Development of Al/Mg Bimetal Prepared by Ultrasonic Vibration-Assisted Compound Casting

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Abstract: The coarse Al-Mg intermetallic compounds and oxide film at the Al/Mg bimetal interface strongly limit and weaken the interfacial bonding performance. The introduction of ultrasonic vibration into the liquid medium could provide high-frequency oscillations and induce unique acoustic effects in liquid melt, which have significant impacts on the flow field and temperature field of the liquid medium, and may be aided for the enhancement of the Al/Mg bimetal interface. In this work, the Al/Mg bimetals were fabricated by ultrasonic vibration-assisted solid-liquid compound lost foam casting. The ultrasonic vibration treatment (UVT) was introduced to the Al/Mg interfaces, and the effects of UVT on the interfacial microstructures and mechanical properties were investigated. The results revealed that the microstructures of the Al/Mg interface with UVT were refined and got more homogeneous, and the oxide film at the Al/Mg interface was fractured and eliminated. The microhardness was more uniform, and the bonding strength of the Al/Mg bimetal with UVT was enhanced to 61.4 MPa, with an increase of 89.5%, compared with that of the Al/Mg bimetal without UVT.

Keywords: Ultrasonic vibration; Lost foam casting; Al/Mg bimetal; Interfacial microstructures; Mechanical properties

1 Introduction

The Al/Mg bimetal composites combines the advantages of Al alloys and Mg alloys [1, 2], which have prominent comprehensive properties on the basis of ensuring light weight, thus expanding the application range of aluminum, magnesium and their alloys in industrial fields [2].

The compound casting is suitable for manufacturing the Al/Mg bimetals with complex shapes and large sizes. However, Al and Mg could dissolve infinitely and form brittle Al-Mg intermetallic compounds (IMCs). These brittle IMCs are with much higher microhardness than the Al and Mg matrix. Cracks initiate at the IMCs firstly, which are detrimental to the bonding performance of Al/Mg bimetals. The oxide inclusions easily formed at the Al/Mg interface, which inhibit the interdiffusion of elements and weaken the metallurgical reaction between Al alloy and Mg alloy. Besides, the Al-Mg IMCs are coarse.

Majorities of efforts have been made to enhance the Al/Mg interface, such as setting interlayers, microalloying of melt and vibration-assisted compound casting [1-3]. The vibration-assisted compound casting is a pollution-free method to enhance castings. Compared with low-frequency mechanical vibration, the ultrasonic vibration introduced to the melt could induce acoustic cavitation and acoustic streaming flow effects, which shows potential application in strengthening Al/Mg interface.

In this study, the effects of ultrasonic powers on the interfacial microstructures and mechanical properties of the Al/Mg bimetals were investigated.

2 Experimental procedure

The commercial AZ91D alloy and A356 alloy ingots were used as the raw materials to fabricate the Al/Mg bimetals. The chemical compositions of the AZ91D alloy and A356 alloy ingots are listed in Table 1.

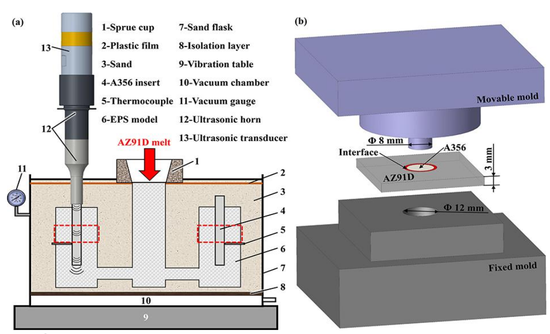

Fig. 1. Schematic diagrams showing (a) the ultrasonic vibration treatment assisted lost foam casting system, the red boxes marked in the image illustrate the position of the Al/Mg bimetal samples cut for microstructure observation and mechanical measurement, (b) the shear strength measurement.

Fig. 1(a) shows the schematic diagram of the UVT-assisted LFC system. The frequency of the ultrasonic device is 20 kHz. After the pouring process, the ultrasonic device was activated, with duration time of 5 s, and ultrasonic power of 75, 150 and 225 W respectively.

Table 1. Compositions of A356 and AZ91D Alloy

Alloy	Mg	Al	Si	Ti	Mn	Fe	Zn
AZ91D	Bal.	9.11	0.02	-	0.24	-	0.61
A356	0.31	Bal.	7.08	0.11	-	0.10	-

The microstructure characteristics and the mechanical properties of the Al/Mg interfaces were investigated. Fig. 1(b) shows the schematic diagram of the shear strength measurement. The loading rate was 0.5 mm/min.

3 Result and discussion

1. Interfacial microstructure

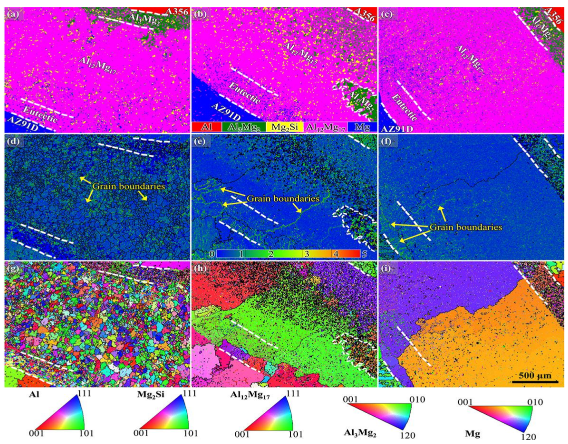

Fig. 2 EBSD results of the Al/Mg interfaces of the UVTed-75 W, UVTed-150 W and UVTed-225 W specimens. (a-c) Phase map, (d-f) grain boundaries and stress map, and (g-i) grain boundaries and IPF map of (a, d, g) the UVTed-75 W specimen, (b, e, h) the UVTed-150 W specimen, (c, f, i) the UVTed-225 W specimen. The white dashed lines illustrate the boundaries among A356, Al3Mg2, Al12Mg17, eutectic structure and AZ91D. IPF: inverse pole figure.

Fig. 2 shows the EBSD results of the Al/Mg interfaces of the UVTed-75 W, UVTed-150 W and UVTed-225 W specimens. The Al/Mg interfaces of the UVTed specimens are composed of Al_3Mg_2, Mg_2Si, $Al_{12}Mg_{17}$ and δ-Mg. Compared with the phase map of the specimen without UVT, the compositions of the Al/Mg interfaces with UVT are not changed. However, the distributions of phases have been significantly changed. Evidently, the Mg_2Si particles are dispersed and uniformly distributed at the whole Al/Mg interface, rather than only distributed at the IMCs area and gathered at the $Al_{12}Mg_{17}$ layer.

2. Mechanical properties

Fig. 3(a) and (b) exhibits the results of shear strength measurement of the Al/Mg bimetals. The shear strength of the specimen without UVT reaches 32.4 MPa. The shear strengths of the UVTed-75 W, UVTed-150 W and UVTed-225 W specimens are 61.4, 51.7 and 50.8 MPa respectively, which are increased by 89.5%, 59.6% and 56.8% respectively, compared with that of the specimen without UVT.

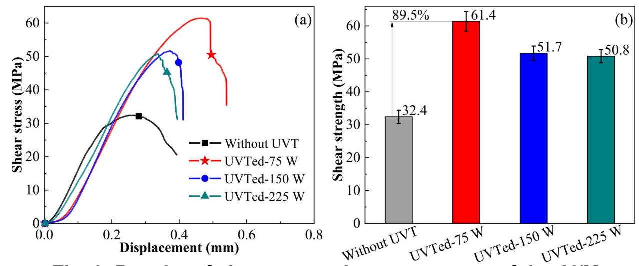

Fig. 3. Results of shear strength measurement of the Al/Mg bimetals: (a) the stress-displacement curves and (b) the shear strengths of the Al/Mg bimetals.

4 Conclusion

(1) With UVT, the oxide film was removed by UVT, and the Mg_2Si particles were refined and dispersed at the whole Al/Mg interface by the acoustic cavitation effect induced by UVT. Grain refinement of the Al/Mg interface with UVT only occurred when the ultrasonic power was 75 W.

(2) The microhardness of the Al/Mg interfaces was increased and got more uniform by UVT. The shear strength of the Al/Mg bimetal with UVT under the ultrasonic power of 75 W was enhanced to 61.4 MPa, increased by 89.5%, compared with that of the Al/Mg bimetal without UVT. It could be ascribed to the more homogeneous microstructure, the refined and uniformly dispersed Mg_2Si particles and the removal of the oxide film.

Acknowledgments

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References

[1] Li Q, Jiang W, Fan Z. Development of prominent bonding strength in Al/Mg bimetal composites prepared by ultrasonic vibration-assisted compound casting: Effects of ultrasonic powers. J. Mater. Sci. Technol. 2024,197:78-93.
[2] Li Q, Fan Z, Jiang W. Development of Al/Mg bimetal prepared by ultrasonic vibration-assisted compound casting: Effects of interface treatment temperatures. Mater. Sci. Eng. A 2024,890:145911.
[3] Li Q, Jiang W, Fan Z. Development of Al/Mg bimetal processed by ultrasonic vibration-assisted compound casting: Effects of ultrasonic vibration treatment duration time. Materials 2023,16:5009.