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MECHANICAL AND TRIBOLOGICAL PROPERTIES OF AA5083 ALUMINUM ALLOY COMPOSITE REINFORCED WITH ZIRCONIA (ZRO_2) AND CADMIUM (CD)

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Abstract: The study examined the mechanical and tribological properties of AA5083 aluminum alloy composites reinforced with zirconia dioxide and cadmium. Four material combinations were analyzed, and the effects on tensile strength, hardness, impact resistance, wear resistance, and friction were evaluated. The addition of ZrO_2 and Cd significantly improved hardness and wear resistance, with the composite containing both reinforcements exhibiting the best mechanical strength and wear performance. Microstructural analysis confirmed a uniform distribution of the reinforcing particles, enhancing load-bearing capacity and wear resistance. ZrO_2 contributed to hardness and thermal stability, while cadmium improved lubrication and surface degradation resistance. These reinforced composites show promise for applications in aerospace, manufacturing, and automotive industries, and further research is suggested to assess their long-term performance under extreme conditions.

Keywords – AA5083, Zirconia dioxide, Cadmium, Stir Casting.

1. INTRODUCTION

Composite materials have gained renewed attention due to industrial innovation, energy concerns, and rising costs. Metal matrix composites (MMCs), known for their enhanced stiffness and strength, are being increasingly used in industries like pistons, rods, filters, and space constructions. Aluminum matrix composites (AMCs) offer improved strength, stiffness, wear resistance, and high-temperature performance, making them ideal for automotive and aerospace applications. They are used in components like brake rotors and heat sinks due to their low density and corrosion resistance. AMCs combine metallic and ceramic phases, improving plastic formation and reducing manufacturing costs. Common reinforcements include SiC, B4C, TiC, and Al_2O_3, with Stir Casting being a widely used production method. Despite the anisotropic nature of composites limiting their use, aluminum alloy AA5083 offers high strength and formability. AA5083, a non-heat-treatable aluminum-magnesium alloy, is popular for its excellent corrosion resistance and moderate strength but has low hardness and wear resistance. Reinforcing aluminum alloys with secondary phases, particularly particle- reinforced composites, helps enhance these properties while maintaining lightweight characteristics. This study focuses on developing a composite using cadmium and zirconium carbide in AA5083 alloy, evaluating its mechanical, tribological, and corrosion properties after forging.

2. MATERIALS AND METHODOLOGY

Selecting the appropriate matrix material and reinforcing elements is crucial for achieving the desired properties in composite materials. Aluminum-based composites are vital in the automotive and aerospace sectors due to their lightweight and high-performance characteristics. Aluminum Alloy 5083, composed of magnesium, manganese, and chromium, offers exceptional corrosion resistance and high strength even after welding. Cadmium is a soft, malleable metal used in rechargeable batteries and corrosion protection, with various applications. Zirconia enhances the strength and corrosion resistance of magnesium alloys and is useful in refractory materials and dentistry. Zirconia is derived from natural or synthetic sources and can contribute to the biodegradability of magnesium alloys.

Fig 2.1: Carbide powders

Fig 2.2: Molten hot metal

Table 6: Percentage composition of Composite samples

Composites	**Code**	**AA5083 (Weight in %)**	**Cd (weight in %)**	**ZrO_2 (Weight in %)**
AA5083	A0	100%	0	0
AA5083/ 4wt%Cd	A1	96%	4%	0
AA5083/ 4wt%ZrO_2	A2	96%	0	4%
AA5083/ 2%Cd/ 2% ZrO_2	A3	96%	2%	2%

3. TESTING

3.1 Rockwell Hardness

Specimen	Al5083	Al5083+Cd	Al5083+ZrO_2	Al5083+Cd+ZrO2
Rockwell Hardness Value	77	85	79.3	78

Table: Hardness value

3.2 Tensile Strength

Specimen	Al5083	Al5083+Cd	Al5083+ZrO_2	Al5083+Cd+ZrO2
Tensile Strength(N/mm^2)	190.019	223.356	222.756	197.613

Table: Tensile Strength value

3.3 Wear Test

Reinforcement	0	3	5	7
Load	4.905	9.81	14.715	19.62
Speed	300	400	500	600

Table: Reinforcement percentages, loads, and speeds

4. OPTIMIZATION

4.1 Grey System Analysis

Grey system theory is a widely applied model for identifying the optimal conditions of input parameters to achieve superior quality characteristics.

The following Stages are involved in GRA

- Data Preprocessing
- Normalization
- Calculating the Deviation Sequence
- Determining the Grey Relational Sequence
- Computing the Grey Relational Grade

S. No.			Normalizing		Deviation Sequence		Grey Relation Coefficient		GRG	Rank
	COF	Wear Rate	COF	Wear Rate	COF	Wear Rate	COF	Wear Rate		
1	0.7749	0.1022	0.290	0.000	0.710	1.000	0.413	0.333	0.373344	16
2	0.571	0.0383	0.533	0.714	0.467	0.286	0.517	0.636	0.576571	12
3	0.4894	0.0204	0.630	0.914	0.370	0.086	0.575	0.853	0.713962	7
4	0.4743	0.0127	0.648	1.000	0.352	0.000	0.587	1.000	0.793424	3
5	0.5506	0.0846	0.557	0.197	0.443	0.803	0.530	0.384	0.456987	13
6	0.3263	0.0564	0.824	0.512	0.176	0.488	0.740	0.506	0.62282	10
7	0.4622	0.0188	0.662	0.932	0.338	0.068	0.597	0.880	0.738486	6
8	0.3976	0.0169	0.739	0.953	0.261	0.047	0.657	0.914	0.785715	4
9	1.019	0.0631	0.000	0.437	1.000	0.563	0.333	0.470	0.401822	15
10	0.724	0.0263	0.351	0.848	0.649	0.152	0.435	0.767	0.601031	11
11	0.3195	0.0351	0.832	0.750	0.168	0.250	0.749	0.666	0.707541	8
12	0.26	0.0197	0.903	0.922	0.097	0.078	0.837	0.865	0.851076	2
13	0.9177	0.0511	0.121	0.571	0.879	0.429	0.362	0.538	0.450318	14
14	0.4079	0.0306	0.727	0.800	0.273	0.200	0.647	0.714	0.68055	9
15	0.2923	0.0255	0.865	0.857	0.135	0.143	0.787	0.778	0.782184	5
16	0.1784	0.01988	1.000	0.920	0.000	0.080	1.000	0.862	0.930868	1
MAX	1.019	0.1022	1	1	Delta Min	1.000				
MIN	0.1784	0.0127			Delta Max	0.000				

Table 12: Optimization Using Grey Relation Analysis Method

4.2 Taguchi Design:

Design Summary

Ref	Load	Speed	GRG	MEAN1
0	4.9033	300	0.666667	0.666667
0	9.8066	400	0.539008	0.539008
0	14.7099	500	0.733621	0.733621
0	19.6133	600	0.882553	0.882553
4	4.9033	400	0.347766	0.347766
4	9.8066	300	0.570279	0.570279
4	14.7099	600	0.779234	0.779234
4	19.6133	500	0.928494	0.928494
4	4.9033	500	0.415895	0.415895
4	9.8066	600	0.655505	0.655505
4	14.7099	300	0.596824	0.596824
4	19.6133	400	0.789306	0.789306
4	4.9033	600	0.440137	0.440137
4	9.8066	500	0.616885	0.616885
4	14.7099	400	0.657024	0.657024
4	19.6133	300	0.739754	0.739754

le 14: Grey Relation Grade and mean corresponding to Design Experiment

Level	Ref	Load	Speed
1	0.6143	0.4206	0.6586
2	0.6674	0.6202	0.6667
3	0.6674	0.7355	0.6455
4	*0.6674*	*0.8403*	*0.6458*
Delta	0.0531	0.4197	0.0212
Rank	2	1	3

Table 15: Response table for means

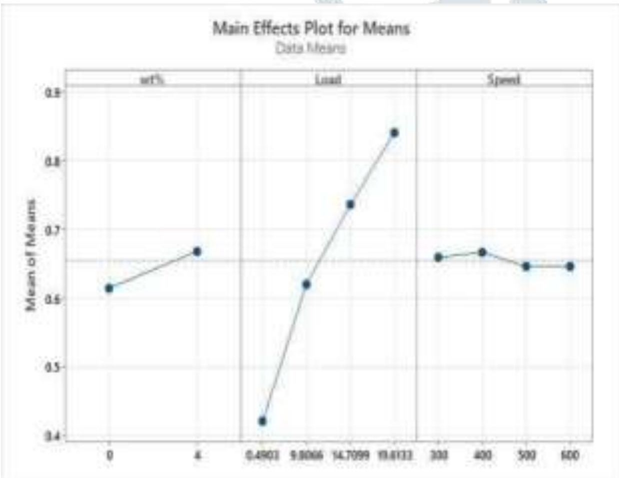

Fig: Main effect plot for means

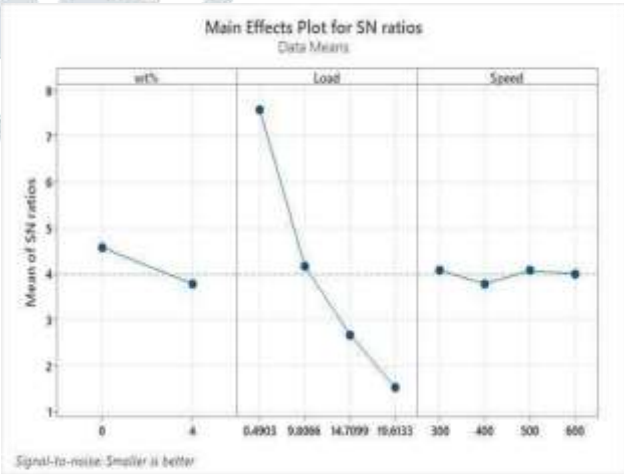

Fig: The Main effects plot for a SN Ratio

6.3 Analysis of Variance:

General Linear Model: GRG versus Ref, Load, Speed

Method

Factor coding (-1,0,+1)

Factor	Type	Levels	Values
Ref	Fixed	4	0,4,4,4
Load	Fixed	4	4.9033,9.8066,14.7099, 19.6133
Speed	Fixed	4	300,400,500,600

Table18: Factor Information

Source	DF	Seq SS	Contribution	AdjSS	AdjMS	F-Value	P-Value
Ref	3	0.01796	63.16%	0.008467	0.008467	3.79	0.088
Load	3	0.28875	24.30%	0.387811	0.129270	57.81	0.000
Speed	3	0.02633	4.52%	0.001288	0.000429	0.19	0.899
Error	8	0.06280	8.02%	0.017888	0.002236		
Total	15	0.415454	100.00%				

Table19: Analysis of Variance

S	R-sq	R-sq(adj)	PRESS	R-sq(pred)	AICc	BIC
.0472865	95.69%	1.93%	.0995844	4.31%	20.75	-36.75

Table 20: The Model Summary

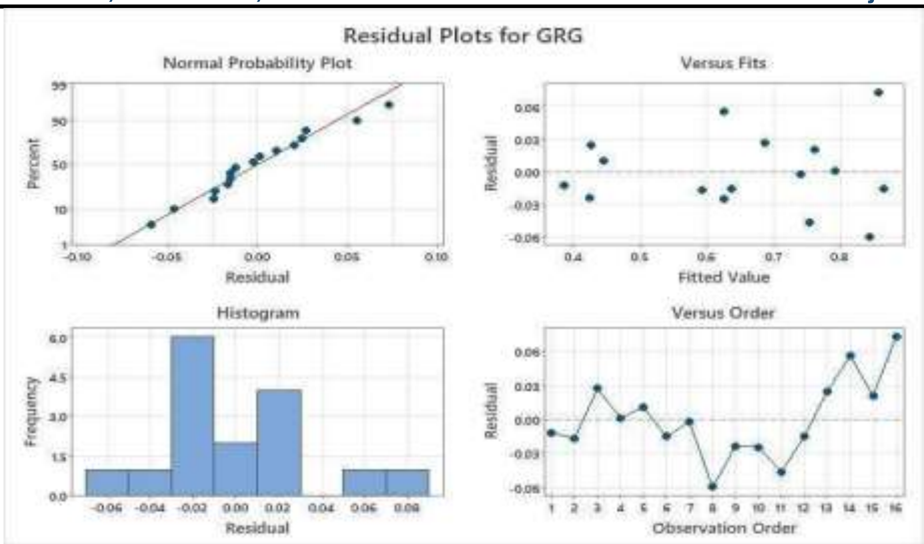

Fig: Four in one Residual Plot

Regression Equation

GRG = 0.6409-0.0266 wt%_0+0.0266 wt%_4-0.2336 load_0.4903-0.0339 load_9.8066+0.0814 load_14.7099+0.1861 load_19.6133+0.0045 speed_300+0.0125 speed_400-0.0087 speed_500-0.0084 speed_600

5. RESULTS AND DISCUSSION

5.1 Effect of reinforcement on Hardness

Incorporating cadmium and zirconia dioxide into AA5083 aluminum alloy improves its characteristics. While 4% cadmium slightly decreases hardness and increases ductility, 4% zirconia dioxide greatly enhances hardness and wear resistance. A combination of 2% cadmium and 2% zirconia dioxide achieves a well-rounded improvement in both hardness and ductility, resulting in a composite that balances strength and toughness, making it ideal for diverse engineering uses.

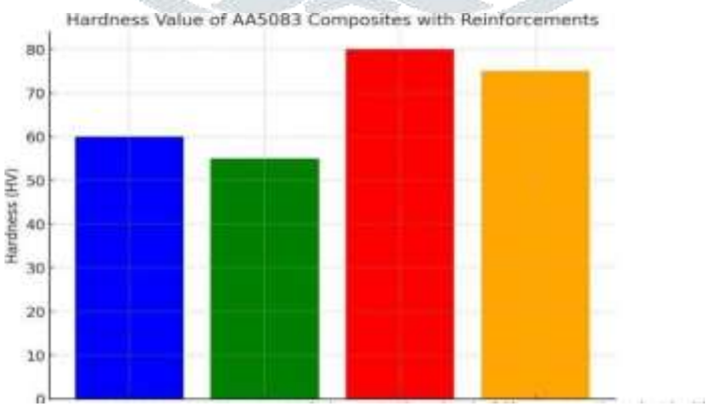

Fig: Hardness Value

5.2 Effect of Reinforcement on Wear

The addition of cadmium and zirconia dioxide to AA5083 aluminum alloy significantly affects its wear behaviour. AA5083, being softer, has a higher wear rate. Adding 2% or 4% cadmium improves lubricity, reducing friction and wear to some degree. However, due to its softness, cadmium alone does not provide significant wear resistance.

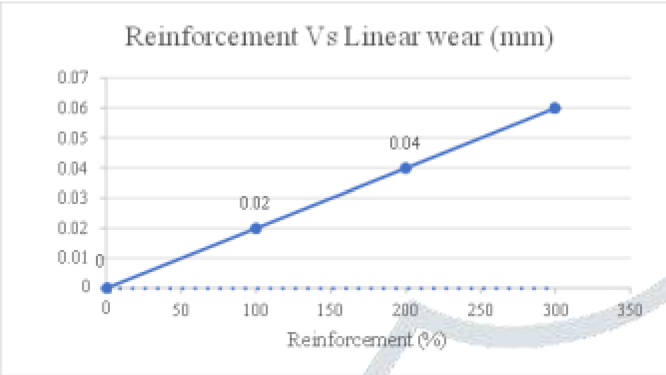

Fig: Percentage reinforcement Vs Linear wear

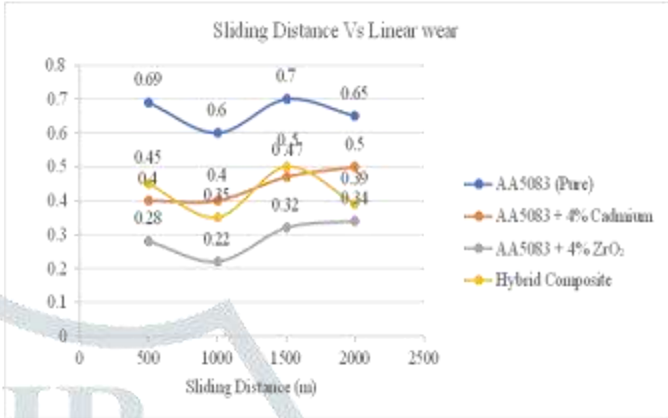

Fig: Sliding distance Vs Linear wear

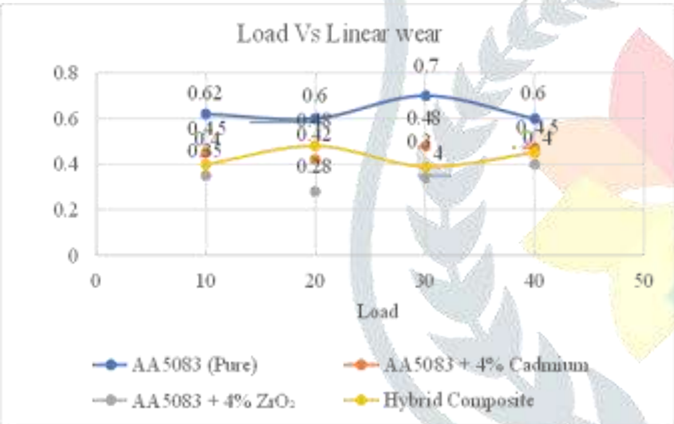

Fig: Load Vs Linear wear

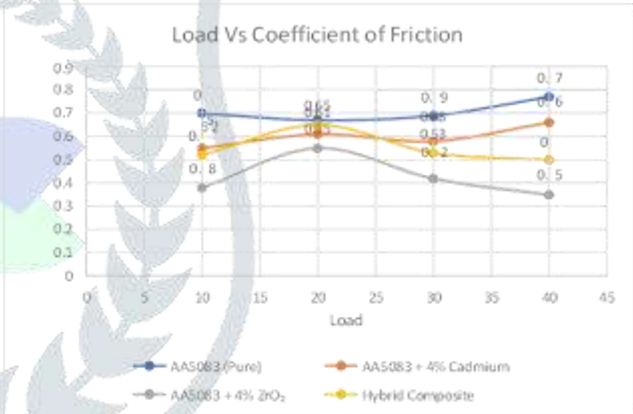

Fig: Load Vs COF

5.3 Result summary:

AA5083, as a base material, exhibits moderate mechanical characteristics with limited hardness and wear resistance. Incorporating 4% cadmium enhances ductility and toughness, but only marginally affects hardness, rendering it unsuitable for wear-resistant applications. Conversely, 4% zirconia dioxide significantly improves hardness and wear resistance, making it ideal for high-surface-strength applications. The combination of 2% cadmium and 2% zirconia dioxide provides a balanced enhancement in hardness, while preserving ductility and toughness, rendering it suitable for applications necessitating both mechanical strength and wear resistance.

6. CONCLUSION

The addition of 4% cadmium to AA5083 reduces the composite's tensile strength and hardness due to cadmium's softness. While cadmium improves ductility and reduces wear by providing a lubricating effect, it decreases the material's overall mechanical strength, making it less effective in high-load or high-stress conditions also, the addition of 4% zirconia dioxide to AA5083 enhances its hardness and tensile strength. Zirconia is a hard ceramic material that improves the composite's strength and stiffness, making it suitable for high-strength applications. The wear resistance is also greatly improved, with zirconia reducing the wear rate and friction, making the composite ideal for applications requiring high wear strength. And The addition of 2% cadmium and 2% zirconia dioxide to AA5083 enhances both strength and ductility, offering a balance ideal for applications requiring both. Zirconia improves strength, while cadmium helps maintain ductility. This combination also improves wear resistance and reduces friction, making the composite suitable for diverse tribological applications.

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