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EXPERIMENTAL INVESTIGATIONS ON Zr COATED AL7475/B4C/WC COMPOSITES

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Abstract: This study examines the influence of ceramic coatings on aluminum alloy that has been reinforced with boron carbide and tungsten carbide, using the plasma spray technique. The samples were produced by sand casting, with 100% aluminum 7475 alloy used for certain samples, and metal matrix composites consisting of 94% aluminum 7475, 3% boron carbide, and 3% tungsten carbide used for others. Following that, zirconia coatings were administered utilizing the plasma spray technique. The study evaluated the Brinell hardness, corrosion behavior by salt spray testing, wear resistance using a pin-on device, and microstructural parameters of the three sample combinations. The results demonstrate that the zirconia-coated samples had increased hardness and greater resistance to corrosion in comparison to the untreated samples. The microstructural study showed a consistently small-grained structure in the samples with a metal matrix coated with zirconia. This indicates that the samples had superior heat barrier capabilities. The compact grain structure resulted in enhanced hardness and consequent resistance to wear in the coated specimens. This study highlights the effectiveness of ceramic coatings, specifically zirconia, in improving the mechanical and corrosion properties of aluminum alloys that are strengthened with boron carbide and tungsten carbide. Therefore, these coatings have considerable potential for various industrial applications.

Keywords: Ceramic coatings, Aluminum alloy, Boron carbide, Tungsten carbide, Plasma spray technique, Corrosion resistance, Microstructure, Zirconia, Wear resistance

I. INTRODUCTION

Aluminum alloys have attracted considerable interest in several industries because of their advantageous blend of characteristics, such as low weight, exceptional strength, and resistance to corrosion [1]. These alloys have a crucial role in the composition of construction materials, packaging, and transportation vehicles like cars and airplanes [2]. Additionally, in order to enhance their performance for certain applications, aluminum alloys frequently undergo the process of reinforcement with elements such as copper, manganese, magnesium, silicon, and zinc [3].

The corrosion resistance of aluminum alloys is contingent upon their composition. Al-Cu alloys of the 2xxx grade have a low tendency to experience pitting corrosion, whereas pure aluminum of the 1xxx grade shows more resistance [4]. However, Al-Si alloys of grade 4xxx and Al-Si-Mg alloys of grade 6xxx exhibit lower resistance to corrosion in wet environments, while Al-Mg alloys of grade 5xxx have comparatively stronger resistance [5]. The variations in corrosion behavior highlight the need of comprehending alloy compositions and their accompanying features.

There has been an increasing interest in improving the mechanical and corrosion characteristics of aluminum alloys by adding ceramic coatings in recent years [6]. Ceramic coatings provide long-lasting protection and excellent smoothness, making them ideal for situations that demand enhanced surface interactions, such as automotive parts [7]. Furthermore, ceramic coatings can function as efficient materials that block heat, offering resistance to thermal energy and improving the durability of components that operate at high temperatures [8].

The utilization of ceramic coatings entails specific techniques such as plasma spraying and detonation cannon, each providing distinct benefits in terms of coating density and adhesion [9]. Coatings are essential for increasing the lifespan of components by improving their mechanical qualities and protecting them against corrosion [10].

Although there have been improvements in aluminum alloy technology and ceramic coating processes, additional research is necessary to investigate the combined impacts of these materials.

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The objective of this study is to examine the influence of ceramic coatings, specifically zirconia, on aluminum alloys that have been strengthened with boron carbide and tungsten carbide. This research aims to enhance the performance and versatility of aluminum alloys in industrial applications by assessing their mechanical properties, corrosion behavior, and microstructural characteristics.

1.1 AIM & OBJECTIVES

1.1.1 Aim:

The main aim of this research is to enhance the mechanical, corrosion, and wear resistance properties of a sand-casted aluminum alloy (94%) by incorporating reinforcements of 3% boron carbide and 3% tungsten carbide. The study further aims to improve these properties by applying a Zirconia coating using the plasma spray technique.

1.1.2 Objectives:

- Find the right aluminum alloy composition with 94% aluminum, 3% boron carbide, and 3% tungsten carbide.
- Produce 20x20x8mm alloy-composition samples via sand casting.
- Investigate plasma spraying Zirconia coating on casted aluminum alloy samples.
- Optimise coating settings for uniform coverage.
- Hardness testing on coated and untreated samples measure indentation resistance and alloy composition and coating effectiveness.
- Use salt spray to imitate extreme weather conditions and test coated and uncovered substrates for corrosion resistance.
- Use a pin-on-disc apparatus to replicate wear conditions and assess aluminum alloy wear resistance with reinforcing and Zirconia coating.
- Use light optical microscopy to examine the microstructure of coated and uncoated surfaces to understand how alloy composition and coating affect structure.
- Compare the test results to determine how the alloy composition and Zirconia coating improved mechanical, corrosion, and wear resistance.
- Summarize and conclude on the improved aluminum alloy's suitability for enhanced attributes.
- Based on study results, suggest applications and research directions.

II. EXPERIMENTAL PROCEDURE

2.1 Sample Preparation

Aluminum alloy samples were fabricated using the sand casting method. Two sets of samples were prepared: one consisting of 100% aluminum 7475 alloy and the other comprising a metal matrix composite with 94% aluminum 7475, 3% boron carbide, and 3% tungsten carbide.

2.2 Composite Fabrication

Metal matrix composites (MMCs) were fabricated by incorporating boron carbide and tungsten carbide particles into the aluminum alloy matrix. The composite composition was optimized to achieve the desired mechanical properties while maintaining good processability.

2.3 Sand Casting

Samples of aluminum alloy and MMCs were prepared using the sand casting method. Sand molds were prepared by compacting fine sand around a pattern or core to create the desired shape of the samples. The molten metal was then poured into the mold cavity and allowed to solidify.

2.4 Plasma Spray Coating

Zirconia ($ZrO2$) ceramic coatings were applied to the surface of the prepared samples using the plasma spray technique. The plasma spray process involved feeding zirconia powder into a high-temperature plasma flame, where it melted and formed a coating on the substrate surface.

2.5 Characterization Techniques

2.5.1 Brinell Hardness

The hardness of the prepared samples was evaluated using the Brinell hardness testing method. A hardened steel ball of predetermined diameter was pressed into the surface of the samples under a specified load, and the diameter of the resulting indentation was measured. The Brinell hardness number (HB) was calculated based on the applied load and the surface area of the indentation, providing a measure of the material's resistance to indentation.

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2.5.2 Corrosion Behavior

The corrosion resistance of the samples was assessed using salt spray testing in accordance with standardized procedures such as ASTM B117. The samples were exposed to a salt spray environment for a predetermined period, simulating corrosive conditions. The extent of corrosion, including the formation of rust or corrosion products, was visually inspected and quantitatively measured using techniques such as weight loss analysis or corrosion rate calculation.

2.5.3 Wear Resistance

The wear resistance of the samples was evaluated using a pin-on device or tribometer. In this test, a controlled load was applied to a pin or disc that slid against the surface of the sample under controlled conditions of speed, temperature, and lubrication. The wear volume or wear rate of the samples was determined based on the extent of material loss or wear scar formation, providing insight into the material's resistance to wear under specific operating conditions.

2.5.4 Microstructural Analysis

The microstructure of the prepared samples, including the coating-substrate interface, was examined using optical microscopy (OM) and scanning electron microscopy (SEM). OM provided low-magnification images of the sample's microstructure, allowing for visual inspection of features such as grain size, porosity, and coating uniformity. SEM provided higher magnification images with enhanced resolution, enabling detailed analysis of microstructural characteristics and coating morphology.

III. EXPERIMENTAL WORKS

3.1 CASTING PROCESS

Fig.(3.1) Melting Stage

Fig.(3.2) Moulding Die

Fig.(3.3) Pattern

Fig.(3.4) Mould Pattern

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Fig.(3.5) Molten Metal

Fig.(3.6) Mould cavity

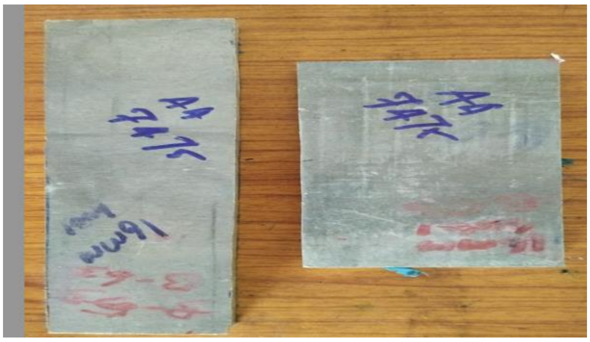

Fig.(3.7) Aluminium alloy 7475

IV. RESULTS AND DISCUSSION

4.1 Hardness

BRINELL HARDNESS TEST

BRINELL HARDNESS TEST (10mm Ball/ 500 kg Load)		
Aluminium Alloy	Casted with 94% AI 7475-3% Boron carbide-3% Tungsten carbide	Casted sample with 94% AI 7475-3% Boron carbide-3% Tungsten carbide Coated with zirconia
35.7	46.7	70.1

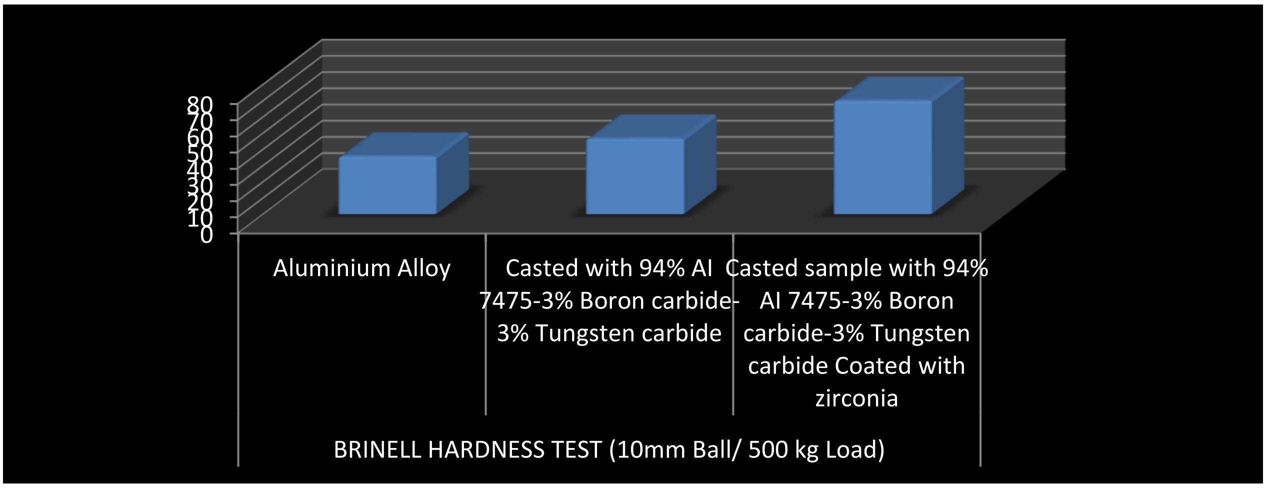

Fig.(4.1) Comparison for Brinell Hardness Test

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The zirconia-coated samples exhibited significantly higher hardness values compared to the uncoated samples. This increase in hardness can be attributed to the presence of the ceramic coating, which acts as a barrier against indentation and deformation.

4.2 Corrosion Resistance

Salt spray testing revealed that the zirconia-coated samples displayed superior corrosion resistance compared to the uncoated samples. The ceramic coating effectively protected the underlying metal substrate from corrosive attack, thereby extending the service life of the components.

Test Description	Test Result		
Test Duration (Hours): 24 Hrs	Aluminium Alloy	Casted with 94% AI 7475 - 3% Boron carbide-3% Tungsten carbide	Casted sample with 94% AI 7475 -3% Boron carbide- 3% Tungsten carbide coated with zirconia
Test starting date (DD/MM/YY): 09.02.2024			
Test ending date (DD/MM/YY): 10.02.2024			
Tower Temperature(°C): 47.5-48.5			
Air Pressure (Psi): 14-18			
Chamber Temperature (°C): 34.5-35.5			
Components Loading in Chamber Position (Degree Angle): 15-30 Degree from vertical			
Concentration of Solution(%):4.80-5.30 % of Nacl			
pH value:6.65 -6.85			
Volume of salt solution colected (ml/hr):1.00 -1.50			
Test Observation	White Rust Formation noticed at 12 Hrs and continued till 24 Hrs	No White Rust Formation noticed up to 24 Hrs	No White Rust Formation noticed up to 24 Hrs

4.3 Wear Resistance

The zirconia-coated samples demonstrated improved wear resistance due to the enhanced hardness and lubrication properties of the ceramic coating. The dense microstructure of the coating prevented abrasive wear and reduced material loss during sliding contact.

Fig.(4.2) Pin-On-Disk Apparatus Setup

Fig.(4.3) Pin-On-Disk Machine

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Fig.(4.4) Measurement of Pin Un-Coated Pin

Fig.(4.5) Measurement of Coated Pin

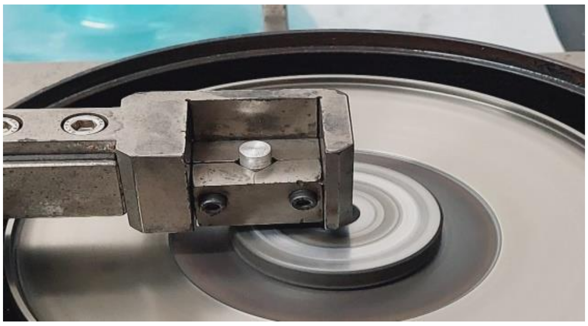

Fig.(4.6) Clamp the Pin

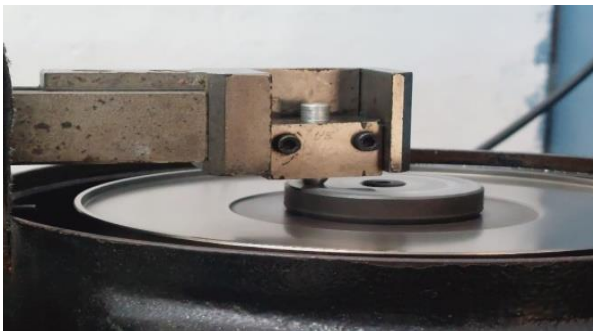

Fig.(4.7) Clamp the Pin

4.3.1 Wear Test Results

Test parameters			
Expt. No.	Applied Load (N)	Sliding velocity (m/sec)	Sliding Distance (m)
Cated 94% Al- 3%B4C-3%WC with Zirconia	20	1.5	800
Cated 94% Al- 3%B4C-3%WC	20	1.5	800
Casted ALUMINIUM alloy	20	1.5	800
Machine setting			
Sliding dia in mm	r.p.m	Time in secs	Time in min:secs
40	717	533.333333	8.887466667
40	717	533.333333	8.887466667
40	717	533.333333	8.887466667

Without Coated

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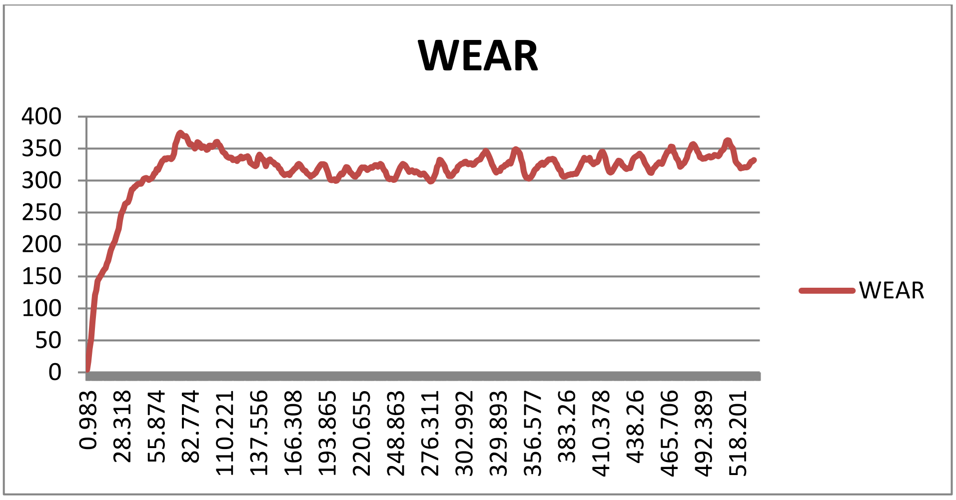
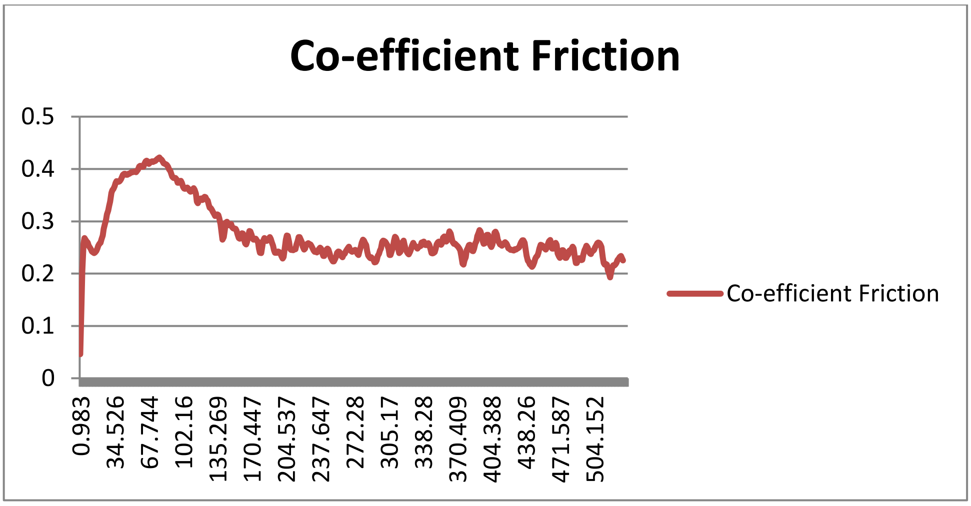
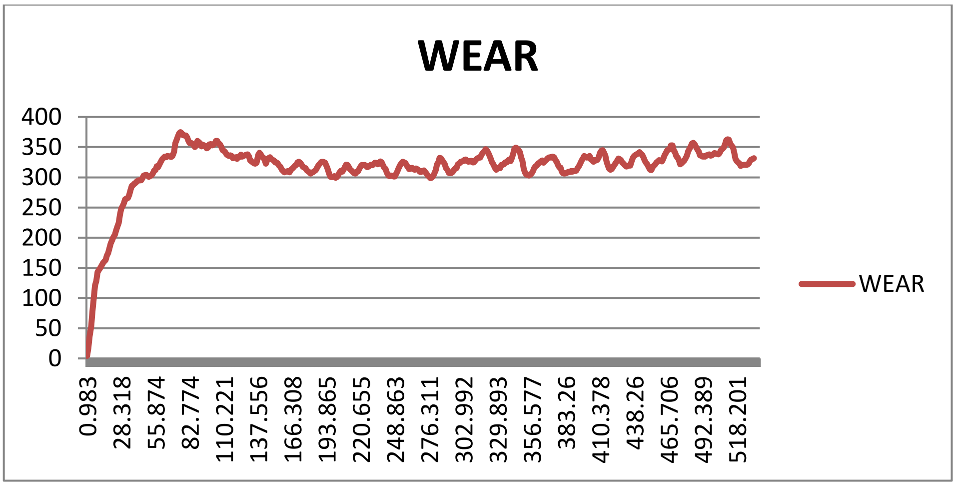
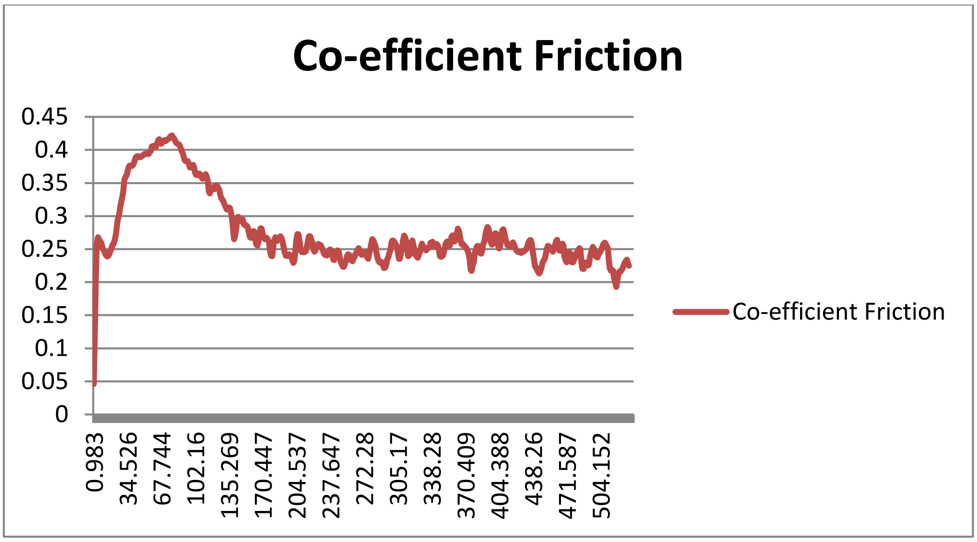




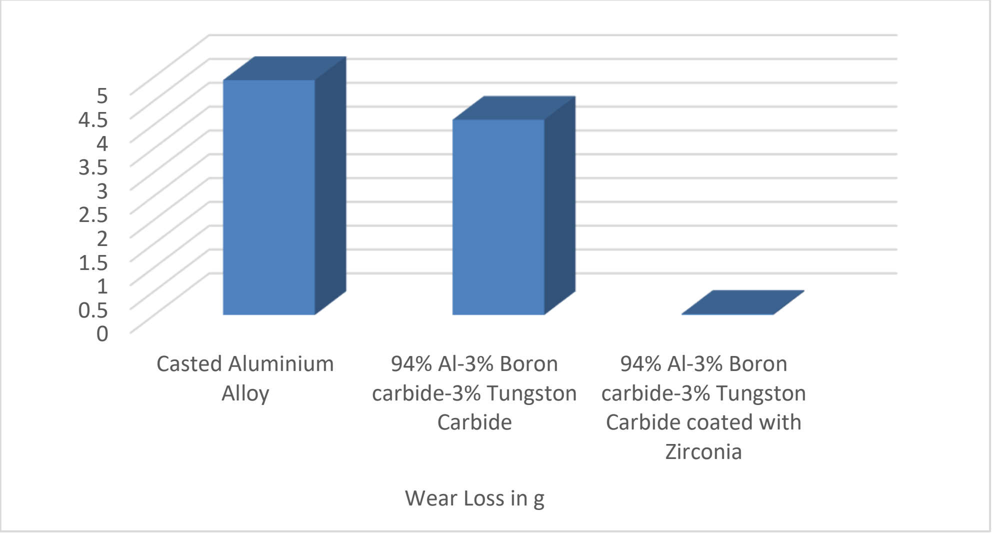
With Coated





4.3.2 Comparison of Results

Wear Loss in g		
Casted Aluminium Alloy	94% Al-3% Boron carbide-3% Tungston Carbide	94% Al-3% Boron carbide-3% Tungston Carbide coated with Zirconia
4.928	4.097	0.022



4.4 Microstructural Analysis

Microstructural examination revealed a fine-grained structure in the zirconia-coated metal matrix samples, indicative of good adhesion and interfacial bonding between the coating and the substrate. This fine-grained structure contributed to the improved mechanical properties and corrosion resistance of the coated samples.

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4.4.1 .Aluminium Alloy

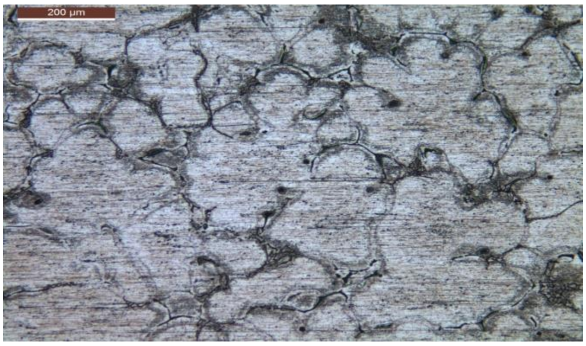

Fig.(4.2) 100X

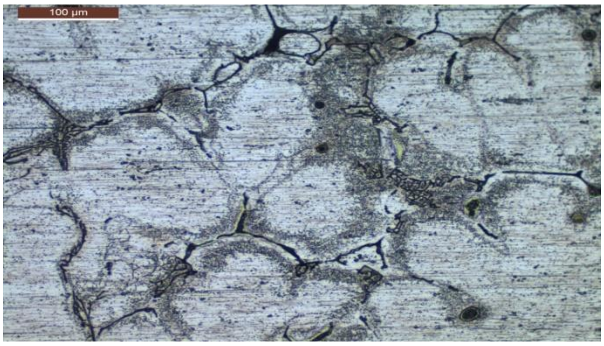

Fig.(4.3) 200XX

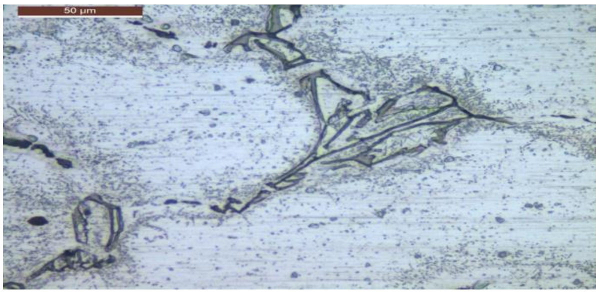

Fig.(4.4) 500X

4.4.2 Casted with 94% AI 7475 - 3% Boron Carbide – 3% Tungste Carbide

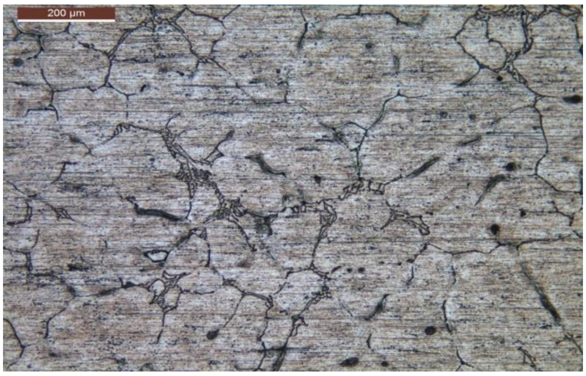

Fig.(4.5) 100X

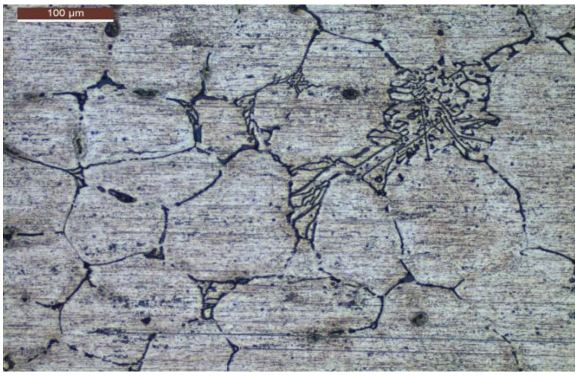

Fig.(4.6) 200XX

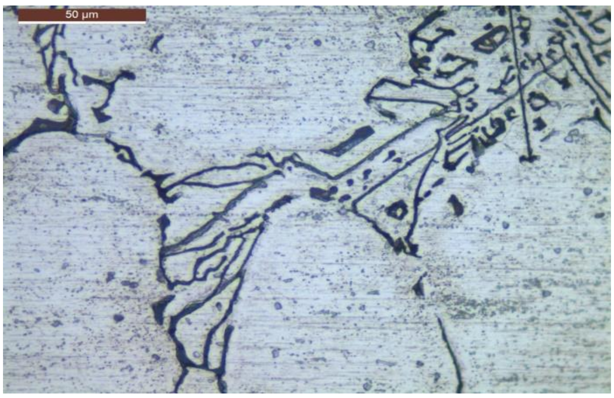

Fig.(4.7) 500X

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4.4.3 Casted Sample with 94% Ai 7475 – 3% Boron Carbide – 3% Tungsten Carbide Coated With Zircoina

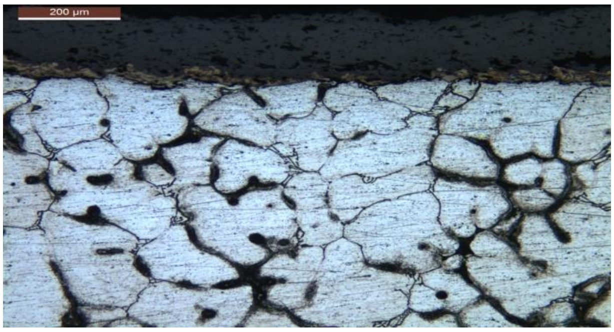

Fig.(4.8) 100X

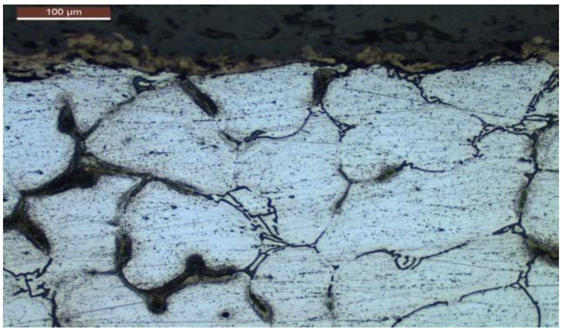

Fig.(4.9) 200XX

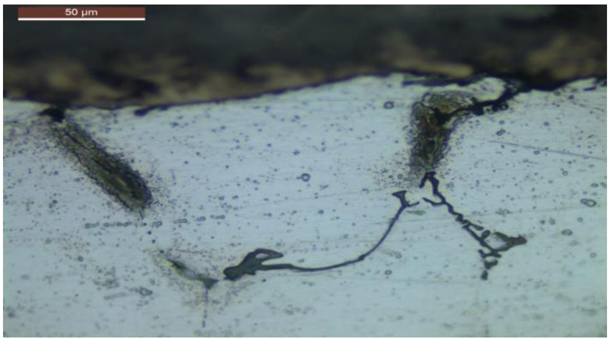

Fig.(4.10) 500X

V. CONCLUSION

Research on zirconia-coated, boron carbide-and tungsten carbide-reinforced aluminum alloy composites has improved our understanding of how to enhance mechanical and corrosion resistance. Coatings made of zirconia significantly increased hardness compared to uncoated samples. The ceramic layer's barrier effect, which provides resistance to deformation and indentation, is responsible for the improvement. Salt spray testing demonstrated that samples coated with zirconia had better corrosion resistance than untreated samples. The ceramic covering adequately shielded the metal substrate from corrosion, allowing the components to last longer. The zirconia coating enhanced the ceramic coating's hardness and lubricating properties, which in turn increased the samples' wear resistance. Abrasive wear was reduced and material loss during sliding contact was minimized by the coating's compact microstructure. A fine-grained structure was observed in the zirconia-coated metal matrix samples, according to the microstructural examination. This indicates that the coating and substrate are strongly adhered to and bonded. The presence of a complex structure contributed to the improvement of the coated samples' mechanical properties and corrosion resistance.

The results highlight the usefulness of zirconia coatings for enhancing the performance and durability of composites made of aluminum alloy in various industrial settings. Combining ceramic coating with reinforcing boron carbide and tungsten carbide offers promising new avenues for the development of materials with superior corrosion resistance and mechanical strength. This study contributes to ongoing efforts to find better ways to leverage surface engineering and new materials to make structural components that are more efficient and reliable for high-demand industries like aerospace and automotive. Research in the future might focus on improving coating parameters, investigating other ceramic materials, and testing coated composites in real-world operational settings to see how long they last.

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