Fabrication of Aluminum/Aluminum Nitride Composites by Reactive Mechanical Alloying

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Abstract

Various reactions and the in-situ formation of new phases can occur during the mechanical alloying process. In the present study, Al powders were strengthened by AlN, using the in-situ processing technique during mechanical alloying. Differential thermal analysis and X-ray diffraction studies were carried out in order to examine the formation behavior of AlN. It was found that the precursors of AlN were formed in the Al powders and transformed to AlN at temperatures above 600°C. The hot extrusion process was utilized to consolidate the composite powders. The microstructure of the extrusions was examined by SEM and TEM. In order to investigate the mechanical properties of the extrusions, compression tests and hardness measurements were carried out. It was found that the mechanical properties and the thermal stability of the Al/AlN composites were significantly greater than those of conventional Al matrix composites.

Keywords : aluminum matrix composites, in-situ processing, mechanical alloying, aluminum nitride

1. Introduction

Various reinforcements have been used for the aluminum matrix composites, such as oxides, carbides, intermetallic compounds and quasi-crystals [1-4]. Aluminum nitride (AlN) is a potential reinforcement for Al matrix composites because of its high strength, high thermal conductivity and good thermal stability [5]. The Al/AlN composite has been fabricated using the powder metallurgy technique or liquid processing technique, such as stir casting and squeeze casting. These *ex-situ* methods limit the scale of the reinforcing phase, which is typically in the range of micrometers to tens of micrometers. In addition, poor wettability between the reinforcements and the matrix due to surface contamination of the reinforcements is unavoidable, and AlN powders are quite costly. However, in the 1990's Al/AlN composites were fabricated by various *in-situ* nitridation methods, such as directed melt nitridation, similar to directed melt oxidation (DIMOX) [6] and mechanical alloying in nitriding atmospheres such as ammonia gas [7,8] or cryomilling in liquid nitrogen [9]. Nonetheless, the AlN phase synthesized by the liquid processing technique, like directed melt nitridation, exhibited inhomogeneous distribution and large particle sizes in the range of micrometers.

Also, the formation mechanisms and mechanical properties of the *in-situ* Al/AlN composites which were produced by mechanical alloying have not yet been clearly understood. In this study, the Al/AlN composite powders were produced by reactive mechanical alloying in a nitriding atmosphere and subsequently consolidated by the hot extrusion process. The effect of nitriding atmosphere on the formation of AlN was investigated, and the mechanical properties of the *in-situ* Al/AlN composites were examined by compression tests and hardness measurements.

2. Experimental and Results

The materials used in this study were 99.5% pure Al powders (-325 mesh) and Al-50wt.% Mg alloy powders (-100 mesh. Mechanical alloying was conducted with a vertical type attritor using a stainless steel container and an impeller, and hardened steel balls as milling media. The milling chamber was purged with high purity Ar gas (99.999%) to prevent the oxidation of the charged powders, and nitriding gas was supplied to the chamber at a constant pressure and flow rate. Nitrogen and ammonia gases were used as nitriding gases. Differential thermal analysis and X-ray diffraction studies were carried out to examine the formation behavior of AlN. The hot extrusion process was utilized to consolidate the milled powders.

The compression tests of the extrusions were carried out on an Instron static machine at an initial strain rate of 2×10^{-4} s^{-1}. The microstructures of the extrusions were investigated by a transmission electron microscope.

Fig. 1 shows the X-ray diffraction patterns of the as-milled powders and the powders which were heat treated at 500°C, 600°C and 900°C for 1 hour in an Ar atmosphere. No AlN peak was observed in the as-milled powders and the powders which were heat treated at 500°C. The powders which were heat treated at 600°C showed evidence of AlN

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formation. The AlN peak was more sharp and obvious in the powders heat treated at 900 °C. It was thought that the precursors of AlN were formed by the reaction between nitriding gas and the fresh metal surface during mechanical alloying, and then the precursors were transformed to AlN.

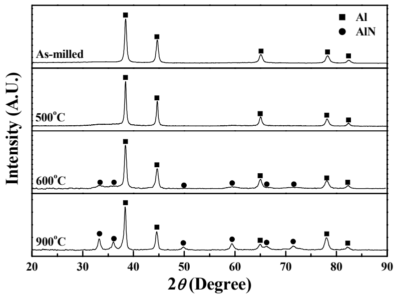

Fig. 3 XRD patterns of the 35 hour milled powders in nitriding gas, and those heat treated at various t emperatures for 1 hour.

In the present study, the condition for the formation of 25vol.% AlN was used. Also, in order to investigate the effect of the alloying element, 1wt.% , 2wt.% and 4wt.% of Mg were added to the initial charge. In order to fabricate the consolidated products of the Al/AlN composites, the hot extrusion process was utilized. The extruded rods were cut to 8 mm (dia.) x 12 mm (height) for compression tests.

Fig. 2 shows the compressive stress-strain curves of the Al/AlN composites. The Al/25AlN composite specimen showed a yield strength of 325 MPa. However, the addition of 4wt.% Mg as an alloying element drastically increased the yield strength to 930 MPa.

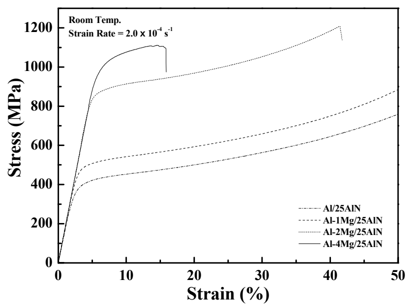

Fig. 4 Compressive stress-strain curves of the Al-Mg /AlN extrusions at room temperature.

Fig. 3 shows the bright field image of Al-4Mg/25AlN composites, and the corresponding selected area diffraction patterns (SADP). It was clear that the size of the Al grains significantly decreased to submicron range. Also, the diffraction patterns showed the characteristics of Al and AlN. This result clearly indicated that the AlN phase was formed during reactive mechanical alloying and hot extrusion. The *in-situ* processing technique used in the present study is favorable compared to other processes because the Al/AlN composites with ultra-fine microstructure can be obtained.

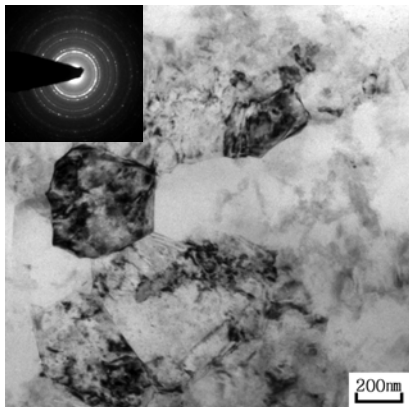

Fig. 3 TEM micrographs of the Al-4Mg/25AlN.

3. Summary

In the present study, Al/AlN composites were fabricated by reactive mechanical alloying in a nitriding atmosphere. Although AlN was not observed in the as-milled powders, it was found in the powders that were heat treated at temperatures above 600°C. It was believed that the AlN precursors formed through reactive mechanical alloying, and then transformed to AlN during the subsequent heat treatment process. The mechanical properties of the Al-Mg/AlN composites drastically increased with the addition of Mg as an alloying element in comparison to conventional Al alloys and Al matrix composites.

4. References

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