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Interfacial structure and mechanical properties of hot-roll bonded joints between titanium alloy and stainless steel using niobium interlayer

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Abstract: The hot-roll bonding was carried out in vacuum between titanium alloy and stainless steel using niobium interlayer. The interfacial structure and mechanical properties were analyzed. The results show that the plasticity of bonded joint is improved significantly. When the bonding temperature is 800 °C or 900 °C, there is not intermetallic layer at the interface between stainless steel and niobium. When the bonding temperature is 1000 °C or 1050 °C, Fe−Nb intermetallic layer forms at the interface. When the bonding temperature is 1050 °C, cracking occurs between stainless steel and intermetallic layer. The maximum strength of ~417.5 MPa is obtained at the bonding temperature of 900 °C, the reduction of 25% and the rolling speed of 38 mm/s, and the tensile specimen fractures in the niobium interlayer with plastic fracture characteristics. When the hot-roll bonded transition joints were TIG welded with titanium alloy and stainless steel respectively, the tensile strength of the transition joints after TIG welding is ~410.3 MPa, and the specimen fractures in the niobium interlayer.

Key words: hot roll bonding; titanium alloy; stainless steel; niobium

1 Introduction

Bonding joint between titanium alloy and stainless steel can be used in nuclear, chemical and aerospace industries [1,2], and the connection method contains brazing [3], diffusion bonding [4,5], explosive welding [6] and hot roll bonding [7,8] but with the problem of intermetallic compounds. The solubility between Ti, Fe and Cr is limited, and Ti is a strong carbide forming element. Therefore, the hard and brittle intermetallic compounds are easily formed at high temperatures [9]. It is the main reason to reduce the bonding strength of titanium alloy and stainless steel and even leads to cracking. To solve this problem we must improve the plasticity of bonded joint on one hand using solid state connection method to reduce the volume fraction of the intermetallic compounds, and on the other hand selecting a suitable interlayer for the titanium alloy and stainless steel to form a solid solution or low brittle intermetallic compounds, thus reducing the brittleness of bonded joint.

The vacuum hot-roll bonding is a solid state connection method by plastic deformation of the materials to achieve close contact and bonding in vacuum; the bonding temperature is low, and the bonding time is very short [10−13]. Because of the short bonding time, it is possible to reduce the volume fraction of the intermetallic compounds at bonding interface effectively. The experiment shows that using copper or nickel as the interlayer makes the strength of the hot-roll bonded joint between titanium alloy and stainless steel higher [7,8], and the volume fraction of the intermetallic compounds decrease obviously compared with diffusion bonding.

Copper, nickel, aluminum [14], silver [15], etc. can be used as the interlayer. Compared with the interlayer material, niobium has good plasticity and high-temperature resistance. Niobium does not form any intermetallic compound with Ti, and its corrosion resistance is better than titanium alloy and stainless steel, so niobium can be used as the interlayer [16].

The transition joint between titanium alloy and

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stainless steel is one of the main applications. So, it is necessary to study the changes in the microstructure and properties of the bonded interface after welding transition joints with titanium alloy and stainless steel respectively, so that to select a suitable welding method and process parameters to weld transition joints with titanium alloy and stainless steel. However, the research on this area is less currently.

The experiment of hot roll boning between titanium alloy and stainless steel using niobium interlayer was carried out. The effect of bonding temperature on the microstructure and the mechanical properties of bonded joints was examined. The TIG welding experiment between hot-rolled transition joints with titanium alloy and stainless steel was completed, tested and the microstructure and properties of hot roll bonded transition join after TIG welding were analyzed.

2 Experimental

The dimensions of Ti−6Al−4V alloy and 0Cr18Ni10Ti stainless steel were 100 mm × 70 mm × 19 mm and 120 mm × 70 mm × 19 mm, respectively. The dimensions of pure niobium foil used as interlayer were 110 mm × 80 mm × 0.5 mm. The chemical composition and tensile properties of Ti−6Al−4V and 0Cr18Ni10Ti used are given in Tables 1 and 2, respectively.

Table 1 Chemical composition and properties of stainless steel (0Cr18Ni10Ti)

w/%				Tensile strength/ MPa	Elongation/ %
C	Ni	Cr	Fe		
0.02	10.00	18.0	Bal.	539	40

Table 2 Chemical composition and properties of titanium alloy (Ti−6Al−4V)

w/%						Tensile strength/ MPa	Elongation/ %
Fe	Si	C	Al	V	Ti		
0.3	0.15	0.1	5.5	4.5	Bal.	895	10

Ti−6Al−4V alloy was etched with an aqueous solution containing HF and H_2O (volume ratio 1:5) for 2 min before bonding. A mixture of HF, HNO_3 and H_2O (volume ratio 1:1:8) solution was used as etchant for 0Cr18Ni10Ti stainless steel for 2−3 min after being heated to 40−50 °C. Niobium foil was etched with an aqueous solution containing HF and HNO_3 (volume ratio 1:3) for 1 min. The front of two metal plates was fixed with two rivets of *d*12.9 mm×45 mm by CSS-WEW1000 hydraulic universal testing machine.

The assembled samples were put in a vacuum furnace with a pressure $(1-3)\times10^{-3}$ Pa, heated up to temperature 800−1050 °C with a heating rate of 400 °C/h, and then heated preservation for 45 min. And then the samples were pushed into rollers by a machine hand. The reduction was 25%. The rolling speed was 38 mm/s. The samples were put in a vacuum chamber and cooled down after rolling.

The tensile strength of joints was measured using an electronic testing machine (Instron−5569). Figure 1 shows that the sheet tensile specimens were machined in the vertical rolling direction with cross-sectional area of 10 mm×3 mm and length of ~30 mm. The Nb interlayer was at the centre of the gauge length. Tensile strength of the rolling joints was evaluated using a tensile testing machine set at a crosshead speed of 1 mm/min at room temperature. Three samples were tested at each process parameter to check the reproductive results.

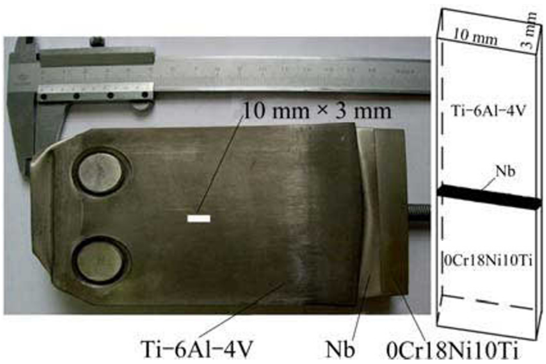

Fig. 1 Cutting location of tensile specimen

The microstructure at interface was observed by a scanning electron microscope (HITACHIS−4700). The chemical composition of the intermetallic layers was detected by energy spectrum (EDAX), and the presence of the intermetallic phases in the reaction zone was confirmed by X-ray diffraction study (D/max-rB) on the fracture surfaces of the couples using Cu target.

Figure 2 shows the schematic diagram of TIG weld of hot-roll bonded joint to titanium alloy and stainless steel. The dimensions of the hot-roll bonded transition joint (the bonding temperature of 800 °C, the reduction

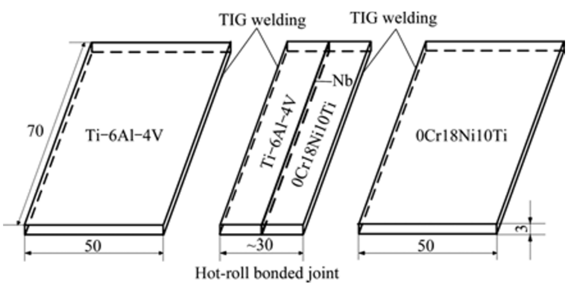

Fig. 2 Schematic diagram of TIG welding of hot-roll bonded joint to titanium alloy and stainless steel (unit: mm)