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Composition and microstructure characteristics in bond area of TIG welding for high strength ZA alloy①

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Abstract: The evaporation and oxidation of zinc during the welding process was studied. The characteristics of microstructure and micro-hardness of the ZA alloy′s bond area that welded by TIG were investigated by using TEM, SEM and other methods. The results show that, by using the same filler metal as the parent metal, zinc content in bond area is lower than that in the weld metal and the base metal. The main structure of the bond area is columnar dendrite, including Zn, Al_4Cu_9, $CuTi_2$, $Al_7Cu_3Mg_6$ phases. There are many changes of structure in the bond area. The structure near the weld is some tiny slice Zn and α-Zn. The structure near the parent metal is rather coarse but is still a little tiny than that of the parent metal. As the tiny structure of the heat affected zone has high hardness, it can strengthen the weld, and thus improve the mechanical properties of the welded joint.

Key words: ZA alloy; TIG; bond area; microstructure
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1 INTRODUCTION

ZA alloy is firstly used as the substitute of bronze and babbit alloy in 1960s. With the development of science and technology, many new ZA alloys have been developed in recent years[1]. They are widely used in such industrial fields as mechanical, instrument, light industry, electromotor and plastics because of their high strength, hardness, and good wear ability and fluidity. As the boiling point of zinc is only 906 ℃, and the welding temperature is much higher than that, it will cause the evaporation and oxygenation of zinc. Thus, composition change occurs in the bond area. During welding process, bond area is in the state of partial melting, and the parent material and the weld metal are not mixed uniformly, thus the bond area is different from the parent material and the weld metal in the composition and structure, and it becomes a weak zone of the welded joint. There were only studies about flame welding of ZA alloy in the past, and no one has studied the bond area[2-5].

On the basis of studying the TIG welding technology of ZA alloy, we carry out deep investigation on the composition and microstructure of the TIG welded bond area. The results will be a reference for the ZA alloy′s weldability.

2 EXPERIMENTAL

The parent material used in this experiment is a new kind of high-strength ZA alloy. The chemical composition and mechanical properties are listed in Table 1. The size of the test plate is 8 mm × 80 mm × 80 mm. The filler metal is electrode with size of d 4 mm × 30 mm whose composition is the same as that of the parent metal. The flux is some chlorides. Purity of argon used in TIG welding is 99.99%.

Before welding, a U-shaped groove was fabricated on the test plate. After cleaning, the test plate was heated up to 100 ℃ by using oxygen-acetylene flame. During this process, the welding place and the electrode were coated with flux. The welding process parameters are given in Table 2. The left-welding method was adopted. The filler material was to be run from one side to the other side to protect welding pool from burning through.

After welding, the structure, composition and

Table 1 Chemical composition and mechanical properties of parent material

Chemical composition (mass fraction)/%					Mechanical property	
Al	Cu	Mn	Mg, Ti and Tu	Zn	σ_b/MPa	δ/%
9-12	3-5	0.2-0.3	A little	Bal.	≥300	> 3

Table 2 TIG welding process parameters

Welding current/A	Diameter of tungsten rod/mm	Flow of argon gas/(L·min^{-1})	Current type	Welding speed/(m·h^{-1})
65-80	3.2	6-7	AC	6.5-7.0

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micro-hardness of the bond area were tested. SEM (JXA-840 type) was used to analyze the microstructure of the bond area. TEM and electron diffractometry were used to investigate the structure and chemical composition of the bond area, respectively. The tested bond area that used in TEM analysis was first machined into slice of 0.25 mm in thickness by string-cutter, then it was ground into 0.08 ~ 0.10 mm by using sand paper. The working voltage is 600 ~ 800 V, and current is 0.2 ~ 0.4 mA.

3 RESULTS AND DISCUSSION

3.1 Chemical composition of bond area

The main element of ZA alloy is zinc. Because the boiling point of zinc is only 906 ℃, and the welding temperature is about 3 000 ℃, zinc is easily to be evaporated and oxidized. The evaporation of zinc not only changes the welding atmosphere resulting in the decline of the shield effect of argon, but also decreases the content of zinc in weld metal and heat affected zone (HAZ), which will affect the structure and property of the welded joint. The change of Zn, Al and Cu content is shown in Fig. 1. From Fig. 1, it can be seen that its content of HAZ is lower than that of weld metal and parent material, and the content of Cu and Al is higher than that of the parent metal. The first reason is that the evaporation and oxygenation of zinc make zinc content decrease. The second reason is that the bond area is in the state of partial melting, thus the flow of the partially melted metal is limited, resulting in incomplete mixing with the weld metal. The third is that the cooling process of bond area is very quick, and the metallurgical reaction is not fully finished, so zinc is not supplied in time. In the weld metal, zinc can be supplied by the flux's shield and deoxidize action. To avoid the inhomogeneity of chemical composition and the decrease of zinc content in bond area, such technical methods as adding special flux, shaking the arc properly, and lowering the current should be used.

3.2 Crystalline shape in bond area

It can be seen from Fig. 2 that the main structures of the TIG welded ZA alloy bond area are columnar dendrite, some ternary eutectic and compounds. It is difficult to find cellular structure. The flake of the columnar dendrite in bond area is fine, and it is clearly seen as flake shaped pearlite in microscope[6-8]. The center of the columnar dendrite is parallel flake. The trunk of it is a little longer and the sideward branch of it is shorter. The structure of the sideward branch is not uniform, and it includes flake, dot and some allotriomorphic grains. Among the branches of the columnar dendrite, there are some tiny composites and there is no any coarse grain near the parent material.

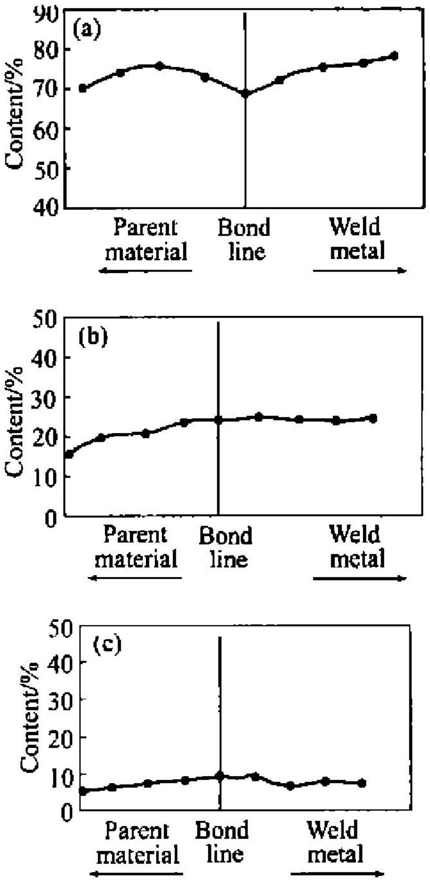

Fig. 1 Changes of chemical composition in bond area

(a) —Zn content; (b) —Al content; (c) —Cu content

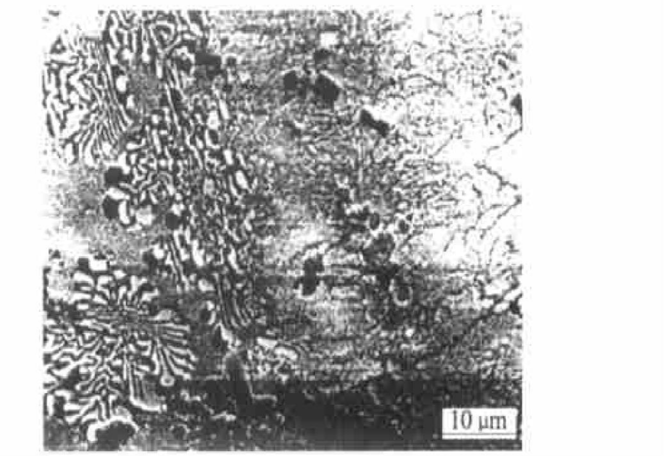

Fig. 2 Morphology in bond area of TIG welding

The real conductivity of the ZA alloy is rather large. At the same welding current and speed, the temperature gradient of the bond area is smaller than that of the low alloying steel, but the range of crystallization temperature is wider than that of the low alloying steel. It looks that the size of bond area should be large, but actually it is smaller than that of low alloying steel. Perhaps this is related to the ZA alloy crystallization and the cooling speed of the ZA alloy. In the welding, the element of the electrode is the same as the parent metal(89. 1% Zn, 7. 05% Al, 3. 85% Cu). Element segregation may occur easily under a certain cooling speed. Though the evaporation of zinc decreases the content of it in bond area, the structure of bond area is still some like the parent metal because of the element segregation. So we can see some ternary eutectics in columnar dendrite in bond area. The rapid cooling makes the growing speed of crystal greater than that of the low alloying steel. During the welding process, the crystallization speed of molten weld pool is very quick, but the crystallization temperature gradients of bond area is very little, and the cooling area is large, so there is little cellular[9]. The areas that have not melted in bond area have also changed in the structure because of heating cycle. In the basis of Zn-Al constitution of binary alloys, there will be a $\alpha + Zn \rightarrow Zn + ZnAl$ transformation in HAZ during heating and in the later process of cooling. ZnAl is extremely unstable, and it will decompose into α and Zn phases with the time going on, accompanied by the irregular expand of volume. This will produce great internal stress, and make the strength and toughness decrease, thus the material becomes brittle which is called "fatigue". And then it will affect the service properties of the welded joint[10-12].

3. 3 TEM and micro-hardness analysis of bond area

3. 3. 1 Micro-hardness of bond area

The micro-hardness of bond area can be seen from Table 3. It shows that the micro-hardness of eutectic and eutectoid is almost the same, generally 120 - 160 HV, but the micro-hardness of intermetallics is greatly harder than that of the eutectic and eutectoid. The main structures of eutectic and eutectoid are α and β phase. Their hardness is low, but their ductility is good.

Table 3 Micro-hardness of HAZ (HV)

	Eutectic	Eutectoid	Compounds
	123. 0	136. 0	700. 8
	131. 2	154. 9	676. 0
	141. 9	157. 3	685. 0
Average	132. 0	149. 4	688. 3

3. 3. 2 TEM analysis of bond area

From the analysis, we can find Zn and α phase and some intermetallics such as Al_4Cu_9 and $CuTi_2$. TEM and electron diffraction photographs are shown in Fig. 3 and Fig. 4.

There have no ZnAl phase in bond area, and this is perhaps because that ZnAl phase is extremely unstable, or there have no $\alpha + Zn \rightarrow Zn + ZnAl$ change in the welding process. From Fig. 3, we can see that the solidification process of bond area is based on the part that have not melted, thus form mutual crystallization. The part that have not melted owes large grain, but it changes into pearlite-like tiny grain after solidification (as shown in Fig. 3 (a)). And this will be helpful to strengthening of the bond area . There are many tiny poly-

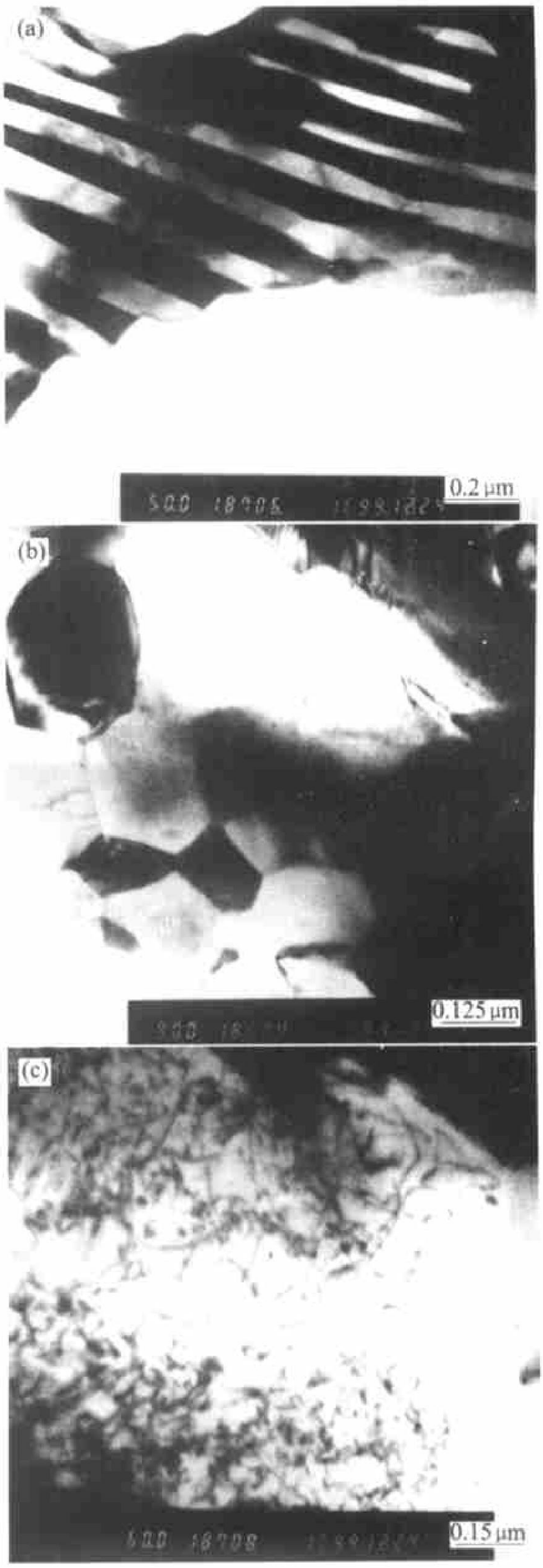

Fig. 3 TEM photographs of bond area
(a) —Structure of bond area;
(b) —Polygon grain of Zn photograph;
(c) —Line defect of α photograph

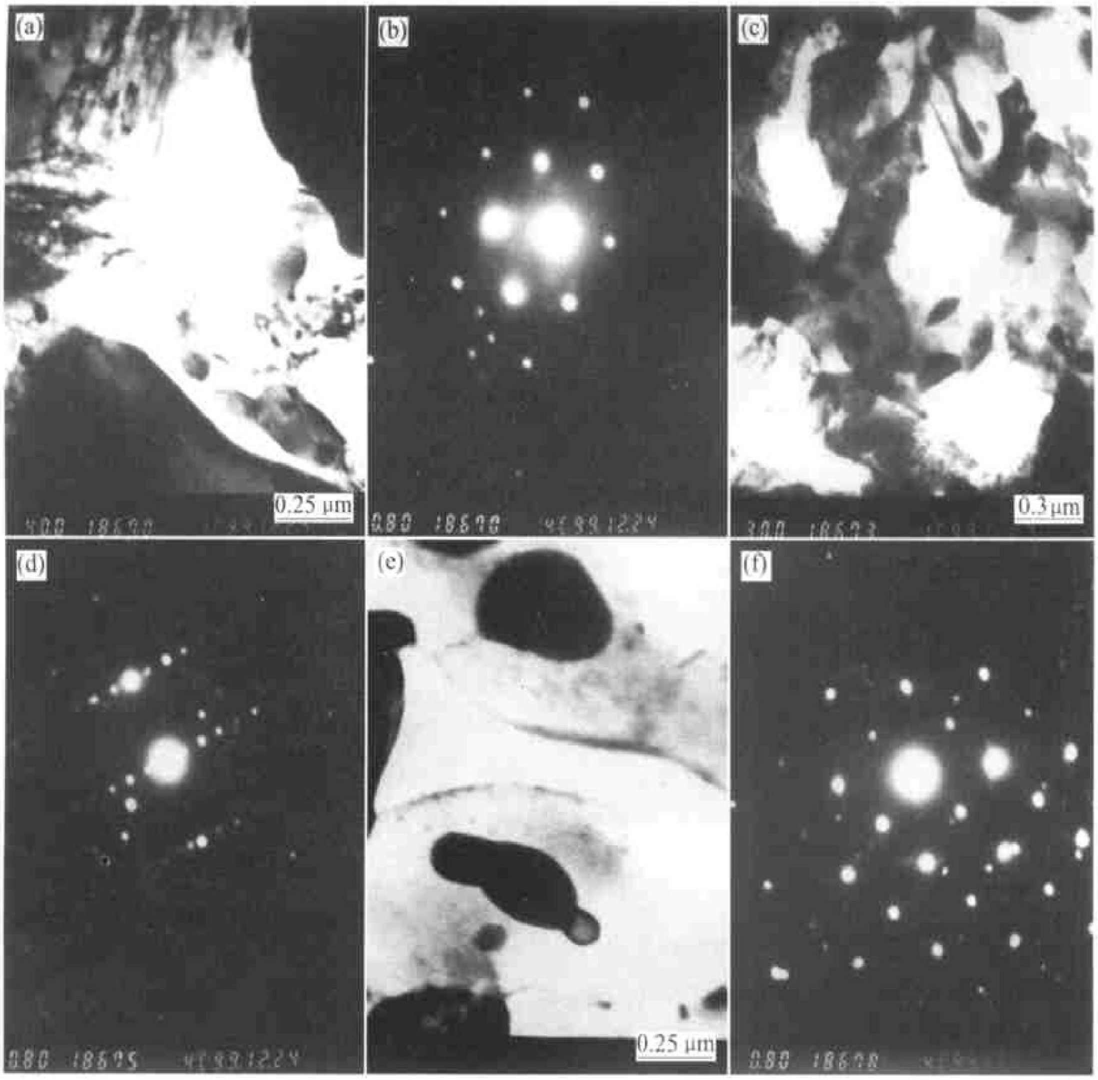

Fig. 4 Morphologies and election diffraction patterns of bond area

(a) —Morphology of Al_4Cu_9; (b) —Electron diffraction pattern of Al_4Cu_9;
(c) —Morphology of $Al_7Cu_3Mg_6$; (d) —Electron diffraction pattern of $Al_7Cu_3Mg_6$;
(e) —Morphology of $CuTi_2$; (f) —Election diffraction pattern of $CuTi_2$

gon sub-grains in the Zn phase of bond area, and the size is 0.1 - 0.3 μm, and it makes the structure of bond area still more tiny (as shown in Fig. 3(b)). There are many small size line deflections and line deflection loops (as shown in Fig. 3(c)). At the boundary of Zn phase there is some strip-shaped Al_4Cu_9 and block-shaped $CuTi_2$. At the boundary of the α phase there is some strip-shaped $Al_7Cu_3Mg_6$ (as shown in Fig. 4). The crystal structure of Zn phase is hexagonal, and the lattice parameters $a = 0.266$ nm, $b = 0.495$ nm. The frame of α phase is FCC lattice, and the lattice parameter $a = 0.404$ nm. The crystal structure of strip-shaped Al_4Cu_9 is cube-centered lattice, and its lattice parameter $a = 0.8704$ nm. There are some orientation relation between Al_4Cu_9 and Zn as $[211]_{Al_4Cu_9} \parallel [212]_{Zn}$, $[001]_{Al_4Cu_9} \parallel [101]_{Zn}$, $[111]_{Al_4Cu_9} \parallel [120]_{Zn}$. The crystal structure of $Al_7Cu_3Mg_6$ is BCC, and the lattice parameter $a = 1.212$ nm. The crystal structure of $CuTi_2$ is square structure, and its lattice $a = 0.297$ nm, $c = 0.1090$ nm[13].

4 CONCLUSIONS

1) The bond area of the TIG welded ZA alloy mainly includes columnar dendrite, and some intermetallics. The structure is very fine. The slice of the columnar dendrite is very small.

2) The main structure of the bond area is Zn phase with hexagonal lattice, α phase with face-centered cubic-lattice, Al_4Cu_9 with cubic lattice, $Al_7Cu_3Mg_6$ phase with body centered cube and $CuTi_2$ with square structure. The micro-hardness of the tiny composite is very large, and it can strengthen the parent metal.

3) The composition of the bond area is not uniform, and it is similar to that of weld.

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