Study of Wear Properties of Recycled Composite Zn-Al Alloy Reinforced with Hybrid Nanoparticles

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Abstract. In this research, the stir casting technique used to produce ZA-12 alloy hybrid composites reinforced by nanoparticles (SiC and BN) with different weight percentages. Pin on disk used for the wear test for ZA-12 alloy and its composites. It is found that the nanoparticles improved the hardness and the wear properties of alloys. Since nanoparticles impede dislocations movement, causing an enhancement in the mechanical properties. The microstructure and the phases formed were analyzed using an optical microscope with various magnifications. SEM analysis denotes the uniform distribution of the different weight percentages of SiC and BN nanoparticles in the based alloy, which explains the improvement in the wear properties.

Keywords. ZA-12 Alloy, Stir casting, Hybrid composite, Nanoparticles, Hardness, Wear rate.

1. Introduction

As a promising material, Zinc-aluminum alloys are used extensively for tribological applications. They become a substitutional material for aluminum cast alloys and bronzes due to their successful casting capability and specific combination of properties. Even when ZA alloys requested under conditions with elevated mechanical loads, medium sliding speeds, and reasonable operating temperatures, they can be competing materials like cast iron, plastics, and steel [1]. ZA alloys are suitable for bearing materials with heavy load and low-speed applications [2]. However, at elevated temperatures above 100 °C, these alloys lose some of their mechanical properties [3]. Ceramic dispersions and several fibers have been supplied as reinforcement particles to enhance their performance [4]. ZA-based composites were fabricated with techniques like stir casting and liquid metal infiltration. These metal-matrix composites strengthened their mechanical properties by using ceramic particles or whiskers [5].

ZA12 alloy is perfect for the use of permanent molding, bearings, and thin wall decorations, as it has excellent strength, hardness, creep properties, and dimensional stability [3, 4]. With more than one reinforcement providing unique properties, hybrid MMCs were produced through strengthening the base matrix. Such composite materials that combine two or more reinforcing particles would enhance the composite’s mechanical properties [6, 7].

B. Adaveesha et al. (2017) examined the wear rate of ZA43 alloys composites, which reinforced using B4C nanoparticles with (3, 6, 9) wt. %, and the influence of the standard load applied as well as the sliding distance of the rate of wear. The ZA43 alloy has been manufactured using a stir casting technique.
Indicated results show that the wear resistance of composites was more significant than the alloy without reinforcing [8]. N. Shivakumar et al. (2017) investigated the ZA-27 alloy-based composites using (1, 2, 3) wt. % aluminum oxide (Al2O3) as a reinforcement nanoparticle. Those alloys produced using the stir casting method. It has been noticed when the wt. % of the reinforced nanoparticles increase, wear resistance increases [9].

N.S. Kumar (2018) developed ZA-27 alloy with adding reinforcement particles of 0.5 wt. % graphite (Gr) and 1.5 wt. % SiC, using the stir casting technique to produce the hybrid composite. Results indicated an increment in the mechanical properties of the hybrid composite when compared with the base metal. At the same time, wear volume loss of the hybrid composite was decreased [10]. R. H. SEKHar et al. (2018) examined the heat treatment influence and the time of aging on mechanical and tribological properties to ZA alloy reinforced with Nickel of (2, 4, 6 and 8) wt. % as a reinforcement particle, which was prepared using the stir casting method. The results indicated an enhancement in mechanical and wear characteristics with increasing the amount of Ni. Also, the wear rate decreased with aging [11].

The current research aims to investigate the mechanical behavior and research the ZA-12 alloy microstructure using stir casting procedure and recycled alloys to produce these alloys. Also, examined the influence of the hybrid composite with various percentages of nanoparticles on mechanical characteristics.

2. Methods and materials

2.1. Selection of materials

2.1.1. Matrix Materials. Due to the significant mechanical properties of zinc-aluminum alloys ZA-12 and their characterization, they were fabricated and used as a matrix material. The Spectrochemical composition is indicated in Table (1).

| Element | Cu % | Al % | Zn% | Other Elements% |
|---------|------|------|-----|-----------------|
| Chemical Composition | 0.8  | 11.4 | 87.5 | 0.3             |

2.1.2. Reinforcing Materials. Boron nitride and silicon carbide are used for reinforcing the ZA-12 alloys. The raw powder morphology was achieved using Scanning Electron Microscopy, which is indicated in Figure (1).

![Figure 1. SEM for (SiC and BN) nanopowders.](image-url)
2.2. Production of matrix material
By using the stir casting process, aluminum scrap (AL alloy 2024), pure AL (electrical wires), and zinc alloy were used to manufacture the ZA-12 matrix material. They were molten within a crucible made of graphite, and an electrical furnace was used to heat up to around 700 °C (more than their melting temperature) to achieve the maximum melt and then mixed via a mechanical stirrer for ensuring the homogeneous mixing forming. With using 0.25 wt. % flux cleaning (KCl - NaCl - NaF) typically more affluent in chlorides to promote the inclusions of oxide wet and better separating of melt. Hexachloroethane has been used to degases the melt to throw away contaminants as well as gases. SiC and BN, the reinforcement nanoparticles with specific weight percent, were applied as wrapped in aluminum foil to the melted matrix. A mechanical stirrer was continuously used for (2-3) times with (1000-1200) rpm speed. Then, the slags removed, and also poured the molten liquid into a specific mold. The casting has been removed from the mold just after solidification and shaped into the required shapes. Figure (2) and Figure (3) show the mold preparation and design.

2.3. Hardness test
The composite hardness has calculated using the Vickers Macro Hardness Tester. It had used to examine the influence of the particles fraction weight on the matrix hardness. The applied load was 294 N for 10 sec. An average of three measurements was taken at different locations on the surface of the specimen.
2.4. Wear test
A dry sliding wear test, pin on disc type based on ASTM G99-95 standards was conducted. The specimen dimensions were 10 mm in diameter with a length of 30 mm, as shown in Figure (4). It has been used to examine the wear rate of ZA-12 alloy reinforced with nanoparticles (BN, SiC). The specimen dimensions were 10 mm in diameter with a length of 30 mm, and loads of (10, 20, 30) N were applied; the rotational disk speed is 950 rpm, and the sliding distance is 65 mm for 15 minutes. The disk is made of stainless steel with a hardness of 55 HRC. Using Equation (1), the wear rate is calculated from the mass loss slope per sliding distance.

\[ W.R = \frac{\Delta W}{2 \pi r \cdot n \cdot t} \]  

Where: \( W.R \): Rate of wear (g/cm), \( \Delta W \): Weight loss, as \( \Delta W = W_1 - W_2 \), \( W_1 \): Weight before testing (g), \( W_2 \): Weight after testing (g), \( r \): Distance of Sliding (cm), \( n \): Disk rotational speed in (r.p.m.) and \( t \): time 15 (min).

![Figure 4. Wear specimen dimensions.](image)

2.5. Microstructure
The microstructure of ZA alloys was achieved by using an optical microscope with various magnifications for analyzing microstructure and phases formed by a metallographic microscope. Specimens have been etched with Keller solution (3 ml HF, H₂O, and 6 ml HNO₃). Also, scanning electron microscopic was used to analyze the microstructure of the hybrid composite and showed the uniform distribution of the different weight percentages of the nanoparticles in the based alloy.

3. Results and discussion
3.1. Hardness measurement
Hardness is one of the essential indicators of material mechanical properties. It is the material ability (under certain conditions) to resist the deformation of another object pressing on it. Vickers hardness value of the specmen was given in Figure (5). The hardness results of the ZA-12 alloy and its composite indicated an increase when the weight percentage of nanoparticles increased [12]. Increasing in hardness was due to the dispersion strengthening of reinforcement nanomaterials, which restrict dislocation movement [3]. Increasing the composite material’s load-bearing capability is affected by the addition of hard reinforcement particles (BN and SiC). At (3%BN and 3%SiC) observed the maximum value of the hardness. The improvement ratio in hardness after the addition was 26%.
3.2. Wear rate measurement

As the adding of nanoparticulate additives continued to increase, the composite’s wear rates decreased, as shown in Figure (6). Increasing the applied load caused increasing the wear rate and a transformation from mild wear to severe wear, which occur at dry lubrication condition load. Compared to composites, the transformation of alloys was much more pronounced than its composites [13]. Maybe the increase in reinforcement has led to increasing hardness, generating a barrier on the surface to resist the penetration by hard particles. Minimum wear loss was confirmed for ZA-12 at reinforcement (3%BN + 3%SiC). With hybrid composite nanoparticles increasing, the wear rate decreased due to the reinforcing materials’ presence, which assumes that the reinforcing materials formed a stable film on surface composites [14]. The composite’s hardness and wear properties have been enhanced by adding the nano-ceramic particles, which help in forming a stable tribo-layer. Compared with the unreinforced matrix, the ZA hybrid composites noted an enhancement in hardness and even a minimum wear rate. The hybrid composites with (3wt. % BN + 3wt. % SiC) exhibited higher mechanical properties than the ZA-12 alloys reinforced single and the hybrid composites. The improvement ratio in wear rate after the addition was 24%.

Figure 5. Hardness values of ZA-12 alloy and its composites.

Figure 6. ZA-12 alloy wear rate and its composites.
3.3. Microstructure Analysis
The microstructure results were examined with an optical microscope to analyze the microstructure and the phases formed using a microscope. In another way, reinforcement dispersion in the matrix became better. While the nano-particles percentage increased in the matrix, the particles of reinforcement increased, and also the space of the inter particles decreased. The microstructure seems to be dendritic; the principal dendrites were divided due to mechanical stirring, which explains the development of the probability of incorporating and trapping nano-sized particles inside the inter-dendritic interface formed mostly during solidification of the dispersed alloys [15], as shown in Figure (7). The SEM analysis of the microstructure of the hybrid composite has indicated a homogenous structure for the ZA-12 alloy-based hybrid composites, as shown in Figure (8).

Figure 7. ZA-12 alloy microstructure reinforced by various percentages of nanoparticles and magnification power of (10x).
4. Conclusion

According to the results obtained from the current investigation, the following conclusions can be pointed out:

- The hardness values of ZA-12 alloy and the hybrid composites materials were increased with increasing the reinforcement percentage.
- The ZA-12 composite reinforced with (3%BN+3%SiC) hybrid nanocomposites indicated a lower wear rate due to the presence of the hard-ceramic materials.
- With dendritic structure, the microstructure of ZA-12 alloy and the hybrid nanocomposites showed a uniform distribution with the presence of agglomeration particles. Consequently, the mechanical properties of the composite were increased with an increase in the weight percentage of the nanoparticles.
- The microstructure analysis showed a uniform distribution of the particles in the matrix provided by the nano reinforcement percentages weight of (BN and SiC) that clarified the enhancement in the wear properties.

5. References

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