International Journal of Scientific and Technological Research
ISSN 2422-8702 (Online)
Vol 1, No.2, 2015

Phase Evolution and Thermal Stabilities of Amorphous $Al_{85}Nd_5Ni_{10}$ Alloy

Alaaddin Gundes (Corresponding author)
Department of Physics, Faculty of Science and Letters, Sutcu Imam University, Kahramanmaras, Turkey. E-mail address: ahmetburak02@yahoo.co.uk

Musa Gogebakan
Department of Physics, Faculty of Science and Letters,
Sutcu Imam University, Kahramanmaras, Turkey.

This work is supported by Turkish State Planning Organisation (DPT) with research programme number of 103K-120-730. and Kahramanmaras Sutcu Imam University (Project No:2007/22-3).

Abstract

In this work, the heat effect on the crystallization of amorphous $Al_{85}Nd_5Ni_{10}$ alloy was produced by means of rapid solidified was investigated in heat treatment by differential scanning calorimetry (DSC) and X-ray diffraction (XRD). Continuous heating DSC trace of amorphous $Al_{85}Nd_5Ni_{10}$ alloy consisted of three exothermic peaks. The onset and peak temperatures for these peaks shifted toward higher temperatures when the heating rate was increased. Activation energies for the three exothermic peaks determined by the Kissinger method, which gives as 251, 341 and 260 kJ/mol, respectively. Isothermal annealing DSC traces for the first crystallization peak was showed one-dimensional growth by JohnsonMehlAvrami kinetics (JMA) with an Avrami exponent n of 1.0-1.4. However isothermal annealing DSC traces for the second and third crystallization peaks were showed nucleation and growth with two-dimensional by JMA kinetics with an Avrami exponent n of 1.85-2.25. The XRD analysis after different heat treatment of three crystallization peaks showed that α-Al phase; fcc-Al phases, Al_3Ni and $Al_{11}Nd_3$ like intermetallic phases; fcc-Al phases, Ni and Nd phases, AlNiNd phases, Al_3Ni and $Al_{11}Nd_3$ like intermetallic phases and unknown phases; respectively.

Keywords: Al-Nd-Ni Amorphous Alloys, Rapid Solidification, Isothermal Annealing, XRD, DSC.

1. Introduction

Conventional aluminum alloys have been well known for their use as light-weight components in engineering applications, particularly in the aerospace industry. However, the increasing demand for higher performance engineering components continuously drives the search for new advanced materials [1]. Recently, Al-based amorphous alloys are of interest due to their unique combination of mechanical, physical and chemical properties applications as high strength with light weight, good ductility have been found in the Al-RE(La, Y, Ce)-TM(Fe, Co, Ni) systems [2]. Interest in these Al-RE-TM amorphous alloys has been stimulated because they exhibit unusual mechanical properties with potentially good corrosion resistance and thermal stability.

The amorphous to crystallization process is very important for the thermal stability of the amorphous alloys, which is critical for their engineering application purposes [3]. Although there have been previous studies of Al-Ndi-Ni ternary alloys, there has been relatively little detailed work on their thermal stability and mechanical properties of this alloy [1-5]. The aim of this study is to investigate the crystallization behaviour and phase evolutions of amorphous $Al_{85}Nd_5Ni_{10}$ alloy, produced by rapid solidification, using a combination of DSC and XRD.

2. Experimental

The ingot ternary alloy of $Al_{85}Nd_5Ni_{10}$ was prepared by induction furnace of appropriate proportions of 99.9 % purity Al, 99.5 % purity Ni and 99 % purity Nd elements in a graphite crucible under an argon atmosphere. Rapidly solidified amorphous $Al_{85}Nd_5Ni_{10}$ alloy ribbons were manufactured by the single roller melt-spinning technique with a wheel surface velocity of 30 m/s under an argon atmosphere. The amorphous/crystalline natures of the as-melt-spun and annealed ribbons were characterized by X-ray diffractometry (XRD) technique. The XRD experiments were performed using a Philips XPert Pro diffractometry with filtered Cu Kα (λ = 0.154 nm), 35 kV and 50 mA. For phase identification, measurements were scanned for a wide range of diffraction angles (2θ) from 20° to 100° with the scanning rate of 0,2 deg/min. The crystallization behaviour of amorphous alloys were analyzed by differential scanning calorimeter (DSC) using a Perkin-Elmers Sapphire DSC-7 at a constant heating rate of 5-40 K min^{-1}. from 323 to 948 K, which are corresponding to limits of the DSC used. Isothermal DSC measurements were carried out by annealing to various temperatures 515 K lower than their crystallization peaks temperatures with the heating rate of 5 K/min, and the heating duration of 3 h.

3. Results and Discussions

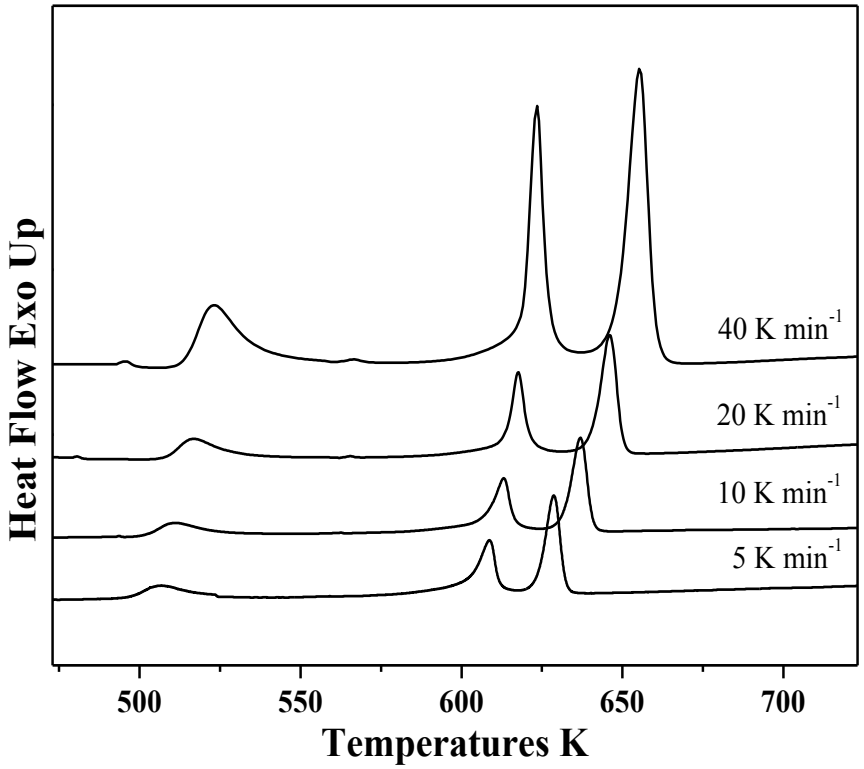

Fig. 1. DSC trace from the amorphous $Al_{85}Nd_5Ni_{10}$ alloy obtained during continuous heating at 5-40 K min^{-1}.

In order to understand crystallization behaviour of amorphous $Al_{85}Nd_5Ni_{10}$ alloy, the melt spun ribbon was crystallized in DSC by continuous heating at rates of 5, 10, 20, and 40 K min^{-1}. Fig. 1 shows typical continuous DSC trace from the amorphous $Al_{85}Nd_5Ni_{10}$ alloys obtained during different continuous heating. DSC trace of amorphous $Al_{85}Nd_5Ni_{10}$ alloy consisted of three exothermic crystallization peaks.

Table 1. Crystallization onset (T_0) and peak temperatures (T_1, T_2, T_3) as a function of heating rate (β) for $Al_{85}Nd_5Ni_{10}$ alloy

β (K min^{-1})	T_0 (K)	T_1 (K)	T_2 (K)	T_3 (K)
5	498	506	609	629
10	501	511	613	637
20	507	517	618	646
40	512	523	623	655

The crystallization onset temperature (T_0) and the three crystallization peak temperatures (T_1, T_2, T_3) for these peaks shifted toward higher temperature and all exothermic peaks became broader when the heating rate (β) was increased as 5, 10, 20, and 40 K min.$^{-1}$. These are listed in Table 1.

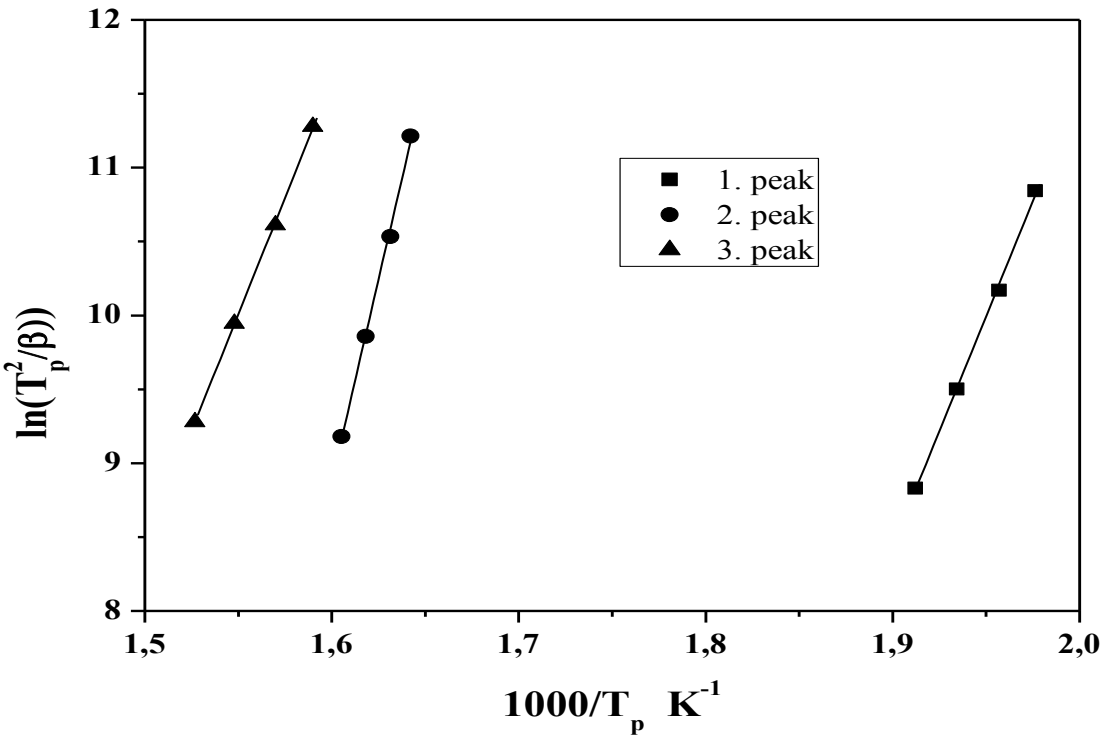

Fig. 2. Kissinger plots of $\ln(T_p^2/\beta)$ vs. $1000/T_p$ K^{-1} for the amorphous $Al_{85}Nd_5Ni_{10}$ alloy

The variation of crystallization peak temperatures with different heating rate can be described by Kissinger method [6]. Fig. 2 shows that Kissinger plots are linear. The activation energies calculated from the slants of these plots are listed in Table 2. As seen in Table 2, the measured values of the overall activation energy for the second exothermic peaks (341±10 kJ/mol) were higher than those of the first (251±10 kJ/mol) and third exothermic peaks (260±10 kJ/mol). The higher activation energy implies that the energy barrier for the glass-to-crystallization phase transformation is higher. This result is supported the XRD results of after the crystallization peak temperatures.

Table 2. Activation energies for the crystallization in $Al_{85}Nd_5Ni_{10}$ alloy

	Kissinger (kJ mol^{-1})
T_1	251
T_2	341
T_3	260

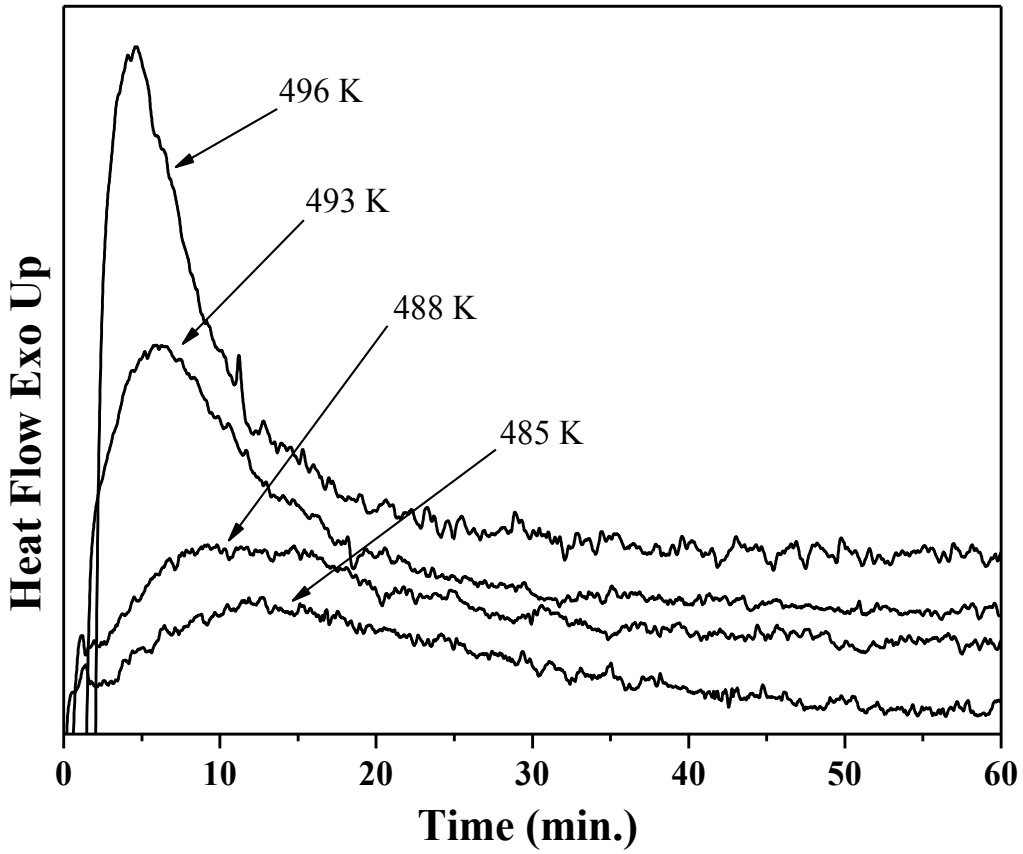

Fig. 3. DSC traces from the amorphous $Al_{85}Nd_5Ni_{10}$ alloy during isothermal annealing at 485-496 K for the first crystallization peak

Fig. 3 shows typical DSC traces from the amorphous $Al_{85}Nd_5Ni_{10}$ alloy obtained during isothermal annealing at 485-496 K before the first crystallization peak temperature. The kinetics of crystallization can be described by the JMA kinetics [7]. The Avrami plots of ln(-ln(1-X)) versus ln(t) for the amorphous $Al_{85}Nd_5Ni_{10}$ alloy was made from Fig. 3 with JMA kinetics and this Avrami plots are shown Fig. 4. The slants of Avrami plots give Avrami exponent n of 1.0-1.4 . The Avrami exponent n indicates that the transformation of amorphous to crystallization is one-dimensional growth for the first crystallization peak.

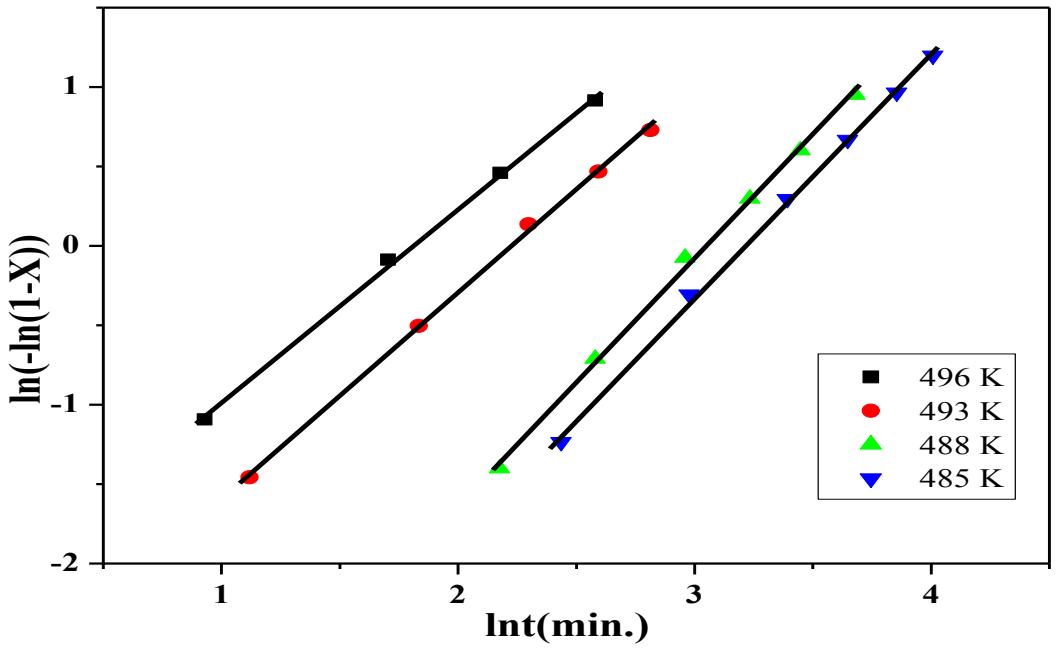

Fig. 4. Avrami plots of ln(-ln(1-X)) vs. lnt(s) for the first crystallization peak of amorphous $Al_{85}Nd_5Ni_{10}$ alloy

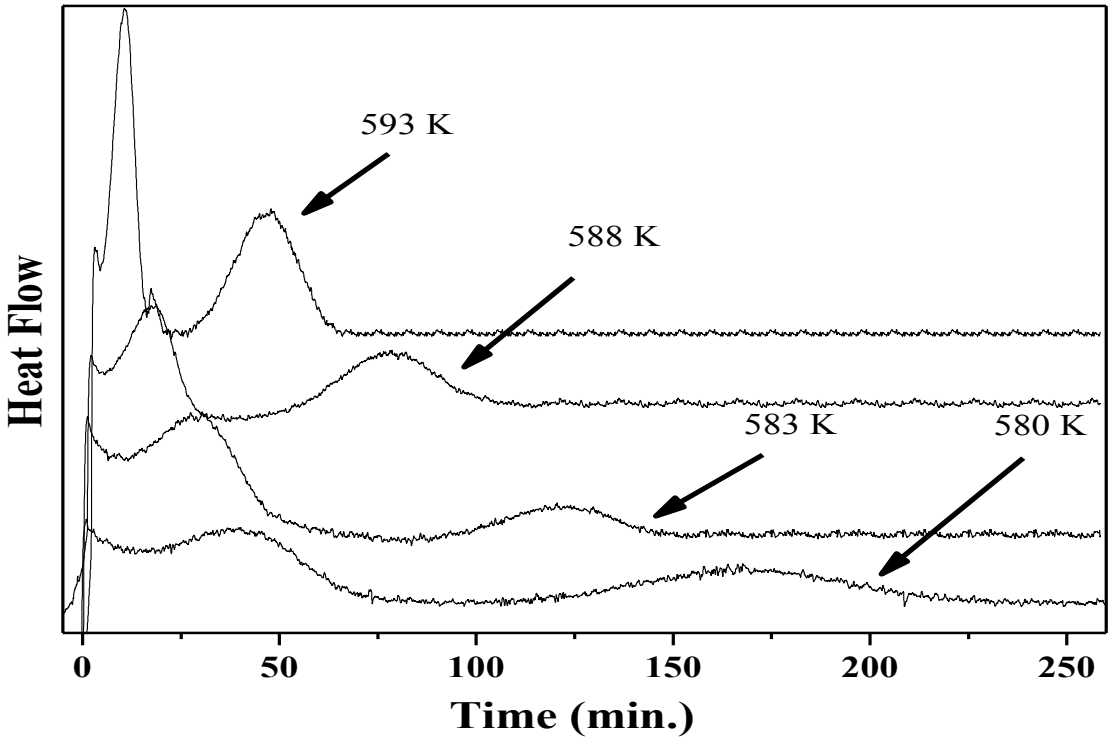

Fig. 5. DSC traces from the amorphous $Al_{85}Nd_5Ni_{10}$ alloy during isothermal annealing at 580-593 K for the second and third crystallization peak

The second and third crystallization peak temperatures are very closely, so isothermal annealing were made for two crystallization peaks before second crystallization peak temperature value at 580-593 K. This is shown Fig. 5. The Avrami plots were made with JMA and these plots are shown Fig. 6, Fig. 7 respectively. The slants of Avrami plots give Avrami exponent n of 1.85-2.25 . The values of Avrami exponent n indicates that the transformation of amorphous to crystallization is nucleation and with two-dimensional growth. This result is consistent with the Kissinger and XRD results.

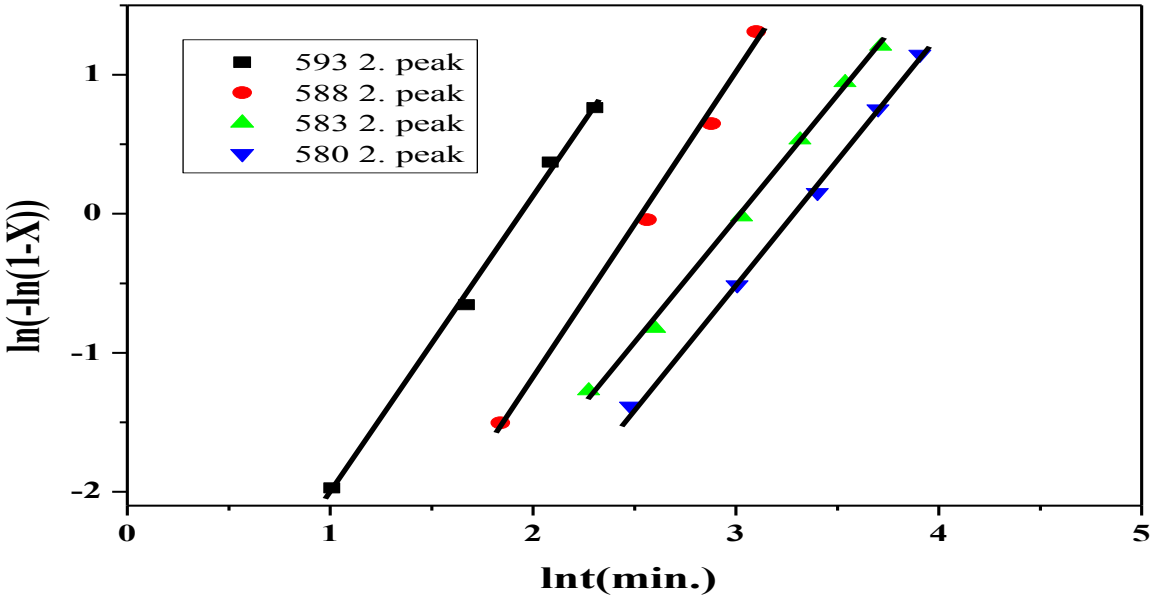

Fig. 6. Avrami plots of ln(-ln(1-X)) vs. lnt(s) for the second crystallization peak of amorphous $Al_{85}Nd_5Ni_{10}$ alloy

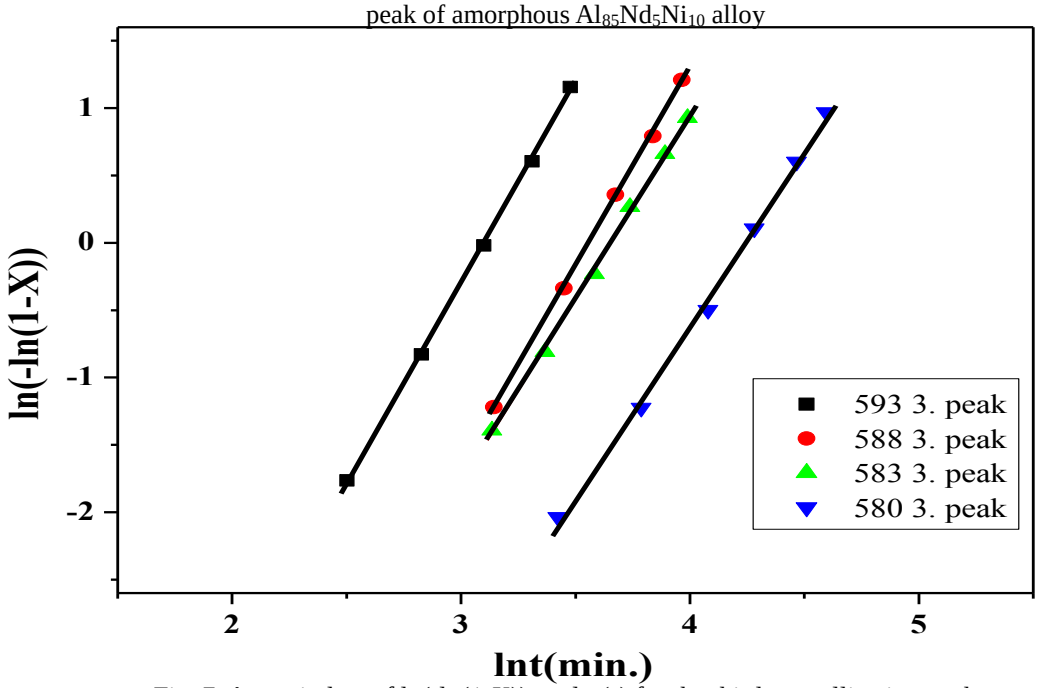

Fig. 7. Avrami plots of ln(-ln(1-X)) vs. lnt(s) for the third crystallization peak of amorphous $Al_{85}Nd_5Ni_{10}$ alloy

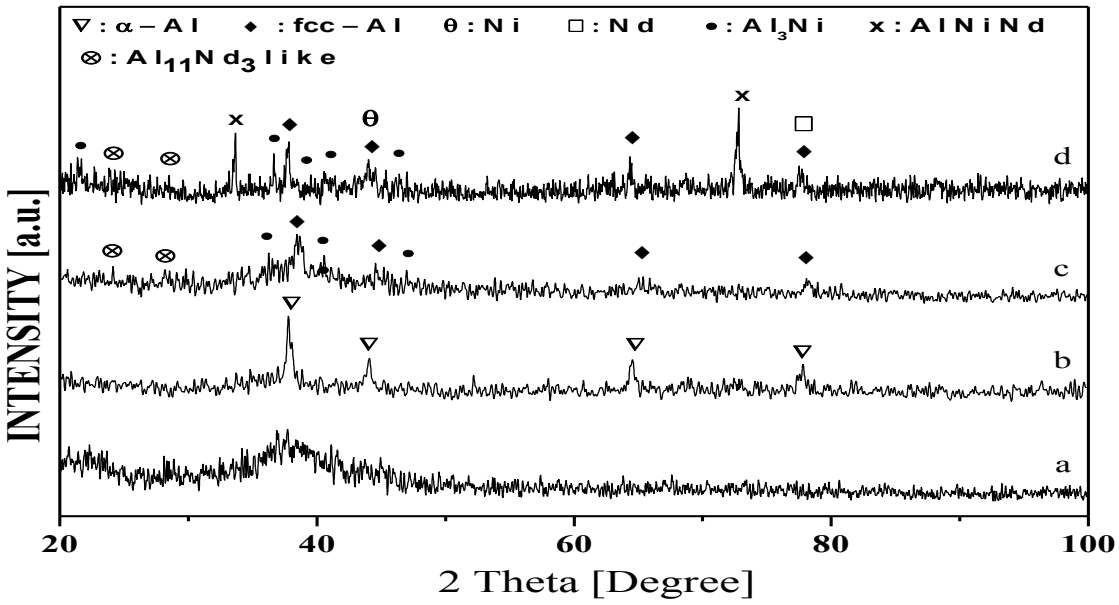

Fig. 8. XRD spectra from (a) the amorphous $Al_{85}Nd_5Ni_{10}$ alloy, (b) heat treatment after the first DSC crystallization peak, (c) heat treatment after the second DSC crystallization peak, (d) heat treatment after the third DSC crystallization peak

In order to understand the heat effect of phase evolutions of the amorphous $Al_{85}Nd_5Ni_{10}$ alloy. Fig. 8 shows XRD spectra from the amorphous $Al_{85}Nd_5Ni_{10}$ alloy (Fig. 8 a) and after heating the end temperatures of the first, second, third crystallization peak. The as-melt-spun $Al_{85}Nd_5Ni_{10}$ alloy showed a broad peak corresponding to amorphous structure. After heating to 550 K, the amorphous alloy began to crystallize of α-Al phases (Fig. 8 b). After heating to 635 K, fcc-Al phases, Al_3Ni and $Al_{11}Nd_3$ like intermetallic phases were observed. This result indicates that intermetallic phases are removed from α-Al phases as a precipitate by heat treatment. Then α-Al phases transform fcc-Al phases. This result is consistent with variation of the lattice constant. After heating 650 K, fcc-Al phases, Ni and Nd phases, AlNiNd phases, Al_3Ni and $Al_{11}Nd_3$ like intermetallic phases and unknown phases are observed. So we can say that amorphous $Al_{85}Nd_5Ni_{10}$ alloy was full crystallized.

4. Conclusion

In this study, in order to investigate the phase evolutions and thermal behaviour of rapidly solidified $Al_{85}Nd_5Nd_{10}$ amorphous ribbons, the samples examined by DSC, XRD. Our experimental results show that:

1. The amorphous $Al_{85}Nd_5Nd_{10}$ ribbons were produced by melt-spinning technique with a wheel surface velocity of 30 m/s. On other hand, the elemental peaks of nominal composition of $Al_{85}Nd_5Nd_{10}$ alloy were completely disappeared and amorphous structure occurred by melt-spinning technique.

2. Crystallization of amorphous $Al_{85}Ni_5Nd_{10}$ alloy during continuous heating takes places in three stages. The crystallization peaks are broader and the crystallization peak temperatures are increasing with the increasing heating rate.

3. Activation energies for the three crystallization peaks calculated by Kissinger method give as 251, 341 and 260 kJ mol^{-1}, respectively.

4. Crystallization of amorphous $Al_{85}Ni_5Nd_{10}$ alloy during isothermal annealing at temperatures 485-496 K for the first crystallization peak. The Avrami exponent n was calculated at 1.0-1.4 by JMA kinetics. The Avrami exponent n indicates that the transformation of amorphous to crystallization is one-dimensional growth. For the second and third crystallization peaks, isothermal annealing at 580-593 K and calculated the Avrami

exponent n of 1.85-2.25 . The values of Avrami exponent n indicates that the transformation of amorphous to crystallization is nucleation and with two-dimensional growth.

5. The XRD analysis after different heat treatment of three crystallization peaks showed that α-Al phase; fcc-Al phases, Al3Ni and Al11Nd3 like intermetallic phases; fcc-Al phases, Ni and Nd phases, AlNiNd phases, Al3Ni and Al11Nd3 like intermetallic phases and unknown phases; respectively.

References

[1] A. Revesz, G. Heunen, L.K. Varga, S. Surinach, M.D. Baro, *J. All. Comp.*, 368 (2004) 164-168.

[2] A. Inoue, K. Ohtera, A.P. Tsai, T. Masumoto, *Jpn. J. Appl. Phys.*, 27 (1988) L280.

[3] K. Lu, R. Lück, B. Predel, *Acta Metall. Mater.* 42 (1994) 2303-2311.

[4] M.L. Ted Guo, Chi Y.A. Tsao, J.C. Huang and J.S.C. Jang, *İntermetallics*, 14 (2006) 1069-1074.

[5] Y. He, S.J. Poon, G.J. Shiflet, *Science* 241 (1988) 1640.

[6] H.E. Kissinger, Anal. Chem., 29 (1957) 1702.

[7] J. W. Christian, *Theory of Transformations in Metals and Alloys*, Pergamon Press, Oxford, 1975.