

SOME PROPERTIES OF Ni-AlNi METALLIC-INTERMETALLIC LAMINATE MATERIAL

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Abstract

Ni-AlNi metallic-intermetallic laminate (MIL) composites have been fabricated in open atmosphere using commercial purity Ni and Al foils with 250 μm initial thickness. Sintering process has performed at 700°C under 2 MPa pressure for 5 hrs. Composite consisting of alternating layers of metallic Ni and the intermetallic AlNi have been fabricated by reactive foil sintering in open atmosphere furnace. The aluminum foil was almost consumed by forming a nickel aluminide intermetallic compound. Thus, the final microstructure consists of alternating layers of intermetallic compound and unreacted Ni metal. Microstructure and phase characterization were performed by scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS) and x-ray diffractometry (XRD). Hardness values of test samples have also measured as 800 HV by vickers indentation method.

Key words: Intermetallic, nickel aluminide, laminate composite, sintering

INTRODUCTION

Intermetallics like titanium tri-aluminide (Al_3Ti) possess a very stable crystalline structure, resulting in increased internal resistance to displacement under applied stress. This inhibition of the slip processes necessary for plastic deformation makes the bulk material very brittle, which limits its use as a structural component. Because intermetallics have high strength without toughness, great effort has been made to reinforce them with particles, fibers and layers of ductile metals. Two of the basic principles behind ductile phase reinforcement are: the generation of zones of bridging ligaments by crack-particle (or laminate) interactions that restrict crack propagation by means of closure tractions in the crack wake, and increasing fracture resistance by employing the work of plastic deformation in the ductile phase (Price 2011)

Metal-intermetallic laminate (MIL) composites are hybrid laminate structures designed to optimize the desirable mechanical properties of intermetallics by incorporating layers of ductile reinforcement. The Ti- Al_3Ti MIL is composed of bonded layers of titanium, and the intermetallic phase Al_3Ti . The microstructures of these MILs can be designed to optimize the desirable characteristics of their constituent components, with the end result being a material that possesses the high strength and stiffness of the intermetallic phase and the high toughness and ductility of the residual metals. The volume fraction of each component in the laminate is determined both by initial foil thickness and the synthesis process, which allows for fine tailoring of the bulk mechanical properties of the material for specific applications. There are several advantages of this approach to MIL fabrication that make it a viable large-scale structural material: the use of commercially available foils lowers cost, and the use of ductile foils allows for the fabrication of non-planar structures (Price 2011, Tiezheng 2004, Tiezheng 2011, Rohatgi 2003).

Laminate composites are being intensively studied for a number of potential applications: electronic devices, structural components, armor, etc. Ceramic-ceramic, metal-ceramic, metal-metal, metal-ceramic-intermetallic and metal-intermetallic systems have shown desirable properties. In particular,

the Ti–Al₃Ti system has a great potential for structural applications because of its low density and excellent specific mechanical properties. Rawers and co-workers demonstrated that these intermetallics could be synthesized by high temperature synthesis reaction. This system has been extensively investigated by Harach and Vecchio, who introduced a number of significant advances. Whereas Rawers and co-workers used a vacuum or argon protective atmosphere, Harach and Vecchio were able to synthesize the laminates in open air. This represents a great technological advantage, since it enables industrial production at significant cost reduction (Tiezheng 2004, Tiezheng 2011, Rohatgi 2003). In particular, titanium–titanium tri-aluminide (Ti–Al₃Ti) or nickel–tri-nickel aluminide (Ni–Ni₃Al) metal–intermetallic laminate (MIL) composite systems have a great potential for aerospace, automotive and other structural applications because of their combination of high strength, toughness and stiffness at a lower density than monolithic titanium or other laminate systems. Furthermore, since Al is relatively inexpensive compared to Ti or Ni, the Ti–Al₃Ti or Ni–Ni₃Al systems are economically more attractive than monolithic Ti or Ni (Peng 2005).

Intermetallic compounds based upon aluminides of several transition metals such as iron, nickel, titanium, cobalt, niobium, and tantalum have been recognized as potential candidates for the high-temperature structural applications (Peng 2005, Rohatgi 2003, Konieczny 2012). Among various aluminides of transition metals, the compounds in the Ni–Al system have been of great interest for their excellent mechanical properties and high degree of structural complexity.

Intermetallics NiAl and Ni₃Al pose high melting point, low density, high strength, good corrosion and oxidation resistance at high temperature (Zhang 2011, Zhang 2008) Nickel aluminide intermetallics have been envisaged as good candidates for a number of industrial sectors, including aerospace, automotive, and power generation industries due to their low density, high temperature stability and high strength to weight ratio. Owing to their excellent corrosion and oxidation resistance especially at the high temperature, nickel aluminides are also considered as materials that might replace current nickel-based superalloys in rugged environments (Zhang 2011).

Nickel-aluminum system is one of the most well known in terms of the formation of intermetallic phase. This system is also in the priority among in laminate composite systems. The objective of the present research is to synthesize nickel–nickel aluminide metallic–intermetallic composites and its microstructural characterization.

EXPERIMENTAL PROCEDURE

Materials and Method

The MIL process consists of stacking commercial purity aluminum and nickel aluminide foils in alternating layers. The foils were provided from Alfa Aesar Company and their properties are shown in the table 1.

Table 1. Properties of foils used in experiments

Foil	Thickness, μm	Purity, %
Ni	250	99,5
Al	250	99,5

The foil dimensions were initially selected to completely consume the aluminum in forming the intermetallic compound with alternating layers of partially unreacted Ni metal. Nickel and aluminium foils were cut into 10mm×10mm rectangular pieces. No special surface preparation treatment was

applied to the nickel and aluminium foils prior to processing. Any contamination on the surface of foils was cleaned using water and then ethanol. After drying rapidly, they were laminated alternatively into nickel/aluminium multilayer samples. In each stack was consisting of 4 nickel and 3 aluminum foil as in shown Fig.1a. An initial pressure of 2.0 MPa is applied at room temperature to ensure good contact between foils (Fig.1b). Sintering process is applied in an open air, electrical resistance furnace at 700°C for 5 hour.

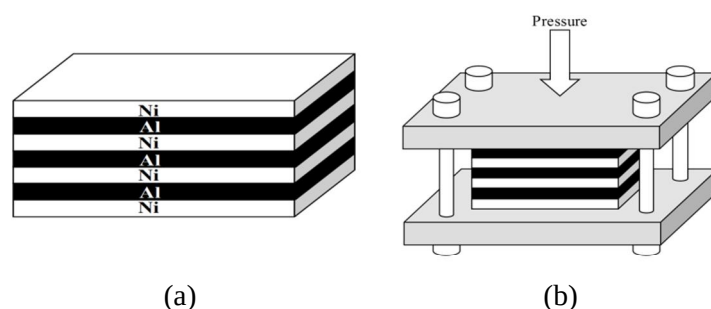


Figure 1. (a) Nickel-Aluminum stack, (b) Schematic diagram of the synthesis apparatus. Image is not to scale and does not show the load frame (İpek 2008)

Samples were ground and polished using standard metallographic techniques. Microstructure analyses of composites were performed with a JEOL JSM-5600 model scanning electron microscope (SEM). The presence of phases formed within the sintered samples was determined by Energy Dispersive Spectroscopy (EDS). Microhardness of composites were determined using a Leica WMHT-Mod model Vickers hardness instrument under an applied load of 300 g for intermetallic zone, and 100 g for metallic zone. Composition of the phases was determined by comparing the results of the microprobe analysis with the data in the binary Ni–Al phase diagram (Fig. 1). In addition, X-ray diffraction using Cu K α radiation with a wavelength of 1.5418 Å over a 2 θ range of 10-80° was employed to identify the intermetallic phases.

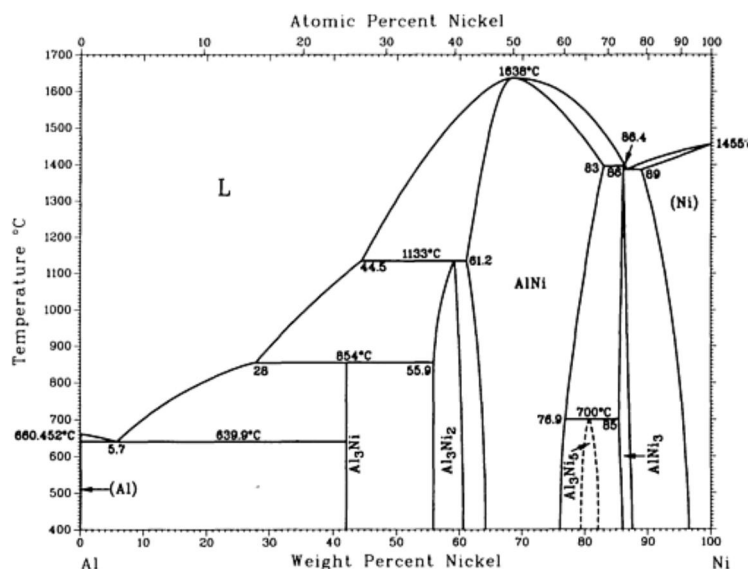


Figure 2. The Ni–Al binary phase diagram (ASM Metals Handbook, 1992)

RESULTS AND DISCUSSION

Microstructure

The typical microstructures of the MIL composites are shown in Fig.3. The presence of different regions indicates that different phases in the composites. In relatively low magnification (Fig.3.a) it is shown that foils are stacked properly. Furthermore, the laminated composites are well-bonded. There is a symmetric change from a light colored phase to another. Following the light colored phase there is a grey colored formation, subsequently, darker grey colored phase and in the center line a black colored phase. The light colored layers consist of unreacted Ni, which are separated by the apparently darker Al_3Ni -layers, as was identified by quantitative EDS analysis (Fig. 4).

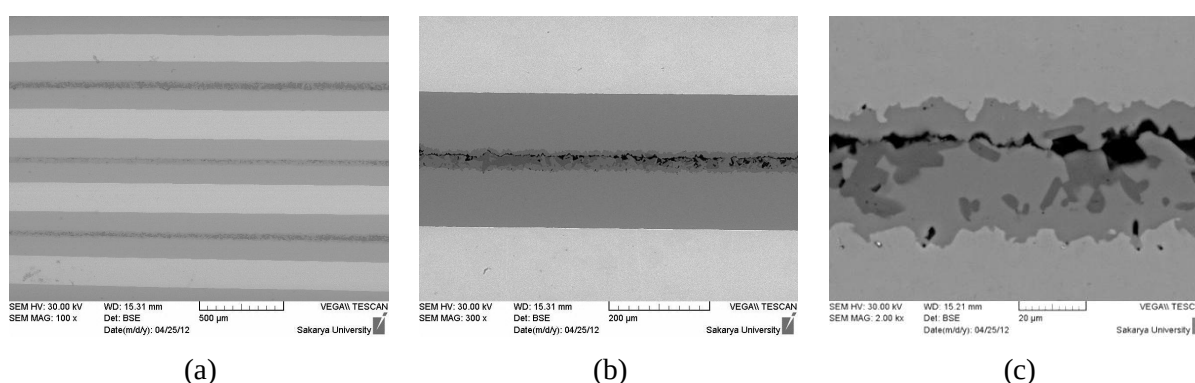


Figure 3. SEM Micrograph of laminated composites produced at 700°C-5h. (a)100X, (b)300X, (c) 2000X

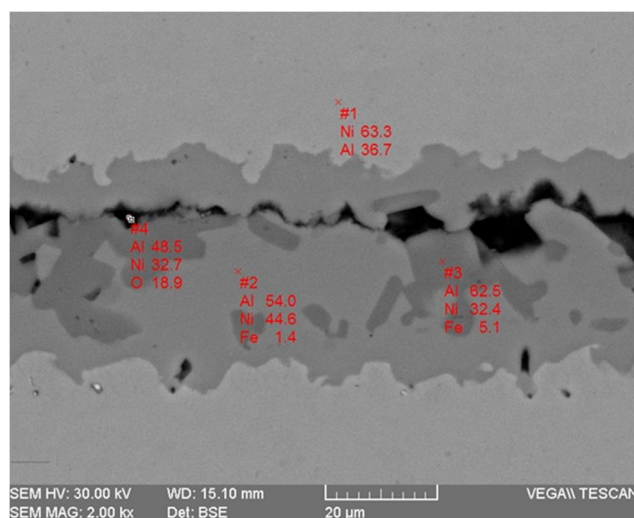


Figure 4. SEM-EDS analysis of Ni-Al metallic-intermetallic composite sintered at 700°C-5h.

In metallic-intermetallic composites, interaction initially occurs at the interface then progress along the center of aluminum foil as well as along nickel foil. But progress reaction along nickel is slower than that of in aluminum. As nickel and aluminum react with each other, the impurities in aluminum or

interface of Ni-Al, shifts in the front of the reaction. If the reaction ended before aluminum consuming these impurities deposited in aluminum, otherwise in centerline of the intermetallic. Because of this it is understood that the centerline is a problematic zone. As evidence in laminate composites centerline is one of the preferred zones for the formation of cracks (Rohatgi 2003).

As in shown in Fig 4, spot 1 is Ni_2Al_3 , spot 2 is NiAl , spot 3 is NiAl_2 , and finally spot 4 consist from some little oxygen content and NiAl phase. Some dark particles, identified as residual Al are also observed in the Al_3Ni layers. Furthermore, the laminated composites are well-bonded and remain some residual porosity in the final microstructure due to the relatively low temperature and time. Also in this EDS analyses show that, formation of intermetallic hasn't completed yet.

Reaction synthesis at 700 °C between Ni and Al foils resulted in a laminated composite microstructure with intermetallics layers sandwiched between nickel layers. It was found that the intermetallic layers comprised predominantly the Ni_2Al_3 intermetallic phase, and additionally the NiAl_3 intermetallic compound and (Al) solid solution (Fig. 5).

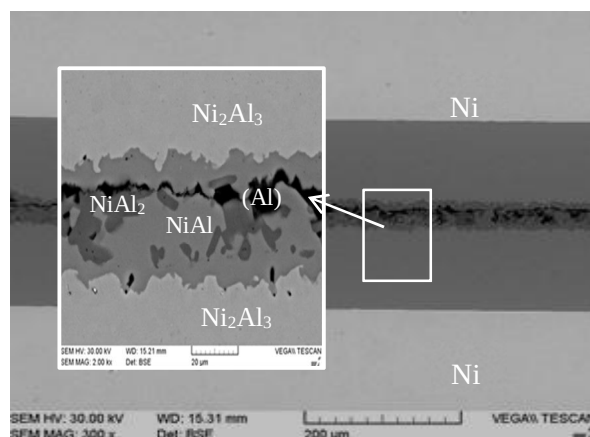


Figure 5. Microstructure of Ni-Al Intermetallic layer.

The ceramic-like aluminide phases (Al_3Ti or Ni_3Al) give high hardness and stiffness to the composite, while the unreacted Ti or Ni provides the necessary high strength, toughness and ductility for the system to concurrently be flexible. The multi-layered structure of the composite allows for variations in the layer thickness and phase volume fractions of the Al and Ti or Ni components simply through the selection of initial thickness, which consequently allows for the optimization of mechanical and thermal management properties for practical application (Peng, 2005, 309-318).

Hardness

When it comes to hardness values, hardness value of ductile metallic nickel phase is approximately 110 HV. Ductile phase overcomes stresses exposed to body by performing plastic deformation whereas intermetallic phase is brittle and has approximately 900 HV hardness values.

XRD

Figure 6 shows XRD patterns of the metallic intermetallic Ni-Al composites sintered at 700°C for 2 h. As it can be seen from Fig. 6, Al_2Ni_3 , metallic Ni and Al_3Ni are dominant phases in the composite. In addition some AlNi_3 , metallic Al and Al_2O_3 were also detected. These results are very compatible with EDS data.

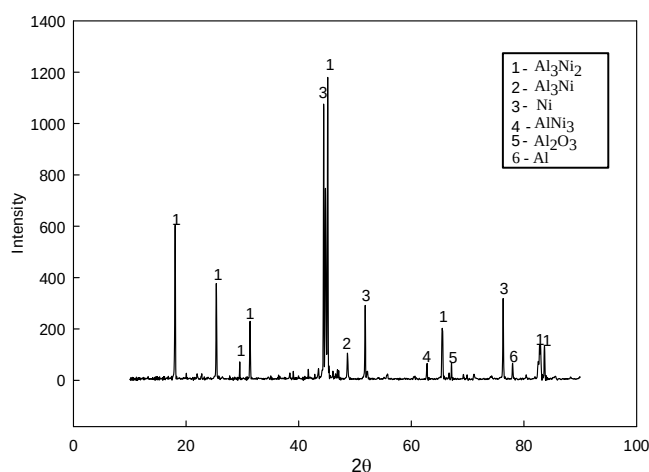


Figure 6. XRD patterns of the metallic intermetallic Ni-Al composites sintered at 700°C for 2 h.

CONCLUSION

The conclusions of this research can be summarized as follows:

By controlling the duration of the reactive foil sintering process, composites can be fabricated in which a tailored amount of residual aluminum remains at the intermetallic centerline. The result is a well-bonded composite with a high degree of microstructural control.

Ni–NiAl metal–intermetallic laminate (MIL) composites have been successfully synthesized by reactive foil sintering technique in open air at 700 °C for 5 hour under 2 MPa pressure. The laminated structure is well-bonded, nearly fully dense.

Microstructural characterization by, SEM and EDS indicates that NiAl, NiAl₃, Ni₂Al₃ are intermetallic phases in the composite. Nickel aluminide phase occurs due to the thermodynamics of the reaction between Ni and Al. The existence of liquid Al phase plays important roles in the nucleation and growth of NiAl particles and the eventual formation of continuous alternative intermetallic layers.

The hardness of fabricated laminated composite was dramatically changed. Whereas the hardness of metallic aluminum and nickel respectively is about 45 and 110 HV, hardness of intermetallic zone is approximately 900 HV.

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REFERENCES

- Price, RD, Jiang, F, Kulin RM & Vecchio, KS, 2011, 'Effects of ductile phase volume fraction on the mechanical properties of Ti–Al₃Ti metal–intermetallic laminate (MIL) composites', *Materials Science and Engineering A*, vol. 528, pp. 3134–3146.
- Li, T, Grignon, F, Benson, DJ, Vecchio, KS, Olevsky, EA, Jiang, F, Rohatgi, A, Schwarz, RB & Meyers, MA, 2004, 'Modeling the elastic properties and damage evolution in Ti–Al₃Ti metal intermetallic laminate (MIL) composites', *Materials Science and Engineering*, vol. 374, pp.10–26.
- Li, T, Olevsky, EA & Meyers, MA, 2008, 'The development of residual stresses in Ti6Al4V–Al₃Ti metal–intermetallic laminate (MIL) composites', *Materials Science and Engineering A*, vol. 473, pp. 49–57.
- Rohatgi, A, Harach, DJ, Vecchio KS, Harvey, KP, 2003, 'Resistance-curve and fracture behavior of Ti–Al₃Ti metallic–intermetallic laminate (MIL) composites', *Acta Materialia*, 51, pp. 2933–2957.
- L.M. Peng, H. Li, J.H. Wang, 2005, 'Processing and mechanical behavior of laminated titanium–titanium tri-aluminide (Ti–Al₃Ti) composites', *Materials Science and Engineering A*, 406, pp. 309–318.
- Peng, LM, Wang, JH, Li, H, Zhao, JH, & He, LH, 2005, 'Synthesis and microstructural characterization of Ti–Al₃Ti metal–intermetallic laminate (MIL) composites', *Scripta Materialia*, 52, pp. 243–248
- Konieczny, M, 2012, 'Microstructural characterization and mechanical response of laminated Ni–intermetallic composites synthesized using Ni sheets and Al foils', *Materials Characterization*, 70, pp.117–124
- Zhang, FL, Yang, ZF, Zhou, YM, Wang, CY, & Huang, HP, 2011, 'Fabrication of grinding tool material by the SHS of Ni–Al/diamond/dilute', *Int. Journal of Refractory Metals and Hard Materials*, 29, pp. 344–350,
- Zhang, LZ, Wang, DN, Wang, BY, Yu, RS, & Wei, L, 2008, 'Identification of lattice vacancies in the B2-phase region of Ni–Al system by positron annihilation', *Journal of Alloys and Compounds*, 457, pp. 47–50.
- Ipek, M, Ustel, F, Zeytin S, 2008, 'Fracture Behaviour of Ti–Al₃Ti Metallic–Intermetallic Laminate (MIL) Composites', pp.1262-1268, *12th International Materials Symposium*, Pamukkale University, Denizli.
- ASM, 1992, *ASM Metals Handbook, Volume 3, Alloy Phase Diagrams*.
- Peng, LM, Li, H, Wang, JH, 2005, 'Processing and mechanical behavior of laminated titanium–titanium tri-aluminide (Ti–Al₃Ti) composites', *Materials Science and Engineering*, vol. 406, pp.309–318.