Alloy", Corrosion Science, Volume 52, Issue 8, Pages 2687–2696 (2009)

[4] Xiao L., Lili T., Peng W., Xiaoming Y., Ke Y., Zhuangqi H., Yangde L., Weirong L., "Characterization Of Micro-Arc Oxidation Coating Post-Treated By Hydrofluoric Acid on Biodegradable ZK60 Magnesium Alloy", Surface & Coatings Technology, Volume 232, Pages 899–905, (2013). https://doi.org/10.1016/j.surfcoat.2013.06.121

[5] Jun-Hua W., Mao-Hua D., Fu-Zhu H., Jing Y., "Effects of The Ratio of Anodic and Cathodic Currents on The Characteristics of Micro-Arc Oxidation Ceramic Coatings on Al Alloys", Applied Surface Science, Volume 292, Pages 658–664, (2013).

[6] Tazegul O., Muhaffel F., Meydanoglu O., Baydogan M., Kayali E., S., Cimenoglu H., "Wear and Corrosion Characteristics of Novel Alumina Coatings Produced by Micro Arc Oxidation on AZ91D Magnesium Alloy", Surface and Coatings Technology, Volume 258, Pages 168–173, (2014). https://doi.org/10.1016/j.surfcoat.2014.09.035

[7] Hong-Yuan W., Rui-Fu Z., Yu-Peng L., Gui-Yong X., Kun H., Y.F. Yuand, Xiao-Ni M., Ying L., "Effect of Sandblasting Intensity on Microstructures and Properties of Pure Titanium Micro-Arc Oxidation Coatings in an Optimized Composite Technique", Applied Surface Science, Volume 292, Pages 204–212 2013.

[8] Dejiu S., Guolong L. , Changhong G., Jie Z., Jingrui C., Donglei H, Haojie M., Fangfei L., "Microstructure And Corrosion Behavior of Micro-Arc Oxidation Coating on 6061 Aluminum Alloy Pre-Treated By High-Temperature Oxidation", Applied Surface Science, Volume 287, Pages 451–456, (2013). https://doi.org/10.1016/j.apsusc.2013.09.178

[9] Huang P., Zhang Y., Xu K., Han Y., Huang P., Zhang Y., Xu K., Han Y., "Surface Modification of Titanium Implant by Micro Arc Oxidation and Hydrothermal Treatment, Journal of Biomedical Materials Research", Chapter: B Applied Biomaterials, Volume: 70B, N:2, 187-190, (2004).

[10] Zhu H., Cai B., Lin Z., Ren D., Tan J., Zhou R., "Fretting Wear Behaviour of Ceramic Coating Prepared by Micro-Arc Oxidation on Al–Si Alloy", Journal of Wear, Volume 263, Issues 1–6, (2007).

[11] Li H., Song R., Ji Z., "Effects of Nano-Additive TiO2 on Performance of Micro-Arc Oxidation Coatings Formed on 6063 Aluminum Alloy", Transactions of Nonferrous Metals Society of China, Volume 23, Issue 2, Pages 406–411, (2012).

[12] Gnedenkov S. V., Khrisanfova O.A., Zavidnaya, A.G., Sinebrukhov, S.L., Gordienko, P.S., Iwatsubo, S., Matsui, A., "Composition and Adhesion of Protective Coatings on Aluminum", Surface and Coatings Technology, Volume 145, Issues 1–3, Pages 146–151, (2001). https://doi.org/10.1016/S0257-8972(01)01307-X

[13] Sebatini G., Cheschini L., Martini C., Williams J., A., Hutchings I.,M., "Improving Sliding and Abrasive Wear Behaviour of Cast A356 and Wrought AA7075 Aluminium Alloys by Plasma Electrolytic Oxidation", Materials and Design, Volume 31, Issue 2, Pages 816–828 (2009).

[14] Investigation of surface roughness of Al7075 material coated with micro-arc oxidation method, Mehmet Erbil Özcan, Latif Özler, and Nihat Parlak, Advances In Materials And Processing Technologies Vol. 1 , Iss. 1-2,2015

[15] H.C. Lin, C. T. Su, C.C. Wang, B.H. Chang, R.C. Juang, "Parameter optimization of continuous sputtering process based on Taguchi methods,

neural networks, desirability function, and genetic algorithms”, *Expert Systems with Applications*, vol. 39, 2012, pp. 12918-12925 https://doi.org/10.1016/j.eswa.2012.05.032

[16] N. Tosun, C. Cogun, G. Tosun, “A study on kerf and material removal rate in wire electrical discharge machining based on Taguchi method”, *J Mater Process Tech*, vol. 152, 2004, pp. 316–322. https://doi.org/10.1016/j.jmatprotec.2004.04.373

[17] S.H. Lee, H.S. Lee, “Optimization of cutting parameters for burr minimization in face-milling operations”, *Int J Prod Res 41*, vol. 3, 2003, pp. 497-511

[18] P.J. Ros Taquchi *techniques for quality engineering. Second Edition*, New York, McGraw-Hill, 1996