Materials and Design 34 (2012) 559–565

Contents lists available at ScienceDirect

Materials and Design

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

Microstructure characteristics and mechanical properties of cold metal transfer welding Mg/Al dissimilar metals

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ARTICLE INFO

Article history:
Received 8 March 2011
Accepted 6 May 2011
Available online 13 May 2011

Keywords:
A. Non-ferros metals and alloys
D. Welding
F. Microstructure

ABSTRACT

AZ31B Mg alloy and 6061 Al alloy were joined by using cold metal transfer (CMT) welding with pure copper (HS201) as the filler metal. The microstructure of Mg/Al CMT weld joint was studied by means of Optical Microscopy, Scanning Electron Microscope (SEM), Energy Dispersive X-ray (EDX), X-ray Diffraction (XRD). Results showed that dissimilar metals of Mg/Al could be successfully joined by CMT under proper processing parameters. The bonding strength of the joint was 34.7 MPa. A variety of Al–Cu intermetallic compounds, i.e. AlCu, $CuAl_2$, Cu_9Al_4, presented in the fusion zone of Al side, and Cu based solid solution was generated in weld zone, while Cu_2Mg and Al–Cu–Mg ternary eutectic structure was formed in the fusion zone of Mg side. The micro-hardness in the both sides of fusion zones increased sharply, which were 362 HV in Mg side and 260 HV in Al side. The joint was brittle fractured in the intermetallic compound layer of the fusion zone of Mg side, where plenty of Cu_2Mg intermetallic compounds were distributed continuously.

1. Introduction

Mg alloys are the best and lightest metal materials which are used in high technology fields such as automotive, electron and aerospace industries. However, the welding technology between Mg alloys and other metals has been an important research field at present. For example, the fusion welding problem of Mg alloys and steel or Al alloys exists in automotive manufacture. Welding of Mg and Al to form a compound structure can reduce the weight of the structure and the cost of the component [1,2]. The intersection of modern industrial materials makes the welding technology of Al and Mg alloys urgently. This technology has become a research focus in the weld field [3,4].

At present, friction stir welding [5,6] and diffusion bonding [7,8] are used to obtain higher strength Al/Mg joints. But the flexibility of friction stir welding is poor, while diffusion bonding is less efficient and needs to be put in a vacuum chamber. So these solid-phase connections are somewhat limited in application. Meanwhile tungsten inert gas welding [9], metal inert gas welding [10], laser welding [11,12] and other conventional fusion welding inevitably make fusion zone generate a thick intermetallic compounds layer, which leads to the cracks seriously affecting the joint strength [13].

The generation of intermetallic compounds was reduced by cold metal transfer (CMT) welding with the characteristics of low heat input [10] and Al/Steel dissimilar metals joint with good performance has been obtained by CMT process [14,15]. In this paper, CMT welding was used to weld Mg alloy and Al alloy with HS201 filler metal, the microstructures and mechanical properties of the joints were studied. The study provides a theoretical reference and practical experience for Mg/Al dissimilar metals connection.

2. Experimental procedure

Samples (100 × 50 × 3 mm) of extruded AZ31B Mg alloy and 6061 Al alloy were welded in this experiment. The chemical compositions of these two metals were shown in Table 1. The pure copper (HS201) filler metal (φ1.2 mm) was chosen and its chemical composition was shown in Table 2.

Before welding, the oxide films on substrates surface were removed by stainless steel wire brush, and acetone were wiped to remove the oil. The dimension of the welding plate and the shape of the weld bead were shown in Fig. 1. The welding equipment was CMT welding machine of Fronius-5000 type. The main welding parameters such as, welding current, welding voltage, wire feed speed and welding speed were shown in Table 3.

A series of specimens were cut along the longitudinal direction of the CMT welded joint by a lining cutting machine and mounted in bakelite for microstructure examination. Mg alloy side of the joint was etched in a solution of 1 ml oxalic acid and 1 ml nitric acid and 1 ml acetic acid and 150 ml distilled water. Al alloy side of the joint was etched in a solution of 2 ml hydrofluoric acid and 5 ml nitric acid and 95 ml distilled water. Microstructure,

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doi:10.1016/j.matdes.2011.05.008

Table 1
Chemical composition of AZ31B and 6061 (wt.%).

Materials	Mg	Al	Zn	Si	Fe	Cu	Mn	Ca	Ti	Cr	Other
AZ31B	Bal.	2.5–3.5	0.6–1.4	0.1	0.005	0.05	0.2	0.04	–	–	0.3
6061	0.8–1.2	Bal.	0.25	0.4–0.8	0.7	0.15–0.4	0.15	–	0.15	0.04–0.35	0.15

Table 2
Chemical composition of filler metal (wt.%).

Cu	Si	Mn	Sn	P	Other
Bal.	⩽0.5	0.5	1.0	0.15	⩽0.05

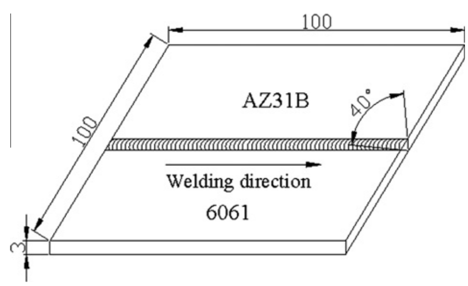

Fig. 1. Dimension of welding plate of Mg/Al dissimilar metals.

Table 3
Welding parameters.

Sample no.	Welding current (A)	Welding voltage (V)	Wire feed speed (m min^{-1})	Welding speed (m min^{-1})
1	114	11.1	5.1	0.65
2	125	11.6	5.5	0.65
3	129	12.0	5.7	0.65
4	134	12.4	5.9	0.65
5	125	11.6	5.5	0.55
6	125	11.6	5.5	0.45

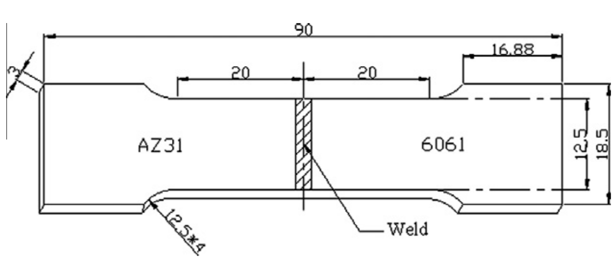

Fig. 2. The geometry of tensile test samples.

fracture morphology and phase composition of joints were observed and analyzed respectively by OLYMPUS (GX71) Optical Microscope, FEI Quanta 200 Scanning Electron Microscope and D8 ADVANCE X-ray Diffraction. The micro-hardness distribution was measured by the HVS-1000 Digital Display Micro-hardness Tester with a load of 0.2 kgf for 10 s. SANS CMT5105 universal testing machine was used for tensile test. The geometry of tensile test samples was shown in Fig. 2.

3. Results and discussion

3.1. Microstructures of joints

3.1.1. Welded joints in different welding parameters

Fig. 3 shows macrophotographs of the weld in different welding parameters listed in Table 3. Welding current of the sample 1 shown in Fig. 3a was minimal. It is obvious that filler metal were not enough, incomplete fusion and lack of penetration could be observed on the back of the weld due to the low feeding speed. Coupled with the solidification shrinkage, the crack parallel to the weld centre appeared immediately after welding. Weld reinforcement and width of samples 2 and 3 as shown in Fig. 3b and c increased gradually due to the increase of the welding current. Sample 3 with good formation was welded at the current of 129 A, voltage of 12.0 V, wire feed speed of 5.7 mm/s and welding speed of 0.65 m/min. Welding current of sample 4 as shown in Fig. 3d was maximal. The color of the weld surface was black, which indicated that weld had been oxidized and burned severely. The heat input of the sample 4 was so large that the weld formation was bad and the weld was cracked immediately after solidification. The phase composition of the weld sample 4 analyzed by X-ray Diffraction (XRD) was shown in Fig. 4. The result showed the existence of a variety of Al–Cu–Mg ternary intermetallic compounds such as Al_2CuMg, AlCuMg, $Al_5Cu_6Mg_2$ and $Al_7Cu_3Mg_6$ in the weld, which led to the cracks after welding.

Samples 2, 5, 6 as shown in Fig. 3b, e, f were in the same welding current and different welding speed. With the decrease of welding speed, weld formation showed the same trend as the samples from 1 to 4.

3.1.2. Microstructures in Al side

Fig. 5 shows optical micrograph in fusion zone of Al side of sample 3 welded at the current of 129 A, voltage of 12.0 V, wire feed speed of 5.7 mm/s and welding speed of 0.65 m/min. A mutual soluble zone between the Al substrate and the weld metal Cu was formed in the processing of weld metal solidification. Columnar crystals, which grew into the weld metal, were distributed in the fusion zone near Al substrate side where heat conducted quickly. The transition from columnar crystals to cellular crystals was existed in fusion zone, where the flaky kainotype compounds was formed due to the changes of solidifying conditions.

Fig. 6a–c shows Scanning Electron Microscope (SEM) micrographs in the Regions 1–3 marked in Fig. 5 respectively, and Energy Dispersive X-ray (EDX) analysis results obtained from different locations (Fig. 6a–c) were illustrated in Fig. 7. SEM micrograph in fusion zone near Al side was shown in Fig. 6a. White phase (point B) was distributed disorderly in black phase (point A). Fig. 7a shows the EDX result from location point A consisted of 94.89 at.% Al and 5.11 at.% Cu, so there was Al-based solid solution. Fig. 7b shows the EDX result from location point B, where Cu element increased to 22.98 at.%, while Al decreased to 75.72 at.%, which indicated that this location was composed of Al-based solid solution and $CuAl_2$ eutectic structure.

SEM micrograph in the fusion zone centre was shown in Fig. 6b. With the fusion between Al substrate and weld metal Cu, white phase (point E) increased, while black phase (point C) decreased,