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Evaluation of mechanically alloyed Cu-based powders as filler alloy for brazing tungsten to a reduced activation ferritic-martensitic steel

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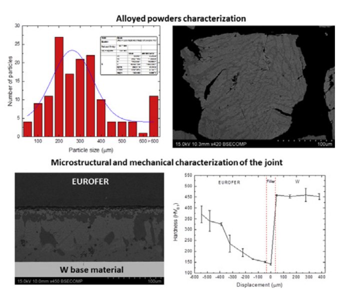
HIGHLIGHTS

- W-Eurofer brazed joints, manufactured using Cu-based mechanically alloyed powders as filler is proposed.
- The benefits derivate from the alloyed composition could improve the operational brazeability of the studied system.
- Tested pre-alloyed fillers have a more homogeneous melting stage which enhances its spreading and flowing capabilities.
- This behaviour could lead to work with higher heating rates and lower brazing temperatures.

GRAPHICAL ABSTRACT



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ABSTRACT

80Cu-20Ti powders were evaluated for their use as filler alloy for high temperature brazing of tungsten to a reduced activation ferritic/martensitic steel (Eurofer), and its application for the first wall of the DEMO fusion reactor. The use of alloyed powders has not been widely considered for brazing purposes and could improve the operational brazeability of the studied system due to its narrower melting range, determined by DTA analysis, which enhances the spreading capabilities of the filler. Ti contained in the filler composition acts as an activator element, reacting and forming several interfacial layers at the Eurofer-braze, which enhances the wettability properties and chemical interaction at the brazing interface. Brazing thermal cycle also activated the diffusion phenomena, which mainly affected to the Eurofer alloying elements causing in it a softening band of approximately 400 μm of thickness. However, this softening effect did not degrade the shear strength of the brazed joints (94 ± 23 MPa), because failure during testing was always located at the tungsten-braze interface.

1. Introduction

Materials selection and their processing have become an important issue to develop next generation of fusion power reactors. First wall (FW) materials have to withstand the hard conditions given inside the reactor such as high thermal loads, high neutron fluxes and sputtering. Tungsten and low activation ferritic-martensitic steels (EUROFER) have been selected as reference material for plasma facing material and structural materials, respectively. The former has been chosen due to its excellent thermophysical properties (high thermal conductivity, high melting point, sputtering resistance) and the latter due to the lack of active elements and its strength under the neutron flux given in the reactor [1–3].

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Tungsten, as a sacrificial layer, will face the plasma against the heat and High Heat Flux (HHF) that could reach 5 MW/m^2 in the transition mode as Edge Localize Mode (ELM) [4]. This sacrificial layer will be held up by an Eurofer structure, which also supports in turn the breeding blankets on the other side [3]. Therefore, it is necessary to develop W-Eurofer joints capable to withstand the conditions given in the reactor.

The W-Eurofer joining has been studied by several authors, considering different bonding procedures, intermediate materials and conditions. Norajitra et al. used Ni-based commercial fillers to develop the joint but they do not fulfil neither the temperature requirements nor the restriction in the composition due to the presence of activation elements in the tested fillers [5,6]. The used of diffusion bonding technique has been also widely studied but the combination of high temperatures and long times produced a thermal affectation of Eurofer-base materials degrading their microstructures and properties [7,8].

At the present work, alloyed powders with a composition of 80Cu-20Ti were fabricated by means of mechanical alloying and they were evaluated for manufacturing brazing fillers to join W to Eurofer. The fabrication procedure of Cu-base pre-alloyed powders by mechanical alloying route has been previously studied for a wide range of applications [9–11]. However, the use of this kind of powders has not been widely studied for its use as brazing fillers, although it could bring interesting advantages with benefits respect on the brazeability of the studied joints. For example, the application of pre-alloyed powders, in relation with mixtures of pure one in the same proportion, could shorten the heating stage. Because pre-alloyed powders already have the 80Cu-20Ti composition, it is not necessary to activate diffusion mechanisms for reaching the braze composition selected for melting and spreading the filler at the brazing temperature.

Ivanov et al. [12] studied the manufacturing and brazing process by using mechanically alloyed filler metals obtained from elemental metal powders. The results showed that costs derived from this process could be cut down by 40–50% and they were successfully tested and accepted by the Ti brazing industry.

At the present work, it has been showed that W-Eurofer brazed joints, manufactured using Cu-based mechanically alloyed powders as filler, could introduce improvements to the brazing procedure, providing a more suitable design of the joints. The microstructure of the brazed joints has been investigated and its correlation with the mechanical properties has been also discussed.

2. Experimental procedure

2.1. Materials

Tungsten-base material was supplied by *Plansee* (>99.97%) in a 12.7 mm diameter rod and Eurofer-base material had a standard composition and microstructure. The 80Cu-20Ti (weight ratio) alloyed powders supplied by *Goodfellow* were manufactured by means of mechanical alloying procedure. The fabrication route of the brazing filler consisted of manual stirring of the alloyed powders with an organic binder (powder/binder weight ratio: 90/10). The obtained mixture is then laminated using two anti-adherent films to produce flexible tapes of 250 μm width [13]. The binder used was polypropylene carbonate (PPC, QPAC 40) supplied by *Empower Materials* in pellets form. In the case of DTA study, a mixture of pure metallic powders with 80Cu-20Ti composition was used for comparative purpose. Ti powders (99.95% purity, −200 mesh) were supplied by *Alfa Aesar* and Cu ones (99.9% purity, 100 mesh) by *Stream Chemical*. Mixtures of both pure powders in the studied proportion were mixed by means of a rotatory milling process.

2.2. Brazing tests

W base pieces were sliced from a 12.7 mm diameter bar in slices of about 1.5 mm thickness and their surfaces were ground with SiC abrasive papers down to a P4000 grit grain grade. The laminated filler was located between the two metal base slices and then placed in a tubular vacuum furnace. Brazing tests were carried out in a high vacuum atmosphere to avoid oxidation using a residual pressure of 10^{-6} mbar and a brazing temperature of 960 °C for 10 min. The heating and cooling rates were 5 °C/min.

2.3. Characterization techniques

Differential Thermal Analysis (DTA) of the alloyed powders and mixture of pure ones with the same average composition were carried out using a DTA equipment (*Setaram Thermic Analyser 16/18*) in argon atmosphere. Solidus and liquidus temperatures both of the alloyed powders and the mixed ones were determined. Thus, a 20 mg of both powders were subjected to the a heating cycle for DTA testing of 10 °C/min heating rate from room temperature up to a temperature 100 °C higher than the theoretical liquidus one. The heat exchanged throughout the process was recorded.

Carbon content microanalysis were carried out at temperatures slightly below the brazing one to analyse the proportion of residual carbonaceous ashes left by the binder during the heating stage before the melting of the filler occurred. For it, an isothermal heat treatment at 900 °C for 10 min was applied to the filler tapes with two binder contents (95/5 and 90/10) in order to analyse the influence of the powder/binder ratio. The chemical analysis was carried out using a *LECO CS-200* equipment.

Brazing specimens were cut perpendicularly to the brazed joint for the cross section microstructural analysis by stereoscopic microscopy (*Leica*), Optical Microscopy (OM, *Leica*) and Scanning Electron Microscopy (*SEM, S3400 Hitachi*) equipped with Energy Dispersive X-ray analysis (EDX). The cross sections were metallographic prepared using the standard polishing technique. Some samples were etched by immersion before microscopic observation to develop the tungsten and steel grains and determine the effect of the brazing thermal cycle on the grain sizes of both parent materials and the precipitation of secondary phases. For it, an etchant solution constituted by10 ml HNO_3, 30 ml HCl and 30 ml glycerol was used.

For the identification of the interfacial phases formed at the braze joint, X-ray diffractions were obtained on the fracture surfaces of the mechanical tested joints. Cu Kα was selected as the x-ray source in a *PANalytical X'Pert Pro MRD diffractometer.*

The possible effect of the brazing thermal cycle on the mechanical properties of the base materials was evaluated by means of Vickers microhardness. Thus, microhardness profiles from EUROFER side to the tungsten one, across the braze were traced with a *MHV-2SHIMADZU* equipment. A 100 g load was applied during 15 s and three indentation lines were made, working always with indentations made at the same distances from the braze interfaces. Separation between neighbours indentations were always kept longer than three times the residual imprint sizes.

Finally, shear strength of the brazed joints were determined by using a compression mode fixture schematically showed in Fig. 1; this configuration ensured the correct alignment of the brazed joint with the applied load, avoiding the flexion of the specimens during the test, which guarantees a pure shear stress on braze surface. The fixture was place between compression platens in a Universal Testing Machine (*Zwick Z100)* at a displacement rate of 1 mm/min. Three brazed specimens were tested to determine the average shear strength of the joint.