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ARTICLE

Effect of Intermetallic Compounds on the Fracture Behavior of Mg/Al Laminated Composite Fabricated by Accumulative Roll Bonding

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Abstract: We observed massive cracked intermetallic compounds at the interface of the laminated Mg/Al composite fabricated by accumulative roll bonding and investigated the effect of the compounds on the fracture process of the Mg/Al composite. Scanning electron microscopy observation reveals that these cracked intermetallic compounds dominate the fracture behavior of the accumulative roll bonded Mg/Al composite during uniaxial tensile testing. The results indicate that obvious Mg/Al interface delamination is promoted by the cracked intermetallic compounds, and the cracks propagate into the softer Mg layer and lead to the rupture of Mg layer. These two factors result in the premature failure of the laminated Mg/Al composite.

Key words: accumulative roll bonding; Mg/Al laminated composite; intermetallic compounds; crack; tensile test; fracture

Multilayered metal composites or laminates consisting of alternately packed layers of different metals or alloys have shown many unique properties combining the ones of the constituent materials, such as fracture toughness, fatigue behavior, impact behavior, wear and corrosion [1]. The multi-layered composites of bimetal systems [2-4] can be fabricated by accumulative roll bonding (ARB) which consists of multiple cycles of rolling, cutting, stacking and solid-state deformation bonding. The advantage of producing multilayered composites through ARB is that the composites can be refined to ultra-fine grained (UFG) microstructure without any geometrical changes. Foremost ARB is easy to carry out and has a good prospect for commercialization [5-7].

Nowadays, clad rolling and ARB were employed to prepare the Mg/Al clad plate and multilayered composite to improve the corrosion resistance and the mechanical properties of Mg sheet[8-10]. Properties of the multilayered composite are significantly influenced by bonding quality [11-13]. However, there are few reports on mechanical properties of the ARB-processed multilayered composite correlating with the bonding quality. In our previous work, the intermetallic compounds were observed appearing at the Mg/Al interface of the ARBed Mg/Al composite, which were verified to be an important factor affecting the tensile property[14]. Effect of these intermetallic compounds on the fracture behavior was still not investigated in detail. The present work is a following research designed to record the fracture history of this kind of ARBed Mg/Al composite during a uniaxial test and to reveal the effect of intermetallic compounds on mechanical properties.

1 Experiment

In this study, a laminated Mg/Al composite (containing 17 layers) was fabricated by ARB processing at 400°C for 3 cycles using the commercial pure magnesium (99.8 wt %) and Al 5052 alloy sheets. The detailed ARB processing and the global microstructure of the laminated sheet were shown in Ref. [14]. A dog-bone shape tensile sample was machined along the rolling direction from the sheet ARBed for 3 cycles and then annealed at 150 °C for 10 min to release residual

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stress. The gauge dimension of the tensile samples was 10 mm×6 mm×1 mm. Prior to the tensile test, the longitudinal plane of the tensile sample was mechanically ground and polished carefully on the abrasive papers of grit size 1000, 2000 and 4000. Then the starting microstructure on the longitudinal plane was observed by HITACHI S3000 scanning electron microscopy (SEM) with EDS. After that, the uniaxial tensile test was carried out on the Instron5569 testing machine at ambient temperature with a ram speed of 1 mm/min. In order to record the facture history of this ARBed Mg/Al laminates, tensile loading was stopped and released at three strain levels after obvious yield during the tensile test. The test was stopped for the first time after obvious yielding (Recorded as Level 1). The last temporary stop was designed to ~0.5% ahead of failure (Recorded as Level 3) while the second was in the middle of Levels 1 and 3 (Recorded as Level 2). The elongation and yielding point were obtained from the continuous tensile test. At each strain level, the tensile sample was removed from the testing machine and one same area on the polished longitudinal plane around necking was observed by SEM. After observation, the tensile test was re-conducted on this sample till next strain level. At last, the fracture profile of the specimen after failure was also examined by SEM.

2 Results and Discussion

The stepped engineering stress-strain curves are plotted in Fig.1. The composite shows a very limited elongation, which is similar to our previous work [14]. Fig.2 displays the SEM microstructure of the longitudinal plane of the specimen before the tensile test. A large number of massive intermetallic compound particles (indicated by the black arrows) with obvious cracks are observed at the Mg/Al interface. The particle was characterized by EDS line analysis (Fig.3) and identified as Al_3Mg_2 at the side of Al layer and $Mg_{17}Al_{12}$ next to the Mg layer. The similar results were reported in Chen's work [10]. The particles formed between layers are thought to be due to the large rolling strain and the high temperature [15], which accelerate the diffusion at the Mg/Al interface. These intermetallic compounds nucleate and grow rapidly during

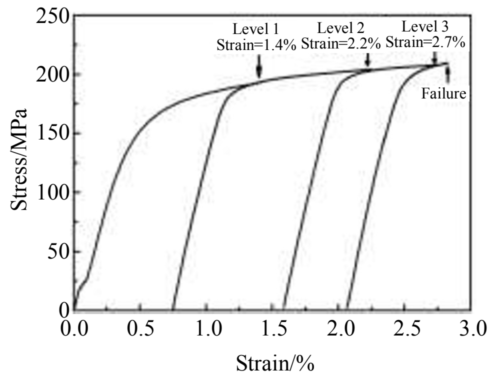

Fig.1 Stepped engineering stress-strain curves of the uniaxial tensile test

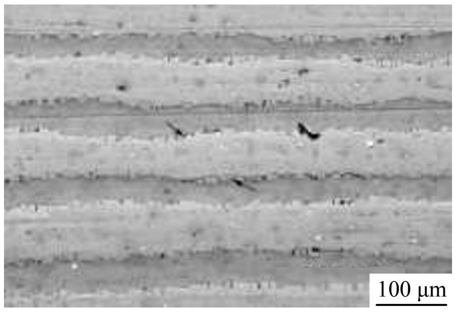

Fig.2 SEM microstructure on the longitudinal plane of the tensile sample before tensile test

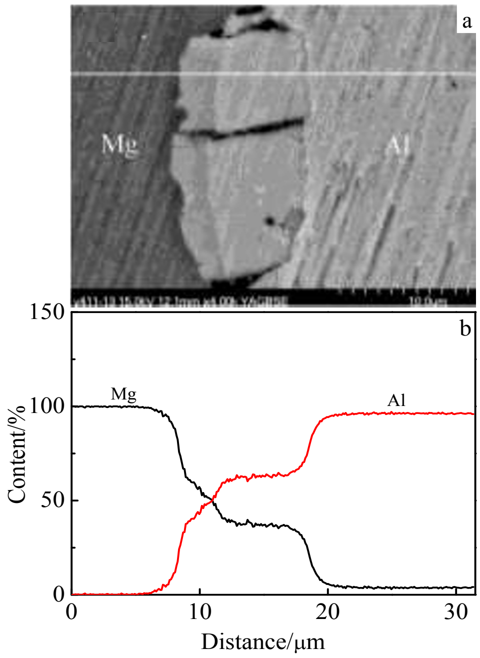

Fig.3 SEM image of an intermetallic compound (a) and EDS line analysis along the intermetallic compound (b)

pre-heating in initial circles of ARB. Then the coarsened particles fracture during the following circles of ARB.

The detailed tensile fracture behavior of the ARBed Mg/Al composite is presented in Fig.4. At strain level 1, an obvious crack is observed along the Mg/Al interface, possibly because of the linkage of cracks in neighbouring intermetallic compounds (see Fig.4a and 4d). This interface crack has not propagated into the intermetallic compounds "1" and "2" which are located ahead of the interface crack-tip at this strain level (Fig.4g). It is worth noting that some incipient crack points marked by the black arrows in Fig.4d are observed in the Mg layer, at the region close to the crack opening of the intermetallic compounds. Above observations show that the pre-existing cracks of the intermetallic compounds cause a crack initiation in the Mg layer at this strain level. On further straining from stain level 1 to strain level 2, the newly introduced micro-cracks locating at the edge of the Mg layer