

Research Progress of Fusion Welding Techniques for Steel to Other Metals

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Abstract: Welding of dissimilar steel and TiNi shape memory alloys, aluminum alloy, magnesium alloy and other metals is an important issue because of its increasing applications in industries. This review aimed to provide a comprehensive overview of the recent progress in welding and joining of steel and heterogeneous metals and to introduce current research and application. However, the base materials on both sides of the traditional fusion welding must melt and the large melting point difference between the two seriously affects the weld formation. The metal compounds formed by the base materials on both sides also hinder the improvement of the mechanical properties of the joint. The methods available for welding steel and dissimilar metals included fusion welding, brazing, diffusion bonding, friction welding and reactive joining. The current state of the understanding and development of fusion welding method for steel and other metals was addressed. This review focused on the fundamental understanding of the microstructural characteristics, processing and property relationships in the welding and joining of heterogeneous joints.

Keywords: Welding, Aluminum Alloys, Steel, Magnesium Alloys, Microstructure, Mechanical Properties

1. Introduction

In recent years, because of the increasing calls for environmental protection and saving energy, steel structures are gradually replaced by structures of dissimilar joints; given the considerable role of dissimilar joints in the reduction of raw material cost and improvement of design conditions, the demand for these joints has also increased [1, 2].

Amongst these joints, TiNi shape memory alloys (SMAs) are a kind of function materials which exhibit a reversible martensitic phase that possesses a special shape memory effect, super-elasticity, excellent erosion resistance and good biocompatibility [3, 4]. It is used in medical equipment, aerospace and automotive industries and other fields [5, 6]. Welding TiNi SMA to SS to make orthodontic arch wires that meet the rigidity and elasticity requirements has broad development prospects [5]. As an extremely light metal, Mg and its alloys have excellent specific strength, excellent sound damping capabilities, good castability, hot formability and

good electromagnetic interference shielding; thus, they have attracted increasing attention [7, 8]. Al and its alloys are widely used in the industry because of their low density, high specific strength, good corrosion resistance and high thermal and electrical conductivities. The welding of steel and Al to reduce the structural weight has become a concerning issue in the automotive industry [9]. In addition, Cu [10], Al, V, cemented carbide and other metals have important applications in specific fields, the use of Ti/Cu compound structure for aircraft engines and Al/Ti compound structure as wing skin in aerospace industry.

2. Research Status

Fusion welding is more flexible than other methods and it has many applications in automobile manufacturing, shipbuilding and other fields. However, the difference in the physical properties between steel and other metals affects the formation of joints. IMCs are formed easily in the weld seam due to the melting of base metals. The heat input must be

precisely controlled during the welding process to improve the formation of joints. Using an intermediate layer could also improve the formation of joints [11]. Arc welding is simple and easy to operate, it can be applicable to any joint configuration in thicknesses up to 6-8 mm, but some porosity can be observed since the insufficient of the molten pool [12, 13]. High power beam welding mainly include laser welding and electron beam welding, it's high efficiency welding has been widely studied and applied in automation industry, however the high energy input result in keyhole and keyhole induced pores [14, 15].

Shamsolhodaei et al. [16] researched the laser welding of $50 \times 50 \mu\text{m}$ TiNi SMA wire and SS AISI316. As shown in Figure 3, the distribution of the microstructure of the joint was uneven. IMCs, such as Fe_2Ti , Cr_2Ti , Fe_3Ti and Ni_3Ti , were formed in the weld zone. These IMCs reduced the mechanical properties of the joint and the tensile strength of the joint was lower than 200 MPa. Li [17] performed laser welding on $0.64 \times 0.48 \text{ mm}$ TiNi SMA wire and AISI304 SS. The distribution of the microstructure of the joint was also uneven and the weld was mainly composed of B2, B19', $\alpha\text{-Fe}$, $\gamma\text{-Fe}$, TiFe_2 , TiFe , TiCr_2 , TiNi_3 , Ti_2Ni and other phases. The average tensile strength of the joint was only 187 MPa. The joint fracture, which was brittle, was located in the fusion zone on the TiNi SMA side.

Chen et al. [18] joined $60 \text{ mm} \times 40 \text{ mm} \times 0.2 \text{ mm}$ TiNi SMA and $1\text{Cr}_{18}\text{Ni}_9\text{Ti}$ SS in a butt-joint configuration. During the welding process, a large amount of Ti and Fe mixed and reacted in the molten pool. Under the action of residual stress, two kinds of longitudinal and transverse cracks appeared in the joint. Qiu et al. [19] used micro-beam plasma arc to weld $0.40 \text{ mm} \times 0.55 \text{ mm} \times 50 \text{ mm}$ TiNi SMA and $1\text{Cr}_{18}\text{Ni}_9\text{Ti}$ SS. The research results showed that occurred micro-crack in joint; the HAZ on the TiNi SMA side widened and the elements such, as Ti and Fe, in the WZ formed a coarse columnar crystal structure. In addition, the intrusion of oxygen affected the mechanical properties of the joint; the tensile strength was only 127–159 MPa and the fracture was located in the centre of the weld. Therefore, the weld formation and structure distribution of plasma arc were worse than those in laser welding. The above papers indicated that the two heat sources formed a large amount of IMCs, such as TiFe_2 and TiNi_3 , resulting in brittle welds and reduced mechanical properties of the joints.

Chen [20] used laser welding to connect dual-phase steel DP980 and A6061 Al alloy (steel plate on top) in a lap joint configuration. As shown in Figure 4, the weld deposited a large amount of δ ferrite that resulted in uneven longitudinal

hardness distribution and formed a $25 \mu\text{m}$ -compound layer of Fe_2Al_5 and FeAl_3 in the weld zone during the welding process. The tensile strength of the joint was only 42 MPa. Some special welding methods, such as laser heat source offset or laser spot welding, were used to improve the joint formation. Most of the welding methods with heat source offset were adopted for TiNi/SS joints. Controlling the melting amount of the base metals on both sides could reduce the Ti-Fe and Ti-Ni IMCs in the joint. Shamsolhodaei et al. [16] conducted laser welding on TiNi SMA and AISI316 SS wire; the dimension of the wire was $400 \mu\text{m}$. They shifted the laser focus by $100 \mu\text{m}$ to the SS side. As shown in Figure 5, the weld was well formed and cracks did not occur. The content of IMCs, such as TiFe_2 , Ti_2Ni , TiNi_3 and TiCr_2 , were reduced and the tensile strength of the joint increased to approximately 380 MPa. Hongmei Li et al. [10] studied the laser welding of $0.64 \text{ mm} \times 0.48 \text{ mm}$ TiNi SMA and SS wire, with a laser focus of 0.2 mm to the SS side. After laser offset, the content of Ti and Ni in the weld was reduced, whereas that of Fe and Cr elements increased, thereby reducing the brittleness of the weld to a certain extent and improving the mechanical properties of the joint. The tensile strength could reach up to 213 MPa.

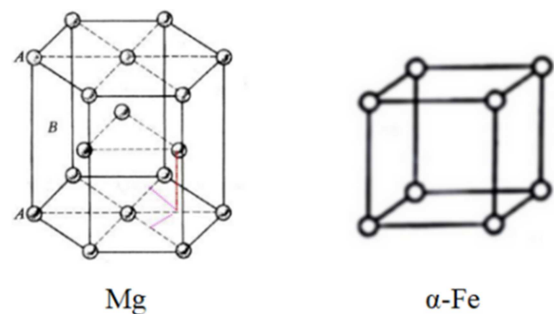


Figure 1. The crystal structure of Mg and $\alpha\text{-Fe}$.

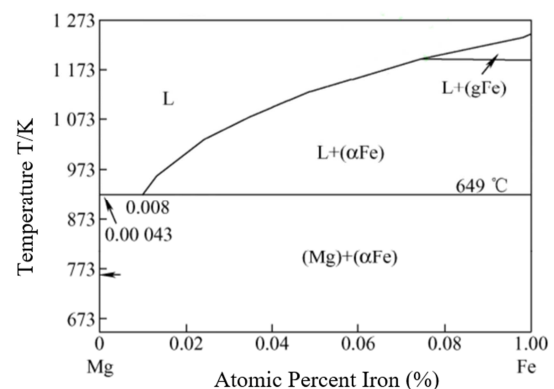


Figure 2. Mg-Fe binary phase diagram.



Figure 3. Microstructure of the weld zone when the laser is focused on the center line (left).

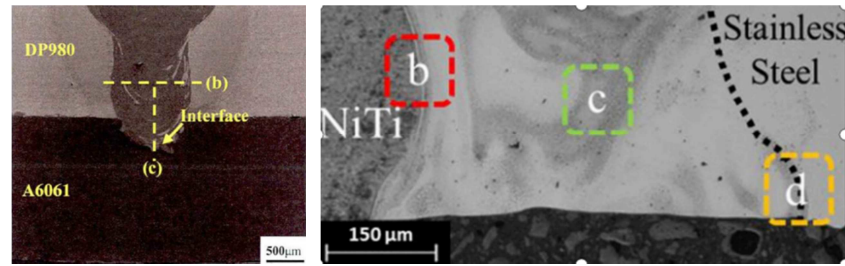


Figure 4. Macro morphology of Fe-Al welded joint, Microstructure of the cross section of the joint with the laser deflected to the SS side 100 μm .

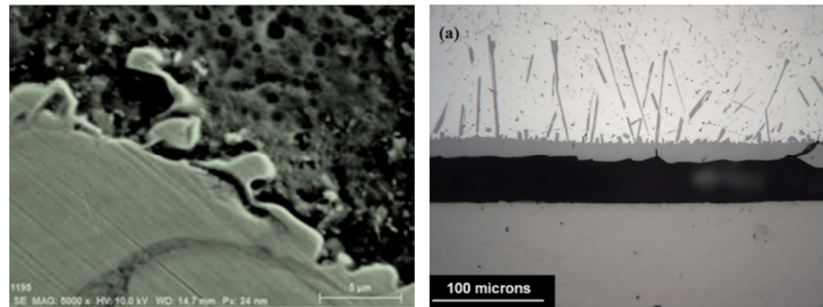


Figure 5. Optical micrograph of steel/aluminum T-joint, Micro-electron microscope of the fusion area of steel/aluminum solder joints.

3. Conclusions

Comparison of the different welding methods showed that fusion welding joints had relatively high strength and flexible welding size. By heat source and using intermediate layer, the content of Ti-Fe IMCs in the weld could be reduced. However, Ti-Fe and other IMCs could not be completely avoided. Thus, how to effectively avoid the formation of Ti-Fe IMCs remains the focus of research, including controlling heat input more precisely or finding more suitable intermediate layers to improve the mechanical properties of the TiNi/SS joints. They could provide a theoretical basis for improving the welding of dissimilar materials. The high hardness and low toughness of Fe-Al IMC the main problem on welding Fe/Al.

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