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Study of the Fe-Ti/W system for joining applications in high-temperature fusion reactor components

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HIGHLIGHTS

- Simulations show good correlation versus experimental results for Fe-Ti/W system.
- The joint is predicted to be stable at the service conditions of the component.
- The predictions could help to analyze different scenarios during its service life.

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ABSTRACT

The interaction of the Fe-Ti/W system in a brazed divertor component of the future fusion power plant has been studied. The reactivity between the substrates and the filler is an important factor to obtain a high quality joint. Thermodynamic and diffusion simulation software can be valuable tools for studying these effects, particularly in scenarios that are difficult to experimentally analyze. Two different strategies have been performed: 1) simulation processes using the Thermo-Calc and DICTRA software to calculate the phase diagram and simulate the diffusion process, respectively, and 2) experimental tests in a furnace to join W-W substrates using a filler with an 86Fe-Ti composition to analyze the operational brazeability and compare it with the simulation results. The simulation processes predicted two of the three phases that formed at the experimental joint (α-Fe and TiC). The interaction at the W-filler interface predicted by DICTRA correlates with the experimental results, where Fe, Ti and C diffused into the W substrate and moved the interface by 25 μm. Simulations also show the stability of the interface over the lifetime of the component. The combined use of Thermo-Calc and DICTRA software enabled the accurate prediction of different scenarios in the system of Fe-Ti-C/W.

1. Introduction

Divertors serve many roles in a fusion device, including the removal of heat, impurities, and ash, and setting the plasma boundary. Two conceptual designs of a He-cooled modular divertor have been investigated: the reference version Helium-cooled Multi-Jet (HEMJ) and the back-up solution He-cooled Modular divertor design with Slot array (HEMS) [1,2]. The main design, which is common to both options, is the use of small tungsten tiles in direct contact with the plasma (approximately 5 mm thick) as a thermal shield and sacrificial layer. The tiles must be joined to a thimble-like structure made of tungsten alloy, directly cooled with He and operating between 600 °C and 700 °C (inlet/outlet temperatures). The tile-thimble forms a cooling finger unit, which is fixed to the supporting structure made of ferritic/martensitic steel by brazing and/or using a mechanical interlock [3].

Brazing is the most suitable technique for joining a tile-thimble structure because of the limited effect on the parent substrates [4,5]. Thus, a metallic phase with a lower melting point (86Fe-Ti) is placed between two substrates. The Fe-Ti equilibrium phase diagram has a eutectic point allowing for this composition to work with lower temperatures (Fig. 1) [6]. This composition is free of elements that can be activated under a neutron flux, which is a requirement for the Demonstration Fusion Power Reactor (DEMO) [7]. The interaction between the substrates and the filler is an important factor in obtaining a high quality joint.

The interaction between the filler (86Fe-Ti) and W has been studied with two different methods: 1) thermodynamic

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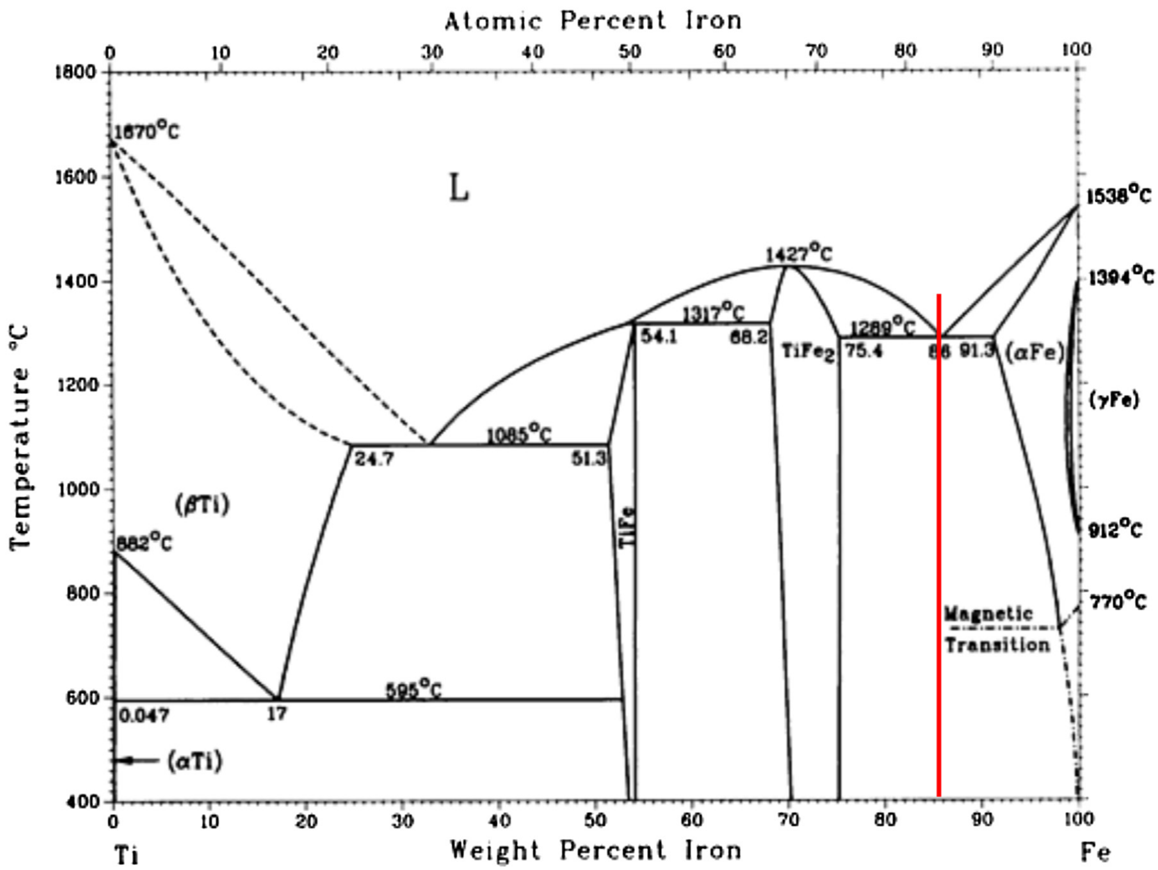

Fig. 1. Phase diagram of the Fe-Ti binary system [6].

calculation and diffusion process simulation (Thermo-Calc and DICTRA); 2) experiment at the furnace. The simulation enabled the prediction of the diffusion of each element through the interface and the phases in equilibrium under certain conditions [8,9]. Furthermore, the position of the interface and its evolution over time were predicted. These software have been used together to predict the phases and diffusion in welding processes [10,11] but not for brazing in the Fe-Ti/W system.

The theoretical results were compared to the experimental one, which was obtained from a brazing test in the furnace. The interface that formed between the filler and W of the system 86Fe-Ti/W was analyzed with SEM.

2. Experimental procedure

2.1. Materials

The tungsten for the experimental tests (>99.97%) was supplied by *Plansee* as a 12.7 mm diameter rod. Commercial Ti (99.95% purity, −200 mesh) and Fe (>99% purity and −200 mesh) metallic powders, supplied by *Alfa Aesar*, were used to fabricate the filler, which consisted of a laminated mixture of 86Fe-Ti and an organic binder (powder/binder ratio: 90/10) to conform flexible tapes. The binder was Polypropylene Carbonate (PPC, *QPAC 40*) and was supplied by *Empower Materials* in pellet form.

2.2. Brazing test

The W substrates were sliced from a 12.7 mm diameter bar in slices of approximately 1.5 mm thickness. The base material surfaces were ground with a silicon carbide paper to grit size P4000.

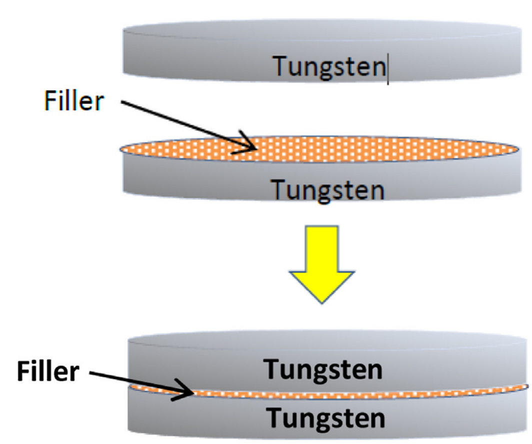

Fig. 2. Schematic representation of the sample for the brazing test.

The laminate filler was set between the two parent substrates and placed in the furnace (Fig. 2). The only load applied to the joint was the weight of the upper tungsten base material, which was approximately 4.5 g. Brazing tests were performed in a high vacuum furnace to avoid oxidation; the residual pressure reached 10^{-6} mbar at the brazing temperature (1350 °C) for 10 min. The heating and cooling rates were 5 °C/min.

2.3. Simulation process

The equilibrium phase diagrams of the studied composition were calculated using the Thermo-Calc software. Based on these equilibrium diagrams, the liquidus temperatures and phases that