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Controlling Al/Cu composite diffusion layer during hydrostatic extrusion by using colloidal Ag

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ABSTRACT

In this study, intermetallic compound formation at the interface between aluminum and copper during hydrostatic extrusion was simulated by performing a solid state diffusion bonding experiment with various processing parameters, including bonding temperature and pressure and holding time, and by inserting an Ag colloid layer between the aluminum and copper. Regression equations were developed to predict thickness of diffusion layer and interface hardness.

An intermetallic compound formed at the interface between the Al and Cu during diffusion bonding at 420 °C and 240 MPa for 60 min, and it was effectively controlled by inserting an Ag colloid. These experimental data will be useful for setting up processing parameters to prepare Al/Cu matrix composite materials by using hydrostatic extrusion.

1. Introduction

Recent industrial technology innovations and improvements in living standards have resulted in strict technical requirements for the net shapes of metallic materials, including multifunctional characteristics, for diverse applications. However, conventional metal, ceramic, and polymeric materials have not been able to meet these requirements. Metal matrix composites (MMCs) have been recognized as suitable materials for meeting such requirements, according to Kaczmar et al. (2000).

There are some limitations encountered during conventional MMC manufacturing processes, especially the liquid phase process, such as volume fraction limitations, reinforcement distribution, and an unstable interface between the matrix and reinforcements (Nami et al., 2011). Solid state processes have been extensively investigated because they are relatively flexible compared to liquid phase processes and because they can overcome these limitations. In spite of the advantages of solid phase processes, their main drawbacks are the high processing costs owing to the usually expensive powdered raw materials, complicated processing steps, and long processing times (Karayannis and Moutsatsou, 2006).

These drawbacks can be overcome using hydrostatic extrusion to fabricate MMC through a single process with shorter processing times and reduced processing costs compared with the solid-phase process. The cost of the hydrostatic extrusion is brought down due to the use of cheap bulk raw materials and a single processing step (Smith et al., 1979). Moreover, hydrostatic extrusion can easily control the size of reinforcement cells, the volume fraction, and the nature of interfaces between the matrix and reinforcement (Fig. 1(a)). If these properties can be controlled, the physical and mechanical properties of the metal matrix composite could be consistently maintained, according to Kim (2000).

However, during the hydrostatic extrusion of clad materials, intermetallic compounds can be generated at the interface and act as reinforcements. Multiple extrusion processes after extrudate stacking could result in the formation of a well-aligned second phase in the matrix having reinforcements. Hence, it is very important to control interfacial reactions, which may cause the formation of brittle phases during thermal deformation (Jin et al., 1993). Kim et al. (2000) reported that the formation of intermetallic compounds affects the mechanical properties of a clad composite. Moreover, the intermetallic layer between the Al and Cu phases causes brittle fractures when its thickness exceeds 2.5 μm, according to Abbasi et al. (2001). The problems with the Cu/Al system are that the formation of the brittle intermetallic layer is inevitable and that it is practically impossible to control its growth rate during the thermo mechanical process.

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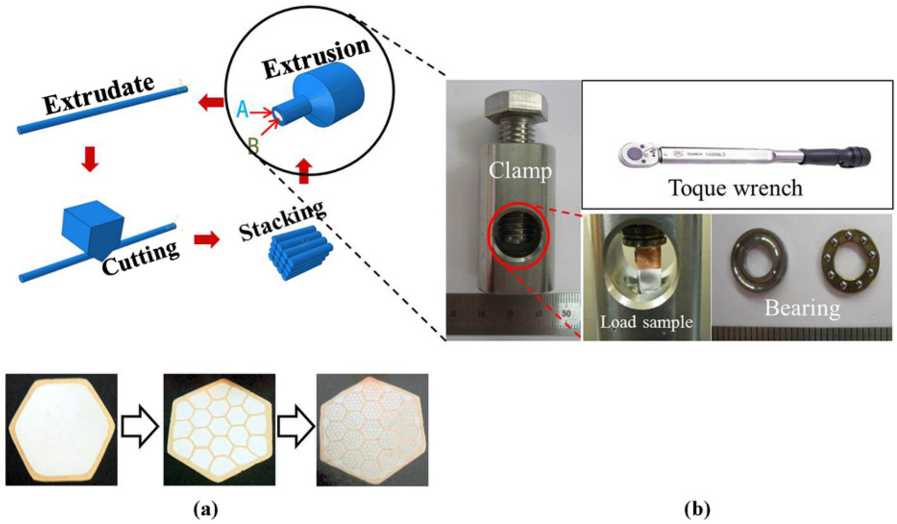

Fig. 1. (a) Schematic diagram of multiple hydrostatic extrusion; and (b) equipment used for solid state diffusion bonding.

In this study, intermetallic compound formation at the interface between aluminum and copper and its growth rate during extrusion were systematically investigate during a solid state diffusion bonding experiment with various processing parameters, such as bonding temperature and pressure and holding time. To control the growth rate of the intermetallic compound, we developed a novel method by inserting an Ag colloid layer between the aluminum and copper layers, and we compared the growth rates for the specimens with and without the Ag layer. These experimental data will be useful for setting up the processing parameters to prepare Al/Cu matrix composite materials by using hydrostatic extrusion.

2. Experimental

2.1. Experimental procedure

The materials used in this study were aluminum alloy (Al6061) and deoxidized high phosphorus (DHP) copper. The samples were cut into size of 6 mm × 6 mm × 5 mm. The chemical compositions and physical properties of the base metals are shown in Table 1. The specimens were then subjected to stress relief heat treatment in a vacuum furnace under 10^{-2} Torr. The specimen surfaces to be bonded were ground by #1200 emery paper. Before the joining experiment, all surfaces were ultrasonically cleaned in an acetone bath to remove adhered contaminants and the dried in air. After ultrasonic cleaning, each specimen was loaded in a bonding clamp and the compression pressure was regulated using a torque wrench. The bonding clamp was itself developed for diffusion bonding experiments in which the bonding pressure can be controlled using a torque wrench. A bearing was inserted between the specimens and the bonding clamp to prevent specimen distortion. Fig. 1(b) shows the equipment used for solid state diffusion bonding.

The specimens were then heated to the bonding temperature in a vacuum furnace under 10^{-2} Torr at a heating rate of 5 °C/min. Finally, the specimens were cooled in the processing chamber under vacuum. The bonding parameters were took from the previous research which varies temperature, time and pressure (Mahendran et al., 2009).

2.2. Ag colloid layer insertion between Al and Cu

An aqueous Ag colloid solution with an Ag concentration of 10,000 ppm was sprayed onto the Al and Cu surfaces. The Ag particle is so fine that the Ag layer was formed immediately after spraying the solution. After drying, the thickness of the Ag layer was measured to be 1 μm. Al/Ag/Cu bonding was conducted under the same conditions for comparison with Al/Cu bonding. The working parameters are listed in Table 2.

2.3. Interface properties

After bonding, a cross section of the sample was polished, and its microstructure was examined using field emission scanning electron microscopy (FE-SEM, JSM 6330F). The chemical composition and thickness of diffusion layer at the interface were analyzed using energy-dispersive X-ray spectroscopy (EDS). Furthermore, the mechanical properties of the diffusion layer itself were examined using a Vickers hardness tester (Model FM-7, Future Tech Co.,

Table 1
Chemical compositions and physical properties of aluminum and copper.

Chemical composition (wt.%)						
Metal	Mg	Si	Cu	Cr	Al	P
Al 6061	1.0	0.6	0.27	0.2	Bal.	–
Copper (DHP)	–	–	Bal.	–	–	0.028

Physical properties					
Metal	Density (g/cm^3)	Melting point (°C)	Specific heat (J/g °C)	Thermal conductivity (W/mK)	Thermal expansion (×10^{-6} K^{-1})
Al 6061	2.7	651.7	0.896	180	23.6
Copper (DHP)	8.89	1083.6	0.385	385	16.4