Effect of Deposition Layers on the Microstructure and Mechanical Properties of Cu/Al Bimetal Fabricated by Wire Arc Additive Manufacturing

Fuyuan Liang[1], Pengfei Xing[2], Mengwu Wu[1,*]
1. School of Automotive Engineering, Wuhan University of Technology, Wuhan 430070, China
2. National Key Laboratory of Intelligent Agricultural Power Equipment, Luoyang 471039, China
*Corresponding address: e-mail: wumw@whut.edu.cn

Abstract: Copper/aluminium bimetallic materials were fabricated by CMT wire arc additive manufacturing, and the effect of deposition layers on the microstructure and mechanical properties of the bimetal interface was investigated. Experimental results show that with the increase of deposition layers, the subsequent thermal cycle promotes the growth of copper/aluminium interfacial layer. And when the number of deposition layers exceeds 5, the thickness of the interfacial layer increases sharply. The shear strength of the interface shows a tendency to increase firstly and then decrease later.

Keywords: Cu/Al bimetal; wire arc additive manufacturing; microstructure; mechanical property

1 Introduction

Copper/aluminium bimetallic materials have the advantages of light weight, good electrical/thermal conductivity, etc., and have been widely used in automotive, power electronics, metallurgical machinery and other fields [1-2]. Wire arc additive manufacturing (WAAM) has the advantages of high deposition efficiency and low cost [3]. Applying WAAM process to fabricate bimetallic materials has become a research hotspot in recent years. In the process of copper/aluminium bimetallic fabrication by WAAM, the subsequent depositing metal will have a thermal effect on the deposited metal, so it is important to understand the effect of thermal cycling on the microstructure and mechanical properties of the copper/aluminium interface.

2 Experimental procedure

304 steel with a dimension of 200×200×5mm is used as a substrate. The filler materials are 1.2mm-diameter Al (4043) and Cu (CuSi-3) alloys. Table 1 shows the composition of the filler materials. The wire arc additive manufacturing equipment consists of a Fronius CMT Advanced 4000R welding machine and a ABB 2600 robot. The DC-CMT mode is used for the deposition of Al alloy and Cu alloy. Initially, 10 layers of Cu alloy is deposited on the 304 steel substrate. Then, Al alloy with various layers is deposited on the Cu alloy. During the WAAM process, k-type thermocouple is used to measure the thermal cycle of Cu/Al interface. After obtaining the Cu/Al bimetal, metallographic samples are cut, polished and etched for 15 s using a standard Keller solution. The microstructure of Cu/Al interface is characterized by scanning electron microscopy (SEM) equipped with an energy dispersive spectroscopy (EDS). Shear tests are carried out using an electromechanical universal testing machine.

Table 1 Composition of the filler materials

Wire	Al	Cu	Si	Mn	Fe
4043	Bal.	0.30	6.00	0.15	0.60
CuSi-3	--	Bal.	3.00	0.80	--

3 Result and discussion

Microstructure of the interface layer

Figure 1 shows the macroscopic morphology of Cu/Al bimetal. It can be seen that there is no obvious macro cracks on the surface of the specimen.

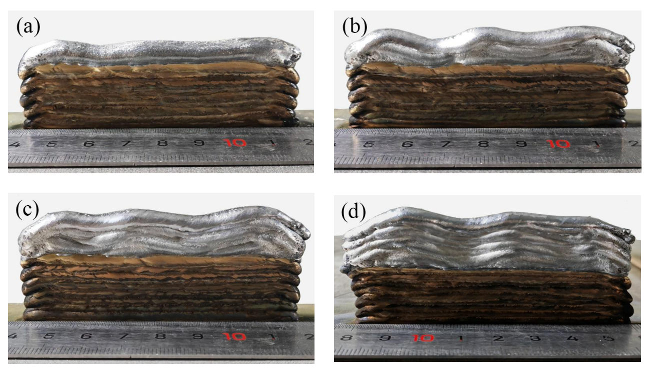

Fig. 1 Macroscopic morphology of Cu/Al bimetal with different deposition layers: (a) 3; (b) 5; (c) 7; (d) 10

Figure 2 shows the microstructure of Cu/Al interface with various Al alloy deposition layer. From Figures 2 (a-b), it can be seen that the thickness of the interface layer is 15 μm and 18 μm, respectively, and the thickness of the interface layer does not change much. As shown in Figure 2 (c-d), the thickness of the interface layer increases dramatically when the aluminium alloy deposition layer is 7 and 10, while the thickness of the interface layer reaches 100 μm and 300 μm, respectively. In addition, it can be seen that when the number of aluminium alloy deposition layer is 10, the intermetallic compounds within the interface layer are obviously broken. This is because the intermetallic compounds within the interface layer are more brittle in the process of depositing aluminium alloy. Affected by the subsequent layer of aluminium alloy depositing, the first layer of aluminium alloy will be remelted and locally uneven melting, the liquid metal flow in the molten pool will impact on the solid-liquid interface. In the process of the liquid metal flow, the brittle intermetallic compounds within the interface layer will be fractured.

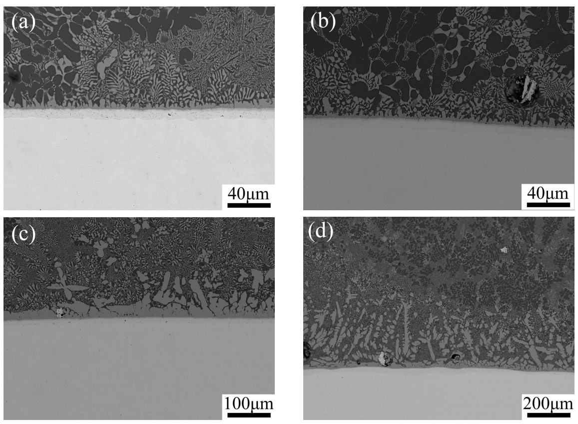

Fig. 2 Microstructure of Cu/Al interface with different deposition layers: (a) 3; (b) 5; (c) 7; (d) 10

Mechanical property

Figure 3 shows the thermal cycle curve at the Cu/Al interface. It can be seen that the layer 1 aluminium alloy is subject to multiple remelting and post-thermal effects. With the increase of the aluminium alloy deposition layer, the distance of the electric arc from the interface gradually increases, the thermal impact of subsequent deposited layer on the interface diminishes, the peak temperature of the interface gradually decreases. When the number of aluminium alloy deposition layer is 10, the peak temperature at the Cu/Al interface still exceeds 400 °C, which indicates that there is a certain thermal accumulation at the Cu/Al interface. The thermal accumulation promotes the growth of intermetallic compounds at the interface.

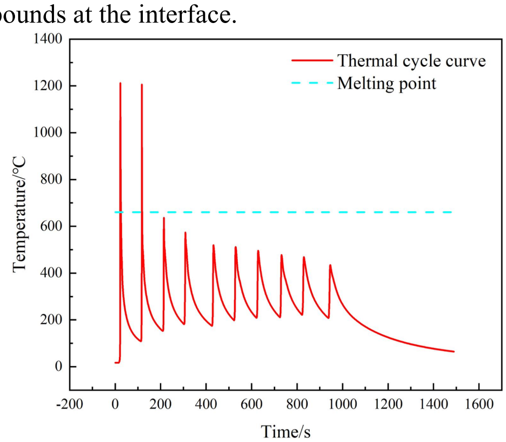

Fig. 3 Thermal cycle curve at the Cu/Al interface

Figure 4 shows the shear strength of the Cu/Al bimetal interface. It can be seen that the shear strength of the composite interface shows a tendency of increasing first and then decreasing. This is due to the fact that the thickness of the interface layer increases dramatically when the number of aluminium alloy deposition layer increases to 7 and 10. Under the action of the load, it is easy to lead to stress concentration and promote the generation of microcracks, which are easy to expand rapidly along the interface layer, and ultimately make the shear strength of the composite interface drop significantly.

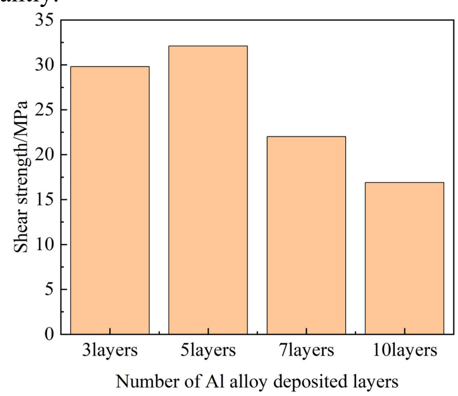

Fig. 4 Shear strength of Cu/Al bimetal interface

4 Conclusion

With the increase in the number of aluminium alloy deposition layer, the Cu/Al bimetal interface undergoes more thermal cycles. The thickness of the copper/aluminium interface layer gradually increases, and the shear strength of the composite interface shows a tendency of increasing first and then decreasing.

Acknowledgments

This work was financially supported by the Key R&D Program of Hubei Province, China (Grant No. 2022BAD100) and the Open Fund of National Key Laboratory of Intelligent Agricultural Power Equipment (Grant No. SKLIAPE2023014).

References

[1] Chen X, Chen Z, Hu B, et al. Strengthening behavior and thermal conductivity of Cu/Al composite with penetration architecture[J]. Transactions of Nonferrous Metals Society of China, 2024, 34: 236-245.
[2] Wu Z, Zuo L, Zhang H, et al. Effect of Liquid-Solid Volume Ratio and Surface Treatment on Microstructure and Properties of Cu/Al Bimetallic Composite[J]. Crystals, 2023, 13: 794.
[3] Gu J, Yang S, Gao M, et al. Influence of deposition strategy of structural interface on microstructures and mechanical properties of additively manufactured Al alloy[J]. Additive Manufacturing, 2020, 34:101370.