Sliding Wear Behaviour of Al-Si-Ti Alloys Using Taguchi Method under Lubrication Condition

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Abstract: The present study deals with investigation relating to the influence of wear parameters like sliding speed, applied load and sliding distance on the sliding wear of aluminium silicon titanium alloys under lubrication condition. The design of experiment approach was employed to acquire data in controlled way using Taguchi method. A pin-on-disc apparatus was used to conduct the sliding wear test under lubrication condition. An orthogonal array, signal-to-noise ratio and analysis of variance were employed to investigate the wear behavior of aluminium and it's alloys. The mathematical model was obtained to determine the wear rate of the aluminium and it's alloys. Addition of titanium in aluminium silicon alloys modifies microstructure as well improves the tribological characteristics.

Keywords: Al-Si-Ti Alloys, Wear; Orthogonal Array, ANOVA, Taguchi Method.

I. INTRODUCTION

Aluminium and aluminium alloy are gaining huge industrial significance because of their outstanding combination of mechanical, physical and tribological properties over the base alloys. These properties include high specific strength, high wear and seizure resistance, high stiffness, better high temperature strength, controlled thermal expansion coefficient and improved damping capacity. These properties obtained through addition of alloy elements, cold working and heat treatment. Alloying elements are selected based on their effects and suitability. The alloying elements may be classified as major and minor elements, microstructure modifiers or impurities, however the impurity elements in some alloys could be major elements in others. Now a days the aluminium-silicon alloys found many industrial application[1]. Francis Uchenna et al studied the effect of parameters on dry sliding wear characteristics of Al-Si alloys. Micro structural characterization was done using optical microscope (OM) and scanning electron microscope (SEM). Hardness and wear characteristics of different samples have shown near uniform behaviour. From this experimentation they found that the wear rate decreased when the percentage of silicon increases and wear was observed to increase at higher applied load, higher sliding speed and higher sliding distance. Also they observed that the wear characteristics of Al-14%Si was superior to those of Al-7%Si and Al-12%Si due to the degree of refinement of their eutectic silicon[1]. Riyadh A et al studied the effect of load and speed on sliding friction coefficient using a pin-on-disc Tribometer with three different loads (10, 20, and 30 N) at three speeds (200, 300, and 400 r/min) and relative humidity of 70%. From the experimentation they showed that the wear rate increased with increasing load and decreased with increasing sliding distance, whereas the friction coefficient decreased with increasing sliding speed before a stable state was reached. Also the friction coefficient decreased with increasing load. They suggested that after maintaining appropriate sliding speed and normal load level combination, frictional force and wear rate can be reduced which will improve the mechanical processes[2].

II. TAGUCHI TECHNIQUE

The Taguchi technique is a powerful design of experiment tool for acquiring the data in a controlled way and to analyze the influence of process variable over some specific variable which is unknown function of these process variables and for the design of high quality systems [16,17]. This method was been successfully used by researchers in the study of wear behavior of aluminium metal matrix composites [18]. The aim of this technique is to make the products that are robust with respect to influencing parameters. Taguchi creates a standard orthogonal array to accommodate the effect of several factors on the target value and defines the plan of experiment [19,20]. The experimental results are analyzed using analysis of means and variance to study the influence of parameters.

III. MATERIALS AND METHODS

Different elements were added to Al-Si alloy to improve their properties for variety of application. In this dissertation work Ti is added to Al-Si eutectic alloys. For preparation of testing alloy permanent mould casting process is used. Basic steps in casting process like melting, pouring, cooling, cleaning and inspections were carried out for each alloy. The alloys were prepared from commercially pure aluminum (99.7%), high purity silicon (99.9%) and electrolytic titanium (99.9%). Alloys were melted in an electric furnace at a temperature of 800^0C and poured into a permanent steel mould at was maintain at a temperature of 200^0C for some time then cooled to room temperature. The mould had

a cylindrical shape with a length of 160 mm and diameter of 16 mm. Then this components were cut into small pieces and machined to the required shape of pin ie diameter 10 mm and length 30 mm for wear testing purpose. Polishing was done for all pins before wear testing with the help of emery paper of 400, 1000 and 2000 grade. Sample were cleaned in acetone before testing. The counter surface disc of EN-32 steel(0.62%Si-0.35Mn-1.02C-1.05Cr-0.3Ni) was used for experimentation. The engine oil 20W40 is used as lubricating oil for testing on pin-on-disc Tribometer.The chemical compositions of the alloys were determined by atomic absorption analysis method. Approximately 1gm of the alloy sample is weighed out accurately into an acid cleaned dry 200ml conical flask and the alloy is reacted with 30 ml of 30% hydrochloric acid. After the reaction has almost stopped the mixture is gently heated and 5ml of concentrated nitric acid are slowly added. The clear sample solution is cooled and transferred to a standard volumetric flask and diluted to exactly 100ml with distilled water. Aliquots of this sample solution may be further, if necessary, in order to bring each metal into the appropriate concentration range for measurement by atomic absorption spectrophotometer. The experiments were conducted as per the standard L9 orthogonal array for material composition given in table 1. The wear parameters selected for the experiment were sliding speed in m/s, load in N and sliding distance in m. The each parameter was assigned three levels which are shown in Table 2. The standard L9 orthogonal array consists of nine tests as shown in the Table 3. The first column is assigned by sliding speed, second column was assigned by load and third column was assigned by sliding distance. The response studied was wear in terms of grams with the objective of "smaller is the better" type of quality characteristic.

Table 1:Chemical Composition of Materials

Material	Chemical Composition in Wt.%
A	Al-0.582%Si-0.016%Zn-0.004%Pb-0.192%Fe
B	Al-**11.362%Si**-0.038%Zn-0.012%Pb-0.51%Fe
C	Al-11.437%Si-0.01%Zn-0.017%Pb-0.242%Fe-**0.47%Ti**

Table 2: Testing Parameters and their Values

Factors	Level 1	Level 2	Level 3
Sliding Velocity (m/s)	1.571	2.095	2.618
Load (N)	29.43	39.24	49.05
Sliding Distance (m)	2827	3771	4712

Table 3:Orthogonal Array (L_9) of Taguchi for Wear Test

L_9 Tests	Sliding Velocity (S)	Load (L)	Sliding Distance (D)	Wear of Al (gms)	Wear of Al-Si (gms)	Wear of Al-Si-Ti (gms)
1	1.571	29.43	2827	0.0015	0.0011	0.0010
2	1.571	39.24	3771	0.0038	0.0029	0.0024
3	1.571	49.05	4712	0.0049	0.0045	0.0037
4	2.095	29.43	3771	0.0018	0.0016	0.0014
5	2.095	39.24	4712	0.0037	0.0031	0.0029
6	2.095	49.05	2827	0.0043	0.0035	0.0027
7	2.618	29.43	4712	0.0042	0.0037	0.0029
8	2.618	39.24	2827	0.0026	0.0022	0.0019
9	2.618	49.05	3771	0.0049	0.0041	0.0035

IV.   RESULT AND DISCUSSIONS

1. S/N Ratios Analysis:

The influence of control parameters such as sliding speed (S), load (L) and sliding distance (D) on wear was been evaluated using S/N ratio response analysis. Process parameter settings with the highest S/N ratio always yield the optimum quality with minimum variance [20]. The sliding wear quality characteristic selected was smaller is the better type and same type of response was used for signal to noise ratio which is given below.

$$\eta = -10 \log_{10} \left\{ \frac{1}{10} \sum_{i=1}^{n} y_i^2 \right\}$$

The S/N ratio response was analyzed using the above Equation for all nine tests and presented in Table 4. Figures 1, 2 and 3 show the main effects plots of S/N ratios for aluminium and its alloys graphically. From the figures it is evident that the average mean wear of aluminium is 0.003522 grams, whereas for the Al-Si alloy it is 0.002967 grams and same for Al-Si-Ti alloy is 0.002489 grams. This shows that wear resistance of Al-Si-Ti alloy is more than that of Al and Al-Si alloys.

Table 4:S/N Ratio for Al and its Alloys

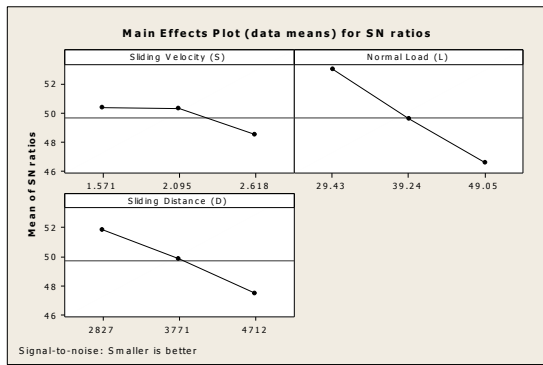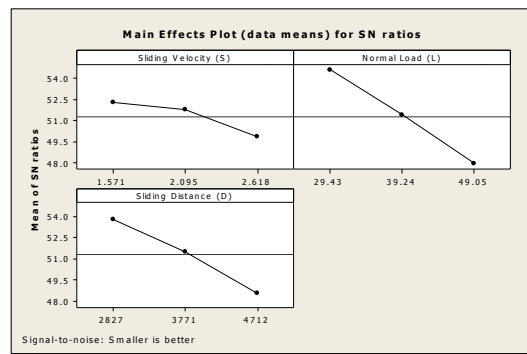| L_9 Tests	S/N Ratio for Al (db)	S/N Ratio for Al-Si (db)	S/N Ratio for Al-Si-Ti (db)
1	56.4782	59.1721	60.0000
2	48.4043	50.7520	52.3958
3	46.1961	46.9357	48.6360
4	54.8945	55.9176	57.0774
5	48.6360	50.1728	50.7520
6	47.3306	49.1186	51.3727
7	47.5350	48.6360	50.7520
8	51.7005	53.1515	54.4249
9	46.1961	47.7443	49.1186

Figure 1:S/N Ratios of Al.

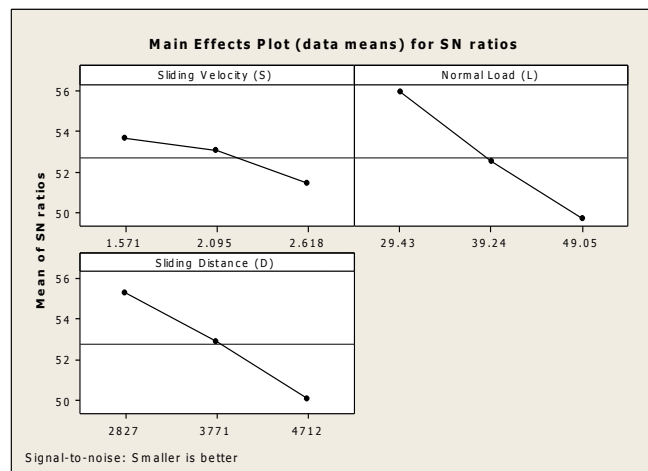Figure 2:S/N Ratios of Al-Si Alloy

Figure 3:S/N Ratios of Al-Si-Ti Alloy

2.ANOVA Analysis:

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 5, 6 and 7 show the results of ANOVA analysis of Al, Al-Si and Al-Si-Ti alloys respectively. We can observe from the ANOVA analysis (Table 5) that the sliding speed, load and sliding distance have the influence on wear of aluminium material. The last column of the Tables 6 and 7 indicate the percentage contribution of each factor on the total variation indicating their degree of influence on the result.

Table 5:ANOVA Table of Al Material

Source	DOF	Seq SS	Adj SS	Adj MS	F	P
Sliding Velocity (S)	2	0.0000007	0.0000007	0.0000003	0.42	0.706
Normal Load (L)	2	0.0000074	0.0000074	0.0000037	4.58	0.179
Sliding Distance (D)	2	0.0000032	0.0000032	0.0000016	2.01	0.333
Error	2	0.0000016	0.0000016	0.0000008		
Total	8	0.000129				

From the ANOVA table 5it is clear that the load (44.96%) and sliding distance (12.40%) have great influence on the wear of the aluminium material. The Table 6 shows ANOVA analysis of Al-Si alloy. From the results, it is found that load (47.12%) and sliding distance (25.00%) have great influence on the wear of the Al-Si alloy.Similarly Table 7 shows ANOVA analysis of Al-Si-Ti alloy. From the results, it is found that load (51.52%) and sliding distance (34.85%) have great influence on the wear of the Al-Si-Ti alloy.

Table6:ANOVA Table of Al-Si Material

Source	DOF	Seq SS	Adj SS	Adj MS	F	P
Sliding Velocity (S)	2	0.0000006	0.0000006	0.0000003	0.86	0.537
Normal Load (L)	2	0.0000057	0.0000057	0.0000028	7.86	0.113
Sliding Distance (D)	2	0.0000034	0.0000034	0.0000017	4.75	0.174
Error	2	0.0000007	0.0000007	0.0000004		
Total	8	0.0000104				

Table7:ANOVA Table of Al-Si-Ti Material

Source	DOF	Seq SS	Adj SS	Adj MS	F	P
Sliding Velocity (S)	2	0.0000003	0.0000003	0.0000002	2.07	0.326
Normal Load (L)	2	0.0000036	0.0000036	0.0000018	21.09	0.045
Sliding Distance (D)	2	0.0000025	0.0000025	0.0000013	15.09	0.062
Error	2	0.0000002	0.0000002	0.0000001		
Total	8	0.0000066				

3.SEM Analysis:

The mechanism of material removal during wear process of the aluminium is by plastic deformation and gouging. The wear resistance of the alloy material is improved due to the presence of hard AlSiTi particles in the material. The wear process in the material is by plastic deformation, gouging and reinforcement particles will crush to very minute

particles and form a very thin sub surface layer. Figures 4 and 5 show the micro structure of the aluminium and its alloys.
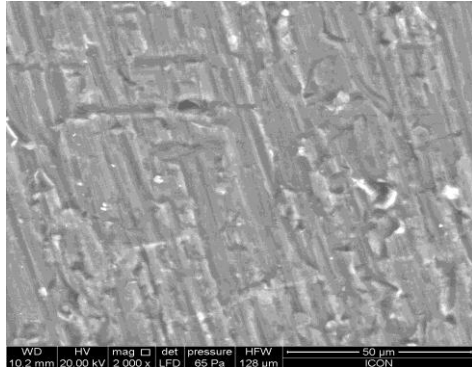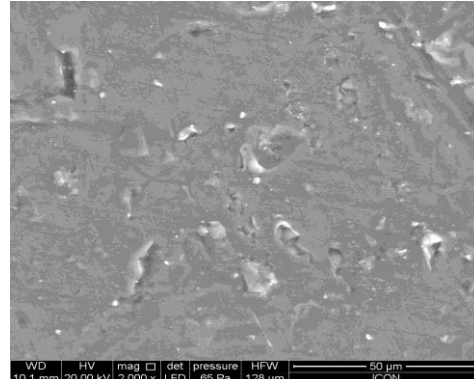

Figure 4:SEM of Al-Si Alloy.   **Figure 5:**SEM of Al-Si-Ti Alloy.

4.Multiple Linear Regression 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. In order to establish the correlation between the wear parameters: sliding velocity (S), normal load (L), sliding distance (D) and the wear (mass loss) in grams, the multiple linear regression model was used.

Wear of Al (gms) = − 0.00481 +0.000477 S + 0.000112 L + 0.000001 D………………………………………….(I)
S = 0.000634730   R-Sq = 84.4%   R-Sq(adj) = 75%
Wear of Al-Si-Ti (gms) = − 0.00483 +0.000477 S + 0.000097 L + 0.000001 D……………………………..(II)
S = 0.000501209   R-Sq = 87.9%   R-Sq(adj) = 80.7%
Wear of Al-Si-Ti (gms) = − 0.00398 +0.000382 S + 0.000078 L + 0.000001 D…………………………......(III)
S = 0.000256026   R-Sq = 95.1%   R-Sq(adj) = 92.1%

Equation (I), (II) and (III) shows the regression equations for Al, Al-Si and Al-Si-Ti respectively. In this study, results obtained from wear in good agreement with regression models (R^2=0.951). It can be noted that since the value of regression coefficient for the model is 0.921, the wear data were not scattered. Since both the values are reasonably close to unity, models provide a reasonably good explanation of the relationship between the independent factors and the response.

It can be observed from (III) for Al-Si-Ti alloy that the coefficient associated with sliding velocity (S),applied load (L) and sliding distance (D)are positive that indicates the wear rate of the material A increases with increasing the above parameter.

V.   CONCLUSION

The following conclusions, from the experiential investigation can be made about the friction and sliding wear behavior of Al, Al-Si Eutectic alloy and Al-Si Eutectic alloy in addition of Titanium as a grain structure modifier under the selected ranges of normal loads and sliding velocities.

1)   The DOE technique is successfully used to dry and wet sliding wear behaviour of , Al-Si Eutectic alloy and Al-Si-Ti Eutectic alloy.
2)   The ANOVA analysis shows that the normal load (47.96%) and sliding distance (12.40%) have significant influence on wear of aluminium in wet condition. The same analysis shows that the normal load (47.12%) and sliding distance (25.00%) have significant influence on wear of aluminium-silicon eutectic alloy in dry condition. Similarly for Al-Si-Ti alloys, the ANOVA analysis shows that the normal load (51.52%) and sliding distance (34.85%) have significant influence on wear in dry condition.
3)   The wear resistance of Al-Si-Ti alloy is more than that of Al-Si alloy and Al in dry condition. The average mean wear of aluminium is 0.003522 grams, where as for the Al-Si, it is 0.002967 grams, similarly for Al-Si-Ti, it is 0.002489 grams for wet condition.
4)   A multiple linear regression model was developed to predict the wear rate of the alloys. The closeness of the results of predictions based on calculated S/N ratios and experimental values show that the Taguchi experimental design technique can be used successfully for both optimization and prediction.

5) Analysis of worn surfaces revealed that at lower load, oxidation was the dominant wear mechanism, whereas at higher load, delamination and adhesion were found to be dominant for the alloys. It was found that mild wear occurs at high velocity and lower applied load, whereas severe wear occurs at high velocity and higher applied load.

6) As a result, it is found that the parameter design of the Taguchi method provides a simple, systematic, and efficient methodology for the optimization of the wear test parameters.

REFERENCES

[1]. Francis UchennaOzioko, "Synthesis and Study on Effect of Parameters on Dry Sliding Wear", Leonardo Electronic Journal of Practices and Technologies, ISSN 1583-1078, Issue 20, January-June 2012, 39-48.

[2]. Riyadh A. Al-Samarai1, Haftirman, KhairelRafezi Ahmad, Y. Al-Douri, "Effect of Load and Sliding Speed on Wear and Friction of Aluminum–Silicon Casting Alloy", International Journal of Scientific and Research Publications, Volume 2, Issue 3, March 2012 1 ISSN 2250-3153.

[3]. Muna K. Abbass, "Effect of Cd on Microstructure and Dry Sliding Wear Behavior of (Al-12%Si) Alloy", The Journal of Engineering Research Vol. 7, No. 1 (2010) 1-10.

[4]. Mustafa Ahmed Rijab, "study the Effect of Ti Addition on the Microstructure of Eutectic Al-12% Si Alloy", Diyala Journal of Engineering Sciences, ISSN 1999-8716, Vol. 2, June 2009, 96-108.

[5]. Wang Jiefang, XieJiegpei, Yan Shuqing, Liu Zhongxia, WengYonggang, Wang Mingxing, Song Tianfu, "Influence of Titanium Content on Wear Resistance of Electrolytic Low Titanium Eutectic Al-Si Piston Alloys", China Foundry, Vol. 5, No. 3, 2008, 162-166.

[6]. M. Zeren and E. Karakulak "Microstructural chracterisation of Al–Si–xTi cast alloys", Materials Science and Technology, 2009, Vol 25 No 10, 1211-1214.

[7]. N. Saheb, T. Laoui, A.R. Daud, M. Harun, S. Radiman, R. Yahay, "Influence of Ti addition on wear properties of Al–Si eutectic alloys", Wear 249 (2001) 656–662.

[8]. S. Anasyida, A. R. Daud and M. J. Ghazali, " Dry sliding wear behaviour of al-4si-4mg alloys by addition of cerium", International Journal of Mechanical and Materials Engineering (IJMME), Vol. 4 (2009), No. 2, 127-130.

[9]. Dr. Adnan Ibrahim Mohammed, Mahdi Muter Hanoon&HaithamRzouqi Saleh, "Effect of Sodium Modifier on the Microstructure and Wear Rate of Al-14 Wt% Si Alloy", VEngineering and Technology Journal, Vol:28, No.: 22, 2010, pg-6615-6622.

[10]. Malek Ali, Ali SamerMuhsan, M.I. Fadhel, M.A. Alghoul, K. Sopian& A. Zaharim, "Developments of Al-12Si alloys by reinforcing TiN particles", Recent Researches in Energy, Environment and Sustainable Development, ISBN: 978-1-61804-105-0, pg. 42-46.

[11]. A. Apasi, P.B. Madakso, D.S. Yawas, V.S. Aigbodion, "Wear Behaviour of Al-Si-Fe Alloy/Coconut Shell Ash Particulate Composites", Tribology in Industry, Vol. 34, No 1 (2012), pg.36-43.

[12]. Amro M. AI-Qutub • Ibrahim M. Allam M. A. Abdul Samad, "Wear and friction of Al-A1203 composites at various sliding speeds", Journal of Material Science (2008) 43, pg. 5797-5803.

[13]. S.Srivastava, S. Mohan, Yogesh Srivastava and Aman J. Shukla, " Study of the wear and friction behavior of immiscible as cast-Al-Sn/Graphite composite", International Journal of Modern Engineering Research (IJMER), ISSN: 2249-6645, Vol.2, Issue.2, Mar-Apr 2012, 025-042.

[14]. Prasad, B K and Venkateswarlu, K and Modi, O P and Jha, A K and Das, S and Dasgupta, R and Yegneswaran, A H, "Sliding wear behavior of some Al-Si alloys: Role of shape and size of Si particles and test conditions," Metallurgical and Materials Transactions A, 29 (11), 1998, pp. 2747-2752.

[15]. Bai, Pramila BN and Biswas, SK "Characterization of dry sliding wear of Al---Si alloys.", Wear, 120 (1), 1987, pp. 61-74.

[16]. Riyadh A. Al-Samarai, Haftirman, KhairelRafezi Ahmad, Y. Al-Douri, "The Tribological Behavior of Hypo and Hyper Eutectic Al-Si Alloys Under Dry Sliding Conditions", International Journal of Mechanical and Production Engineering Research and Development (IJMPERD), ISSN 2249-6890 ,Vol. 3, Issue 1, Mar 2013, 111-124.

[17]. FeritFicici, Murat Kapsiz, Mesut Durat, "Applications of taguchi design method to study wear behaviour of boronized AISI 1040 steel ", International Journal of the Physical Sciences, Vol. 6(2), ISSN 1992 – 1950, January 2011, 237-243.

[18]. ShanmughaSundaramPalanisamy, Subramanian Ramanathan, Ravikumar Rangaraj, "Analysis of Dry Sliding Wear Behaviour of Aluminium-Fly Ash Composites: The Taguchi Approach", Advances in Mechanical Engineering,Volume 2013, 1-10.

[19]. H. B. Bhaskar, Abdul Sharief, "Dry Sliding Wear Behaviour of Aluminium/$Be_3Al_2(SiO_3)_6$ Composite Using Taguchi Method", Journal of Minerals and Materials Characterization and Engineering, 2012, 11, 679-684.

[20]. S. Rajesh, S. Rajakarunakaran, R. SudhakaraPandian , "Modeling and Optimization of Sliding Specific Wear and Coefficient of Friction of Aluminum Based Red Mud Metal Matrix Composite Using Taguchi Method and Response Surface Methodology", Material Physics and Mechanics, vol. 15, 2012, 150-166.