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Thermomechanical characterization of joints for blanket and divertor application processed by electrochemical plating

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HIGHLIGHTS

- Electroplating isa relevant technology for brazing of blanket and divertor parts.
- Tungsten, Eurofer and steel joints successfully fabricated.
- Reactive interlayers improve adherence and reduce failure risks.
- Qualification of joints performed by thermomechanical testing and aging.
- Shear strength of joints comparable with conventionally brazing of steels.

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ABSTRACT

Fusion technology requires in the fields of first wall and divertor development reliable and adjusted joining processes of plasma facing tungsten to heat sinks or blanket structures. The components to be bonded will be fabricated from tungsten, steel or other alloys like copper. The parts have to be joined under functional and structural aspects considering the metallurgical interactions of alloys to be assembled and the filler materials. Application of conventional brazing showed lacks ranging from bad wetting of tungsten up to embrittlement of fillers and brazing zones. Thus, the deposition of reactive interlayers and filler components, e.g. Ni, Pd or Cu was initiated to overcome these metallurgical restrictions and to fabricate joints with aligned mechanical behavior.

This paper presents results concerning the joining of tungsten, Eurofer and stainless steel for blanket and divertor application by applying electroplating technology. Metallurgical and mechanical characterization by shear testing were performed to analyze the joints quality and application limits in dependence on testing temperature between room temperature and 873 K and after thermal aging of up to 2000 h. The tested interlayers Ni and Pd enhanced wetting and enabled the processing of reliable joints with a shear strength of more than 200 MPa at RT.

1. Introduction

Tungsten and its alloys are designated in fusion technology to be applied as plasma facing materials with functional background, e.g. due to the high sputtering resistance and excellent heat conductivity or as structural alloy in the field of He-cooled divertor development, where heat loads of up to 15 MW/m^2 should be removed. Whereas DEMO relevant divertor design based on water cooling will have a heat sink fabricated from copper alloys. Looking onto the blanket designs, the structural material of the first wall will be of type Eurofer steel, which may be covered by tungsten to enhance its performance [1,2].

Analyzing such design concepts, different alloys will be applied and have to be joined. Combinations will range from tungsten with itself or vs. Eurofer steel over steel type joints (if intermediate connections are also considered, e.g. for mechanically or thermally graded applications) up to joints with copper alloys. Brazing of He-cooled divertor components had shown that tungsten joints easily suffer from reliable wetting due to passivating surface scales or missing miscibility if, e.g. copper is used as filler metal [3] or from not desirable reactions of filler and base material forming brittle layers [1]. To overcome such restrictions, electrochemical plating tools were developed to deposit reactive interlayers, e.g. on tungsten together with filler component copper to process promising and reliable joints for fusion relevant alloy combinations [4]. In the first development phase the comparison of brazing and diffusion bonding as joining methods was in the foreground.

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This contribution will focus mainly on the characterization of the processed joints in the state as fabricated and also after annealing to point out an eventually appearing aging behavior. The mechanical performance of the produced joints was analyzed by shear testing at different temperatures to give hints for application ranges.

2. Experimental procedure

2.1. Fabrication of joints

2.1.1. Selection of interlayers

Brazing tests of tungsten (W) with itself or other materials showed that insufficient wetting easily occurred if copper fillers were applied as usual in standard industrial processing without active components. Thus, an applicable tool to overcome this lack will be the deposition of reactive interlayers on top of the parts to be joined. Elements like Ti, V, Cr, Fe, Pd or Ni promise the ability to activate surfaces during joining processes as it can be evaluated from phase diagram analyses [3], e.g. due to miscibility or phase formation with tungsten compared to pure copper-tungsten reactivity. Electrochemical plating was chosen as deposition technology for reactive interlayers due to its common use in industrial applications, its ability to coat complex shapes, good controllability of layer thickness by processing time and plating current, and also considering costs of future industrial application.

For analyzing the general applicability and demonstrating the benefits of electrochemical plating in joining technology, Pd and Ni were selected as master elements for interlayers. Both can be processed from aqueous electrolytes similar to copper which is used as filler component for these joining tests.

2.1.2. Electrochemical plating

The cylindrical samples used for the joining tests had a diameter of 8 mm and length of 10 and 26 mm and were fabricated from rod material by electro discharge machining (EDM) and turning. After joining the samples were characterized mechanically by performing shear tests at room temperature (RT) and elevated temperatures of up to 873 K. Fig. 1 shows schematically the deposition sequence of the interlayers and filler components on the cross sectional area and additionally an image of a pair of coated pieces. However, a general requirement for application of coating technologies and also for electrochemical plating as tool for deposition of reactive interlayers and/or filler components is the adherence of the deposited layers on the surfaces of the substrates. Especially tungsten will be covered ab initio due to its physicochemical nature at least by oxide/hydroxide scales and sometimes also by layers coming from machining (e.g. Zn impurities from EDM cutting). Such scales have to be removed and also a surface activation has to be performed to increase adhesion before functional layers for joining are deposited. The etching process given in [4] applying $K_3[Fe(CN)_6] \times KOH$ as reactant was used for the tungsten conditioning. Eurofer (E) and stainless steel (S, DIN 1.4571) surfaces were cleaned by etching to remove oxides based on (Fe, Cr, Ni) in a solution of H_2SO_4–HCl–H_2O at the ratio of 9/18/73 for 5 min at 50 °C and of HNO_3–HF–H_2O at the ratio of 20/3/77 for 30 s at 50 °C, respectively.

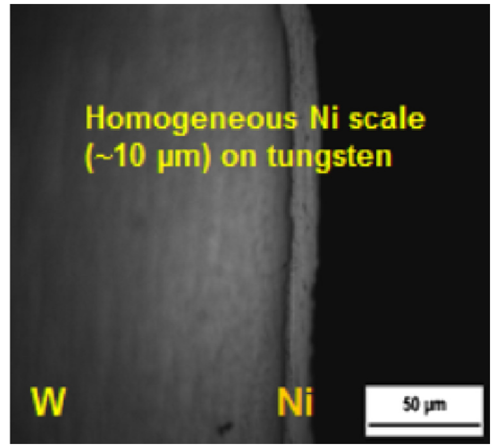

Fig. 2. Micrograph of Ni interlayer deposited on tungsten with homogeneous and defect free structure.

The selected interlayers Ni and Pd were deposited by electroplating from aqueous electrolytes. The electrolyte used for Ni plating consisted of a mixture of nickel sulfamate with a Ni^{2+} content of 76 g/l, boric acid and a fluorinated surfactant. A consumable Ni electrode was applied for keeping the Ni concentration constant during the electroplating. Homogeneous and well adherent layers were obtained applying current densities near 10 mA/cm^2 and a working temperature of about 50 °C (Fig. 2). The pH of the electrolyte was held constant in a range of 3.3 to 3.5. The layer thickness was about 10 μm for the test series to activate the reaction with the filler.

Pd deposition was done using a commercially available electrolyte from AMI DODUCO company, which is designed to work near a pH value of 7.5. The current densities were in the range of 0.4 to 0.8 mA/cm^2 and an insoluble Ti plated Pt anode was used. Deposition experiments of Pd directly on tungsten have shown that the parameter window is rather narrow to obtain well adherent layers due to low hydrogen overvoltages favoring H_2 formation and therefore increased palladium hydride formation. This risk can be reduced by covering the tungsten surface by seeds or a thin Cu layer of sub micrometer dimension.

The main filler component Cu was subsequently electroplated onto the reactive interlayers. For electrodeposition an electrolyte based on $CuSO_4$ was used, as it is described in literature [4]. The Cu plating was conducted at a current density of about 30 mA/cm^2. A consumable Cu anode was used as reservoir to keep Cu concentration constant during electroplating. Homogeneous layers could be processed in the thickness range of 5 to 200 μm in reproducible manner by simple control of deposition time. A layer of 70 μm could be deposited within roughly 1 h as used for the brazing tests. The characterization of deposited layers showed well adherence and

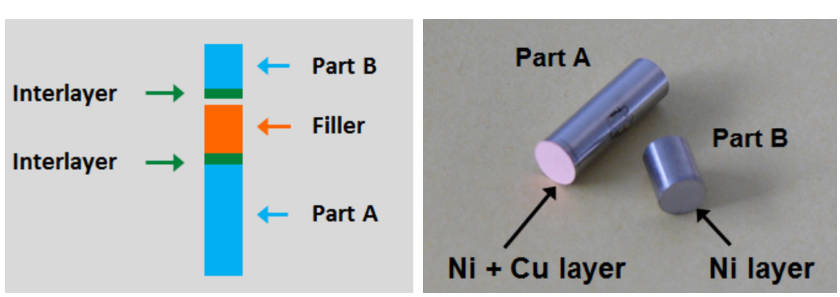

Fig. 1. Electroplating procedure and plated parts for joining.