

Experimental Investigation of Wear Properties of Aluminium Hybrid Composite through Pin-On Disc Method.

G.Vairamani¹, B.Ganesh², J.Naveen³, C.Anbarasu⁴.

Assistant Professor¹, Department of Mechanical Engineering, V.S.B Engineering College, Karur,

UG Scholar² Department of Mechanical Engineering, V.S.B Engineering College, Karur,

UG Scholar³ Department of Mechanical Engineering, V.S.B Engineering College, Karur,

UG Scholar⁴ Department of Mechanical Engineering, V.S.B Engineering College, Karur,

Abstract

This research focuses on the experimental investigation of the wear behavior of Al 7075-T6 alloy reinforced with Silicon Carbide (SiC) and Zirconium Dioxide (ZrO₂) particles in an equal weight ratio of 5:5, prepared using the stir casting technique. The composite samples were processed with controlled stirring to ensure uniform dispersion of the reinforcements within the aluminum matrix. X-ray Diffraction (XRD) analysis was performed to confirm the presence and distribution of SiC and ZrO₂ in the matrix. Wear testing was conducted using a Pin-on-Disc apparatus under various loads and sliding speeds to evaluate the material's wear resistance. The results indicate a significant enhancement in wear performance compared to the unreinforced Al 7075-T6 alloy, due to the presence of hard ceramic reinforcements that effectively reduce material loss during sliding. The study concludes that incorporating SiC and ZrO₂ in a 5:5 weight ratio improves the wear characteristic of the aluminum composite, making it suitable for wear-critical applications like aerospace, aluminium casing.

Keywords: Al 7075-T6, Stir Casting, Wear Behavior, Silicon Carbide (SiC), Zirconium Dioxide (ZrO₂), Hybrid Composite, 5:5 Weight Ratio, XRD Analysis, Pin-on-Disc Test

1. Introduction

Aluminum and its alloys are extensively used in modern engineering industries due to their excellent properties such as high strength-to-weight ratio, good corrosion resistance, thermal conductivity, and ease of machining. Among various aluminum alloys, Al 7075-T6 is one of the most widely used in aerospace and structural applications because of its exceptional mechanical strength. However, despite these advantages, the wear resistance of Al 7075-T6 in high-friction and abrasive environments is relatively low, which limits its application in tribologically demanding conditions such as gears, brakes, and structural joints.

To overcome the limitations of conventional aluminum alloys, Metal Matrix Composites (MMCs) have been developed by reinforcing a metallic matrix with ceramic materials. The inclusion of hard ceramic particles significantly enhances the wear, corrosion,

and thermal resistance of the base metal. This has led to increased research interest in the fabrication and characterization of aluminum matrix composites (AMCs) reinforced with materials such as Silicon Carbide (SiC) and Zirconium Dioxide (ZrO₂).

Silicon Carbide (SiC) is a commonly used reinforcement material due to its high hardness, thermal stability, and ability to improve wear resistance. Zirconium Dioxide (ZrO₂), on the other hand, is known for its toughness, resistance to thermal shock, and ability to withstand high temperatures. When combined, these reinforcements can potentially create a

hybrid composite with superior tribological performance, offering a balanced improvement in wear behavior.

In this study, Al 7075-T6 is reinforced with SiC and ZrO₂ in an equal weight ratio of 5:5, forming a hybrid composite. The composite is fabricated using the stir casting technique, which is one of the most economical and scalable methods for producing MMCs. Stir casting involves melting the base metal, followed by the incorporation of reinforcements under continuous mechanical stirring to ensure uniform distribution. This method is widely preferred for its simplicity, low cost, and capability for large-scale production.

After fabrication, X-Ray Diffraction (XRD) analysis is employed to confirm the presence and distribution of reinforcement particles within the matrix and to analyze the phases present in the composite. XRD is an effective tool for examining crystalline structures and verifying the incorporation of reinforcement particles in the metal matrix.

To evaluate the wear behaviour, the Pin-on-Disc test is used. This test involves pressing a pin-shaped specimen against a rotating disc under controlled conditions of load and speed. It simulates actual sliding contact and provides vital data on the material's wear resistance. Parameters such as wear rate and coefficient of friction are recorded and compared with those of the unreinforced alloy to understand the effect of hybrid reinforcements.

The main aim of this investigation is to study the influence of SiC and ZrO₂ particles on the wear performance of Al 7075-T6 alloy. Through systematic testing and analysis, this research seeks to develop a composite material that exhibits improved tribological characteristics, suitable for high-performance applications in the aerospace, automotive, and defence sectors.

2. Materials and Experimental Procedure

2.1 Matrix Material

The base material used for this study was Al 7075-T6, a high-strength aluminum alloy known for its excellent mechanical properties and lightweight nature. It is widely used in the aerospace and structural industries due to its good fatigue resistance and strength-to-weight ratio. However, its wear resistance is relatively low, which necessitates the addition of reinforcements for tribological improvement.

2.2 Reinforcement Materials

To enhance the wear resistance of the aluminum alloy, two ceramic reinforcements

were used: Silicon Carbide (SiC) and Zirconium Dioxide (ZrO₂). These were selected for their excellent wear resistance, thermal stability, and mechanical compatibility with the aluminum matrix. SiC provides high hardness and thermal conductivity, while ZrO₂ offers good toughness and thermal resistance. Both reinforcements were added in equal weight ratios—5 wt% SiC and 5 wt% ZrO₂, making a total of 10 wt% reinforcement.

Fig 2.1: ZrO₂, SiC, Al 7075-T6 Table 1: Reinforcement properties of composites

Property	Silicon Carbide (SiC)	Zirconium Dioxide (ZrO ₂)
Chemical Formula	SiC	ZrO ₂
Density (g/cm ³)	3.1	5.68
Hardness (Mohs scale)	9.2	7.5–8.0
Melting Point (°C)	~2,730	~2,715
Elastic Modulus (GPa)	410	200–210

Thermal Conductivity (W/m·K)	120–270	2–3
Coefficient of Friction	~0.2 (varies with conditions)	~0.4 (depends on surface finish)
Thermal Expansion ($\mu\text{m}/\text{m}\cdot\text{K}$)	4.0	10.3
Toughness	Moderate	High (especially in Yttria-stabilized ZrO ₂)
Chemical Stability	Excellent (resistant to oxidation)	Excellent (especially in high-temp environments)

2.3 Stir Casting Process

The fabrication of the composite was carried out using the stir casting technique, which is one of the most economical and effective methods for producing metal matrix composites with a fairly uniform distribution of reinforcements. First, Al7075-T6 ingots were melted in a

graphite crucible using an electric resistance furnace, and the melt temperature was maintained at approximately 750°C. Simultaneously, the SiC and ZrO₂ powders were preheated to 600°C for about one hour to remove any moisture and to improve wettability with the molten aluminum.



Fig 2.2 stir casting machine

Once the matrix was fully molten, the ceramic particles were slowly added to the vortex created by a mechanical stirrer operating at 500–600 rpm for around 10 minutes.



Fig 2.2 Casting image

This ensured homogeneous dispersion of the reinforcements within the molten aluminum. The slurry was then poured into preheated metal molds and left to solidify at room temperature. The solidified castings were removed and machined into standard test specimens for wear testing and XRD analysis.

Table 2 String parameters:

Parameter	Details
Reinforcement percentage	Silicon Carbide (SiC) – 5% Zirconium Oxide (ZrO ₂) – 5%

Total Composite Weight	2kg
Reinforcement Weight	SiC = 100 g ZrO ₂ = 100g
Matrix Weight	1.8kg (Aluminium 7075-T6)
Melting Temperature	750°C – 800°C
Preheating Temperature of Reinforcements	600°C
Stirring Speed	500rpm – 600 rpm
Stirring Duration	5 – 10 minutes
Stirring Type	Mechanical Stirring
Mold Preheat Temperature	300°C – 350°C
Casting Temperature	720°C – 740°C

2.4 X-Ray Diffraction (XRD) Analysis

To confirm the successful incorporation of the ceramic reinforcements and to analyze the phases present in the composite, X-Ray Diffraction (XRD) analysis was performed. The XRD scan was conducted using a powder diffractometer over a 2θ range of 20° to 80° , with a scanning rate of 2° per minute. The resulting diffraction patterns were used to identify the various phases present and to verify the presence of SiC and ZrO_2 in the aluminum matrix.



Fig 2.3 X-Ray Diffraction.

2.5 Wear Test Using Pin-on-Disc Method

The wear behavior of the developed hybrid composite was studied using a Pin-on-Disc apparatus, which simulates dry sliding conditions. Composite specimens were machined into cylindrical pins of 10 mm diameter and 30 mm length. The pins were polished to

ensure a uniform and smooth contact surface. The wear tests were carried out under different normal loads of 10 N, 20 N, and 30 N at a constant sliding speed of 1 m/s and a total sliding distance of 1000 meters. A hardened EN32 steel disc served as the counterface. The wear loss was measured by weighing the pins before and after the test using a high-precision electronic balance with an accuracy of 0.1 mg. The wear rate was calculated based on the mass loss per unit sliding distance, and the coefficient of friction was recorded continuously throughout the test using the integrated software of the apparatus.

Fig 2.4 Pin-on Disk

This procedure ensured accurate evaluation of the tribological performance of the composite and enabled a comparative analysis with the base alloy to determine the effect of hybrid ceramic reinforcement on wear resistance.

3. Results and Discussion

3.1 Experimental Results

The wear behavior of the Al7075-T6 hybrid composite reinforced with 5 wt% SiC and 5 wt% ZrO_2 was evaluated using a Pin-on-Disc apparatus under varying loads of 10 N, 20 N, and 30 N. The experimental results indicated a significant improvement in wear resistance compared to the unreinforced Al 7075-T6 alloy. It was observed that the addition of ceramic particles led to a reduction in material loss during sliding, primarily due to the high hardness and thermal stability of SiC and the toughness of ZrO_2 . The wear rate decreased notably at lower loads, and even at higher loads, the reinforced composite demonstrated better wear resistance than the base alloy.

Under a load of 10 N, the wear rate was minimal, suggesting effective load-bearing and friction-reducing capabilities of the composite surface. As the applied load increased to 20 N and 30 N, a gradual increase in wear rate was noted, which is expected due to higher contact stress and heat generation. However, the rate of increase in wear was lower for the composite than typically seen in unreinforced alloys.

Table3:Result valuesofthepin ondisc apparatus

S.NO		Load (Kg)	Speed (rpm)	Time(sec)	Frictional Force(N)	Wear (μ)
1	A	10	200	200	0.6	14
	B	20	200	200	1.3	30
	C	30	200	200	1.9	45
2	A	10	400	200	1.5	30
	B	20	400	200	2.8	62
	C	30	400	200	3.9	79
3	A	10	600	200	2.5	47
	B	20	600	200	3.4	64
	C	30	600	200	4.6	86
4	A	10	200	400	1.2	23
	B	20	200	400	2.7	52
	C	30	200	400	4.9	81
5	A	10	400	400	1.7	35
	B	20	400	400	3.5	65
	C	30	400	400	5.6	108
6	A	10	600	400	3.9	52
	B	20	600	400	5.2	89
	C	30	600	400	8.5	120
7	A	10	200	600	2.8	65
	B	20	200	600	4.5	105
	C	30	200	600	7.8	132

8	A	10	400	600	3.6	58
	B	20	400	600	5.8	92
	C	30	400	600	9.2	128
9	A	10	600	600	4.4	72
	B	20	600	600	7.2	109
	C	30	600	600	10.3	145

Resulted values graph:

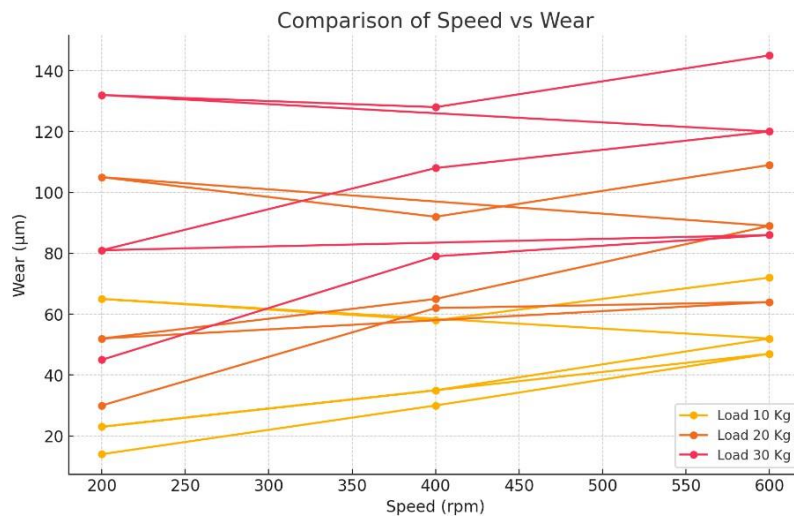


Fig3.1 graph for wear vs speed

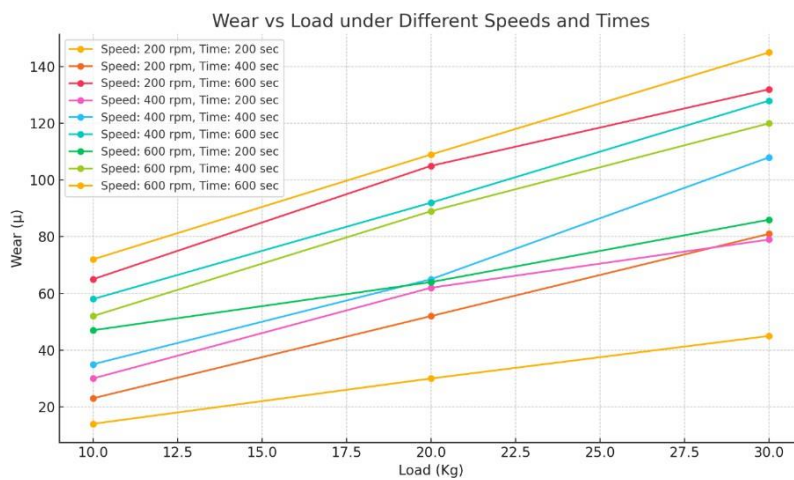


Fig3.2 Wear vs Load Under different speed and load graph

It is clear that as both load and speed increase, the composite material experiences higher wear rates. This behavior can be attributed to the rise in frictional forces and temperature

at the interface during the test, leading to faster material removal. The presence of SiC and

ZrO₂ reinforcement helps improve the wear resistance compared to unreinforced Al7075-T6, but under high load and speed conditions, wear still becomes significant.

Thus, the optimal wear performance is achieved at lower speeds and lower loads, while at higher speeds and loads, the material degradation is more severe.

Resulted graph for XRD analysis

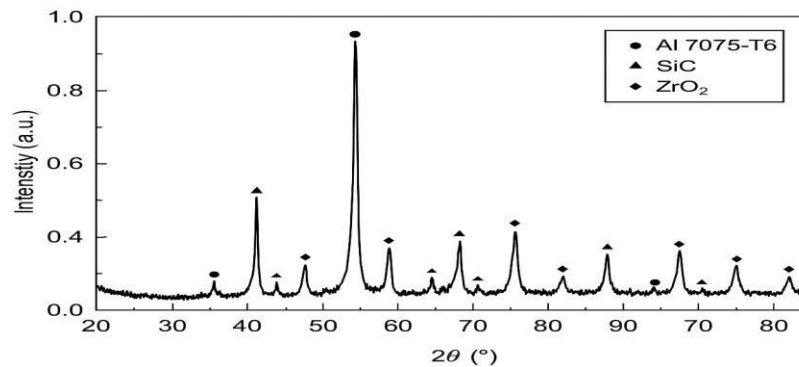


Fig3.3 Graph for XRD analysis

The XRD analysis confirms the presence of Al7075-T6, SiC, and ZrO₂ phases in the composite. Strong peaks at around 50° indicate the dominance of the aluminum matrix. Distinct peaks of SiC and ZrO₂ confirm their successful reinforcement.

The sharp, clear peaks suggest good crystallinity and stable composite formation. No unwanted phases were detected, indicating a successful stir casting process.

4. Conclusions

This project focused on the development and evaluation of Al 7075-T6 matrix composites reinforced with 5wt% Silicon Carbide (SiC) and 5wt% Zirconium Dioxide (ZrO₂), synthesized using the stir casting technique. The wear behavior was analyzed through pin-on-disc testing under various loads, speeds, and durations. X-ray diffraction (XRD) analysis confirmed the successful incorporation and distribution of SiC and ZrO₂ particles within the aluminum matrix.

The experimental findings revealed that the hybrid reinforcement significantly improved the wear resistance of the Al 7075-T6 alloy. The composite showed a reduced wear rate and more consistent frictional performance, especially under increased loads and prolonged testing times. The SiC particles contributed to enhanced resistance to abrasion, while the ZrO₂ particles improved the composite's toughness and thermal durability.

Wear rate increased with higher loads and longer durations; however, the hybrid composite consistently outperformed the unreinforced alloy in resisting material loss. This demonstrates the effectiveness of the selected reinforcement combination in enhancing the tribological performance of the base alloy.

In conclusion, this project proves that the Al 7075-T6 hybrid composite with 5% SiC and 5% ZrO₂ is a highly promising material for engineering applications requiring superior wear resistance and mechanical stability, particularly in automotive, aerospace, and structural industries.

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