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Research on welding technology and properties of aluminum alloy and dissimilar metals

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Research on welding technology and properties of aluminum alloy and dissimilar metals

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Abstract. This paper summarized the characteristics of welding technology between aluminum alloy and dissimilar metal. The welding technology and properties of different metals between aluminum alloy and steel, magnesium and copper were described in detail. The influences of welding parameters and metal composition on the microstructure and properties of welded joints were analyzed. In the future, it is necessary to strengthen the research on the welding of aluminum alloy, ultra-high strength steel, titanium and other high-end metals. New welding methods, new improved welding technology, adding suitable alloy elements and so on are needed to carry out for in-depth theoretical and practical research.

1. Introduction

The 21st century is a new era of green, environmental protection and intelligence [1,2,3]. It is a trend to save energy and reduce emissions. Aluminum alloy is widely used in mechanical manufacturing, transportation machinery, power machinery and aviation industry, etc. [4,5]. The fuselage, skin, compressor and other aircraft are often made of aluminum alloy in order to reduce the weight. If aluminum alloy is used instead of steel plate, the weight of the structure parts will be reduced by more than 50%. Aluminum is the most abundant metal element in the earth's crust after oxygen and silicon. The structure parts made up of one kind of metal material are often difficult to meet the requirements for use, so the structure parts made up of dissimilar metal welding have been widely used, which also leads to the application of dissimilar metal welding technology more and more widely [6]. The structure formed by the combination of dissimilar metals has its own excellent performance, and has the advantages of lower manufacturing difficulty, lower cost and higher efficiency, so more and more dissimilar metal welded structural parts are applied in industry. However, due to the great differences in chemical composition and microstructure properties of dissimilar metals, there are many problems in the welding process [7], such as metal incompatibility, tissue stress and weld joint melting zone defects, which make the welding of dissimilar metals more difficult.

This paper introduces the development status of welding between aluminum alloy and dissimilar metals, mainly elaborates and analyzes the welding process and properties of aluminum steel, aluminum magnesium and aluminum copper, and accumulates valuable experience and beneficial attempt for future welding between aluminum alloy and dissimilar materials.

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2. Welding technology and properties of dissimilar metals of aluminum and steel

J L Song et al., from the State Key Laboratory of Modern Welding Production Technology, Harbin Institute of Technology, studied how to improve the performance of aluminum steel dissimilar metal joints by adding alloying elements [8]. In his opinion, Si can reduce the melting point of welding wire, enhance the wettability and spreadability of liquid welding wire on the surface of steel, inhibit the generation of intermetallic compounds, and improve joint strength. Cu can reduce the melting point of the solder and play a solid solution strengthening role, so as to improve the strength of the joint. Manganese and zinc elements can improve the wettability of the liquid filler metal on the steel surface and improve the joint bonding strength. B and Zr can improve the plasticity. Ti can form $TiAl_2$, which becomes the non-spontaneous core and plays a role in refining grain structure and weld structure. Ga can reduce the brittleness of joints. Sr is a surface active element, and its plasticity and wettability can be improved by solid solution treatment. Lanthanide metal elements such as La, Ce can enhance heterogeneous nucleation. Sc can refine grain structure and so on.

B Y Zhao and Y Q Qin et al. [9] studied the microstructure and properties of 7075 aluminum alloy and galvanized steel sheet by CMT welding. The ER4047 welding wire was used to weld the lap joint. The connection between aluminum alloy and galvanized sheet can be well formed. The aluminum side of the joint is melted, which is the fusion weld. The steel side of the joint is not melted, which is the brazed weld. The joint is composed of four parts, which are steel side interface area (A), welding side area (B), zinc rich area (C) and aluminum side heat affected area (D), as shown in Figure 1. The steel side interface area is composed of $Al_{7.2}Fe_2Si$ compounds with a thickness of 2-3μm. The weld microstructure consists of α-Al solid solution and Al-Si second phase. There is zinc enrichment in the front of the solder flow. The fracture of the joint occurs in the heat-affected zone of the aluminum side, which is caused by the softening of the microstructure in the heat-affected zone of the aluminum side.

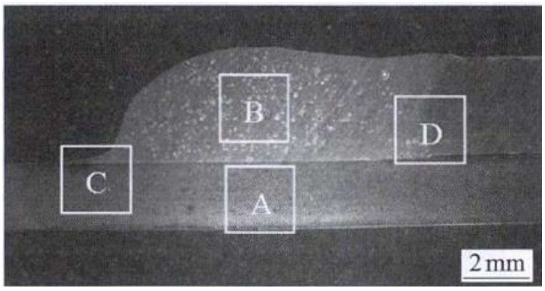


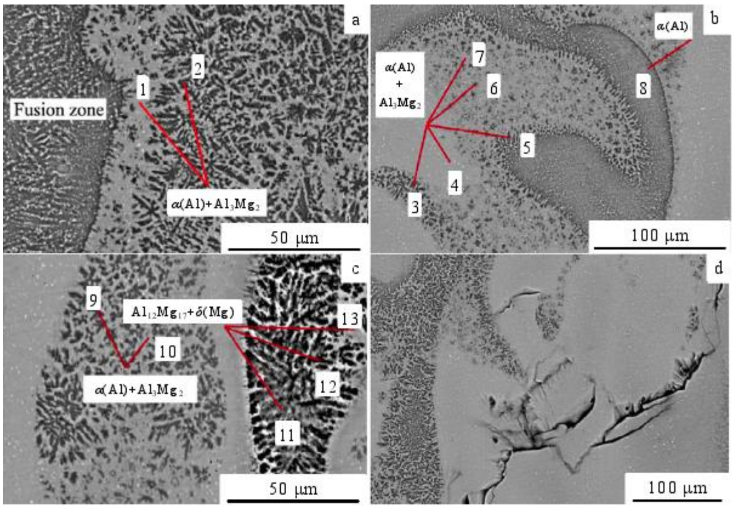
Figure 1. Appearance of 7075 aluminum/galvanized weld-brazed joint

C G Gong and W Hu, School of Materials, Lanzhou University of Technology, studied the friction stir welding by using 6061-T6 aluminum alloy with a thickness of 3mm and DP600 galvanized steel plate with a thickness of 1mm [10]. Based on the orthogonal test results and joint surface forming, the optimized process window of keyhole free friction stir spot welding was determined: the rotational speed was 1000-1400r/min, the friction time was 4-6s, and the stirring needle protrusion was 1.6-3.2mm. Within the scope of this window, good mechanical properties can be obtained without keyhole, and the influence of factors on the mechanical properties of the joint is from the main to the secondary: friction residence time, the rotation speed of the mixing head, and the length of the stirring needle extension.

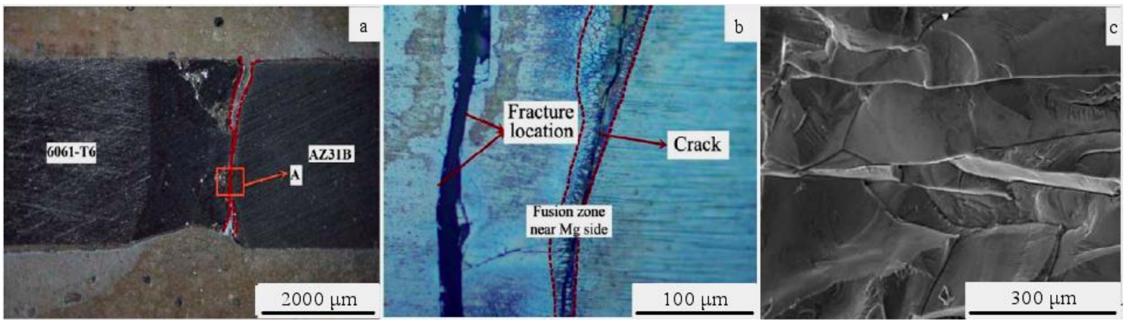
G L Qin et al., Institute of Modern Welding Technology at Shandong University, systematically introduced the brazing process of aluminum/steel dissimilar metal materials and its research status [11]. Aluminum/steel brazing process is based on TIG welding and MIG welding of arc heat source and laser welding and electron beam welding of high energy beam heat source. To enhance the performance of aluminum alloy and steel butt joint, we should take measures from the aspects of technology and metallurgy to improve the spread of liquid metal on the steel surface. Suitable alloy elements are added to regulate the microstructure and properties of aluminum alloy and steel joints. In addition, the specially medicated cored wire suitable for aluminum alloy and non-coated steel should be developed. In the basic theory, the thermodynamic and metallurgical conditions of Fe-Al intermetallic compound growth at the brazing interface of aluminum alloy steel are studied in depth and systematically, which lays a theoretical foundation for the control of microstructure and properties of aluminum alloy steel braze joint. It is also necessary to strengthen the research and development of the butt joint and corner joint of aluminum with galvanized steel or non-galvanized steel thick plates, and expand the application field of aluminum alloy with composite structure of different materials.

3. Welding technology and properties of dissimilar metals of aluminum and magnesium

Z T Zhu et al. from Southwest Jiaotong University conducted laser welding with IPGYLS-4000 in the lap joint of 6061-T6 aluminum alloy and AZ31B magnesium alloy [12]. Under the condition of laser power of 4kW and welding speed of 70mm/s, the fusion welding connection of 3mm thick aluminum magnesium dissimilar metal butt joint was realized, as shown in Figure 2 and Figure 3. There is a large amount of $Al_{12}Mg_{17}$ phase and a small amount of δ(Mg) mixed microstructure in the weld zone and magnesium fusion zone of the laser welding joint, which leads to the increase of brittleness tendency and brittle fracture. Other areas of the joint are mainly composed of a mixed structure of α(Al) and Al_3Mg_2. The presence of intermetallic compounds $Al_{12}Mg_{17}$ and Al_3Mg_2 causes the microhardness inside the weld to be significantly higher than that of the base metal on both sides, and the hardness changes greatly due to the changes in the content and position of intermetallic compounds. The tensile fracture occurs in the weld zone of the magnesium side, and the feature of fracture is the typical brittle fracture. The main cause of fracture is the presence of a large amount of $Al_{12}Mg_{17}$ in the weld zone and the fusion zone of magnesium side.



(a) Weld zone on Al side; (b) Weld center; (c) Weld zone on Mg side; (d) Cracks in weld zone
Figure 2. Microstructures of laser welded joint 6061-T6/AZ31B joint



(a) Cross section morphology of tensile specimen after fracture; (b) Magnification of the area A in Figure 3(a); (c) SEM fracture morphology
Figure 3. Fracture position and morphologies of 6061-T6/AZ31B laser welded joint

G L Li explored the welding performance of AZ31B magnesium alloy plate and 6061 aluminum alloy plate by using CMT welding technology. The plate thickness was 3mm and the welding wire was ER4043 aluminum welding wire [13]. The results show that Mg_2Al_3 and $Mg_{17}Al_{12}$ can weaken the strength of welded joint. However, as the welding specification becomes smaller, the diffusion between elements gradually decreases and the production of intermetallic compounds gradually decreases.

4. Welding technology and properties of dissimilar metals of aluminum and copper

Y B Zhang et al. used the high frequency induction brazing machine to weld 2mm-thick T2 copper plate and 3mm-thick 1060 aluminum plate. Three kinds of Zn-Al flux cored wire with diameter of 2mm were used as the solder, respectively Zn-2Al, Zn-2Al-Ag and Zn-13Al-5Ag. The core used CsF-AlF_3 as brazing agent [14]. The microhardness of the three brazing areas is significantly higher than that of Cu and Al parent material, and the microhardness of Cu parent material is greatly improved and the hardness peak appears. The microhardness of Zn-13Al-5Ag brazing joint is the highest. The microhardness of Zn-2Al and Zn-2Al-Ag brazing joints are similar. Before and after corrosion, the shear strength of Zn-13Al-5Ag brazing joint is the largest, while that of Zn-2Al brazing joint is the smallest. The shear strength loss rate of the joints with Zn-2Al, Zn-2Al-Ag and Zn-13Al-5Ag wire brazing is 29%, 25% and 22%, respectively. The corrosion resistance of the three kinds of brazed joints is all higher than that of the Al brazed joint. The corrosion resistance of the three kinds of brazed joints is from high to low in order: Zn-13Al-5Ag brazed joints, Zn-2Al-Ag brazed joints and Zn-2Al brazed joints.

To sum up, the current analysis methods of aluminum alloy and dissimilar metal welding are mainly studied from the aspects of numerical simulation, microstructure analysis, hardness, tensile strength and other mechanical properties. However, the theory is not perfect enough, and it needs to be further studied through the new welding methods, the improvement of welding process and the addition of suitable alloy elements.

5. Conclusions

This paper summarizes the welding of aluminum alloy with steel, magnesium and other metals, and comprehensively analyzes the influence of welding process parameters and composition on the structure and performance of the welded joint, and the following conclusions are drawn:

(1) In the study of dissimilar steel welding of aluminum alloy and steel, there are few studies on high-strength steel. In the future, the study on the welding of ultra-high strength steel and aluminum alloy should be strengthened.

(2) In the welding of aluminum and dissimilar metals, most of the welding is focused on the welding of aluminum alloy with steel, magnesium and other metals, and there is little welding with new aerospace materials such as titanium. In the future, the welding research of aluminum alloy with titanium and other high-end metals should be strengthened.

(3) Most of the welding studies on aluminum alloy and dissimilar metals focus on the welding of 2 series aluminum alloy and 6 series aluminum alloy. It is necessary to strengthen the research of dissimilar welding between different series of aluminum alloy and different metals.

(4) Most of the researches on the welding of aluminum alloy and dissimilar metals focus on the CMT welding, friction stir welding, TIG welding and other welding methods, which need to be further studied by means of new welding methods, new improved welding process and adding appropriate alloying elements.

Acknowledgments

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