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Tribological Behaviuor On Aluminium –Nano Metal Matrix Compositre with Addition of Titanium Di Oxide and Solid Lubricant (Powder Metalurgy Process)

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ABSTRACT

Aluminium metal matrix composite with improved mechanical and physical properties are emerging as an essential part of the aerospace and automobile applications. The aluminium metal matrix composite reinforced with nano titanium di oxide with added graphite as solid lubricant has better tribological properties. This study is made with an attempt to trace the preparation and wear properties of the composite. Here the aluminium matrix with 7% titanium dioxide and graphite with equal percentage in nano size. The wear test conducted in pin on disc apparatus with loads 5N, 7N, 10N, at the velocities of 1.5m/s, 2m/s, 2.5m/s. The optimal condition attaining the minimum specific wear rate is at the sliding velocity of 1.5 m/s and load of 5 N with the 5 gram sample.

Keywords : Aluminium nano MMC, solid lubricant, tribology, powder metallurgy

I. INTRODUCTION

The composite material has emerged as an important class of materials for structural, thermal, wear, transportation and electrical applications. In modern engineering the materials that are stronger, lighter, wear resistant, and less expensive are of great demand [1][2]. This paper is concentrated on the special metal matrix composite composed of aluminium, titanium di-oxide in nano scale and graphite which posses high strength to weight ratio and strength to cost ratio. The current trends, aluminium metal matrix composites are fast in replacing conventional metallic alloys in wide range of applications as their use have been emerging aerospace, manufacturing and automobile to defense, marine, sports and machine tool industries [3]. These MMC‘s are materials in which one constituent is necessarily a metal and other constituent embedded metal matrix usually reinforcement. The selection of the reinforcement is primarily based on the size, shape, composition and mainly on mechanical, physical and chemical properties of the reinforcement [4].

Tribology is the science and study of interacting surfaces in relative motion, particularly focusing on the principles of friction, wear, and lubrication. The term "tribological behavior" refers to how materials behave under these conditions.

In the context of your question, you are specifically referring to the tribological behavior of an aluminum-nano metal matrix composite (Al-NMMC) with the addition of titanium dioxide (TiO_2) and a solid lubricant. This composite is manufactured using the powder metallurgy process [5].

Here's an overview of the components involved and their role in enhancing the tribological behavior of the composite:

Aluminum (Al): Aluminum is the base metal in the composite. It is known for its lightweight and good mechanical properties, making it an attractive choice for many engineering applications.

Nano Metal Matrix: The addition of nano-sized metal particles, such as nanoparticles of other metals or metal oxides, can improve the mechanical properties of the composite, including hardness, strength, and wear resistance.

Titanium Dioxide (TiO_2): TiO_2 is a ceramic material that is often used as a reinforcement in composites. It can enhance the hardness and wear resistance of the composite due to its high melting point and hardness.

Solid Lubricant: The inclusion of a solid lubricant in the composite is intended to reduce friction and wear between the sliding surfaces. Solid lubricants act as boundary lubricants and form a protective layer on the contacting surfaces, reducing direct metal-to-metal contact.

Powder Metallurgy Process: Powder metallurgy is a manufacturing process where metal powders are mixed, compacted under pressure into a desired shape, and then sintered at high temperatures to fuse the particles together. This process allows for precise control over the composition and microstructure of the composite.

The addition of TiO_2 and solid lubricant in the Al-NMMC through powder metallurgy is expected to improve the tribological behavior of the material, making it more resistant to wear and reducing friction in sliding or rotating applications [6]. The specific performance of the composite will depend on the type and concentration of the added particles, the sintering process parameters, and the application conditions.

Tribology, the science of interacting surfaces in relative motion, plays a pivotal role in enhancing the performance and longevity of engineering components subjected to friction and wear. In this context, the study of novel materials and their tribological behavior becomes crucial to meet the ever-increasing demands of modern industrial applications. The present study delves into the tribological behavior of an innovative composite material, specifically an Aluminum-Nano Metal Matrix Composite (Al-NMMC), engineered with the incorporation of Titanium Dioxide (TiO_2) nanoparticles and a solid lubricant [7].

Aluminum, renowned for its lightweight and favorable mechanical properties, serves as the base metal in this composite. To further augment its mechanical attributes and tribological performance, nano-sized metal particles are introduced, forming the Nano Metal Matrix [8]. Additionally, Titanium Dioxide, a ceramic material, is strategically integrated into the matrix to enhance hardness and wear resistance. Moreover, the inclusion of a solid lubricant is aimed at mitigating friction and wear during sliding or rotating interactions, offering potential benefits of reduced direct metal-to-metal contact. The fabrication process of the Al-NMMC, utilizing the Powder Metallurgy technique, ensures precise control over composition and microstructure [9]. This enables tailoring the material's characteristics to suit specific application requirements, ultimately improving its tribological response [10].

In the subsequent sections of this study, we will delve into the experimental methodologies employed to characterize the tribological properties of the Al-NMMC composite. Various parameters, such as load, sliding speed, and environmental conditions, will be systematically investigated to evaluate the effects on friction, wear, and lubrication behavior. The findings will shed light on the composite's suitability for diverse engineering applications, including those involving high wear and frictional stresses. Through a comprehensive understanding of the tribological behavior of the Al-NMMC composite with the incorporation of Titanium Dioxide and a solid lubricant, this research aims to contribute valuable insights into the design and development of advanced materials, leading to enhanced performance and extended service life for critical engineering components in diverse industrial sectors.

In this study the aluminium metal matrix composite added with nano titanium di oxide and nano graphite particle as solid lubricant is fabricated and the experimental tests were made. This reinforcement was selected based on the previous research works [11]. Due to the addition of the reinforcement in the nano scale this composite is called as the aluminium nano metal matrix composite. Further experimentation was made on the fabricated composite to test the wear and hardness properties of the material.

II. MATERIALS

Aluminium

Aluminium is one among the most cheapest and abundant material which is more weak as an individual. Its alloys are mostly used in the automobile and aerospace industry. Here we use aluminum of 50μm sized powder with 99% purity, with the following properties.

TABLE I. Experimental properties of Aluminium

Properties	Value
Density (g/cm3)	2.69
Boiling point (˚C)	2480
Melting Point (˚C)	660.2
Modulus of Elasticity (GPa)	68.3
Poisson’s Ratio	0.34
Purity (%)	99

Titanium Di Oxide

Titanium is one of the hardest and wear resistant materials available in the natural oxide form as titanium di oxide (TiO_2). Here TiO_2 nano powder material used consists of the following properties.

TABLE II. Experimental properties of Titanium di oxide

Properties	Value
Density (g/cm³)	3.78
Boiling point (˚C)	2972
Melting Point (˚C)	1843
Modulus of Elasticity (GPa)	230
Compressive strength (MPa)	680
Micro Hardness(HV0.5)	880
Purity (%)	99.99

Graphite

Graphite is a crystalline allotrope of carbon, a semimetal, a native element mineral, and a form of coal. The individual layers are called graphene. The graphite with the following properties is employed in the experiment.

TABLE III. Experimental properties of graphite

Properties	Value
Density (g/cm^3)	2.66
Hardness (MPa)	326
Melting Point (˚C)	3800
Modulus of Elasticity (GPa)	27.6

III.EXPERIMENTATION PROCEDURE

In this work, the material is developed in two stages

A. Material composition selection
B. Specimen preparation

Material composition selection

Selecting the appropriate material composition for a specific application is a critical step in engineering and design. The choice of materials directly affects the performance, durability, cost, and safety of the final product. Clearly define the functional requirements and specifications of the product or component. Consider factors such as mechanical properties, thermal properties, corrosion resistance, weight, cost, manufacturability, and environmental impact. Utilize material databases, engineering literature, and expert advice to identify materials that match the desired properties and requirements.

Aluminium, titanium di oxide and graphite in the preferred size are taken. The size consideration is based on the previous experimentation and survey. The materials are tested for the confirmation of the properties. The composition of the specimen is tabulated below.

TABLE IV. Composition of various samples

Specimen	Sample weight In grams	Composition by weight in percentage		
		Aluminium	Titanium di-oxide	Graphite
A1	5	86	7	7
A2	6	86	7	7

Specimen preperation

Specimen preparation is a crucial step in material testing and characterization. It involves the creation of representative samples or specimens from the chosen materials for subsequent analysis and evaluation. Choose the appropriate material or material composition based on the requirements of the testing or analysis. etermine the size, shape, and geometry of the specimens to ensure they represent the actual application and enable accurate testing.

The cylinder pin specimen was prepared to undergo a tribological test on pin on disc tribometer. The preparation of pin was done by using a die set. The diameter of the in is 10mm and the minimum height was 25mm.powder metallurgical technique was adopted in fabricating specimens. Various steps involved in specimen preparation are as follows:

a. Blending of powders
b. Compaction
c. Sintering

The blending process is done by the ball milling method. A ball mill is a type of cylindrical grinder used to grind and blend materials. The ball sized ranged from 10mmball milling was done for 1 hour at a speed of 300 r.p.m.

The principal goal of the compaction is to apply pressurize and bond the particle to form cohesion among the powder particle termed as green strength. The compaction was done in a Universal Testing Machine with a pressure of 8.5 MPa (85bar).

Sintering involves raising the temperature of the green compact, to certain level and keeping it at that temperature for certain amount of time. Temperature is usually between 70% and 90% of the melting point of the powder metal. Sintering is carried at a temperature of 540˚C for a time of 90 minutes.

IV.EXPERIMENTAL TESTING

The following experimental testing were made on the prepared specimen,

A. Hardness testing

B. Tribological wear testing

Hardness testing

The hardness was tested using micro hardness tester in the vicker's scale with the load of 0.3 kg. It was absorbed that the hardness was increasing in weight percentage of nano TiO_2 and Graphite.

TABLE V. Vicker's hardness testing

Sample	Average Density (Kg/m³)	Test 1 (VH)	Test 2 (VH)	Test 3 (VH)
A1	2045.98	95.9	90.0	91.1
A2	2495.35	73.5	70.1	72.2

Tribological wear testing

Tribology is the study of science that deals with the study of friction, lubrication and wear of the interactive surfaces that are in the relative motion.. The pin on disk apparatus is used to measure the wear rate of the sample pin provided with the flat tip. The testing parameters are stated below.

TABLE VI. Testing parameters

Parameter	A1	A2
Normal Load (N)	7	10
Sliding distance (m)	1000	1000
Sliding velocity (m/s)	2	2.5

The wear test is conducted based on the above parameters and the results of the test is calculated and stated below.

V. RESULTS

TABLE VII. Specific wear rate calculation of the specimen

Sample	Sliding distance (m)	Load (N)	Sliding velocity (m/s)	Specific wear rate (mm³/Nm) In terms of 10^{-5}	
				A1	A2
1	1000	5	1.5	1.14	2.03
2	1000	5	2	1.29	2.2
3	1000	5	2.5	1.58	2.19
4	1000	7	1.5	1.24	1.95
5	1000	7	2	1.3	2.41
6	1000	7	2.5	1.94	3.11
7	1000	10	1.5	1.35	2.59
8	1000	10	2	2.1	3.01
9	1000	10	2.5	2.95	5.62

The results of the test taken are presented in graphical representation

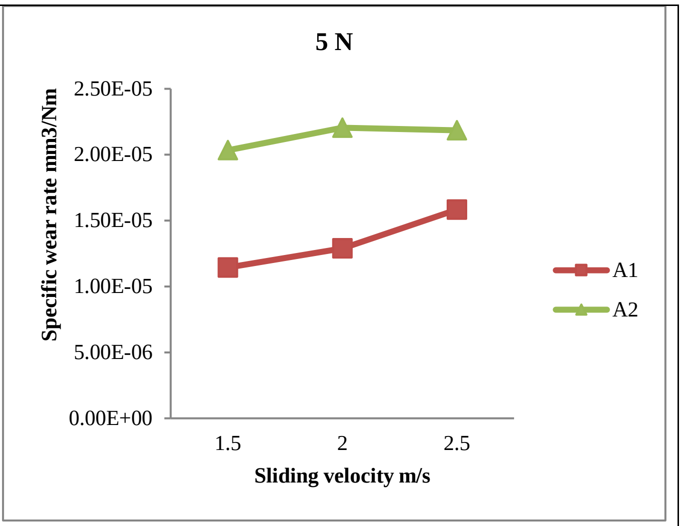

Fig. 1. Specific wear rate versus sliding velocity at 5N load

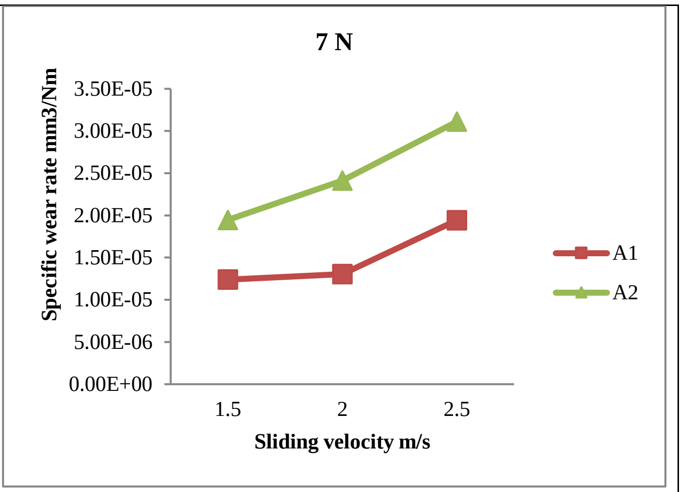

Fig. 2. Specific wear rate versus sliding velocity at 7N load

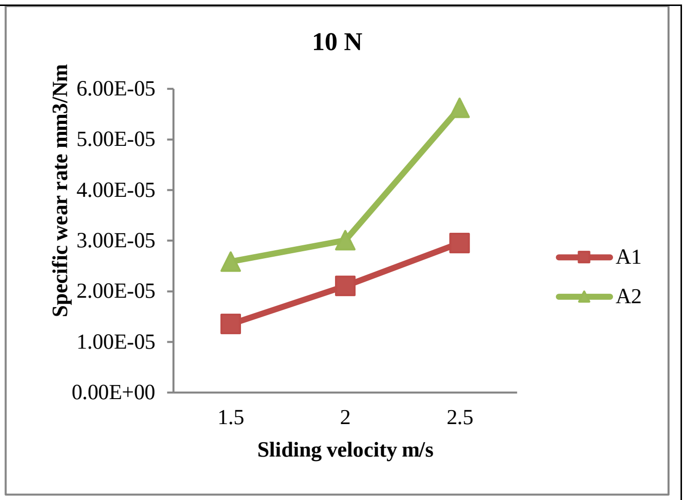

Fig. 3. Specific wear rate versus sliding velocity at 10N load

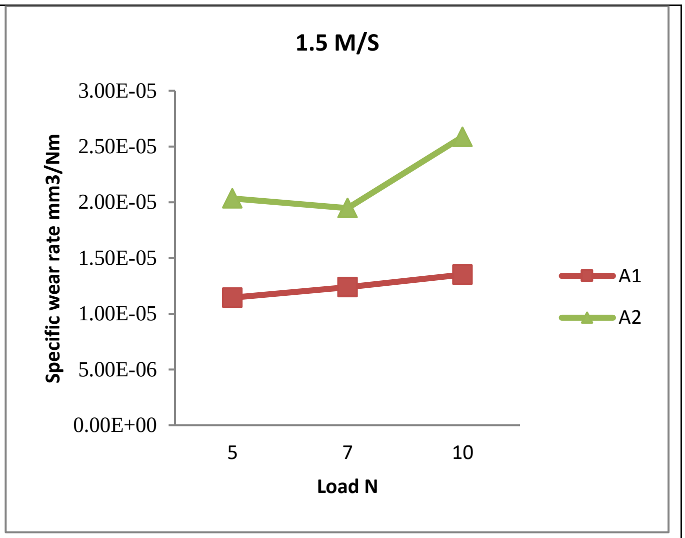

Fig. 4. Specific wear rate versus Normal load at 1.5m/s sliding velocity

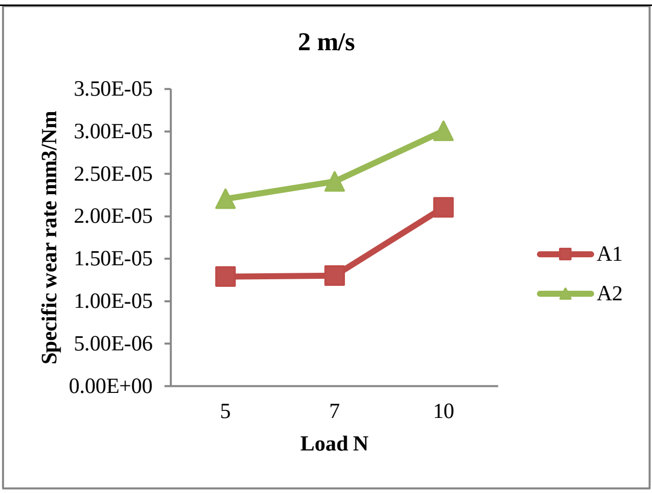

Fig. 5. Specific wear rate versus Normal load at 2m/s sliding velocity

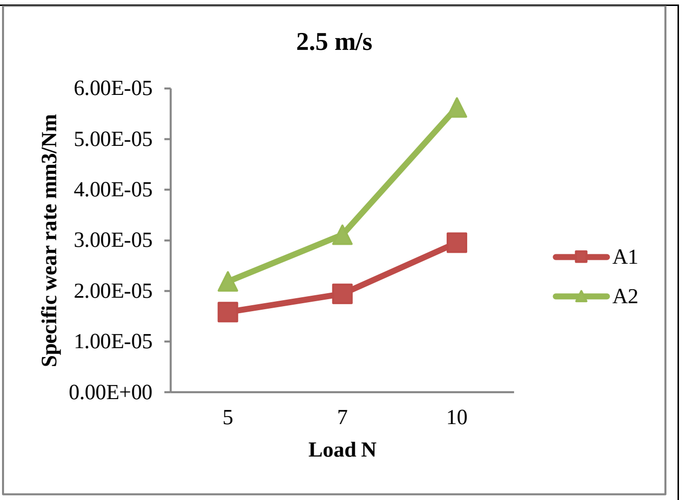

Fig. 6. Specific wear rate versus Normal load at 2.5m/s sliding velocity

The analysis of test results from the graphical data state that the sample A1 is with the minimum wear rate considered among all the samples.

TABLE VIII. Result analysis

Parameter	**Sample**	**Load N**	**Sliding velocity m/s**	**Specific wear rate mm^3/N m**
Maximum specific wear rate	A2	10	2.5	6.94×10^{-5}
Minimum specific wear rate	A1	5	1.5	1.14×10^{-5}

VI.CONCLUSION

The Al-TiO_2-Gr hybrid composites were successfully fabricated using the powder metallurgy route and the tribological wear properties are investigated. The hardness and density of the hybrid composites decreased with an increase in graphite content more than 5%. The composites sample with 5 wt% graphite exhibited both excellent wear resistances at the 5 gram specimen. The optimal condition for attaining the minimum specific wear rate of 1.14 mm3/Nm is at the sliding velocity of 1.5m/s and load of 5 N.

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