Optimization of Wear Parameters of AZ80-Sn-RE-Ca Alloy on Pin on Disk Tribometer Using Grey Relation Analysis and Taguchi Method

M. Madusudanprasad, Dr.V. Ramachandra Raju

ME Department, University College of Engineering Kakinada, JNTUK, Kakinada, India.

Abstract: - In general, reducing the amount of wear that mechanical systems generate during operation is one of the most crucial design issues. Determining the ideal process parameters based on research findings regarding wear amounts for various material compositions and configurations is one of the best ways to address this problem. Friction between moving parts produces heat at the points of contact, shortening component life and increasing power consumption. This wear and tear is a common occurrence in mechanical parts. The current project work involves experimenting with the pin-on-disc wear test method parameters and using magnesium tin alloy under dry sliding conditions as the material of study. A wear test research was conducted using various sliding speeds, load values, track diameter values, and sliding durations. Grey relation analysis and the Taguchi method are used in the Design of Experiments (DOE) methodology to anticipate wear and analyze variance (ANOVA).

Keywords: *Magnesium alloy, Wear test, Pin on disk, Taguchi method, Grey relation analysis.*

1. Introduction

When designing and operating mechanical equipment, engineers encounter many wear-related issues. In this case, it is necessary to know the wear limit, which is often provided by the manufacturer and must be ascertained by testing. One method for measuring wear in an operating system is to remove the parts and use various displacement measurement devices to gauge the wear. This is typically a costly procedure and might not always be feasible. Wear gauges can be installed for a variety of applications (such as brakes) and provide a continuous measurement of the dimensional changes. When wear occurs during an operation, it is frequently detected indirectly using techniques like ferrography, oil analysis, or wear tests produced in pin-on-disk systems employing materials, loads, and wearing distances. Impact erosion is the predominant form of erosion that occurs when material is removed from a surface by plowing, cutting, or scratching. Concomitant systems are used to detect the wear in order to determine these qualities. In the current study, the significance of each process parameter on the variation of wear loss of the Magnesium-Tin alloy was ascertained using a statistical method based on Taguchi, grey relation, and ANOVA techniques.

To get the best results with the fewest experiments possible, the Taguchi method is used to design the abrasive wear study experiment. Instead of performing every possible combination, Taguchi's experimental design uses orthogonal arrays to arrange the factors affecting the process and the levels at which these factors must be varied systematically to complete the experiment with the fewest number of trials and save time, money, and resources.

Tedesco, N. R., Pallone, E. M. J. A., &Tomasi, R [10] discussed about a pin-on-disc test of a high density, sub-micrometer grain size alumna and the effects of applied load and sliding speed was discussed in terms of the specific wear rate and worn surface analyzes. It was observed the increase of grooves (and therefore the ploughing micro abrasion mechanisms) with the increase of wear rate. The increase of sliding speed for higher loads leads to the plastic deformation of the tribo film and to inter granular fractures on the ceramic surface. Soy, U., Ficici, F., &Demir[16], found that the specific wear rate of the aluminium and its composites decreases with the increase in load and increases with the increment of sliding speed. This decrease in the specific wear coincides with the studies of Rohatgi et al. and Straffelini et al. Among the tested materials, unreinforced aluminum has the highest specific wear rate value .In general; the applied load has a stronger effect on the specific wear rate of aluminium and its composites than the sliding speed.

Arunachalam, Vairamuthu, et,al.[18] has chosen L9 Orthogonal arrays to perform dry sliding wear test for AZ31B/ZrSiO4 composite prepared through stir casting process using Taguchi’s S/N analysis. Liquid state stir casting process starts with melting the (AZ31B) aluminium upto 700 Cand mixing the preheated (ZrSiO4) powder content with suitable stirring speed. Owing to mechanical stirring, the ZrSiO4 particles are equably distributed in the Mg molten metal. Subsequently the molten metal is poured into the die. Three different material samples with0, 4 and 8 wt% of ZrSiO4 inclusion were made. The ANOVA was conducted to determine the critical variables and to quantify their influence on the response properties. The AZ31B/ZrSiO4 composite hardness test values revealed that the AZ31B/ZrSiO4 composites have higher indentation resistance when compared to the basic magnesium matrix. Sliding distance is the most influential parameter, for obtaining minimum wear rate followed by wt% of reinforcement and there is no significance of applied load.

Amol S.Mali, et,al.[19] studied the Wear and frictional characteristics of aluminum alloy-based hybrid composite material with the help of tribometer testing apparatus. Tribological behavior of LM25 reinforced with Fly ash and Alumina with a varying percentage from 4%, 8%, 12% manufactured with stir casting technique and studied. The study was planned on Taguchi's approach, and the L9 array has been used for experimentation. In this research, experiments were conducted as per ASTM-G99 standard and with pin-on-disk (POD) tribo testing machine for characterization of Hybrid metal matrix composite. The speed of disc has the most significant impact, on the wear in micron after that the Normal loads and the reinforcement percentage. The reinforcement percentage shows more effect on coefficient of friction in hybrid composite material. The SEM images shows that abrasive wear of Hybrid composite material occur during Sliding wear of specimen on Pin-on-disc apparatus. The validation of results was done with the help of SEM (Scanning Electron Microscope) studies with the experimental results.

Up to now, wear studies were reported on various materials, alloys and composites. But optimization of wear process parameters on Magnesium (Mg)-Tin(Sn)-Rare Earth(RE)-Calcium(Ca) alloy is rarely reported. In the present study, both Taguchi grey relation analysis and Taguchi analysis is carried out to optimize the wear process parameters using Pin-On-Disc tribometer for Mg-Sn-RE-Ca alloy.

2. Experimentation and Methodology:

The wear tests were conducted using the Pin-on-disc tribometer, as illustrated in Figure 1. The samples are pressed up against a revolving steel roller, measuring 10 millimeters in diameter and 24 millimeters in height. The apparatus is configured in a way that the stationary plate serves as the test sample and the revolving roller serves as the counter face material. A loading pan that is suspended to hold the dead weight is at one end of the loading lever, while a counterweight is at the other. The loading lever's pivot point is quite close to the load sensor. It is a versatile piece of equipment designed to study wear under sliding circumstances. The majority of the time, sliding occurs between a rotating disc and an immobile pin. Because of the load, the arm will stay in contact with the disc even after its wear-and-tear-induced contact surface has worn away. Even after the arm has experienced wear and tear, this will still be the case. This makes it possible to calculate the maximum wear. This procedure determines the expected degree of wear. A sliding wear test was conducted with three different levels of variation in the applied load, time, speed, and track diameter among other parameters. A total of 9 different tests were conducted based on the run order that was established using the Taguchi model. The response that the model offers is wear, temperature and friction force (FF). Forward-Looking Infrared (FLIR) is used to record temperature. The applied load, time, speed, and track diameter are indicated in Table 1 first, second,

third, and fourth columns. The responses are saved and analyzed in a computer connected to tribometer and tabulated in Table 1. The responses were tallied, and the results were subjected to an analysis of variance (ANOVA). Both Taguchi analysis and grey relation analysis is carried out to optimize wear process parameters.

Fig 1: Pin-On-Disk Tribometer

3. Results and Discussions

3.1 METHOD 1: Taguchi Grey Relation Analysis

Table 1: Input and Output parameters in Minitab software: -

Sl. No.	load	time_1	speed	track dia	FF	wear	temp	FF	wear	temp
1	30	6	200	50	7.32	101.95	33.4	0.020	0.000	0.000
2	30	8	300	60	7.21	410.06	49.4	0.000	1.000	0.578
3	30	10	400	70	7.24	286.74	50.1	0.005	0.600	0.603
4	40	6	300	70	9.42	215.26	50.1	0.403	0.368	0.603
5	40	8	400	50	9.18	245.66	36.7	0.359	0.466	0.119
6	40	10	200	60	9.69	208.78	46.4	0.453	0.347	0.469
7	50	6	400	60	10.93	327.89	61.1	0.679	0.733	1.000
8	50	8	200	70	12.69	288.4	44.5	1.000	0.605	0.401
9	50	10	300	50	11.76	206.62	41.6	0.830	0.340	0.296

Case 1: FINDING OUT THE OPTIMAL VALUES (LARGER THE BETTER)

Table 2: OPTIMAL VALUES (LARGER THE BETTER)

Sl.No.	load	time_1	speed	track dia	FF	wear	temp	FF	wear	temp
1	30	6	200	50	7.32	101.95	33.4	0.020	0.000	0.000
2	30	8	300	60	7.21	410.06	49.4	0.000	1.000	0.578
3	30	10	400	70	7.24	286.74	50.1	0.005	0.600	0.603
4	40	6	300	70	9.42	215.26	50.1	0.403	0.368	0.603

5	40	8	400	50	9.18	245.66	36.7	0.359	0.466	0.119
6	40	10	200	60	9.69	208.78	46.4	0.453	0.347	0.469
7	50	6	400	60	10.93	327.89	61.1	0.679	0.733	1.000
8	50	8	200	70	12.69	288.4	44.5	1.000	0.605	0.401
9	50	10	300	50	11.76	206.62	41.6	0.830	0.340	0.296
Optimum	50	8	400	60	11.54	190.53	59.8	0.790	0.287	0.953

Take the Grades from the Analytical part of Case-1 Larger the Better and Analyse in Taguchi Method, then we can obtain the response Tables for Means and the SN ratios and also the graphs. The Optimal Condition is obtained from the Signal to Noise Ratio Graphs. The noise factors in the output responses should be low i.e., The values of SN ratios should be Nearer to the value "0" i.e., it indicates lower noise factors.

Table 3: TA: Grade-1 versus load, time, speed, track dia

Level	load	time	speed	track dia
1	0.4808	0.5245	0.4905	0.4313
2	0.4595	0.5748	0.5470	0.6147
3	0.6519	0.4929	0.5547	0.5462
Delta	0.1925	0.0819	0.0643	0.1834
Rank	1	3	4	2

Table 4: Response Table for Signal to Noise Ratios (Larger is better)

Level	load	time	speed	track dia
1	-6.638	-6.082	-6.537	-7.457
2	-6.767	-4.971	-5.289	-4.394
3	-3.806	-6.158	-5.386	-5.360
Delta	2.961	1.187	1.248	3.063
Rank	2	4	3	1

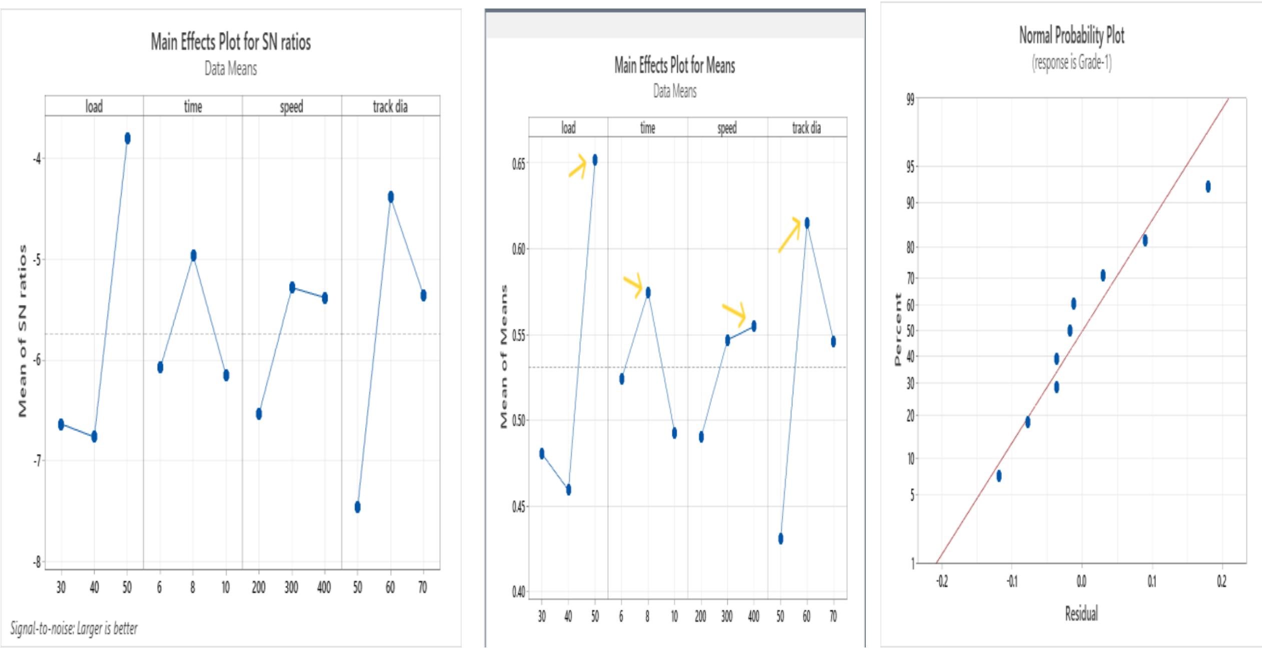


Fig 2: Main effects plot and normal probability plot for larger is better case

Optimal condition for Case-1 larger the better is obtained

1. According to the analytical calculations in Excel it is

Load=50, time=6, speed=400, track diameter= 60 and its corresponding Grade = 0.754

2. According to the Analysis done in Minitab software it is

Load=50, time=8, speed=300, Track diameter=60 and

This experiment is not on the primary Taguchi matrix, So we have to find its Grade by using Regression equation by substituting the above Minitab software values

Grade 1 = -0.189 + 0.00856 load –0.0079 time+ 0.000321 speed + 0.00575 track dia

Grade-1 = 0.6171

Therefore, the grade must be higher, so Optimal condition for Case-1 i.e., Larger the better is

Load=50, time=6, speed=400, track diameter= 60 and its corresponding Grade = 0.754

Regression Analysis: Grade-1 versus load, time, speed, track dia

Regression Equation

Grade 1 = -0.189 + 0.00856 load –0.0079 time+ 0.000321 speed + 0.00575 track dia

ANOVA FOR CASE-1(LARGER THE BETTER):

General linear model; Grade -1 versus load, time, speed, track dia

Table 5: Analysis Of Variance

SOURCE	DF	SEQ SS	CONTRIBUTION	ADJ SS	ADJ MS
Load	2	0.066792	49.12%	0.066792	0.033396
Time	2	0.010237	7.53%	0.010237	0.005119
Speed	2	0.007389	5.43%	0.007389	0.003694
Track dia	2	0.051546	37.91%	0.051546	0.025773
TOTAL	8	0.135964	100%		

The figure 2 represents the main effects plot and normal probability plot for larger is better case.

Case 2: FINDING OUT THE OPTIMAL VALUES (SMALLER THE BETTER)

Table 6: Optimal Values (Smaller The Better)

						Normalization			Deviation sequence			grey relational co-efficient						
Sl. No.	load	time_1	speed	track dia	FF	wear	temp	FF	wear	temp	FF	wear	temp	FF	wear	temp	grade	rank
1	30	6	200	50	7.32	101.95	33.4	0.980	1.000	1.000	0.020	0.000	0.000	0.961	1.000	1.000	0.987	1
2	30	8	300	60	7.21	410.06	49.4	1.000	0.000	0.422	0.000	1.000	0.578	1.000	0.333	0.464	0.599	4
3	30	10	400	70	7.24	286.74	50.1	0.995	0.400	0.397	0.005	0.600	0.603	0.989	0.455	0.453	0.632	3
4	40	6	300	70	9.42	215.26	50.1	0.597	0.632	0.397	0.403	0.368	0.603	0.554	0.576	0.453	0.528	7
5	40	8	400	50	9.18	245.66	36.7	0.641	0.534	0.881	0.359	0.466	0.119	0.582	0.517	0.808	0.636	2
6	40	10	200	60	9.69	208.78	46.4	0.547	0.653	0.531	0.453	0.347	0.469	0.525	0.591	0.516	0.544	5
7	50	6	400	60	10.93	327.89	61.1	0.321	0.267	0.000	0.679	0.733	1.000	0.424	0.405	0.333	0.388	9
8	50	8	200	70	12.69	288.4	44.5	0.000	0.395	0.599	1.000	0.605	0.401	0.333	0.452	0.555	0.447	8
9	50	10	30	50	11.	206	41	0.1	0.6	0.7	0.8	0.3	0.2	0.3	0.5	0.6	0.5	6

			0		76	.62	.6	70	60	04	30	40	96	76	95	28	33	

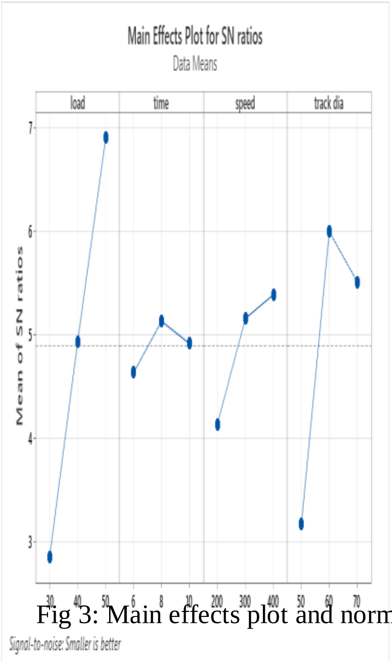
Take the Grades from the Analytical part of Case-2 Smaller the Better and Analyse in Taguchi Method, then we can obtain the response Tables for Means and the SN ratios and also the graphs. The Optimal Condition is obtained from the Signal to Noise Ratio Graphs. The noise factors in the output responses should be low i.e., The values of SN ratios should be Nearer to the value "0" i.e., it indicates lower noise factors.

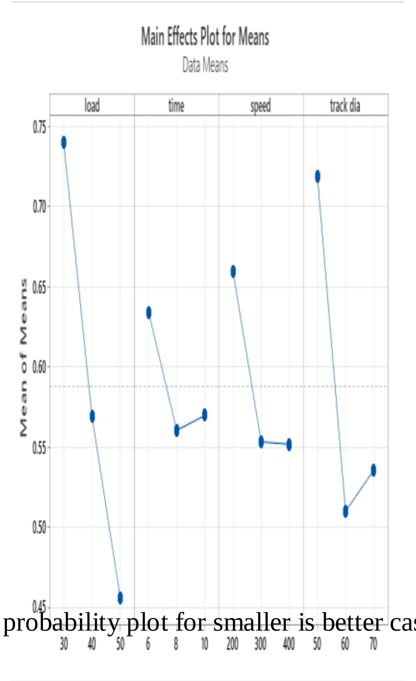
Table 7: TA: grade-2 versus load, time, speed, track dia

Level	**load**	**time**	**speed**	**track dia**
1	0.7395	0.6342	0.6593	0.7186
2	0.5690	0.5605	0.5533	0.5102
3	0.4559	0.5698	0.5519	0.5357
Delta	0.2836	0.0736	0.1074	0.2085
Rank	1	4	3	2

Table 8: Response Table for Signal to Noise Ratios

Level	**load**	**time**	**speed**	**track dia**
1	2.848	4.632	4.133	3.171
2	4.927	5.127	5.155	5.991
3	6.896	4.912	5.383	5.509
Delta	4.049	0.495	1.250	2.820
Rank	1	4	3	2





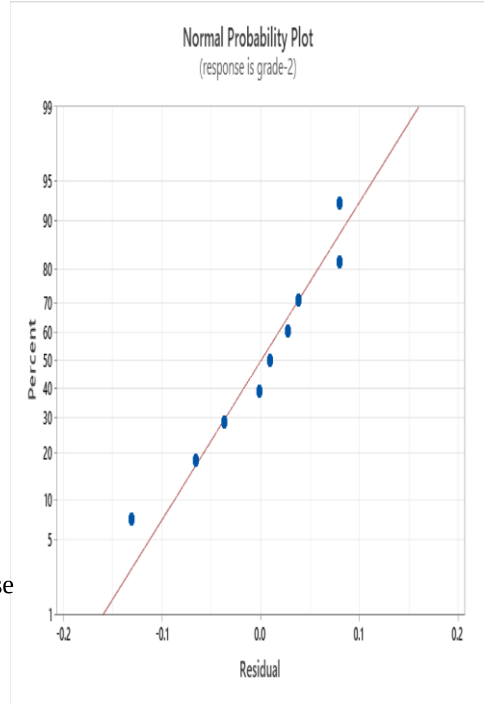


Fig 3: Main effects plot and normal probability plot for smaller is better case

Optimal condition for Case-2 Smaller the better is

1. According to the analytical calculations in Excel it is

Load=30, time=6, speed=200, track diameter= 50 and

its corresponding Grade = 0.987

2. According to the Analysis done in Minitab software it is

Load=50, time=8, speed=400, Track diameter=60 and

• This experiment is not on the primary Taguchi matrix So we have to find its Grade by using Regression equation by substituting the above Minitab software values

Garde-2 = 1.994 – 0.01418 load- 0.0161 time – 0.000537 speed – 0.00915 track dia

Grade-2 = 0.3924

Regression Analysis: grade-2 versus load, time, speed, track dia

Regression Equation

grade-2 = 1.994 - 0.01418 load - 0.0161 time - 0.000537 speed - 0.00915 track dia

Therefore, the grade must be higher, so Optimal condition for Case-1 i.e., Larger the better is

Load=30, time=6, speed=200, track diameter= 50 and its corresponding Grade = 0.987

ANOVA FOR CASE-2 (SMALLER THE BETTER):

General linear model; Grade -2 versus load, time, speed, track dia

Table 9: Analysis Of Variance

SOURCE	DF	SEQ SS	CONTRIBUTION	ADJ SS	ADJ MS
Load	2	0.122323	52.66%	0.122323	0.061162
Time	2	0.009650	4.15%	0.009650	0.004825
Speed	2	0.022770	9.80%	0.022770	0.011385
Track dia	2	0.077566	33.39%	0.077566	0.038783
TOTAL	8	0.232309	100%		

The figure 3 represents the main effects plot and normal probability plot for smaller is better case.

3.2 Method 2: Taguchi Analysis: -

• In Taguchi Analysis, we are finding the optimal condition for each parameter separately. We have to understand which process parameter is best suitable for the parameters such as frictional force, Wear and Temperature. And their optimum values for the corresponding material inputs.

Case 1: Taguchi analysis for frictional force:

Take the output Frictional force (smaller the better) obtained during the experimentation for the Taguchi Matrix and Analyse in Taguchi Method, then we can obtain the response Tables for Means and the SN ratios and also the graphs. The Optimal Condition is obtained from the Signal to Noise Ratio Graphs. The noise factors in the output responses should be low i.e., the values of SN ratios should be Nearer to the value "0" i.e., it indicates lower noise factors.

Table 10: TA: FF versus load, time, speed, track dia

Level	load	time	speed	track dia
1	7.257	9.223	9.900	9.420
2	9.430	9.693	9.463	9.277
3	11.793	9.563	9.117	9.783
Delta	4.537	0.470	0.783	0.507
Rank	1	4	2	3

Table 11: Response Table for Signal to Noise Ratios

Level	load	time	speed	track dia
1	-17.21	-19.18	-19.70	-19.32
2	-19.49	-19.49	-19.35	-19.22
3	-21.42	-19.44	-19.07	-19.58
Delta	4.20	0.31	0.62	0.36
Rank	1	4	2	3

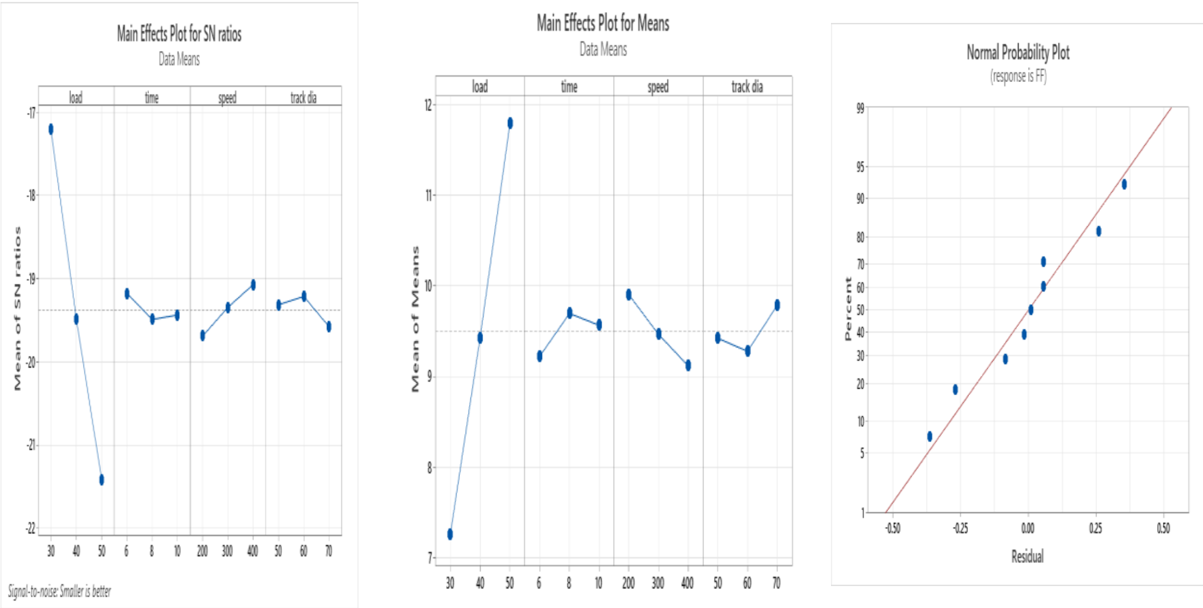


Fig 4: Main effects plot and normal probability plot for frictional force smaller is better case

Based on the Taguchi Analysis,The wear Parameter has Optimal condition at

Load= 30, time= 6, speed= 400, Track diameter= 60

This experiment is not on the primary Taguchi matrix So we have to find its optimal value by using Regression equation by substituting the above Minitab software values.

Regression Equation

FF = -0.18 + 0.2268 load + 0.0850 time - 0.00392 speed + 0.0182 track dia

Frictional force (FF) = 6.658

ANOVA FOR FRICTIONAL FORCE:

General linear model: FF versus load, time, speed, track dia

Table 12: Analysis Of Variance

SOURCE	**DF**	**SEQ SS**	**CONTRIBUTION**	**ADJ SS**	**ADJ MS**
Load	2	30.8901	94.82%	30.8901	15.4450
Time	2	0.3534	1.08%	0.3534	0.1767
Speed	2	0.9245	2.84%	0.9245	0.4622
Track dia	2	0.4093	1.26%	0.4093	0.2046
TOTAL	8	32.5772	100%		

The Figure 4 represents the main effects plot and normal probability plot for frictional force smaller is better case.

Case 2: Taguchi Analysis for Wear:

Take the output Wear (smaller the better) obtained during the experimentation for the Taguchi Matrix and Analyse in Taguchi Method, then we can obtain the response Tables for Means and the SN ratios and also the graphs. The Optimal Condition is obtained from the Signal to Noise Ratio Graphs. The noise factors in the output responses should be low i.e., The values of SN ratios should be Nearer to the value "0" i.e., it indicates lower noise factors.

Table 13: TA: wear versus load, time, speed, track dia

Level	load	time	speed	track dia
1	266.3	215.0	199.7	184.7
2	223.2	314.7	277.3	315.6
3	274.3	234.0	286.8	263.5
Delta	51.1	99.7	87.1	130.8
Rank	4	2	3	1

Table 14: Response Table for Signal to Noise Ratios

Level	load	time	speed	track dia
1	-47.19	-45.71	-45.25	-44.76
2	-46.95	-49.75	-48.41	-49.66
3	-48.61	-47.28	-49.09	-48.34
Delta	1.65	4.04	3.84	4.90
Rank	4	2	3	1

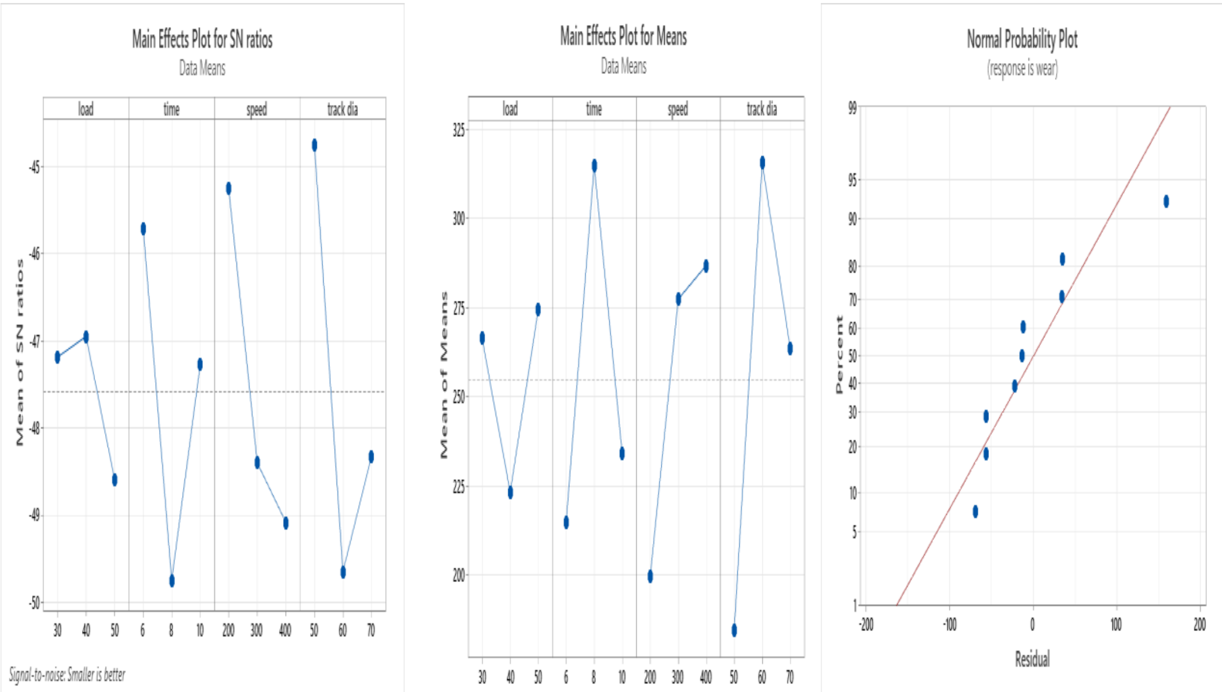


Fig 5: Main effects plot and normal probability plot for wear smaller is better case

Based on the Taguchi Analysis,the wear Parameter has Optimal condition at

Load= 40, time= 6, speed= 200, Track diameter= 50

- This experiment is not on the primary Taguchi matrix So we have to find its **optimal value** by using Regression equation by substituting the above Minitab software values

Wear = -166 + 0.40 load + 4.8 time + 0.435 speed + 3.94 track dia

Wear = 162.8

ANOVA FOR WEAR:

General linear model: Wear versus load, time, speed, track dia

Table 15: Analysis Of Variance

SOURCE	DF	SEQ SS	CONTRIBUTION	ADJ SS	ADJ MS
Load	2	4523	7.41%	4523	2262
Time	2	16802	27.52%	16802	8401
Speed	2	13690	22.43%	13690	6845
Track dia	2	26030	42.64%	26030	13015
TOTAL	8	61046	100%		

The Figure 5 represents the main effects plot and normal probability plot for wear smaller is better case.

Case 3: Taguchi Analysis for Temperature:

Take the output Temperature (smaller the better) obtained during the experimentation for the Taguchi Matrix and Analyse in Taguchi Method, then we can obtain the response Tables for Means and the SN ratios and also the graphs. The Optimal Condition is obtained from the Signal to Noise Ratio Graphs. The noise factors in the output responses should be low i.e., The values of SN ratios should be Nearer to the value "0" i.e., it indicates lower noise factors.

Table 16: TA : temp versus load, time, speed, track dia

Level	load	time	speed	track dia
1	44.30	48.20	41.43	37.23
2	44.40	43.53	47.03	52.30
3	49.07	46.03	49.30	48.23
Delta	4.77	4.67	7.87	15.07
Rank	3	4	2	1

Table 17: Response Table for Signal to Noise Ratios

Level	load	time	speed	track dia
1	-32.78	-33.40	-32.26	-31.38
2	-32.87	-32.71	-33.42	-34.31
3	-33.69	-33.24	-33.67	-33.65

Delta	0.91	0.69	1.41	2.93
Rank	3	4	2	1

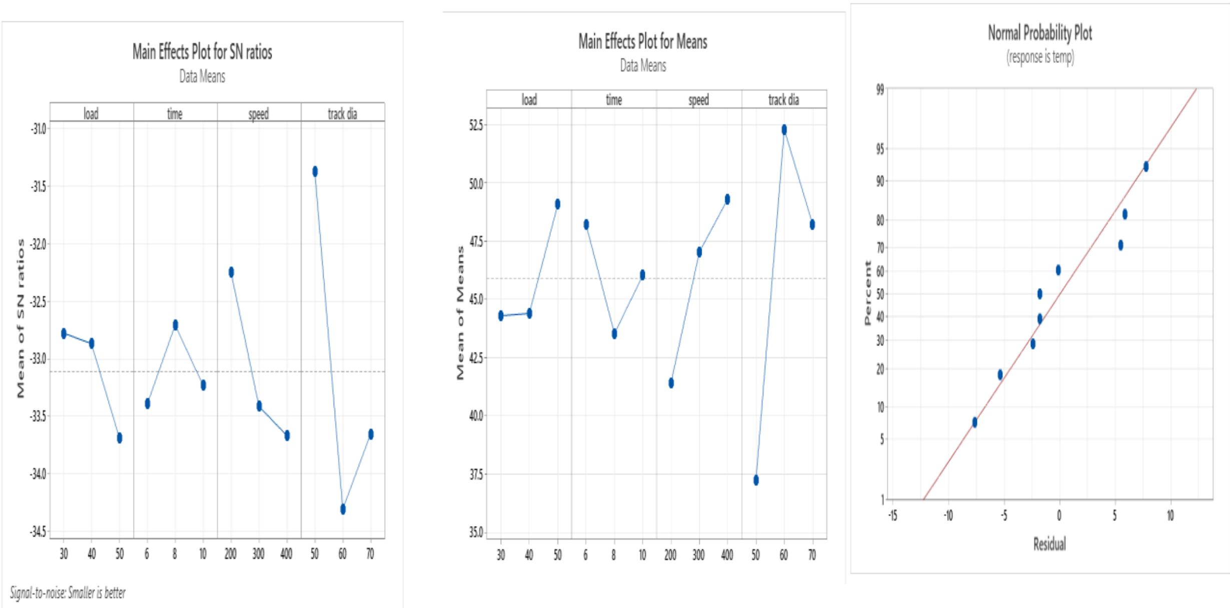


Fig 6: Main effects plot and normal probability plot for temperature smaller is better case

Based on the Taguchi Analysis, the wear Parameter has optimal condition at

Load= 30, time= 8, speed= 200, Track diameter= 50

This experiment is not on the primary Taguchi matrix So we have to find its optimal value by using Regression equation by substituting the above Minitab software values

Regression Equation

temp = -4.1 + 0.238 load - 0.54 time + 0.0393 speed + 0.550 track dia

Temperature = 34.08

Anova For Temperature:

General linear model: Temp versus load, time, speed, track dia

Table 18: Analysis Of Variance

SOURCE	DF	SEQ SS	CONTRIBUTION	ADJ SS	ADJ MS
Load	2	44.51	8.24%	44.51	22.25
Time	2	32.72	6.06%	32.72	16.36
Speed	2	98.38	18.21%	98.38	49.19
Track dia	2	364.54	67.49%	364.54	182.27
TOTAL	8	540.16	100%		

The Figure 6 represents the main effects plot and normal probability plot for temperature smaller is better case.

2. Conclusion

1. In Taguchi grey relation analysis, for larger the better case the optimum values obtained at Load- 50 N, TIME- 6 MN, SPEED- 400 RPM, TRACK DIA- 60 MM and their contributions are 49.12%, 7.53%, 5.43% and 37.91% respectively.

2. In Taguchi grey relation analysis, for smaller the better case the optimum values obtained at Load- 30 N, TIME- 6 MN, SPEED- 200 RPM, TRACK DIA- 50 MM and their contributions are 52.66%, 4.15%, 9.8%, and 33.39% respectively.

3. In Taguchi analysis, for frictional force the optimum values obtained at Load- 30 N, TIME- 6 MN, SPEED- 400 RPM, TRACK DIA- 60 MM and their contributions are 94.82%, 1.08%, 2.84%, and 1.26% respectively. Similarly for wear the optimum values obtained at Load- 40 N, TIME- 6 MN, SPEED- 200 RPM, TRACK DIA- 50 MM and for temperature optimum values obtained at Load- 30 N, TIME- 8 MN, SPEED- 200 RPM, TRACK DIA- 50 MM.

Refrences

[1] AchuthamenonSylajakumari, P., Ramakrishnasamy, R., &Palaniappan, G. (2018). Taguchi Grey Relational Analysis for Multi-Response Optimization of Wear in Co-Continuous Composite. Materials, 11(9), 1743. doi:10.3390/ma110917 43

[2] Alaneme, K. K., & Sanusi, K. O. (2015). Microstructural characteristics, mechanical and wear behaviour of aluminium matrix hybrid composites reinforced with alumina, rice husk ash and graphite. Engineering Science and Technology, an International Journal, 18(3), 416-422

[3] Bressan, J. D., &Schopf, R. A. (2011). Abrasive Wear Resistance of Tool Steels Evaluated by the Pin-on-Disc Testing. doi:10.1063/1.3589769

[4] SUMIT SHARMA, AJAY SHARMA, Investigation of Wear Characteristics of Aluminum Disc with Pin on Disc Tribometer.

[5] Federici, M., Straffelini, G. &Gialanella, S. Pin-on-Disc Testing of Low-Metallic Friction Material Sliding Against HVOF Coated Cast Iron: Modelling of the Contact Temperature Evolution. Tribol Lett 65, 121 (2017).

[6] Khomdram Herojit Singh, Abhishek Kumar, Rajender Kumar, Optimization of Quality and Performance of Brake Pads Using Taguchi's Approach

[7] Al-Qutub, I.M. Allam, and T.W. Qureshi, "Effect of sub-micron Al2O3 concentration on dry wear properties of 6061 aluminium based composite", Journal of Materials Processing Technology 172 (2006) 327–331.

[8] Ashok Kr. Mishra, Rakesh Sheokand, Dr. R K Srivastva , "Tribological behaviour of Al-6061 / SiC metal matrix composite by Taguchi's techniques ", International Journal of Scientific and Research Publications, Volume 2, Issue 10, October (2012) ISSN 2250-3153.

[9] Changxia Liu, Jianhua Zhang, Junlong Sun, and Xihua Zhang, "Tribological properties of pressureless sintered advanced alumina matrix ceramic materials improved by Al–Ti–B and diopside", Wear 265 (2008) 286–291.

[10] Tedesco, N. R., Pallone, E. M. J. A., &Tomasi, R. (2010). Effects of the Pin-on-Disc Parameters on the Wear of Alumina. Advances in Science and Technology, 65, 39–44.

[11] F. Xiong, and R.R. Manory, "The effect of test parameters on alumina wear under low contact stress", Wear 236 (1999) 240–245

[12] Bera, T., & Acharya, S. Utilization of Fly Ash Cenosphere as Reinforcement for Abrasive Wear Behaviour of LM6 Al Alloy Metal Matrix Composites. Iranian Journal of Science and Technology, Transactions of Mechanical Engineering, 1-8.

[13] Bharat Admile, S. G. K., S.A.Sona wane. (2014). Review on Mechanical & Wear Behavior of Aluminum-Fly Ash Metal Matrix Composite. International Journal of Emerging Technology and Advanced Engineering, 4(5), 4.

[14] Canute, X., & Majumder, M. (2018). Mechanical and tribological behaviour of stir cast aluminium/boron carbide/fly ash composites. Journal of Engineering Science and Technology, 13(3), 755-777.

[15] Dinaharan, I., Nelson, R., Vijay, S., & Akinlabi, E. T. (2016). Microstructure and wear characterization of aluminum matrix composites reinforced with industrial waste fly ash particulates synthesized by friction stir processing. Materials Characterization, 118, 149-158.

[16] Soy, U., Ficici, F., &Demir, A. (2011). Evaluation of the Taguchi method for wear behavior of Al/SiC/B4C composites. Journal of Composite Materials, 46(7), 851–859.

[17] Fei, N. C., Mehat, N. M., &Kamaruddin, S. (2013). Practical Applications of Taguchi Method for Optimization of Processing Parameters for Plastic Injection Moulding: A Retrospective Review. ISRN Industrial Engineering, 2013, 1–11.

[18] Arunachalam, U., &Vairamuthu, J. (2020). Tribological analysis on magnesium alloy AZ31B with reinforced ZrSiO4 through Taguchi technique. Materials Today: Proceedings. doi:10.1016/j.matpr.2020.08.436

[19] Amol S. Mali , S.T. Vagge, Aniket Kolekar, Tribological behaviour of LM25 hybrid metal matrix composites by using Taguchi's techniques. Materials Today: Proceedings, Volume 50, Part 5, 2022, Pages 1827-1834. https://doi.org/10.1016/j.matpr.2021.09.221