Annealing Effect on Structural, Thermal and Mechanical Properties of the Binary Al_{85} Ni_{15} Alloy Composition

Efecto de annealing sobre las propiedades estructurales, térmicas y mecánicas de la composición de aleación binaria Al_{85} Ni_{15}

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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_3Ni_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. 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 (δ_H) value was calculated to be 0.85. The micro-hardness values are decrease with the increase of annealing temperatures.

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INTRODUCCTION

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 interested 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 dawn 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 ºCmin^{-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_3Ni intermetallic. Fig. 1a represents the composition Al_{85}-Ni_{15} at room temperature will produce Al and Al_3Ni 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_3Ni_2 and $Al_{0.42}Ni_{0.58}$ composed intermetallic phases for annealed alloy at 200ºC. The peak intensities due to Al_3Ni_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_3Ni_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_3Ni_2 and AlNi phases. For annealing temperature of 500ºC composition phases of $Al_{0.802}Ni_{0.198}$, $AlNi_3$ and Al_3Ni_2 were defected from the XRD pattern in Fig. 1e.

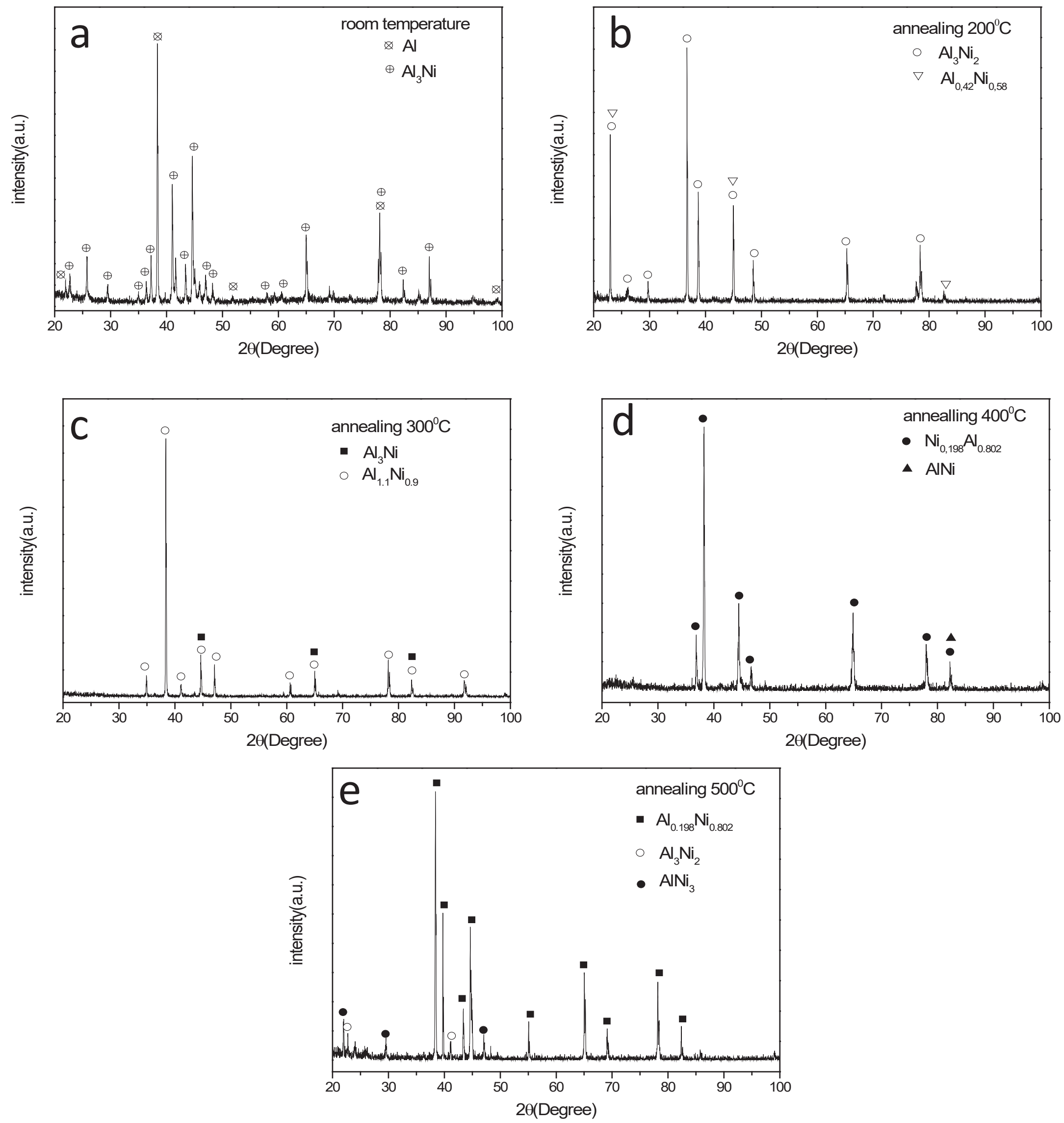

Figure 1. XRD patterns for the $Al_{85}Ni_{15}$ composition-based alloy for the as grown and heat-treated samples: (a) As grown, (b) 200 ºC, (c) 300 ºC, (d) 400 ºC and (e) 500 ºC.

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).

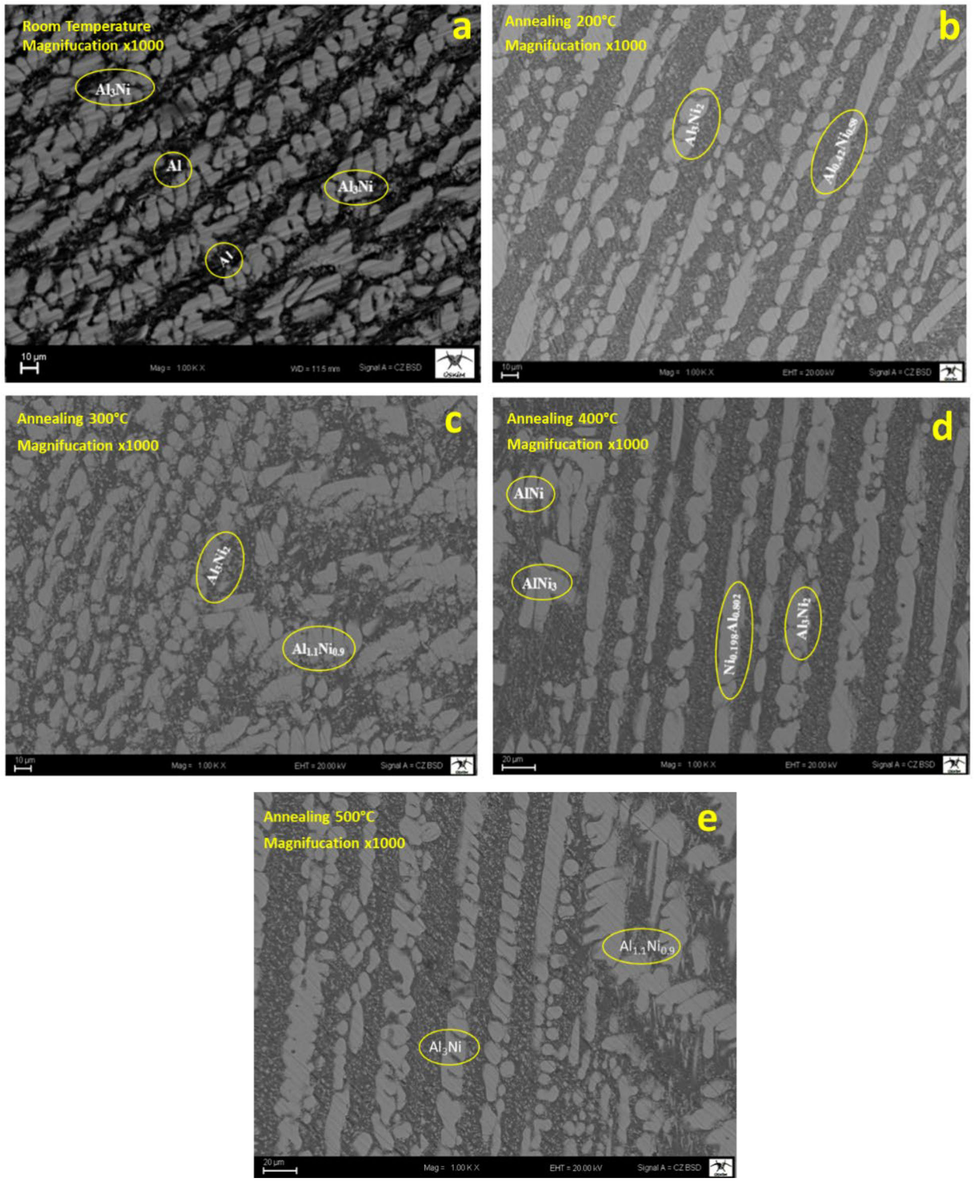

Figure 2. SEM micrographs for the as grown Al85Ni15 system alloy before and after annealing temperature: (a) as-grown, (b) 200 ºC, (c) 300 ºC, (d) 400 ºC and (e) 500 ºC

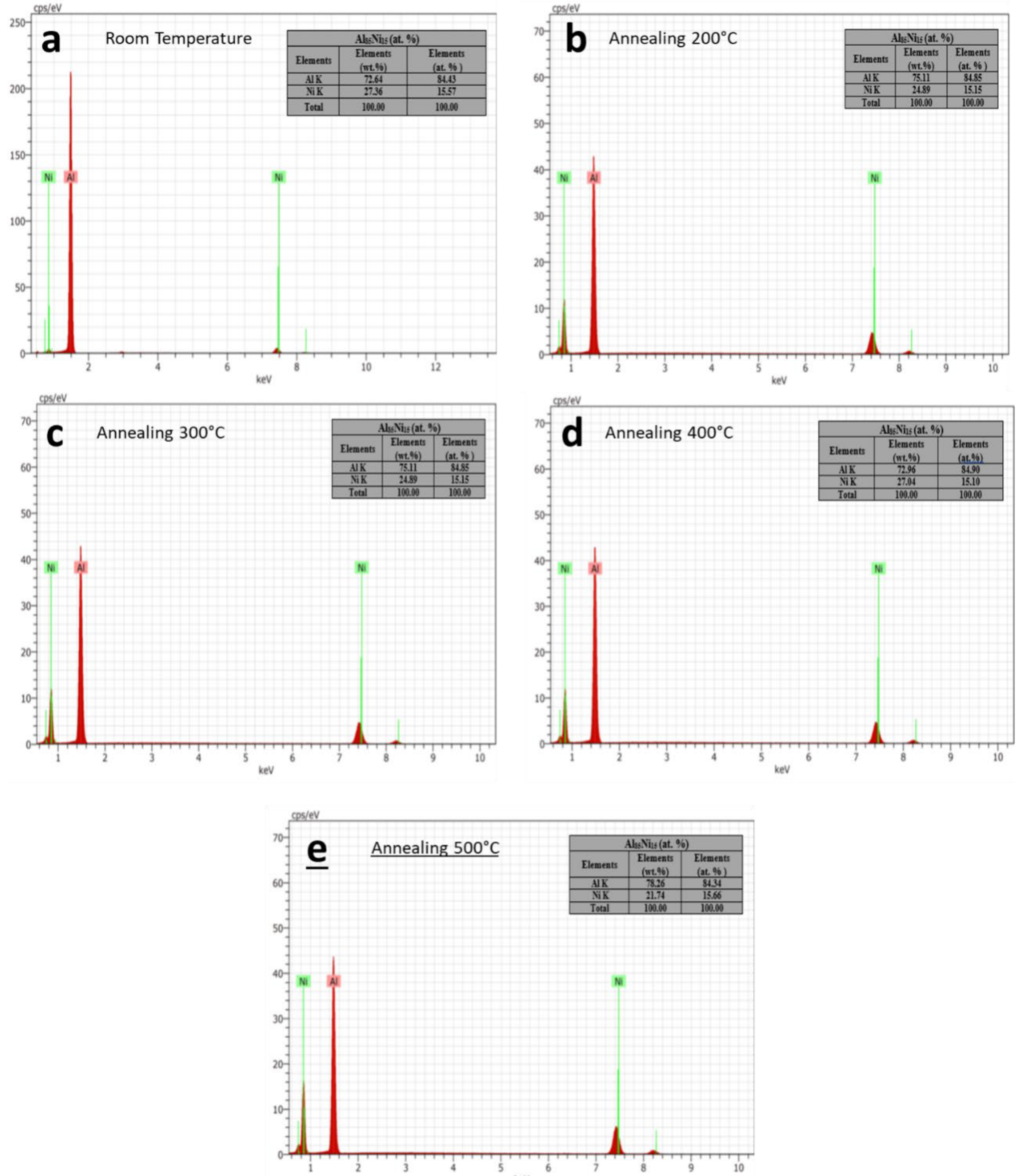

Figure 3. EDX Spectrums for the Al85Ni15 system alloy before and after annealing temperature: (a) as-grown, (b) 200 ºC, (c) 300 ºC, (d) 400 ºC and (e) 500 ºC.

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 656.6ºC and a relatively two other smaller peaks occurs at around 812.3 and 1023.8ºC. 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_3Ni phase; while the third peak is considered to be due to the dissolution of the Al_3Ni phase.

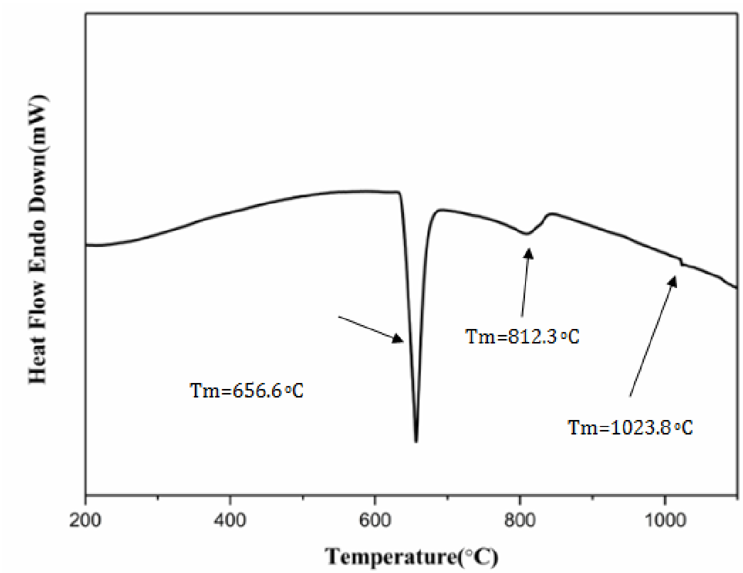

Figure 4. DTA curve of conventionally solidified $Al_{85}Ni_{15}$ composition alloy

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 indicts the highest melting point will be for $Al_{85}Ni_{15}$ phase.

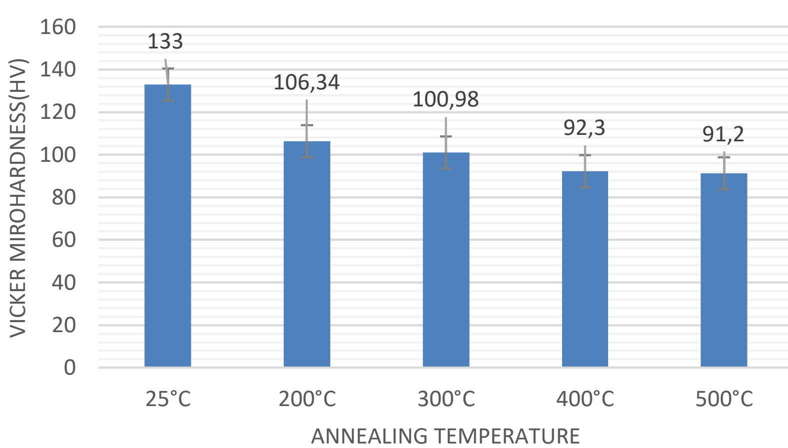

Figure 5. Microhardness versus heat-treated temperature

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 929.6K 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 (δ_H) which is the measure of martials brittleness also calculated by using the following equation; $\delta_H = 1 - 14.3\ (1 - \upsilon - 2\upsilon^2)\ HV/E$(13), where υ 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.

DISCUTION

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, Al_3Ni_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.

REFERENCES

1. Aindow M, Alpay SP, Liu Y, Mantese JV, Senturk BS. Base metal alloys with self-healing native conductive oxides for electrical contact materials. Applied Physics Letters. 2010; 97(15):152-103. https://doi.org/10.1063/1.3499369
2. Wu Y, Wang S, Li H, Liu X. A new technique to modify hypereutectic Al-24% Si alloys by a Si-P master alloy. Journal of Alloys and Compounds. 2009; 27(1-2):139-44. https://doi.org/10.1016/j.jallcom.2008.10.015
3. Zhou J, Duszczyk J, Korevaar BM. Microstructural features and final mechanical properties of the iron-modified Al-20Si-3Cu-1 Mg alloy product processed from atomized powder. Journal of materials science. 1991; 26(11):3041-50. https://doi.org/10.1007/BF01124840
4. Karaköse E, Keskin M. Microstructure evolution and mechanical properties of intermetallic Ni-xSi (x= 5, 10, 15, 20) alloys. Journal of Alloys and Compounds. 2012; 5: 528:639. https://doi.org/10.1016/j.jallcom.2012.02.165
5. Mukhtarov SK, Valitov VA, Dudova NR. Thermal stability and mechanical properties of nano-structured nickel based alloy Inconel 718.
6. Sheng LY, Guo JT, Tian YX, Zhou LZ, Ye HQ. Microstructure and mechanical properties of rapidly solidified NiAl-Cr (Mo) eutectic alloy doped with trace Dy. Journal of Alloys and Compounds. 2009; 475 (1-2):730-4. https://doi.org/10.1016/j.jallcom.2008.07.109
7. Dutra AT, Ferrandini PL, Costa CA, Gonçalves MC, Caram R. Growth and solid/solid transformation in a Ni-Si eutectic alloy. Journal of alloys and compounds. 2005; 399(1-2):202-7. https://doi.org/10.1016/j.jallcom.2005.03.039
8. Bei H, George EP, Pharr GM. Effects of composition on lamellar microstructures of near-eutectic Cr-Cr3Si alloys. Intermetallics. 2003; 11(4):283-9. https://doi.org/10.1016/S0966-9795(02)00251-0
9. Karaköse E, Keskin M. Microstructure evolution and mechanical properties of intermetallic Ni-xSi (x= 5, 10, 15, 20) alloys. Journal of Alloys and Compounds. 2012; 528:63-9. https://doi.org/10.1016/j.jallcom.2012.02.165

10. Çadırlı E, Herlach DM, Volkmann T. Characterization of rapidly solidified Ni-Si and Co-Al eutectic alloys in drop tube. Journal of Non-Crystalline Solids. 2010; 356(9-10):461-6. https://doi.org/10.1016/j.jnoncrysol.2009.12.019
11. Çadırlı E, Herlach DM, Davydov E. Microstructural, mechanical, electrical and thermal characterization of arc-melted Ni-Si and Co-Si alloys. Journal of Non-Crystalline Solids. 2010; 356(33-34):1735-41. https://doi.org/10.1016/j.jnoncrysol.2010.06.005
12. Skinner DJ, Zedalis M. Elastic modulus versus melting temperature in aluminum based intermetallics. Scripta metallurgica. 1988; 22(11):1783-5. https://doi.org/10.1016/S0036-9748(88)80284-9
13. Milman YV, Galanov BA, Chugunova SI. Plasticity characteristic obtained through hardness measurement. Acta metallurgica et materialia. 1993; 41(9):2523-32. https://doi.org/10.1016/0956-7151(93)90122-9
14. Trefilov VI, Mil'man YV, Lotsko DV, Belous AN, Chugunova SI, Timofeeva II, Bykov AI. Studies of mechanical properties of quasicrystalline Al-Cu-Fe phase by the indentation technique. In-Doklady Physics 2000; 45(8): pp. 363-366). https://doi.org/10.1134/1.1310723
15. Mukhopadhyay NK, Weatherly GC, Embury JD. An analysis of microhardness of single-quasicrystals in the Al-Cu-Co-Si system. Materials Science and Engineering: A. 2001; 315(1-2):202-10. https://doi.org/10.1016/S0921-5093(01)01186-8
16. Qiang JB, Zhang W, Xie G, Kimura H, Dong C, Inoue A. An in situ bulk Zr58Al9Ni9Cu14Nb10 quasicrystal-glass composite with superior room temperature mechanical properties. Intermetallics. 2007; 15(9):1197-201. https://doi.org/10.1016/j.intermet.2007.02.008