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RESEARCH ARTICLE

OPTIMIZATION OF FRICTION PERFORMANCE OF A HEAT TREATED MODIFIED ZA-27 ALLOY USING DESIGN OF EXPERIMENTS

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ABSTRACT

This paper describes some aspects of concerning the effect of heat treatment on friction coefficient for Modified ZA-27 alloy. Experiments were conducted based on the plan of experiments generated through Taguchi's technique. A L25 orthogonal array was selected for analysis of the data. Orthogonal arrays of Taguchi, the signal-to-noise (S/N) ratio, the analysis of variance(ANOVA) and regression analysis are employed to find the optimal process parameter levels and to analyze the effect of these parameters on coefficient of friction. The result shows that Normal Pressure is the more sensitive parameter.

INTRODUCTION

Amongst the zinc-based alloys, the ZA family has been extremely popular during recent years. Zinc-based alloys with high amount of aluminium comprise a new family of die-casting alloys that have proven themselves in a wide variety of demanding applications (Jovanovic *et al*., 2005; Jovanovic *et al*., 2007). ZA-27 alloy belongs to a group of zinc alloys with increased content of aluminium (ZA alloys) which has been used in technological applications for several decades (Bobic *et al*., 2011). ZA-27 alloy with a nominal aluminium content of 27wt% is distinguished with highest strength and lowest density of all ZA alloys. These alloys feature clean, low temperature and energy-saving melting, supreme castability, high as-cast strength and hardness, corrosion resistance and equivalent or even superior bearing and wear properties as compared to standard bronze bearing (Sharma *et al*., 1998; Sharma *et al*., 1995; Ahmet Turk *et al*., 2006; Mukundadas Prasanna Kumar and Kanakuppi Sadashivappa, 2006; Shanta Satry *et al*., 2001; Yuanyuan *et al*., 1996 and Seenappa and Sharma, 2011). Babic Miroslav *et al*. (2009) studied the effect of heat treatment on friction coefficient of ZA-27 alloy.

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It reveals that Friction coefficient increase with applied load and decrease with the sliding speed. This is in accordance with the regime of lubrication. Miroslav Babic *et al*. (2010) focused on the influence of solutionizing temperature of 370^0C for a short period of time on coefficient of friction of ZA-27 alloy. The result obtained is improved in coefficient of friction. The heat-treated alloy samples attained improved tribological behavior (reduced coefficient of friction an over as-cast ones, for all applied loads. Babic *et al*. (2007) obtained results that better coefficient of friction for as-cast alloy when the alloy casted in sand compared to mold cast alloy. However, when mold cast alloy is heat treated showed positive effect on friction coefficient when compared to sand cast alloy.

The degree of improvement depends on the corresponding annealing duration time. Shuqing yan *et al*. (2010) results show that coefficient of friction of ZA-27 alloy is non linear with increasing in load. The mating surface between metals during friction is usually in an elastoplastic state and the true contact area is nonlinear to the applied load. This results in a fluctuation in the coefficient of friction with increasing applied loads. Seenappa *et al*. (2011) studied that coefficient of friction increases with increase in the sliding speed in turn increase in the applied load for all tested alloy. Although the effect of heat treatment on the coefficient of friction of Modified zinc-aluminium alloys has been studied in the past and there is still a lack of information.

Therefore, purpose of this work is to analyze the effects of annealing treatment at temperature of 370^0C for 5 hours, followed by water quenching and also furnace cooling on friction coefficient of Modified ZA-27 alloy in dry sliding condition using taguchi method. Tribological tests were conducted by varying in normal pressure and in sliding speed.

Experimental Procedures

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%, and balance Zn with an addition of 1%Mn alloy content and Si – 3.5% 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. The process parameters and their levels and codes are shown in the Table 1 each process parameters having five levels.

Table 1. Control and Noise Factors

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

Wear test

Dry sliding wear tests were conducted on flat-ended 10mm diameter, 33mm long cylindrical (pin) samples using a pin-on-disc machine (Model: TR-20, DUCOM) as per ASTM: G99 – 05 as shown in Fig 1. 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 friction force is measured by a frictional force sensor that uses a beam type load cell.

The coefficient of friction is evaluated by the following equation

$$\text{CoF} = \frac{Frictional\ force(N)}{Load(N)} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Fig. 1. Wear and Friction Monitor Testing Machine

Experimental Design

The design of experiments (DOE) approach using Taguchi method is a powerful tool for design of high quality systems. 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. It allows carrying out modeling and analysis of the influence of process variables on the response variables. This optimization technique is carried out in a three stage approach such as system design, parameter design and tolerance design.

Based on taguchi method an orthogonal array (OA) is considered to determine the optimal friction coefficient for Modified ZA-27 alloy. For this experiment, L25 orthogonal array is chosen. The 1^{st} column is assigned to Normal Pressure (A) and 2^{nd} column is assigned to sliding speed (B). Table 2 shows the L25 orthogonal array with design factors assigned. 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 computed as logarithmic transformation of the loss function is given as

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

Where MSD = Mean square Deviation

For the lower the better characteristic,

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

Where Y_1^2, Y_2^2, Y_3^2 are the response and ‘n’ is the number of tests in a trial.

Table 2. Results of L25 Orthogonal array for Modified ZA-27 Alloy (As-received)

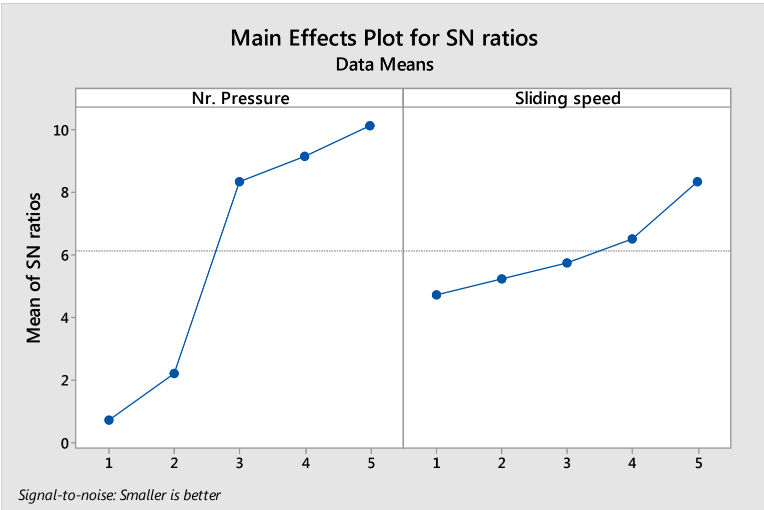
S.No.	Process Parameters	Codes	Level 1	Level 2	Level 3	Level 4	Level 5
1	Normal Pressure (MPa)	A	0.06245	0.1249	0.24981	0.37471	0.49962
2	Sliding Speed (m/s.)	B	0.5	1.0	1.5	2.0	2.5

Table 2.1. Response Table for S/N Ratios for Modified ZA-27 Alloy (As-received)

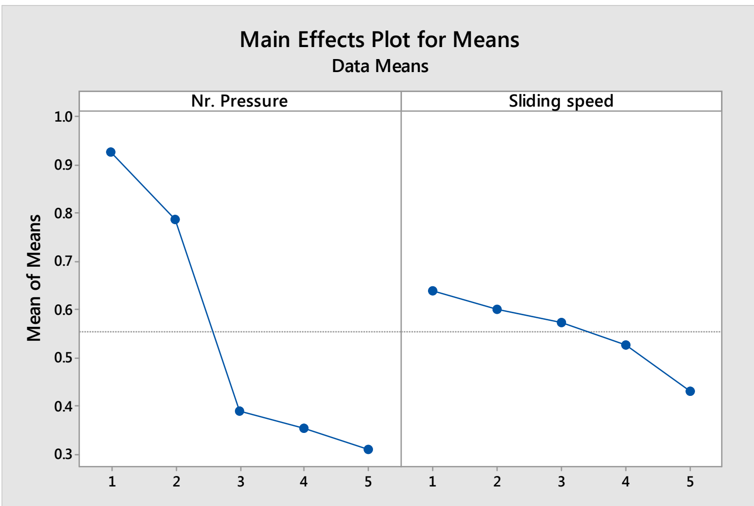
Level	A	B
1	0.7043	4.7093
2	2.1973	5.2453
3	8.3522	5.7416
4	9.1543	6.5327
5	10.1545	8.3336
Delta	9.4502	3.6243
Rank	1	2

Table 2.2. Response Table for Means for Modified ZA-27 Alloy (As-received)

Level	A	B
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



(a)



(b)

Fig. 2. Main effects plots for coefficient of friction of Modified ZA-27 Alloy (As- received) S/N Ratios (b) Mean

RESULTS AND DISCUSSION

Analysis of Control factors

The influence of control factors like Nr. Pressure and sliding speed on coefficient of friction was been criticized using S/N ratio response analysis. The ranking of control factors using S/N ratio obtained for different parameters levels for coefficient of friction is given in Table 2, Table 3 and Table 4 respectively for As-received, Quenching and furnace cool for Modified ZA-27 alloy. Figure 2 (a and b) shows main effects plots of S/N and mean for As-received Modified ZA-27 alloy. Figure 2 (a and b) shows main effects plots of S/N and mean for Quenched Modified ZA-27 alloy. Figure 2 (a and b) shows main effects plots of S/N and mean for Furnace cool Modified ZA-27 alloy. It suggests that the optimum condition for minimum coefficient of friction is the combination of A_5B_5, A_3B_4 and A_3B_2. From the Fig 2, 3 and 4 it is evident that Normal pressure is the most dominating factor controlling the friction coefficient behavior of Modified ZA-27 alloy the optimum condition for wear rate as shown in Table 8.

Table 3. Results of L25 Orthogonal array for Modified ZA-27 Alloy (Quenched)

S.No	Nr. Pressure (MPa)	Sliding Speed (m/s)	CoF	S/N Ratio (db)
01	0.06245	0.5	1.44750	-3.21237
02	0.06245	1.0	1.38634	-2.83740
03	0.06245	1.5	1.12130	-0.99444
04	0.06245	2.0	1.01937	-0.16664
05	0.06245	2.5	0.89704	0.94376
06	0.12490	0.5	0.79511	1.99146
07	0.12490	1.0	0.78491	2.10360
08	0.12490	1.5	0.76453	2.33211
09	0.12490	2.0	0.64220	3.84659
10	0.12490	2.5	0.95821	0.37079
11	0.24981	0.5	0.69317	3.18320
12	0.24981	1.0	0.56065	5.02616
13	0.24981	1.5	0.53007	5.51334
14	0.24981	2.0	0.36697	8.70739
15	0.24981	2.5	0.48930	6.20850
16	0.37471	0.5	0.58784	4.61482
17	0.37471	1.0	0.55046	5.18548
18	0.37471	1.5	0.70336	3.05645
19	0.37471	2.0	0.54366	5.29345
20	0.37471	2.5	0.43833	7.16398
21	0.49962	0.5	0.54536	5.26633
22	0.49962	1.0	0.60143	4.41630
23	0.49962	1.5	0.54536	5.26633
24	0.49962	2.0	0.41284	7.68436
25	0.49962	2.5	0.62691	4.05590

Table 3.1. Response Table for S/N Ratios for Modified ZA-27 Alloy (Quenched)

Level	A	B
1	-1.253	2.369
2	2.129	2.779
3	5.728	3.035
4	5.063	5.073
5	5.338	3.749
Delta	6.981	2.704
Rank	1	2

Table 3.2. Response Table for Means for Modified ZA-27 Alloy (Quenched)

Level	A	B
1	1.1743	0.8138
2	0.7890	0.7768
3	0.5280	0.7329
4	0.5647	0.5970
5	0.5464	0.6820
Delta	0.6463	0.2168
Rank	1	2

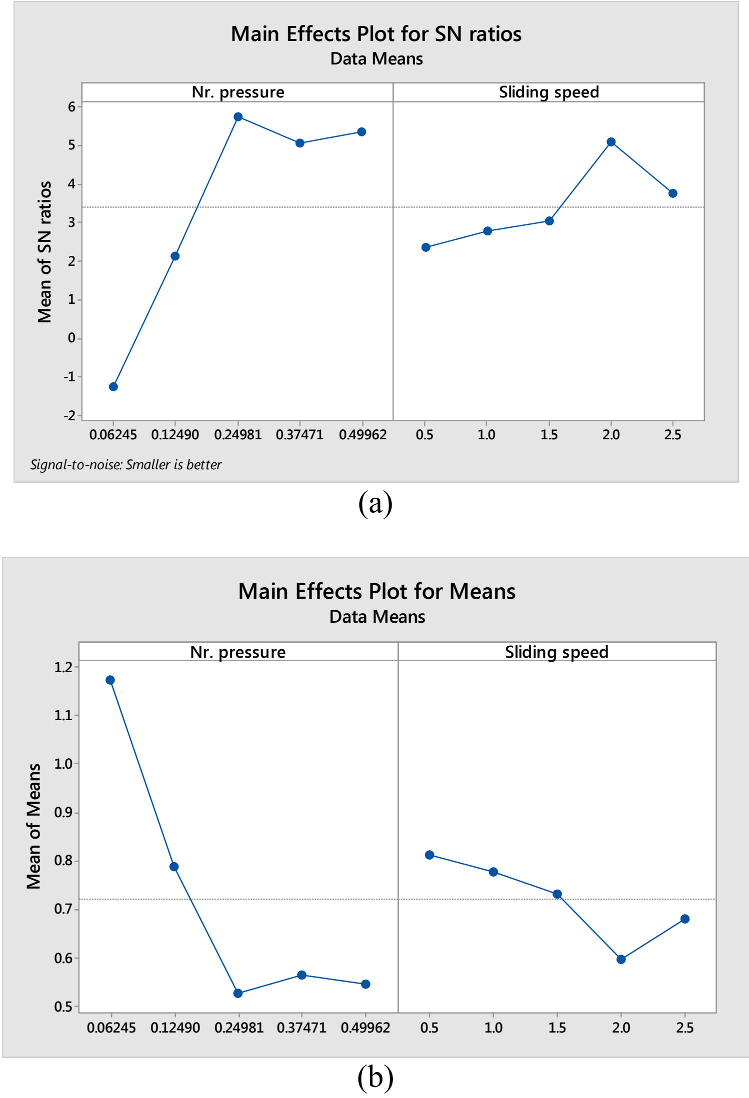


Fig. 3. Main effects plots for coefficient of friction of Modified ZA-27 Alloy (Quenched) (a) S/N Ratios (b) Mean

Table 4. Results of L25 Orthogonal array for Modified ZA-27 Alloy (Furnace Cool)

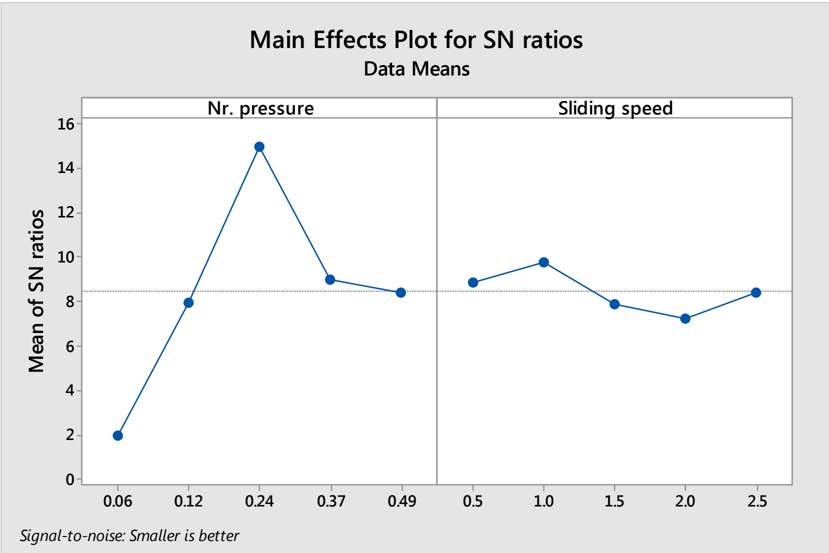
S.No	Nr. Pressure (MPa)	Sliding Speed (m/s)	CoF	S/N Ratio (db)
01	0.06245	0.5	0.95821	0.3708
02	0.06245	1.0	0.83588	1.5571
03	0.06245	1.5	0.81549	1.7716
04	0.06245	2.0	0.79511	1.9915
05	0.06245	2.5	0.63201	3.9855
06	0.12490	0.5	0.51988	5.6819
07	0.12490	1.0	0.41794	7.5777
08	0.12490	1.5	0.36697	8.7074
09	0.12490	2.0	0.34659	9.2037
10	0.12490	2.5	0.37717	8.4693
11	0.24981	0.5	0.15800	16.0269
12	0.24981	1.0	0.07645	22.3325
13	0.24981	1.5	0.22936	12.7896
14	0.24981	2.0	0.35168	9.0770
15	0.24981	2.5	0.18349	14.7278
16	0.37471	0.5	0.28542	10.8903
17	0.37471	1.0	0.34659	9.2037
18	0.37471	1.5	0.35338	9.0352
19	0.37471	2.0	0.42813	7.3685
20	0.37471	2.5	0.38056	8.3915
21	0.49962	0.5	0.26758	11.4509
22	0.49962	1.0	0.38481	8.2951
23	0.49962	1.5	0.43833	7.1640
24	0.49962	2.0	0.37971	8.4110
25	0.49962	2.5	0.46891	6.5782

Table 4.1. Response Table for S/N Ratios for Modified ZA-27 Alloy (Furnace Cool)

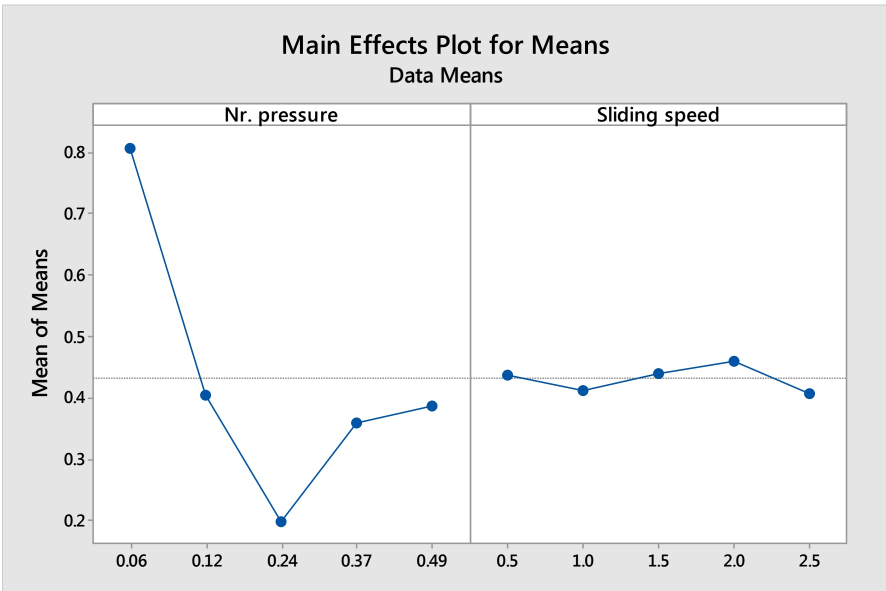
Level	A	B
1	1.935	8.884
2	7.928	9.793
3	14.991	7.894
4	8.978	7.210
5	8.380	8.430
Delta	13.055	2.583
Rank	1	2

Table 4.2. Response Table for Means for Modified ZA-27 Alloy (Furnace Cool)

Level	A	B
1	0.8073	0.4378
2	0.4057	0.4123
3	0.1998	0.4407
4	0.3588	0.4602
5	0.3879	0.4084
Delta	0.6075	0.0518
Rank	1	2



(a)



(b)

Fig. 4. Main effects plots for coefficient of friction of Modified ZA-27 Alloy (Furnace Cool) (a) S/N Ratios (b) Mean

Analysis of variance (ANOVA)

The experimental results were examined with analysis of variance (ANOVA) which is used to carry out a systematic influence of the parameters like, Nr. Pressure and sliding speed that significantly affect the performance measures. Statistically, F test tool is performed to see which design parameters have a significant effect on the quality characteristic. The F-ratio is a ratio of the mean square error to the residual error and is traditionally used to determine the significant of a factor. The P-value reports the significant level (suitable and unsuitable) in Table 5, 6 and 7. Percentage of contribution is defined as the significance rate of process parameters on the coefficient of friction.

Table 5. Analysis of Variance for Modified ZA-27 Alloy (As- received)

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%

Table 6. Analysis of Variance for Modified ZA-27 Alloy (Quenched)

Source	DF	Seq SS	Adj SS	Adj MS	F-Value	P-Value	% of contribution
Nr. pressure	4	1.5113	1.5113	0.37783	24.20	0.000	79.34%
Sliding speed	4	0.1438	0.1438	0.03595	2.30	0.103	7.55%
Error	16	0.2498	0.2498	0.01561			13.11%
Total	24	1.9049					100.00%

Table 7. Analysis of Variance for Modified ZA-27 Alloy (Furnace Cool)

Source	DF	Seq SS	Adj SS	Adj MS	F-Value	P-Value	% of contribution
Nr. pressure	4	1.01397	1.01397	0.253492	28.98	0.000	87.17%
Sliding speed	4	0.00925	0.00925	0.002312	0.26	0.897	0.80%
Error	16	0.13995	0.13995	0.008747			12.03%
Total	24	1.16317					100.00%

Table 8. Optimum level Process parameters for Volumetric Wear rate

Sl.No	Modified ZA-27 Alloy	Nr. Pressure (MPa)	Sliding speed (m/s)	COF	S/N Ratio (db)
01	As-received	A5	B5	0.62691	4.05590
02	Quenched	A3	B4	0.36697	8.70739
03	Furnace cool	A3	B2	0.56065	5.02616

This analysis is performed for a significance level of $\alpha = 0.05$, i.e. for a confidence level of 95%. Thus, if a P-value is less than 0.05, than the result would be considered as a statistically significant.

Multiple Linear Regression Model

A multiple linear regression model is used to develop using statistical software 'MINITAB 16'. This model gives the correlation between the effective factors (Normal pressure and sliding speed) and the coefficient of friction (quality characteristic) to observed data.

The regression equation for Modified ZA-27 alloy (As-received)

COF = 0.55392 - 0.2420 (A) - 0.1231 (B) -------Eq (2)

R-sq = 98.09%

The regression equation for Modified ZA-27 alloy (Quenched)

COF = 0.7205 - 0.1925 9 (A) - 0.1235 (B) ------- Eq (3)

R-sq = 86.89%

The regression equation for Modified ZA-27 alloy (Furnace cool)

COF = 0.4319 - 0.2321 Nr. Pressure (A) - 0.0196 (B) -- Eq (4)

R-sq = 87.97%

From Eq (2), Eq(3) and Eq(4) noticed that the negative value of coefficient of Nr. Pressure and sliding speed reveals that increase in Nr. Pressure and sliding speed decreases the coefficient of friction of Modified ZA-27 alloy.

Conclusions

The experimental reveals the following conclusions.

- Taguchi method can be used to analyze the friction coefficient of Modified ZA-27 alloy.
- Normal Pressure (90.78%) has the highest influence on coefficient of friction followed by sliding speed (7.31%) for Modified ZA-27 alloy (As-received).
- Normal Pressure (79.34%) has the highest influence on coefficient of friction followed by sliding speed (7.55%) for Modified ZA-27 alloy (Quenched).

- Normal Pressure (87.17%) has the highest influence on coefficient of friction followed by sliding speed (0.80%) for Modified ZA-27 alloy (Furnace cool).
- The optimal tribological testing combination for minimum coefficient of friction is found to be A_5B_5, A_3B_4 and A_3B_2 for As-received, Quenched and Furnace cool specimen.
- The Normal Pressure parameter can be considered as statistically significant for As-received, Quenched and Furnace cool specimen.

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