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Investigation of The Effect of Annealing on Resistivity in Aluminum-based Amorphous Alloys

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In this study, electrical properties of Al-Y-Ni alloys produced by melt-spinning method were investigated. Before annealing, XRD analyzes were performed and the samples were found to be amorphous. Exothermic peaks were observed in DSC measurements and crystallization stages of the alloys were determined. $Al_{85}Y_{11}Ni_4$, $Al_{85}Y_{10}Ni_5$ and $Al_{85}Y_5Ni_{10}$ samples were annealed at some temperature and their electrical resistivity was measured by four-point method. The large decrease in resistivity was observed during crystallization between 200 - 400 ˚C. These results were consistent with XRD and DSC measurements.

Keywords: amorphous alloy, crystallization, electrical resistivity.

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Introduction

The most important feature that distinguishes amorphous alloys or metallic glasses from other alloys is that they do not have the atomic order of normal crystals and consequently do not have crystal structure. This structural and chemical state is felt in all properties and behaviors of metallic glasses, especially mechanical, chemical and electrical-magnetic. Scientists' work on amorphous alloys is quite intense [1-10]. Some properties of Al-Y-Ni alloy which is one of amorphous alloys were investigated. some of those; Chang et al, $Al_{85}Ni_5Y_{10}$, $Al_{85}Ni_7Y_8$ and $Al_{85}Ni_{10}Y_5$ amorphous alloys produced by melt-spinning method, They determined phase transition temperatures by DSC measurements, annealed at these temperatures and made their X-ray analysis. They also examined in detail how the effect of ratios in alloys and the speed of the disc affect the amorphous structure [11]. Freitag et al., $Al_{85}Y_xNi_{15-x}$ (x = 3 - 12 at.%) amorphous alloys, investigated the effect of aluminum (Al) and yttrium (Y) on resistivity at room temperature [12]. Pekala, $Al_{85}Y_{10}TM$ (TM = Cu, Ni, Co, Fe) amorphous alloys produced by melt spinning method, determined the effect of metal atoms on electron-photon interaction and examined thermoelectric power at temperatures between 20 - 300 ˚K [13]. Again, Pekala explained the thermoelectric power and electrical resistivity of $Al_{90-x}Y_{10}Ni_x$ (x = 0, 2, 5, 8) amorphous alloys by Faber-Ziman theory. It measured the resistivity of these alloys at temperatures between 300 - 800 ˚K by four-point method. He also examined and compared the thermoelectric strength of these alloys in their crystalline and amorphous state [14]. Göğebakan, $Al_{85}Y_{11}Ni_4$,

Table 1
Production parameters of used alloys

Samples	Crucible hole diameter (mm)	Production speed V(m/s)	Sample thickness W (μm)
$Al_{85}Y_{11}Ni_4$	1.0-1.2	50-60	≈ 25-30
$Al_{85}Y_{10}Ni_5$	0.9-1.2	50-60	≈ 25-30
$Al_{85}Y_5Ni_{10}$	0.9-1.0	30-50	≈ 40-50

$Al_{85}Y_{10}Ni_5$, $Al_{85}Y_8Ni_7$, $Al_{85}Y_5Ni_{10}$ and $Al_{85}Y_2Ni_{13}$ alloys produced by melt spinning method, examined the mechanical properties, Tensal strength (σf), Young's modulus (E) and Vickers hardness (Hv) measured and compared alloys [15]. Vasiliev et al., (Al–2.6Y–9.5Ni), (Al–4.5Y–10.1Ni), (Al–4.3Y–3.5Ni) and (Al–1.7Y–6.4Ni) in atomic ratios of amorphous alloys, with electron microscopy (TEM) investigated the morphology and crystal structure of each phase. In each alloy group, have observed the formation of α-Al, Al3Ni or Al3Y and a triple phase [16]. Min Young Na. et al. conducted research on thermoplastic formability and electrical conductivity in Al–Ni–Y metallic glasses [17]. In this study, electrical properties of Al-Y-Ni amorphous alloys were investigated.

I. Experimental

Samples used in this study were produced by melt-spinning technique. Production parameters of the alloys used are given in Table 1 [18].

DSC (Differential scanning calorimetry) was measured by Perkin Elmer Sapphire. X-ray diffraction analysis, Rigaku D/max-IIIC diffractometer using CuK_∞ (λ = 1,542 A°) radiation. Measurements were carried out at room temperature in the range of $20 \leq \theta \leq 90$ with 0.02˚ steps.

Electrical measurements were made by Lucas Pro 4 device using four probe method. Here, the samples were annealed at some temperatures (not in situ), measured several times and averaged.

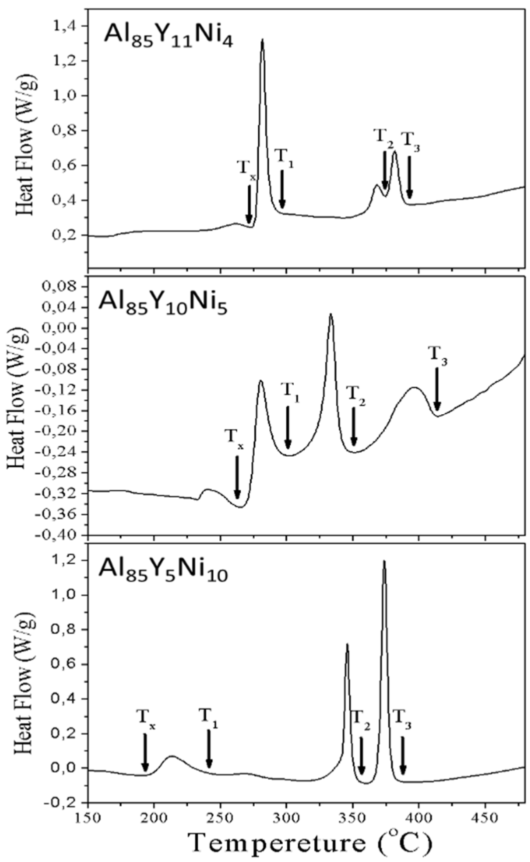

Fig. 1. DSC analysis results of samples.

II. Results and discussion

Differential Scanning Calorimetry (DSC) peak patterns for $Al_{85}Y_5Ni_{10}$, $Al_{85}Y_{10}Ni_5$ and $Al_{85}Y_{11}Ni_4$ samples are shown in Figure 1. In the DSC analysis obtained by continuous heating, three exothermic peaks were observed for the alloys used. Figure 1 shows the crystallization temperatures T_x and crystallization peaks T_1, T_2, T_3 of the samples. As can be seen from the figure, the crystallization temperature T_x increased with increasing amount of Y in the alloy. In X-ray diffraction analysis of samples before heat treatment, as can be seen from Figure 2, it is generally of amorphous structure.

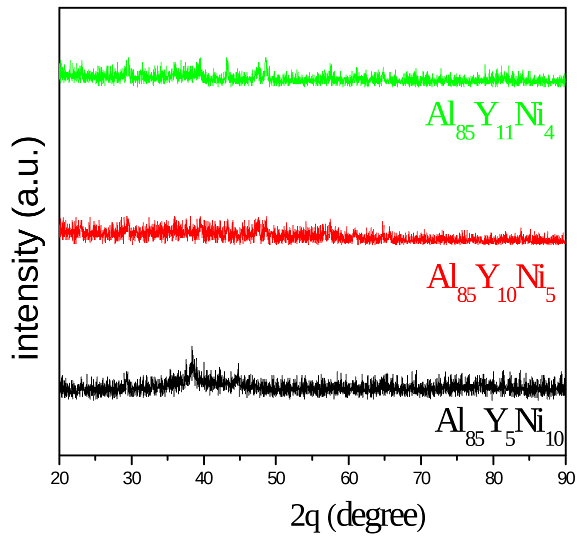

Fig. 2. X-ray analysis of samples.

One of the amorphous alloys ($Al_{85}Y_5Ni_{10}$) was annealed at certain temperatures and detailed XRD measurements were taken. In Figure 3 shows the X-ray diffraction patterns of the $Al_{85}Y_5Ni_{10}$ sample to before annealing and annealing at 250 ˚C, 355 ˚C and 390 ˚C. The sample was annealed for 15 minutes for each temperature. As can be seen from the figure, the diffraction pattern of the alloy before heat treatment shows a extensive peak in conformity with the amorphous structure. Samples were annealed at peak temperatures of crystallization taking DSC measurements into consideration.

It is seen that the amorphous sample annealed at T_1 = 250 ˚C starts to crystallize to give crystal aluminum peaks. It is observed that the alloy continues to crystallize around T_2 = 355 ˚C annealing temperature and the structure generally consists of Al and Al_3Y phases. At an annealing temperature of T_3 = 390 ˚C, the structure is completely crystallized and generally consists of phases Al_3Y and Al_3Ni.

The samples were annealed for 15 minutes at some

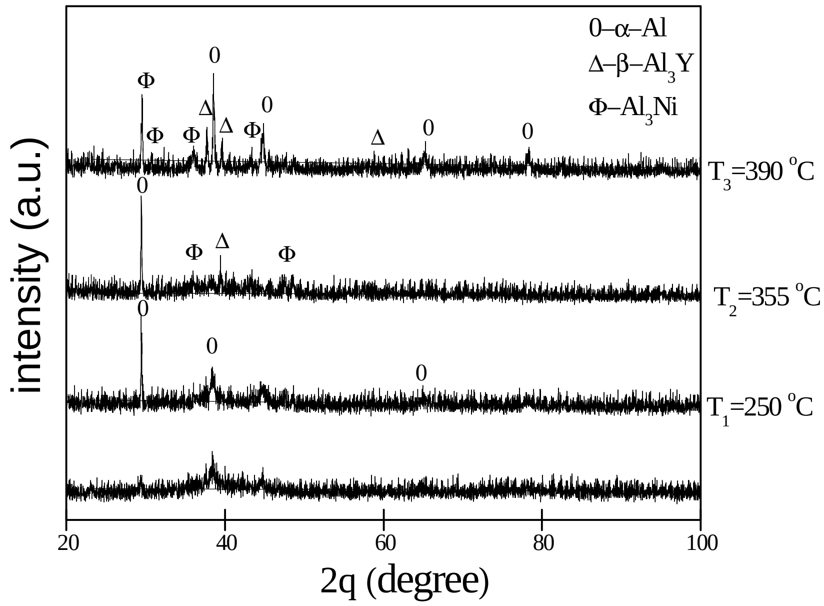

Fig. 3. X-ray diffraction patterns of some annealing temperatures of $Al_{85}Y_5Ni_{10}$ alloy.

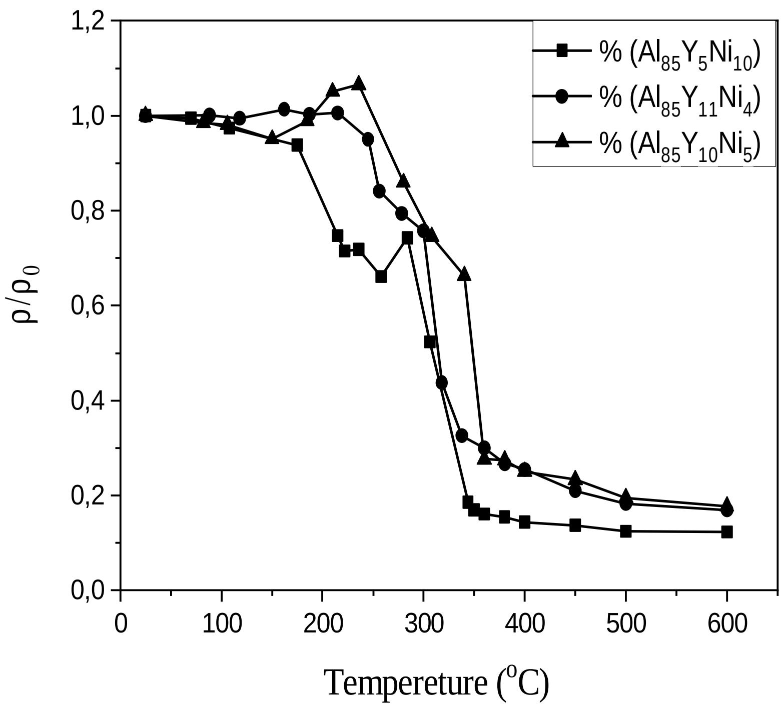

Fig. 4. ρ/ρ_0 versus temperature.

temperature values between 25 ˚C and 600 ˚C and their resistivities were measured by four-point method at room temperature. It was observed that the resistivity of the samples decreased significantly at the temperature between which the samples started to crystallize (T_x) and completely crystallized (T_3).

Figure 4 shows the temperature-dependent resistivity of the $Al_{85}Y_{11}Ni_4$ alloy between 25 ˚C and 600 ˚C. In the

DSC analysis shown in Figure 1, it was observed that the resistivity of the sample started to decrease at the temperature at which crystallization started ($T_x \approx 245$ ˚C). The large drop in resistivity continued until the $T_3 \approx 400$ ˚C temperature, where the sample completely crystallized.

In the $Al_{85}Y_{10}Ni_5$ alloy, the resistivity of the sample started to decrease at the temperature (Tx ≈ 240˚C) at which the crystallization started in the DSC analysis shown in Figure 1. The large drop in resistivity continued until the T3 ≈ 360 ˚C, where the sample completely crystallized. Again in the $Al_{85}Y_5Ni_{10}$ sample, the resistivity of the sample began to decrease at the temperature ($T_x \approx 190$ ˚C) at which the crystallization started in the DSC analysis shown in Figure 1. The large drop in resistivity continued until the T3 ≈ 350 ˚C, where the sample completely crystallized. The reason why the resistivity drops in this way can be explained by the transition of the semi-stable amorphous alloys to the stable (crystal) structure. In addition, it is observed that the resistivity continues to decrease at a little with the increasing of annealing temperature of the crystallized samples. This is thought to be related to the reduction of grain boundaries as a result of the growth of the particles in the alloy at high annealing temperatures. There are similar studies aluminum-based amorphous alloys and our results are compatible with them [14, 19-22]. In all alloys, a great decrease in resistivity is observed when it changes from amorphous structure to crystal structure.

Conclusion

In this study, electrical properties of Al-Y-Ni alloys previously obtained by melt-spinning method were investigated. The resistivity of the samples were measured by using four point technique at room temperature and annealing at some temperatures between 25 ^{o}C and 600 ^{o}C. X-ray analysis showed that the samples were amorphous before annealing. At the peaks obtained by DSC analysis, the crystallization temperatures of the samples were determined to be approximately 200 - 400 ˚C. A significant decrease in the resistivity of the samples was observed in this temperature range. The reason for the decrease in resistivity in this way can be explained by the transition of the semi-stable amorphous alloys to stable (crystal) structure. It was observed that resistivity increased as Y ratio increased in samples. Similarly, as Ni content decreased, resistance decreased.

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[1] W.K. Jun, R.H. Willens, P.O.L. Duwez, Nature 187(4740), 869 (1960) (doi:10.1038/187869b0).
[2] K. YH, K. Hiraga, A. Inoue, T. Masumoto, Materials Transactions, JIM, 35(5), 293 (1994) (https://doi.org/10.2320/matertrans1989.35.293).
[3] A. Inoue, Acta materialia 48(1), 279 (2000). (https://doi.org/10.1016/S1359-6454(99)00300-6).
[4] T.C. Hufnagel, C.A. Schuh, M.L. Falk, Acta Materialia 109, 375 (2016) (https://doi.org/10.1016/j.actamat.2016.01.049).
[5] S. Lan, Y. Ren, X.Y. Wei, B. Wang, E.P. Gilbert, T. Shibayama, X.L. Wang, Nature communications 8, 14679 (2017) (https://doi.org/10.1038/ncomms14679).
[6] Y. He, P. Yi, M.L. Falk, Physical review letters, 122(3), 035501 (2019) (https://doi.org/10.1103/PhysRevLett.122.035501).
[7] F. Zhu, S. Song, K.M. Reddy, A. Hirata, M. Chen, Nature communications 9(1), 3965 (2018). (https://doi.org/10.1038/s41467-018-06476-8).
[8] Y. Gao, H. Bei, Progress in Materials Science 82, 118 (2016) (https://doi.org/10.1016/j.pmatsci.2016.05.002).
[9] H. W. Bi, A. Inoue, F.F. Han, Y. Han, F.L. Kong, S.L. Zhu, A.L. Greer Novel deformation-induced polymorphic crystallization and softening of Al-based amorphous alloys. Acta Materialia, 147, 90-99. (2018) (https://doi.org/10.1016/j.actamat.2018.01.016).
[10] F.G.Cuevas, S. Lozano-Perez, R.M. Aranda, E.S. Caballero, Intermetallics 112, 106537 (2019) (https://doi.org/10.1016/j.intermet.2019.106537).
[11] I.T.H. Chang, P. Svec, M. Gogebakan, B. Cantor, Trans Tech Publications. 225, 335 (1996) (https://doi.org/10.4028/www.scientific.net/MSF.225-227.335).
[12] J.M. Freitag, Z. Altounian, Materials Science and Engineering A, 226, 1053 (1997) (https://doi.org/10.1016/S0921-5093(97)80104-9).
[13] K. Pękała, Journal of non-crystalline solids 250, 800 (1999) (https://doi.org/10.1016/S0022-3093(99)00181-7).
[14] K. Pękała, Journal of non-crystalline solids, 287(1-3), 183 (2001) (https://doi.org/10.1016/S0022-3093(01)00555-5).
[15] M. Gögebakan, Journal of Light Metals 2(4), 271 (2002) (https://doi.org/10.1016/S1471-5317(03)00011-7).
[16] A.L. Vasiliev, M. Aindow, M.J. Blackburn, T.J. Watson, Intermetallics 12(4), 349 (2004) (https://doi.org/10.1016/j.intermet.2003.11.007).
[17] M.Y. Na, S.H. Park, K.C. Kim, W.T. Kim, D.H. Kim, Metals and Materials International 24(6), 1256 (2018) (https://doi.org/10.1007/s12540-018-0130-7).
[18] M. Göğebakan, Amorphous and Nanocrystalline Al-based Alloys. University of Oxford. Ph.D. thesis, 164s. (1998).

[19] K. Pękała, (2007). Journal of Non-Crystalline Solids 353(8-10), 888 (https://doi.org/10.1016/j.jnoncrysol.2006.12.094).

[20] K.L. Sahoo, A.K. Panda, S. Das, V. Rao, Materials Letters, 58(3-4), 316 (2004) (https://doi.org/10.1016/S0167-577X(03)00477-4).

[21] Ü. Alver, S. Kerli, M. Göğebakan, Electrical Resistivities and Magnetic Properties of Amorphous AI-Y-Ni Alloys. In AIP Conference Proceedings (899, 1, 614). AIP. (2007). (https://doi.org/10.1063/1.2733355).

[22] V. Sidorov, P. Svec, Sr. P. Svec, D. Janickovic, V. Mikhailov, E. Sidorova, L. Son, Journal of Magnetism and Magnetic Materials 408, 35 (2016) ((https://doi.org/10.1016/j.jmmm.2016).