Materials and Design 32 (2011) 1152–1158

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

Entrance analysis of 7075 Al/Mg–Gd–Y–Zr/7075 Al laminated composite prepared by hot rolling and its mechanical properties

X.P. Zhang [a,b,*], S. Castagne [b], T.H. Yang [a], C.F. Gu [a], J.T. Wang [a]

[a] School of Materials Science and Engineering, Nanjing University of Science and Technology, Nanjing 210094, People Republic of China
[b] School of Mechanical and Aerospace Engineering, Nanyang Technological University, Singapore

ARTICLE INFO

Article history:
Received 4 June 2010
Accepted 27 October 2010
Available online 2 November 2010

Keywords:
B. Laminates
C. Forming
E. Mechanical properties

ABSTRACT

Entrance of 7075 Al/Mg–12Gd–3Y–0.5Zr/7075 Al laminated composites produced by a hot rolling bonding method was investigated. The results showed that using a wedge-end and multi-step process ensured that the assembly of multi-layered plates could enter the rollers area at the beginning of the process. The conventional entrance prerequisite for a single plate during rolling, i.e. having an entrance angle smaller than the friction angle, was not sufficient for multi-layered plates. In addition, a condition for preventing the tail end of the aluminum alloy plates lifting up when these plates come in contact with the rollers must be taken into account. The bonding strength and the ultimate tensile strength of the laminated composite were also studied and it was shown that the mechanical bond played a major role in the bonding strength of the samples produced. The ultimate tensile strength of the laminated composite was lower than that of 7075 Al alloy and higher than that of Mg–12Gd–3Y–0.5Zr Mg alloy. This result could be explained by calculating the stress distribution in the laminated composite under tensile loading.

1. Introduction

Magnesium alloys are being increasingly used in the automotive and aerospace industries due to their low density and high specific strength. One of the major drawbacks of magnesium alloys in many applications is their low corrosion resistance [1]. Liu et al. [2] reported that introducing an aluminum alloying layer on the surface of a magnesium component could improve the corrosion resistance of the magnesium substrate effectively, while maintaining the low density and high specific strength of the assembly. If aluminum alloys and magnesium alloys were fabricated as an Al/Mg/Al trilaminated composite using aluminum alloys as protective layers, improvement of the corrosion resistance of the magnesium alloys would also be expected.

Al/Mg laminated composites have been developed using various techniques, such as diffusion bonding [3–8], equal channel angular extrusion [9], explosive welding [10]. Roll bonding, a solid phase welding method consisting of bonding similar or dissimilar metals by rolling deformation processes at room temperature or elevated temperature, has also been applied to fabricate laminated composites. In particular, Matsumoto et al. demonstrated the feasibility to produce an Al/Mg–Li alloy clad layer by a cold rolling method [11]. Accumulative roll bonding (ARB), a mutli-pass roll bonding process normally used to refine the microstructure of metallic materials, is also suitable to produce laminated composites. For example, Wu et al. used this technique to fabricate a pure magnesium/Al5052 alloy laminated composite with maximum ultimate tensile strength of about 240 MPa [12]. Chen et al. also used the ARB process to obtain a multilayer compound between Al/Mg layers with excellent bonding characteristics and fine grain microstructure [13]. Chang et al. used Mg/Al laminated composites fabricated by ARB and applied the neutron diffraction method to measure their texture [14].

Many researches on mechanical properties of laminated composites prepared by roll bonding have been published [11–16]. However, few data have been reported on the entrance conditions of an assembly of multiple plates during roll bonding. The entrance of the assembly does not influence the final mechanical properties of laminated composites; however, the possibility of the material to enter the rollers gap at the beginning of the process is one of the major prerequisites for successful roll bonding. The entrance requirement for a multi-plate assembly was different from that of a single plate as the plates in the assembly might separate during rolling.

In this work, hot rolling techniques to fabricate an Al/Mg/Al trimetallic laminated composite were investigated. The entrance conditions of a multi-plate assembly during the rolling process, and the bonding strength and tensile strength of the fabricated laminated composite were also studied.

* Corresponding author. Address: School of Materials Science and Engineering, Nanjing University of Science and Technology, Xiaolingwei 200, Nanjing 210094, People Republic of China. Tel./fax: 086 025 84303983.
E-mail address: xpzhang@mail.njust.edu.cn (X.P. Zhang).

0261-3069/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.matdes.2010.10.030

2. Material and methods

2.1. Rolling test

The addition of rare earths (RE) elements including yttrium and gadolinium remarkably improves the mechanical properties of magnesium alloy at room temperature and high temperature [17]. 7075 Al alloy is a high strength aluminum alloy. Thus, the base materials chosen for this study were as-rolled Mg–12Gd–3Y–0.5Zr (in wt.%) magnesium alloy and 7075 aluminum alloy. The chemical composition of the 7075 Al alloy is (wt.%): Al; 5.6% Zn; 2.5% Mg; 1.6% Cu; 0.23% Cr. The solidus temperature of Mg–12Gd–3Y–0.5Zr Mg alloy calculated using Procast 2008 was higher than that of 7075 Al alloy, 547 °C and 477 °C, respectively. Thus, the rolling temperature should be under 477 °C. In addition, uniform deformation is one of the primary requirements during rolling. To ensure uniform deformation, the flow stress of Mg–12Gd–3Y–0.5Zr Mg alloys is required to be near that of 7075Al alloy. In our prior work, it was found that the suitable rolling temperature to produce the laminated composite was in the range of 450–475 °C due to the uniform deformation of the experimental alloys during the hot rolling process and good ductility of the Mg alloy at these temperatures [18]. Therefore, in this work, three rolling temperatures were adopted: 450 °C, 465 °C and 475 °C.

The initial thickness of the Al alloy plates was 5 mm and that of the Mg alloy plate was 10 mm. The total height of the Al/Mg/Al assembly was 20 mm.

Three processing techniques were designed for this project. For technique 1, the Al alloy plates of initial dimensions of 100 mm × 75 mm × 5 mm and an Mg alloy plate of initial dimensions of 100 mm × 75 mm × 10 mm were used. Both types of plates had flat ends. An assembly of the alloys, which included two pieces of the Al alloy plates with one piece of the Mg alloy plate between them, was hot rolled with a reduction ratio of 50% in a single pass. For technique 2, the alloy plates and the assembly were the same as those used for technique 1. The assembly was hot pressed to 90% of the initial thickness, and then hot rolled to 50% of the initial thickness after a second preheating phase. For technique 3, the plates had a wedge-end whose dimension and shape are illustrated in Fig. 1, and the assembly was hot rolled with a reduction ratio of 50% in a single pass. The rollers diameter was 470 mm, and the rotational speed of the rollers was 60 rpm. After hot rolling, analysis of the final component was performed to verify if the Al and Mg alloys were bonded and to propose an optimal hot rolling technique to fabricate the Al/Mg/Al laminated composite.

Before preheating, the plates were cleaned and mechanically ground using 240 and 600 grit SiC papers to remove the oxidation films and to form a rugged surface. A drying treatment was performed for both components after rinsing in ethanol.

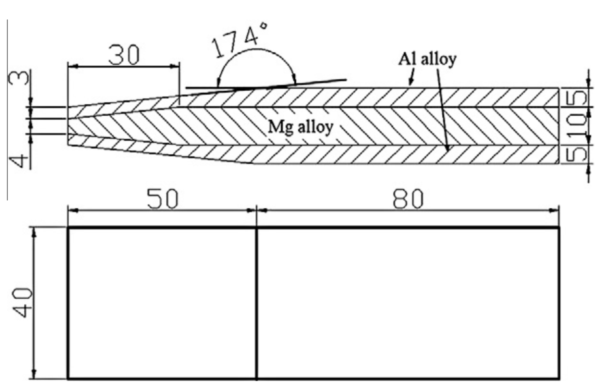

Fig. 1. Shape and dimension of the alloy plates used in technique 3.

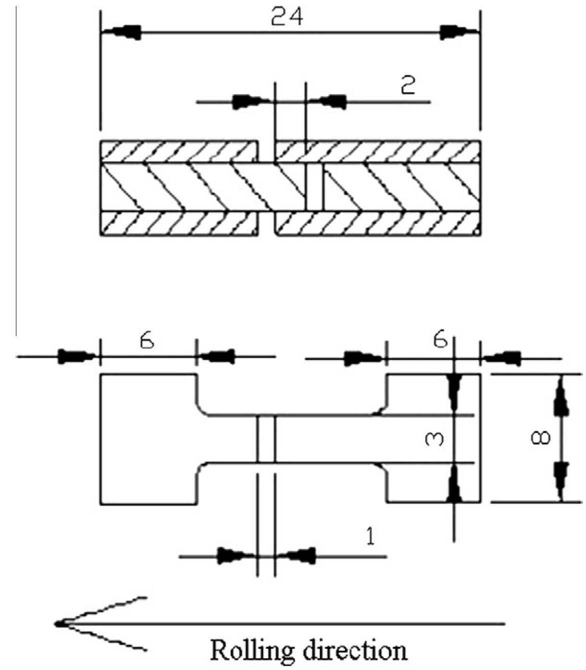

Fig. 2. Schematic of the specimens for bonding strength test.

2.2. Mechanical properties tests

The shape and dimension of the specimens for the measurement of the bonding strength of the composites are schematized in Fig. 2. No dimensions are defined along the thickness direction as the thicknesses of the Al and Mg alloy layers varied with the reduction ratio. The bonding strength test was performed at room temperature using a SANS-CMT5105 tensile testing machine with an initial strain rate of $1 \times 10^{-3}\,s^{-1}$. The repeated number of tensile testing specimens for every case was five. The average bonding strength was taken as,

$$\text{Average bonding strength} = \text{Peak Load}/(\text{Bond Width} \times \text{Bond Length}) \quad (1)$$

2.3. Characterization

The microstructure of the bond interfaces before and after the bonding strength tests was observed by scanning electron microscopy (SEM) using a Philips Quanta200 instrument with an Energy Dispersive X-ray Detector (EDX).

3. Results and discussion

3.1. Entrance results

The entrance results for the three techniques are listed in Table 1. Typical external characteristics of the laminated composites after processing are shown in Fig. 3. For technique 1, the Al alloy plates did not join with the Mg alloy. This unsuccessful trial is due to the fact that the plates in the assembly did not enter into the rollers gap together, as shown in Fig. 3a. For techniques 2 and 3, the Al alloy plates joined with the Mg alloy after rolling, as shown in Fig. 3b and c.

3.2. Mechanical properties

Compared with technique 2, the machining cost for the configuration of technique 3 was higher. However, there was only one