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Rudimentary investigation of the HIP process for tungsten target

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ABSTRACT

Zr alloy and 316-Ti stainless steel (S.S.) were selected as cladding materials for a W target. The HIP processes were performed at 1200, 1300 and 1400 °C and 180 MPa. The observation and determination for micro-morphology of the interface, diffusion depth and composition as well as their micro-hardness were conducted. The results indicated that the bonding of W–Zr and W–S.S. was good under the testing conditions. No pores or micro-cracks in the interface were observed. Grain growth of W was not observed at 1200 and 1300 °C, but it was observed at 1400 °C. The diffusion of Zr–W on the interface of W–Zr was preferred during the HIP process. The diffusion layer was 6–13 μm in thickness for W–Zr, and 13 μm for W–S.S. A peak of the hardness was observed at the interface of W–Zr or W–S.S. A part of the stainless steel cladding melted after HIP using an oxygen absorber (Zr) at 1300 °C and 180 MPa. The conditions of 1200 °C and 180 MPa without using an oxygen absorber Zr are suitable for W–S.S. bonding, while 1300 or 1400 °C and 180 MPa are better for W–Zr bonding.

1. Introduction

Two kinds of neutron production targets are currently studied for the future accelerator driven clean nuclear power system (ADS): liquid metal targets and solid metal targets. Tungsten is the most promising solid target material due to its high neutron yield and high strength at high temperature. The compatibility of tungsten and stagnant water without irradiation is good, however, tungsten will be attacked by flowing water [1–3], and machinable tungsten will be embrittled and corroded under irradiation [4]. In this case, another material with high irradiation and corrosion resistance and excellent neutron properties has to be used as the cladding of a solid tungsten target.

In order to increase the life time of a tungsten target, the cladding has to be able to transfer the heat from the W body to the coolant quickly and efficiently. Therefore, any pores or gaps between the W body and the cladding are not desired. The HIP seems to be the most promising and attainable method to eliminate pores or gaps between the W body and the cladding [2,3]. Zr alloy and 316-Ti stainless steel were selected as the cladding materials in this work.

2. Preparation of HIP samples

2.1. Chemical composition of testing materials

The chemical composition of the Zr alloy cladding is in wt%: 98.88% Zr, 1.0% Nb, 0.12% O. For the 316-Ti S.S. cladding, the composition is in wt%: 0.0404 C, 16.8 Cr, 12.5 Ni, 1.67 Mn, 0.73 Si, 3.75 Mo, 0.63 Ti, 0.0078 S, 0.016 P, Fe in balance.

2.2. Size of samples

A polished W-bar of 8 mm in diameter and rotary swaged W-bars of 5 and 8 mm in diameter were used in this work. Both types of W-bars had a purity of 99.9%. Samples of 30 mm length were cut from both W-bars. The cladding of the polished and rotary swaged W-bar of 8 mm in diameter is Zr alloy cladding of 9.6 mm outer diameter and 0.75 mm wall thickness, and the cladding of the rotary swaged W-bar of 5 mm in diameter is S.S. cladding of 6 mm outer diameter and 0.4 mm wall thickness.

2.3. Preparation of samples

The Zr alloy and S.S. claddings were chemically polished to remove oxide scale on the surfaces. The Zr alloy cladding was polished in a solution of 5% HF + 39% HNO_3 + 56% H_2O at 30–39 °C for 1–2 min. The stainless steel cladding was polished in a solution of 4% HCl + 1% HNO_3 + 0.5% H_2SO_4 + 5% CH_3COOH + H_2O at 80–100 °C for 2 min.

After inserting the W-bars into the corresponding Zr alloy and S.S. cladding tubes, the tubes were sealed by electron-beam welding (EBW). For the S.S. cladding, the EBW was conducted in a vacuum of 2.66×10^{-2} Pa at 60 kV with 6 mA, while for the Zr alloy cladding, it was conducted at 6.66×10^{-3} Pa, 60 kV with 8 mA

3. HIP process and parameters

HIP was conducted at Beijing General Research Institute for Non-ferrous Metal. The facility was QIH-6 type HIP machine made in USA.

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Table 1
Parameters of the HIP process for the W–Zr alloy cladding

Temperature (°C)	Pressure (MPa)	Duration (h)	Rate of *T* increase (°C/h)	Oxygen absorber	Container	Feeding gas
1200	180	4	300	Sponge Zr	Al_2O_3 crucible with a Zr lid	Ar (5N)
1300						
1400						

Table 2
Parameters of HIP process for W–S.S. cladding

Temperature (°C)	Pressure (MPa)	Duration (h)	Rate of *T* increase (°C/h)	Oxygen absorber	Container	Feeding gas
1200	180	4	300	No	Al_2O_3 crucible without lid	Ar (5N)
1300				Sponge Zr	Al_2O_3 crucible with a Zr lid	

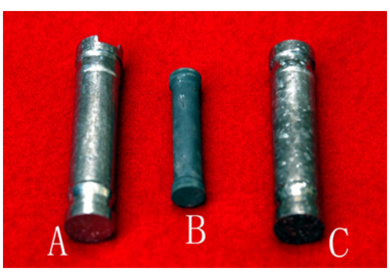

Fig. 1. Samples after HIP processing. (A) W–Zr sample, at 1300 °C, (B) W–S.S. sample, at 1200 °C, (C) W–Zr sample, at 1400 °C.

The prepared W–Zr and W–S.S. cladding samples were individually put into an Al_2O_3 crucible which was placed in the furnace of HIP machine with a graphite heater. In order to prevent the oxidation of Zr alloy and S.S. cladding, argon (Ar) gas with purity of 99.999% (5N) was used as a feeding gas, and sponge Zr was put in Al_2O_3 crucible as an oxygen absorber. The cladding samples were covered up with the sponge Zr, and a Zr piece was used as the lid of the Al_2O_3 crucible.

The furnace was degassed by pumping to about 1–2 Pa, and then fed with the pure Ar gas. The degassing and feeding were repeated once more. Afterwards, HIP process was started by increasing the pressure up to 50 MPa, then increasing the temperature up to the desired temperature with a rate of 300 °C/h, and finally adjusting the pressure to 180 MPa. The HIP'ing pressure was held for 4 h.

The HIP process for the W–S.S. cladding samples was conducted at 1200 °C without an oxygen absorber.

The parameters of the HIP process for the W–Zr alloy cladding are shown in Table 1, and those for W–S.S. cladding are listed in Table 2. The samples after HIP processing are shown in Fig. 1.

4. Results and discussion

4.1. Micro-morphology of interface

4.1.1. W–Zr cladding

The micro-morphologies of the W–Zr bonding interfaces are shown in Fig. 2. The optical microscopy observation indicates that there are no pores or micro-cracks in the W–Zr interfaces. At testing temperatures of 1200 °C and 1300 °C, grain growth in the tungsten is not observed, but it is obvious at the fabrication temperature of 1400 °C. There is a band with dark color on the Zr alloy side of the interface, the EDS analysis indicates that the main composition of the dark band is Zr, it proved that the dark band is resulted from the grinding during the preparation of the metallog-

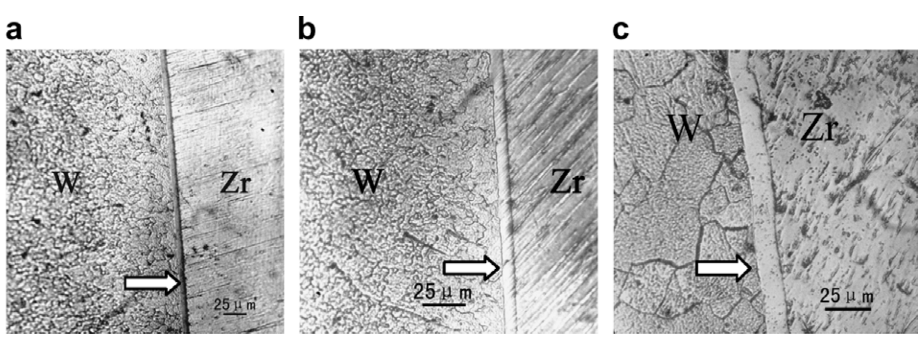

Fig. 2. Micro-morphologies of the W–Zr bonding interfaces after HIP'ing at (a) 1200 °C (b) 1300 °C (c) 1400 °C.

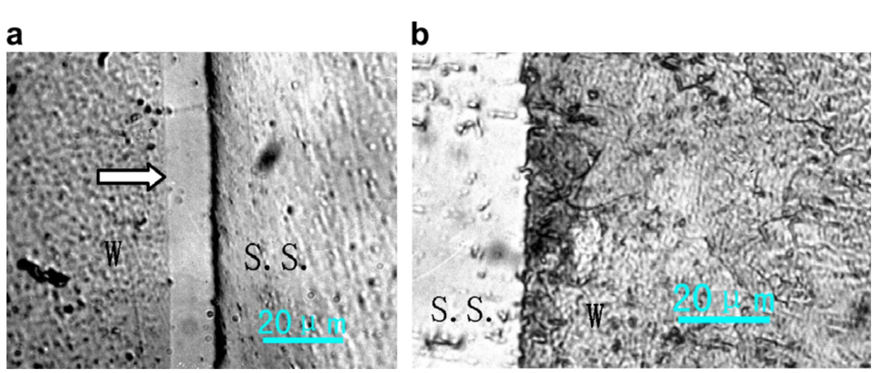

Fig. 3. Micro-morphologies of the W–S.S. bonding interface after HIP'ing (a) at 1200 °C without Zr and (b) at 1300 °C containing Zr.