

Influence of intermetallic compounds on the microstructure and strength properties of diffusion bonded W–steel joints using Ti/Ni composite interlayer

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ABSTRACT

Dissimilar W/steel metals were successfully joined by diffusion bonding process with the help of a Ti/Ni composite interlayer. The effect of bonding temperature and holding time on interfacial microstructure and mechanical properties of the bonded joints were investigated. Metallographic and compositional analyses show that no intermetallic compound was observed at the W/Ti and Ni/steel interfaces, but Ti_2Ni , TiNi and TiNi_3 were formed at the Ti/Ni interface at 850–1050 °C for 0.5–2 h. Tensile test showed that variations in the strength of the joint were strongly related to the intermetallic compounds in the diffusion zone of the Ti/Ni interface. The maximum tensile strength of ~267 MPa was obtained for the joint diffusion bonded at 950 °C for 1 h, and the failure took place at both the W/Ti interface and W substrate. With further increase of the joining temperature, the holding time or both, the joint strength dropped as a function of the increase in the width of Ti–Ni intermetallic compounds, and the failure occurred at intermetallics layers of the Ti/Ni interface.

1. Introduction

The present design concept of helium cooled high performance divertors for fusion DEMO reactors calls for the joining of tungsten (W) or W alloys to ferritic–martensitic high chromium steels [1]. However, W and steel have significant differences in physical properties, in particular the mismatch of their coefficients of thermal expansion (CTE, $4.5 \times 10^{-6} \text{ K}^{-1}$ for W and $12\text{--}14 \times 10^{-6} \text{ K}^{-1}$ for steel at room temperature (RT)), which causes high thermal residual stress in the W/steel joints after joining. This results in a degradation of the mechanical properties of the joint.

Until now several joining techniques including brazing [2–4] and solid state diffusion bonding [5–7] have been developed for the joining of W and steel. Although brazing alloys are metallurgically compatible with parent materials, the brazing temperature, 1150 °C, is high enough to cause grain coarsening and phase transformation in steel (e.g., EUROFER97 [8]), and consequently leads to the degradation of material properties. Diffusion bonding, a solid–state bonding process that allows contacting surfaces to be joined under lower joining temperature with minimum macroscopic deformation, and by means of diffusion bonding, it is possible to bond the materials whose chemical and metallurgical properties are different [9,10]. Basuki and Aktaa [11] reported that, for solid–state diffusion bonding carried out between W

and steel, a very high tensile strength was achieved at 1050 °C but for the bonding processes with post bonding heat treatment (PBHT), all specimens failed at the bonding seam already during the cutting of the specimens by electrical discharge machine (EDM) due to the high residual stresses, and possibly a remaining brittle oxide layer. The use of appropriate intermediate materials can reduce the residual stress and minimize formation of harmful brittle phases. Previous studies along this line dealt with the diffusion bonding of W to steel using Ni [12,13], Nb [8], Ti [14], or V [15] as interlayer materials. Though such sandwich designs reduced the stress concentration and suppressed the direct reaction between the bonding partners (which promotes the formation of brittle intermetallic phase FeW and metal carbides [11]), the single metal interlayer itself in all cases reacted with one or both of the joint metals to form again intermetallic compounds or other brittle phases. In particular, Zhong et al. [14] and Wang et al. [15] have shown that Ti can be used as the interlayer material for diffusion bonding of W to steel because the CTE of Ti ($8.4 \times 10^{-6} \text{ K}^{-1}$) is between that of W and steel which is expected to help mitigate the residual stress in the joint, as well as it forms continuous solid solution with W. However, the Ti interlayer is prone to form intermetallics at the Ti/steel interface, such as Fe_2Ti and FeTi , which exhibited detrimental effects on the joint strength. On the other hand, Ni has substantial solid solubility in Fe, and Ni–steel diffusion couples were found to be free from intermetallic

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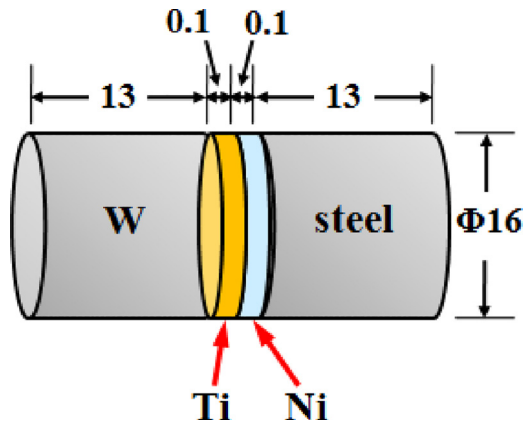


Fig. 1. Schematic representation of the sample assembly (all dimensions are in mm).

compounds [13,17,18]. In addition, He et al. [19] reported that Ti–Ni intermetallic phases have higher plasticity than those of Ti–Fe intermetallics. Consequently, the combination of Ti and Ni is considered as a constructive intermediate material for diffusion bonding of W and steel.

The present study reports diffusion bonding of dissimilar metals of W and steel, in which a double layer of Ti and Ni foils as interlayer was used. The effect of bonding temperature and holding time on interfacial microstructure and strength properties were examined.

2. Experimental procedure

Commercially available pure W (99.95% purity) and Fe–17Cr (wt. %) ferritic stainless steel cylindrical samples with 16 mm diameter and 13 mm length were used in this study. The commercial Ti (99.95% purity, 0.1 mm thick) and Ni (99.9% purity, 0.1 mm thick) foils were used as insert metals. The joining surfaces of W and steel were polished down to 1 μm finish, and Ti and Ni interlayers were polished using 1500 grit emery paper. All the materials were cleaned in an ultrasonic bath using acetone for 15 min and finally dried in air prior to bonding.

The prepared materials, assembled in the structure of W/Ti/Ni/steel as shown in Fig. 1, were mounted in a graphite mold, and then introduced in a vacuum furnace ($< 10^{-3}\text{Pa}$). The diffusion bonding process was performed in the temperature range of 850–1050 $^{\circ}\text{C}$ for 0.5–2 h at a heating rate of 10 $^{\circ}\text{C}/\text{min}$. Uniaxial load of 10 MPa was applied along the longitudinal direction of the sample. Once the bonding process was completed, the load was removed, and the joints were cooled at a rate of 5 $^{\circ}\text{C}/\text{min}$ to 400 $^{\circ}\text{C}$ and followed by furnace cooling in vacuum to RT.

The cross-sections of the diffusion bonded joints were cut perpendicularly to the joining interface and were prepared for metallographic examination by standard polishing techniques down to 1 μm . The microstructures of the reaction layers near the diffusion bonding interface were examined in a field-emission scanning electron microscope (Novatm Nano SEM230) using back-scattered mode (SEM–BSE). The chemical compositions of the bond interfaces were analyzed by electron probe microanalysis (EPMA, JXA8530F). The presence of intermetallic phases in the Ti/Ni reaction zone was confirmed by X-ray diffraction

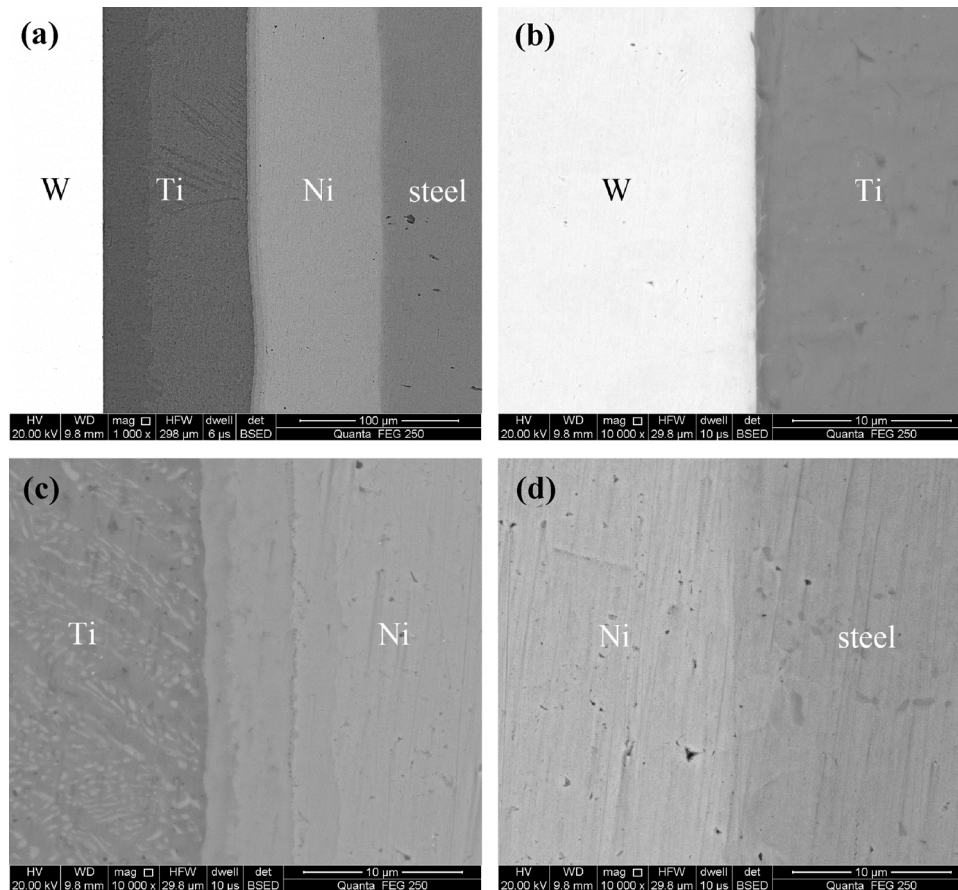


Fig. 2. SEM–BSE images of the cross-sections of W/steel joint bonded at 950 $^{\circ}\text{C}$ for 0.5 h: (a) general view, (b) W/Ti, (c) Ti/Ni, and (d) Ni/steel interfaces.

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