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Research Paper

EXPERIMENTAL INVESTIGATION ON FRICTION CHARACTERISTICS OF MODIFIED ZA-27 ALLOY USING TAGUCHI TECHNIQUE

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In this paper a friction performance for modified ZA-27 alloy is studied using taguchi method. The parameters considered for this experimental study are Nr. Pressure and sliding speed. The friction behaviour of the specimens was investigated using wear and friction monitor apparatus. The experiments were conducted by the plan of experiments generated by using taguchi method. The orthogonal array, signal-to-noise ratio and analysis of variance (ANOVA) were employed to optimize the testing parameters on modified ZA-27 alloy. Multiple linear regression analysis was carried out to develop a amount of relation for friction with the process parameter.

Keywords: ANOVA, COF, Modified ZA-27 alloy, multiple linear regressions, S/N ratio, wear and friction monitor

INTRODUCTION

The family of zinc–aluminium (ZA) alloys, containing between 8 to 50 wt% aluminium (Babic Miroslav *et al.*, 2009), were developed in the 1960's and 1970's and became a substitute for the brass, cast and malleable iron for the fabrication of wear-resistant parts (Shuqing Yan *et al.*, 2010). During the 1980's the wear properties of the ZA alloys were improved by the addition of 3-5 wt% of Si, due to precipitation of Si in the alloys. Further improvement in the wear properties is achieved by adding copper by 2 wt%. Zinc based alloy have emerged as a potential cost and energy effective substitute material system for various ferrous and non ferrous alloys for different engineering applications (Seenappa K V Sharma, 2001; B K Prasad, 2003). One of the important varieties in the category of high strength Zn–based alloys consists of 11.0–12.0% Al along with Cu and Mg, the alloy composition has been exploited considerably

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to establish its application potential at different levels. However, limited efforts have been made to understand its wear response in various test conditions, especially in terms of analyzing material removal mechanisms and factors responsible for typical wear characteristics in specific situations. Superior wear performance of zinc- based alloy tribo-components has been reported in heavy mining machineries in comparison to conventionally used bronze/gun metal counter parts in slow – medium speed conditions (R Michalik, 2013).

ZA alloys have a strength comparable to aluminium casting alloys, wear resisting properties comparable to bearing bronzes while have lower cost and properties similar to many cast irons but are easier to machine. They have been applied to many high performance parts as substitutes for cast irons and aluminium alloys, or applied to bearings and bushings as substitutes for bronzes. For bearings working under heavy load, high mechanical properties as well as good tribological properties at room and elevated temperatures are required (Li Yuan Yuan *et al.*, 2002) . However, one of the major limitations of the zinc based alloys has been observed to be their property deterioration at temperatures above 120°C (P Choudhary *et al.*, 2002; B K Prasad *et al.*, 1998). ZA-27 alloy has been substituted for conventional journal bearing materials in a wide range of industrial applications. The journal bearings produced from these alloys have been used in earthmoving equipments, mining and milling machines, wear resisting parts, valves, pulleys, cable winches and compressors (Hamdullah Cuvalcr and Hasan Serdar Celik, 2011; Yuanyuan Li *et al.*, 1996). The ZA-27 alloys are also used in heavy and dusty environments such as underground machines, mining equipments, ore crashers and rock drills.

M Babic (2004) presented a paper the tribological parameter (friction) of the Zn-Al alloy is compared to parameter of the lead-tin bronze. The established decrease of the friction coefficient increase of the contact pressure, based on obtained results, besides prominent advantage with respect to the friction coefficient characteristic. Hamdullah Cuvalc (2004) studied a frictional behavior of thin-walled journal bearings produced from Zn-Al-Cu-Si alloys using a purpose-built journal bearing test rig. The results showed that friction coefficient decreased with increasing bearing pressure especially in the mixed and full film lubrication zone. It was found that high surface roughness led to high friction coefficient. Temel Savaskan (2004) effect of copper on the friction coefficient of monotectoid based zinc-aluminium alloy, the coefficient of friction was found to be generally less for the copper containing alloys than the one without the element.

Gencaga Purcek (2002) determined the friction of two near-eutectoid and two monotectoid permanent-moulded zinc-based alloys and an SAE 660 bronze, they found that there is a sharp increase in friction coefficient during the transient-state sliding period with steady-state levels reached after about 300m.Tthe top most layer was the hardest and this is considered to be responsible for the reduced coefficient of friction and lower wear rate of the zinc-based alloys

Chen Tijun (2009) investigated the effect of silicon particle on friction properties of casting in-situ silicon particle reinforcing ZA-27 composites on friction coefficient, the friction coefficient initially increased and then increased with increasing silicon particle content. The friction coefficients changed irregularly for the different composites with the increase f testing temperature. Seenappa[16] studied the effect of Nickel content on the friction properties ZA alloys containing high percentage of aluminium with 1,2 and 3 wt% nickel. The nature of that dependence, in all the tested alloys, manifests as increase of the friction coefficient with increase of the sliding speed. In all the tested alloys, the friction coefficient increases with increase of the load.

In view of this information, the present study considers the influence of Manganese content on friction properties of modified ZA-27 alloy under varying conditions of Nr. Pressure and sliding speed.

EXPERIMENTAL PROCEDURES

Material Preparation

The material preparation of experimental alloys in weight percent were based on the ZA-27 alloy (Al-27 wt%, Cu-2wt%, Mg-0.04 wt%, Si-3.5% and balance Zn). Manganese (Mn) is used as a Modified elements. An alloy is prepared with Mn content by gravity die casting. High melting point elements were introduced in the form of master alloys with aluminium. Processing temperature is controlled below 700^{0}C to avoid loss of Zn. Raw materials were melted in a graphite crucible. After degassing the molten metal was poured into a mould, which has pre heated an approximately up to 150^{0}C in open air.

Tribological Test

The tribological tests are carried out using a pin-on-disc wear tester (Model: TR-20, DUCOM) as per ASTM: G99-05 (Figure 1). It is used to measure the friction of modified ZA-27 alloy dry non lubricated condition. 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. The frictional force is measured by a frictional force sensor that uses a beam type load cell. The friction tests were performed out at different Nr. Pressure and sliding speed.

The COF is calculated using the equation

$$COF = \frac{Frictional\ Force\ (N)}{Load\ (N)} \quad ...(1)$$

Experimental Design

The experiment was carried out to analyze the process parameters on frictional property of modified ZA-27 alloy. The experimental plan was formulated by considering two parameters and five levels based on Taguchi technique. Nr. Pressure (A) and sliding speed (B) are the process parameters are considered for the study. The levels of these parameters chosen for experimentation are given in the Table 1. An L25 orthogonal array was chosen (Table 2) for statistical analysis. The experiments were conducted based on the run order generated by Taguchi technique and the results were obtained. This analysis includes the rank based on the delta statistics, which compares the relative value of the effects. The experimental results were transformed into S/N ratios. The S/N ratio for the COF using 'smaller the better' characteristics, which can be calculated as logarithmic transformation of the loss function is given as

$$S/N = -10 \log10 (MSD) \quad ...(2)$$

where MSD = Mean square Deviation

For the lower the better characteristic,

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

where Y_1^2, Y_2^2, Y_3^2 are the response and 'n' is the number of tests in a trial.

RESULTS AND DISCUSSION

Analysis of S/N Ratio

Minitab 17 is used for analyzing the S/N ratio of the influence of each control factor such as Nr. Pressure and sliding speed on the friction properties. The experimental values of COF and calculated values of S/N ratios are listed in the Table 3. The response table of the testing process is shown in the Table 4. The control factor that has the strongest influence is determined depending on the value of delta as shown in Table 4. Delta value is calculated by the difference between maximum and minimum value of S/N ratios for each control factor. The higher the value of delta, the more influential is the control factor. From the Tables 4 and 5, it can be seen that the strongest influence was found out by Nr. Pressure (A) and sliding speed (B) respectively.

It is clear from the Figure 2 that S/N ratio is higher at level 5 for parameter A, at level 5 for parameter B respectively.

Analysis of variance (ANOVA)

The statistical methodology for comparing several means is called analysis of variance. In analysis of variance, a continuous response variable, known as a dependent variable, is measured under experimental conditions identified by classification variables, known as independent variables. The variation in the response is assumed to be due to effects in the classification, with random error accounting for the remaining variation.

Table 1: Control and Noise Factors

S.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

Figure 1: Wear and Friction Monitor Testing Machine

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 of COF for the modified ZA-27 alloy. From the table 6, it is observed that the normal pressure and sliding speed have the influence on wear

Table 3: Combination of Parameters in (L25) Orthogonal Array

S. No	Nr. Pressure (MPa)	Sliding Speed (m/s)	COF(μ)	S/N Ratio	Mean
01	0.06245	0.5	0.97859	0.1880	0.97859
02	0.06245	1	0.97859	0.1880	0.97859
03	0.06245	1.5	0.95821	0.3708	0.95821
04	0.06245	2	0.93782	0.5576	0.93782
05	0.06245	2.5	0.77472	2.2171	0.77472
06	0.1249	0.5	0.95821	0.3708	0.95821
07	0.1249	1	0.85627	1.3478	0.85627
08	0.1249	1.5	0.81549	1.7716	0.81549
09	0.1249	2	0.71356	2.9314	0.71356
10	0.1249	2.5	0.59123	4.5649	0.59123
11	0.24981	0.5	0.49439	6.1186	0.49439
12	0.24981	1	0.45362	6.8662	0.45362
13	0.24981	1.5	0.38736	8.2377	0.38736
14	0.24981	2	0.34149	9.3324	0.34149
15	0.24981	2.5	0.27523	11.2061	0.27523
16	0.37471	0.5	0.40775	7.7921	0.40775
17	0.37471	1	0.39076	8.1618	0.39076
18	0.37471	1.5	0.38056	8.3915	0.38056
19	0.37471	2	0.35678	8.9520	0.35678
20	0.37471	2.5	0.23785	12.4739	0.23785
21	0.49962	0.5	0.35168	9.0770	0.35168
22	0.49962	1	0.32875	9.6627	0.32875
23	0.49962	1.5	0.31855	9.9364	0.31855
24	0.49962	2	0.28542	10.8903	0.28542
25	0.49962	2.5	0.27523	11.2061	0.27523

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 (90.78%) was the most significant parameter on the friction property of modified ZA-27 alloy followed by sliding speed (7.31%). 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 1.91%.

Table 4: Response Table for Signal to Noise Ratios

Level	Nr. Pressure	Sliding Speed
1	0.7043	4.7093
2	2.1973	5.2453
3	8.3522	5.7416
4	9.1543	6.5327
5	10.1545	8.3336
Delta	9.4502	3.6243
Rank	1	2

Table 5: Response Table for Means

Level	Nr. Pressure	Sliding Speed
1	0.9256	0.6381
2	0.7870	0.6016
3	0.3904	0.5720
4	0.3547	0.5270
5	0.3119	0.4309
Delta	0.6137	0.2073
Rank	1	2

Figure 2: Main Effects Plot for SN Ratios

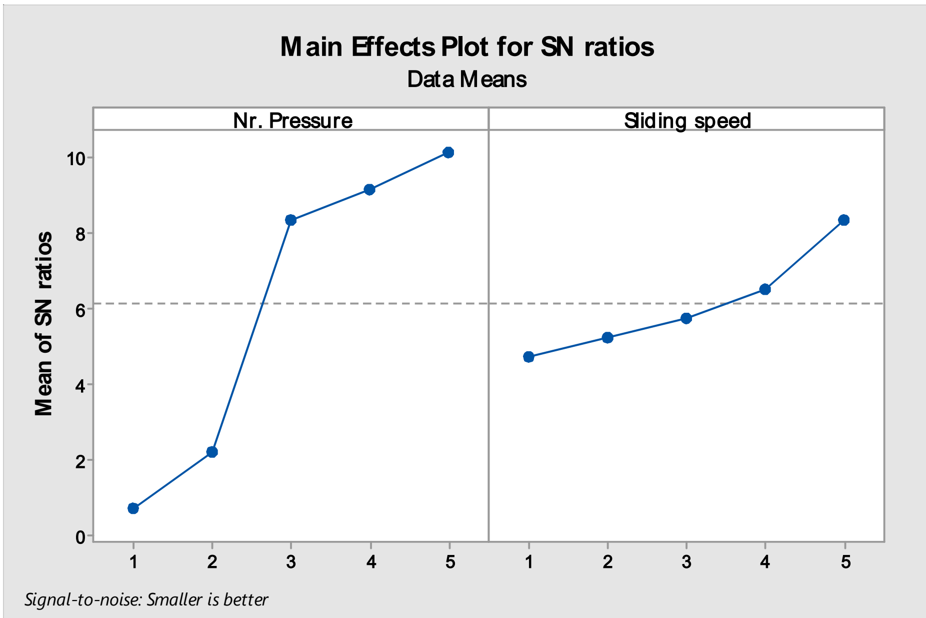

Figure 3: Main Effects Plot for Means

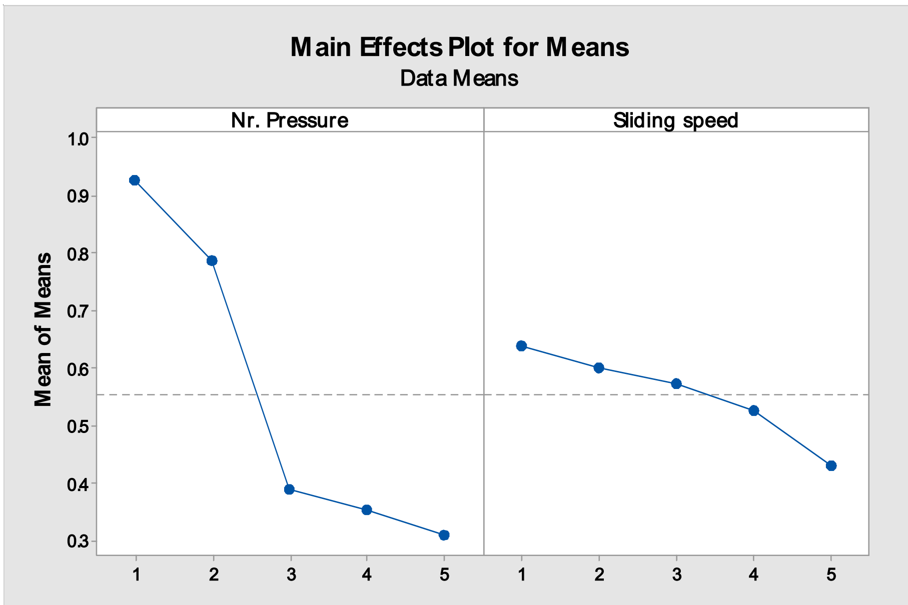

Table 6: Analysis of Variance

Source	DF	Seq SS	Adj SS	Adj MS	F-Value	P-Value	% of contribution
Nr. Pressure	4	1.58703	1.58703	0.396758	190.61	0.000	90.78%
Sliding speed	4	0.12781	0.12781	0.031952	15.35	0.000	7.31%
Error	16	0.03330	0.03330	0.002081			1.91%
Total	24	1.74814					100.00%

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,

$$\text{Wear rate} = 0.55392 - 0.2420\,(A) - 0.1231\,(B) \quad \ldots(3)$$

R-sq = 97.14%

CONCLUSION

The analyses were made based on the above results. The following conclusions are drawn from the present study.

1. Taguchi method provides a systematic and efficient methodology for the design and optimization of friction performance with far less effort than would be required for most optimization methods.
2. The optimal tribological testing combination for minimum friction is found to be A5B5 that is highest level of both parameters.

3. Nr. Pressure is an important factor with a contribution of (90.78%).
4. The Nr. Pressure and sliding speed are most significant factors.

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