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Microstructure and bonding strength of diffusion welding of Mo/Cu joints with Ni interlayer

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ABSTRACT

The possibility and appropriate processing parameters of diffusion bonding of Mo and Cu using a Ni interlayer was investigated. The microstructure of the bonded joints was studied by SEM, EPMA and XRD, and the main factors affecting diffusion bonding process were analyzed. The results showed that the solid solutions formed in both Mo–Cu and Cu–Ni interfaces during the diffusion bonding process, and no intermetallic compound appeared. The thickness of Ni layer decreased with the bonding temperature raising. The fracture of the joints had taken place in the Mo/Ni interface rather than the Ni/Cu interface. With the increasing of bonding temperature or holding time, the tensile strengths of the joints increased firstly and then decreased. The Mo/Ni/Cu joint bonded at 800 °C for 30 min exhibited a maximum value of tensile strength of 97 MPa.

1. Introduction

Controlled thermonuclear fusion energy is expected to be the main source of energy for mankind in the later 21st century [1]. Plasma facing materials (PFMs), the key structural component, is a very important issue related to the basic controlled nuclear fusion engineering [2]. Mo, a high Z material, is nominated as potential candidate for armor materials of plasma facing components due to its high melting point, good thermal conductivity, low vapor pressure and very low sputtering erosion yield; Cu is selected as heat sink materials for nuclear fusion device due to its good thermal conductivity [3–5]. The welding technology of Mo alloy and Cu alloy, leading to the connection between PFMs and heat sink materials is to be an important project in high-tech development. Therefore, achieving the connection of Mo/Cu could be significative meaning for thermonuclear fusion energy applications. However, Mo and Cu are essentially immiscible with each other in liquid or solid states, the welding of Mo–Cu by the traditional fusion welding method is difficult [6].

Diffusion bonding, a solid-state bonding process that allows contacting surfaces to be joined under pressure and at elevated temperatures with minimum macroscopic deformation, has been used for bonding of metals, alloys, ceramics and composites whose bonding was not appropriate by classical welding methods [7–9]. By means of diffusion bonding, it is possible to bond all the materials whose chemical and metallurgical properties are different. This welding process has an inherent advantage over conventional welding because it does not involve the formation of unexpected phases at the bond interface that may occur in some advanced materials and the usual defects of fusion welding processes such as crack, distortion and segregation can be avoided [10,11]. In the diffusion bonding, the materials transport by atomic motion, which is enhanced by the increase in temperature. Particularly, the dissimilar metals have different diffusion characters and intrinsic diffusion coefficients; bring out an effect, which is known as Kirkendall effect [8]. Because of this effect, in some bonding conditions micro-voids propagate into the bond region [12]. Moreover, these micro-voids affect badly the mechanical and physical properties of bimetals. Currently, the application of interlayer is commonly applied in diffusion bonding since the interlayer is utilized to minimize or eliminate problems caused by special chemical or metallurgical issues of the alloys [13–15]. Ni is considered to be a potential candidate to be used as intermediate material in the Mo to Cu joint because Ni does not form intermetallic compounds with Mo, and it has completed solid solubility with Cu, which may enhance the properties of the joints. Moreover, Ni resolves the interfacial stress issues since its linear expansion coefficient ranges between Mo and Cu [16].

In the present study, efforts are made to bonded Mo and Cu using Ni as an interlayer. The microstructures and mechanical properties of the joints are studied, the reaction products and the interface structure of the joints are also researched. The study provides a theoretical reference and practical experience for Mo/Cu dissimilar metals connection.

2. Experimental procedure

The base materials used for diffusion bonding were commercially pure Mo (99.97 wt.%) and commercially pure Cu

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(99.95 wt.%). The size of the sample was cut into ∅25 mm × 21 mm. The 10 μm pure Ni interlayer was used. The surfaces to be bonded were ground flat by silicon carbide paper down to 800, 1000 grits and then polished by 0.5 μm Al_2O_3 powder. Before the joining experiment, all surfaces were ultrasonically cleaned in an acetone bath to remove adhered contaminants and then dried in air.

The Mo–Ni–Cu assemblies were kept in contact in a fixture and were placed in a vacuum hot-press furnace (ZRY-50) of the diffusion bonding equipment (Fig. 1) under vacuum at a pressure of 1×10^{-3} Pa. Diffusion-bonded joints were processed at 730, 750, 780, 790, 800, 810, 830 and 850 °C for 30 min and 10, 20, 25, 30, 35, 40, 50, 60 min at 800 °C. The constant uniaxial compression load of 5 MPa was applied along the longitudinal direction of the specimens. In each bonding process, the assemblies were heated up at a rate of 10 °C/min until reach 100 °C of the bonding temperature. After that, heating rate was 5 °C/min up to 50 °C before the bonding temperature and finally the heating rate was 2 °C/min until the bonding temperature was reached. Fig. 2 showed the schematic diagram of diffusion bonding process. Finally, the assemblies were cooled in the processing chamber under vacuum.

Fig. 3 showed the specimen and schematic diagram in the tensile test. The tensile strength test refers to ASTM E8-04 standard [17]. The sample size was devised at the certain ratio of the standard to measure the tensile strength of the joints. The specimens were cut into pieces of ∅8 mm × 21 mm for tensile testing by wire-electrode cutting, the tensile strengths of the joints were tested using MTS-810 universal machine at a velocity of 5×10^{-5} m/s, and the final value of strength is the average of five values.

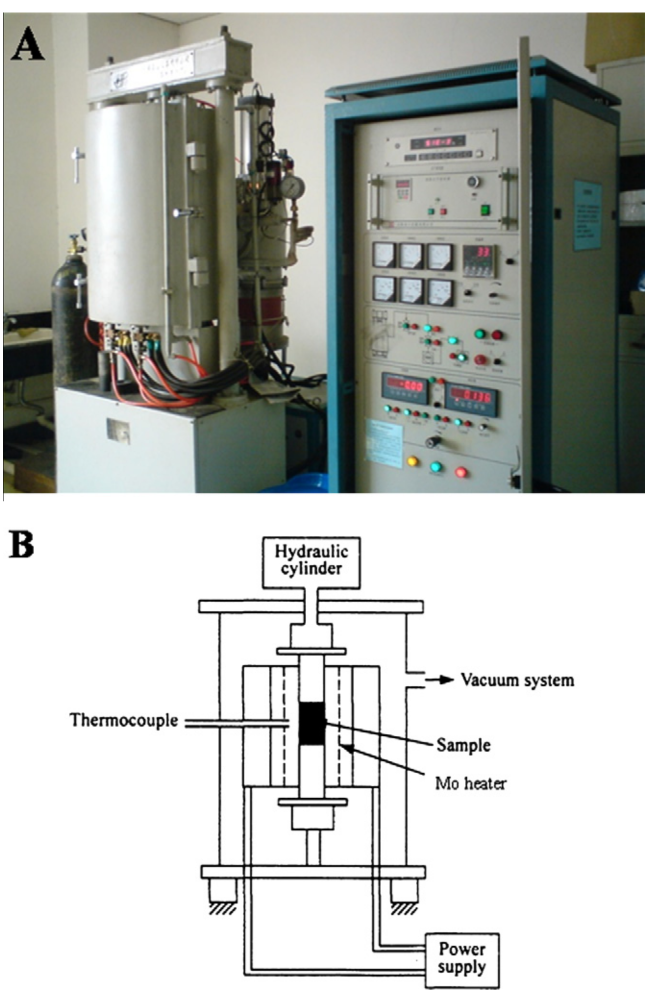

Fig. 1. The experimental setup for diffusion bonding.

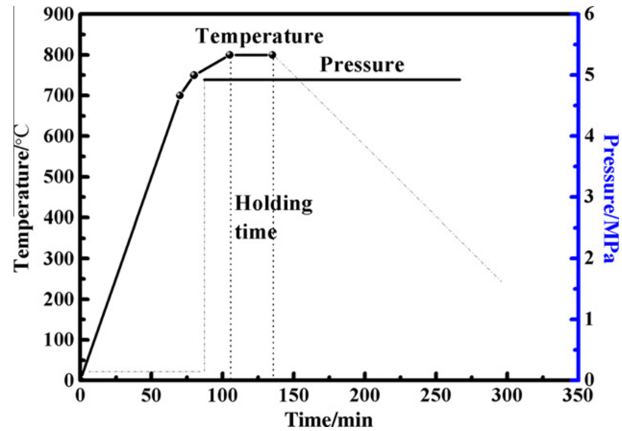

Fig. 2. Schematic diagram of diffusion bonding process.

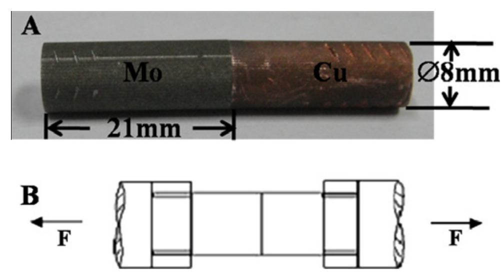

Fig. 3. (A) Tensile test specimen and (B) schematic diagram of tensile test.

The metallographic specimens were cut longitudinally from the bonded assemblies, grounded, polished, Mo side was etched by a solution of 10 g KOH and 100 ml H_2O, Cu side was etched by a solution of 2 g $K_2Cr_2O_7$, 8 ml H_2SO_4, 4 ml NaCl and 100 ml H_2O. The microstructure and fracture analysis of the joints were characterized by S-3400 scanning electron microscope (SEM), the dispersion of the element across the interfaces were evaluated by JXA-8100 electron probe micro-analyzer (EPMA), the phase constitution of different regions on the fracture surface were identified using a Rigaku ultima III X-ray diffraction system (XRD) and Cu Kα was selected as the X-ray source.

3. Results and discussion

3.1. XRD studies

Fig. 4 is the XRD pattern of fracture surfaces at different temperature. Intermetallic compounds did not form under the diffusion bonding. When temperature is above 750 °C, the phase on the Mo side of the interface is Mo, while on the Cu side just the Ni phase was founded. In other word, it can be inferred that the fracture has taken place somewhere at the interface of Mo and Ni, which is the weak point at the Mo/Ni interface. Moreover, at a temperature lower than 750 °C, the joint is physical connected and the elements insufficiently inter-diffuse, therefore Ni peaks appear on the Mo side and Cu peaks on the Cu side.

Fig. 5A and B shows that there are deviations in the diffraction angle between raw and bonded materials, whose parameters are 800 °C for 30 min. This indicates that solid solution Mo (Ni) and Ni (Mo) are generated in the Mo/Ni interface [18], where is the fracture interface.