TLPB of Tungsten to Copper-based precipitation-hardened alloys

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I. Introduction

Within the International Thermonuclear Experimental Reactor (ITER), one of the most challenging components is the divertor, whose main function is to extract the power from the scrape-off layer of the plasma and to maintain plasma purity.

The divertor design consists of Tungsten-based plasma-faced armour bonded to an actively cooled heat sink made of high-strength, high-conductivity precipitation-hardened Cu (0.4-1.5) % Cr (0.03-0.25) % Zr alloy (CuCrZr-IG).

The heat-treatment of the ITER Grade (IG) alloy includes solution annealing at 980-1000 °C for 1 hour, water quench, and aging at 450-480 °C for 2-4 hours [1].

Apparently, the use of brazing with Cu- or Ni-based filler alloys proposed for fabrication of the W/CuCrZr-IG joints [2, 3] can **significantly soften** CuCrZr-bronze.

II. Our approach to the problem

One can envisage that through the judicious selection of the material for the interlayer between Tungsten and CuCrZr-bronze, Transient Liquid Phase Bonding (TLPB) can be achieved well below the aging temperature (450-480 °C) of the CuCrZr-alloy, and the resulting joints will be capable of service at elevated temperatures.

III. Transient Liquid Phase Bonding of Tungsten to CuCrZr-IG bronze using Ga- based interlayer

Gallium attracts a special attention because of liquid Ga can wet most of metallic surfaces and inherently forms an instantaneous thermal contact.

To improve wetting, the Tungsten parts can be pre-coated with Copper.

Although mutual solubility of Cu and W in the solid state is negligible [4], the Cu-layer adhesion to Tungsten can be improved by annealing in vacuum or in dry inert gas.

A thin layer (few microns) of Gallium can be deposited electrochemically from sufficiently acid or sufficiently alkaline solutions. This can be appreciated just by looking at the Pourbaix diagram for Gallium shown in Fig. 1 [5].

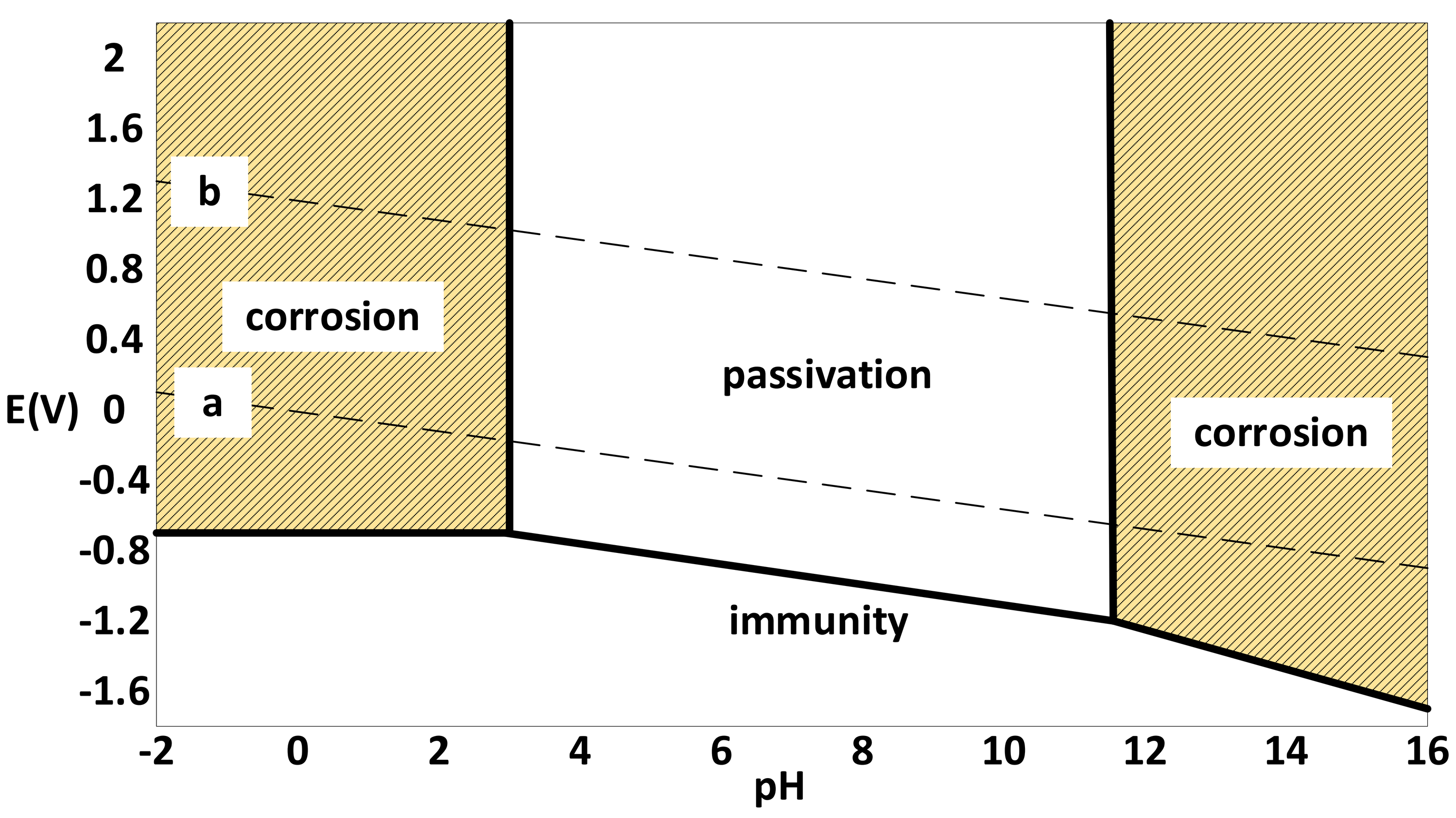

***Fig. 1:** Theoretical conditions for corrosion, immunity and passivation of Gallium at 25 ℃ (Pourbaix diagram) [5]. Lines denoted by **a** and **b** define the domain of thermodynamic stability of water in aqueous solutions under a pressure of 1 atm of H_2 and 1 atm of O_2*

Upon annealing at the temperature above melting point, the Ga-interlayer between the Cu-plated Tungsten and CuCrZr-alloy will form a transient liquid phase, which facilitates bonding via a braze-like process as shown schematically in Fig. 2.

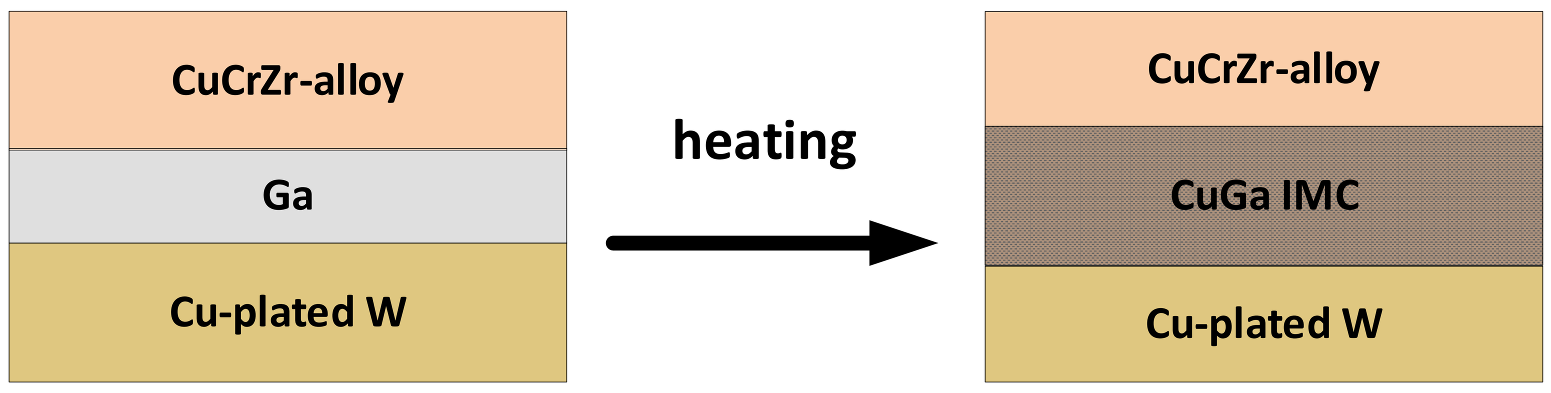

***Fig. 2:** Schematic representation of the joint design for TLP bonding of Cu-plated Tungsten and CuCrZr-alloy (The Cu-Ga IMC is stated for binary intermetallic compounds of the Cu-Ga system).*

In contrast to conventional brazing, the liquid disappears, and a higher melting point phase is formed at the bonding temperature (Fig. 3)

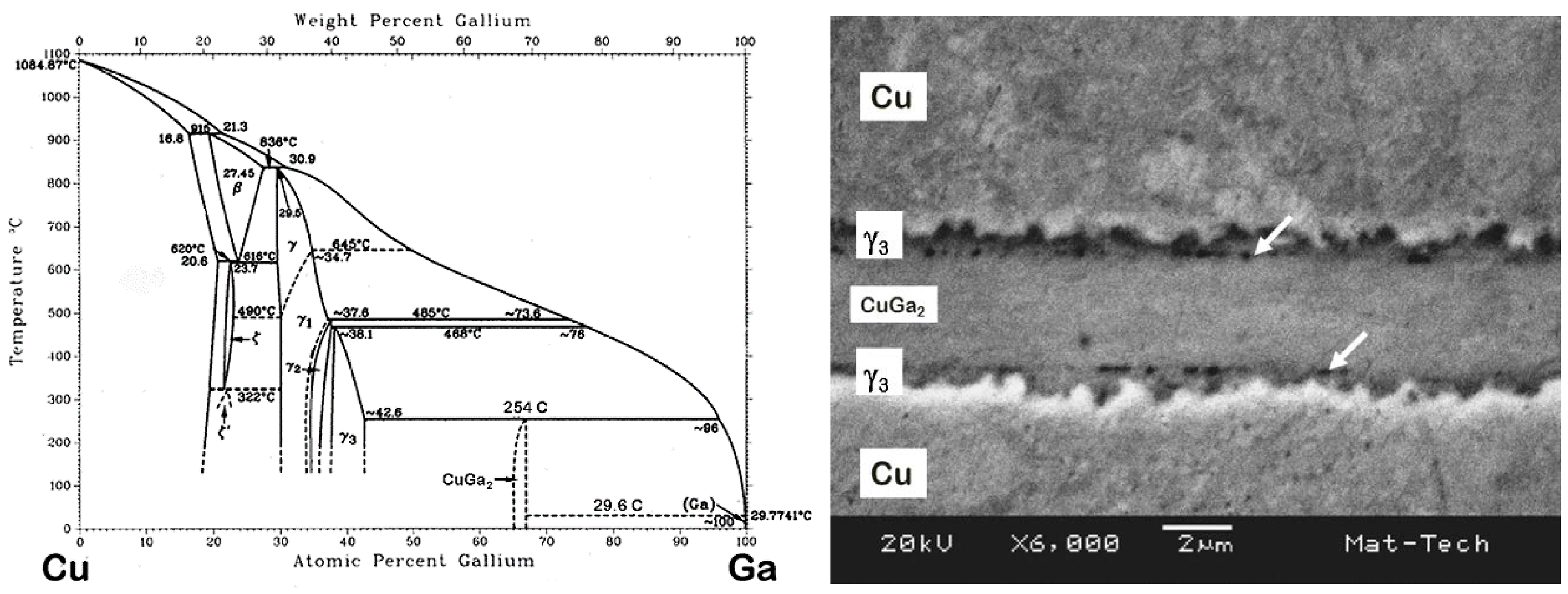

***Fig. 3:** The binary Cu-Ga phase diagram [4] in (a) and b) Secondary Electron Image of the reaction zone in the Cu /Cu joint produced by the TLP bonding technique using Gallium-interlayer (100℃; 4 hours). Location of the original contact surfaces are indicated by arrows.*

Sound bonding can, in principle, be achieved even in air at 250-300 °C which is below oxidation temperature of Tungsten [6].

IV. Concluding Remarks

Joining of Tungsten to the precipitation hardened CuCrZr-alloy can be accomplished at temperatures well below the aging temperature (450-480 °C) of the bronze by means of Transient Liquid Phase Bonding (TLPB) using a Ga-based interlayer.

The use electroplating for application of the Ga-interlayer renders the suggested TLP bonding technique compatible with existing technologies.

To enhance wetting, Tungsten parts should be pre-coated with Copper.

During annealing, the Ga-interlayer reacts with the constituents of the assembly, which facilitates bonding between Cu-plated Tungsten and CuCrZr-alloy.

The resulting joints are capable of service at elevated temperatures.

The proposed approach allows to perform joining in air at temperatures below oxidation temperature of Tungsten, which will significantly lower production costs, as much less expensive equipment (no vacuum or protective gas atmosphere) is required.

V. References

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