TRIBOLOGICAL CHARACTERIZATION AND PROCESS PARAMETERS OPTIMIZATION OF AA8011 REINFORCED WITH TiO_2 AND WC HYBRID COMPOSITE

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Abstract: This research focuses on the fabrication of an AA8011 hybrid composite reinforced with Titanium Oxide (TiO_2) and Tungsten Carbide (WC) using the Stir Casting technique. The tribological properties, such as wear behavior and coefficient of friction, of the AA8011 composite samples were assessed through Pin-on-Disk testing under dry sliding conditions. The incorporation of Titanium Oxide in the AA8011 alloy enhanced its Tensile strength, as evidenced by the Universal Testing machine. And the addition of Tungsten Carbide in AA8011 improved the hardness of the composite, as demonstrated by the Rockwell hardness test, also helped in reducing wear. The study considered factors like reinforcement percentage, sliding velocity, and applied load to evaluate the wear rate and friction coefficient. The relationships between these variables were analyzed, and process parameters were optimized using the Grey Relation Analysis method.

Keywords: AA8011/WC/TiO2 Hybrid Composite, Grey relational Analysis, ANNOVA Coefficient of Friction, Wear rate.

1. INTRODUCTION

Lightweight materials are being increasingly used to enhance energy efficiency, particularly in response to friction-induced energy loss in mechanical systems. This has led to substantial research, especially in the automotive and aerospace sectors. Metal Matrix Composites provide superior strength, stiffness, fatigue resistance, and wear resistance, making them ideal for advanced applications. Aluminium Alloy 8011 is commonly used, but its resistance to creep and wear is limited. To address this, AA8011 is modified into MMCs by incorporating reinforcements like WC, TiO2, B4C, and SiC, improving its hardness, wear resistance, and performance. Stir casting is an efficient technique for producing uniform MMCs, with factors like reinforcement amount, stirring speed, duration, and temperature significantly impacting the final product's strength. Strength tests show increased stirring time and reinforcement can significantly boost tensile strength. Hardness is also a key property, with Rockwell, Brinell, and Vickers tests commonly used. AA8011 composites exhibit enhanced tensile strength and wear resistance, making them suitable for aerospace and automotive uses. However, the full potential of aluminum MMCs remains largely untapped, particularly in replacing steel and cast iron, presenting significant opportunities for future advancements.

2. MATERIALS AND METHODOLOGY

In this research work, the AA8011 alloy composite was manufactured by stir casting method by reinforcing the Titanium di-oxide 4% and Tungsten carbide 4% and tungsten carbide 2% +

Titanium di-oxide 2% particles . The composite manufacturing was done in muffle furnace. The matrix and reinforcement materials were placed inside the furnace and the temperature of furnace was raised to 750 °C with the step of 100 °C. At each 100 °C rise, the furnace was kept at that temperature for 15 minutes for stabilization purpose. After attaining 750 °C, the furnace was kept at that temperature for another 30 minutes. Moreover, the stirring process was executed with the help of mechanical stirrer operated for 5 minutes at the speed of 300 rpm. Stirring process assists to create better mix between matrix and reinforcements. Eventually, the mixture was transferred to the mould for solidification purpose.

Fig 2.1: Materials

Fig 2.2: Stirrer

Table 2.1: Formulation of composites

Composites	**Code**	**AA8011 (wt %)**	**WC (wt %)**	**TiO2 (wt %)**
AA8011	S0	100	-	-
AA8011/4wt%WC	S1	96	4	-
AA8011/4wt%TiO2	S2	96	-	4
AA8011/2%WC/2% TiO2	S3	96	2	2

3. TESTING OF COMPOSITES

3.1 Tensile Strength

Specimen	Al8011	Al8011+WC	Al8011+ TiO2	Al8011+ TiO2+WC
Tensile Strength (N/mm^2)	110.256	123.731	142.294	112.063

Table 3.1: Tensile Strength value

3.2 Rockwell Hardness

Specimen	Al8011	Al8011+WC	Al8011+ TiO2	Al8011+ TiO2+WC
Rockwell HardnessValue	65	76	69	69.5

Table 3.2: Hardness value

3.3 Wear Test

	1	2	3	4
Reinforcement	0	4	4	2+2
Load	4.905	9.81	14.715	19.62
Speed	300	400	500	600

Table 3.3: Reinforcement percentages, loads, andspeed

4. OPTIMIZATION

4.1 Grey relational analysis:

The Grey system theory is one of the most widely used models to determine the optimum condition of various input parameters to get the best quality characteristics.

The following Stages are involved in GRA

i. Data Pre-processing
ii. Normalizing
iii. Deviation Sequence
iv. Grey Relation Sequence
v. Grey Relation Grade

S.No.			Normalizing		Deviation Sequence		Grey Relation Coefficient		GRG	Rank
	COF	Wear Rate	COF	Wear Rate	COF	Wear Rate	COF	Wear Rate		
1	0.3467	0.0863	0.790	0.000	0.210	1.000	0.704	0.333	0.519	13
2	0.2345	0.0323	0.930	0.714	0.070	0.286	0.877	0.636	0.757	7
3	0.2243	0.0172	0.943	0.914	0.057	0.086	0.897	0.853	0.875	2
4	0.1784	0.0107	1.000	1.000	0.000	0.000	1.000	1.000	1.000	1
5	0.469	0.0756	0.637	0.142	0.363	0.858	0.579	0.368	0.474	14
6	0.3365	0.0504	0.802	0.475	0.198	0.525	0.717	0.488	0.602	12
7	0.3331	0.0168	0.807	0.919	0.193	0.081	0.721	0.861	0.791	4
8	0.2549	0.0151	0.904	0.942	0.096	0.058	0.840	0.896	0.868	3
9	0.9789	0.0458	0.000	0.536	1.000	0.464	0.333	0.519	0.426	16
10	0.418	0.0274	0.701	0.779	0.299	0.221	0.626	0.694	0.660	11
11	0.2991	0.0229	0.849	0.839	0.151	0.161	0.768	0.756	0.762	6
12	0.4333	0.0229	0.682	0.839	0.318	0.161	0.611	0.756	0.683	8
13	0.6934	0.0553	0.357	0.410	0.643	0.590	0.437	0.459	0.448	15

14	0.4486	0.023	0.662	0.837	0.338	0.163	0.597	0.754	0.676	9
15	0.367	0.0307	0.764	0.735	0.236	0.265	0.680	0.654	0.667	10
16	0.3569	0.0173	0.777	0.913	0.223	0.087	0.692	0.851	0.771	5
Max	0.9789	0.0863	1	1	Delta Min	1.000				
Min	0.1784	0.0107			Delta Max	0.000				

Table 4.1: Optimization Using Grey Relation Analysis Method

4.2 Taguchi Design:

Design Summary

Ref	**Load**	**Speed**	**GRG**	**MEAN1**
0	4.905	300	0.519	0.518659
0	9.810	400	0.757	0.756716
0	14.715	500	0.875	0.875196
0	19.620	600	1.000	1
4	4.905	400	0.474	0.473711
4	9.810	300	0.602	0.602293
4	14.715	600	0.791	0.791142
4	19.620	500	0.868	0.867637
4	4.905	500	0.426	0.425926
4	9.810	600	0.660	0.659558
4	14.715	300	0.762	0.762154
4	19.620	400	0.683	0.683464
4	4.905	600	0.448	0.448025
4	9.810	500	0.676	0.675739
4	14.715	400	0.667	0.666847
4	19.620	300	0.771	0.771464

Table 4.2: Grey Relation Grade and mean corresponding to Design of Experiment

Level	**Ref**	**Load**	**Speed**
1	0.7876	0.4666	0.6636
2	0.6523	0.6736	0.6452
3	0.6523	0.7738	0.7111
4	0.6523	0.8306	0.7247
Delta	0.1353	0.3641	0.0795
Rank	2	1	3

Table 4.3: Response table for means

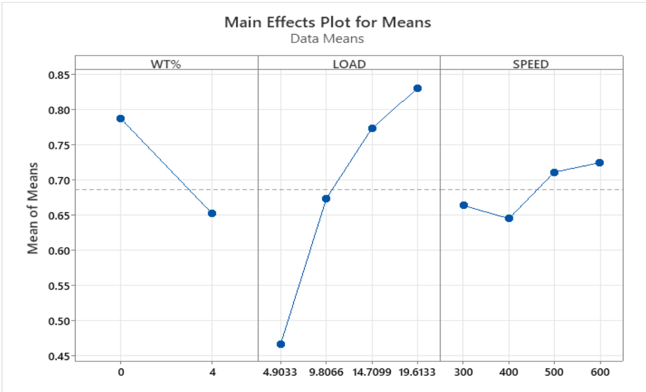

Fig 4.1: Main effects plot for means

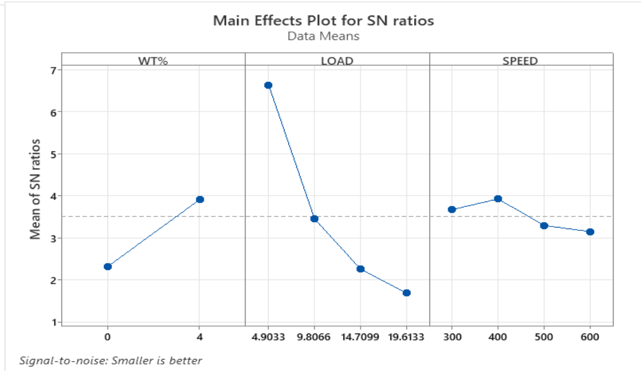

Fig 4.2: Main effects plot for SN Ratio

4.3 Analysis of Variance:

Source	DF	Adj SS	Adj MS	F-Value	P-Value
WT%	1	0.05493	0.054929	19.77	0.002
LOAD	3	0.30774	0.102581	36.93	0.000
SPEED	3	0.01717	0.005724	2.06	0.184
Error	8	0.02222	0.002778		
Total	15	0.40207			

Table 4.4: Analysis of Variance

S	R-sq	R-sq(adj)	R-sq(pred)
0.0527068	94.47%	89.64%	78.65%

Table 4.5: Model Summary

4.4 Regression Equation

GRG = 0.7200 + 0.0677 WT%_0 - 0.0677 WT%_4 - 0.2196 LOAD_4.9033 - 0.0126 LOAD_9.8066+ 0.0877 LOAD_14.7099+ 0.1445 LOAD_19.6133- 0.0225 SPEED_300 - 0.0410 SPEED_400+ 0.0250 SPEED_500 + 0.0385 SPEED_600

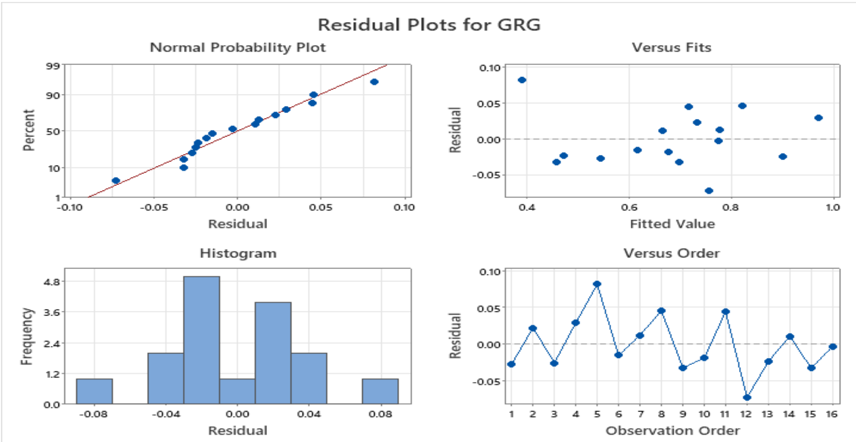

Fig 4.3: Four in one Residual Plot

5. RESULTS AND DISCUSSION:

After fabricating the composite compositions, the materials were precisely cut into specimens to ensure a smooth surface finish suitable for testing. Initially, the hardness of the composite material was evaluated. Subsequently, the specimens were cut into tensile test dimensions by ASTM E8 standards to characterise the mechanical properties of the composite.

5.1 Tensile Strength

The findings indicate that introducing 4% of TiO_2, to AA8011 led to improve tensile strength compared to the base metal. Notably, TiO_2 4% exhibited a noteworthy tensile strength value of 142.294 MPa. This value represents a 32.03% increment over the base AA8011's tensile strength of 110.256 MPa.

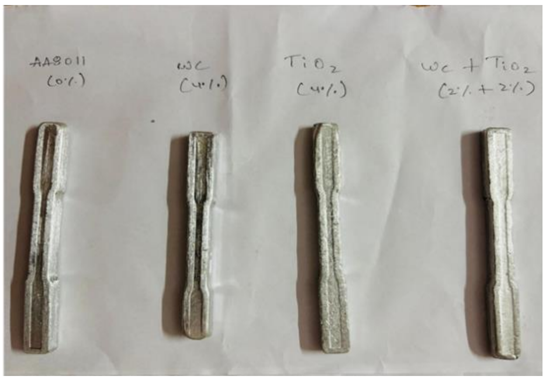

Fig 5.1: Machined Samples

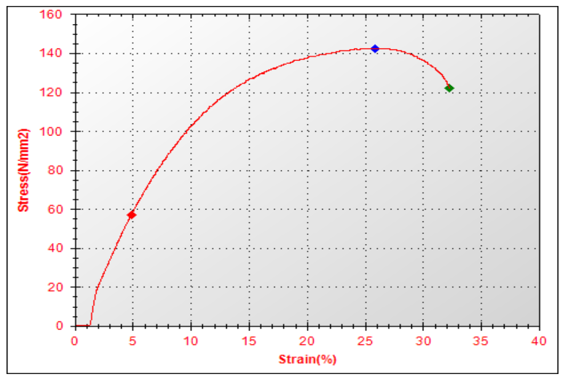

Fig 5.2: Stress Vs Strain

5.2 Hardness

Among these composites, the AA8011 + WC 4% composite exhibited the greatest hardness, measuring 79 RHN. This value is 11% higher than the base metal AA8011, which had a hardness of 65 RHN.

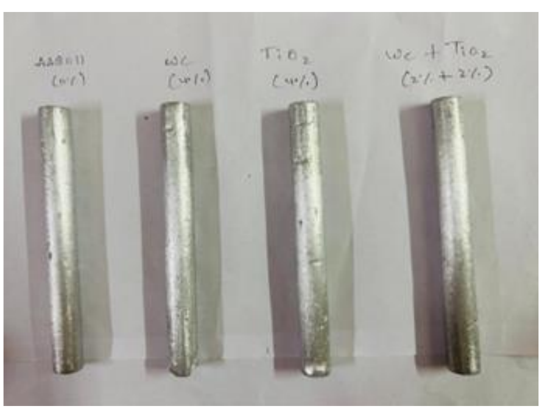

Fig 5.3: Machined Samples

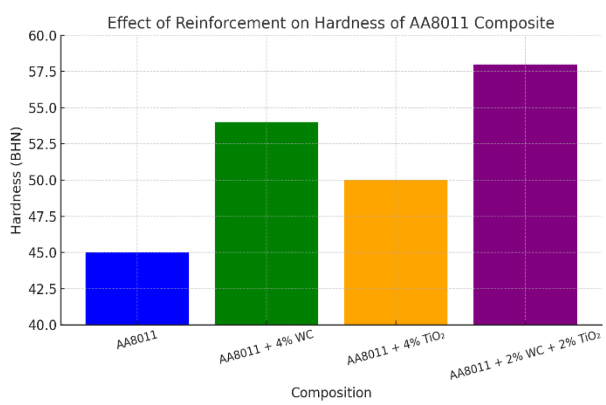

Fig 5.4: Graph of Hardness parameters

5.3 Wear rate

The addition of reinforcements such as Tungsten Carbide (WC) and Titanium Dioxide (TiO_2) to AA8011 Aluminium Alloy significantly enhances its wear resistance under varying operating conditions. These reinforcements contribute to the overall mechanical properties of the alloy, particularly improving its ability to withstand wear and reduce material degradation during sliding interactions. Reinforcement with WC and TiO_2 plays a significant role in improving the wear resistance of AA8011 Aluminium Alloy. The hybrid composite (AA8011 + 2% WC + 2% TiO_2) provides the best performance, showing the lowest wear rate and making it suitable for high-wear applications such as in automotive, aerospace, and manufacturing industries where enhanced wear resistance is crucial.

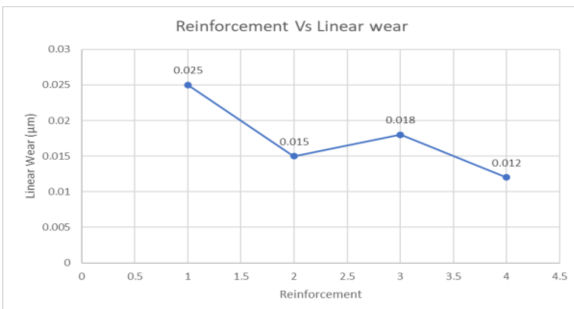

Fig 5.5: Percentage reinforcement Vs Linear wear

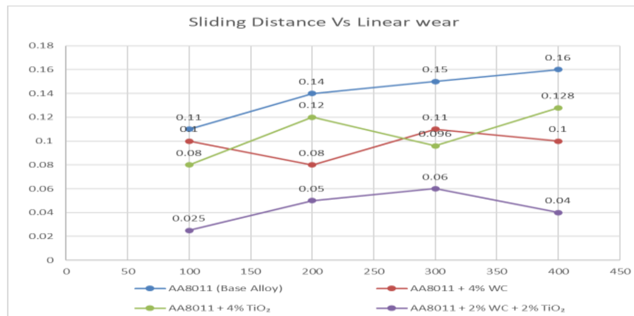

Fig 5.6: Sliding distance Vs Linear wear

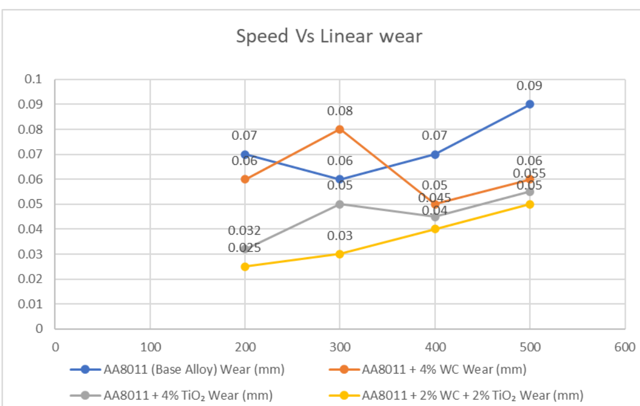

Fig 5.7: Speed Vs Linear wear

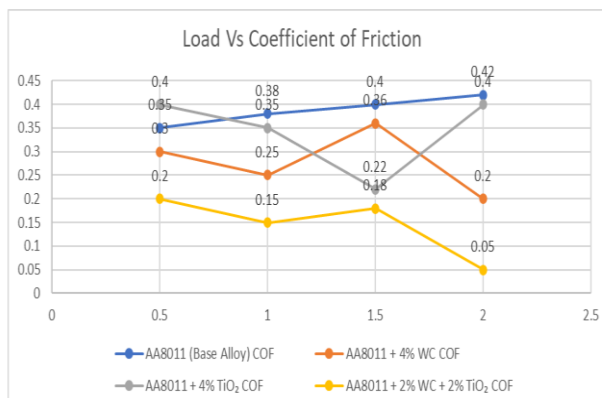

Fig 5.8: Load Vs Coefficient of friction

5.4 Result summary

AA8011 Aluminium Alloy composites reinforced with Tungsten Carbide (WC) and Titanium Dioxide (TiO_2) significantly enhance the material's mechanical and tribological performance. Hybrid reinforcement (2% WC + 2% TiO_2) provides the best overall results in terms of wear resistance and coefficient of friction, making it a promising material for high-wear and high-load applications. The results suggest that these composites would be ideal for use in applications requiring both high strength and low friction, such as in automotive, aerospace, and machinery components.

6. CONCLUSION

Incorporating 4%, of each WC, TiO_2, WC+TiO_2 into aluminum alloy AA8011 led to improve tensile strength also resulted in heightened hardness and showed superior wear resistance property compared to the base metal. Among these composites, AA8011 + TiO_2 exhibited a noteworthy tensile strength value of 142.294 MPa.Also AA8011 + WC 4% composite exhibited the greatest hardness, measuring 79 RHN and showed superior wear resistance property relative the base alloy and the other samples considered in this project. The 8th experiment with process parameters 19.620 N Load, 4% WC reinforcement and speed of 500 RPM was ranked 1st by Grey Relational Analysis method. The Analysis of Variance conducted on Grey Relational Grade shows that Reinforcement percentage is most significant followed by the load.

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