Optimization Of Wear Process Parameters On Aluminium Based In-situ Formed TiB_2 MMC

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Abstract - *This paper reports the dry sliding wear behaviour of Al/8wt.% TiB_2 composite fabricated by liquid metallurgy technique. A statistical approach, known as the Taguchi method, was implemented to identify optimum wear parameters. The wear test has been conducted in a pin-on-disc (EN32 steel) wear testing machine. Analysis of variance (ANOVA) technique is applied to check the validity of the developed model. Wear loss and co-efficient of friction were measured in an applied load range of 30 - 50 N, sliding velocity range of 0.5- 2.5 m/s and sliding distance of 1200 - 1500 m. Micro structures of worn surfaces were characterized by scanning electron microscope (SEM).*

Key Words: Al/TiB_2, Taguchi method, ANOVA, Optimization, Wear loss, co-efficient of friction, Micro-structure.

1.INTRODUCTION

The optimization of wear process parameters is a critical aspect in enhancing the performance of aluminum-based in-situ formed Titanium Diboride (TiB_2) Metal Matrix Composites (MMCs). These composites, known for their lightweight and high-strength characteristics, hold significant promise for applications in industries such as aerospace and automotive. This research endeavors to systematically investigate and optimize the wear process parameters, including factors such as applied load, sliding speed, and the concentration of TiB_2 reinforcement, with the goal of improving the wear resistance of the composite. By delving into the intricate interplay of these parameters, this study aims to provide valuable insights into maximizing the durability and tribological properties of aluminum-based in-situ formed TiB_2 MMCs, thereby contributing to the advancement of materials engineering for cutting-edge industrial applications.

2. Literature Survey

1. Udaya Devadiga, PeterFernandes (2021) : Taguchi analysis for sliding wear characteristics of carbon nanotube-flyash reinforced aluminium nano composites.

2. Essam B. Moustaf,Asmaa M. Khalil, Haitham M. Ahmed, Mohammed Hefni and Ahmed O. Mosleh (2021) : Microstructure, Hardness, and Wear Behavior Investigation of the Surface Nanocomposite Metal Matrix Reinforced by Silicon Carbide And Alumina Nanoparticles.

3. S.Abu shanab, Essam b. Moustafa (2020): Effect of friction stir processing parameters on the wear resistance and mechanical properties of fabricated metal matrix nano-composites (MMnCs) surface.

4. Navid Molla Ramezani,Behnam Davoodi,Mohammad Aberoumand, Mojtaba Rezaee Hajideh (2019) : Assessment of tool wear and mechanical properties of Al 7075 nanocomposite in friction stir processing (FSP)Assessment of tool wear and mechanical properties of Al 7075 nanocomposite in friction stir processing (FSP).

5. A. Fathy, A. Abu-Oquail, A. Wagih (2018): Improved mechanical and wear properties of hybrid AL-Al_2O_3/GNPs electro-less coated Ni nanocomposite.

6. Bhanu k Goriparthi, PHE Naveen, H Ravi sankar and Somanth Ghosh (2018): Effect of functionalization and concentration of carbon nanotubes on mechanical, wear and fatigue behaviours of polyoxymethylene/carbon nanotube nanocomposites.

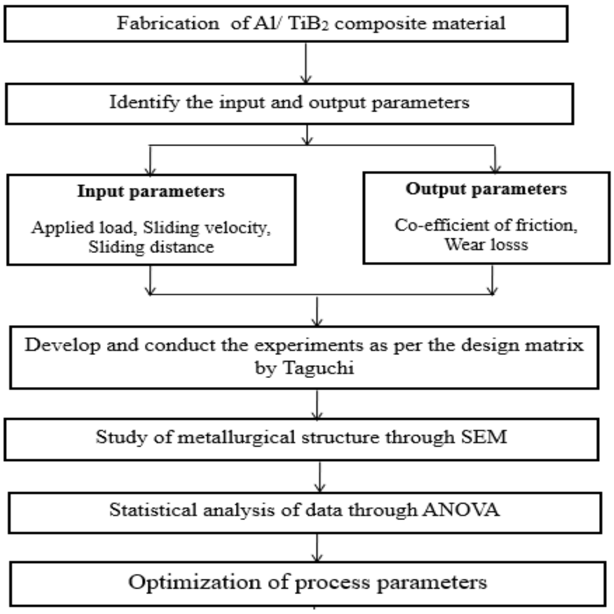
3. Problem Statement

- In-situ formed composites represent an alternative way to overcome the current limitations of ex-situ composites and monolithic materials. The main issue faced during the ex-situ composites in the Al-MMCs is low mechanical, tribological properties.

- In-situ formed (TiB_2) is known to be an excellent material for the strength and better ability to transfer the load. Moreover, refine the grain boundaries results in better mechanical and tribological properties as compared with ex-situ composites.

- Hence, an attempt has been made to fabricate the Al/ TiB_2 MMC and optimize the wear parameters by using Taguchi method.

4. Methodology



5. Experimental Work

Fabrication of In-Situ composite

The Potassium Hexa Fluro Titanate (K_2TiF_6), Potassium Tetra Fluro Borate (KBF_4) (fig. 5.1) and wrought Aluminium (A356) (fig.5.2) were used as the initiating materials. These halide salts with stoichiometric composition corresponding to 8wt % of TiB_2 in the Al/ TiB_2 composites was mixed. Melting of the aluminium was carried out in a graphite crucible.

Fig 5.1 Calculated B & Ti salts

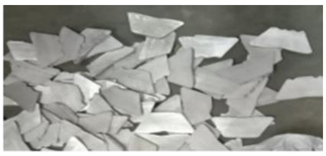


Fig 5.2 Aluminium (A356)

An electrical resistance furnace operating under normal ambient conditions was employed as shown fig.5.3. The (K_2TiF_6) and (KBF_4) salts were preheated at 250°C for 30 minutes before it was manually mixed into the molten aluminium that had been maintained at 820 °C followed by the 30 minutes stirring time. Heating was maintained at this temperature for 15 minutes to allow the in-situ TiB_2 particles to develop in the matrix. Nitrogen gas supplied through a fine copper tube was used at intervals to avoid atmospheric contamination. The dross was skimmed off twice from the surface of the melt, once before adding salts and the other just before the pouring. The composite melt was cast in a sand mould to produce a cast ingot as shown in fig. 5.4.

Table 5.1 Chemical composition of base metal (A356)

Elements	Si	Mg	Mn	Fe	Cu	Ni	Ti	Al
Cast Al alloy	7	0.33	0.3	0.5	0.1	0.1	0.2	Bal

Fig 5.3 Experimental Setup for stir casting furnace

Fig 5.4 Final cast ingot taken from mould

Fig 5.5 Testing samples

Fig 5.6 Pin on disc testing apparatus

The composite was machined in to nine wear samples shown fig. 5.5, dimension are 10 mm diameter and 20 mm length as per the ASTM guidelines. Pin on disc machine setup is shown in fig. 5.6.

6. Result And Discussion

Optimization of wear parameters using Taguchi Method

The wear process parameters and levels are selected based on the literature survey as shown in table 6.1. Pin on disc wear test was conducted according to the all the samples as per the Taguchi's L9 orthogonal array design results are shown in table 6.2. Results of pin on disc wear test conducted according to the Taguchi's L9 orthogonal array for various combinations of parameters are given in Table 6.2. Statistical software package MINITAB Release 18 was used to analyses the results of the L9 orthogonal array, depending on the number of factors, and their levels. The Signal to Noise ratio of "Smaller is Better" is selected for Co-efficient of friction and wear loss, since the goal is to find the lowest Co-efficient of friction and wear loss values.

Table 6.1 Control factors and their levels

Control factors	Units	levels		
Applied load	N	30	40	50
Sliding velocity	m/sec	0.5	1.5	2.5
Sliding distance	m	1200	1300	1500

Table 6.2 Experimental result using L9 orthogonal array

S.No	Applied Load (N)	Sliding Velocity (m/sec)	Sliding Distance (m)	Coefficient of Frictions	Wear loss (µ)
1	30	0.5	1200	0.275	79
2	30	1.5	1300	0.262	48
3	30	2.5	1500	0.265	10
4	40	0.5	1300	0.275	130
5	40	1.5	1500	0.293	90
6	40	2.5	1200	0.252	62
7	50	0.5	1500	0.312	142
8	50	1.5	1200	0.282	192
9	50	2.5	1300	0.272	158

Taguchi Analysis for Coefficient of Frictions
Table 6.3 Response Table for Signal to Noise Ratios
Smaller is better

Level	Applied Load (N)	Sliding Velocity (m/sec)	Sliding Distance (m)
1	11.46	10.85	11.39
2	11.28	11.10	11.39
3	10.81	11.61	10.77
Delta	0.65	0.76	0.62
Rank	2	1	3

Regression Analysis for Coefficient of Frictions
Table 6.4 Analysis of Variance (ANOVA)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	0.002309	0.000770	17.41	0.004
Applied Load (N)	1	0.000683	0.000683	15.44	0.011
Sliding Velocity (m/sec)	1	0.000888	0.000888	20.09	0.007
Sliding Distance (m)	1	0.000738	0.000738	16.70	0.009
Error	5	0.000221	0.000044		
Total	8	0.002530			

Table 6.5 Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0066497	91.26%	86.02%	75.35%

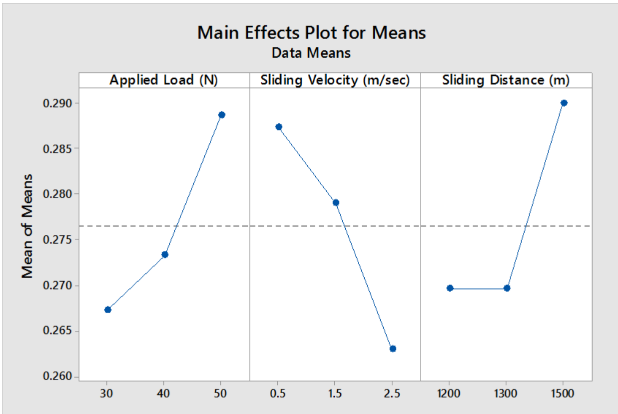


Fig 6.1 Main effects plot for Means ratio for co-efficient of friction

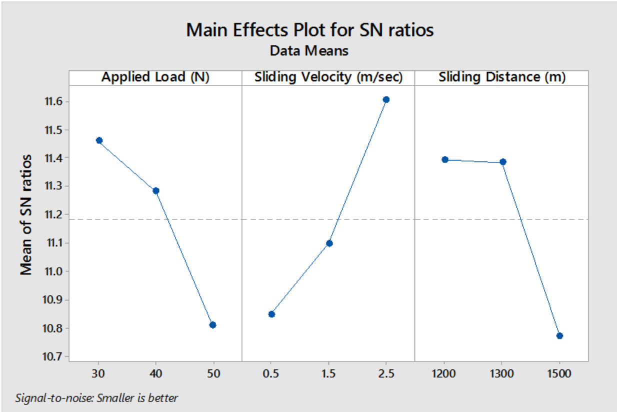


Fig 6.2 Main effects plot for signal to noise ratio for co-efficient of friction

Regression Equation: Coefficient of Frictions =

0.1552 + 0.001067 A - 0.01217 B + 0.000073 C

Coefficient of Frictions = 0.1552 + 0.001067 A - 0.01217 B + 0.000073 C

where A, B and C indicate Applied load, sliding velocity and sliding distance respectively.

Co-efficient of friction = 0.3119.

Further validation experiments were conducted for the predicted optimum conditions and volumetric wear loss from the validation experiments was obtained as **0.285.** The percentage error was also calculated and found to be **4.87 %** confirming the success of statistical analysis.

Taguchi Analysis for Wear loss (µm)
Table 6.6 Response Table for Signal to Noise Ratios Smaller is better

Level	Applied Load (N)	Sliding Velocity (m/sec)	Sliding Distance (m)
1	-30.53	-41.09	-39.82
2	-39.07	-39.46	-39.96
3	-44.23	-33.27	-34.04
Delta	13.70	7.82	5.92
Rank	1	2	3

Regression Analysis for Wear loss (µm)
Table 6.7 Analysis of Variance (ANOVA)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	25109	8369.7	19.39	0.003
Applied Load (N)	1	21004	21004.2	48.66	0.001
Sliding Velocity (m/sec)	1	2440	2440.2	5.65	0.063
Sliding Distance (m)	1	1665	1664.8	3.86	0.107
Error	5	2158	431.7		
Total	8	27268			

Table 6.8 Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
20.7770	92.08%	87.33%	69.09%

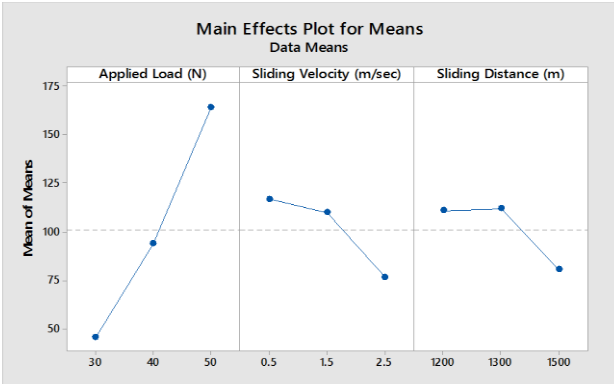


Fig 6.3 Main effects plot for Means ratio for wear loss

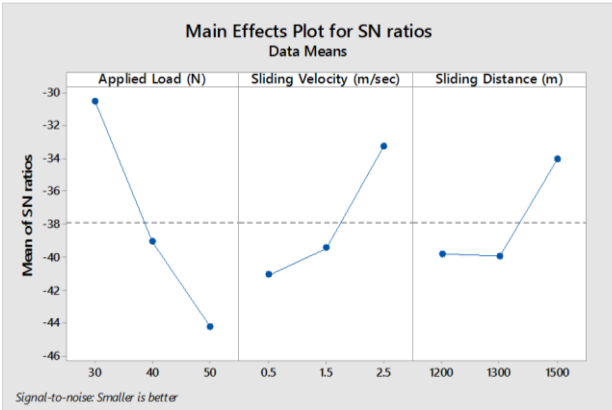


Fig 6.4 Main effects plot for SN ratios for wear loss

Regression Equation

Wear loss (µm) = 40.2 + 5.917 A - 20.17 B - 0.1090 C

Wear loss (µm) = 40.2 + 5.917 A - 20.17 B - 0.1090 C

where A, B and C indicate Applied load, sliding velocity and sliding distance respectively.

Wear loss (µm) = 162.46 µm

Further validation experiments were conducted for the predicted optimum conditions and volumetric wear loss from the validation experiments was obtained as **154 µm.** The percentage error was also calculated and found to be 5.49 % confirming the success of statistical analysis.

Microstructural analysis

Micro structural study of Al/8wt.% composite has been analysed using Scanning Electron Microscopy (JEOL, JSM-6610LV, Japan) which is available in the Department of Mechanical Engineering, KPN College of Engineering, Coimbatore, India. After Casting process, the composite was cut into small pieces (10 mm diameter & 10 mm length) to study the wear parameters. Fig. 6.5 a & b indicates the SEM result of worn surface. The ploughing or grooves were observed at low sliding velocity of 0.5 m/sec and high normal load of 50 N due to effect of hard particles move relative to the contact surface parallel to the sliding direction.

The depth of the grooves depends on the hardness of the particles. The worn surface shown in Fig. 6.5 a & b has mostly grooves, indicative of abrasion being dominant wear mechanism

In this condition the TiB_2 particles were pull out from the surface due to the wear of the Aluminium is more rapid.

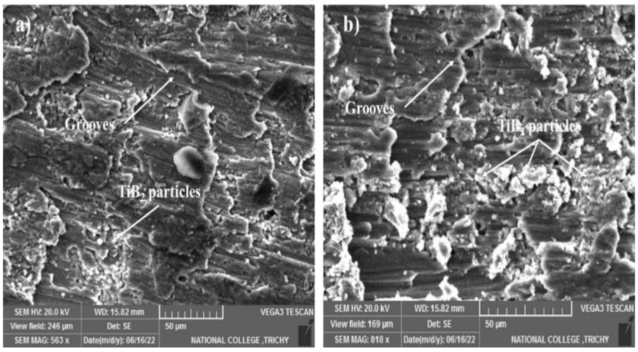


Fig 6.5 SEM result of wornout surfaces
a) Poor & b) Best

Fig 6.6 Scanning Electron Microscope

7. Conclusion

The following conclusions were drawn from this study:

- The Taguchi's L9 design matrix was successfully used to analyse the optimal wear parameters for the Al/8wt.% TiB_2 Composite. The most influencing parameter for coefficient of friction is Sliding velocity whereas in wear loss is applied load. Other parameters sliding velocity and sliding distance was not play major role in influencing the wear behaviour.

- Signal-to-noise ratio factor effect plots indicate the effect of parameters on wear individually. The plot was useful in identifying the optimal conditions for coefficient of friction as well as wear loss. The optimum conditions for the co-efficient of friction are 0.5 m/s sliding velocity, 50 N applied load and 1500 sliding distance whereas optimum condition for wear loss is 0.5 m/s sliding velocity, 50 N applied load and 1300 sliding distance.

- The regression model can be used to predict the coefficient of friction and wear loss were successfully developed. Predicted values using developed mathematical model for coefficient of friction and wear loss were in close agreement with the results obtained in validation experiments.

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