# Research status and prospect of dissimilar light alloy welding technology

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**Abstract:** Magnesium alloys, aluminum alloys and titanium alloys are currently widely used light alloy materials with good prospects. The welding of Mg/Al/Ti dissimilar light alloys has a wide range of application requirements in aerospace, automobile manufacturing, electronic information and other fields, and is a hot topic of current research. This article summarizes the welding research results of Mg/Al/Ti dissimilar light alloys in recent years, outlines the current research status of welding technology of Mg/Al/Ti dissimilar light alloys, analyzes the common problems and solutions in welding, and proposes further Carry out the research of Mg/Al/Ti welding technology and basic theory, look forward to the effective ways to improve the welding performance of Mg/Al/Ti dissimilar light alloys and future research directions, and promote the promotion of Mg/Al/Ti dissimilar light alloy joints The practicality of it is of great significance.

**Keywords:** Magnesium alloy; aluminum alloy; titanium alloy; welding technology.

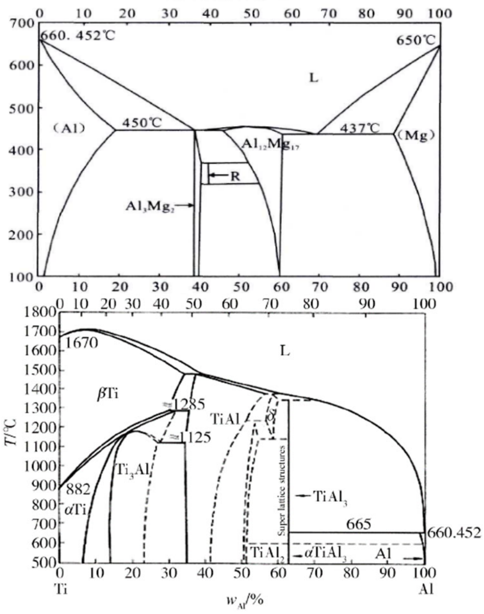
## 1. Introduction

With the rapid development of science and technology, higher requirements are put forward for the lightweight of metal structural materials. While meeting the design cost requirements, the performance advantages of the materials must be fully reflected. The applications of the three light alloys of aluminum, magnesium, and titanium are extensive and cross-cutting, and meet the current requirements for lightweight. Therefore, it is necessary to weld the three to form composite structural parts with complementary advantages. At present, research in this area has received widespread attention. For example, magnesium-aluminum composite structural parts have the characteristics of low density and high specific strength. Under the condition that the strength is ensured, the weight of the structural parts can be effectively reduced and the goal of light weighting can be achieved. Titanium-aluminum composite structural parts can not only take advantage of the high strength of titanium alloy, but also show the light weight characteristics of aluminum alloy. The sandwich structure of the American NASA YF-12 fighter wing is a composite structure. It has two parts, one is the skin, mainly made of titanium alloy, which is used to enhance the strength of the aircraft structure and ensure the limit of vibration resistance, and the other is the sandwich, which is made of aluminum. Alloys are mainly used to reduce the weight of aircraft; the new composite material automobile exhaust system developed by the German Titan company has a weight reduction of 40% compared to the steel exhaust system, and can be used in service at temperatures exceeding 800°C [1] .

With the development of many industrial branches in the direction of lightweight, the effective connection of magnesium/aluminum/titanium dissimilar light alloys by welding has broad application prospects. Dissimilar light alloy welded joints with strong interface bonding can not only give full play to the respective performance advantages of dissimilar light alloys, but also reduce structural weight, save materials, and balance material performance and economic effects.

## 2. Weldability analysis of Mg/Al/Ti

In the welding of dissimilar light alloy materials, melting point, atomic radius, crystal structure, thermal conductivity and linear expansion coefficient are the main influencing factors. According to the physical properties of the three light alloys of magnesium/aluminum/titanium, first, magnesium alloys and aluminum alloys have lower melting points, while titanium alloys have a higher melting point of about 1000°C. Magnesium alloys and aluminum alloys with low melting points, When the temperature exceeds 660°C, it is in a molten state, and the high melting point titanium alloy is still mainly solid, which makes the magnesium alloy and aluminum alloy with low melting point easy to evaporate and lose the alloy elements during welding, which makes it impossible to weld the joint. Second, the thermal conductivity and linear expansion coefficients of the three light alloys are greatly different, which makes the deformation capacity of the light alloys in the heating and cooling processes different. When the molten pool is crystallized, large residual stresses will be generated in the joints after welding. One stress cannot be eliminated by heat treatment. For the metals on both sides of the weld, the stress state is different, which easily leads to cracks in the weld, and even the phenomenon of separation between the weld and the base metal. Third, the three light alloys have huge differences in lattice constants, lattice structures, atomic radii, etc., resulting in metallurgical incompatibility between light alloys, low mutual solubility, and low mutual solubility, which makes it very difficult to form a fusion zone. Fourth, the three light alloys are all typical active metals, which easily react with oxygen to produce oxides such as MgO, Al2O3, and TiO2. In particular, Al2O3 has a very compact structure and a very high melting point, reaching 2050°C. Removal is very difficult. During the welding process, the oxides produced will seriously affect the bonding between the magnesium/aluminum/titanium dissimilar light alloys, and cause defects such as inclusions and cracks in the joint area, resulting in poor joint bonding performance and difficulty in welding. In addition, combined with the Mg-Al binary phase diagram (Figure 1), we can conclude that magnesium and aluminum can easily form a large amount of Mg-Al brittle intermetallic compounds such as Mg2Al3 and Mg17A112 during welding. Under different high temperature conditions, titanium and aluminum react, producing many Ti-Al brittle intermetallic compounds, such as TiAl. The intermetallic compound lowers the bonding strength of the welded joint, causing the joint to be prone to brittle fracture. Therefore, the above analysis shows that the weldability of the magnesium/aluminum/titanium dissimilar light alloy is poor and the welding is very difficult [2].



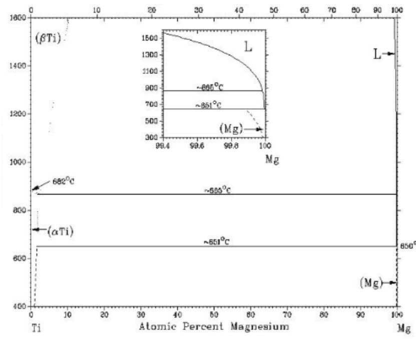




**Fig. 1** Binary phase diagram between Mg、Al and Ti

## 3. Dissimilar light alloy welding technology of Mg and Al

At this stage, for magnesium alloys, the welding methods commonly used for magnesium alloys and aluminum alloys are fusion welding and solid welding. Among them, the most effective welding method is fusion welding, such as tungsten argon arc welding (TIG), electron beam welding (EBW). ) And laser welding (LAW), etc. Ben-Artzy and Munitz et al. [3] investigated the weldability of 6063 aluminum alloy with AM50 and AZ31 through TIG and EBW, and came to the following conclusions, the application of TIG will produce a heat-affected zone around the magnesium alloy, which is around AZ31 magnesium alloy. The width of the heat-affected zone is several millimeters, and the width of the heat-affected zone around AM50 magnesium alloy is hundreds of microns, and there is a eutectic structure at the joint fusion position. The core position of the fusion zone is γ-$Mg_{17}(Al,Zn)_{12}$ The phase is dominant, and a continuous brittle phase is formed near the grain boundary. The application of EBW will not produce a heat-affected zone around the magnesium alloy, but there will be β-$Mg_{17}(Al,Zn)_{12}$ phases in the joint fusion zone. Peng Liu et al. [4] used TIG to weld magnesium (230) and aluminum (1060). They found that there are brittle intermetallic compounds of $Mg_{17}Al_{12}$ and $Mg_2Al_3$ in the fusion zone around the Mg welded joint. For the fusion zone, it has two Part, one is the melting crystallization zone, and the other is the semi-melting crystallization zone. For the melting zone, it has two kinds of structure, one is columnar crystal, and the other is columnar dendritic structure..Rattana Borrisutthekuld et al. [5] used LAW to weld magnesium and aluminum alloys, because many brittle intermetallic compounds, such as $Mg_{17}Al_{12}$, were formed during the welding process. The thickness of the inter-compound layer is reduced to enable them to be effectively overlapped. Takehiko et al.[6] compared and analyzed the tensile properties of magnesium alloy and aluminum alloy spot welded joints, and found that for resistance spot welded joints, its strength is only 1/4 to 1/5 of the strength of the same magnesium alloy. The thickness of the intermetallic compound layer between Mg and Ag decreases with the increase of the thickness of the added Ag metal foil, and the thickness of the eutectic reaction layer between Ag and Al increases with the increase of the thickness of the Ag metal foil, thereby improving the joint strength . Liu Xujing et al. [7] used laser-TIG composite heat source to weld different types of magnesium alloys and aluminum alloys. The study found that laser-TIG composite heat source welding is fast and can effectively stir the molten pool, thereby improving the welding of two light alloys. The microstructure shows that the intermetallic compound of the welded joint is transformed from uninterrupted layered to diffuse.

Solid phase welding uses physical effects such as friction, pressure or thermal diffusion to overcome the roughness of the two connecting surfaces, and remove oxide films or other impurities, so that the atoms on the two connecting surfaces can approach each other to the lattice distance, and then Achieve solid-state connections. At this stage, there are many solid-phase welding methods, such as diffusion welding, friction stir welding (FSW) and explosive welding. Solid phase welding is used to weld Mg/Al dissimilar metals, which overcomes defects such as cracks, deformation, and pores caused by fusion welding, and can obtain joints with excellent performance. Li Yajiang's research group [8-10] deeply analyzed the influence of vacuum diffusion welding process on the microstructure and mechanical properties of magnesium/aluminum light alloy welded joints. Through research, it is concluded that under the best process parameters such as heating temperature and holding time, a dense Mg/Al dissimilar metal diffusion welding joint can be obtained. The interface transition zone formed by the diffusion of Mg/Al atoms is mainly composed of three parts. One is the $Mg_2Al_3$ phase layer, the second is the Mg-Al phase layer, and the third is the $Mg_3Al_2$ phase layer. These new features have an important impact on the performance of the joint. Liu Peng et al. deeply explored the vacuum diffusion welding method of Mg/Al dissimilar light alloy. The study found that through effective control of vacuum diffusion welding process parameters, such as holding time, heating temperature, and welding pressure, a welded joint with good performance can be obtained. The maximum shear strength can reach 18.94MPa. For Mg/Al diffusion welded joint area , It has three phase layers, one is $Mg_2Al_3$ phase, which is the transition zone on the aluminum side, the other is Mg-Al phase, which is the intermediate diffusion zone, and the third is $Mg_3Al_2$ phase, which is the transition zone on the magnesium side. The hardness of the different phase layers is very large. The difference seriously affects the performance of the joint. Zhao Limin et al. used zinc interlayer to connect Mg/Al by diffusion welding at 365°C. Through research, it is concluded that there are mainly three layers in the interface area of magnesium-aluminum welded joints, one is the aluminum-zinc reaction layer, the other is the insufficient diffusion layer, and the third is the zinc-magnesium reaction diffusion layer. The addition of zinc interlayer effectively prevents the diffusion between magnesium and aluminum. The shear strength of zinc interlayer magnesium-aluminum diffusion welded joints far exceeds the shear strength of magnesium-aluminum direct vacuum diffusion welded joints. Fracture analysis shows that the fracture occurs in the zinc-magnesium reactive diffusion layer.

In addition, in recent years, many new welding methods have been produced, such as electromagnetic pulse welding, high-energy pulse laser welding, multi-beam laser welding, etc., which have effectively avoided various defects caused by welding of magnesium and aluminum dissimilar light alloys. Good seam mechanical properties. However, no matter what kind of welding method, it will be restricted under the established welding situation. How to effectively play the role of different welding methods is one of the topics that scientific researchers must pay attention to in the future.

## 4. Dissimilar light alloy welding technology of Mg and Ti

The connection of magnesium alloy and titanium alloy is restricted by the huge difference in properties between the two, and it is difficult to effectively connect the Mg/Ti alloy through the previous fusion welding process. At this stage, most of the welding research related to Mg/Ti alloys focuses on the following three aspects. First, special welding methods are used, such as transient liquid phase diffusion welding (TLP), laser welding, explosive welding, ultrasonic spot welding (USW), etc. Even for arc welding, optimization methods such as cold metal transition technology (CMT) or ultrasonic assistance are used; second, other alloy elements are added to effectively adjust the metallurgical reaction during the welding process; third, special welding methods are combined with other elements The organic connection can effectively solve the welding problem of Mg/Ti alloy. Xiong Jiangtao et al. used aluminum foil as an intermediate layer to carry out transient liquid phase diffusion welding of Mg/Ti alloy, and thoroughly explored its connection principle. GAO et al. used laser welding technology to realize Mg/Ti alloy butt welding and revealed its connection principle. Relevant personnel from Kumamoto University in Japan and Komazawa University in Japan used magnesium alloy sheet as the intermediate layer, and used explosive welding technology to connect TP270 titanium alloy plate and AZ31 magnesium alloy plate underwater. When the explosive device tilt angle α is 30° When the distance D between the explosive and the sample is between 5-35mm, a magnesium-titanium alloy joint with excellent performance can be obtained. Daxin Ren et al. of Dalian University of Technology realized the ultrasonic spot welding (USW) connection of Mg/Ti dissimilar alloys. Within a certain process range, with the increase of ultrasonic energy, the overall strength of the joint showed an upward trend. Lan Shaojuan et al. used heterogeneous ultrasonic welding to conduct a large number of experiments on magnesium and titanium alloys to study the influence of welding parameters on welding results, analyze the formation principle of solder joints, and optimize the ultrasonic welding process for future research on ultrasonic welding technology. Provided for reference. Japanese scholar Watanabe T et al. took magnesium and titanium alloy sheets as examples, carried out friction stir welding on them, and carried out in-depth research on the microstructure of the interface diffusion zone and the mechanical properties of the joints, and realized the comparison between ZK60 magnesium alloy and titanium alloy sheets. Metallurgical connection between. Masayuki Aonuma et al. performed FSW welding on three magnesium alloys with different Al content and Ti, respectively, and analyzed the influence of Al element on the interface structure of welded joints. The results showed that the thickness of the Ti-Al compound layer at the interface varies with the content of the magnesium base material. The amount of A1 increases, and the tensile strength of the joint decreases with the increase of the amount of A1 in the magnesium base metal. R. Cao et al. used CMT technology to realize the welding and brazing connection of titanium and magnesium alloys. Through research, it is concluded that with the cooperation of AZ61 magnesium alloy welding wire, the connection mode between magnesium and titanium is higher, and the strength of the joint is higher. Although the research on the welding technology of Mg/Ti dissimilar light alloys has made some progress, it is still in the initial stage. The influence of welding parameters and material properties on the welding effect, and the formation mechanism of the welding joints need to be further studied. Especially in view of the special property differences between Mg/Ti alloys, a reliable connection of Mg/Ti can be achieved only by applying various special welding methods with other elements to adjust the interface reaction.

## 5. Dissimilar light alloy welding technology of Al and Ti

At this stage, there are many welding methods for Ti/Al alloys, such as argon tungsten arc welding, laser welding, friction stir welding, diffusion welding, and fusion brazing. Ma Zhipeng et al. used tungsten argon arc welding to connect TC4 titanium alloy and aluminum alloy. Through research, it was found that when the welding current is 110-120A, the tensile strength of the joint reaches the maximum value of 158MPa, and the weld structure is mainly composed of A1-Si eutectic phase and $TiAl_3$ intermetallic compound composition. When the welding current exceeds 140A, the thickness of the intermetallic compound at the joint weld increases to 300μm, resulting in a continuous decrease in the tensile strength of the joint. Foreign scholars Vaidya et al. studied the 4KW split beam YAG laser welding $Ti_6Al_4V$ titanium alloy and 6056 aluminum alloy. The laser beam irradiates the aluminum alloy to melt and wrap it on the titanium alloy to directly form a welded joint. Only $TiAl_3$ is formed at the interface of the welded joint. Phase, the maximum tensile strength can reach 255MPa, and the joints are all broken in the base material. Chen Yuhua et al. used friction stir welding to butt TC1 titanium alloy and LF6 aluminum alloy. Through research, it is concluded that the interface between the titanium alloy base material and the weld nugget is not flat, and there are white granular intermetallic compounds at the boundary position, while the interface between the aluminum alloy base material and the weld nugget is relatively flat. There are two types of Ti in the aluminum base metal in the weld nugget area. -Al intermetallic compound. Yao Wei et al. used diffusion welding to join 5A06/TA2 dissimilar light alloys. Research has shown that when the welding temperature is higher than 525°C, the $Al_{18}Ti_2Mg_3$ type mesophase appears in the joint. The strength of the welded joint is closely related to the new phase area and is related to solid solution metallurgy. The bonding zone is closely connected. With the growth of the new phase zone of the diffusion reaction, the bonding strength continues to decrease, and with the increase of the solid solution metallurgical bonding zone, the bonding strength continues to increase.

The physical and chemical properties of titanium/aluminum dissimilar alloys are quite different, and it is difficult to obtain welded joints with excellent properties. Although the current welding technology can solve welding defects such as missing alloy elements, high temperature oxidation, pores and cracks, it cannot solve the generation of brittle intermetallic compounds. The type, quantity and distribution of intermetallic compounds will have a direct impact on the performance of the joint. Therefore, controlling the production of brittle intermetallic compounds during welding is still an important issue in the welding of titanium/aluminum dissimilar alloys.

## 6. Conclusion

At present, many scholars have conducted a lot of research on the welding methods of Mg/Al/Ti dissimilar light alloys. Among them, welding technologies such as fusion welding, brazing, diffusion welding, explosive welding, friction stir welding, electromagnetic pulse welding, etc. but there are still certain problems and limitations. Among them, brazing requires a vacuum working environment, which will be restricted by the size and shape of the workpiece. Brazing technology, brazing material design, etc. have not formed a mature theoretical system. The strength of brazing joints still needs to be improved; diffusion welding requires high parts assembly, expensive equipment, and long heat preservation time, which is difficult to meet industrial production requirements. Need; Fusion welding is prone to produce intermetallic chemicals, which can easily deteriorate the performance of the joint; the explosive speed in explosive welding is not stable, and the quality of the obtained weld is not good; friction stir welding has high requirements for the joint form and is only suitable for plate welding; Electromagnetic pulse welding is still in the initial stage of research and development, and the low power of the welding machine limits its application areas.

Although the welding technology of dissimilar light alloys has achieved phased results, the current research results can only reduce the impact of intermetallic compounds on joint performance, and affect the formation of different intermetallic compounds at the welding interface. The mechanism, distribution law and its correlation with joint performance still need to be further studied; on the other hand, there are still many limitations in welding technology that need to resolve. Therefore, the welding technology of dissimilar light alloys will still be the focus of future research.

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