Effect of ZrO2 Nano Particles on Mechanical and Corrosion Behaviour of Al2024 Alloy

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Abstract

In this study, Mechanical and Corrosion behaviour of Aluminium 2024 (Al-2024) alloy reinforced with varying weight percentage (0, 2, 4 and 6%) of ZrO_2 nano particles have been investigated. The composite was prepared through stir casting route. The rockwell hardness method was used to evaluate the hardness of the composites. The Electrochemical polarization test was carried out in 3.5% NaCl solution (sea water environment) to evaluate the corrosion resistance of the alloy. The results showed that the corrosion resistance of the alloy is significantly increased in sea water environment with increasing in addition of ZrO_2 nano particles. The corrosion morphology of the samples after corrosion were examined using Scanning electron microscope.

Keywords: Al 2024, ZrO2, Hardness, Electrochemical Corrosion.

1. Introduction

Metal matrix nano composites (MMnC) are becoming an advanced class structural material by replacing conventional metals such as steel, cast iron copper etc. Combined properties of hard ceramic particles and the matrix phase have extended the interest of MMnC in different applications such as structural, aerospace and automobile industries [1]. MMnC offers high specific strength, high specific stiffness, excellent corrosion and wear resistance, high elastic modulus etc., which makes them superior when compared to monolithic metals and alloys [2-6]. The performance of any MMnCs depends on selection of proper matrix-reinforcement combination. Owing to their low density (2.7 g/cm^3), aluminium and aluminium alloys have gained a great attention to use in MMnCs for many engineering applications, especially where weight reduction is more concerned. Various ceramic materials such as SiC, Al_2O_3, ZrO_2, Y_2O_3, B_4C etc., used as reinforcement either in micron size or nano size [7-11]. Among these ceramic materials, ZrO_2 nano particles are the most promising reinforcing agents especially suitable for anticorrosion coatings. ZrO_2 offers excellent mechanical properties, excellent wear and chemical resistance. The addition of ZrO_2 nano particles also improves overall mechanical properties of composites [12-15].

Processing of MMnC remains challenging in order to produce defect free composites and as well as to achieve desired properties. Literature have witnessed use of different processing techniques for MMnC such as stir casting, powder metallurgy, dis integrated melt deposition etc.,. Among these techniques stir casting found more suitable and effective method for producing MMnC. Despite of poor interfacial reaction between matrix and reinforcement, stir casting is considered to be the most economical due to its lower processing cost, flexibility and high production rate [16]. Therefore, In present study an attempt is made to investigate hardness and corrosion resistance of Al 2024/ ZrO_2 nano composites by varying ZrO2 nano particles.

2. Experimental Procedure

Aluminium 2024 alloy which contains copper as a chief alloying agent was used as a matrix material. Al 2024 alloys used in the form of ingots to melt. The chemical composition of Al 2024 obtained from Atomic Absorption Spectroscopy which is given in the Table 1. ZrO_2 nano particles with 99.9% purity, spherical shape and average diameter of 50 nm were used as a reinforcement material. Fig.1 shows SEM image of zirconia nano powder which confirms the size of particles below 50 nm.

Table 1 Chemical Composition of Al 2024

Element	Cu	Mg	Mn	Fe	Zn	Al
Content %	4.3	1.4	0.3	0.5	0.5	balance

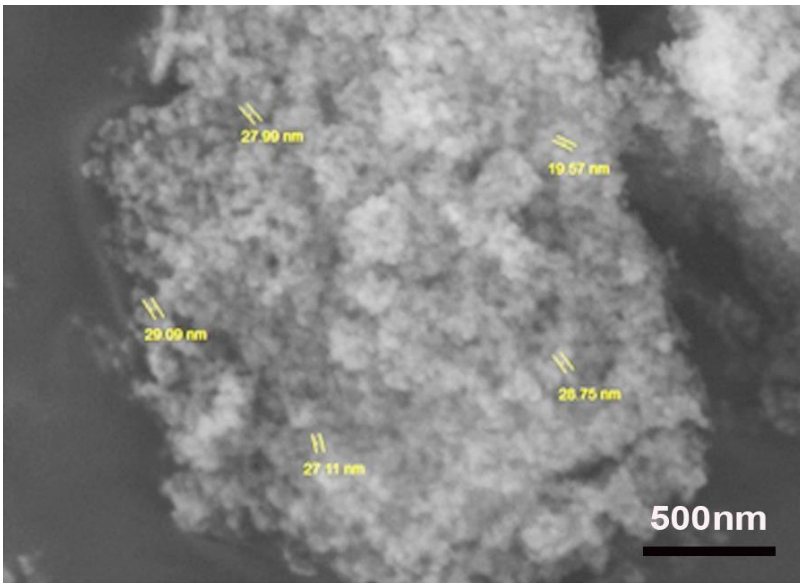

Fig. 1 SEM image of ZrO_2 nano particles

Temperature of molten alloy maintained at 800^0C (above the melting temperature of aluminium). ZrO_2 nano particles was preheated to 300^0C and added to molten alloy. Stirring was carried out using a steel impeller with the rotation speed of 500 rpm. The melting temperature was brought down to 650^0C in order to homogenize the mixture and composites were poured into 350^0C preheated mould. Composites were prepared in 3different compositions i.e. 0%, 2%, 4% and 6% of ZrO_2 nano particles. EDS test was carried out to verify the distribution of nano particles in matrix phase.Specimens of 50 mm diameter, 30 mm length for Rockwell hardness test with 100kgf load was applied and 1/16” ball indenter was used to make the indentation. The specimen size of 25mm x 5mm x 0.8mm were prepared for Tafel polarization test. Three electrode modes in conjunction with a potentiostat were used to carry out the polarization experiments. The specimen was made as working electrode, platinum was used as counter electrode and silver/silver chloride was used as the reference electrode. 3.5% NaCl solution (sea water environment) and 3.25% NaCl + 0.25% $(NH)_2SO_4$ (industrial environment). SEM studies are carried out to evaluate the corrosion behaviour of the composite.

3. Results and discussions

3.1 Microstructural and Mechanical Characterization

The SEM image of 2% ZrO_2/Al_2O_3 nano composite is shown in Fig.2. It reveals uniform distribution of ZrO_2 nano particles in Al2024 aluminium alloy matrix. However, segregation of ZrO_2 nano particles are observed in some parts due to improper dispersion caused by poor wettability of nano particles with matrix phase. The EDS was carried out to know the distribution and presence of nano particles. Intensity of the peaks in EDS confirms the presence of ZrO nano particles (Fig.2.b).

The results of the Rockwell hardness test as shown in Table 2. It clearly indicates that significant increase in hardness of MMnCs with increase in the percentage of ZrO_2 reinforcement. Hardness was increased from 70 to 80. The increase hardness is due to the inherent hard nature of the ceramic reinforcement. The reinforcement particles also act as obstacles to the movement of dislocations, which strengthens the material. Hence, with increase in the percentage of reinforcement, the material gains strength and hardness.

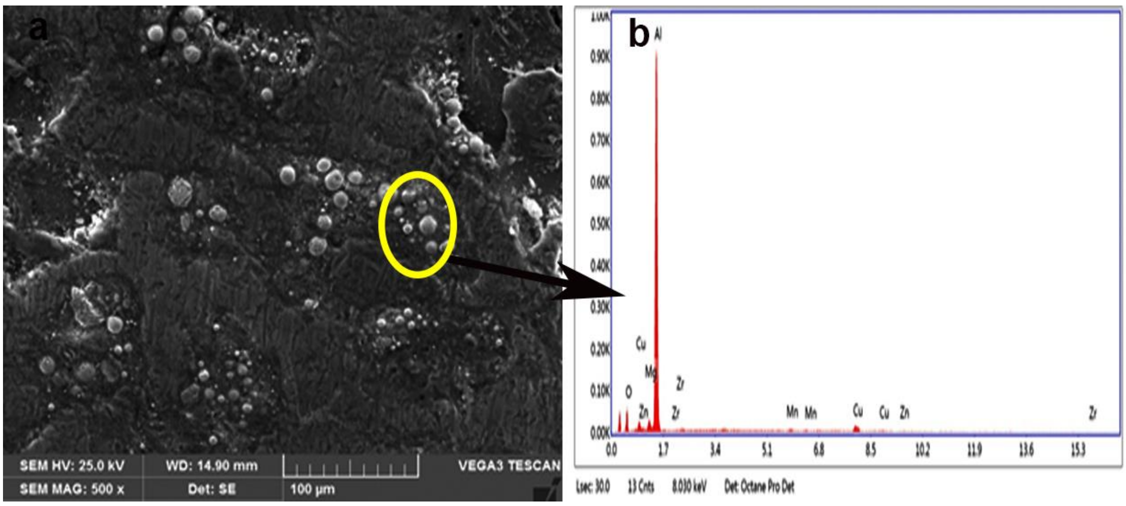

Fig. 2 (a) SEM image and (b) 2% ZrO_2/Al 2024 nano composite

Table 2 Hardness values of prepared MMnC

Sl no	% Reinforcement	Average hardness value (B scale)
1	0	70
2	2	75
3	4	78
4	6	80

3.2 Corrosion behaviour of Al2024/ZrO_2 nano composite

Fig. 3 shows Potentiodynamic polarization curve of base alloy and MMnC in sea water (NaCl) environment. Table 3 shows the values of corrosion potential, corrosion density and corrosion rate derived from tafel fit. It is observed that corrosion potential was shifted from 0.719V to -0.745V and current potential decreased with increasing the percentage of ZrO_2. This clearly authenticates that adding of ZrO_2 nano particles increases the corrosion resistance than the base alloy.

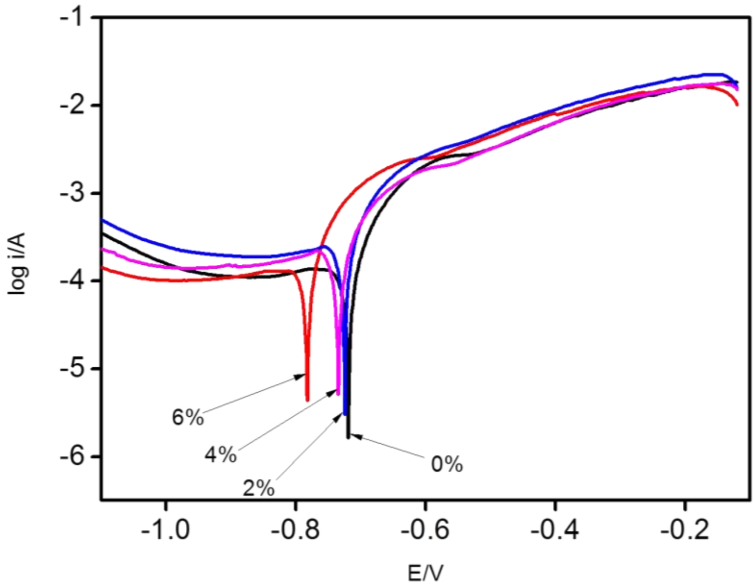

Fig. 3 Potentiodynamic polarization curve of base alloy and MMnC in sea water environment

Table 3 Data derived from Tafel fit of MMCs in NaCl electrolyte

Sl no.	% Reinforcement	Corrosion potential(V)	Corrosion current density (A/cm^2)	Corrosion Rate mm/yr
1	0	-0.719	5.79	0.18
2	2	-0.735	5.52	0.15
3	4	-0.752	5.36	0.12
4	6	-0.745	5.29	0.10

This is due to the fact that the reinforcement is a ceramic, which is a passive material. Also, the particles of the reinforcement locally prevent exposure of the metallic surface to corrosion environment which increases corrosion resistance.

Fig.4 shows the morphology of corroded surfaces of Al2024/ rO_2 reinforced nano composites. The Fig 4a shows the corrosion morphology of base alloy. It shows corrosion pits observed on the surfaces. The presence of discontinuity like porosity which acts as the starting point for pitting corrosion. Thus results in the production of positive ions in the pit which tends to attract the negative ions from the electrolyte. This leads to formation of Aluminium chloride molecule in the pit at a fast rate due to which corrosion takes place rapidly leading to dissolution of the metal. Fig 4d shows the uniform corrosion resistance. Thus adding of ZrO2 oxide increased the corrosion resistance of the composite.

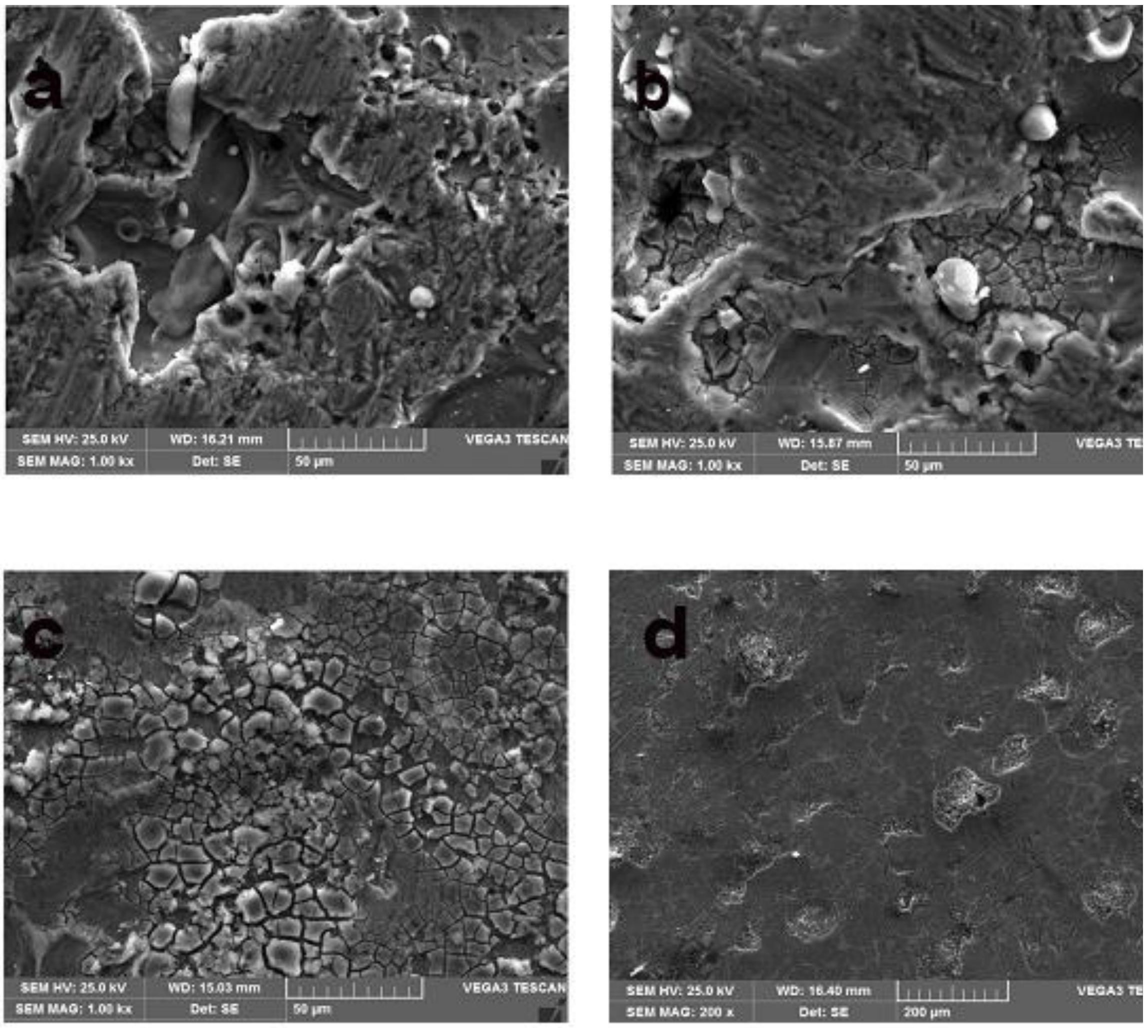

Fig 4 a) base alloy b) 2% ZrO_2 c) 4% ZrO_2 d) 6% ZrO_2

Conclusion

- Al 2024/ZrO_2 nano composites are fabricated through stir casting technique. Distribution of nano particles found uniform however formation of clusters was observed at some portions.
- Hardness of the composites found higher compared to base alloy. Hardness increased with increase in percentage of nano particles.
- In salt water environment (3.5% NaCl), the adding of ZrO_2 nano composites increases the corrosion resistance of the composite. Thus ZrO_2 reinforcement has a positive impact on improving the corrosion resistance in the case of pitting corrosion prevalent in sea water.

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