Available online at www.sciencedirect.com
ScienceDirect
Trans. Nonferrous Met. Soc. China 24(2014) 108−114
Transactions of Nonferrous Metals Society of China
www.tnmsc.cn

Influences of different filler metals on electron beam welding of titanium alloy to stainless steel

Ting WANG[1,2], Bing-gang ZHANG[1], Ji-cai FENG[1,2]

1. Shandong Provincial Key Laboratory of Special Welding Technology, Harbin Institute of Technology at Weihai, Weihai 264209, China;
2. State Key Laboratory of Advanced Welding and Joining, Harbin Institute of Technology, Harbin 150001, China

Received 3 December 2012; accepted 13 April 2013

Abstract: Electron beam welding experiments of titanium alloy to stainless steel were carried out with different filler metals, such as Ni, V, and Cu. Microstructures of the joints were examined by optical microscopy, scanning electron microscopy and X-ray diffraction analysis. Mechanical properties of the joints were evaluated according to tensile strength and microhardness. As a result, influences of filler metals on microstructures and mechanical properties of electron beam welded titanium-stainless steel joints were discussed. The results showed that all the filler metals were helpful to restrain the Ti−Fe intermetallics. The welds with different filler metals were all characterized by solid solution and interfacial intermetallics. For each type of the filler metal, the type of solid solution and interfacial intermetallics depended on the metallurgical reactions between the filler metals and base metals. The interfacial intermetallics were Fe_2Ti+Ni_3Ti+$NiTi_2$, TiFe, and Cu_2Ti+CuTi+$CuTi_2$ in the joints welded with Ni, V, and Cu filler metals, respectively. The tensile strengths of the joints were dependent on the hardness of the interfacial intermetallics. The joint welded with Ag filler metal had the highest tensile strength, which is about 310 MPa.

Key words: titanium alloy; stainless steel; filler metal; electron beam welding; mechanical property

1 Introduction

Titanium alloys are preferred structural materials in the aeronautics and astronautics industries because of their high specific strength [1], but they are expensive. Stainless steel is a widely used, inexpensive material in most industrial fields [2]. Therefore, there are urgent needs to join titanium and stainless steel so that these alloys can be applied to reduce the mass and cost of various products.

It has been acknowledged that traditional fusion welding methods are not feasible for joining titanium alloys to stainless steels because of metallurgical incompatibilities. Therefore, solid-state joining method is a viable solution to overcome this difficulty by prevention of diffusion of alloying elements [3]. However, direct solid-state joining is also very difficult. This is attributed to the low solubility of iron in alpha titanium at room temperature. KUNDU et al [4] suggested that the brittleness of Fe−Ti and Fe−Cr−Ti intermetallics compromised the mechanical properties of diffusion bonds between titanium alloys and stainless steels. DEY et al [5] and MOUSAVI and SARTANGI [6] proved that Ti−Fe intermetallics formed in the interfaces during friction welding and explosion welding of titanium alloys to stainless steels. Fracture occurred at the intermetallic-based interface and the strength decreased with thickening of the intermetallic layer. Currently, indirect joining is generally realized by adding an intermediate metal layer such as Ni, Cu, or Al to prevent atomic diffusion between Ti and Fe, Cr, or Ni [7−9]. Among the interlayer metals mentioned above, copper is most frequently used. Copper does not produce brittle intermetallics with iron, chromium, nickel, or carbon. Moreover, it is a soft metal which can deform and relax the stress caused by the linear expansion mismatch.

In the above references, copper as well as other metals was used as interlayer during diffusion bonding, however, the process was time consumable to implement. Particularly, the components with complex geometric shapes could not be joined by diffusion bonding as well as other solid state bonding methods due to the limitation

Foundation item: Project (2011DFR50760) supported by International Science & Technology Cooperation Program of China
Corresponding author: Bing-gang ZHANG; Tel: +86-451-86412911; E-mail: zhangbg@hit.edu.cn
DOI: 10.1016/S1003-6326(14)63034-X

of the joint shape. Consequently, a feasible fusion welding method to join these two dissimilar metals is necessary for further development. As a non-contact fusion joining technique with high efficiency and flexibility, laser welding of titanium and steel with Mg was considered, but $Mg_{17}Al_{12}$ would be formed, which lowers the strength of the joint [10]. Electron beam welding is considered to be the most frequently used fusion welding technique for joining dissimilar metals because of certain advantages such as high energy density, vacuum atmosphere and precise control of heating position and area [11]. Moreover, a very narrow heat affected zone can be produced. ZHANG et al [12] joined Ti_3Al and TC4 titanium alloys with electron beam welding. The highest tensile strength of the joints reached 92% of that of the base metal. KIM and KAWAMURA [13] investigated the electron beam welding of Zr-based BMG to Ni metal. The flexural strength of the welded joint was higher than the yield strength of the Ni metal. Therefore, it is reasonable to consider electron beam welding as a preferred candidate process for the fusion welding of titanium alloys to stainless steels.

As with diffusion bonding, filler metal is also required for electron beam welding. In this work, near α-type TA15 titanium alloy and 304 stainless steel were electron beam welded with different filler metals, such as Ni, V, and Cu. The metallurgical processes of the Ti/Fe welds with different filler metals were discussed by microstructural analysis. The feasibilities of the filler metals for joining titanium alloy to stainless steel were compared by mechanical property testing. Finally, a selecting law of the filler metal for electron beam welding of titanium alloy to stainless steel was concluded.

2 Experimental

2.1 Materials and preparation

The materials used in these experiments were the near α-type TA15 titanium alloy and 304 austenitic stainless steel. The chemical compositions of TA15 and 304 SS are shown in Tables 1 and 2. The physical properties of these alloys are listed in Table 3.

Table 1 Chemical compositions of TA15 titanium alloy (mass fraction, %)

Al	Mo	Zr	V	Ti
5.5−7.0	0.5−2.0	1.5−2.5	0.8−2.5	Bal.

Table 2 Chemical compositions of 304 stainless steel (mass fraction, %)

C	Ni	Cr	Mn	Si	Fe
≤0.07	8−11	17−19	≤2.0	≤1.0	Bal.

Table 3 Physical properties of base metals at room temperature

Alloy	Melting point/ °C	Specific heat capacity/ ($J \cdot kg^{-1} \cdot K^{-1}$)	Thermal conductivity/ ($W \cdot m^{-1} \cdot K^{-1}$)	Linear expansion coefficient/ ($10^{-6}K^{-1}$)
TA15	1677	495	7.4	8.6
304	1450	461	14.6	16.0

In Table 3, large differences in thermal conductivity and linear expansion coefficient between the two base metals can be found. These will lead to large temperature gradients and thermal stresses in the joint during the welding process [14]. The metals were machined into 50 mm × 25 mm × 2.5 mm plates and then mechanically and chemically cleaned before welding. 0.5 mm thick commercially pure vanadium, nickel, and copper sheets were used as filler metals and embedded in the contact faces before welding as BARREDA et al [15] did in their research.

2.2 Welding process

Electron beam welding was used to join titanium alloy to stainless steel. Electron beams were focused on the centerlines of the filler metal sheets with the following parameters: accelerating voltage of 55 kV, focus current of 2450 mA, welding speed of 6 mm/s and beam current of 9−12 mA. A schematic diagram of the welding procedure is shown in Fig. 1.

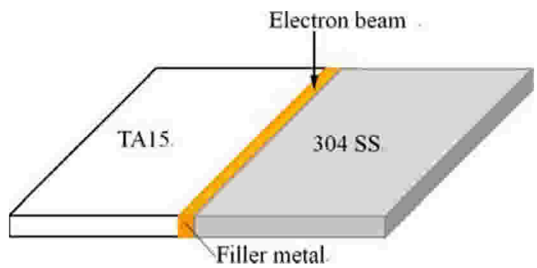

Fig. 1 Schematic diagram of welding procedure

2.3 Test work

Specimens for microstructure characterization and hardness examination were prepared metallographically and then etched in a solution of 20 mL HNO_3, 20 mL HF and 80 mL H_2O. Microstructure observations on cross-sections of the joints were carried out by optical microscopy and scanning electron microscopy. The elemental composition was evaluated by SEM−EDS in spot and line scan modes. X-ray diffraction analysis was carried out to identify the intermetallics. The operating voltage was 50 kV and the current was 25 mA using a Cu target. The scanning range was 20°−100° at a speed of 3 (°)/min. Vickers microhardness was measured using a load of 100 g. Tensile testing at room temperature was performed to evaluate the joint strength. The specimens were prepared in rectangular bars (50 mm × 5 mm × 2.5 mm). The displacement speed was 0.5 mm/min.