Materials Letters 166 (2016) 219–222

Contents lists available at ScienceDirect

Materials Letters

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

Joining Mg alloys with Zn interlayer by novel ultrasonic-assisted transient liquid phase bonding method in air

Zhiwei Lai [a,c,e], Xiaoguang Chen [b,*], Chuan Pan [c], Ruishan Xie [d], Lei Liu [b], Guisheng Zou [b,*]

[a] School of Materials Science and Engineering, Tsinghua University, Beijing 100084, China
[b] Department of Mechanical Engineering, Key Laboratory for Advanced Manufacturing by Materials Processing Technology, Tsinghua University, Beijing 100084, China
[c] China Iron & Steel Research Institute Group, Beijing 100081, China
[d] College of Material Science and Engineering, Taiyuan University of Technology, Taiyuan, Shanxi 030024, China
[e] R&D Department, Yong Tai Electronic (Dong Guan) LTD., Dongguan, Guangdong 523583, China

ARTICLE INFO

Article history:
Received 1 August 2015
Accepted 7 November 2015
Available online 10 November 2015

Keywords:
Ultrasonic
Welding
Magnesium alloys
Microstructure
Mechanical properties

ABSTRACT

A novel ultrasonic-assisted transient liquid phase bonding method was developed to joining magnesium alloys with Zn interlayer at 370 °C in air. The influence of ultrasonic time on the microstructure and mechanical property of the joints was investigated. The introducing of ultrasonic into transient liquid phase bonding process showed benefit effects on inducing and promoting the eutectic reaction between Mg and Zn, and also accelerating the isothermal solidification process. The joint shear strength increased nonlinearly with the ultrasonic time lengthened and had a relationship with the thicknesses of the $Mg_{51}Zn_{20}$ and MgZn intermetallic compound layer, α-Mg(Zn) solid solution layer, and the total joint area. The highest average shear strength of the joints for 120 s ultrasonic time reached to 106.4 MPa, which was nearly equal to the strength of Mg base metal.

1. Introduction

Magnesium alloy has broad application prospect for various industrial fields due to its high strength to weight ratio. The development of suitable and diversified joining techniques can expand the application of magnesium alloys. Transient liquid phase (TLP) bonding method utilizes the low-temperature eutectic reaction between the interlayer and the base metal. The TLP bonding of Mg alloys with various interlayers has been investigated [1–4], such as Mg–Al–Mg (maximum shear strength: 76.1 MPa, bonding temperature: 480 °C, holding time: 60 min) [1], Mg–Ag–Mg (70 MPa, 480 °C, 30 min) [2], Mg–Cu–Mg (70.2 MPa, 530 °C, 30 min) [3], Mg–Ni–Mg (36 MPa, 515 °C, 120 min) [4]. The traditional TLP method needs high bonding temperature and longer holding time to achieving the adequate atom diffusion. Vacuum environment is also necessary to avoid oxidation which blocks the interface eutectic reaction. Ultrasonic vibration can generate an acoustic softening effect when propagating in a plasticity materials [5–7]. Utilizing this effect to break the oxide film at the solid/solid interface can make the TLP bonding carry out in air having feasibility. Zn element is usually used in joining Mg alloys [8,9], but no relative report is found in TLP method. In the present study, ultrasonic-assisted transient liquid phase (U-TLP) bonding method was firstly proposed and adopted in joining Mg alloys with a Zn foil at 370 °C in air. The effects of ultrasonic time (UT) on the microstructure and joint strength were studied.

2. Experimental procedures

ME20M magnesium alloys with a chemical composition of Mg–(1.3–2.2)Mn–(0.15–0.35)Ce–0.3Zn (wt%) were used. The Mg base metal was cut to dimensions of 20 × 20 × 3 (mm) and 16 × 16 × 3 (mm), grinded by SiC paper to a 1000 grit finish, and then ultrasonically cleaned in acetone for 15 min. The schematic diagram of U-TLP process is shown in Fig. 1a. Pure Zn foil with a thickness of 0.05 mm was inserted between two Mg specimens. High-frequency induction heating device was used with constant parameters of 5.0 A and 225 kHz. During the bonding process, an ultrasonic horn was imposed on the sandwich structure under a 0.15 MPa pressure, and the ultrasonic with 200 W power at a frequency of 20 ± 0.1 kHz was applied for different UT when the specimens were heated to 370 ± 5 °C, and finally the samples was cooled in air. The morphology and microstructure of the joint was

* Corresponding authors.
E-mail addresses: xgchenhit@126.com (X. Chen), zougsh@mail.tsinghua.edu.cn (G. Zou).

http://dx.doi.org/10.1016/j.matlet.2015.11.031
0167-577X/

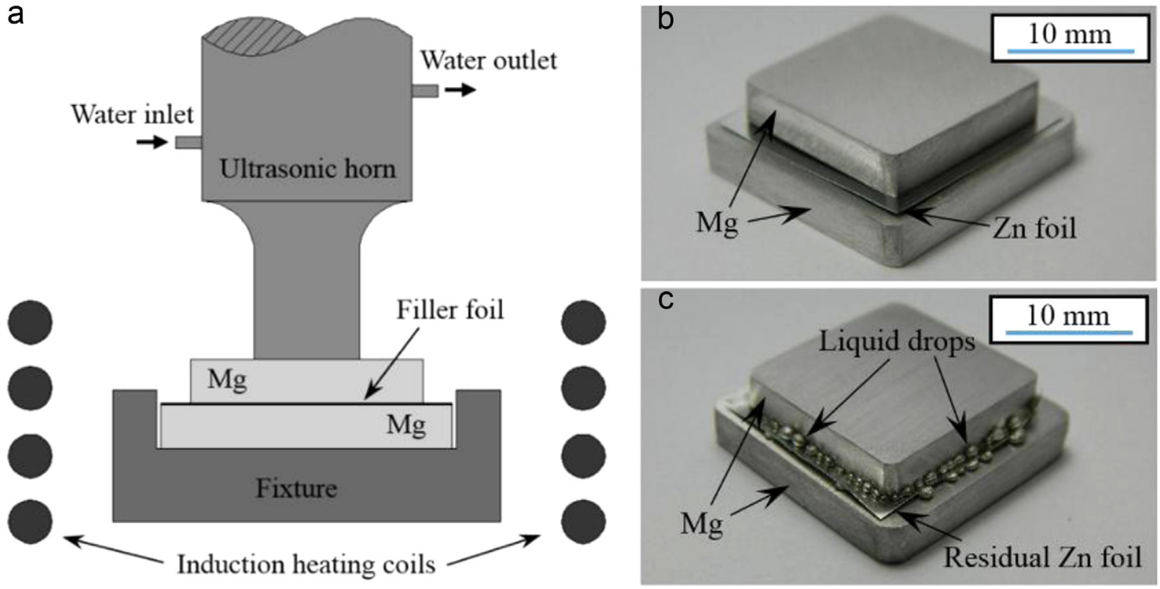

Fig. 1. (a) Schematic diagram of the U-TLP process; typical morphology of the Mg/Zn/Mg sandwich structures without ultrasonic (b) and with ultrasonic (c).

observed by optical microscope (OM) and scanning electron microscopy (SEM) equipped with an energy dispersive X-ray spectrometer (EDS). X-ray diffraction (XRD) was applied to identify the phase constitution. The specimens for shear tests were cut from the original joints and had a uniform dimension of $10 \times 5 \times 6$ (mm) and a joint area of 50 mm^2. The shear strength was evaluated by an electron tension testing machine.

3. Results and discussion

Not weld occurred when the Mg alloys were bonded only with 0.15 MPa pressure and without ultrasonic assistant at 370 °C (Fig. 1b). It is because that surface oxide film grew when heating in air, which acted as a barrier layer for the eutectic reaction. When applying ultrasonic assistant at the same condition, liquid globules appeared at the edge of faying surface (Fig. 1c). New liquid globules kept appearing until shutting down the ultrasonic, even though the temperature and pressure were still the same. When the UT time was longer than 5 s, the appearance of new liquid was barely observed.

It is believed that the ultrasonic played a critical role on both the startup and continuous of the eutectic reaction, which was account for the liquid globules. When ultrasonic wave transmitted in a solid, it could create an additional stress field and induce ultrasonic softening or temporary softening [5,7]. The softening

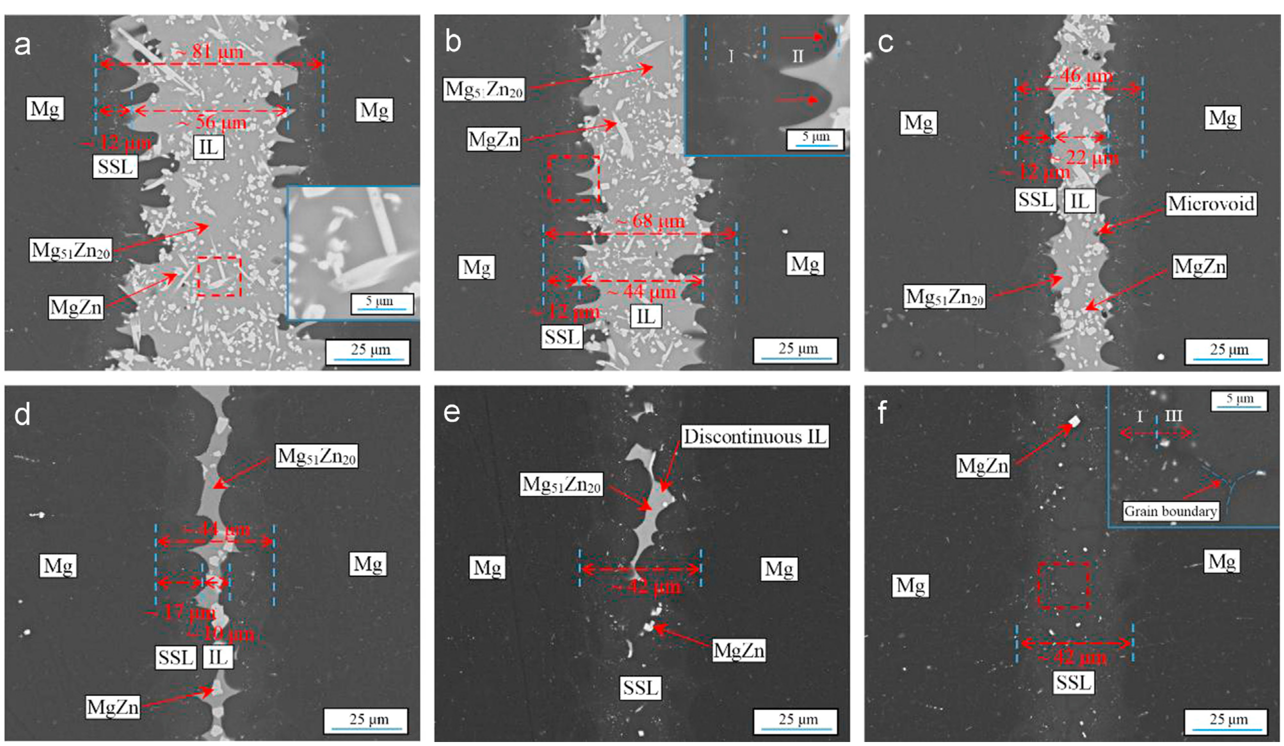

Fig. 2. Microstructure of the joints for different UT: (a) 1 s, (b) 2 s, (c) 5 s, (d) 30 s, (e) 60 s, (f) 120 s.(the smaller images in a, b, and f are the local magnification of the corresponding square areas).