Corrosion Behavior of Zinc Alloy Based Metal Matrix Composites Reinforced with nano BN

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Abstract. In this study, zinc alloy metal matrix nanocomposites reinforced by different weight percentage (2%, 4%, 6%, 8%) of nano BN particles were produced using the stir casting technique. The corrosion behaviors of both unreinforced alloy and reinforced composites were examined using potentiostat test in a salt solution (3.5 wt.% NaCl). Optical microscopy was used to examine the microstructure of the composites surface have been found to be stable with the distribution of uniformed reinforce particles and strong interfacial bonding between the matrix alloy and reinforcement. The results improve corrosion resistance for metal matrix composites exhibited better corrosion resistance than the matrix in 3.5 wt. % NaCl solution. Increasing the weight percentage of the reinforcement nano BN particulates decreased the corrosion rate of the composites.

Keywords: Zinc Alloy, Stir Casting, Nano composite, Nanoparticles, Corrosion behavior & potentiostat.

1. INTRODUCTION

High aluminum zinc alloy (ZA alloys) for the last few decades are occupying attention of both researches and industry, as a tribomaterial of significant potential. It can be said that, at this moment, ZA alloys commercially available, due to good castability and unique combination of properties, which become the alternative material primarily for many aluminum cast alloys and bearing bronzes, also plastic materials, even for steels that operate under conditions of high mechanical loadings and moderate sliding speeds. The interest in extending the practical application of these alloys, besides the tribological, the economic and ecological character. They are known to be cheap material processed energetically, efficiently and without endangering the environment [1].

Zinc alloy die castings have been used in a multitude of applications for many decades with great success. Their good physical and mechanical properties, excellent finishing characteristics, and resistance to atmospheric corrosion have enabled them to withstand the test of time[2]. They allow for greater variation in section design and for the maintenance of closer dimensional tolerances [3].

ZA-8 is the high strength performer of the zinc alloys. It is also the lightest alloy and offers excellent bearing resistance, the higher aluminum and copper contents give them several distinct advantages over the traditional zinc alloys, including higher strength, superior wear resistance, superior creep resistance and lower densities. However, when wear resistance properties are needed, ZA-8 has demonstrated extraordinary performance [4].

The attractive properties of the ZA-8 alloy have inspired researchers to reinforce them with ceramic dispersions in order to obtain much more enhanced mechanical and tribological properties. The reinforcement of the alloy with
graphite and SiC has shown improvement in the mechanical and wear properties. The Metal Matrix Composite (MMCs) based on ZA-8 matrix are being increasingly applied as light-weight and wear resistant materials[5]. In the real casting conditions, the ZA alloys have the typical dendritic structure, which depends on several factors. Namely the cooling rate imposes strong influence on the structure fineness [6]. The hybrid metal matrix composites contains two or more type of reinforcements. Reinforcements in terms of mixtures of particles, whiskers and fibers with different weight percentage and varying sizes are utilized in metal matrix for multi functional properties. Particle distribution in the matrix material during the melt stage of casting process depends on the viscosity of the slurry, the extent to which particles can be successfully incorporated in the melt. The characteristics of the reinforcement particles themselves influence the settling rate and the effectiveness of mixing in breaking up agglomerates, minimizing gas entrapment and distributing particles [7].

Seah et al. [8] compared the hardness of as-cast and artificial aged specimens of ZA-27/Gr particulate composites that had effect only on the matrix rather than the alloy. Inclusion of Gr particles reduced the hardness considerably for as-cast, at the same time increased for aged specimens. Babic et al. [9] compared the as cast and heat treated ZA-27 alloy with Gr reinforced composite specimens. The results for alloy showed reduced UTS and hardness with increase in elongation. Inclusion of Gr particulates with the alloy showed reduction in the hardness. Ranganath et al. [10] studied the mechanical properties of ZA-27 reinforced with different % by wt. of TiO2. The conclusion drawn was, with the inclusion of reinforced particles improved UTS, Young’s modulus, yield strength and hardness in composites was observed while there was reduction in the ductility. Prasad [11] evaluated the tensile property of ZA-27 and the effect of microstructure, composition and test conditions. Experiments were carried at different temperatures and strain rates. The tensile strength of the alloy improved with increase in the strain rate, but at higher temperature, reverse trend followed. Elongation had no effect on strain rate or temperature which kept increasing.

The aims of the study work to evaluate the corrosion behavior and microstructure of ZA-8 alloy by using a recycled alloys produced by stir casting and study the effect of different percentages of nano BN particles on Zn alloy.

METHODS AND MATERIALS
2.Materials Selection
2.1. Matrix Materials
Matrix material used in this research was ZA-8 which has excellent properties with a wide range of applications. Its chemical composition is shown in table (1).

| Element                  | Al% | Cu% | Mg%      | Fe% | Cd%  | Pb%  | Zn%   |
|--------------------------|-----|-----|----------|-----|------|------|-------|
| Nominal Chemical Comp., standard [12] | 8.8 | 0.8-13 | 0.015-0.03 | 0.075 | 0.006 | 0.006 | Rem   |
| Actual chemical Composition of ZA-8 alloy | 8.34 | 5.14 | 0.013 | 0.014 | 0.0015 | 0.0009 | Rem   |

2.2 Nano Boron Nitride as a Reinforcing Materials
It was used a ceramic powder (nano BN) as reinforcement for ZA-8 alloy. The morphology of raw powder was done made with Scanning Electron Microscopy (SEM) as shown in figure (1).
2.3 Production of Matrix Material and its Composite

For the production of matrix material (ZA-8 alloy) it used The weight of melting alloys was approximately equal to 265 gm , which included 225 gm electrolytic zinc (99.99%), 10 gm pure aluminum , 20 gm master alloy 50 Cu-50Al and 10 gm AA2024. All the alloys were melted in a graphite crucible using gas furnace to about 700 °C (above its melting point) to ensure full melting [13]. The molten material was mixed using a mechanical stirrer to get a homogenous mixture. Flux cleaning (KCl- NaCl- NaF) with weight percentage 0.25% were used which usually richer in chlorides to facilitate wetting of the oxide inclusions for easier separation from the melt. The melt was degassed using hexachlorethane to get rid of impurities and gases [14,15]. The reinforcement nanoparticles (BN, Si3N4) with different weight percentages were added to the melted matrix as packaged in aluminum foil and continuously stirred using a mechanical stirrer for 2-3 times and speed 1000-1200 rpm. to get a uniform mixing of particulate reinforcing material in the matrix. The slag was removed and then the molten material was poured into a cylindrical graphite mold (permanent mold casting) for casting and the temperature was gradually lowered. Figure (2) and figure (3) show the mold preparation and sketch of mold with dimensions, respectively.

Figure (1): SEM of nano BN powder.

Figure (2): Mold preparation
2.4. Polarization measurements

All experiments were carried out in (500) ml of test solution by using a three electrodes cell with saturated calomel electrode (SCE) as a reference, platinum electrode as counter electrode and the cylindrical specimens of the alloy with active flat disc of (0.78) cm² as the working electrode. All the values of potential are therefore referred to the SCE. Finely polished composite and base alloy specimens were exposed to corrosion medium and allowed to establish a steady state open circuit potentially, followed by polarization measurements at a scan rate of (3) mV/s for Tafel plots. Fig. (4) Shows the experimental set up for electrochemical measurement.
Figure. 4 Experimental set up for electrochemical measurement.

The values of corrosion current density ($i_{corr}$) were obtained from the point of intersection of both linear parts of the anodic and cathodic polarization curves with the stationary corrosion potential ($E_{corr}$).

Corrosion rate can be calculated by using the following equation [16]:

$$\text{corrosion rate} = \frac{3.27 \times 10^{-3}}{\rho} \times i_{corr} \times EW \quad (1)$$

Where, $i_{corr}$ (in $\mu A/cm^2$) is the corrosion current density; $EW$ in (gm) is the equivalent weight of the corroding species, and $\rho$ in (g/cm$^3$) is the density of the corroding species.

3. Results and Discussion

3.1 Corrosion behavior in 3.5% NaCl Solution

The corrosion parameters of ZA-8 alloy and its composites in 3.5% solution NaCl are given in Table (2). It can be clearly observed that corrosion rate of unreinforced alloy is higher than in the case of composites due to nano particles is hardly affected by salt medium and not affect the corrosion mechanism of the composite.

| Composite        | (3.5% NaCl) solution |
|------------------|----------------------|
|                  | $i_{corr}$ (\mu A/cm$^2$) | Corrosion Rate (mm/y) |
| ZA-8 alloy       | 127.54               | 1.2754                |
| ZA-8 alloy/2%BN  | 36.98                | 0.3698                |
| ZA-8 alloy/4%BN  | 23.75                | 0.2375                |
| ZA-8 alloy/6%BN  | 8.61                 | 0.0861                |
| ZA-8 alloy/8%BN  | 3.51                 | 0.0351                |

It can be observed from the polarization curves Figures (5) to (9) and Table (2) that the corrosion current density ($i_{corr}$) values and the corrosion rate decreases with increase in nano particles content in the composites. The addition of hard particles into the alloy can increase the corrosion resistance by the physical properties of reinforcement. Uniform dispersion of reinforcement particles in ZA-8 alloy which shows the better corrosion resistance. Increasing the weight percentages of the reinforcement nanoparticles increasing the corrosion resistance of the composite. It has been found that the hybrid composites show better corrosion resistance when compared with the base alloy and nanoparticulates are ceramic materials and they remain inert. However, during preparation of composites, it observed that no reaction between the reinforcement material and the metal matrix occurs that increasing nano particles could enhance the corrosion resistance.
Figure 5 Polarization curves for ZA-8 alloy in (3.5% NaCl) solution

Figure 6 Polarization curves for ZA-8 alloy/2%BN composite in (3.5% NaCl) solution
Figure 7 Polarization curves for ZA-8 alloy/4%BN composite in (3.5% NaCl) solution

Figure 8 Polarization curves for ZA-8 alloy/6%BN composite in (3.5% NaCl) solution
3.2 Microstructure Analysis

The microstructure was studied by an optical microscope in order to examine the microstructure and the formed phases using metallographic microscope. It noticed better dispersion of reinforcement in the matrix. As the weight percentage of nano particles increases in the matrix, the reinforcement particles increases and the inter particle space decreases. There is no indication of agglomeration of reinforcement in the matrix. The microstructure is dendritic, the primary dendrites are fragmented because of mechanical stirring that explains the improvement in the possibility of incorporating and entrapping nano-sized particles within the interdendritic interface developing during the solidification of the dispersed alloys as shown in Fig. (10).

4. CONCLUSION

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

- The composites reinforced with nanoparticles were exhibited higher corrosion resistance in (3.5%NaCl solution) than the base alloy.
- Corrosion current density values (icorr) decrease with increase in nano particles content in the composites for (3.5% NaCl solution).
- The reinforcement with (8% BN) nanoparticles were the best nanocomposites for corrosion resistance due to nanoparticulates are ceramic materials and they remain inert due to non-reactivity of nanoparticles with corrosive medium.
- The microstructure of ZA-8 alloy reinforced with nano particles seem to be distributed uniformly and strong interfacial bonding between the matrix alloy and reinforcement. Thus, increased nanoparticles with weight percentage increases the corrosion resistance of the composite.
Figure 10. Microstructure of ZA-8 alloy matrix with nano particles at different weight percent
A) ZA-8 alloy  B) ZA-8 alloy/2%BN  C) ZA-8 alloy/4%BN
D) ZA-8 alloy/6%BN  E) ZA-8 alloy/8%BN

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