Influence of 10 wt% Sic Reinforcement on The Sliding Wear Behaviour of The Zinc-Aluminum Based Alloy And Its Comparison With Conventional Cast Iron

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Abstract- *The present investigation aims to assess the influence of TiC reinforcement on the sliding wear behavior of a zinc-aluminum (ZA) based alloy and its composites, comparing the results with those obtained from cast iron. Sliding wear tests were performed using a pin-on-disc machine under dry and partially lubricated conditions. The pin specimen was evaluated against a rotating disc, and properties such as friction coefficient and frictional heating were examined. Comparing the materials, cast iron exhibited higher density and hardness compared to the ZA-based alloy and composites. Under dry sliding conditions and with only oil lubrication at sliding speeds of 2.1 m/s and 4.2 m/s, cast iron outperformed the alloy and composite in terms of wear rate up to a critical applied load and/or sliding speed. These findings provide valuable insights into the sliding wear performance of the ZA-based alloy and composites with TiC reinforcement under various sliding conditions and loads. Interestingly, the wear behavior of the ZA alloy was observed to be higher beyond 4.2 m/s. However, when graphite was introduced to the oil, the ZA alloy outperformed both the composites and cast iron. The friction coefficient showed its highest values for all test materials at 8.4 m/sec in an oil + 5 wt% graphite (100 µm) and oil + 5 wt% graphite (100 µm) lubricated environments, respectively, at an applied load of 1 kg. At a sliding speed of 2.1 m/sec in an oil-lubricated environment, the friction coefficient demonstrated a different pattern. At higher loads (20 kg), there was a reversal of the tendency in the friction coefficient between Grey Cast Iron and ZA-Alloy, while the composite showed a mixed behavior. It is noteworthy that a specific set of test parameters, such as load and speed, can lead to the best wear performance, with the advantageous effects of the load-bearing capacity of different phases playing a significant role, regardless of the material composition and microstructure. These findings contribute to a better understanding of the sliding wear behavior of the studied materials.*

Keywords- wear performance, friction coefficient, sliding speed etc.

I. INTRODUCTION

1.1 Wear

Wear is a multifaceted phenomenon. Friction can arise when surfaces slide against each other, even when a lubricant is present. According to the American Society for Testing and Materials (ASTM), wear is the process of material loss on a solid surface caused by the relative motion between that surface and a contacting substance or substances. The ASTM definition of substance encompasses various sources of wear, including solid surfaces, particles, liquids, electric arcs, and gas streams. Wear can be defined as the amount of volume lost per unit distance slid. Machine part wear refers to the deterioration of components, leading to decreased precision, reduced efficiency, and increased replacement costs. The wear rate, denoted as ‘Wr’, is influenced by factors such as bearing pressure (W/A), sliding speed (S), and the material properties and surface geometry [1].

1.2 Grey Cast Iron

Grey cast iron is widely used in engineering due to its broad range of applications. One primary advantage of grey cast iron is its ability to be easily cast into intricate shapes. The material can be readily shaped and machined due to its composition, which includes free graphite. This is especially true when the phosphorus content is minimal [2]. The commonly utilized grey cast iron typically consists of carbon ranging from 2.4 to 3.8% silicon ranging from 1.2 to 3.5%, and trace amounts of other elements [3]. Grey cast iron is commonly employed in the manufacturing of brakes and clutches.

1.3 Zinc Based Alloy

Zinc-based alloys are being considered as a possible replacement for cast irons and non- ferrous alloys in applications that require sliding wear resistance, due to their cost- effectiveness [10-12]. Zinc-based alloys possess desirable characteristics such as low weight, high strength, ductility, hardness, fatigue strength, and excellent tribological properties, including seizure resistance, friction coefficient, and resistance to frictional heating. These properties are particularly advantageous in situations where lubrication is delayed, limited, or absent. Zinc-based alloys have been found to have limitations, such as inferior elevated temperature properties, due to their low melting characteristics [11,12]. The addition of high melting elements and second phase dispersoid particles has been found to enhance the mechanical and tribological properties of zinc-based alloys at elevated temperatures [13-17].

1.4 Objectives of the Present Investigation

1. This study examines the impact of incorporating TiC reinforcement on the sliding wear behaviour of a Zinc-Aluminum based alloy. The wear behaviour of this alloy is then compared to that of conventional cast iron.
2. The impact of the test environment on the experiment includes:
   i. The effects of load and sliding speed.
   ii. The impact of oil lubrication.
   iii. The impact of graphite addition and its particle size on oil lubrication.

II. LITERATURE SURVEY

2.1 Introduction

Tribology, originating from the Greek term "tribos" meaning rubbing, refers to the scientific and technological study of surfaces that interact while in motion, along with related subjects and practices. The concept of tribology, which encompasses physics, chemistry, metallurgy, and engineering, has been widely neglected or overlooked due to its interdisciplinary nature. The neglect of mechanical engineering design has resulted in its hindered development and significant financial losses due to avoidable issues such as wear, friction, breakdowns, and wasted energy.

2.2 Background history

Metal wear has been a longstanding concern for metal users throughout history. The historical pursuit of more wear-resistant metals can be understood by recognizing the significance of properly maintaining hunting knives, axes, and swords. While the majority of scientific studies on wear have been conducted in the latter half of the 20th century, an interesting investigation was published 182 years ago. During the reign of King George III (1760-1820), there was significant concern regarding the coins in the United Kingdom. This incident was not the final instance in which the currency of the United Kingdom faced concerns. However, the issue was specifically related to tribology [41].

The king formed a committee of Privy Council and appointed two Fellows of the Royal Society, Mr. Henry Cavendish and Mr. Charles Hatchett, to investigate the issue. The publication of this information occurred in 1803 in the Philosophical Transactions [42]. Hatchett identified two primary aspects of the issue of coinage diminution or wear and developed three pieces of equipment for their examination. The wear testing machine developed by Mr. Hatchett was a manually operated reciprocation machine that could test up to 28 specimens at once. To fully comprehend the trajectory of research in the field of wear over the past few decades, it is imperative to grasp the underlying motivations that drive such investigations. Wear studies are typically conducted for various reasons, including: [43]

1. To comprehend the wear characteristics of a specific group of materials.
2. To optimize or select materials for a specific application, such as simulation and screening.
3. To investigate the impact of specific variables on a specific type of wear or process.
4. To facilitate the creation of predictive or descriptive models for wear in particular tribo- systems.

2.3 Wear research development

Peterson conducted a comprehensive examination of the progression and utilization of tribo-materials [44]. The study determined that metals and their alloys are the prevailing engineering materials employed in wear-related scenarios. Grey cast iron, such as that used in 1388, has a long history of utilization. A significant portion of wear research conducted in the last five decades has focused on ceramics, polymers, composite materials, and coatings [43].

2.4 Types of wear

Burnwell and Strang [51] initially proposed a fundamental classification scheme for wear. Burnwell [52] later expanded the classification to encompass five distinct types of wear: adhesive or galling, abrasive or cutting, corrosive, surface fatigue, and erosive.The term "wear mechanism" refers to the various micro events that contribute to the process of wear. Fracture is the primary mechanism for material removal from a dry surface. There are two main types of fractures based on the dominant force components: shear fractures and normal fractures. In practical applications, it is common for two or more tribo-fracture modes to occur simultaneously.

III. OBJECTIVE OF RESEARCH WORK

1. Previous investigations suggest that, Cast iron is commonly utilized in various tribological applications that involve sliding wear conditions. Zinc-based alloys

have the potential to replace cast iron in engineering applications. The addition of TiC particles to zinc-based alloys enhances their performance.

2. Most tribological applications primarily utilize liquid lubricants, often in combination with solid lubricants. Delayed lubrication may result in conditions that are similar to a lack of lubrication. The optimal wear performance of a solid lubricant mixed with a liquid lubricant may depend on the quantity used, which can vary depending on the combination of sliding materials and experimental conditions.
3. The application potential of cast irons and zinc-based alloys has been demonstrated through the use of engineering components. However, there has been limited focus on understanding the various phenomena related to wear operations in these materials.
4. The phenomenon of wear on surfaces is inherently complex. The wear performance of a material is influenced by several material and operational parameters.
5. The wear behaviour is influenced by the applied load and the environment. Material- related aspects encompass the chemical composition as well as the nature and characteristics of different phases. The effects of factors on material wear response are diverse and intricate due to the existing synergism.

This study aims to analyze the sliding wear behaviour of a zinc-based alloy and its composite, which is reinforced with 10 wt% TiC particles. The analysis considers the effects of different applied loads and speeds under dry and partially lubricated conditions. The lubrication conditions include oil, oil with 5 wt% graphite particles (10µm), and oil with 5 wt% graphite particles (100µm). This study investigates the impact of varying graphite particle size in oil lubricants on the control of wear behaviour in samples. The Grey Cast Iron has been tested under identical conditions to assess the impact of different parameters.

IV. EXPERIMENTAL WORK

This chapter describes the techniques used for synthesizing test materials, analyzing their microstructure, measuring their hardness and density, and characterizing their wear properties.

4.1. Processing of Test Materials

The grey cast iron, zinc-based alloys, and composites were synthesized using a melting and casting technique. Melting was conducted by employing graphite crucibles within an oil-fired furnace. The cast iron was solidified in sand moulds in the form of cylindrical castings with a diameter of 10 mm and a length of 150 mm. The zinc-based alloy and composite melts were solidified in cast iron moulds as cylindrical castings with a diameter of 20 mm and a length of 150 mm. A mechanical stirrer was used to disperse 10% TiC particles (size: 63-100 µm) into a zinc-based alloy melt using the vortex technique. Fig. 4.1 depicts a schematic representation of the melting facility. Table 4.1 displays the chemical compositions of materials utilized in wear studies.

Fig. 4.1 Schematic representation of the Furnace used for Casting

Table 4.1 Elemental Composition of the Test Material

Material	ElementalComposition(inwt,%)									
	Zn	Al	Cu	Mg	TiC	C	Mn	P	S	Fe
Zinc-based alloy	Balance	37.5	2.5	0.2	-	-	-	-	-	-
Composite	Balance	37.5	2.5	0.2	10	-	-	-	-	-
CastIron	-	-	-	-	2.32	3.35	0.56	0.08	0.08	Balance

4.2 **Microstructure Observation**:

Specimens measuring 15 mm in diameter and 25 mm in length were prepared for microstructural analysis through cutting and machining techniques. The samples underwent metallographic polishing using standard techniques. The process involved several steps, including polishing the specimen with various grades of emery papers and, ultimately, with fine alumina paste using a polishing cloth. The cast iron was polished and then etched with a 0.5% Nital solution. The (zinc-based) matrix alloy and composite were etched using diluted aqua regia. Microstructural analysis was conducted using an optical microscope.

4.3 Density Measurement

$$\text{Density} = \frac{\text{Weightinair}}{\text{Weightinair} - \text{Weightinwater}}$$

4.4 **Hardness Measurement**

Using a Vickers hardness tester, the test materials' hardness was determined. The samples underwent metallographic polishing and thorough cleaning prior to hardness testing. For all of the samples, a 30 kg force was applied while assessing hardness. Ten readings were averaged.

4.4.1 **Partially lubricated sliding wear tests**

Sliding wear tests were conducted using three lubricants viz, oil, oil with 5% graphite particles (size 10 µm), and oil with 5% graphite particles (size 100 µm). The procedures used in these tests were identical to those used in dry conditions, with the exception of the inclusion of oil. The wear testing procedure consisted of inserting the disc into a lubricant or lubricant mixture and allowing it to rotate at a speed of 3.35 m/s for a duration of 5 seconds. The lubricated disc was rotated to achieve a consistent and minimal thickness by removing the surplus lubricant through spinning. Thus, it is important to maintain conditions that resemble mixed lubrication, which is commonly observed in situations involving limited lubrication and during the initiation and cessation of fully lubricated sliding operations. The additional sample was secured in the specimen holder, enabling the disc to rotate at a predetermined sliding speed for a fixed distance of 2500 m or until the specimen seized, whichever happened first.

Fig. 4.2 Schematic diagram of the wear testing machine

4.4.2 Calculation

Wear rate was estimated by measuring the weight in the specimen after each test and weight loss Δw in the specimen was obtained. Cares have been taken after each test to avoid entrapment of wear debris in the specimen. Wear rate which relates to the mass loss to sliding distance (s) was calculated using the expression:

$$\text{WearRate}(W_r) = \frac{\text{Weight loss}}{(\Delta w)\text{Density}(\rho)*\text{SlidingDistance}(s)}$$

V. OBSERVATION OF RESULTS

This chapter examines the microstructural characteristics of Grey Cast Iron, ZA-37 matrix alloy, and ZA-37 Alloy composite. The obtained results from the measurements of hardness, density, and the sliding wear test.

5.1 Microstructure

Fig 5.1 represents the microstructure of the samples. The matrix alloy revealed primary dendrites of α and eutectoid α + η and ∈ phases in the Inter dendritic region. (Fig 5.1a, regions marked 1, 2 and oval respectively). The composite showed features similar to the matrix alloy except the presence of the dispersoid TiC particles. (Fig 5.1b). In the case of cast iron, flakes of graphite were observed in the matrix; the latter comprised of (majority of) pearlite and ferrite (Fig 5.1c,) regions marked by 3, 4 and 5.

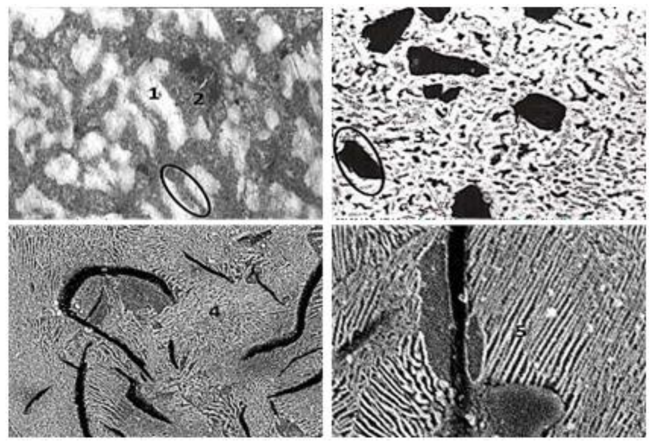

Fig. 5.1 Microstructure of (a) ZA-37 Matrix Alloy, (b) ZA-37 Alloy Composite, (c) and(d) Cast Iron

5.2 Hardness and Density

Table 5.1 represents various properties of the specimens. The composite attained somewhat higher hardness than the corresponding (ZA-37) matrix alloy while that of the grey cast iron was the maximum. So far as the density of the specimen is concerned, it was highest for the cast iron followed by that of the (ZA-37) matrix alloy and the composite.

Table 5.1 Hardness and Density of Specimen

Specimen No.	Type	Vickers Hardness	Density g/cm^3
1	ZA-37 Matrix Alloy	127	4.47
2	ZA-37 Alloy Composite	137	4.43
3	Grey Cast Iron	221	7.4

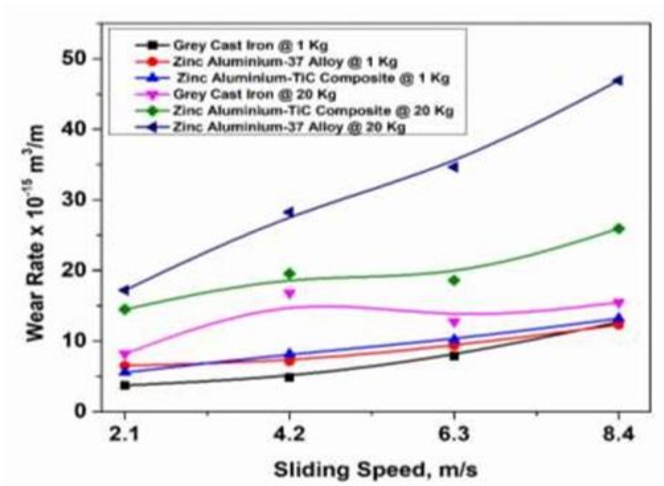

Fig. 5.2 Wear Rate of the samples plotted as a function of Sliding Speed in Oil + 5% Graphite (10 µm) Lubricated Environment at 1 & 20 Kg Load

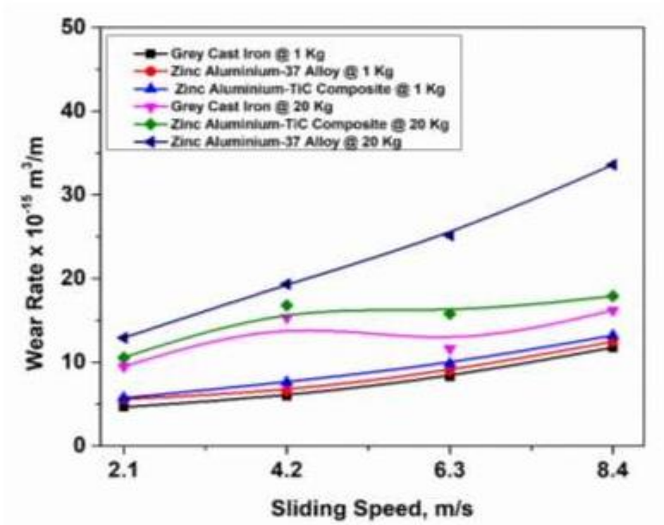

Fig. 5.3 Wear Rate of the samples plotted as a function of Sliding Speed in Oil + 5% Graphite (100µ) Lubricated Environment at 1 & 20 Kg Load

The wear rate of the samples was plotted against the applied load at a sliding speed of 2.1 m/sec under three lubricated conditions: dry, oil, and oil with 5% graphite (10µm and 100µm). These results are shown in Fig. 5.36, Fig. 5.37, and Fig. 5.38, respectively. The maximum wear rate is observed in dry environments for all materials. Among these, Grey Cast Iron has the highest wear rate, followed by ZA-37 alloy and ZA-TiC composite in all environments.

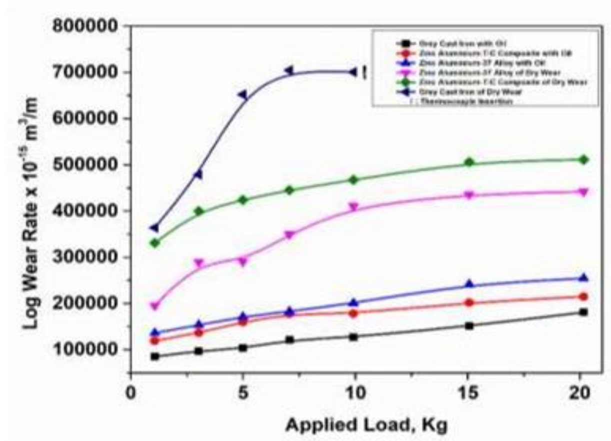

Fig. 5.4 Wear Rate of the samples plotted as a function of Applied Load in Dry & Oil Lubricated Environment at Sliding Speed of 2.1m/sec

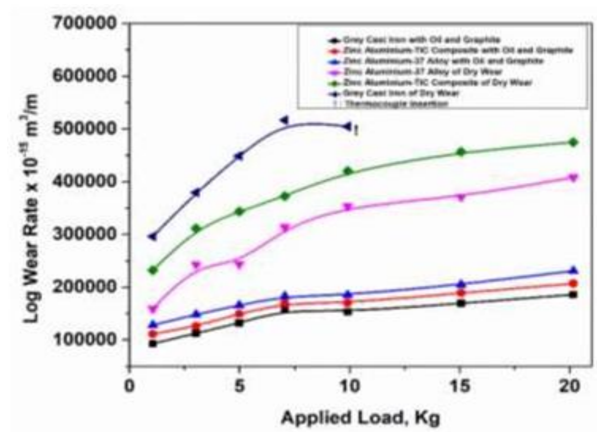

Fig. 5.5 Wear Rate of the samples plotted as a function of Applied Load in Dry & Oil + 5% Graphite (10 µm) Lubricated Environment at Sliding Speed of 2.1m/sec

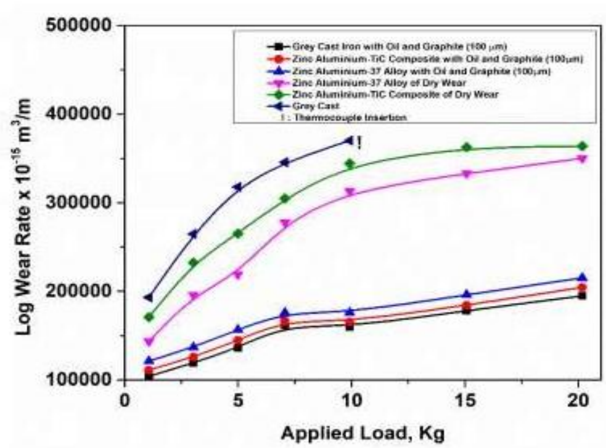

Fig. 5.6 Wear Rate of the samples plotted as a function of Applied Load in Dry & Oil + 5% Graphite (100µ) Lubricated Environment at Sliding Speed of 2.1m/sec

5.2.1 Frictional Heating

For Grey Cast Iron, ZA-Alloy and ZA-TiC composite at Sliding Speed of 2.1 & 8.4 m/sec and with an applied load of 1 & 20 Kg, the temperature near the contacting surface is plotted with the intermediate sliding distance for various Lubricated test environments. The trend of the temperature increase is strange. The oil + 5% graphite (100 µm) lubricated environment produces the highest temperature rise for all testing materials at 8.4 m/sec sliding speed, followed by the oil and oil + 5% graphite (100µm) lubricated environment.

Both loads (1 kg and 20 kg) exhibit the same pattern of temperature rise, however the 20 kg load exhibits a greater rise in temperature.

The sample's near-contacting surface temperature frequently increased with test length and load when tested in a dry sliding situation. At the reduced load, the ZA-Alloy experienced the lowest temperature rise, followed by Grey Cast Iron and the ZA-TiC composite. As illustrated in the plots, the Grey Cast Iron reached its maximum temperature at the maximum load, followed by the alloy and composite.

The sample was tested in partial lubrication conditions of Oil, Oil + 5% graphite (10µm), and Oil + 5% graphite (100µm), which exhibited a nearly identical trend but less temperature rise than the dry state. For oil lubrication, the maximum temperature attained by ZA-alloy was followed by the ZA-TiC composite and Grey Cast Iron regardless of sliding speed at lower load, while the minimum temperature attained by ZA-TiC composite, Grey Cast Iron, and ZA-alloy was shown at higher load.

The maximum temperature in an oil + 5% graphite (10µm) and oil + 5% graphite (100µm) lubricated environment is reached by grey cast iron first, then by ZA-alloy, and finally by ZA-TiC composite at all sliding speeds and loads, with the exception of 1 kg load at 8.4 m/sec, where composite reached the maximum temperature.

As it is clearly revealed in Figs. 5.39, 5.40, and 5.41, the severity of the increase in maximum temperature was greater in a dry environment than it was when lubricant was present. All of the information shows a mixed trend. However, Fig 5.42, 5.43, and 5.44 depict the greatest temperature rise in the Oil + 5% graphite (100µm) lubricated environment. Temperature initially rises with load and then falls after reaching a specific point (Figs. 5.45, 5.46, 5.47, and 5.48). Additionally, for a 20 kg load, the maximum temperature rise for grey cast iron is at 4.2 m/sec (Figs. 5.49, 5.50, & 5.51).

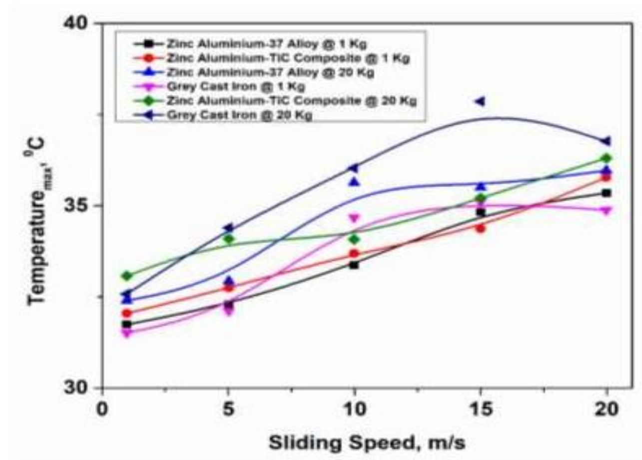

Fig. 5.7 Maximum Temperature near the contacting surface of Samples plotted as a function of Sliding Speed in Oil lubricated environment at an Applied Load of 1 & 20 Kg

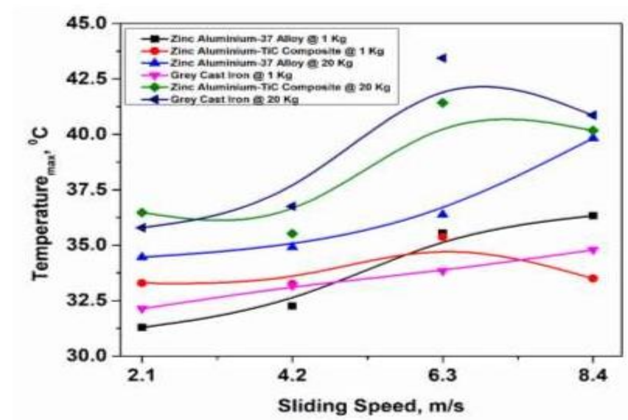

Fig. 5.8 Maximum Temperature near the contacting surface of Samples plotted as a function of Sliding Speed in Oil + 5% Graphite (10 µm) lubricated environment at an Applied Load of 1 & 20 Kg

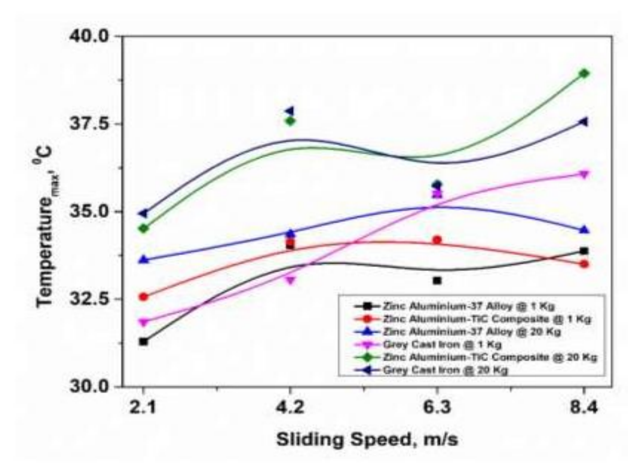

Fig. 5.9 Maximum Temperature near the contacting surface of Samples plotted as a function of Sliding Speed in Oil + 5% Graphite (100 µm) lubricated environment at an Applied Load of 1 & 20 Kg

5.2.2 Friction Coefficient

The sliding speeds are 2.1 and 8.4 m/sec at 1 kg and 20 kg, respectively. The highest friction coefficient was found at 2.1 m/sec in an oil-lubricated environment, with the highest friction coefficients for all test materials being obtained at 8.4 m/sec in an oil + 5 wt% graphite (100 µm) and Oil + 5 wt% graphite (100 µm) lubricated environment, respectively, at an applied load of 1 kg. Grey Cast Iron & ZA-Alloy show a reverse tendency at higher loads (20 Kg), whereas composite shows a mixed trend.

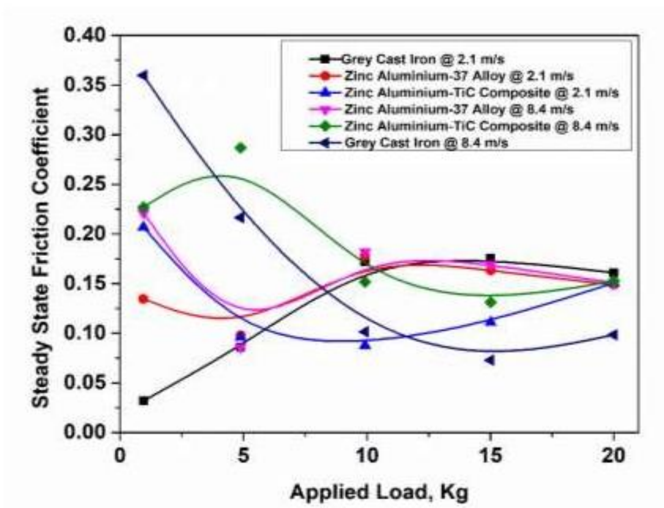

Fig 5.10 Steady State Friction Coefficient of the samples plotted as a function of Applied Load in Oil + 5% Graphite (100µm) Lubricated environment at Sliding Speed of 2.1 & 8.4 m/sec

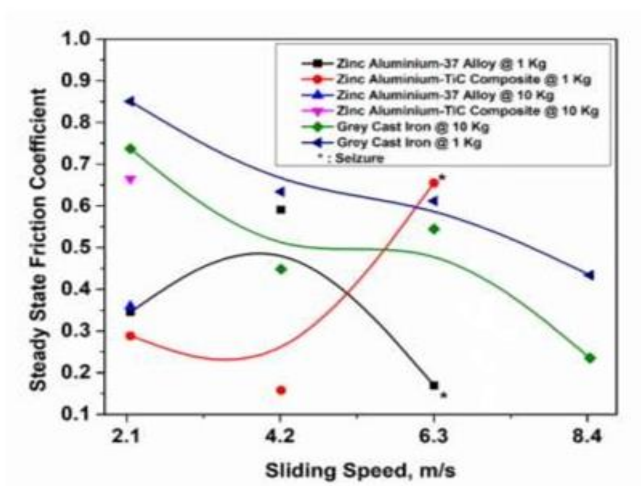

Fig 5.11 Steady State Friction Coefficient of the samples plotted as a function of Sliding Speed in Dry environment at an Applied Load of 1 & 10 Kg

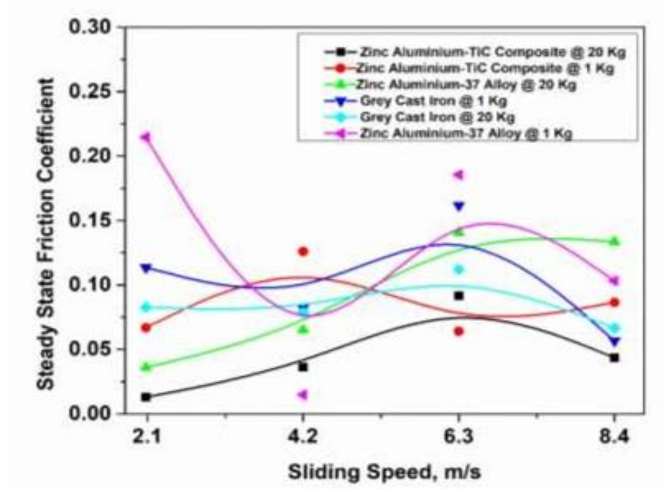

Fig 5.12 Steady State Friction Coefficient of the samples plotted as a function of Sliding Speed in Oil Lubricated environment at an Applied Load of 1 & 20 Kg

In Figs. 5.84, 5.85, and 5.86, the steady state friction coefficient of the samples has been displayed as a function of sliding speed in an oil, oil + 5% graphite (10 µm), and oil + 5% graphite (100 µm) lubricated environment, respectively, at an applied load of 1 and 20 kg. When a 1 kg force is applied, it is seen that the ZA-TiC composite exhibits the highest steady state friction coefficient, ZA-alloy is intermediate, and Grey cast iron has the lowest steady state friction coefficient. However, when a 20 kg weight is applied, a mixed trend in the behaviour of the steady state friction coefficient is produced.

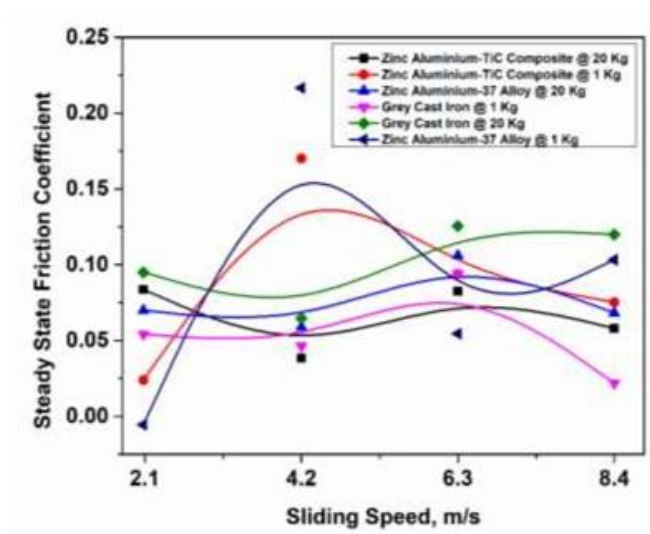

Fig 5.13 Steady State Friction Coefficient of the samples plotted as a function of Sliding Speed in Oil + 5% Graphite (10 µm) Lubricated environment at an Applied Load of 1 & 20 Kg

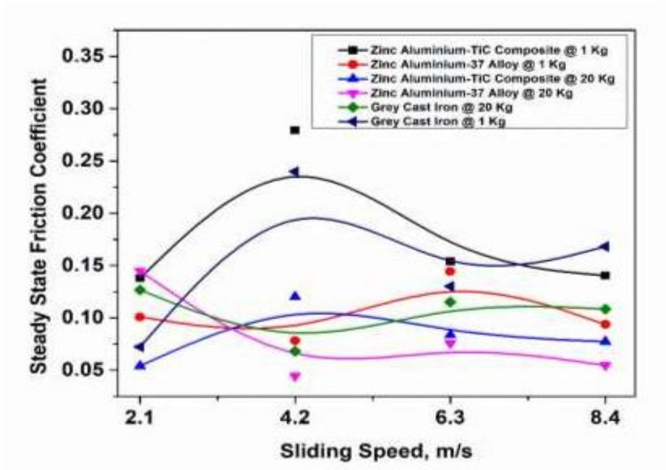

Fig 5.14 Steady State Friction Coefficient of the samples plotted as a function of Sliding Speed in Oil + 5% Graphite (100 µm) Lubricated environment at an Applied Load of 1 & 20 Kg

In Figs. 5.87, 5.88, and 5.89, the Steady State Friction Coefficients for the Samples in the Environments of Dry and Oil, Dry and Oil + 5% Graphite (10 µm), and Dry and Oil + 5%

Graphite (100 µm) have been compared as a function of the Applied Load at 2.1 m/sec. It is obvious that Grey Cast Iron achieves the highest steady state friction coefficient in a dry environment, followed by ZA-Alloy and ZA-TiC composite. The Steady state friction coefficient is significantly decreased by the addition of lubricant. In all lubrication environments, ZA-TiC composite, ZA-Alloy, and Grey Cast Iron achieve the lowest steady state friction coefficient.

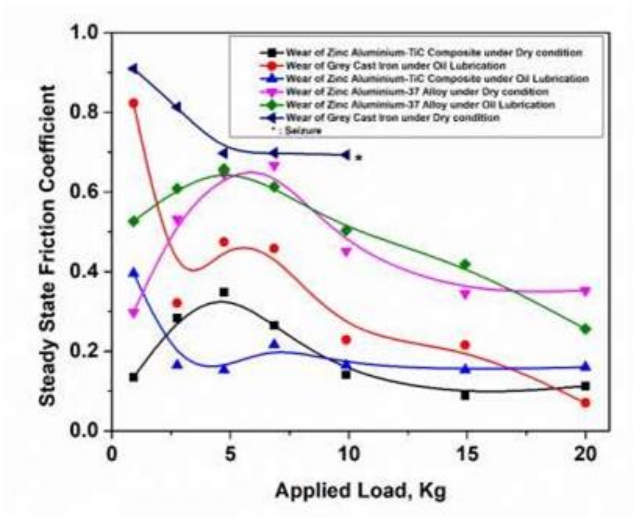

Fig 5.15 Steady State Friction Coefficient of the samples plotted as a function of Applied Load in Dry & Oil lubricated environment at Sliding Velocity of 2.1 m/sec

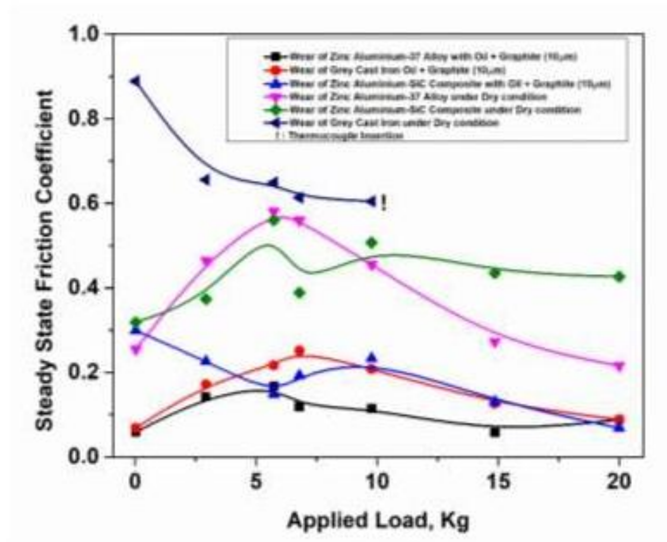

Fig 5.16 Steady State Friction Coefficient of the samples plotted as a function of Applied Load in Dry & Oil + 5% Graphite (10 µm) lubricated environment at Sliding Speed of 2.1 m/sec

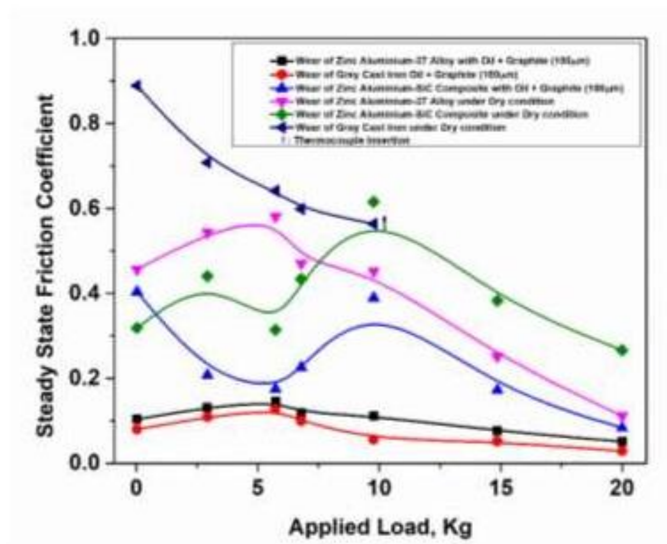

Fig 5.17 Steady State Friction Coefficient of the samples plotted as a function of Applied Load in Dry & Oil + 5% Graphite (100 µm) lubricated environment at Sliding Speed of 2.1 m/sec

VI. OUTCOME OF RESEARCH WORK

1. While the composite revealed the presence of the scattered TiC particles in addition to the characteristics of the matrix alloy, the matrix alloy contained primary α, $\alpha+\eta$ and ε. The matrix of the cast iron revealed pearlite and a little amount of ferrite. Flakes of graphite were present in the cast iron's microstructure.
2. The rate of sliding wear increases with load. While the wear performance of the matrix alloy and composite was

equal to each other, the cast iron suffered from its highest wear rate in dry conditions.

3. The materials' sliding wear rate was significantly lowered by the lubricating oil's presence. When tests were run under an oil-lubricated situation, the composite showed a lower wear rate than the matrix alloy. At lower stresses, cast iron wore out the least whereas at greater loads, it wore out halfway between the matrix alloy and the composite.
4. Samples tested under oil and graphite lubricated conditions wore out less quickly than samples tested under oil alone. A 5% graphite (7–10 µm) addition to the oil lubricant resulted in the lowest wear rate. The wear rate for the composite was the lowest, whereas the wear rate for the matrix alloy was the highest, and the cast iron showed a moderate wear response.
5. Frictional heating increases with load and test time, at first, the frictional heating increased more quickly, but as the test durations grew longer, the rate of increase decreased. In terms of frictional heating, cast iron in a dry state and the matrix alloy came in second and third, respectively.
6. Testing the samples under oil-lubricated circumstances reduced their friction coefficient compared to testing them under dry conditions, particularly when the loads were light. Friction coefficient was influenced inconsistently by test length. The coefficient of friction was further decreased by adding graphite to the lubricating oil. The graphite content (of the oil) had no discernible effect on the materials' friction coefficient. Thecomposite achieved the highest friction coefficient, followed by cast iron and the matrix alloy, same as in dry conditions.
7. In lubricated conditions compared to dry conditions, the range of variation of the steady state friction coefficient of materials was comparatively smaller. The amount of graphite added to the oil was at its ideal level, resulting in the lowest friction coefficient.

VII. FUTURE SCOPE OF WORK

In the present study, the effect of adding lubricating oil and various contents of graphite therein on the sliding wear behaviour of a cast iron, a zinc- based matrix alloy and composite was examined over the one in dry condition at various loads at a typical speed.. The observations made in this investigation could further be refined /elaborated /strengthened by studying:

1. The role of graphite addition in the oil lubricant over a range of sliding speeds and loads.
2. The role of graphite addition in several other lubricating oils.
3. The effect of other solid lubricants like molybdenum disulphide, lead, etc. in various lubricating oils.
4. The effect of counter face materials, microstructure, composition and properties.

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