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Corrosion Behavior of Al-Ni Matrix Composites in a dilute sodium chloride solution

Nawal Mohammed Dawood[1], Abrar Ayad Hassan[2]

Asst. Professor, Dept. of Metallurgical Engineering, Materials Engineering College, Universityof Babylon, Babylon, Iraq[1]
Materials Engineering, University of Babylon, Babylon, Iraq[2]

ABSTRACT— Aluminum Matrix Composites (AMCs) have been used in several applications in aerospace and automotive industries. Although several technical challenges exist with casting technology. Achieving a uniform distribution of reinforcement within the matrix is one such challenge, which affects directly on the properties and quality of composite. Hence, this work aims to improve the mechanical and corrosive resistance of aluminum by reinforcing with yttrium oxide and nickel through stir casting using vortex technique. Al-Ni-Y_2O_3 composite with the percentage of Ni fixed at 20 % and Y_2O_3differed through 3-9% in increments of 3 wt.%. The hardness value of the aluminum matrix composite improved with increased percentages of Y_2O_3, and the maximum increase was obtained for 9% Y_2O_3 composite, viewing an increase of about 52%. Potentiostatic polarization test for the Al-20%Ni base alloy and the prepared composite were carried out in 3.5wt% NaCl solution as corrosive medium. There was a noticeable improvement in the corrosion resistance of the aluminum composite compared to its purest form, owing to the presences of nickel. However, the increase in Y_2O_3 percentage decreased the corrosion rates. The extreme decrease in corrosion rates was obtained for 6% Y_2O_3 composite in 3% wt. NaCl solution which reach to 5.51 in (mpy) unit for composite material which is lower than that of the base alloy 118.59 (mpy).

KEYWORDS: Metal matrix composite, Stir casting, Corrosion, NiAl, Potentiostatic polarization test.

1. INTRODUCTION

Owing to the weak mechanical properties of pure aluminium, many works have been performed to enhance the properties of aluminium by alloying and heat treatment. Through alloying, high mechanical strength can be obtained by the formation of a fine and homogeneous distribution of intermetallic compounds [1]. Recently, intermetallic compounds have attracted much attention due to their potential technological applications as high-temperature materials. Among these intermetallic compounds, Al–Ni system compounds stand out as promising candidates for high-temperature materials for the use in harsh environments [2]. The Al–Ni alloy has good performance such as light weight, high strength, and high temperature stability [3]. The vital use of nickel is, they are characterized by better strength, ductility, and resistance to corrosion environment. It is a silvery-white, hard, malleable, and ductile metal [4]. In aluminum matrix composite system (AMCs), the most common types of reinforcement that can be used are SiC, Si_3N_4, Y_2O_3, TiC, and Al_2O_3. Among these ceramics, Y_2O_3 was selected as the reinforcement to be used in this study due to its high strength, hardness, melting point, and thermal conductivity. Yttria is an air-stable particle, white in color and solid in substance. By adding the yttria to the aluminum, the strength, corrosion resistance, and wear properties are improved. Yttria is well sintered to a high density and low coefficient of thermal expansion, and has excellent strength properties [5]. The properties of MMCs are dependent on many factors such as type of processing method, volume fraction, type of matrix, and geometry of reinforcement. There are several techniques for fabricating MMCs like Stir casting, Powder metallurgy, Gas infiltration, Spray forming, Chemical vapor deposition, Electroplating, etc. Out of all these techniques, Stir casting is the most common as it is simple to use as well as it is cost effective in nature [6]. The current research aims to improve the corrosion resistance of aluminum after strengthening it with nickel and yttrium oxide by preparing specimens of aluminum-nickel- yttrium oxide composite materials in a way of manufacturing stir casting where the percentage of nickel is fixed at 20 wt.% with different weight percentages of yttrium oxide (3-6-9 wt.%). the corrosion behavior of all composites in seawater (3.5% NaCl solution) were investigated in this study.

2. EXPERIMENTAL WORK

2.1 Materials and procedures

The materials shown in Table 1 were used to prepare the Al–20wt. % Ni alloys alone without and with different weight percentage of Y_2O_3 with average sizes of particles, purity and origin of ingredients.

Table 1: Materials Used in this Study

Material	Conditions	Purity %	origin of ingredients.
Aluminum (Al)	Al-wire	99.97	Local markets
Yttria (Y_2O_3) powder	5.54 particle size	99.87	Fluke - Swiss made
Nickel (Ni)	Flakes	99	Changxing galaxy international Trade CO., LTD

2.2 Preparation of Al-20wt. % Ni Specimens

Aluminum pieces were charged into the graphite crucible which was put in electric furnace. Temperature development inside the crucible was monitored using thermocouple type-k and the furnace temperature was raised to liquids temperature (750°C) in order to melt the aluminum completely. An argon stream was applied on molten to eject the slags on surface and remove these slags using alumina spoon. Then, nickel flakes were added gradually and stirred until it melted. Subsequently, the melt was poured into the steel die which was dried before the casting process at 200°C using drying instrument. To produce Al–Ni alloy with fixed ratio of nickel, pure aluminium (99.8%) and pure nickel (99.98%) were used. The casting process was carried out in an electrical induction furnace with a graphite crucible. The molten metal was put into the metal mould at a pouring temperature of 750 ºC. Pure aluminum was melted in the beginning of the melting process, and then certain amounts of nickel were added to the molten metal to obtain Al–Ni alloys with fixed Ni contents (weight ratio 20%). The casting was left in the air to cool down. The specimens of prepared alloy had dimensions of 10 mm in diameter and 90 mm in height.

2.3 Preparation of Al-20wt.% Ni – Y2O3 Composites Specimens by Stir Casting

The stir casting technique was used to prepare composite specimen. In this experiment, a prepared alloy (Al-20%Ni) was first cut to small pieces in order to facilitate its melting in the furnace. It was then superheated above the liquids temperature to create a vortex in the melt using a graphite stirrer. An electrical stirrer was used to mix the Y_2O_3 particles (size of 5μm) with the molten Al-20%Ni alloy and in the production of Y_2O_3 particles reinforced Al-20%Ni matrix composites. Y_2O_3 particles (3, 6, 9 wt%) were wrapped in high-purity aluminum foils and heated to 300°C for 60 minutes in the heating furnace. The heated Y_2O_3 particles were added to the molten Al-20%Ni alloy and the mixture was stirred for ten minutes at a speed of 500rpm. Then, the molten was poured into a pre-heated steel mould to 200°C by gravity casting. The specimens of the prepared alloys had dimensions of 10 mm in diameter and 90 mm in height. The organized stir casting system is shown in Figure 1.

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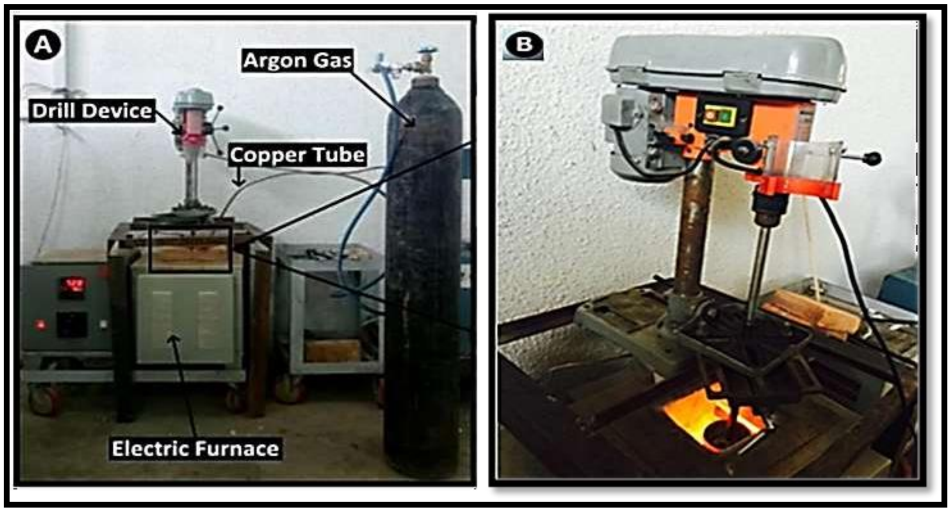

Figure 1: (A): Stir Casting Operation and (B): Electric furnace with stirrer

2.4 Heat Treatments

The heat treatment was conducted at a temperature of 450˚C for 6 hours in order to homogenize the composition, eliminate the semi-soluble phases, and ensure that the casting elements and impurities were homogenously distributed in the alloy, giving the alloy hardness and homogeneous mechanical properties. Table 2 demonstrate the specimen code in this research.

Table 2: Specimens code and chemical compositions of the prepared alloys by stir casting.

Specimen code	Alloys compositions wt%	Weight percentage of the reinforcing(%) particles
A	(Al-20wt%Ni) base alloy	0
B1	(Al-20wt%Ni-3 wt% Y_2O_3)	3
B2	(Al-20wt%Ni-6 wt% Y_2O_3)	6
B3	(Al-20wt%Ni-9 wt% Y_2O_3)	9

2.5 X-Ray Fluorescent Analysis (XRF)

Handheld (XRF) analyzer type (DS-2000) American, is used to explain the chemical composition for castings alloys

2.6 X-Ray Diffraction Analysis

X-ray diffraction analysis have been conducted for Al- 20%Ni and Al-20%Ni-9wt%Y_2O_3 using XRD instrument type Mini flex2. X-ray generator with CuKα radiation at 30.0 mA and 40.0 kV were used in this test.

2.7 Metallographic examination

The microstructures of the cast specimens (Al -20% Ni/3, 6, and 9 %Y2O3 and base alloy) were investigated using a scanning electron microscope (SEM; type: VEGA3 LM) equipped with energy dispersive X-ray spectroscopy (EDX). Metallographic specimens were polished in the usual manner, with final polishing carried out using 3 µm diamond. Specimens were etched with Keller's reagent (1%HF,5%HCl,5 HNO_3 and 95%H_2O) [7] to reveal the microstructures clearly.

2.8 Hardness Test

The hardness test was conducted according to ASTM E10 standard. A hardened steel ball indenter of 10 mm diameter was used to create an indentation on the specimen. The load applied was 31 kg. The diameter of the Indentation was measured across perpendicular direction and the average diameter obtained from three readings were factored into the calculation.

2.9 Corrosion Test

Potentiodynamic polarization test in 3.5 wt% NaCl solution were conducted at room temperature for all alloys with 1.76 cm_2 area in order to understand the corrosion behavior of Al-20wt%Ni without and with Y_2O_3 additions with different percentages. The following procedures were conducted:

1. After Mounting of specimens the grinding and polishing were achieved, each specimen grinded with SiC emery paper in different grits starting from 600,800, 1000 grit to get flat and scratch free surface and finally these specimens were polished with diamond past of 3 µm to get a bright mirror finish for the final step.
2. Calculation of the OCP (open circuit potential) of each specimen in 3.5 wt% NaCl solution, the open circuit potential measurement was maintained up to (10) minute with reading every 10 second. Corrosion rate measurement is obtained by applying the following equation [8].

Corrosion rate (mpy) = 0.13 i_{corr}(E.W.)/A.ρ ……….1

Where: E. W. = equivalent weight (g/ eq)
A = area (cm^2)
ρ = density (g/ cm^3)
0.13= metric and time conversion factor
$i_{corr.}$ = current density (µA / cm^2).
The improvement (I%) was calculated from polarization curves using Eqn. 2 below, [8]:

I% = (CR0 _ CR / CR0) * 100 ………………………..2

Where: CR0 = Corrosion rate of base specimen.
CR = Corrosion rate of specimen (after reinforcement).

3. RESULTS AND DISCUSSION

3.1 Chemical Composition of the Prepared Specimens

The chemical composition for the casting alloy, were analyzed by using (X-ray florescent test). The composition analysis confirm that the main alloying elements are presented within the specified limits. As shown in Table 3 and Table 4 for base alloy (Al- 20wt.%Ni) and composite alloys (Al- 20wt.%Ni-9wt.%Y_2O_3) respectively.

Table 3: Chemical compositions of Al-20 wt% Ni.

Element	**Ni%**	**Cu%**	**Mg%**	**Zn%**	**Mn%**	**Pb%**	**Fe%**	**Cr%**	**Sn%**	**Bi%**	**Cd%**	**La%**
Measured	19.16	0.24	0.15	0.29	0.44	0.14	0.53	0.06	0.31	0.11	0.27	0.05
Eement	**Ce%**	**Y%**	**Al%**									
Measured	**0.03**	**0.00**	**Bal.**									

Table 4: Chemical composition of the composite alloys (Al- 20wt.%Ni-9wt.%Y_2O_3)

Element	**Ni%**	**Cu%**	**Mg%**	**Zn%**	**Mn%**	**Pb%**	**Fe%**	**Cr%**	**Sn%**	**Bi%**	**Cd%**

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Measured	18.80	0.41	0.21	0.21	0.35	0.15	0.44	0.04	0.24	0.25	0.33
Element	**La%**	**Ce%**	**Y%**	**Al%**							
Measured	0.05	0.02	7.43	Bal.							

3.2 Scanning Electron Microscopy (SEM)

The micrograph gained from A, B2 and B3 alloys after being etched with the above mentioned etching solution are shown in Figures 2,3, and 4.

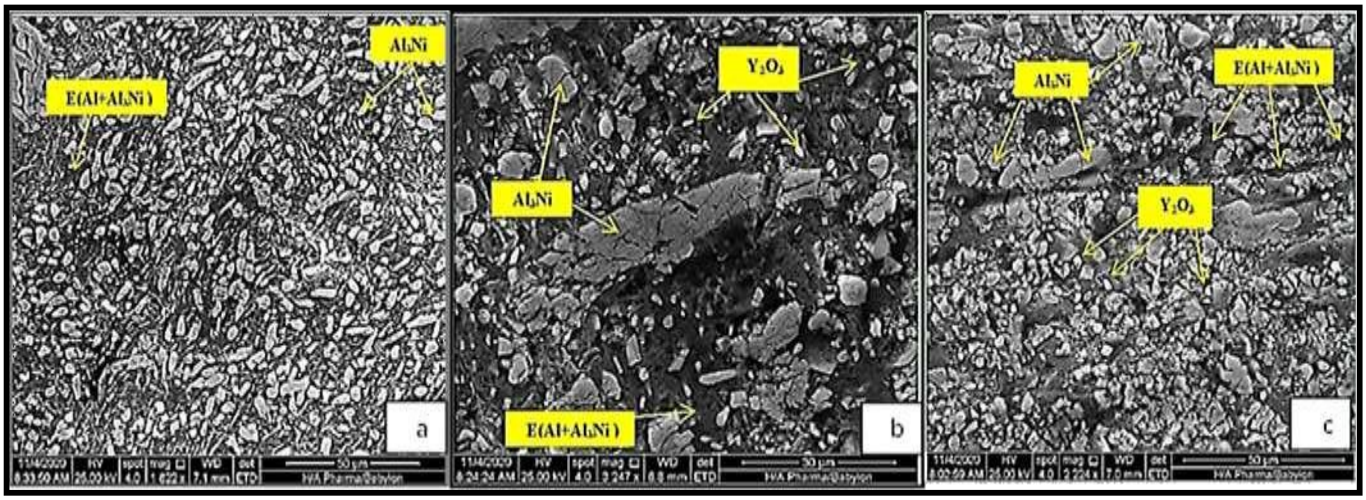

Figure 2: SEM micrograph of (a): Al 20%Ni, (b): Al 20%Ni+6% Y_2O_3 and (c): Al 20%Ni+9% Y_2O_3 specimens evidencing the Al-rich phase (black regions) and the eutectic mixture with Al_3Ni intermetallic particles.

Microstructural observations showed that the addition of nickel to pure aluminum causes appearance of (Al_3Ni– αAl) eutectic phase. When nickel content in the alloy reach to 20%wt. the amount of Al_3Ni increases in the microstructure as shown in Figure (2a). Figures (2b) and (2c) demonstrate SEM images of the composites containing different percentages (6 and 9) %wt of Y_2O_3 additions respectively. The microstructures show the increasing content of reinforcements in the matrix, and suggest the distribution is uniform. Also the microstructures show appears Al_3Ni besides eutectic phase consists of Al3Ni fibers in the αAl matrix these results are similar to [9].

3.3 Energy Dispersive Spectrometer (EDS) Analysis

Energy dispersive Spectrometer (EDS) analyzer is attach to the SEM machine to analyze the chemical composition of the casting specimens as in Fingers 3 and 4 for Al-20%Ni without and with 9%Al_2O alloy respectively. As it can be seen, the results of EDS analysis were relatively close to the percentage of addition, because the values gained from EDS analysis do not cover the total area only the spot where the electron stroke. Furthermore, the EDS results aide in verifying the purity of the initial elemental powders as well as the prevention of contamination [10]. Fig. 4 shows the presence and distribution of the basic element aluminum and nickel with the presence of Y_2O_3 in another region on the same sample surface that reinforce with Y_2O_3 mention during casting and the production of alloys.

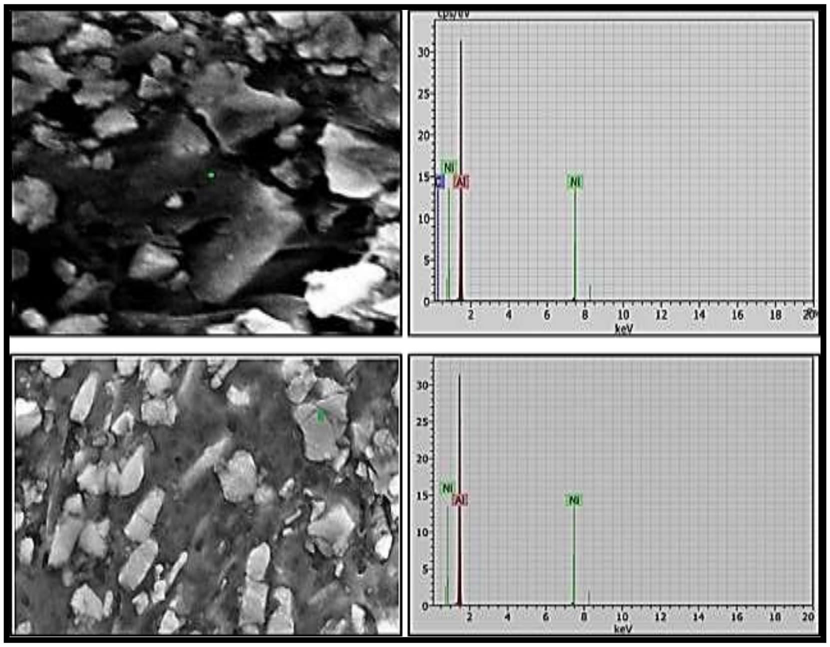

Figure 3: EDS Spectrum analyses of Al-20%Ni alloy

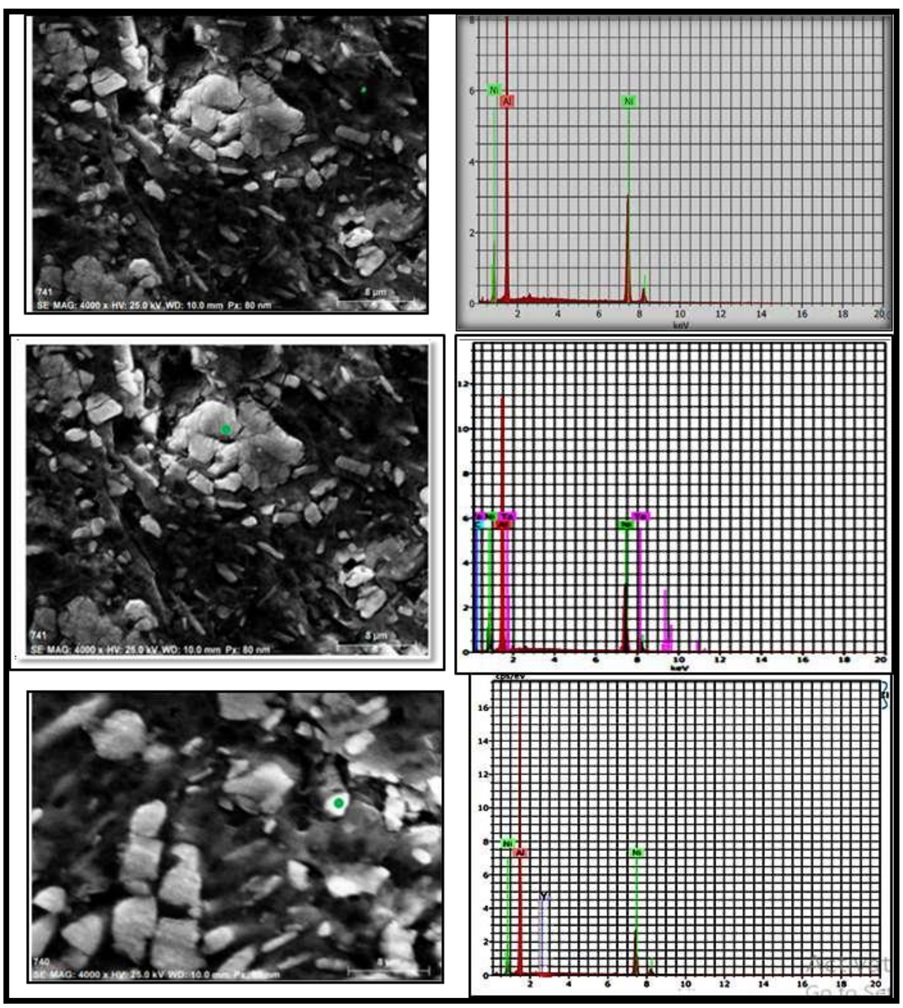

Figure. 4: EDS Spectrum analyses of Al-20%Ni-8%Al2O3 alloy

3.4 X-ray Diffraction (XRD) Test

The technique of XRD is important to identify the phases of crystalline structure. Figures 5 and 6 show the XRD patterns for A and B3 alloy respectively. it can be observed that Al, Ni transformed to (Al_3Ni) phase and E (αAl- Al_3Ni).

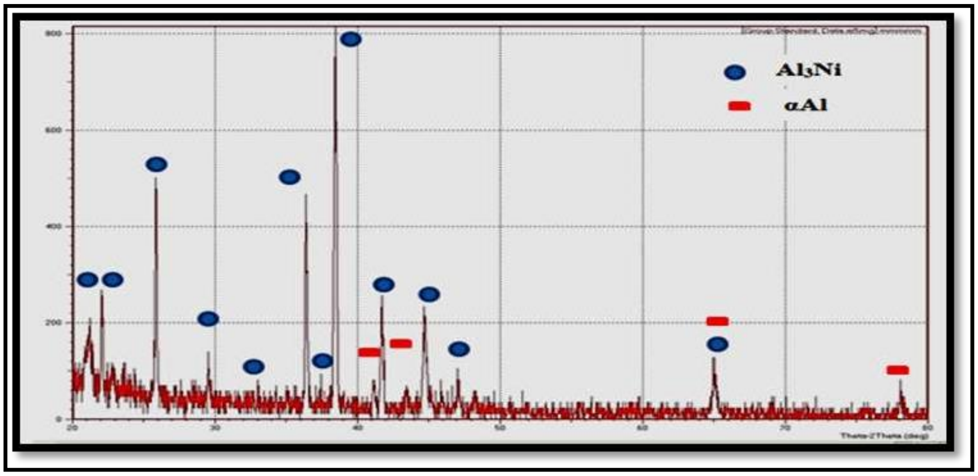

Figure 5: XRD patterns for A alloy.

The phases identified by XRD analysis were similar for all composite, therefor X-Ray diffraction test was done for (B3) alloy after The phases identified by XRD analysis were similar for all casting. It can be observed that α Al, (Al_3Ni) and Yttria (Y_2O_3) were detected as expected and these results are similar to SEM results [11].

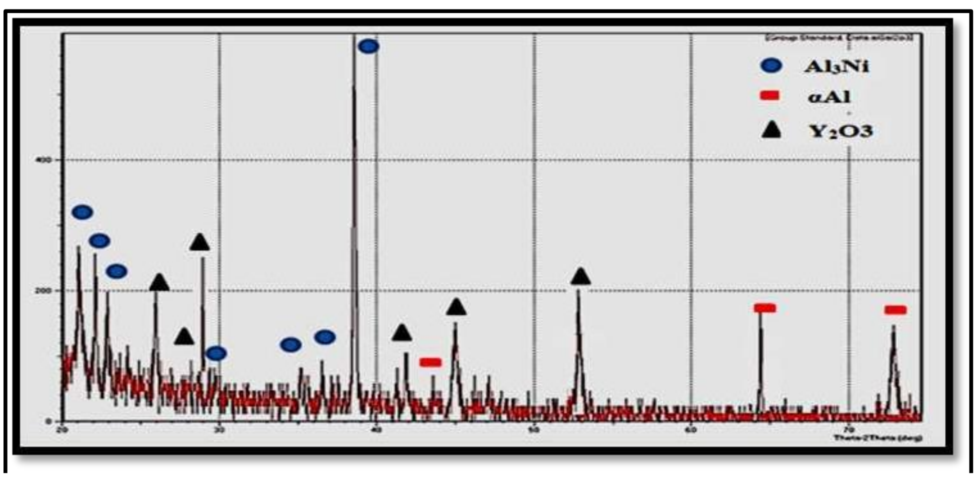

Figure 6: XRD patterns for B3 alloy

3.5 Hardness Test

In the current work, the hardness of the specimens of all alloys after preparation had been measured by the Brinell hardness test and the results have been illustrated in Figure 7. The greatest value was recorded for B3 specimen with an Y2O3 percentage of 9%. This increment could be attributed to the high hardness of Y2O3 particles itself which act as barrier to the dislocation motion [12]. The increment percentage of Brinell hardness is 27%, 46%, 52% for B1, B2, and B3 specimens, respectively, when compared with specimen A. These results are in agreement with the references [13] with an acceptable difference that belongs to the difference in type of reinforcement and average size of used Y2O3.

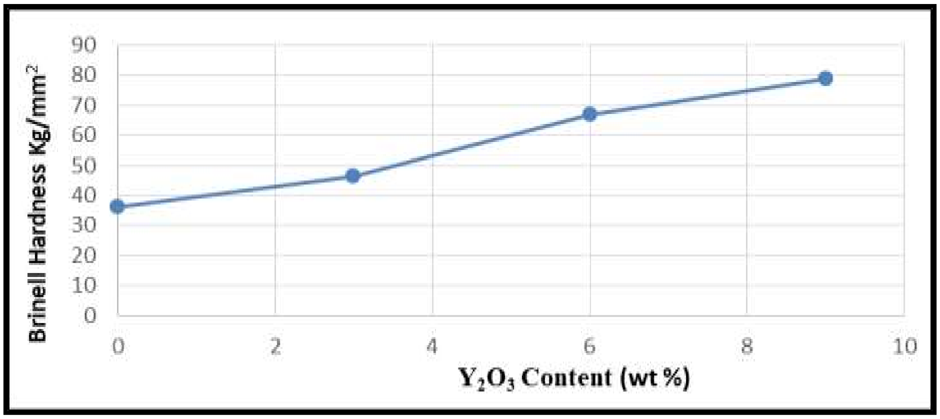

Figure 7: Effect of Y_2O_3 content on the hardness of Al-20%Ni alloys with out and with 3,6, and 9% Y_2O_3

3.6 Potentiodynamic polarization results

Fig. 8 illustrates polarization curves for the Al-20%Ni alloy and composite specimens in 3.5%NaCl solution. The corrosion current is determined by converting log currents into actual values. It should be noticed that there is an important shift toward lower current densities of the polarization curves for composites with different Y_2O_3 particulates. For example, Al-20%Ni corrosion current density is around 0.1660µA/ cm^2 while for 3% Y_2O_3 is about 0.0942 µA/ cm2 and for 6% Y2O3, it is about 0.0077 µA/ cm2 but at 9% Y_2O_3, the corrosion current density is 0.0227 µA/ cm^2. Further, it can be seen the highest improvement percentage is 95% when the concentration of Y2O3 particulates is 6%. According to electrochemical measurements, the B1, B2 and B3 cast alloys are more resistant to corrosion than the A cast alloy. This improvement was mainly attributed to the formation of a more homogeneous passive film and the rapid re-passivation of the bare metal. These finding are in agreement with other studies [14], [15]. Corrosion parameters (corrosion potential, corrosion current), extracted from these curves, are shown in Table 5.

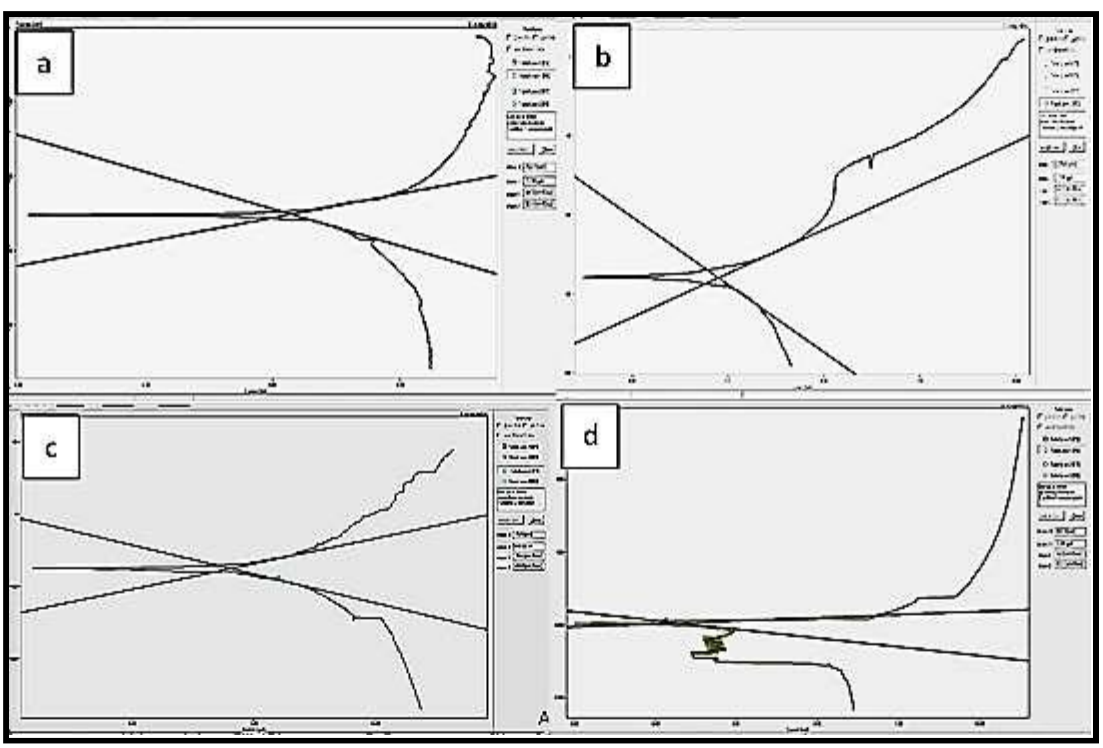

Fig. 8: Polarization curves for Al-20%Ni alloy with out and with 3,6, and 9% Y_2O_3 specimens in 3.5%NaCl solution.

Table 5: The corrosion potential (E_{corr}), corrosion current (I_{Corr}), Corrosion Rate, Current Density and Improvement percentage, of specimens in 3.5 wt% NaCl at 25°C

Alloy	Specimen code	I_{Corr} (µA)	E_{corr} (mV)	Corrosion Rate (mpy)	Current Density (µA/cm^2)	Improvement percentage %
AL-20Ni	A	13.94	-7027.0	118.595	0.1660	
AL-20Ni+3Y_2O_3	B1	7.91	-279.8	67.294	0.0941	43.25
AL-20Ni+6 Y_2O_3	B2	0.64	-75.5	5.518	7.7243*10^{-3}	95.34
AL-20Ni+9 Y_2O_3	B3	1.91	-997.3	16.250	0.0227	86.29

4. CONCLUSIONS

Fabricated composites containing 20% Ni and 3, 6, & 9% of Y_2O_3 particle as reinforcements in base matrix of pure aluminum using stir casting was optimized. The hardness of the Al 20% Ni matrix composites increased with increasing percentage of Y_2O_3; a maximum increase was obtained for 9% Y_2O_3 composite with an increase of 73%. There was a noticeable decrease in the corrosion rate of the composites with compare to pure Al due to the presence of Ni. Further, the increase in Y_2O_3 percentage decreased the corrosion rate in 3.5wt%NaCl solution.

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