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Effects of Ni foil thickness on the microstructure and tensile properties of reaction synthesized multilayer composites

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Abstract

The effects of Ni foil thickness on the microstructure and tensile properties of reaction synthesized multilayer composites have been systematically investigated. Multilayer composites have been fabricated by reaction annealing of their foil laminates consisting of 10 μm thick Al foils and 20, 50 and 80 μm thick Ni foils. Ni_3Al multilayer composites prepared from 20 μm Ni foils were very brittle. Ni/Ni_3Al multilayer composites prepared from 50 μm Ni foils exhibited significant work-hardening and behaved more like a ductile alloy, rather than a composite, with an ultimate tensile strength of 1050 MPa and elongations of >18%. The composites fabricated from 80 μm Ni foils, which contain Ni_3Al precipitates, had a low yield strength and ultimate tensile strength (about 160 and 470 MPa, respectively), and had a very good capacity for plastic deformation (>34% elongation). The dislocations in Ni and Ni_3Al layers can slide through the Ni_3Al/Ni interfaces, with the result that the Ni and the Ni_3Al layers in the composites can cooperatively deform during tensile testing. Delaminated interfaces containing Al_2O_3 inclusions further promote the capability of the Ni_3Al layers for plastic deformation. As a result, the Ni/Ni_3Al multilayer composites exhibit good tensile strengths and a high ductility. The existence of Ni_3Al precipitates in the Ni layers inhibits cross-slip of dislocations, which results in dislocation networks in the Ni layers which have a preferred orientation.

Keywords: Reaction synthesis; Ni_3Al; Multilayer composites

1. Introduction

Metal-intermetallic composites (MICs) offer an attractive combination of high strength, chemical stability and low density of the intermetallic compound together with the high toughness of the metal. Metal-intermetallic multilayer composites have proven to be more effective in improving the toughness of Ni_3Al than reinforcement with ductile metals in the form of particles and fibers [1]. Metal-intermetallic multilayer composites have been produced by magnetron sputtering [2,3], electron beam evaporation–deposition [4,5] and reaction synthesis of metal foils [1,6–13]. Reaction synthesis has many advantages over the other methods, including: cost-savings; use of conventional technology; ease in achieving full-density and near-net-shape products through pre-deformation prior to reaction sintering; formation of well-bonded interfaces between the metal and the intermetallics; possibility of obtaining MICs with high fracture toughness, high strength and high elastic modulus.

The reaction mechanisms, microstructural evolution, mechanical properties, failure mechanisms and deformation behaviour of Ni/Ni aluminide multilayer composites produced by reaction synthesis from Ni and Al foils had been reported in a previous paper [14]. In this study, the effects of Ni foil thicknesses on the microstructure and tensile properties of these reaction synthesized multilayer composites were investigated in detail.

2. Materials and experimental procedures

Ni foils of 20, 50 and 80 μm thickness (Central Iron & Steel Institute, Beijing, PR China) and Al foils of 10 μm thickness (Northeast Light Alloys Co., Harbin, PR China) were used in this study. Foils with dimensions of about 80 mm × 80 mm were cut from the stock sheets, and were degreased in an acetone solvent for 0.5 h. Any contamination on the surface of the foils was removed with degreased cotton swabs. The Ni and Al foils were then stacked into laminates in an alternating sequence. In order to produce 10 mm thick multilayer composites, either 300, 200, or 100 pieces of both the Ni and the Al foils were used

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depending on the thickness of the Ni foils. The foil laminations were heated to 620 °C in vacuum (0.1 Pa) and held for 60 min under a uniaxial pressure of 0.1 MPa for reaction synthesis. They were then further diffusion-annealed at 1200 °C for 1 h under a pressure of 5 MPa, and then cooled to room temperature in a furnace. The multilayer composites prepared from 20, 50 and 80 μm thick Ni foils are denoted as Samples Ni20, Ni50 and Ni80, respectively.

Flat, dog-bone shape tensile coupons were electro-discharge machined from the processed multilayer composites to determine the room-temperature mechanical properties. The surfaces of the tensile coupons were parallel to the interfaces between the layers of the composites. The dimensions of the coupons were about 80 mm long by 20 mm wide. The effective gauge length, width and thickness were 30, 10 and 1 mm, respectively. Prior to testing, the surfaces of the coupons were polished using fine SiC abrasive papers. The tensile tests were performed in an Instron tensile test machine at a constant crosshead speed of 1 mm/min, corresponding to a strain rate of $2.08 \times 10^{-4}\ s^{-1}$ in the gauge section. The results are reported as engineering stress–engineering strain curves, which were calculated from the load–displacement curves.

Miniature tensile coupons of Sample Ni50 were used to observe the morphology of the slipbands on the surfaces during tensile testing. The miniature tensile coupons have the same shape as the standard ones, but a reduced thickness (0.8 mm), and the other dimensions are reduced by 2.5 times. The surfaces of the miniature tensile coupons are perpendicular to the interfaces between the layers of Sample Ni50. Prior to testing, the surfaces of the coupons were first polished using fine SiC abrasive papers, and then by 0.05 μm alumina powders, and lightly etched with 2% muriatic acid solution to reveal the layers. The coupons were pulled to a strain of about 5% at the same strain rate as the standard tests.

The microstructures of the multilayer composites before and after tensile testing were examined using a JEOL micro-probe in the back-scattered mode with a TN 5502 energy dispersive X-ray analysis system (Japan Electron Optics Laboratory Co., Ltd., Mitaka, Japan) and Philips transmission electron microscope (TEM). The fracture surfaces of each sample were examined using scanning electron microscopy (SEM, Japan Electron Optics Laboratory Co., Ltd.). The cross-sectional views of the fracture of each sample were examined using the JEOL probe in the back-scattered mode.

3. Results and discussion

3.1. Microstructures

Given that the densities of Ni and Al are 8.9 and 2.7 g/cm^3, respectively, the Ni:Al atomic ratios of the composites made from 20, 50 and 80 μm thick Ni foils and 10 μm thick Al foils would be 3.03:1, 7.58:1 and 12.13:1, respectively. If the Al were totally converted into Ni_3Al, and the solution of Al in the Ni layers and the plastic deformation were not counted, the thickness of Ni_3Al layer in all samples should be 13.54 μm and the thicknesses of the Ni layers in Samples Ni20, Ni50 and Ni80 should be 0.2, 30.2 and 60.2 μm, respectively.

The microstructure in Sample Ni20 mainly consisted of polycrystalline Ni_3Al layers as shown in Fig. 1a. The average thickness of Ni_3Al layers was 11.6 μm. Due to the solution of Al in the Ni layers and the plastic deformation, the Ni layer became discontinuous. The individual Ni grains containing Ni_3Al precipitates were occasionally observed between two polycrystalline Ni_3Al layers that had grown face to face. Some isolated Ni grains were observed surrounded by a large Ni_3Al grain, which indicates that recrystallization occurred between the polycrystalline Ni_3Al layers during face-to-face growth.

The interfaces between the polycrystalline Ni_3Al layers that grew back-to-back remained relatively straight and parallel to each other. This suggests that no recrystallization occurred between the polycrystalline Ni_3Al layers that grew back-to-back. Our work on the microstructural evolution of these multilayer composites [14] showed that the interfaces contain many

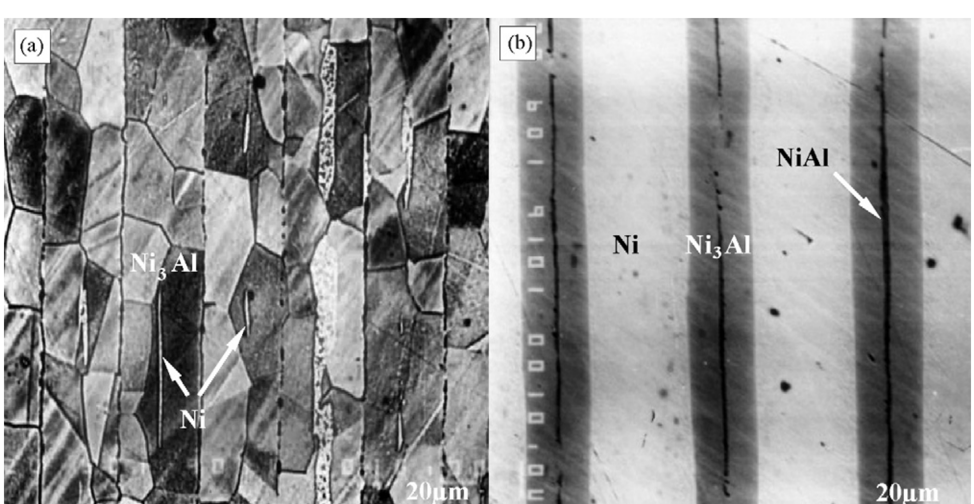

Fig. 1. Microstructure of multilayer composites (back-scattered electron image, SEM). (a) Sample Ni20 and (b) Sample Ni50.