Analysis of Wear Behaviour of a Heat Treated Modified ZA-27 Alloy by Taguchi Technique

Veerabhadrappa Algur[1]
[1]Department of Industrial and Production Engineering,
Rao Bahadur Y Mahabaleshwarappa Engineering College,
Bellary, India.
veereshalgur@gmail.com

V.R. Kabadi[2]
[2]Department of Mechanical Engineering,
Nitte Meenakshi Institute of Technology,
Yelahanka, Bengaluru, India.
omvrk@rediffmail.com

Ganechari S M[3]
[3]Thakur Polytechnic,
Kandivali, Mumbai,
Maharashtra State, India.
ganecharism@rediffmail.com

P.B. Shetty4
4Department of Mechanical Engineering,
Nitte Meenakshi Institute of Technology,
Yelahanka, Bengaluru,
pbcshetty@hotmail.com

Poornima Hulipalled[5]
[5]PG Student, Department of MCA,
Rao Bahadur Y Mahabaleshwarappa Engineering College
Bellary, India.
Poornima.algur@gmail.com

Abstract: - The aim of this paper is to examine the dry sliding wear beahviour of as-received and heat treated Modified ZA-27 alloy. The alloys were prepared by conventional melting and casting route technique. The as-received samples were annealed at 370^{0}C for 5 hours, followed by water quenching and also furnace cooling. The experiments were conducted according to plan of experiments generated through taguchi technique. A L25 Orthogonal array was selected for analysis of the data along with the analysis of variance (ANOVA) were employed to investigate the influence of process parameters on the wear behaviour of as-received and heat treated Modified ZA-27 alloy. Regression models were used to investigate the influence of process parameter on wear rate. The result reveals that Normal Pressure is the more sensitive parameter.

Keywords: *ANOVA, orthogonal array, Regression Models, volumetric wear rate.*

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I. INTRODUCTION

The wear of material is one of the enormous and unavoidable losses in engineering applications, so the developments of new wear-resistance materials become an important task in which many researches are interested. The family of Zinc-aluminium (ZA) alloys was developed in 1960's and 1970's and became a substitute for brass and cast malleable iron to produce the wear resistant parts[1]. In particular, the ZA-12 and ZA-16 families were developed by the International Lead Zinc Research Organization (ILZRO) during 1960's while the ZA-8 and ZA-27 were developed by Noranda Co. in the late 1970's. Such coding (in which the numerical code denotes the eventual content of aluminium) is accepted also by the ASTM standards B 669-89, while according to European norm EN 1774-98 the following codes are used: ZL8, ZL12 and ZL27 [2-3].

Zinc-aluminium (ZA) based cast alloys by virtue of their superior castability, wear resistance and good mechanical properties[4-6] have found significant industrial usage during the past few years. ZA alloys exhibit better wear resistance under higher loads, lower cost, better emergency characteristics and have been used as replacement for bronze and brass in the bearing industry[7-13]. These alloy containing high aluminum content and observed to be cost effective and energy effective substitute to a variety of materials [14- 16]. However, one of the major limitations of the zinc based alloys has been observed to be their property deterioration at temperatures above 150^{o}C.

Heat treatment of the conventional zinc–aluminum alloys improves dimensional stability[17] and ductility[3, 18, 19 and 20]. However, the majority of the heat treatments lead to a reduction in hardness and tensile strength[19, 20, and 21]. In spite of reduced hardness, the heat-treated alloys attain improved tribological properties[18, 21 and 22].

Moreover, very limited studies have been carried out with regard to the effects of the heat treatment on the dry sliding wear response of the alloys. Therefore, an attempt has been made to access the effect of heat treatment on wear behaviour of modified ZA-27 alloy under dry sliding conditions using taguchi technique.

II. EXPERIMENTAL PROCEDURES

A. *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 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 loss of Zn. The melt was then degassed and stirred well before being poured into the molds, which were preheated to approximately 150^0 C in open air.

B. 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 as shown in Fig 1. 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. Wear tests were carried out up to a sliding distance 2500m.The wear losses of sample pins were recorded using an electronic microbalance having an accuracy of ±0.001mg. After wear test specimens were cleaned thoroughly and weighed again. The wear rate was calculated by a weight-loss method.

The volumetric wear rate is evaluated by the following equation.

$$W = \frac{\Delta m}{\rho S} \longrightarrow \{mm^3/m\} \quad \text{------- (1)}$$

C. Experimental Design.

The experiments were carried out to examine the influence of testing parameters on wear rate of Modified ZA-27 Alloy. The experiments were conducted according to L25 Orthogonal array as shown in Table 2. The first column is assigned by Normal pressure and second column by Sliding speed. A total of 25 experiments were conducted based on the run order generated by taguchi model. The response (S/N ratio) studied for the model is volumetric wear rate with the objective of “Smaller the better” type of quality characteristics. The response was calculated for each level of process parameters. Finally, analysis of variance was carried to verify which parameters were statistically significant. The measured results were analyzed using the commercial software MINITAB 16 specifically used for design of experiment applications. The process parameters, code and their levels are shown in the Table 1 each process parameters having five levels

III. RESULTS AND DISCUSSION

A. Analysis of Control factors

The examination of influence of control parameters such as Normal pressure and Sliding speed has been studied by using S/N ratio response type. The calculated S/N ratio for each level of parameters has shown in the Table 2, 3 & 4. The strongest influence of the control factor is determined depending on the value of Δ (delta) as shown in Tables 2.1, 3.1 & 4.1. Delta is the difference between maximum and minimum value of S/N ratios for a particular control factor. When the value of delta is high, more dominant is the control factor. It can be seen in Table 2.1, 3.1 & 4.1, that the strongest influence was exerted by the Normal Pressure (A) followed by Sliding speed (B). Means response table presented in Table 2.2, 3.2 & 4.2 also give the same results on the ranking of the influence of the factor. Figs 2, 3 & 4 show that main effect plot for S/N ratio and mean for Modified ZA-27 Alloy. It suggests that the optimum condition for minimum volumetric wear rate is the combination of A_3B_5, A_1B_5 & A_1B_3. From the figs 2, 3 & 4 it is evident that Normal pressure is the most dominating factor controlling the wear behavior of Modified ZA-27 alloy. The optimum condition for volumetric wear rate is shown in Table 8.

B. Analysis of variance (ANOVA).

The conducted experimental results were analyzed by using Analysis of Variance (ANOVA) which is used to examine the influence of wear parameters like Normal pressure and Sliding speed. By using ANOVA, it can be decided which independent factor dominates over the other and the percentage contribution of that particular independent variable. This analysis was carried out for a level of 5% significance that is up to a confidence level of 95%. Sources with a P-value less than 0.05 were considered to have a statistically significant contribution to the performance measures. Tables 5, 6 and 7 show the results of ANOVA analysis of Modified ZA-27 alloy of As- received, Quenching and Furnace cool.

It can be noticed from the Tables 5, 6 and 7, that the Normal pressure has the highest influence (Pr = 53.28%, Pr = 68.87% and Pr = 83.53%) on volumetric wear rate. Hence the Normal pressure is an important process parameter to be taken into account into consideration during wear process followed by sliding speed (Pr = 34.96%, Pr = 6.14% and Pr = 4.11%). The Normal Pressure can be considered as statistically significant from the Tables 5, 6 and 7.

C. Multiple Linear Regression Models

The multiple linear regressions is used to develop the correlation between the effective factors (Normal pressure and sliding speed) and the Volumetric wear rate (quality characteristic) to observed data.

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

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

R-sq = 88.24%

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

Volumetric Wear rate = 0.001724 - 0.001042 (A) - 0.000347 (B) ------- (3)

R-sq = 75.01%

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

Volumetric Wear rate = 0.001758 - 0.001106 (A) - 0.000110 (B) ------- (4)

R-sq = 87.64%

IV. CONCLUSIONS

Based on the above study the following conclusion can be summarized as follows.

1. The present study is discussed an application of Taguchi technique for optimizing the process parameters on wear rate.
2. Normal Pressure (53.28%) has the highest influence on volumetric wear rate followed by sliding speed (34.96%) for Modified ZA-27 alloy (As received).
3. Normal Pressure (68.87%) has the highest influence on volumetric wear rate followed by sliding speed (6.14%) for Modified ZA-27 alloy (Quenched).
4. Normal Pressure (83.53%) has the highest influence on volumetric wear rate followed by sliding speed (4.11%) for Modified ZA-27 alloy (Furnace cool).
5. The optimal tribological testing combination for minimum volumetric wear rate is found to be A_3B_5, A_1B_5 & A_1B_3 for As received, Quenched and Furnace cool specimen.
6. The Normal Pressure parameter can be considered as statistically significant for As received, Quenched and Furnace cool specimen

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Table 1: Control and Noise Factors.

Sl.No	Nr. Pressure (MPa)	Sliding Speed (m/s)	Wear rate (mm^3/m)	S/N Ratio (db)
1	0.06245	0.5	0.001	60
2	0.06245	1	7.19E-04	62.8613
3	0.06245	1.5	2.14E-04	73.3807
4	0.06245	2	7.12E-04	62.9542
5	0.06245	2.5	5.89E-04	64.594
6	0.1249	0.5	0.00207	53.6806
7	0.1249	1	0.00132	57.5885
8	0.1249	1.5	0.00107	59.4123
9	0.1249	2	0.00103	59.7433
10	0.1249	2.5	4.21E-04	67.5166
11	0.24981	0.5	0.00134	57.4579
12	0.24981	1	0.00103	59.7433
13	0.24981	1.5	3.29E-04	69.6545
14	0.24981	2	1.76E-04	75.0893
15	0.24981	2.5	6.50E-04	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	54.334
25	0.49962	2.5	8.42E-04	61.496

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

Sl.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	1.5	2	2.5

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4095 - 4104

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

Level	A	B
1	64.76	55.13
2	59.59	57.67
3	65.14	62.8
4	55.75	61.85
5	55.35	63.14
Delta	9.78	8.01
Rank	1	2

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

Level	A	B
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

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

Sl.No	Nr. Pressure (MPa)	Sliding Speed (m/s)	Wear rate (mm^3/m)	S/N Ratio (db)
1	0.06245	0.5	0.00181	54.8464
2	0.06245	1	0.0002372	72.4966
3	0.06245	1.5	0.0001377	77.2184
4	0.06245	2	0.0002602	71.6943
5	0.06245	2.5	0.0009642	60.3164
6	0.1249	0.5	0.00229	52.8033
7	0.1249	1	0.00116	58.7108
8	0.1249	1.5	0.00171	55.3401
9	0.1249	2	0.000926	60.6681
10	0.1249	2.5	0.0004974	66.0656
11	0.24981	0.5	0.00116	58.7108
12	0.24981	1	0.00162	55.8097
13	0.24981	1.5	0.00186	54.6097
14	0.24981	2	0.00152	56.3631
15	0.24981	2.5	0.0006122	64.262
16	0.37471	0.5	0.00127	57.9239
17	0.37471	1	0.00119	58.4891
18	0.37471	1.5	0.00316	50.0063
19	0.37471	2	0.0029	50.752
20	0.37471	2.5	0.00166	55.5978
21	0.49962	0.5	0.00318	49.9515
22	0.49962	1	0.00308	50.229
23	0.49962	1.5	0.00321	49.8699
24	0.49962	2	0.00354	49.0199
25	0.49962	2.5	0.00315	50.0338

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

Level	A	B
1	67.31	54.85
2	58.72	59.15
3	57.95	57.41
4	54.55	57.7
5	49.82	59.26
Delta	17.49	4.41
Rank	1	2

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

Level	A	B
1	0.000682	0.001942
2	0.001317	0.001457
3	0.001354	0.002016
4	0.002036	0.001829
5	0.003232	0.001377
Delta	0.00255	0.000639
Rank	1	2

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

Sl.No	Nr. Pressure (MPa)	Sliding Speed (m/s)	Wear rate (mm^3/m)	S/N Ratio (db)
1	0.06245	0.5	0.0009336	60.5967
2	0.06245	1	0.0006199	64.1542
3	0.06245	1.5	0.0005892	64.594
4	0.06245	2	0.0005739	64.8226
5	0.06245	2.5	0.0005433	65.2987
6	0.1249	0.5	0.00207	53.6806
7	0.1249	1	0.00107	59.4123
8	0.1249	1.5	0.0005357	65.4219
9	0.1249	2	0.0005357	65.4219
10	0.1249	2.5	0.0009183	60.7402
11	0.24981	0.5	0.00222	53.0729
12	0.24981	1	0.00145	56.7726
13	0.24981	1.5	0.0009948	60.045
14	0.24981	2	0.0013	57.7211
15	0.24981	2.5	0.0009183	60.7402
16	0.37471	0.5	0.00191	54.3793
17	0.37471	1	0.00145	56.7726
18	0.37471	1.5	0.00199	54.0229
19	0.37471	2	0.0026	51.7005
20	0.37471	2.5	0.00298	50.5157
21	0.49962	0.5	0.00375	48.5194
22	0.49962	1	0.00329	49.6561
23	0.49962	1.5	0.00413	47.681
24	0.49962	2	0.00283	50.9643
25	0.49962	2.5	0.00375	48.5194

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

Level	A	B
1	63.89	54.05
2	60.94	57.35
3	57.67	58.35
4	53.48	58.13
5	49.07	57.16
Delta	14.83	4.3
Rank	1	2

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

Level	A	B
1	0.000652	0.002177
2	0.001026	0.001576
3	0.001377	0.001648
4	0.002186	0.001568
5	0.00355	0.001822
Delta	0.002898	0.000609
Rank	1	2

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	0.000006	0.000006	0.000001	18.12	0	53.28%
Sliding speed	4	0.000004	0.000004	0.000001	11.89	0	34.96%
Error	16	0.000001	0.000001	0			11.76%
Total	24	0.000011					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	Contribution
Nr. pressure	4	0.000019	0.000019	0.000005	11.02	0	68.87%
Sliding speed	4	0.000002	0.000002	0	0.98	0.445	6.14%
Error	16	0.000007	0.000007	0			24.99%
Total	24	0.000027					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	Contribution
Nr. pressure	4	0.000026	0.000026	0.000007	27.03	0	83.53%
Sliding speed	4	0.000001	0.000001	0	1.33	0.301	4.11%
Error	16	0.000004	0.000004	0			12.36%
Total	24	0.000032					100.00%

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Table 8: Optimum level Process parameters for Volumetric Wear rate.

Sl.No	Modified ZA-27 Alloy	Nr. Pressure (MPa)	Sliding speed (m/s)	Volumetric wear rate (mm3/m)	S/N Ratio (db)
1	As-received	0.24981	2.5	6.50E-04	63.7355
2	Quenched	0.06245	2.5	0.0009642	60.3164
3	Furnace cool	0.06245	1.5	0.0005892	64.594

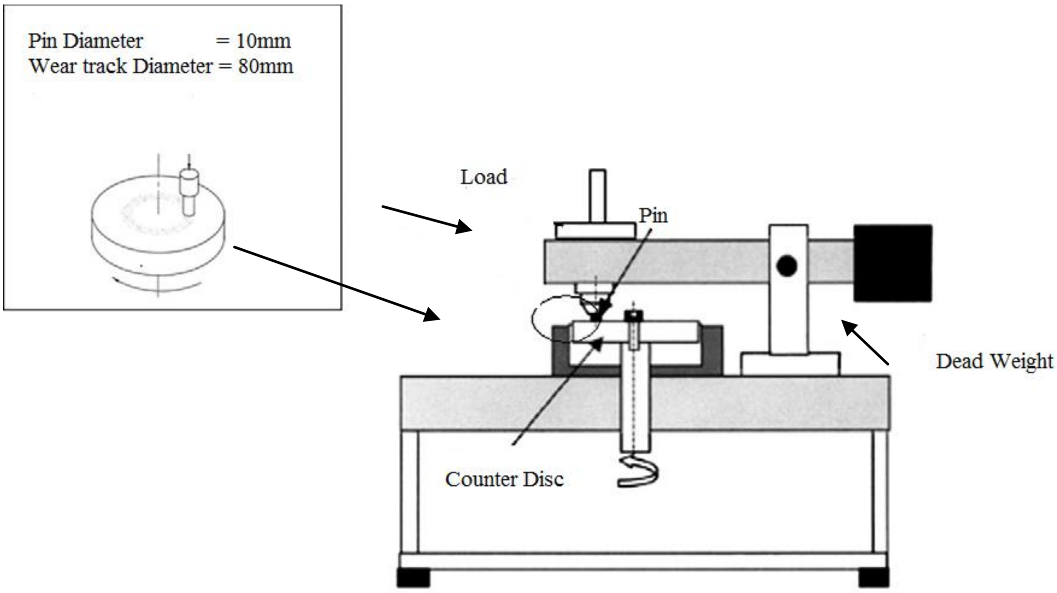
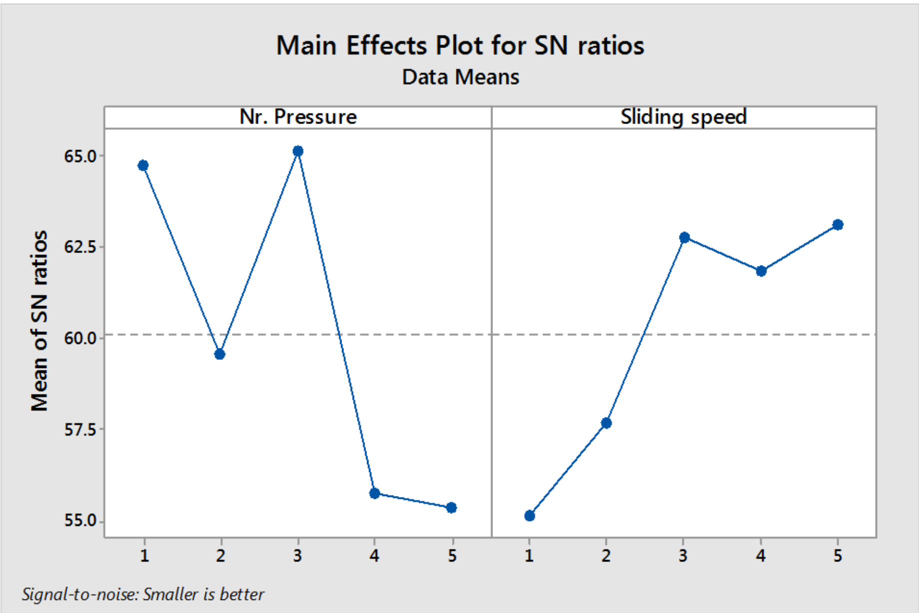


Fig 1: Schematic representation of Pin-on-Disc wear testing machine



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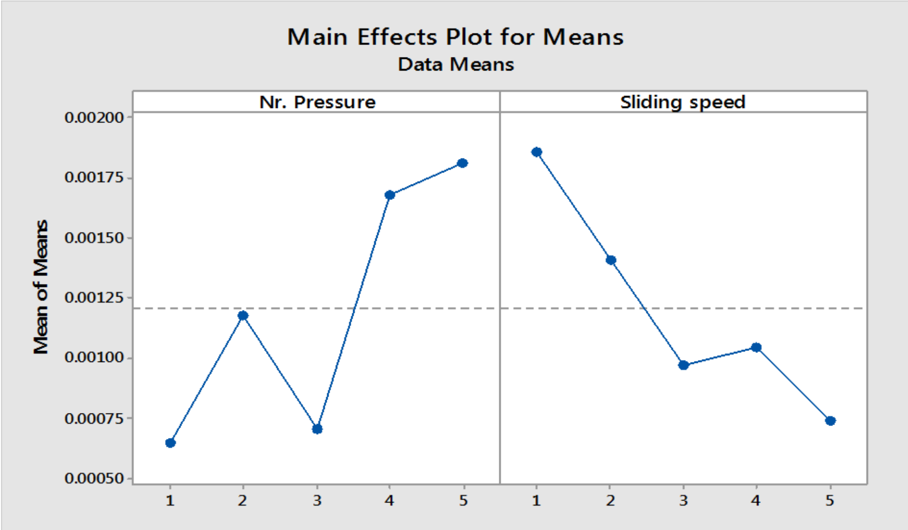
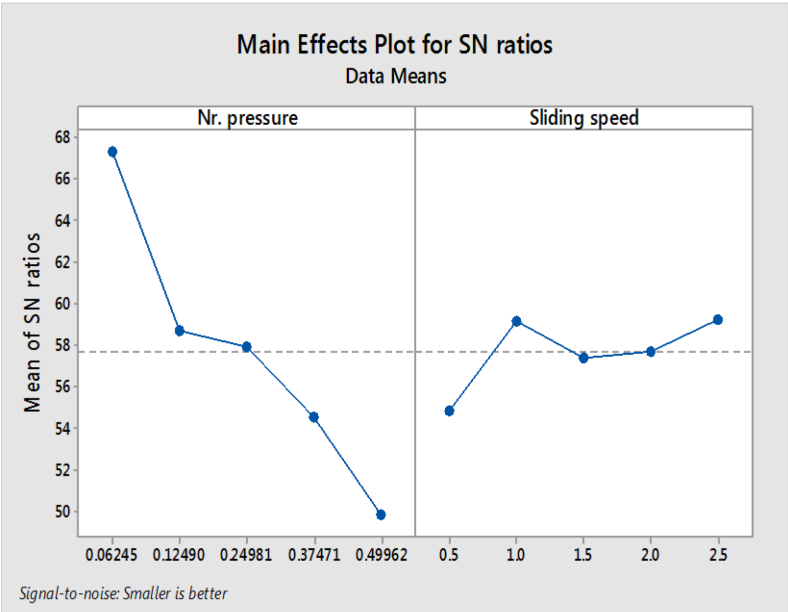
ISSN: 2321-8169
4095 - 4104



(b)

Fig 2: Main effects plots for volumetric wear rate of Modified ZA-27 Alloy (As- received) S/N Ratios (b) Mean.



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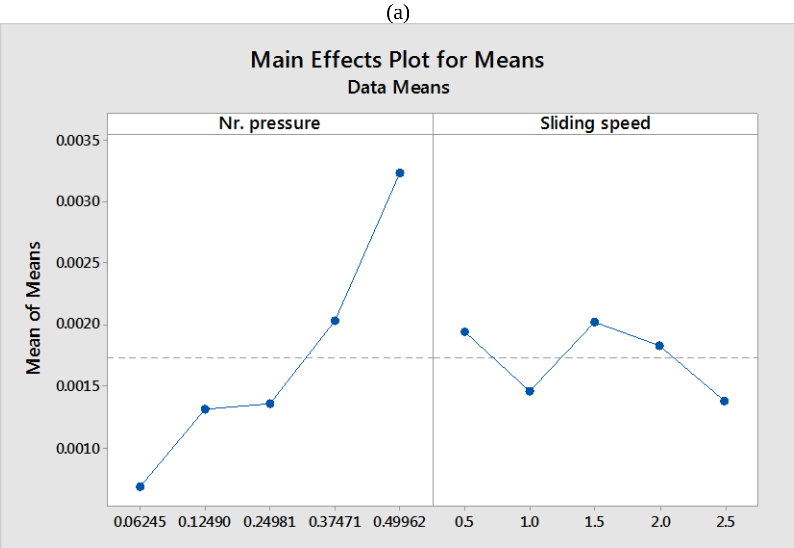
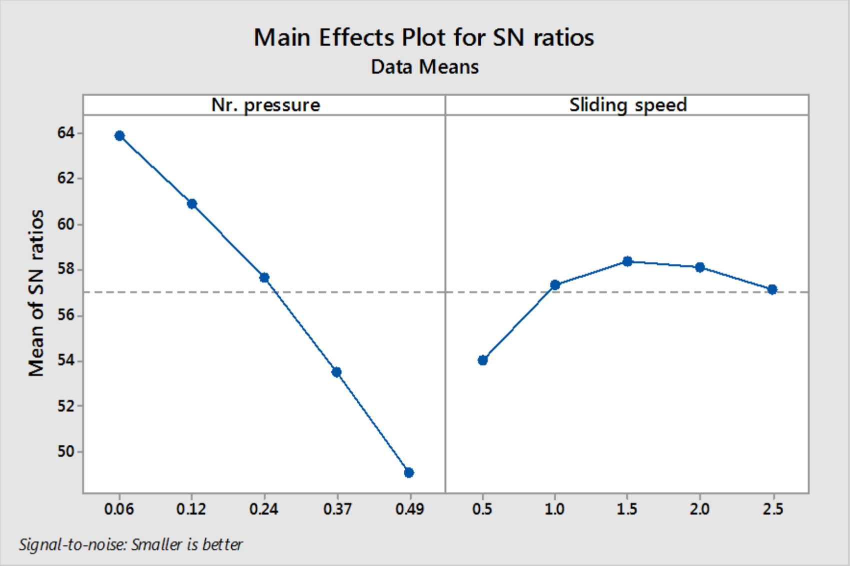


(b)

Fig 3: Main effects plots for volumetric wear rate of Modified ZA-27 Alloy (Quenched) (a) S/N Ratios (b) Mean.

ISSN: 2321-8169
4095 - 4104



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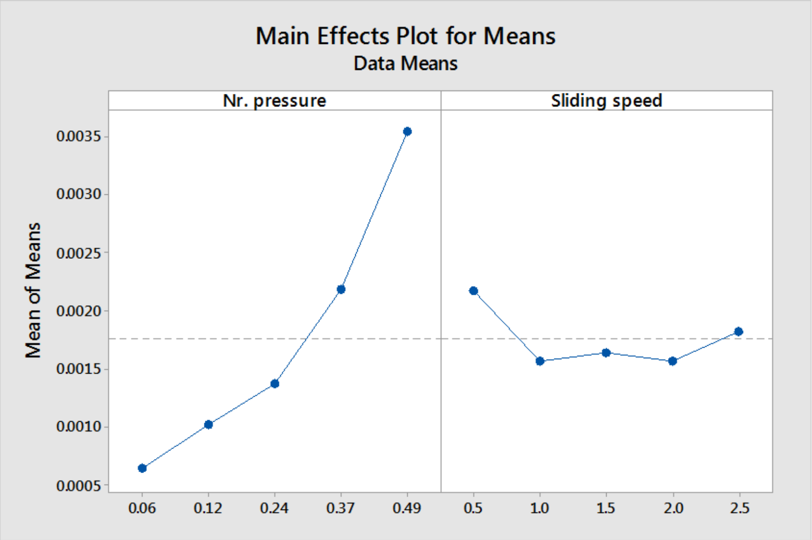

(b)

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