Investigation of dual phase (β+γ) CoNiAl MSMA Micro structure effect on the Mechanical Properties and Bio-Corrosion Resistance

Dr. J. A. Al-Hahidary
Production and Metallurgy Engineering Department, University of Technology/ Baghdad
Email: jalhaidary@yahoo.com
Dr. Sehama E. Salih
Materials Engineering Department, University of Technology / Baghdad
Email:Sehama_saleh@yahoo.com
Dr. P.Mukhopadyiay
S N Bose ,N C B S/ Kolkata , India
M. N. Arbilei
Production and Metallurgy Engineering Department, University of Technology/ Baghdad

Received on:8/10/2013 & Accepted on:21/4/2016

ABSTRACT

In this study five compositions of CoNiAl alloy with fixed Al content were prepaid to investigate the effect of chemical composition on the microstructure and phase volume fractions. It was found that by increasing Co the volume fraction of β phase increases and by increasing the β phase the grain size will be increased. This increase will be reflected on increasing the hardness of this alloy. Further investigations for the corrosion resistance in simulated body environment were done. It was found that phase volume fractions increased corrosion rate by increasing the volume fraction of β phase.

Keywords: Co Ni Al, Bio-Medical Corrosion, Hardness, Microstructure

INTRODUCTION

The new ferromagnetic shape memory CoNiAl alloy system are considered as alternative alloy for the expensive brittle well known NiMnGa due to their better ductility and a lower cost of constituent elements. The origin of good ductility came from the presence of γ phase precipitates at grain boundaries of β phase [1, 2].

In general, the investigation of microstructure control in Co-Ni-Al alloys is focusing on (1) the grain size of the β phase and (2) the volume fraction and distribution of the precipitates [3, 4]. Several studies have been devoted to this attractive field. Tanaka et al. investigated the quantitative effect of the γ phase on the mechanical and shape memory properties by annealing treatment [5]. Kainuma et. al. [3] pointed out that the dendritic structure is not favorable for hot-workability. The β phase in a limited composition range experiences a martensitic transformation to a $L1_0$ structure on cooling. It is the active phase for shape memory effect. However, it has been found that the presence of the γ phase affects the martensitic transformation behavior of the β phase and, at the same time, enhances the ductility of the matrix.

https://doi.org/10.30684/etj.34.9A.14
2412-0758/University of Technology-Iraq, Baghdad, Iraq

Whilst enhancing the mechanical applicability of the alloys due to the latter effect, γ phase reduces the shape memory functionality of the alloys by suppressing their martensitic transformation. Therefore, for optimizing the microstructural design of the alloys, it is necessary to understand the phase formation, phase stability and phase properties of Co-Ni-Al alloys [6, 7].

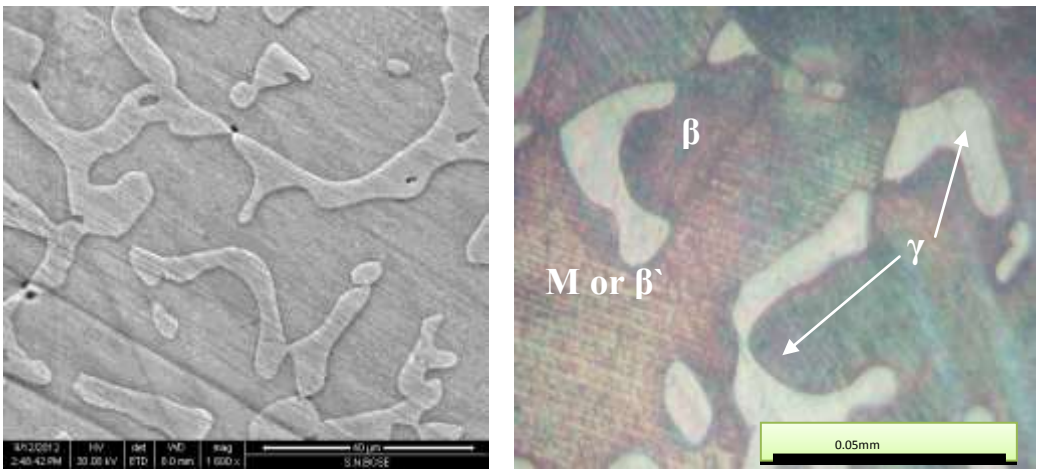
This study was focused on the effect of Co and Ni on β and γ volume fractions and grain size of β phase on the mechanical properties of this alloy presented by Vickers Hardness.

Experimental Work:

Five polycrystalline ingots with different compositions of pure element of 99.9% electrical Co Ni and Al were prepared. The first four samples were prepared with a fixed Al Atomic percent of 28% the last sample was with 25% as presented in Table (1). All samples were melted 4 times by ARC melting for homogenization. The compositions of the four alloys prepared according to the samples were annealed at 1200^{o}C in a sealed quartz tube and subsequently quenched in ice water for periods of (6 and 12 h). All samples were optically investigated and digitally analyzed by sophisticated software (Image J2X). All samples were characterized by X-ray diffraction (XRD) and analyzed by SEM with EDAX. The hardness values were determined by Vickers Micro hardness. A human body simulated corrosion sell was designed to represent the biomedical application environment. Ringer solution was used at 37^{o}C. Tafel curves were investigated using poteniostate instrument.

Results and Discussion

The microstructure and chemical analysis of samples were presented in Table (1). Where it was found that the structure of these alloys consisted of two main phases (β and γ) where the β phase presented with in the structures with two forms (β and β` or M). The γ phase was precipitated at the grains boundaries of β grains as shown in Figure (1). All samples were investigated and digitally analyzed by computer to determine the phase volume fractions and grain size.



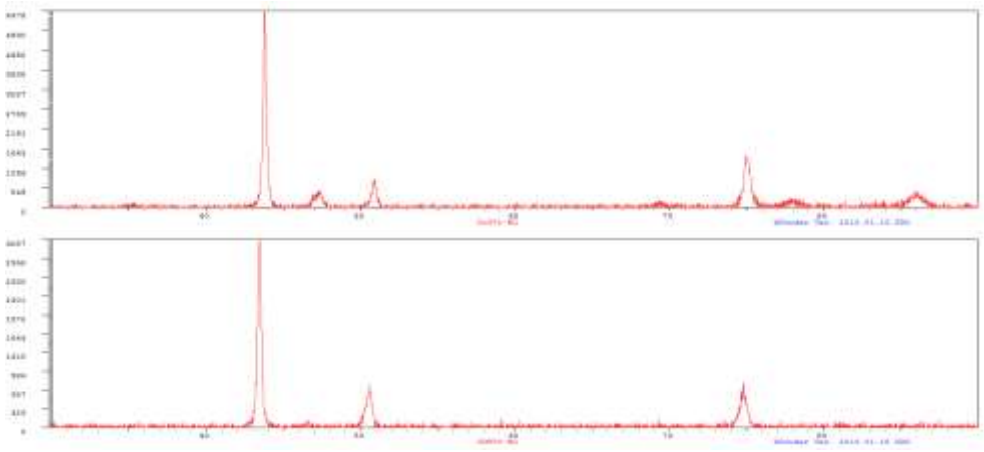


Figure (1) The Microstructure of Co Ni Al alloy by SEM and Optical Microcopy and XRD Pattrens

All samples investigated by SEM supported with EDAX and XRD in order to investigate the microstructure an analysis the chemical compositions of both phases as presented for one of the samples. Where it was found by analyzing the first four samples that there was two different chemical composition all over the sample one of them are rich with Aluminum which presented the β phase and the other was rich with cobalt represented the γ phase [4]. The chemical analysis showed the chemical analysis of each phase for 1st group of samples. While only β phase compositions for last two samples were determined.

The volume fractions grain size and hardness values were presented in Table (1). All volume fraction and grain size has been determined by using Image J 2X software. According to these results it could be found that the volume fraction of β phase was increased by increasing the heat treatment time and by increasing the volume fraction the grain size of β grains was also increased as presented in Table (1) regarding Samples CO1, CO2 and CO5 when compared after treatment for 6 hours and 12 hours respectively. In addition to the effect of heat treatment it was found that the chemical composition also effected on the volume fraction and the grain size of β phase that will effect by increasing the hardness values.

Table (1) the chemical analysis and hardness values for the alloys with different heat treatment periods and the phase's volume fractions and grain size for each case.

Sample	Alloy	β Analysis (at%)			γ Analysis (at%)			Annealing time (h)	β%	GS µm	Hv
		Co	Ni	Al	Co	Ni	Al				
CO1	Co35Ni37Al28	35	39	26	42	39	19	6	53	55	290
								12	52	60	312
CO2	Co36Ni36Al28	32	37	31	43	37	21	6	61	65	261
								12	58	65	287
CO3	Co37Ni35Al28	35	35	30	44	34	22	12	64	70	373
CO4	Co38Ni35Al28	36	34	30	45	37	18	12	80	75	438
CO5	Co37Ni38Al25	26	39	35				6	40	25	261
								12	55	30	284

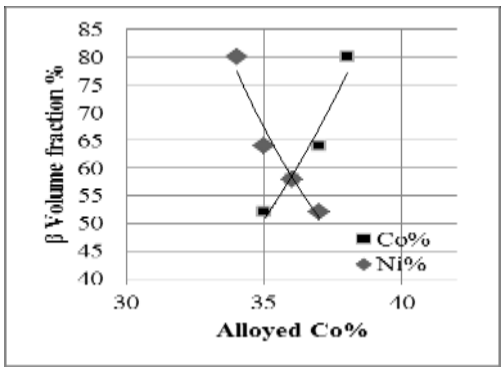


Figure (2) effect of Chmical Composition on β phase voulme fraction

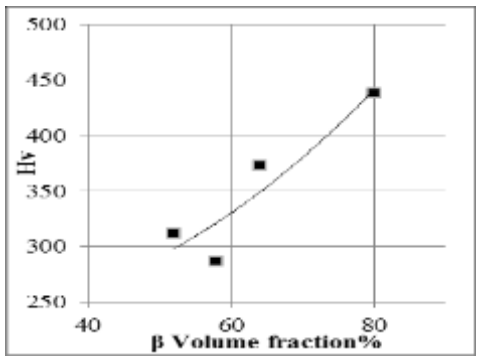


Figure (3) The effect of β Voulume fraction on Vickers Hardness

Figure (3) showed the effect of β phase volume fraction on hardness. According to the increase in grain size it was indicated that the amount of the ductile γ phase around the grain boundaries will be reduced as shown in Figure (4).

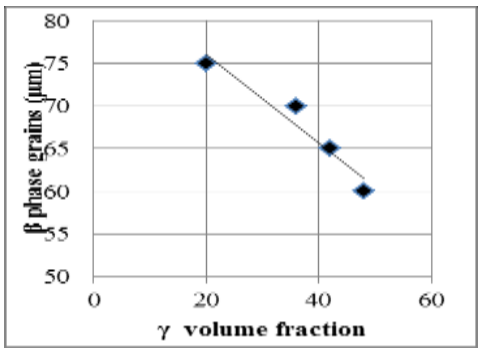


Figure (4) The Relation Between the grain size of β phase and the volume fraction of γ phase

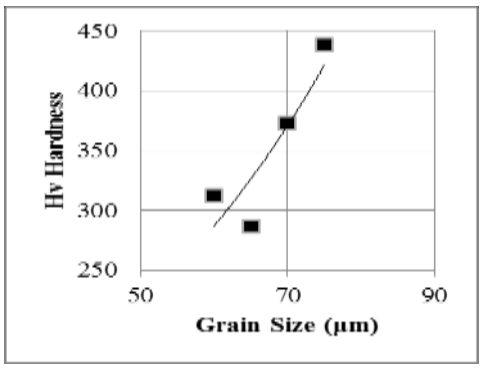


Figure (5) The realtion between the grain size of β phase and hrdness values.

The ductile phase when precipitated around the grains of β phase will work as a dumper for external forces when applied on the grains that will minimize the effect of hardness indenter on the β grains accordingly the hardness will be reduced. These results were explained more through Figure (5) were by increasing β volume fraction that hardness will increase.

By investigation the corrosion behavior of CO5 samples that were treated for 6 and 12 hours in a simulation body environment. The corrosion behavior was explained through the TAFEL curves.

Figure (6 A & B) showed TAFEL Curves. According to TAFEL curves determinations that presented in Table (2). The corrosion rate was increased by increasing the volume fraction of β phase. That because the β phase which presented as martensite phase is a stressed phase which will be preferred to behave as an anode.

Table (2) Corrosion behavior parameters for CO5T1 and CO5T2

Sample	Area cm^2	β %	G.S µm	I corr $\mu A/cm^2$	E corr mV	CR MMPY	I pp $\mu A/cm^2$	E pp mV
CO5T1	0.28	45	28	5	-650	0.12	1.2	-620
CO5T2	0.21	50	30	0.69	-990	0.33	0.9	-1010

The calculation of corrosion rate have been done depending on Icorr and according to ASTM Standards G102 as shown in equation below [8]:

$$CR = \frac{I_{corr} \cdot K \cdot EW}{dA}$$

Where: EW is equivalent weight for the alloy according to its chemical compositions. d is the Density, and A is the sample area. While K is a constant depends on the unit of corrosion rate.

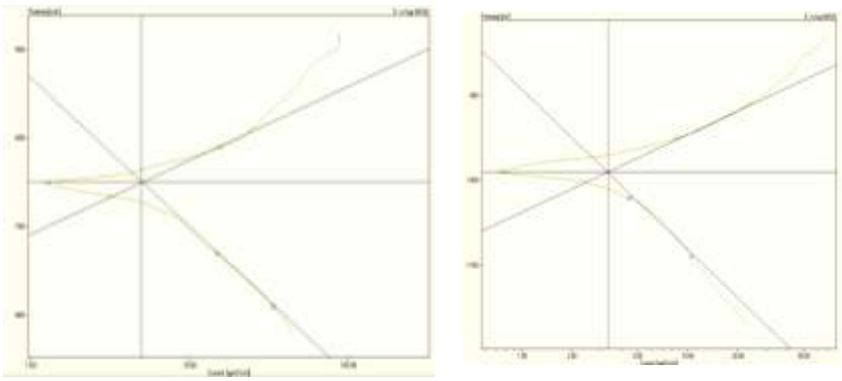


Figure (6) Tafel Curves for (A) CO5T1 and (B) CO5T2

The cyclic corrosion curves that were presented in Figure (7 A & B) it was found that area between the two anodic curves indicated that there is no possibility for pitting corrosion for both treatments

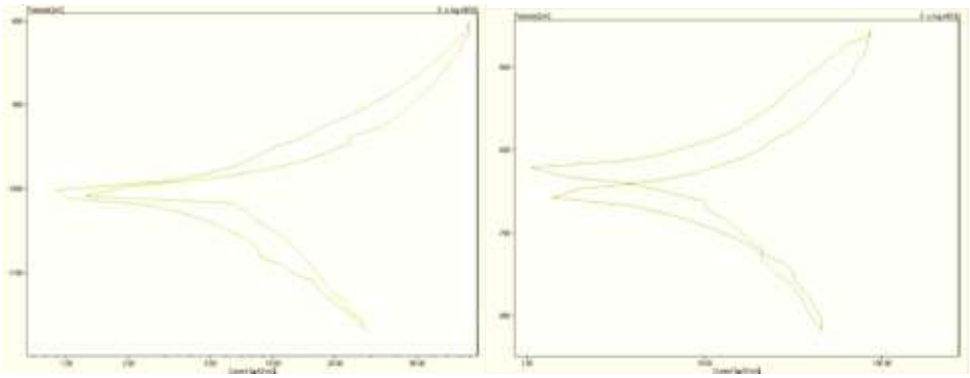


Figure (7) The cyclic corrosion curves for (A) CO5T1 and (B) CO5T2

CONCLUSIONS

1- The microstructure was consisted of two main phases (β and γ) where the β phase presented with two forms. These forms were Austenite phase (β) and the Martensitic Phase (M or β`).

2- Increasing the heat treatment time will increase both the volume fraction and grain size β phase.

3- The volume fraction and grain size of β phase increasing the increasing Co at% decreasing Ni At%.

4- The increase in γ phase will be related to decreasing in β phase grain size.

5- The increase in β grain size will increase the values of Vickers hardness

6- The corrosion rate increased with increasing on the volume fraction of β phase moreover.

Acknowledgments:

This work was done with help of S n Bose Center for Basic Sciences, Kolkata, India. This research also supported by the Department of Materials engineering university of Technology, Iraq, Baghdad.

REFERENCES:

[1].J. Pons, E. Cesari, C. Segui, F. Masdeu, R. Santamarta, "Ferromagnetic Shape Memory Alloys: Alternatives to Ni–Mn–Ga", 2008, Materials Science And Engineering PP. 481–482

[2].K. Oikawa T. Ota, F. Gejima, T. Ohmori, "phase equilibria and phase transformations in new B2-type Ferromagnetic shape memory alloys of Co-Ni-Ga and Co-Ni-Al systems", 2001, Materials Transections Vol. 42 No.11 PP 2472-2475.

[3].K. Oikawa, L. Wulff, T. Iijima, F. Gejima, T. Ohmori, "Promising ferromagnetic Ni–Co–Al shape memory alloy system", 2001, Applied Physics Letters VOL. 79, No. 20,PP. 3290-3292.

[4].Y. Tanaka, Toshihiro Ohmoril, K. Oikawa, R. Kainumal and K. Ishidal, "Ferromagnetic Co-Ni-Al Shape Memory Alloys with (β+γ) Two-Phase Structure", 2004, Materials Transactions, Vol. 45, No. 2, PP. 427-430

[5].Y.Tanaka, K. Oikawa, Y. S utou, T. Omori. R. Kainuma, K. Ishida, "Martensitic transition and superelasticity of Co–Ni–Al ferromagnetic shape memory alloys with β+ γ two-phase structure", 2006, Materials Science and Engineering A (438–440), PP. 1054–1060.

[6].J. Liu, J. G. Li, "Microstructure, shape memory effect and mechanical properties of rapidly solidified Co–Ni–Al magnetic shape memory alloys", 2007, Materials Science and Engineering A (454–455), PP. 423–432.

[7].Patrik Schmutz, "Metallic Medical Implements: Electrochemical Characterization Of Corrosion Processes", 2008, The Electrochemical Society Interface, PP.35-40

[8].ASTM Standard G102, "Standard Practice for Calculation of Corrosion Rates".