ELSEVIER
Journal of Materials Processing Technology 143–144 (2003) 551–554
Journal of Materials Processing Technology
www.elsevier.com/locate/jmatprotec

The effect of Cu-macroalloying on β-NiAl intermetallic compound obtained by mechanical alloying

S. García-Galán [a,*], G. Arámburo-Pérez [a], C. González-Rivera [a], J. Juárez-Islas [b]

[a] *Departamento de Ingeniería Metalúrgica, Facultad de Química, Universidad Nacional Autónoma de México (UNAM), Circuito Institutos s/n Edificio "D", Ciudad Universitaria, Mexico 04510 DF, Mexico*

[b] *Facultad de Química, Instituto de Investigaciones en Materiales, Universidad Nacional Autónoma de México (UNAM), Circuito Institutos s/n Edificio "D", Ciudad Universitaria, Mexico 04510 DF, Mexico*

Abstract

The synthesis and bending strength of nanocrystalline β-phase NiAl intermetallic compound macroalloyed with copper are discussed in this paper. Nanocrystalline NiCuAl powders were prepared by mechanical alloying of elemental Ni, Al and Cu powders under argon atmosphere. The alloyed nanocrystalline powders were consolidated by double action pressing at a pressure of 1.20 GPa and sintered at 1000 °C during 20 min to 80% dense compacts. X-ray diffraction patterns show that 40 min was enough to transform Ni, Cu and Al elemental powders into NiAl intermetallic compound. The crystallite size measurements revealed that the grain size of the NiCuAl phase decreased from 8.5 to 5.4 nm with increasing mechanical alloying time from 40 to 240 min. Bending strength shows an increment as the copper content is raised up to 7.5 at.%. After this point bending strength values decrease. The modulus of elasticity shows the same behavior as the bending strength.

Keywords: Mechanical alloying; Intermetallic NiAl compound; Bending strength; Nanocrystalline materials

1. Introduction

NiAl has been studied extensively as a potential structural material. The attractive attributes of NiAl leading to this interest include: a high melting temperature, low density, good environmental resistance, high thermal conductivity, attractive modulus and metal-like properties, above a modest ductile-to-brittle transition temperature. The principal limitations of unalloyed NiAl are poor toughness and damage at room temperature, and inadequate strength and creep resistance at elevated temperature [1].

The technique of high-energy ball milling has been extensively used to synthesize powders with interdispersed phases (for ductile materials) and to reduce the grain size of brittle material. More recently, it has been discovered that this method can be used for mechanical alloying of elemental powder mixture on an atomic scale [2]. Considerable effort has been devoted over the past several years to prepare nanocrystalline intermetallic powders and to consolidate them to bulk form, while maintaining an ultrafine microstructure, often in the hope of obtaining alloys exhibiting high hardness, high strength or improved ductility [3–5].

Mechanical alloying is capable of producing homogeneous, fine-grained alloys in the solid state, thus providing a processing technique that can avoid the large-grained inhomogeneous structures resulting from conventional casting processes. Although it is well-established now that mechanical alloying leads to a fully nanocrystalline microstructure, there is still a limited understanding of the fundamentals of nanostructure formation which is necessary for tailoring materials with specific physical properties. In particular, little is known about the influence of the composition of the material and the properties of the nanocrystalline powders [6].

The purpose of this work is to explore the effect of Cu-macroalloying on the mechanical properties of β-NiAl obtained by mechanical alloying as revealed by the bending test.

2. Experimental procedure

In order to study the influence of Cu-macroalloying on the β-NiAl intermetallic compound obtained by mechanical alloying, Cu-additions were made by maintaining a fixed ratio of $X_{Ni}/X_{Al} = 1$ as indicated in Table 1. The cases of interest are shown on the relevant zone of the Ni–Cu–Al ternary phase diagram, in Fig. 1.

* Corresponding author.
E-mail address: sergiogg@servidor.unam.mx (S. García-Galán).

0924-0136/$ – see front matter © 2003 Elsevier Science B.V. All rights reserved.
doi:10.1016/S0924-0136(03)00353-4

Table 1
Copper added to Ni + Al elemental powders

Alloy	Ni (at.%)	Al (at.%)	Cu (at.%)
A0-1	50	50	0
A0-2	48.75	48.75	2.5
A0-3	47.5	47.5	5.0
A0-4	46.25	46.25	7.5
A0-5	44.68	44.68	10.64

Ni, Al and Cu powders, with nominal purity of 99, 99.97 and 99.9%, respectively, with particle sizes within the range 20–50 μm were mechanically alloyed in a SPEX 8000 mixer/mill using an AISI 304 stainless steel vial. The ball-to-powder weight ratio was 15:1.

In order to establish the milling time needed to obtain the mechanical alloying of NiAl, milling of alloy A0-1 was performed for time periods ranging between 0 and 240 min. Specifically, the milling times were 20, 40, 60, 120, 180 and 240 min. The obtained powders were examined by means of a Siemens D-5000 X-ray diffractometer enabling the selection of the milling time used during the mechanical alloying of Ni–Cu–Al powders (alloys A0-2 to A0-5).

After milling, the powders were consolidated using a pressure of 1.2 GPa to obtain compacts of 3.2 cm in length, 1.27 cm in width and 0.15 cm in thickness. The compacts

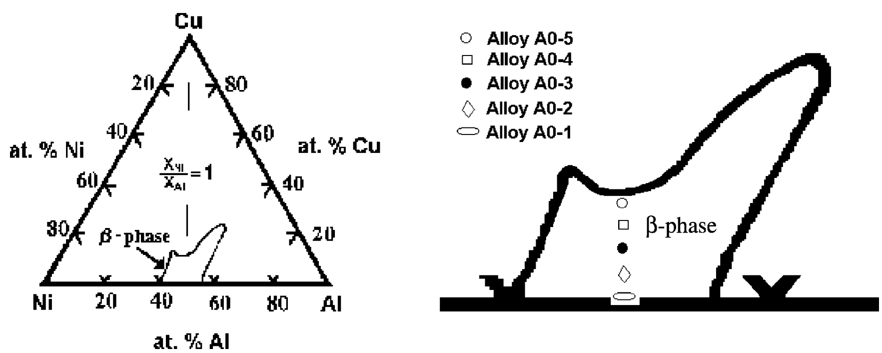

Fig. 1. Ni–Cu–Al ternary phase diagram and β-phase stability zone.

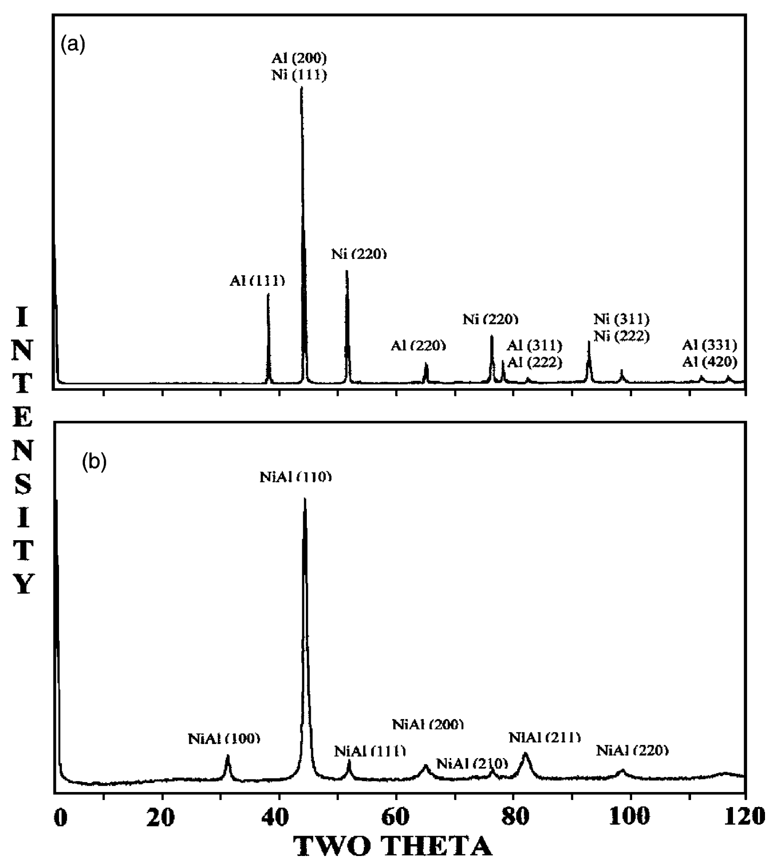

Fig. 2. X-ray diffraction pattern of NiAl elemental powder mixture (a) initial condition; Ni and Al elemental powders and (b) ball milled for 40 min where a complete transformation into NiAl is detected.

Table 2
Average grain size of A0-1 as a function of milling time

Milling time (min)	Species detected by using X-ray diffraction patterns	Average grain size (nm)
0	Ni	35
	Al	39
20	Ni	22
	Al	30
40	NiAl	8.5
60	NiAl	6.5
120	NiAl	5.9
180	NiAl	5.5
240	NiAl	5.4

were sintered during 20 min at 1000 °C under Ar atmosphere.

The room temperature mechanical properties of the sintered compacts were studied by the bending test, using an Instron 1125 testing machine (50 kg load). At least three sintered probes of each case under study were tested.

3. Results and discussion

Using the X-ray diffraction patterns it was possible to establish that the NiAl intermetallic compound was completely formed after 40 min of milling (Fig. 2). Taking into account that NiAl shows an explosive compound-formation reaction according to Atzmon [2], the grain size of NiAl after this reaction must be smaller than the initial grain size. Grain size was determined from the X-ray diffractograms using the Scherrer equation [7].

Table 2 shows the results of grain size as a function of milling time and the species obtained in each case. As can be observed as the result of NiAl formation there is a notorious decrease of the grain size after a milling time of 40 min followed by a slight decrease for higher milling times contrarily to the work of Chen et al. [8].

Mechanical alloying of alloys A0-2 to A0-5 (see Table 1) was performed using a milling time of 40 min. The results of the bending test are shown in Figs. 3–5 including the observed dispersion at 95% confidence intervals. Fig. 3 shows

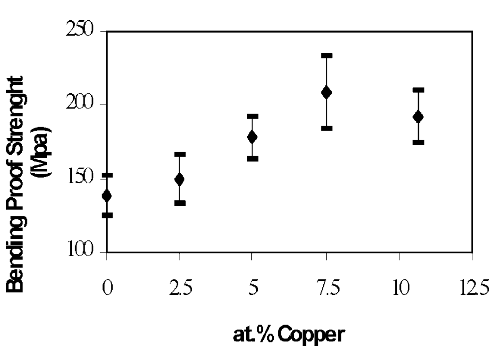

Fig. 3. Bending proof strength as a function of Cu additions.

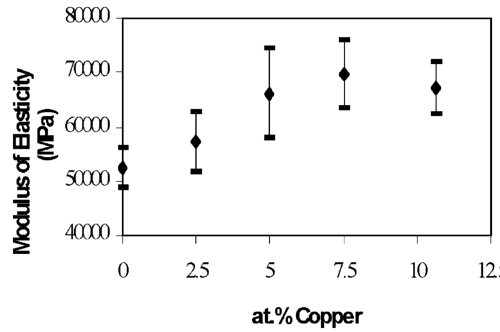

Fig. 4. Modulus of elasticity as a function of Cu additions.

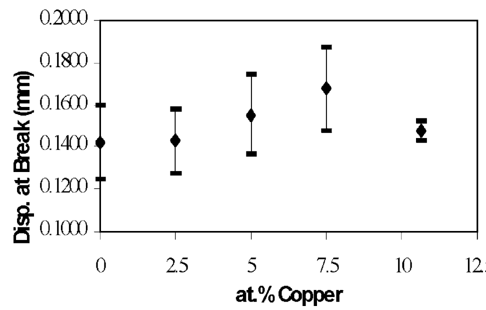

Fig. 5. Displacement at break as a function Cu additions.

the effect of copper content on the bending strength of the probes, where it can be seen that the bending strength trend as a function of copper content apparently shows a maximum for a copper content of 7.5 at.%, reaching an increase in the bending strength of approximately 37%, when compared with the corresponding value associated to the binary β-NiAl.

It can be observed in Figs. 4 and 5 that the modulus of elasticity and the displacement at break as a function of copper content shows a similar trend to that shown by the bending strength. At the maxima, there is an increase of 44 and 12%, in modulus of elasticity and displacement at break, respectively, with respect to the binary β-NiAl.

From the results depicted in Figs. 3–5 it is apparent that the mechanical properties of β-NiAl obtained by mechanical alloying can be enhanced by macroalloying with copper, at least in the experimental conditions present in this work.

Further work is needed to explain this behavior and to explore the effects of Cu-macroalloying in the Ni-rich and Al-rich zones of the β(Ni, Cu)-Al ternary phase diagram.

4. Conclusions

A maximum of bending strength, modulus of elasticity and displacement at break was obtained for the β-NiAl alloy with 7.5 at.% Cu. The outcome of this work shows that mechanical properties of β-NiAl obtained by mechanical alloying may be enhanced by macroalloying with copper, at least in the experimental conditions present in this work.

Acknowledgements

The authors would like to thank Eng. A. Maciel Cerda, Mr. E. Hinojosa and Mr. P. Cabrera for the experimental work. DGAPA IN 108799 supported this research.

References

[1] D.B. Miracle, R. Doralia, in: J.H. Westbrook, L.R. Fleischer (Eds.), Intermetallic Compounds, vol. 2, Practice, Wiley, New York, 1994, p. 53.
[2] M. Atzmon, Phys. Rev. Lett. 64 (4) (1990) 487.
[3] R. Bohn, T. Haubold, R. Biringer, H. Gleiter, Sci. Metall. Mater. 15 (1991) 811.
[4] C. Suryanarayana, F.H. Froes, Metall. Trans. A 23 (1992) 1071.
[5] S. Bose, Mater. Sci. Eng. A 196 (1995) 105.
[6] J. Eckert, I. Börner, Mater. Sci. Eng. A 239–240 (1997) 619.
[7] L.Z. Zhou, J.T. Guo, Scripta. Mater. 40 (2) (1999) 139.
[8] T. Chen, J.M. Hampikian, N.N. Thadhani, Acta Mater. 47 (8) (1999) 2567.