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TO INVESTIGATE DRY SLIDING WEAR OF MICRO ARC OXIDATED AL 6061

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Abstract - *Micro Arc oxidation (MAO) is a surface treatment for the production of ceramic oxide coatings with great properties, such as high wear and corrosion resistance, on metal substrates, particularly aluminum and magnesium alloys. In the present investigation dry sliding wear behavior of micro arc oxidated Al 6061 has been investigated to determine weight loss of samples on Pin on Disk set up. Three parameters are selected to investigate the dry sliding wear i.e. Load, Speed and Sliding Distance. The design of experiments (DOE) approach using Taguchi method (L27 Orthogonal Array) was employed to analyze the wear behavior of MAO Al 6061 Alloy. Signal-to-noise ratio, analysis of variance (ANOVA) and regression equation were used to investigate the influence of parameters on the wear rate.*

Key Words: Micro Arc Oxidation, Al alloy, Design of Experiments, Orthogonal Array, ANOVA, Regression equation

1. Introduction

Micro arc oxidation (MAO) is a relatively novel surface modification technique to create ceramic coatings on the surface of metals such as aluminum, magnesium, titanium, zirconium and their alloys. Other terminologies used for this process include Plasma Electrolytic oxidation (PEO), anodic oxidation by spark discharge, and spark anodizing. In this study the Micro arc oxidation is used because it has become the dominant term over the past decade. MAO is similar to conventional anodizing, but in contrast to anodizing, which is performed at voltages in the range of 10-50 V, MAO is applied above the breakdown voltages of the original oxide films, typically 400-800 V. Applying high potentials results in the formation of plasma micro-discharge events which appear as numerous sparks on the surface of the sample. Due to the local thermal action of the sparks, ceramic coatings composed of both oxides of the substrate and more complex oxides containing elements from the electrolyte are formed. MAO coatings have excellent adhesion to the substrate, high hardness and wear resistance, and good electrical and corrosion resistances. Additionally, the process can produce coatings with wide range of functional properties with little effect on the mechanical properties of the substrate material because of the negligible heating of the substrate. MAO is gaining increased attention as a cost-effective, environmentally friendly surface engineering technique for depositing thick, dense and ultra-hard ceramic coatings on light metals and alloys. Currently, the MAO process is in a transition phase from research to commercial application, with a primary focus on the corrosion and wears protection of light alloys, and has recently gained great attention as a promising surface treatment for Biomedical applications.

2. Taguchi Method

The Taguchi method involves reducing the variation in a process through robust design of experiments.Taguchi developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varies. Instead of having to test all possible combinations like the factorial design, the Taguchi method tests pairs of combinations. This allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resources. In the present investigation weight loss of samples is calculated to analyze the influence of parameters like Load, Speed and Sliding Distance and their interactions on wear of micro arc oxidated Al 6061alloy.

3 Experimental Details

3.1 Material

Al 6061 was selected as substrate material for present study. The specimens with dimensions (30x7x7) each in mm were prepared. To ensure a reproducible initial surface condition, samples were polished with 600 grit emery polishing paper followed by degreasing in propanol and rinsing with distilled water.

Fig-1: Specimen's detail (MAO coating on Al Alloy)

The specimen Chemical Composition test was done at M/S Indiana Ferro Alloys, Mohali according to ASTM E1231-2011 as shown in Table 1.

3.2 MAO coating on Al 6061

A MAO unit equipped with a AC power supply was used to produce the coatings on above specimen at M/S SAI surface coating technologies Patancheru, Telangana. MAO coatings were produced using AC mode with a square waveform applied at a frequency of 900 Hz. Samples were coated at a duty cycle (Dt) of 20%. The MAO process was carried out at a constant current density of 10 A/dm².The electrolyte was a solution of 10 g/l Na_2SiO_3 and 0.5 g/l KOH in deionized water. The electrolyte temperature was maintained below 30 °C.

3.3. Procedure for Wear Test

A pin on disc tribometer shown in figure 3 was used for testing in Tribology Lab (DUCOM TR-20) of BBSBEC, Fatehgarh Sahib to determine the sliding wear characteristics of the MAO Al 6061. The contact surface of the sample (pin) was made flat and in contact with the rotating disk. During the test, the pin is held pressed against a rotating EN 8 steel disc (hardness of 65HRC) by applying load that acts as counterweight and balances the pin.

Table-1: Chemical Composition of Al (Wt. %)

Element	Cu	Mg	Si	Fe	Ni	Mn	Zn	Pb	Sn	Ti	Cr	Al
Conc %	.0263	.9603	0.121	0.171	0.0085	0.605	0.0488	0.0539	<0.0100	0.0709	0.0650	Bal

The track diameter (80mm) was kept constant and the parameters such as the load, sliding speed and sliding distance were varied in the range given in Table2. A LVDT (load cell) on the lever arm helps determine the wear at any point of time by monitoring the movement of the arm. Once the surface in contact wears out, the load pushes the arm to remain in contact with the disk. This movement of the arm generates a signal which is used to determine the maximum wear. Weight loss of each specimen was obtained by weighing the specimen before and after the experiment by a single pan electronic weighing machine with an accuracy of 0.0001g after thorough cleaning with acetone solution.

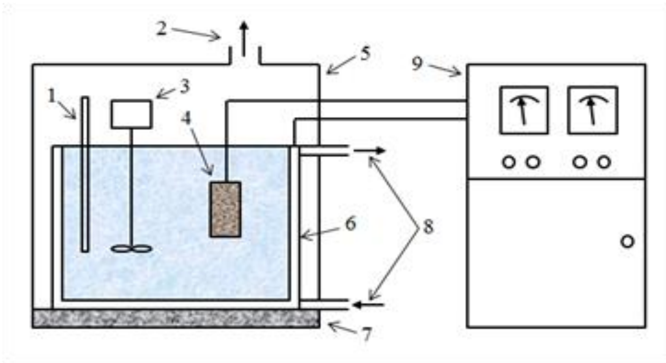


Fig-2: Typical arrangement of the equipment used for MAO coating: (1) thermocouple, (2) exhaust/ventilation system, (3) mixer, (4) work piece, (5) grounded case, (6) bath, (7) insulating plate, (8) flow circulation via cooling system/filter, (9) power supply unit.

Fig-3: Pin on Disk Tribometer

The experiments were conducted as per the standard L27 (3^3) orthogonal array. The wear parameters selected for the experiment were Load in N Sliding speed in m/s, and sliding distance in m. The each parameter was assigned three levels which are shown in Table 2.

Table-2: Process parameters with values at three levels.

Sr.No	LOAD(N)	SPEED(m/s)	DISTANCE(m)
1	5	.5	300
2	10	1	600
3	20	2	1200

The standard L27 orthogonal array consists of twenty seven tests as shown in the Table 5. The first column is assigned by Load, second column was assigned by Speed and 5th column was assigned by sliding distance. The response studied was weight Loss with the objective of "smaller is the better" type of quality characteristic.

4. Results and Discussion

The Wear process parameters were analysed using Minitab 17 software (Trial Version)

4.1. S/N Ratio Analysis

The influence of control parameters such as load (L), speed (S), and sliding distance (D) on weight Loss was evaluated using S/N ratio response analysis. Process parameter settings with the highest S/N ratio always yield the optimum quality with minimum variance. The sliding wear quality characteristic selected was smaller is the better type and same type used for signal to noise ratio which is given below of response was

$S / N = -10\log 1/n \sum y^2$------------ (1)

The S/N ratio response was analyzed using the above Equation (1) for all 27 tests and presented in Table 5. Figure 3 and Figure 4 show the main effects plots of S/N ratios and main effects plots of means for wear of coated aluminium alloy. From the figure it is evident that the average mean weight loss of aluminium is 0.0021 grams. The response table for SN ratio depicts the rank of Process parameters with Delta as static criteria, From Table 3, it has been observed that Load has significant impact on weight loss followed by Speed and Sliding Distance. The main effects plot for Means shown in figure 4 infers that weight Loss decreases for increase in load from 5N to 20N.

4.2. Analysis of Variance

The analysis of variance (ANOVA) was used to analyze the influence of wear parameters like sliding speed, load and sliding distance. The ANOVA establishes the relative significances of factors in terms of their percentage contribution to the response. This analysis was carried out for a level of significance of 5% (*i.e.*, the level of confidence 95%). Tables 6 shows the results of ANOVA analysis of MAO coated Al 6061. The last column of Table shows the percentage of contribution (P %) of each parameter on the response, indicating the degree of influence on the result. It can be observed from the results obtained that Load was the most significant parameter having the highest statistical influence (21.3%) on the dry sliding wear of MAO Al6061 followed by Speed (6.95%) and Distance (4.18%). From an analysis of the results obtained in Table6, it is observed that the interaction effect S*D (20.3%) is influencing weight loss of coated samples.

Table-3: Response Table for Signal to Noise Ratio (Smaller is better)

Level	LOAD	SPEED	DISTANCE
1	60.07	63.84	63.81
2	67.78	72.03	68.87
3	74.65	66.62	69.82
Delta	14.58	8.19	6.01
Rank	1	2	3

Table-4: Response Table for Means (Smaller is better)

Level	LOAD	SPEED	DISTANCE
1	0.003467	0.005211	0.004711
2	0.002544	0.000311	0.001000
3	0.000222	0.000711	0.000522
Delta	0.003244	0.004900	0.004189
Rank	3	1	2

Table-5: Orthogonal array (L27) of Taguchi for wear test.

Sr.No	LOAD	SPEED	DISTANCE	Wt.Loss (grams)	SNRA1
1	5	0.5	300	0.0202	33.8930
2	5	0.5	600	0.0058	44.7314
3	5	0.5	1200	0.0002	73.9794
4	5	1.0	300	0.0010	60.0000
5	5	1.0	600	0.0002	73.9794
6	5	1.0	1200	0.0003	70.4576
7	5	2.0	300	0.0003	70.4576
8	5	2.0	600	0.0010	60.0000
9	5	2.0	1200	0.0022	53.1515
10	10	0.5	300	0.0199	34.0229
11	10	0.5	600	0.0001	80.0000
12	10	0.5	1200	0.0001	80.0000
13	10	1.0	300	0.0002	73.9794
14	10	1.0	600	0.0002	73.9794
15	10	1.0	1200	0.0002	73.9794
16	10	2.0	300	0.0002	73.9794
17	10	2.0	600	0.0011	59.1721
18	10	2.0	1200	0.0009	60.9151
19	20	0.5	300	0.0001	80.0000
20	20	0.5	600	0.0001	80.0000
21	20	0.5	1200	0.0004	67.9588
22	20	1.0	300	0.0001	80.0000
23	20	1.0	600	0.0004	67.9588
24	20	1.0	1200	0.0002	73.9794
25	20	2.0	300	0.0004	67.9588
26	20	2.0	600	0.0001	80.0000
27	20	2.0	1200	0.0002	73.9794

Table-6: ANOVA Analysis for SN Ratio-weight Loss

Source	DF	Adj SS	Adj MS	F Val	P Val	Pr (%)
L	2	957.1	478.57	2.49	0.14	21.3
S	2	312.4	156.18	0.81	0.47	6.95
D	2	187.9	93.97	0.49	0.63	4.18
L*S	4	322.1	80.53	0.42	0.79	7.16
L*D	4	258.2	64.55	0.34	0.84	5.74
S*D	4	914.8	228.70	1.19	0.38	20.3
Error	8	1538.6	192.32			
Total	26	4491.1				

Fig-3: Mean Effects Plot for SN Ratio

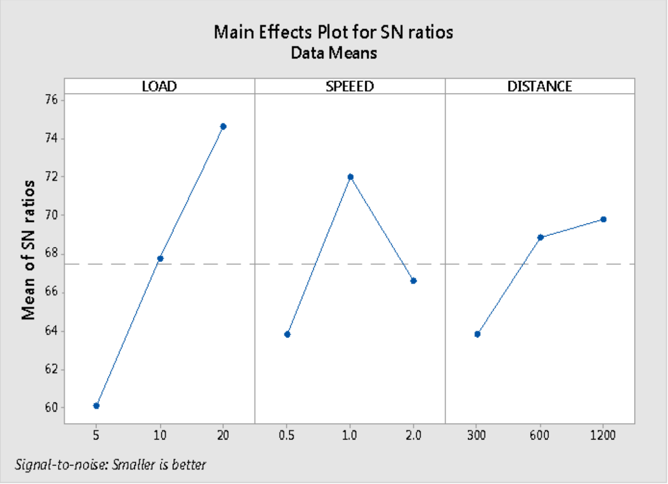
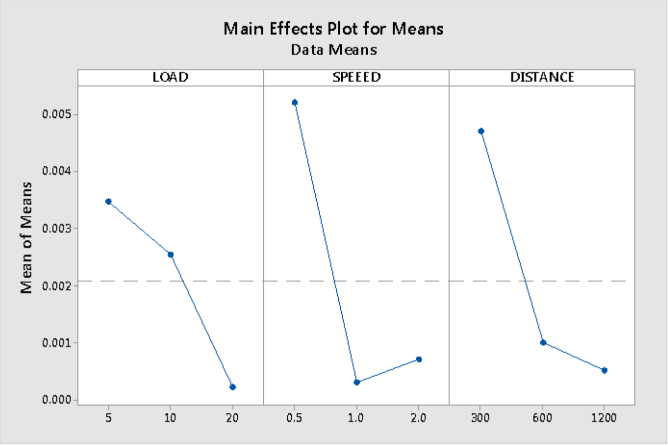


Fig-4.Main Effects Plot for Means



4.3 Multiple Linear Regression Model Analysis

A multiple linear regression analysis attempts to model the relationship between two or more predictor variables and a response variable by fitting a linear equation to the observed data. Based on the experimental results, a multiple linear regression model was developed using MINITAB 17.

Regression Equation

$$\text{Weight Loss} = 0.02466 - 0.000875\,L - 0.01153\,S - 0.000019\,D + 0.000291\,L*S + 0.000291\,L*S + 0.000000\,L*D + 0.000008\,S*D$$

The above equation can be used to predict the weight loss of the MAO Al 6061. The constant in the equation is the residue. From the above regression equation it is found that weight Loss of Al 6061 is inversely proportional to load, speed and distance.

5. Conclusions

1) The analysis of variance shows that weight Loss was highly influenced by applied load (21.3%) followed by sliding speed (6.95%) and sliding distance(4.18%) respectively and interaction term S*D(Speed*Distance) [20.3%] was found most predominant among different interaction parameters.

2) The optimum Parameters were found to be with high signal to noise ratio from response Table 3 i.e.Load-20N,Speed-1m/s and Sliding Distance-1200m

3) From the regression equation it was found that weight Loss decreases with increase in load, speed and distance.

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