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Short communication

Vacuum brazing niobium using the clad 50Ti-35Ni-15Nb foil

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ABSTRACT

Ti-35Ni-15Nb brazed Nb joint has been evaluated. The joint consists of Ti_2Ni, TiNi intermetallic compounds and globular (β-Ti, Nb) particles. The existence of brittle Ti_2Ni deteriorates bonding strength of the Nb/Ti-35Ni-15Nb/Nb joint. However, the amount of Ti_2Ni is decreased with increasing the brazing temperature due to the Ti alloyed in globular (β-Ti, Nb) particles at higher brazing temperature. The clad Ti-35Ni-15Nb foil shows potential in brazing Nb for industrial application.

1. Introduction

Niobium (Nb) belongs to the category of refractory metals with the melting point above 2450 °C [1]. It has been widely applied in aircraft, aerospace and defense industries due to its high creep strength and good corrosion resistance [2–6]. Joining technology is important in application of Nb and its alloys, because the joint should satisfy specific requirements such as creep strength, corrosion resistance and toughness etc. [7]. Joining of Nb can be properly performed by laser or electron beam welding [3,8–9]. However, brazing must be considered if the welding is not appropriate such as manufacturing of the plate heat exchanger [10–11]. Brazing has the advantage over welding because of less effect on base-metal properties [3,10]. For example, the recrystallization temperature of Nb is around 985–1150 °C. If the maximum joint strength is preferred, Nb is brazed at temperatures below the recrystallization temperature. However, brazing at higher temperatures may be required due to high service requirement [12].

Selection of the proper filler metal is important in brazing Nb and its alloys. Most Ag/Cu-based filler metals are not appropriate because of their poor creep strength and corrosion resistance [3,12]. In contrast, some high-temperature brazing fillers, e.g., Ti-Cr-V and Mo-Ru, may deteriorate Nb substrate properties because of coarsening of Nb grains in brazing [12]. The clad Ti-Ni-Nb filler foil has the liquidus temperature below 1050 °C, and it has been successfully applied in brazing Mo in literature [13]. The Nb is completely soluble with β-Ti, and the Ni is served as a melting point depressant of Ti in the braze alloy [10,12,14]. Accordingly, the Ti-Ni-Nb filler shows great potential in brazing Nb. The feasibility of brazing Nb using Ti-35Ni-15Nb has been evaluated in the experiment. Microstructural evolution, phase identification and shear strength of brazed joints are assessed in the test.

2. Experimental procedure

In this experiment, sintered Nb rod with the diameter of 25 mm was machined into templates with the size of 15 mm × 7 mm × 3 mm. The brazing filler was clad Ti-35Ni-15Nb (wt%) foil with the thickness of approximately 50 μm. Nb templates were first ground by sandpaper up to 800 grids, and subsequently placed into an alcohol solution for ultrasonic cleaning in order to remove superficial oxide and grease on both mating surfaces. The clad filler foil was cut into the size of 15 mm × 3.5 mm. In vacuum brazing experiment, three Nb templates and two Ti-35Ni-15Nb filler foils were fastened by a graphite fixture into a double-lapped sandwich specimen for shear test [15,16]. The above assembled specimens were placed into a vacuum furnace with a vacuum of 5×10^{-3} Pa. The heating rate was set at 0.33 °C/s throughout the brazing process. All brazed specimens were preheated at 900 °C for 1800 s in order to reach thermal equilibrium of the brazed specimen. The solidus/liquidus temperatures of 50Ti-15Nb-35Ni are 934/1020 °C, respectively [17]. According to the previous studies, the suggested brazing temperatures of Ti-Ni-Nb filler metal were in between 1020 and 1250 °C [13,17]. Therefore, vacuum brazing was performed at 1000, 1050, 1100 and 1150 °C for 180 s. A thermocouple was

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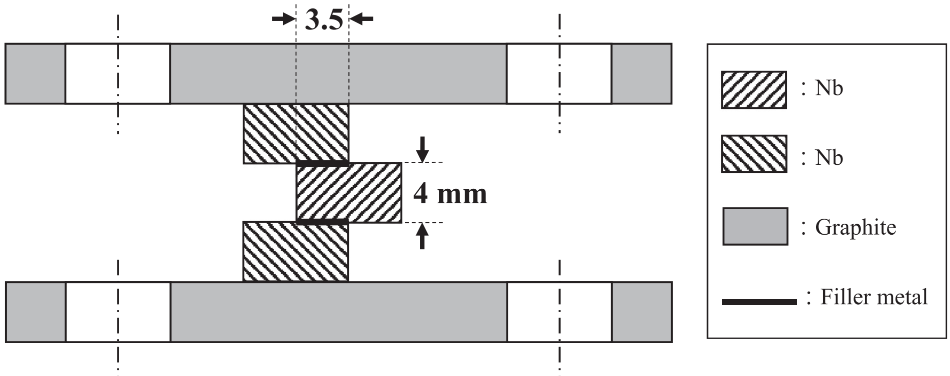
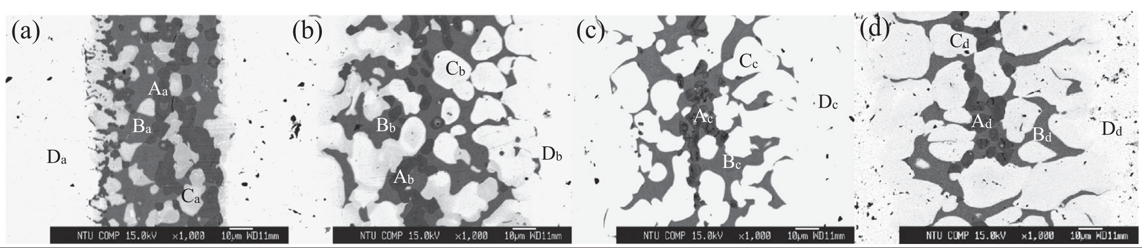


Fig. 1. Schematic diagram of the shear test specimen [15,16].



at %	A_a	A_b	A_c	A_d	B_a	B_b	B_c	B_d	C_a	C_b	C_c	C_d	D_a	D_b	D_c	D_d
Nb	2.6	4.3	2.6	3.1	1.2	1.4	0.7	1.8	63.7	63.3	51.2	76.8	100	99.9	98.8	99.1
Ti	64.8	63.8	65.4	64.8	50.6	50.9	51.2	49.8	35.1	34.9	46.2	21.6	0	0	0.8	0.7
Ni	32.5	31.9	32.1	32.2	48.2	47.7	48.1	48.4	1.2	1.9	2.6	1.6	0	0.1	0.3	0.2
Phase	Ti_2Ni				TiNi				(β-Ti, Nb)				Nb			

Fig. 2. EPMA BEIs and WDS quantitative chemical analysis results of Nb/Ti-35Ni-15Nb/Nb joints vacuum brazed at (a) 1000 °C, (b) 1050 °C, (c) 1100 °C and (d) 1150 °C for 180 s.

in contact with the specimen in order to obtain accurate thermal cycle measurements in brazing. All brazed specimens were furnace cooled to room temperature.

Microstructures and quantitative chemical analysis of vacuum brazed joints were made by using a JEOL JXA-8200 EPMA (Electron Probe Microanalyzer). The joint was sectioned by a slow-speed diamond saw, and mounted into a thermosetting epoxy. It was ground by sand papers up to 1000 grids, and then polished with 1 μm and 0.3 μm alumina suspensions. The polished sample was dropped into an ultrasonic bath in order to remove the residual alumina particles before EPMA examination.

After the completion of the brazing process, shear tests were made in order to evaluate bonding strength of selected brazed joints. A symmetrical double lap joint, Nb/Ti-35Ni-15Nb/Nb, was used for shear test of the brazed specimen. Fig. 1 illustrated the schematic diagram of the shear test specimen enclosed in the graphite fixture [15,16]. The two bold black lines, 3.5-mm wide, in the middle of the graph indicated the brazing filler metal. A Shimadzu AG-10 universal testing machine with the compressive cross head speed of 0.017 mm/s was applied in the shear test. The average shear strength of brazed joint was obtained from at least three test data for each brazing condition. After the shear test, the fractured surface was observed by using a JEOL-6510 SEM (Scanning Electron Microscope) in order to unveil fracture mechanism of the brazed specimen. The secondary electron image (SEI) was used to obtain fractographs of the fractured surfaces after shear test.

3. Results and discussion

Fig. 2 shows SEM backscattered electron images (BEIs) and EPMA quantitative chemical analysis results of Nb/Ti-35Ni-15Nb/Nb joints vacuum brazed at 1000, 1050, 1100 and 1150 °C for 180 s. Based on the Fig. 2, there are at least three phases readily identified from the brazed joints, including black Ti_2Ni intermetallic compound as marked by A, dark gray TiNi intermetallic compound matrix as marked by B and globular white (β-Ti, Nb) as marked by C. Fig. 3(a) displays Ti-Ni binary alloy phase diagram [14]. The initial Ni/Ti ratio in 50Ti-35Ni-15Nb filler metal is 41/59 in weight percent. According to Ti-Ni binary alloy phase diagram, the chemical composition of initial braze melt is located at the left side of TiNi primary field as displayed in Fig. 3(a). TiNi intermetallic phase is a non-stoichiometric compound with the melting point of 1310 °C, and it was formed at the early stage of brazing. The Ti was readily reacted with Ni, and formed TiNi intermetallics. There is a peritectic reaction, $L + TiNi \rightarrow Ti_2Ni$, at 984 °C. The residual liquid riched in Ti further reacted with TiNi, and formed Ti_2Ni intermetallic compound upon cooling cycle of brazing. In Fig. 2, the amount of TiNi intermetallic phase is more than that of Ti_2Ni. Both Ti_2Ni and TiNi are alloyed with a few percent Nb. Additionally, the amount of Ti_2Ni/TiNi intermetallics is decreased with increasing the brazing temperature.

The dilution of Nb substrate can be expressed by $\{A_s/(A_s + A_b)\} \times 100$ [18]. A_s is the melted cross-sectional area of the substrate, and A_b is the melted cross-sectional area of braze filler metal.