



Study of mechanical properties and creep behavior of Al 1050/Mg AZ31B bilayer sheets Experimentally

Faraz Raisie

School of Mechanical Engineering, Iran University of Science and Technology, Narmak, Tehran, 1684613114, Iran

Mohammad Mahdi Touiserkani

School of Mechanical Engineering, Yazd University, Safaeih, Yazd, 8915818411, Iran

Abstract

In this study, special attention has been paid to mechanical properties and creep behavior of Al1050/MgAZ31B laminated metal composite. This composite consists of 2mm Aluminum and 1.5mm Magnesium sheet which has been preheated at 400°C for 20 minutes before single pass rolling performed with the reduction ratio of 40% to fabricate bilayer composite; Then uniaxial tensile test and creep tensile test at 30MPa loading and temperature of 225°C were carried out. The results indicate that bimetal has ultimate tensile strength of 110MPa, elongation of 10.3% and Work of fracture 6.83 MJ/m³. Further, the existence of two drops in the stress–strain curve was noticeable that the first stress drop was associated with magnesium fracture. Immediately, after the fracture of the magnesium, the bonding was separated, and eventually, the fracture of the aluminum occurred; in addition, under creep loading, 10.74 μm diffusion layer has been formed which after 4.18 hour and 9.65% elongation has failed.

Key Words: Laminated metal Composite (LMC), Creep Behavior, Mechanical Properties, Aluminum, Magnesium

Introduction

Al/Mg Bilayer Sheet as one of the most widely used laminated metal composites can encompass a wide range of different properties such as low weight, high stiffness, high strength and desirable corrosion and creep resistance required in different applications and be used in the manufacture of spacecraft, heat exchangers and household appliances. Due to the numerous advantages of using Al/Mg bilayer sheets and consequently their many applications in different industries, Investigation of creep behavior has always been very important and many researchers have studied the microstructure and mechanical properties of Al/Mg bilayer sheets. Zhang et al. [1] showed that by increasing temperature and holding time in anneal process, the thickness of diffusion layer formed in the interface increase; However, intermetallic layers of $Mg_{17}Al_{12}$ and Al_3Mg_2 would form at the lamellar interface when Al/Mg bilayer sheet were annealed at 300 °C or above temperature [2]. Wu et al. [3] showed that proper solid-state bonding should include both mechanical and diffusion bonding. Also, they declared that without mechanical bonding, the establishment of diffusion bonding was challenging. Macwan et al. [4] concluded that increases in the elongation and ultimate tensile strength due to annealing above 300°C is usually because of softening in aluminum alloy and increases in the thickness of interface. Rouzbeh et al. [5] showed that in roll-bonded samples, fracture in the aluminum sheet appears due to mixture of ductile and brittle fracture while, the absence of micro-voids in the magnesium sheet leads to brittle fracture, with no plastic deformation. Moreover, when the annealing temperature exceeds the eutectic point of 439°C, a reaction takes place between aluminum and magnesium, resulting in the melting of the bimetal at the bond interface according to $\alpha\text{-Mg} + \beta\text{-Mg}_{17}\text{Al}_{12} \rightarrow L$ [6].

Experimental Process

After 400°C annealing for 20 minutes of holding time, 2 mm Al 1050 and 1.5 mm Mg AZ31B were hot rolled by 40% of reduction ratio to fabricate bilayer sheet. The chemical compositions of these materials are presented in Table 1, respectively as determined through the quantometric test.

Table 1- Chemical composition of Al 1050 and Mg AZ31b in terms of weight percentage (wt.%)

Mtrl	Element	Al	Mg	Zn	Fe	Si	Mn	Cu	Ni	Sb
Al1050	Wt%	99.305	0.005	0.096	0.472	0.095	-	0.095	0.004	0.021
Mg Az31b	Wt%	2.488	96.98	-	0.004	0.0049	0.186	-	-	-

Then prepared samples according to JIS Z 2201:1998 and ASTM E139 went under uniaxial tensile test with constant strain rate and Creep test at temperature of 225°C and stress level of 30 MPa respectively. In addition to evaluate the microstructure the SEM analysis was carried out [7].

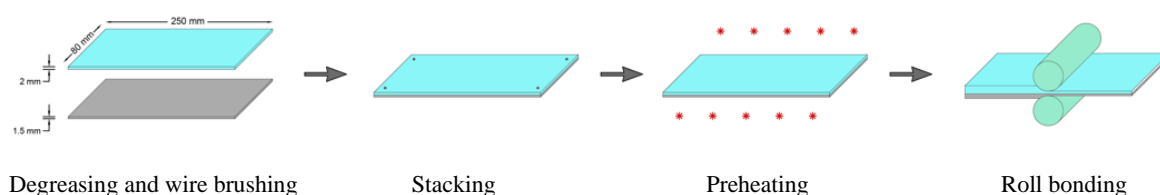


Figure (1) illustration of the roll bonding process

Results and Discussion

As depicted in Fig. 2, according to brittle behavior of magnesium layer and slight plastic deformation that endure, first the fracture appears in magnesium sheet and after that, delamination between aluminum and magnesium take place and finally the fracture in aluminum sheet occurs. Moreover, during the tensile test after the initial stress drop a significant span take place, which was accompanied by the necking of aluminum sheet and the relative wide span formed in the stress-strain curve of bilayer sheet was due to the high toughness of the aluminum sheet. Li et al. [8]

introduced the different toughness of composite sheets as the main reason for the interface separation and, consequently, the stress-strain curve splitting into two stages. Table 2, summarizes the result of tensile test.

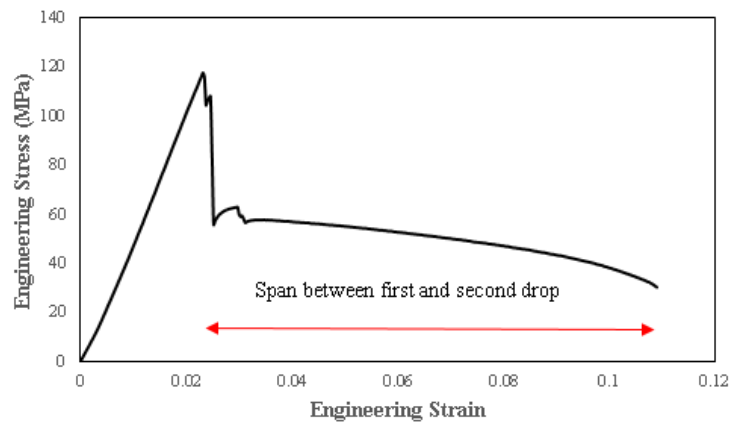


Figure (2) Engineering stress-strain curve for bilayer sheet

Table 2- Summary of results obtained from tensile test

Material	UTS (MPa)	Elongation (%)	Work of fracture ((MJ/m ³))
Al/Mg	110	10.3	6.83

In order to investigate the microstructure, after creep test bilayer sheet were evaluated by using SEM microscope as shown in Fig. 3. According to line scan analysis, due to X shape distribution of aluminum and magnesium in the transverse direction of bilayer sheet, 10.74 μm thick diffusion layer were formed with the respect to aluminum and magnesium diffusion to the border and no intermetallic compounds were formed. A brittle intermetallic phase negatively affects bonding strength and mechanical properties. Hence, the absence of an intermetallic phase suggests that roll bonding has successfully achieved proper bonding between aluminum and magnesium at the interface.

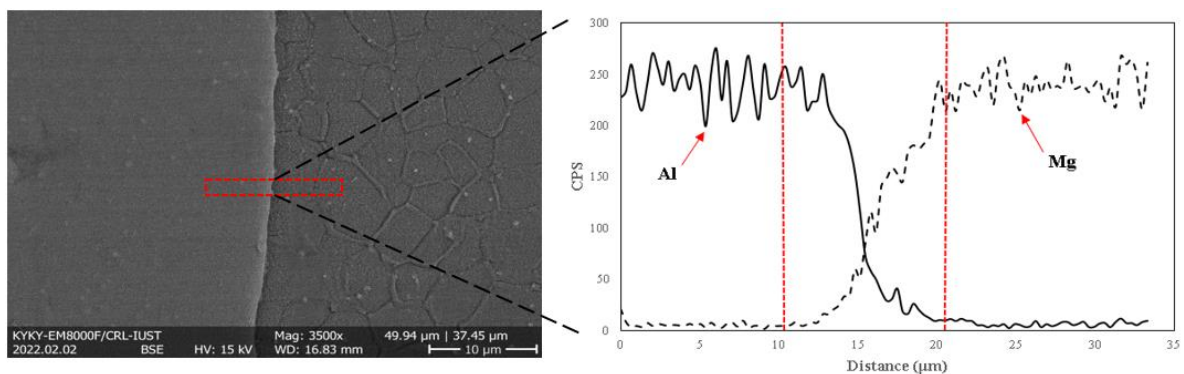


Figure (3) SEM analysis of bilayer sheet

Strain-time curve in 225°C and 30 MPa of creep loading for Al/Mg bilayer sheet has been depicted in Fig. 4 that after 4.18 hour and tolerate strain of 0.096 fracture occurs.

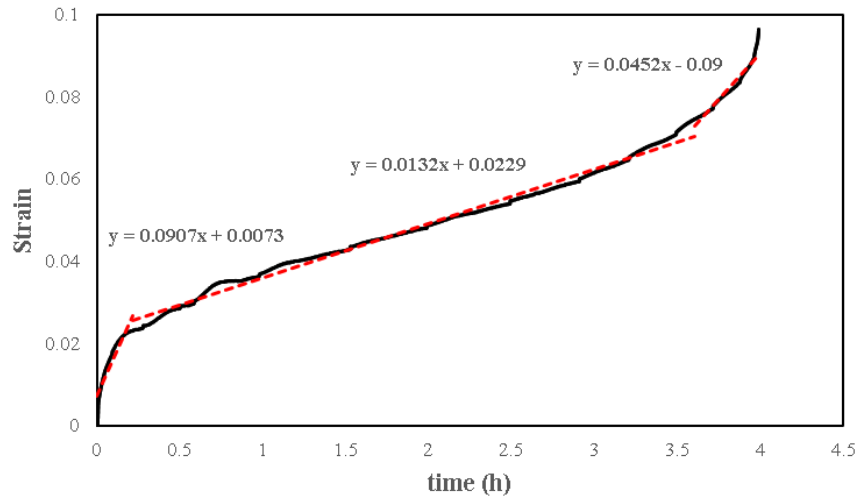


Figure (4) Creep curve of bilayer sheet

A typical creep curve as shown in Fig. 4 can be divided into three stages; primary creep, secondary creep, and tertiary creep. Primary creep that occurs after instantaneous deformation, the creep strain is increasing with respect to time which Work hardening increases the creep resistance and slow inelastic deformation occurs. In the secondary creep, the slope remains constant due to the balance between thermal recovery and work hardening and finally in Tertiary creep, creep strain increases rapidly till rupture. Table 2, represent the slope of creep curve in different stages.

Table 3- Slope of creep curve in different stage

Creep Stage	1st	2nd	3rd
Slope	83.70°	52.85°	77.52°

The fracture cross-section of Al/Mg bilayer sheet in creep loading depicted in Fig. 5. The existence of multiple dimples in aluminum side confirm ductile creep fracture; Inconstant, the cleavage fracture of magnesium indicates brittle creep fracture and lack of micro voids in magnesium side confirm this type of fracture.

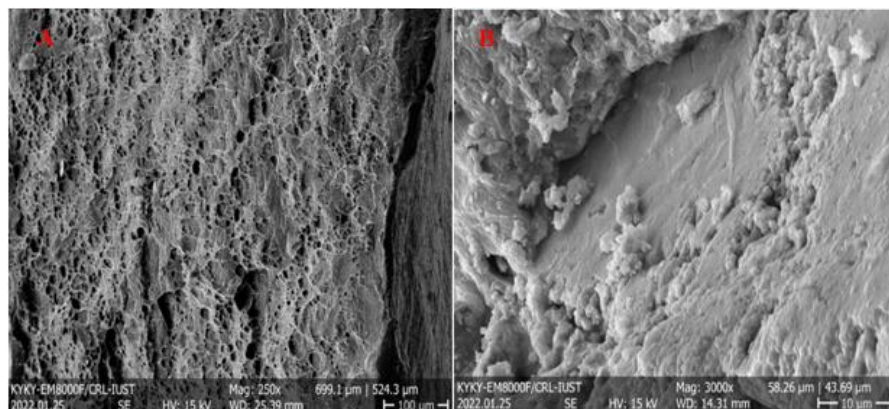


Figure (5) Fracture cross section of bilayer sheet in creep loading

Conclusion

1. The tensile test indicates, first magnesium layer failed, then delamination between aluminum and magnesium occurred and eventually the aluminum layer fractured.
2. In creep loading, diffusional interface with the thickness of $10.74\mu\text{m}$ appears and the samples failed after 4.18 hour and tolerate of 0.096 strain.
3. Creep fractography of cross section shows that the fracture in aluminum and magnesium are ductile and brittle respectively.

Acknowledgment

Acknowledgments are made briefly to those contributing to the research in a sentence or two.

References

- [1] W. L. and H. L. Jian-jun Zhang, Effect of thickness of interfacial intermetallic compound layers on the interfacial bond strength and the uniaxial tensile behaviour of 5052 Al/AZ31B Mg/5052 Al clad sheets, no. 127. 2015
- [2] X. Hao et al., "In-situ investigation of crack initiation and propagation in roll-bonded five-ply ASS/Al/Mg/Al/ASS laminated composites during tensile test," J. Alloys Compd., vol. 822, p. 153608, May 2020, doi: 10.1016/j.jallcom.2019.153608
- [3] N. H. ZHAO Congming, DENG Kunkun , NIE Kaibo, ZHANG Xuanchang, "Effect of extrusion-cladding rolling on microstructure and mechanical property of SiCP reinforced magnesium alloy(AZ91) clad plate," Acta Mater., vol. 37(1);, no. 1, pp. 164–172, 2020.
- [4] A. Macwan, X. Q. Jiang, C. Li, and D. L. Chen, "Effect of annealing on interface microstructures and tensile properties of rolled Al/Mg/Al tri-layer clad sheets," Mater. Sci. Eng. A, vol. 587, pp. 344–351, Dec. 2013, doi: 10.1016/j.msea.2013.09.002.
- [5] A. Rouzbeh, M. Sedighi, and R. Hashemi, "Comparison between Explosive Welding and Roll-Bonding Processes of AA1050/Mg AZ31B Bilayer Composite Sheets Considering Microstructure and Mechanical Properties," J. Mater. Eng. Perform., vol. 29, no. 10, pp. 6322–6332, Oct. 2020, doi: 10.1007/s11665-020-05126-9.
- [6] C. Luo, W. Liang, Z. Chen, J. Zhang, C. Chi, and F. Yang, "Effect of high temperature annealing and subsequent hot rolling on microstructural evolution at the bond-interface of Al/Mg/Al alloy laminated composites," Mater. Charact., vol. 84, pp. 34–40, Oct. 2013, doi: 10.1016/j.matchar.2013.07.007.
- [7] F. Raisie, M. Sedighi & A. Rouzbeh, " An Experimental Study on the Creep Behavior of Al 1050/Mg AZ31B Bilayer Sheet Fabricated via Roll Bonding", Journal of Materials Engineering and Performance, 2023.
- [8] C. Y. Liu et al., "Microstructures and mechanical properties of Mg/Mg and Mg/Al/Mg laminated composites prepared via warm roll bonding," Mater. Sci. Eng. A, vol. 556, pp. 1–8, Oct. 2012, doi: 10.1016/j.msea.2012.06.046.