International Research Journal of Education and Technology
Peer Reviewed Journal
ISSN 2581-7795

TRIBOLOGICAL BEHAVIOR OF ALUMINIUM BASED HIGH ENTROPY ALLOY

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ABSTRACT:

High entropy alloys (HEAs) have gained significant attention due to their exceptional mechanical and tribological properties arising from their unique multi-principal element composition. This study focuses on the tribological behavior of an aluminum-based high entropy alloy (HEA), synthesized using advanced metallurgical techniques to ensure a homogeneous microstructure. Wear resistance and frictional characteristics were evaluated under various operational conditions, including different loads, sliding speeds, and environmental factors. The findings demonstrate excellent wear resistance and reduced friction, attributed to the synergistic effect of the constituent elements and the formation of a stable oxide layer during sliding. Microstructural analysis revealed the influence of solid solution strengthening and phase uniformity in enhancing tribological performance. These results highlight the potential of aluminum-based HEAs for applications in demanding environments, such as aerospace, automotive, and heavy-duty machinery, where superior wear resistance and durability are essential.

KEYWORDS:

- High entropy alloys (HEAs)
- Aluminum-based alloy
- Tribological behavior
- Wear resistance
- Frictional performance

1. INTRODUCTION:

High Entropy Alloys (HEAs), characterized by their composition of five or more principal elements, have emerged as a significant class of materials due to their unique micro-structure and exceptional mechanical properties.These alloys, unlike conventional alloys, exhibit a combination of high strength, wear resistance, and thermal stability, making them suitable for various high-performance applications such as aerospace, automotive, and energy sectors . Aluminum-based HEAs, especially the Elements such as Al, Cu, Co, Fe, and Ni, provide enhanced tribological properties due to the formation of a solid solution matrix that stabilizes both face-centered cubic (FCC) and body-centered cubic (BCC) phases. The combination of these phases leads to significant improvements in hardness and wear resistance, particularly in high-temperature environments, the synthesis techniques, such as mechanical alloying (MA) and Sintering, have been instrumental in achieving the desired micro-structural and mechanical characteristics for the alloy.

This research explores the tribological behavior of an aluminum-based HEA composed of Al, Fe, Co, Cu, and Ni . The primary goal is to investigate the alloy's wear resistance, hardness, and frictional behavior under different conditions, contributing to the potential growth in industrial applications.

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2. OBJECTIVE:

The primary objective of this project is to explore the tribological behavior of aluminum-based high entropy alloys (HEAs) with a focus on understanding their wear resistance, frictional performance, and overall durability under varying operating conditions such as load, speed, and temperature. The study aims to investigate the role of the alloy's unique multi-principal element composition in enhancing its tribological properties, including the formation of protective oxide layers and the effect of solid solution strengthening. Additionally, the project seeks to analyze the micro-structural features, such as phase distribution and grain structure, and their correlation with the material's superior performance in demanding environments. Ultimately, this research aims to establish aluminum-based HEAs as a viable material choice for applications in aerospace, automotive, and other industries requiring exceptional wear resistance and mechanical reliability.

3. METHODOLOGY:

In this study, high-purity elemental powders of aluminum, copper, cobalt, iron, and nickel were selected to form the aluminum-based high entropy alloy. The powders were then mixed using a planetary ball mill to ensure a uniform distribution of all elements. After mixing (Fig 1), the powders were compacted into green compacts using a hydraulic press under high pressure, forming the initial shape of the alloy. The green compacts were subsequently sintered in a furnace under an inert atmosphere, which prevented oxidation and ensured proper bonding and declassification of the material.

After sintering (Fig 2), the samples were polished to achieve a smooth surface suitable for testing. The micro-structure of the sintered alloy was examined using optical and scanning electron microscopy, while phase identification was carried out using X-ray diffraction (XRD). For the tribological evaluation, wear resistance and friction were measured using a pin-on-disc tribometer under varying loads, speeds, and sliding distances. The wear tracks were carefully analyzed to understand the wear mechanisms.

The data collected from the tribological tests were analyzed to correlate the alloy's micro structural features, such as phase distribution and grain structure, with its tribological behavior. This approach allowed for a comprehensive understanding of the alloy's performance under different operating conditions.

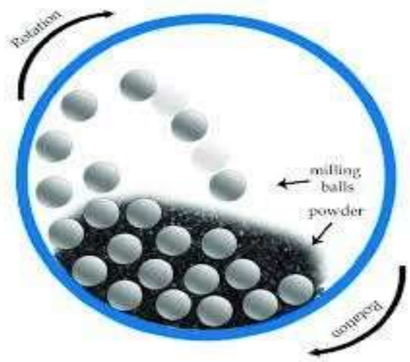

Fig-1: Ball Millong

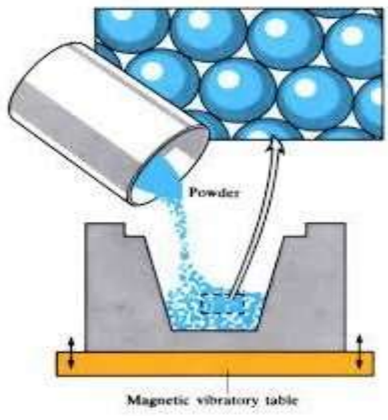

Fig-2: Sintering

4. PROPOSED METHODOLOGY:

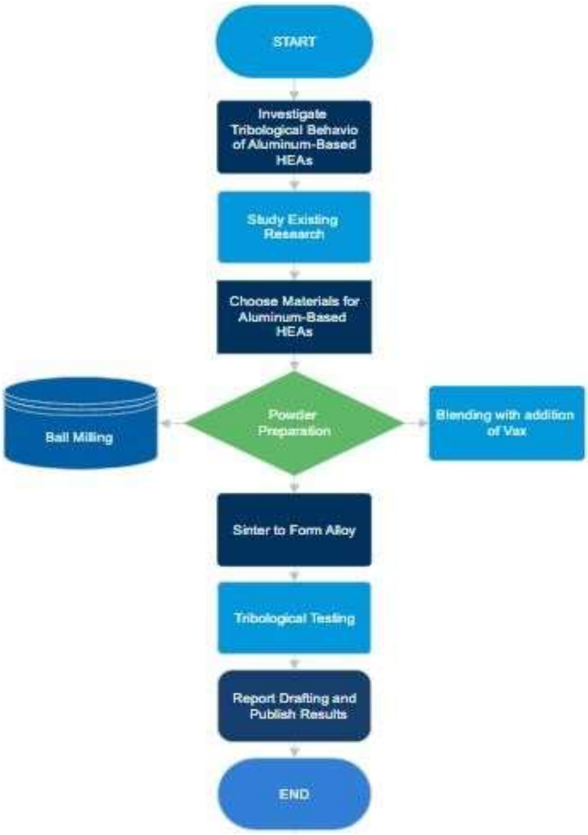

Fig-4: Workflow diagram

5. CHOICE OF COMPONENTS:

5.1 Powder Metallurgy

Achieving a uniform distribution of elements is fundamental to the quality and performance of aluminum-based high entropy alloys. This process begins by precisely weighing and mixing the elemental powders according to the desired composition. Accurate weighing and mixing are crucial steps to prevent elemental segregation and to ensure consistency in the alloy's properties throughout the final product.

The alloy's composition centers around Aluminum (Al) as the primary base element, combined with alloying elements Cobalt (Co), Iron (Fe), Copper (Cu), and Nickel (Ni) in near-equiatomic proportions. These elements are strategically chosen for their specific contributions to the alloy's properties, such as hardness, corrosion resistance, and thermal stability

○ **Aluminum (Al)** is the primary base metal, chosen for its lightweight characteristics and excellent oxidation resistance. These properties
make it ideal for applications where weight reduction and environmental durability are crucial.

○ **Cobalt (Co)** is added to enhance wear resistance and hardness, properties that are essential in environments with high friction. Cobalt's ability to improve hardness also helps the alloy withstand
surface wear and extend its service life in demanding applications.

○ **Iron (Fe)** provides essential structural integrity and mechanical strength to the alloy, contributing to its ability to bear loads and resist deformation. Its inclusion helps maintain the alloy's stability under mechanical stress.

○ **Copper (Cu)** contributes to improved ductility and hardness, making the alloy more resilient under load while also enhancing wear resistance. Additionally, copper promotes good bonding within 27the alloy, contributing to the overall stability and durability of the micro-structure.

○ **Nickel (Ni)** is included to enhance toughness and thermal stability, key characteristics for applications where the alloy may be exposed to high temperatures. Nickel helps in maintaining structural integrity at elevated temperatures, improving the alloy's overall performance in thermally challenging environments.

5.2 Compaction and Sintering:

The compacted powder is sintered in a controlled atmosphere at a temperature below the melting points of the constituent metals. Sintering promotes atomic diffusion, bonding the particles together to form a dense, solid alloy with minimal porosity

5.3 Microstructural Analysis

5.3.1 X-Ray Diffraction (XRD)

X-Ray Diffraction (XRD) is a pivotal analytical technique employed to investigate the crystallographic structure of materials, including aluminum-based high entropy alloys. This method involves directing X-rays onto a sample and measuring the resulting diffraction patterns to discern the arrangement of atoms within the alloy. By analyzing these patterns, XRD effectively identifies the various crystalline phases present in the material, allowing researchers to confirm the formation of a solid solution, which is essential for understanding the alloy's overall properties.

5.3.2 Scanning Electron Microscopy (SEM)

Scanning Electron Microscopy (SEM) is an advanced imaging technique that plays a crucial role in materials science, particularly in the analysis of aluminum-based high entropy alloys. SEM allows for the acquisition of high-resolution images that reveal intricate details of the alloy's micro-structure. Through the utilization of focused electron beams, SEM generates images that showcase critical features such as grain size, grain boundaries, and phase distributions within the material

5.3.3 Tribological Testing (Pin on Disk)

1. Testing Setup:

○ **Objective**: To simulate sliding wear and friction under controlled conditions.

○ **Equipment**: A pin-on-disk apparatus, where a pin of the HEA is pressed against a rotating disk under a specified load. This test simulates real-world conditions of sliding wear, which are common in industrial applications.

○ **Procedure:** Parameters such as load, rotation speed, and temperature are varied to simulate different wear conditions. The frictional force and wear rate are recorded over a set time, providing data on the alloy's wear resistance and friction coefficient. The test parameters, such as load, speed, and duration, are varied to assess how the alloy performs under different conditions, providing a comprehensive view of its wear and friction behavior.

2. Data Collection and Analysis:

○ **Wear Rate**: The wear rate is calculated based on the volume of material lost during the test. Lower wear rates indicate better wear resistance, which is a key factor for tribological applications.

○ **Friction Coefficient**: The coefficient of friction is recorded throughout the test to evaluate the alloy’s frictional characteristics. A lower coefficient of friction is desirable, as it reduces energy losses and material degradation in moving parts

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6. RESULT AND DISCUSSION:

The tribological testing of the aluminum-based high entropy alloy revealed that the material exhibited excellent wear resistance and a relatively low coefficient of friction (CoF) under varying testing conditions. The wear rate was significantly lower compared to conventional alloys, indicating superior durability in high-stress environments. The frictional performance of the alloy was found to improve with increased sliding distance, suggesting that a stable oxide layer formed on the surface during the test, which helped reduce friction.

Microstructural analysis showed a homogeneous distribution of the alloying elements, with a fine-grained structure that contributed to the material's enhanced mechanical properties. Scanning electron microscopy (SEM) images of the wear tracks indicated mild abrasive wear, with minimal surface damage. The formation of a protective oxide layer on the surface was evident, which played a crucial role in reducing wear and improving the alloy's overall tribological performance.

X-ray diffraction (XRD) analysis revealed the presence of multiple phases in the alloy, including solid solution phases, which contributed to the improved strength and wear resistance. The alloy's microstructure, including its phase distribution and grain boundaries, was closely related to its wear resistance and frictional properties.

Comparing the results with other high entropy alloys and conventional materials, the aluminum-based alloy demonstrated competitive tribological properties. The alloy's low friction and wear resistance, coupled with its robust microstructure, make it a promising material for high-performance applications such as aerospace,

Fabricated Sample:

The image shown below (Figure 3) displays the cylindrical samples produced through the powder metallurgy and sintering processes. These samples were fabricated for the experimental phase of this project to investigate the tribological behavior and wear resistance of an aluminum-based high entropy alloy (HEA)

Fig-3: Samples

Element Composition Analysis:

The EDS analysis (Fig - 4) confirms the presence of Aluminum in the sample, along with other elements, primarily Iron. The adjustments for error margins and correction factors enhance the reliability of these quantitative results, providing essential insights into the material's composition. These findings are foundational for understanding how the composition, particularly the Aluminum content, influences the material's tribological properties.

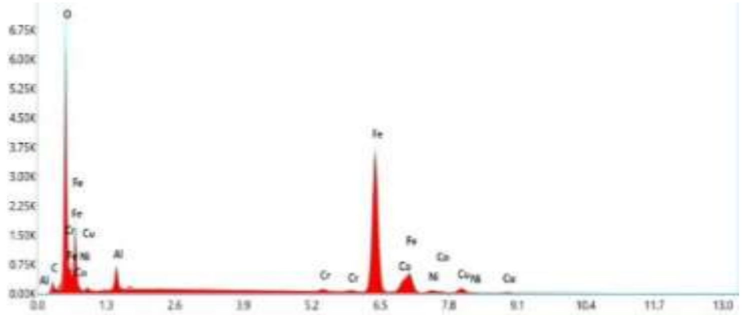

Fig-4: EDS

X_Ray Spectroscope and Element Mapping :

These values highlight Aluminum's contribution to the sample's composition. Despite its relatively low concentration compared to Iron (Fe) and Oxygen (O), Aluminum remains a focal element due to its anticipated impact on the material's tribological properties.

The elemental mapping and overlay images (Figure : 5) provide a visual representation of the distribution of each element within the sample. This analyzes each detected element's spatial occurrence, which helps in understanding the micro structural composition and the influence of individual elements on the alloy's properties.

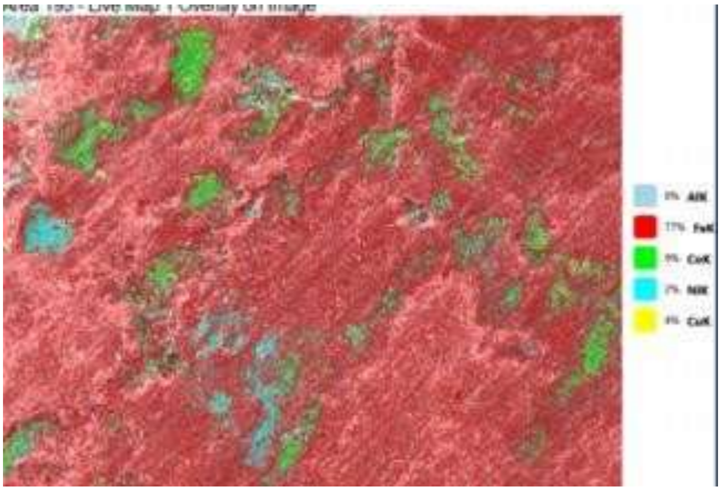

Fig-5: ED

This study highlights the potential for further exploration of HEAs in industrial applications, potentially leading to a new class of materials that outperform traditional alloys in strength, durability, and environmental resistance. Expanding research into HEAs with similar elements may yield alloys with tailored properties for specialized applications, pushing the boundaries of material performance.

7. CONCLUSIONS

In this study, the tribological behavior of an aluminum-based high entropy alloy (HEA) was investigated to evaluate its wear resistance and frictional performance under various operational conditions. The results showed that the alloy exhibited excellent wear resistance and a low coefficient of friction compared to conventional materials. This superior performance can be attributed to the unique micro-structural characteristics of the alloy, including a uniform distribution of constituent elements and the formation of a stable oxide layer during sliding. The alloy demonstrated minimal wear and surface degradation, which is indicative of its durability under high-stress conditions.

Microstructural analysis revealed that the HEA possessed fine grains and multiple phases that contributed to its mechanical properties, particularly in enhancing its resistance to wear and reducing friction. The results from the X-ray diffraction (XRD) analysis supported the presence of solid solution strengthening, which further contributed to the alloy's overall strength and tribological performance.

The aluminum-based HEA displayed competitive tribological properties, making it a promising candidate for applications in fields such as aerospace, automotive, and tooling industries, where material performance in demanding conditions is critical. Moreover, the alloy's unique combination of low friction, high wear resistance, and strength offers an opportunity for further optimization to meet specific industrial requirements.

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