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Some Investigations on the Tribological Wear Behaviour of Modified ZA–27 Alloy Based On Taguchi Method

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Abstract: **In the present investigation an attempt has been made to improve the tribological property of ZA-27 alloy by adding 1% Mn alloy. The wear behaviour of the modified ZA-27 alloy was studied by performing dry sliding wear test using pin-on-disc wear and friction monitor tester by varying Nr. Pressure and sliding speed. Experiments were conducted based on the plan of experiments generated through taguchi technique. An orthogonal array, signal-to-noise ratio and analysis of variance were employed to investigate the wear behaviour of modified ZA-27 alloy. The mathematical model was obtained to determine the wear rate of the modified ZA-27 alloy. The confirmation tests were conducted to verify the experimental results. In this study we found that the Nr. Pressure and sliding speed are more sensitive parameters.**

Keywords: **ANOVA, Modified ZA-27 alloy, orthogonal array, Regression analysis, S/N Ratio, Taguchi technique, wear rate.**

1. INTRODUCTION

Zinc-based alloys have been widely used as tribological components for various machines because of their lower density, excellent castability, fluidity, lower energy requirement for shaping and superior wear properties [1–3]. Zinc based cast alloys, commonly referred to as “ZA” alloys, has been developed during the past year and is now increasing in commercial usage. The chemical requirements for these alloys are specified in ASTM B669 [4].

Zinc-aluminium (ZA) based cast alloys by virtue of their excellent castability, wear resistance and good mechanical properties [1-3] have found significant industrial usage during the past few years. These alloys exhibit good wear resistance under higher loads, poor lubrication conditions and have been used as replacement for bronze and brass in the bearing industry [4-10]. These alloy containing high aluminum content and observed to be cost effective and energy effective substitute to a variety of materials [11- 13].

In the earlier investigations, the effect of different Al content on the mechanical and wear properties of Zn-based alloy containing 2.5% Cu and 0.03% Mg has been studied[14], in their experiments, higher strength and elongation properties were obtained with the alloy having 27.5 wt %Al. Also, as the quantity of Al increased up to 47.5 wt.%, the strength and elongation decreased. Higher strength at elevated temperatures was exhibited as the Al content increased. Wear test results showed that at a speed of 0.42ms−1, the alloy having 27.5 wt% Al performed best. Copper has been added to zinc–aluminum-based alloys and its effects on these alloys studied in detail [14–16]. These studies have shown that copper addition improves mechanical properties of these alloys but it causes dimensional instability especially at high working temperatures [17]. In order to reduce this problem and to improve wear resistance, silicon was added to zinc–aluminum based alloys [18]. The effect of Ni on the wear response of a high-aluminum zinc alloy. The alloy has been modified with 0.3 and 0.9 wt% Ni, and wear tests have been carried out at sliding speeds of 3.925 and 6.54 m/s. An addition of Ni in appropriate amount reduces the abrasion wear loss of a high-aluminum zinc alloy Improvement in wear resistance increases with the amount of Ni[19].

From the review of existing literature it is apparent that many studies have been carried out on the wear behaviour of ZA-27 alloy, but no study is available on optimization of process parameters for minimum wear response. The present study considers optimization of wear behaviour of modified ZA-27 alloy using Taguchi orthogonal design with two process parameters viz. Normal pressure and sliding speed. The test results are analyzed for optimal combination of process parameters for minimum wear. A confirmation test is done to validate the optimal combination of process parameter as predicted by Taguchi method. Furthermore, Analysis of Variance (ANOVA) is carried out to analyze the effect of process parameters on the wear behaviour of the material.

2. TAGUCHI METHOD

The taguchi method was developed by Dr.Genichi Taguchi. He developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels. This technique is carried out in a three stages approach such as system design, parameter design and tolerance design. System design reveals the usage of scientific and engineering information required for producing a part. Parameter design is used to obtain the optimum levels of process parameters for developing the quality characteristics and to determine the product parameter values. Tolerance deign is used to determine and analyze tolerance about the optimum combination suggested by parameter design. In the present study, parameter design is used to optimize the wear behaviour of modified ZA-27 alloy.

3. EXPERIMENTAL DETAILS

3.1 Alloy preparation

The chemical composition of the alloy studies was based on the ZA-27 containing Al – 27 wt%, Cu – 2 wt%, Mg – 0.04 wt%, Si – 3.5% and balance Zn with an addition of 1%Mn alloy content was prepared. The chemical compositions of these alloys were weighted according to ratios and melted in a graphite crucible. Alloying temperature was controlled below 700^0 C to avoid the lost of Zn. the melt was then degassed and stirred well before being poured into the sand molds, which were preheated to approximately 150^0 C in open air.

3.2 Design of Experiment

The experimental plan was formulated considering two parameters (variables) and five levels based on the Taguchi technique. Normal Pressure (A) and Sliding Speed (B), these are process parameters are considered for the study. Process parameters setting with the highest S/N ratio always yield the optimum quality with minimum variance. The levels of these variables chosen for experimentation are given in the Table 1.

In the present investigation an L25 orthogonal array was chosen as shown in table 3. The selected of the orthogonal array is based on the condition that the degrees of freedom for the orthogonal array should be greater than, or equal to, the sum of the variables. The experiments were conducted based on the run order generated by Taguchi model and the results were obtained. This analysis includes the rank based on the delta statistics, which compares the relative value of the effects. S/N ratio is a response which consolidates repetitions and the effect of noise levels into one data point. The experimental results were transformed into signal-to-noise ratio (S/N) ratios. An S/N ratio is defined as the ratio of the mean of the signal to the standard deviation of the noise. The S/N ratio indicates the degree of the predictable performance of a product or process in the presence of noise factors. The S/N ratio for the wear rate using 'smaller the better' characteristics, which can be calculated as logarithmic transformation of the loss function is given as

$S/N = -10 \log_{10} (MSD)$ ------------ (1)

Where MSD = Mean Square Deviation

For the smaller the better characteristic,

$MSD = (Y_1^{\ 2} + Y_2^{\ 2} + Y_3^{\ 2} + \ldots\ldots\ldots) \times 1/n$

Where Y1, Y2, Y3 are the responses and 'n' is the number of tests in a trial.

Table 1: Control and Noise Factors

Sl.No.	Process Parameters	Level 1	Level 2	Level 3	Level 4	Level 5
1	Normal Pressure (MPa),	0.06245	0.1249	0.24981	0.37471	0.49962
2	Sliding Speed (m/s.),	0.5	1.0	1.5	2.0	2.5

Table 2: ORTHOGONAL ARRAY (L25)

Sl.No	Nr. Pressure	Sliding speed
01	1	1
02	1	2
03	1	3
04	1	4
05	1	5
06	2	1
07	2	2
08	2	3
09	2	4
10	2	5
11	3	1
12	3	2
13	3	3
14	3	4
15	3	5
16	4	1
17	4	2
18	4	3
19	4	4
20	4	5
21	5	1
22	5	2
23	5	3
24	5	4
25	5	5

3.3 Wear test

In the present research one of the commonest and simplest methods to test for wear rate was by using a pin-on-disc wear tester (Model: TR-20, DUCOM) as per ASTM: G99 – 05. The counterpart disc was made of quenched and tempered EN-32 steel having a surface hardness of 65 HRC. The specimens of size Ø10×33 mm were machined out from all the as cast specimens. The track diameter of 80mm enabled the rotational speeds of 136, 272, 409, 545 and 682 rpm to attain linear sliding speeds of 0.5, 1.0, 1.5, 2.0 and 2.5 m/s respectively. Load on the specimen was increased in steps until the specimen seized before traversing a fixed sliding distance of 2500m.The surfaces of the pin sample and the steel disc were ground using emery paper prior to each test. In ordered to ensure effective contact of fresh surface with the steel disc, the fresh samples were subjected to sliding on emery paper of 240grit size fixed on the steel disc. During sliding, the load is applied on the specimen through cantilever mechanism and the specimens brought in intimate contact with the rotating disc at a track radius of 80mm.Before each test the disc was cleaned with organic solvents to remove contaminants. The wear losses of sample pins were recorded using an electronic microbalance having an accuracy of ± 0.01mg. After wear test specimens were cleaned thoroughly and weighed again. The wear rate was calculated by a weight-loss method.

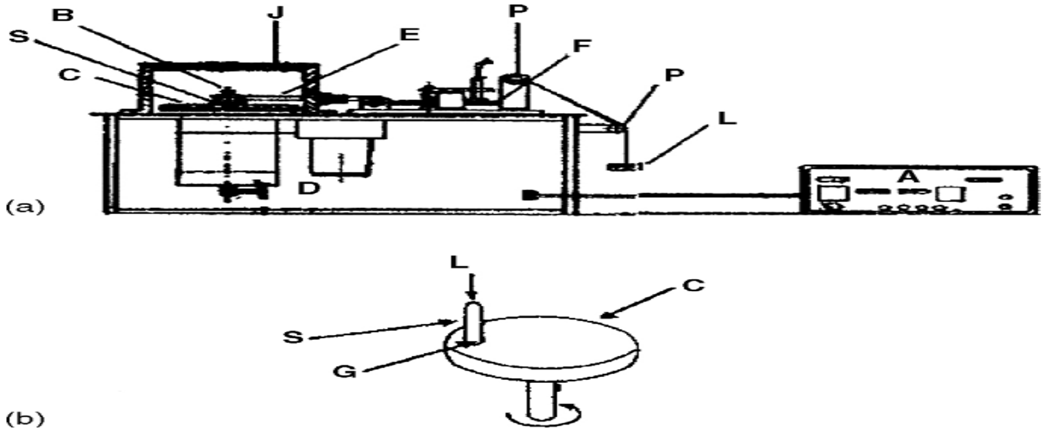

Fig. 2: Schematic representations of (a) the pin-on-disc wear test apparatus and (b) wear test configuration (A: control and display unit, B: specimen holder, C: disc, D: motor drive system, E: cantilever, F: load cell/force transducer, G: thermocouple, J: environmental chamber, L: load, P: pulley, and S: specimen).

Table 3: Combination of parameters in (L25) orthogonal Array

Sl.No	Nr. Pressure (MPa)	Sliding speed (m/s)	WEAR RATE (mm^3/m)	S/N Ratio for Wear rate
01	0.06245	0.5	0.001	60.0000
02	0.06245	1	7.19342E-4	62.8613
03	0.06245	1.5	2.14272E-4	73.3807
04	0.06245	2	7.11689E-4	62.9542
05	0.06245	2.5	5.89248E-4	64.5940
06	0.1249	0.5	0.00207	53.6806
07	0.1249	1	0.00132	57.5885
08	0.1249	1.5	0.00107	59.4123
09	0.1249	2	0.00103	59.7433
10	0.1249	2.5	4.20892E-4	67.5166
11	0.24981	0.5	0.00134	57.4579
12	0.24981	1	0.00103	59.7433
13	0.24981	1.5	3.29061E-4	69.6545
14	0.24981	2	1.76009E-4	75.0893
15	0.24981	2.5	6.50469E-4	63.7355
16	0.37471	0.5	0.00245	52.2167
17	0.37471	1	0.00181	54.8464
18	0.37471	1.5	0.00155	56.1934
19	0.37471	2	0.00139	57.1397
20	0.37471	2.5	0.00121	58.3443
21	0.49962	0.5	0.00243	52.2879
22	0.49962	1	0.00216	53.3109
23	0.49962	1.5	0.00171	55.3401
24	0.49962	2	0.00192	54.3340
25	0.49962	2.5	8.41783E-4	61.4960

4. RESULTS AND DISCUSSION

The experiments were conducted based on the run order generated by Taguchi model, with the aim of relating the influence Normal pressure (MPa) and sliding speed (m/s) for the wear test. The result obtained for various combinations of parameters was obtained and was shown in table 3.

4.1 Analysis of S/N Ratio

In Taguchi method, the term ‘signal’ represents the desirable value (mean) for the output characteristics and the term ‘noise’ represents the undesirable value for the output characteristics. Taguchi uses S/N ratio to measure the quality characteristics deviating from the desired value. The influence of control parameters such as Normal pressure, and Sliding speed content has been analyzed and the rank of involved factors like wear rate of modified ZA-27 alloy which supports S/N ratio response is given in the table 4 and response table for mean is in the table 5. It is evident from the table that among these process parameters, normal pressure is a dominant factor on the wear rate. The influence of controlled process parameters on wear rate are graphically represented in figures 3 and 4.

Table 4: Response Table for S/N Ratio

Level	Nr.Pressure	Sliding speed
1	64.76	55.13
2	59.59	57.67
3	65.14	62.80
4	55.75	61.85
5	55.35	63.14
Delta	9.78	8.01
Rank	1	2

Table 5: Response Table for Means

Level	Nr. Pressure	Sliding speed
1	0.000647	0.001858
2	0.001182	0.001408
3	0.000705	0.000975
4	0.001682	0.001046
5	0.001812	0.000742
Delta	0.001165	0.001116
Rank	1	2

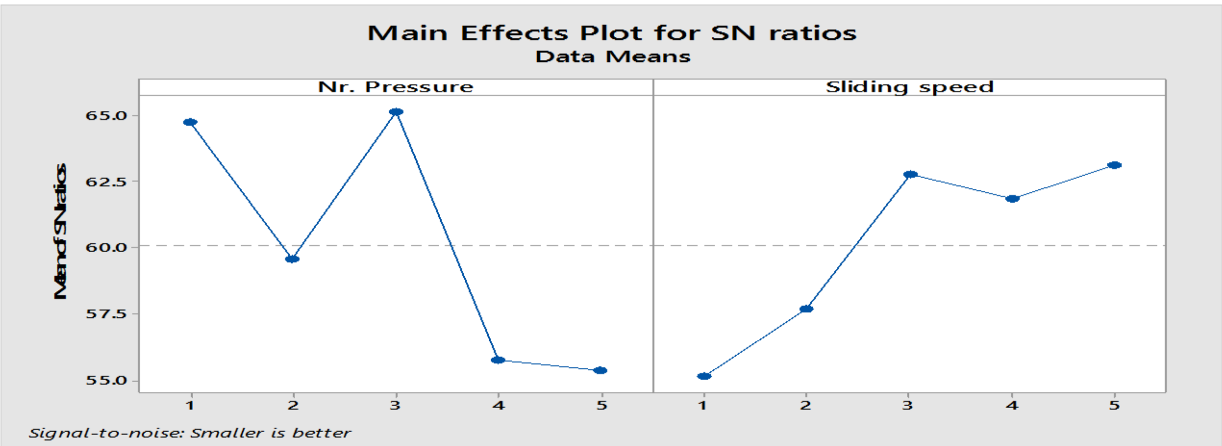

Fig 3: Main Effects Plot for SN ratios – wear rate

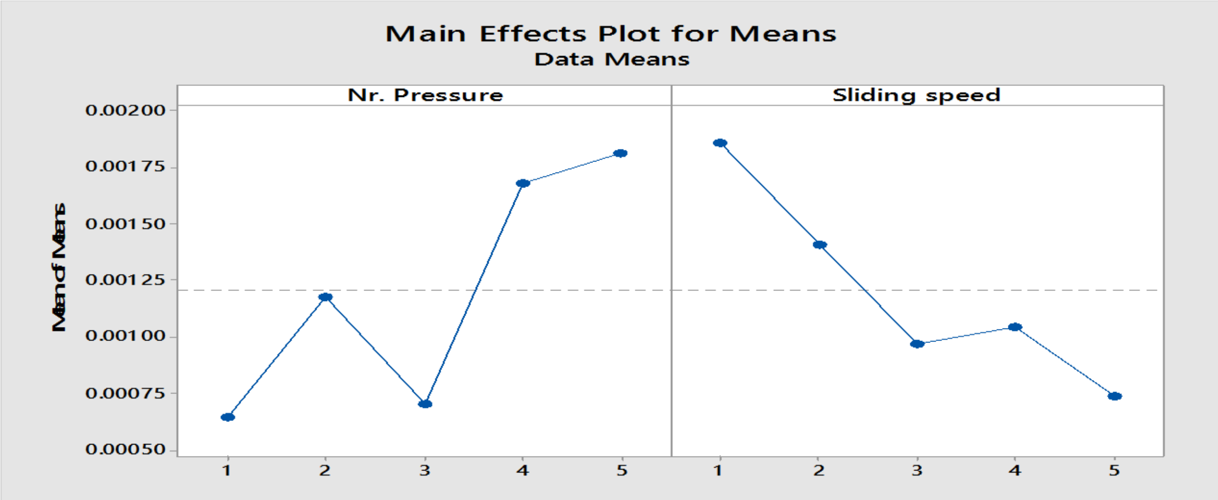

Fig 4: Main Effects Plot for Means- wear rate

4.2 Analysis of variance

Analysis o variance (ANOVA) was introduced by Sir Ronald Fisher. This analysis was carried out for a level of significance of 5%, i.e., for 95% level of confidence. The purpose of ANOVA is to investigate the percentage of contribution of variance over the response parameter and to find the influence of wear parameters. The ANOVA is also needed for estimating the error of variance and variance of the prediction error. The table 6 shows analysis of variance for wear rate of the modified ZA-27 alloy. From the table 6, it is observed that the normal pressure and sliding speed have the influence on wear of modified ZA-27 alloy. The last column of the table 6 indicates the percentage contribution of each other on the total variation indicating their degree of influence on the result. It can be observed from the ANOVA table that the normal pressure (53.28%) was the most significant parameter on the dry sliding wear of modified ZA-27 alloy followed by sliding speed (34.96%). When the P-value for this model was less than 0.05, then the parameter can be considered as statistically significant. The Nr. Pressure and sliding speed can be considered as statistically significant. The pooled error associated in the ANOVA table was approximately about 11.76%. This approach gives the variation of means and variance to absolute values considered in the experiment and not the unit value of the variable.

Table 6: Analysis of Variance for wear rate (mm^3/m)

Source	DF	Seq SS	Adj SS	Adj MS	F-Value	P-Value	% of contribution
Nr. Pressure	4	0.000006	0.000006	0.000001	18.12	0.000	53.28%
Sliding speed	4	0.000004	0.000004	0.000001	11.89	0.000	34.96%
Error	16	0.000001	0.000001	0.000000			11.76%
Total	24	0.000011					100.00%

4.3 Multiple Linear Regression Models

Statistical software MINITAB R17 is used for developing a multiple linear regression equation. This developed model gives the relationship between independent/predictor variable and a response variable using by fitting a linear equation to the measured data.

The regression equation developed for wear rate is,

Wear rate = 0.001206 - 0.000501 (A) - 0.000231 (B) ------------ (2)

R-sq = 88.24%

4.4 Confirmation Experiment

Finally, confirmation test was performed for composite material by selecting the set of parameters as shown in table 7. The table 8 shows the results obtained using regression equation and the experimental results. From the analysis, the actual wear rate is found to be varying from the calculated one using regression equation and the error percentage ranges between 7.01% to 9.59% for wear rate. The mathematical model obtained from the multiple linear regression models evaluates the wear of the modified ZA-27 alloy with reasonable degree of approximation.

Table 7: Confirmation Experiment for Wear Rate

Level	Normal Pressure (MPa)	Sliding Speed (m/s)
1	0.06245	0.5
2	0.1249	1.0
3	0.1874	1.5
4	0.3123	2.0
5	0.4372	2.5

Table 8: Result of Confirmation Experiment and their Comparison with Regression Model

Expt. No.	Expt. Wear rate (mm^3/m)	Reg. model eqn(1), Wear rate (mm^3/m)	% Error
1	0.0008035	0.0007656	4.72
2	0.000753	0.000703	6.64
3	0.000645	0.000587	8.99

5. CONCLUSIONS

Based on the above analysis the following conclusions are drawn from the present study.

1. Taguchi method provides a systematic and efficient methodology for the design and optimization of wear rate parameters with far less effort than would be required for most optimization techniques.
2. For Modified ZA-27 alloy the optimal tribological testing combination for minimum wear rate is found to be A3B3. All the factors Nr. Pressure (A) and sliding speed (B) are found to affect the wear rate significantly.
3. The analysis of variance shows that the Normal pressure (53.28%) is the wear factor that has the highest statistical influence on the dry sliding wear of modified ZA-27 alloy followed by sliding speed (34.96%).
4. The pooled error associated with the ANOVA analysis was 11.76% for the factors and the correlation between the wear parameters was obtained by multiple linear regression models.
5. From confirmation tests, the errors associated with wear rate ranges between 4.72% to 8.99% resulting in the conclusion that the design of experiments by Taguchi method was successful for calculating wear rate from the regression equation.
6. The Nr. Pressure and sliding speed parameters can be considered as statistically significant.

REFERENCES

[1] T. Sava¸skan, The structure and properties of zinc–aluminium based bearing alloys, Ph.D. Thesis, University of Aston, Birmingham, 1980.

[2] T. Calayag, D. Ferres, High-performance, high-aluminium zinc alloys for low-speed bearings and bushings, in: SAE Annual Conference, Paper no. 820643, 1983, pp. 2241–2251.

[3] E. Gervais, H. Levert, M. Bess, The development of a family of zinc-based foundry alloys, Trans. Am. Foundrym. Soc. 88 (1980) 183–194.

[4] Boyer, H. E. and Gall, T. L.(1992). *Metals Handbook* (Metals Park Ohio: American Society for Metals), 11.4-11.5.

[4] Sharma, S. C., Girish, B. M., Kamath, R., Satish, B. M. "Graphite particles reinforced ZA-27 alloy composite materials for journal bearing applications" Wear 219,1998,162- 168.

[5] Sharma, S. C., Rao, P. R., Girish, B. M. "Mechanical properties of as-cast and heat-treated ZA-27/silicon carbide particulate composites" Materials and Design, 16 ,(5) 1995: 277-280.

[6] Ahmet Turk, Mehmet Durman, E. Sabri Kayali "The effect of Ti-B and Sr on the mechanical behavior of the Zinc-aluminum based ZA-12 alloy produced by gravity casting" Intl Journal of Materials Research, Volume 97, 2006(8), 1-6

[7] Mukundadas Prasanna Kumar, Kanakuppi Sadashivappa "Dry sliding wear behaviour of garnet particles reinforced Zinc aluminium alloy metal matrix composites" Materials Science, Volume 12, 2006 ,1392–1320

[8] Shanta Satry, M.Krishna, Jayagopalan Uchil "A study on damping behavior of aluminite particulate reinforced ZA-27 alloy metal matrix composites" J. Alloys and Compounds, Volume 314 , 2001, 268-274.

[9] Yuanyuan, Tungwai,Wei Xia,Wen Zhang "Effect of Mn content on the tribological behaviour of ZA27%Al-2%Cu alloy" Wear, Volume 198, 1996, 129-135.

[10] Seenappa, K.V.Sharma "Effect of alloying additions on tribological properties of ZA alloys" International Journal of Advanced Engineering & Application, Volume2, Jan 2011, 152–155.

[11] B.K. Prasad, A.K. Patwardhan, and A.H. Yegneswaran, "Characterization of the wear response of a modified Zinc-based alloy Vis-Avis a conventional Zinc-based alloy and a bearing bronze", Metall. Mater. Trans., Vol 27A, 1996, 3513-3523

[12] Prasad, B. K "High stress abrasive wear behavior of a zinc based alloy and its composite compared with a gray cast iron under varying track radius and load conditions" Materials Science and Engineering A. Volume 381,(2004) 343-354.

[13] Choudhury, K. Das and S. Das "Evolution of as-cast and heat-treated microstructure of a commercial bearing alloy" Materials Science and Engineering A, 398 (2005) 332-343.

[14] Pratt GC. Int Met Rev 1973; 18:1–27.

[15] Gervais E, Levert H, Bess M. Development of a family of zinc base foundry alloys. Trans AFS 1980; 88:183–94.

[16] Kubel EJ. Expanding horizons for ZA alloys. Adv Mater Process 1987; 132:51–7.

[17] Prasad BK. Wear 2000; 240:100–12.

[18] Savas, kan T, Purcek G, Murphy S. Wear 2002; 252:693–703.

[19] P. CHOUDHURY, S. DAS, B. K. DATTA, "Effect of Ni on the wear behavior of a zinc-aluminum alloy", Journal Of Materials Science 37 (2002) 2103 – 2107.