Annealing Effect on Structural, Thermal and Mechanical Properties of the Binary Al$_{85}$Ni$_{15}$ Alloy Composition

ABSTRACT

Introduction: The Al$_{85}$Ni$_{15}$ alloy with 99.99% purity of Al and Ni were prepared by an arc melting technique system. The annealing effect on the microstructure properties, phase transformation and micro-hardness for the Al-Ni alloy system were investigated. Material and Methods: The alloys were characterized by X-ray Diffraction (XRD), Scanning Electron Microscopy (SEM), and Differential Thermal Analysis (DTA) as well as Vickers micro-hardness measurement. Results and Discussion: The quantitative results confirm that the chemical composition of the alloys is very close to compositions and the microstructures are in typical lamellar morphology. Mechanical properties for the as-prepared samples and subsequently heat-treated samples were measured by a Vickers indenter. Values of the micro-hardness ($HV$) Conclusions: According the XRD pattern analysis a multi phases produced, such as Al, AlNi$_3$, in room temperature, Al$_{1.1}$Ni$_{0.9}$ at 200ºC, Al$_{0.42}$Ni$_{0.58}$ at 300ºC and Al$_{0.802}$Ni$_{0.198}$, AlNi$_3$ and AlNi at 400ºC, and Al$_{0.802}$Ni$_{0.198}$, AlNi$_3$ and AlNi for 500ºC. Similar approached were obtained from the results of SEM and DTA measurements. Annealing treatments are visibly affecting the alloy phase formation with different phases at different temperature. and the elastic modulus (E) of the as prepared sample are 132.9±0.1 kgfmm$^{-2}$ (1.329±0.1 GPa) and 80.340±0.1 GPa, respectively. Furthermore, the characteristic of the materials plasticity ($\delta$) value was calculated to be 0.85. The micro-hardness values are decrease with the increase of annealing temperatures.
INTRODUCTION

High strength alloys play a significant role in automotive, electrical, aerospace and electronics industries. Improving applications and properties of alloys generated by Al in particular different areas are the researches subject to grow interest in the field of materials science (1),(2),(3). Since aluminium-based alloys Al-Ni in particular have exceptional properties against harsh conditions such as corrosion and high resistance to oxidation, resistance gives interest-ended to investigate its properties particularly mechanical, microstructure, electrical and thermal properties (4),(5),(6). However, the material properties in general are strongly dependent on their microstructure phases. As related to simultaneous diffusion coupled growth microstructures phases for two or more solids have been investigated by Caram 2005 (7). Pharr et al., 2003, used solidification technique to investigate composite materials for the purpose of developing a high temperature materials application, these particularly when one of phases is based on Ni (8). Based on the background knowledge we in this work try to perform microstructure properties, behaviour of thermal transformation and micro-hardness for the binary Al-Ni alloy with nominal composition of Al$_{85}$Ni$_{15}$ alloy.

MATERIALS AND METHOD

An ingot alloy composition of Al$_{85}$Ni$_{15}$ alloy was prepared by using the arc melting technique, from a mixture of high purity elements (99.99%) under a purified argon atmosphere. The suitably shaped pieces cut from ingot alloy were subjected to a heat-treatment by using a special furnace (Protherm Furnaces) at 200, 300, 400 and 500ºC for up to 45 minutes. The samples were naturally cooled down to room temperature. X-ray Diffraction (XRD) with device type of Philips X’Pert PRO XRD and CuKα radiation (λ = 0.154056 nm), set at 40 kV and 30 mA used to determine the structure characterization for all samples in the angles from 20º to 100º for 1 second at 0.02º/s.

The Scanning Electron Microscopy (SEM) (ZEISS EVO LS10 SEM) was used for surface examination. Differential Thermal Analysis (DTA) type Perkin-Elmer Diamond TG/DTA with the heating rate of 20 °C/min$^{-1}$ under the atmospheric of nitrogen was used to investigate both the ingot and annealed alloy samples.

Vickers indenter was used to measure the mechanical properties of samples under a load of 0.98N with a rating of 23.5 mN$^{-1}$ s. For each load five indentation tests as a minimum were made. Experimental errors were taken in to accounts for all the testing procedures mentioned above.

RESULTS

X-ray Diffraction (XRD) Analysis

Fig. 1 shows the XRD patterns for four heat-treated alloy samples of Al$_{85}$Ni$_{15}$ alloy at 200, 300, 400 and 500ºC with annealing time of 45 minutes. These patterns indicate two different phases, Al solid solution and Al$_3$Ni intermetallic. Fig. 1a represents the composition Al$_{85}$Ni$_{15}$ at room temperature will produce Al and Al$_3$Ni phases under an equilibrium condition. These results are very similar to those reported by Karakose and Keskin (9) and Cadırlı et al. (10) for conventionally solidified Al-Ni-10 wt. % Ni alloy and by rapidly solidified Al-Ni-12 at % Ni respectively. Fig. 2b represents patterns for Al$_3$Ni$_2$ and Al$_{0.42}$Ni$_{0.58}$ composed intermetallic phases for annealed alloy at 200ºC. The peak intensities due to Al$_3$Ni$_2$ (Fig 1b) represents a high percentage phase compared to that belong to Al$_{0.42}$Ni$_{0.58}$. The increase of annealing temperature to 300ºC, phases of Al$_3$Ni$_2$ and Al$_{1.1}$Ni$_{0.9}$ are produce as in Fig. 1c. While more decomposition phases were produced at 400ºC annealing temperature as distinguished in the XRD pattern shown in Fig. 1d, namely Al$_{0.802}$Ni$_{0.198}$, AlNi$_3$, Al$_3$Ni$_2$ and AlNi phases. For annealing temperature of 500ºC composition phases of Al$_{0.802}$Ni$_{0.198}$, AlNi$_3$ and Al$_3$Ni$_2$ were defected from the XRD pattern in Fig. 1e.
Figure 1. XRD patterns for the Al$_{85}$Ni$_{15}$ composition-based alloy for the as grown and heat-treated samples: (a) As grown, (b) 200 °C, (c) 300 °C, (d) 400 °C and (e) 500 °C.

SEM-EDX Micrograph Analysis
According to the surface images obtained by SEM and EDX data shown in Fig. 2(a-e) and Fig. 3(a-e) respectively. The conventionally solidified Al$_{85}$Ni$_{15}$ alloys give a microstructure formation of phases change with the annealing temperature. The surface microstructures contain a directional dendritic, non-directional regular lamellar, directional lamellar and fine faced crystal features which exhibits well-developed primary as well as secondary arms. The quantitative area from EDX data in right side table in Fig. 3(a-e) are agree well to that of the chemical compositions obtained from the XRD data given in (Fig. 1).
Figure 2. SEM micrographs for the as grown Al85Ni15 system alloy before and after annealing temperature: (a) as-grown, (b) 200 °C, (c) 300 °C, (d) 400 °C and (e) 500 °C
DTA Analysis
The phase transformation behaviour of the as-grown Al$_{85}$Ni$_{15}$ ingots alloy system was investigated with DTA as shown in Fig.4. This figure shows the continuous DTA traces at a heating rate of 20K min$^{-1}$. The curve shows three endothermic reactions. The first which is a large peak occurs at around 656.6°C and a relatively two other smaller peaks occurs at around 812.3 and 1023.8°C. The first endothermic peak considered to be corresponding the melting point of the Al phase. The second endothermic peak is representing the melting point of the Al$_3$Ni phase; while the third peak is considered to be due to the dissolution of the Al$_3$Ni phase.
Vickers Microhardness Analysis (HV)

Fig. 5 gives a systematic decrease of micro-hardness with the annealing temperature for the as-cast Al$_{85}$Ni$_{15}$ alloy system. However, the new alloy phase detected by XRD due to the annealing temperature explains well such a dependence shown in this figure. Such dependence behaviour may be related to the materials melting points of Al-Ni system compounds. However, the phase diagram for this system indicates the highest melting point will be for Al$_{85}$Ni$_{15}$ phase.

Furthermore, from the melting temperature measured by DTA the elastic modulus (E) was calculated by using the empirical relation $E = 0.123T_m - 34$, which is applicable to Al-based alloys$^{12}$. Where $T_m$ is the melting temperature and has a value of 929.6 K for Al$_{85}$Ni$_{15}$. E calculated to be 80.340 GPa, and that comparable experimental value of 75 ± 5 GPa. Moreover, a plasticity factor ($\delta_H$) which is the measure of materials brittleness also calculated by using the following equation; $\delta_H = 1 - 14.3 (1 - \nu - 2\nu^2) \frac{HV}{E}$

**Figure 4.** DTA curve of conventionally solidified Al$_{85}$Ni$_{15}$ composition alloy

**Figure 5.** Microhardness versus heat-treated temperature
where $\nu$ is the Poisson coefficient and have a value of 0.28 for Al$_{85}$Ni$_{15}$ [14]. With the above calculated values for $E$, the plasticity factor obtained to be equal to 0.85.

**DISCUSSION**

According to the indication of XRD, annealing temperature will strongly affect Al-Ni. Alloy formation phases based on the composition Al$_{85}$Ni$_{15}$. SEM images for Al$_{85}$Ni$_{15}$ composition alloy are consisted a primary Ni-rich phase having cellular morphology with a lamellar structure. Similar to that of the annealing temperature effect examined by the X-ray and SEM micrograph shape indicate the change of microstructure from coarse dendrites to lamellar morphology. However, similar effects due to annealing temperature are reported for the alloy systems of (Al-Ni$_x$) [9] and (Al-Ni–xSi) [10,11]. Moreover, in DTA analysis curve has been obtained three peaks of endothermic reactions, were these indications are agreeing with the results obtained by XRD and SEM techniques. Finally, the value of plasticity factor puts this alloy as a brittle material since a standard value at room temperature for $\delta_H \leq 0.9$ [15,16].

**CONCLUSIONS**

According the XRD pattern analysis the alloy system Al-Ni has an element percentage of 85 and 15 respectively, produce a multi phases such as Al, AlNi$_3$ in room temperature, AlNi$_3.2$, Al$_{0.42}$Ni$_{0.58}$ at 200ºC, Al$_{1.1}$Ni$_{0.9}$ at 300ºC and Al$_{0.802}$Ni$_{0.198}$, AlNi$_3$ and AlNi at 400ºC, and Al$_{0.802}$Ni$_{0.198}$, AlNi$_3$ and AlNi for 500ºC. Similar approached were obtained from the results of SEM and DTA measurements. Annealing treatments are visibly affecting the alloy phase formation with different phases at different temperature. The value of plasticity factor calculated from the melting temperature, micro-hardness and Poisson relation puts Al$_{85}$Ni$_{15}$ alloy in the brittle material categories.

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