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# Interfacial metallurgy study of brazed joints between tungsten and fusion related materials for divertor design

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## HIGHLIGHTS

- We created brazed joints between tungsten and EUROFER 97, Cu and SS316L with Au80Cu19Fe1 filler.
- No elemental transitions were detected between the W and the AuCuFe filler in either direction.
- Transition regions between filler to EUROFER97/316L showed similar elastic modulus and hardness to the filler.
- Smooth elemental and mechanical properties transition were detected between the filler and Cu.

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## ABSTRACT

In the developing DEMO divertor, the design of joints between tungsten to other fusion related materials is a significant challenge as a result of the dissimilar physical metallurgy of the materials to be joined. This paper focuses on the design and fabrication of dissimilar brazed joints between tungsten and fusion relevant materials such as EUROFER 97, oxygen-free high thermal conductivity (OFHC) Cu and SS316L using a gold based brazing foil. The main objectives are to develop acceptable brazing procedures for dissimilar joining of tungsten to other fusion compliant materials and to advance the metallurgical understanding within the interfacial region of the brazed joint. Four different butt-type brazed joints were created and characterised, each of which were joined with the aid of a thin brazing foil (Au80Cu19Fe1, in wt.%). Microstructural characterisation and elemental mapping in the transition region of the joint was undertaken and, thereafter, the results were analysed as was the interfacial diffusion characteristics of each material combination produced. Nano-indentation tests are performed at the joint regions and correlated with element composition information in order to understand the effects of diffused elements on mechanical properties. The experimental procedures of specimen fabrication and material characterisation methods are presented. The results of elemental transitions after brazing are reported. Elastic modulus and nano-hardness of each brazed joints are reported.



## 1. Introduction

Tungsten and tungsten alloys have been considered as primary candidate materials for helium cooled DEMO divertor and possibly for protection of helium cooled first wall in DEMO applications [1–4]. This is directly related to their attractive physical properties, namely, high melting point, high thermal conductivity, high ultimate tensile strength, high yield and shear strength and relatively low coefficient of thermal expansion [1,2]. Joining tungsten divertor components to other suitable structural materials is critical to the success of DEMO and high temperature brazing has been chosen as one of suitable joining technologies [1,3,4]. In the developing HEMJ divertor design [2], each of the cooling fingers consists of a W tile for shielding and a W-1%$La_2O_3$ (WL10) thimble for heat sinking. The fingers are connected to a reduced activation ferritic-martensitic (RAFM) EUROFER steel body by brazing. Considering the large mismatch in thermal expansion coefficients of W ($4.2 \times 10^{-6}$ 1/K at RT) and RAFM steel (ca. $12 \times 10^{-6}$ 1/K at RT) [5] under the severe DEMO divertor working conditions, the brazed joints are critical as a result of them being exposed to thermal cyclic loads in both water-cooled and he-cooled divertor applications. Furthermore, other dissimilar material properties such as the Young's moduli and yield stress, in combination with the

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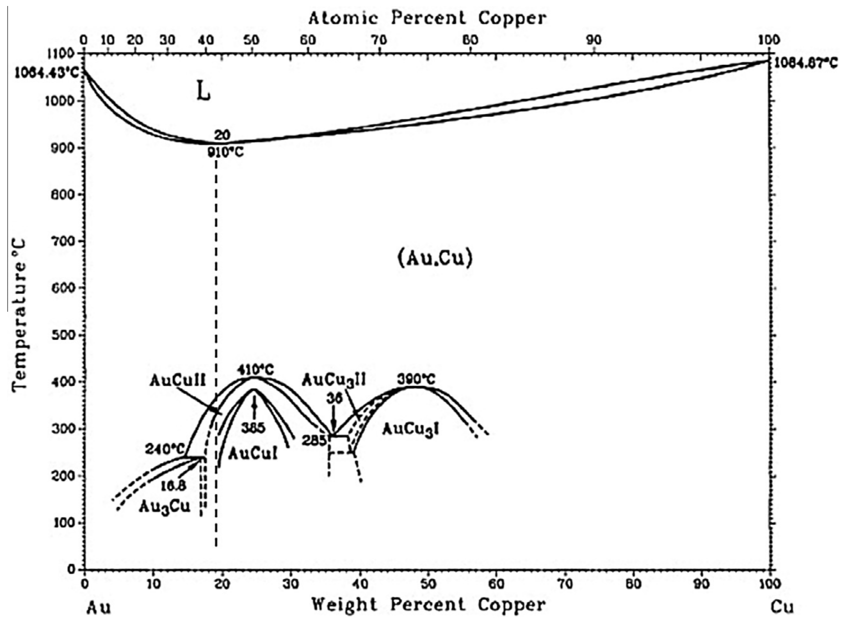


**Fig. 1.** Au–Cu phase diagram [10].

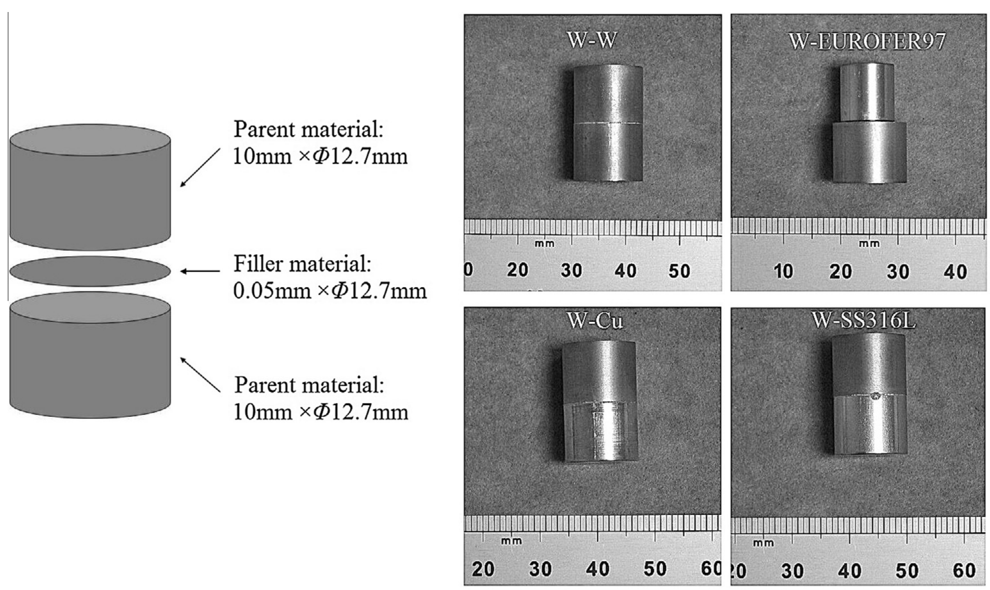


**Fig. 2.** Material dimensions and butt joined brazed specimens.

mismatch in thermal expansion coefficient, results in high residual stresses in the joint regions as a result of the joining process [2]. Kalin [6] developed a brazing process to join W to a ferritic/martensitic steel for use on Helium-cooled divertors and other plasma facing components. It was found that cracks initiated in the tungsten a small distance away from the brazed layer due to significant residual stresses. This phenomenon raises significant challenges in relation to brazed joints between W and other dissimilar metals, either during service conditions or as a result of the fabrication process.

In previous research [1–3], Pd60Ni40 (liquidus temperature $T_{lq}$ = 1238 °C) was used for brazing W-WL10 and Pd18Cu82 ($T_{lq}$ = 1100 °C) was used for WL10-steel using the vacuum furnace brazing method. In both cases successful brazed joints were achieved. In the W-WL10 joint with PdNi filler, significant diffusion of tungsten was observed in the brazed layer. In Munez's [7] work, Ni55Ti45 alloy filler wire was used for joining W–Ti–$Y_2O_3$ alloy and EUROFER steel by means of laser brazing and it was found that NiTi filler showed low brazeability. Cracks caused by residual stresses initiated from the brazed layer and extended to the parent materials. Energy dispersive X-ray spectroscopy (EDS) analysis showed elements of tungsten alloy and NiTi filler diffused into each other after brazing. However Ehrlich [8] detected nickel alloys with significant embrittlement effects after neutron loading testing (c. 150 dpa) and indicted a reduction of performance. Reiser [5] noted that the brazed joint of W to structural materials is a critical area when exposed to thermal cyclic load and reported that brittle intermetallic compounds should be avoided under all circumstances and W solid solution should be avoided if possible. It was also noted that producing W laminates, the joining of the foils is also an essential issue [9].

In the present study commercial quality Au80Cu19Fe1 brazing filler was used as gold-based alloy foils are recognised as providing good wettability on tungsten, good resistance to oxidation and