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# Development and characterisation of Be/Glidcop® joints obtained by hot isostatic pressing for high temperature working conditions

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**Abstract**

Beryllium is a suitable candidate for plasma facing components (PFC) such as divertor or first wall in the ITER project. Due to their high thermal conductivity, copper alloys are used as the heat sink material. Consequently, use of beryllium requires that it has to be joined to the Cu heat sink by some method. In this study, the joining of beryllium onto the copper alloy Glidcop® is achieved by hot isostatic pressing diffusion bonding (HIPB). This joining technique allows a homogeneous bonding. As direct bonding between Be and Cu alloy induces intermetallics that are deleterious to the joint, an interlayer is placed between the two materials. The interlayer has been chosen regarding the metallurgical structure and the mechanical properties of beryllium relatively to the Glidcop® alloy. This paper describes the structure of joints performed with the help of HIPB at temperature higher than 800°C. 

## 1. Introduction

The joining of beryllium onto copper alloys is necessary for the fabrication of ITER plasma facing or divertor components. The two main competing technologies for the fabrication of such components are Be coating using low pressure plasma spray and joining techniques such as brazing or diffusion bonding. Brazing materials are still in a research and development stage (see for instance [1,2]). The hot isostatic pressing bonding (HIPB) of Be to Glidcop® IGO alloy has been studied for few years at CEA/Grenoble [3]. The first interlayer family used was based on Al deposited onto beryllium. In order to avoid the excessive Al diffusion into copper, different diffusion barriers have been studied [3]. As aluminium has a low melting point, the use of an Al interlayer should restrict the working temperature to 200–300°C. This paper describes the development and characterisation of Be to Glidcop® joining technique using HIPB for high temperature working conditions.

## 2. Junction design: Metallurgical point of view

Copper and nickel are considered as two potential interlayers because of the large intersolubility of these elements with beryllium. The use of copper interlayer was tested [4] but it seems that it restricts the working temperature because of deleterious intermetallic formation (see for instance reference in [1]). Joints performed with nickel have poor resistance also [5]. Zinc, silicon and germanium are known to form no intermetallics with beryllium. However, there is no or very poor solubility of these elements with beryllium. Melting point of zinc is too low for the working conditions, and silicon and germanium are very brittle. Most of the transition elements are immiscible with copper.

From a process point of view, the temperature of the diffusion bonding must not be higher than 850°C, otherwise the intermetallic compounds $AlFeBe_4$ present within the beryllium S65C alloy will be solubilised and

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thus, the Be mechanical resistance will be lowered [6]. The Cu–Ti binary phase diagram [7] shows an intersolubility at temperatures higher than 800°C (Fig. 1). Titanium can solubilise few at.% copper in the α or β phase. The same situation occurs for the solubility of titanium in copper. The Be–Ti binary phase diagram [7,8], reported in Fig. 2, shows that a solid-solution of Be in the βTi phase exists at temperatures higher than 810°C. On the Be rich side of the phase diagram, there are four different intermetallics, some of them with a complex structure [8]. Titanium appears to offer the best choice for an interlayer material.

## 3. Experimental procedure

### 3.1. Materials and sample preparations

The composition of Be S65C and Glidcop® are given in Table 1. The 50 μm thickness titanium foil has a purity of 99.6%, the remaining being essentially oxygen, nitrogen, iron and aluminium. The Be and Glidcop® sample sizes were: $10 \times 10 \times 5$ mm$^3$. The titanium interlayer, the beryllium and Glidcop® alloys were cleaned chemically before the placement in a stainless steel container. When the pile-up Be/Ti/Glidcop® was in place in

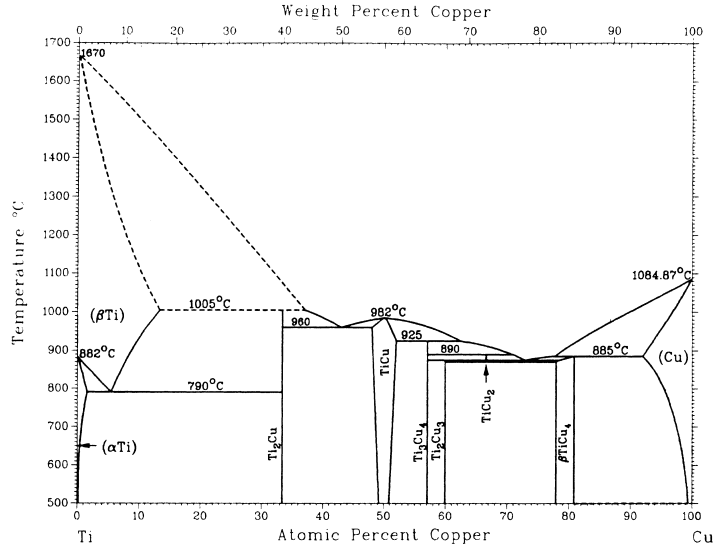


Fig. 1. Ti–Cu phase diagram [7].

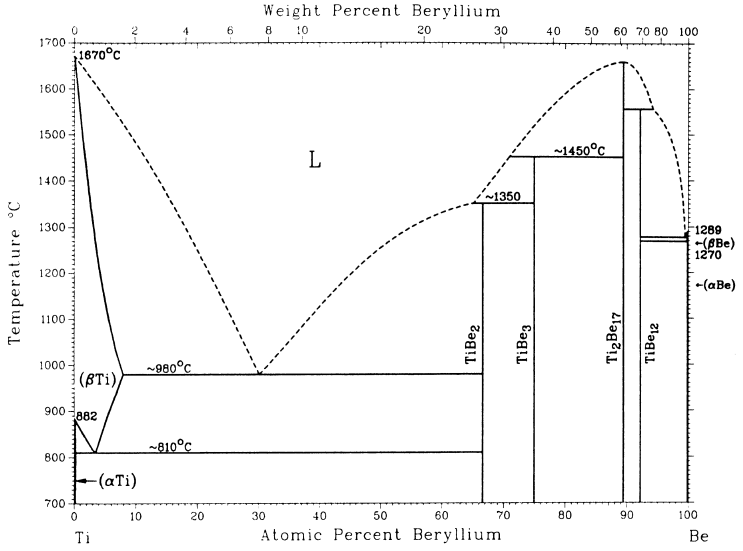


Fig. 2. Ti–Be phase diagram [7].

Table 1
Be (S65C) and Glidcop® (IG0) chemical composition in wt%

| Materials | Chemical elements | | | | | | |
|---|---|---|---|---|---|---|---|
| | Cu | Al | Fe | Pb | B | | |
| Glidcop® (IG0) | 99.51 | 0.25 | 0.0023 | 0.0006 | 0.017 | | |
| | Be | BeO | Fe | C | Al | Mg | Si |
| Be (S65C) | 99.4 | 0.6 | 0.07 | 0.03 | 0.02 | <0.01 | 0.03 |

the container, the different parts of the container were welded under vacuum. The tightness of the containers was checked with a helium test before the HIPB cycle. After the HIPB cycle, the tightness was also checked in order to verify that no leak occured during the joining process. The container was then removed and the joined material cut by electro-discharge machining for metallographic examination and shear testing.

### 3.2. Hot isostatic pressing bonding

Two different HIPB cycles have been tested. The process parameters are reported in Table 2. Two cooling down cycles were performed in order to have different stress relaxation processes at the joint. For the first one, it was performed in 5 h. The second one was carried out in three steps: cooling down to about 400°C followed by a plateau at that temperature and a final cooling down to room temperature.

## 4. Results

### 4.1. Microstructural observation

Fig. 3 gives a typical joint structure observed with an optical microscope. Interdiffusion between beryllium, titanium and Glidcop® has led to six different interlayers and a zone with precipitates in the Glidcop® against the layers. Fig. 4 reports the profile in at.% for Cu, Ti and Be obtained with X-microprobe analysis. There is a gradual interdiffusion between Cu and Ti and also between Be and Ti. The Cu–Ti–Be ternary phase diagram does not exist thus, it is not possible to give a precise description of the phase composition at the joint. In the titanium layer (central part of the profile), there is about 3 at.% Cu and 10 at.% Be. As the solubility of these two elements is very low at room temperature (Figs. 1 and 2), the central part of the profile must be a Ti matrix with precipitation of intermetallics such as $TiBe_2$ or $Ti_2Cu$ or ternary $TiCu_xBe_y$ intermetallic types. The thickness of that layer is about 30 μm. The precipitation should have strengthened the titanium layer. There is some beryllium at the Ti–Cu interface and some copper at the Ti–Be interface. The extent of the titanium beryllides with a Be content higher than 66 at.% is about 15 μm. The extent of the titanium–copper intermetallics with a Cu content higher than 33 at.% is about 20 μm. Thus, the inter-diffusion between copper and beryllium is limited by the titanium interlayer: some beryllium is present in copper and some copper is present in beryllium, both of them at a very low level. Fig. 5 gives an interpretation of the joint structure based on the Cu–Ti and Ti–Be binary phase diagrams (Figs. 1 and 2). Holes into beryllium may have been induced by sample polishing. After the thermal fatigue tests at the Jülich facility [10], cracks occur at the interface of the layer ($Ti_2Cu_3$+ $Ti_3Cu_4$). No cracks have been detected in the titanium beryllide intermetallics.

### 4.2. Mechanical test

The mechanical resistance of the joint was performed using a shear test apparatus described in Fig. 6. The Be is placed in the fixed part and the Glidcop® in the moving one. The junction is located just between the fixed and

Table 2
HIPB cycle parameters

| | Cycle 1 | Cycle 2 |
|---|---|---|
| Heating up to... | 850°C and 100 MPa in 3 h | 850°C and 120 MPa in 3 h |
| Plateau at... | 850°C, 100 MPa during 2 h | 850°C, 120 MPa during 2 h |
| Cooling down to... | – | 400°C and 3 MPa in 2 h |
| Plateau at... | – | 400°C and 3 MPa during 2 h |
| Final cooling to... | RT and 0.1 MPa in 5 h | RT and 0.1 Mpa between 1 and 2 h |

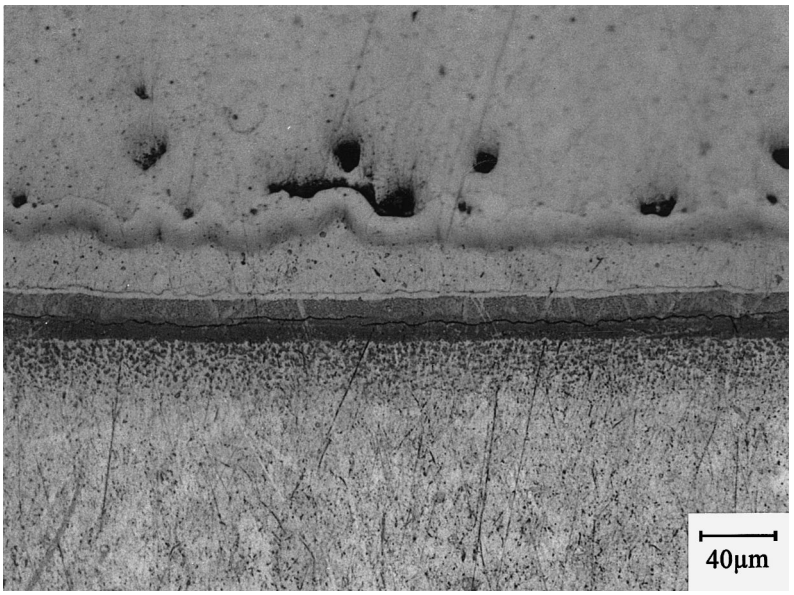


Fig. 3. Interface structure Be/Ti/Glidcop®.

moving parts. The moving part is pulled down in order to obtain a shear at the joint. Shear test has been performed at room temperature for the junctions obtained with the two cycles. The ultimate shear stress was about 30 MPa for the HIPB cycle 1 joint and 108 MPa for the HIPB cycle 2 joint. The rupture shear stress for the base materials i.e. beryllium and Glidcop®, tested in the same conditions, are respectively 268 and 218 MPa. Thus, the ultimate shear strength of the HIPB cycle 2 joint is about 50% of the Glidcop® rupture shear strength measured with the same equipment. The rupture occurs at the interface between Be and the titanium beryllide intermetallics.

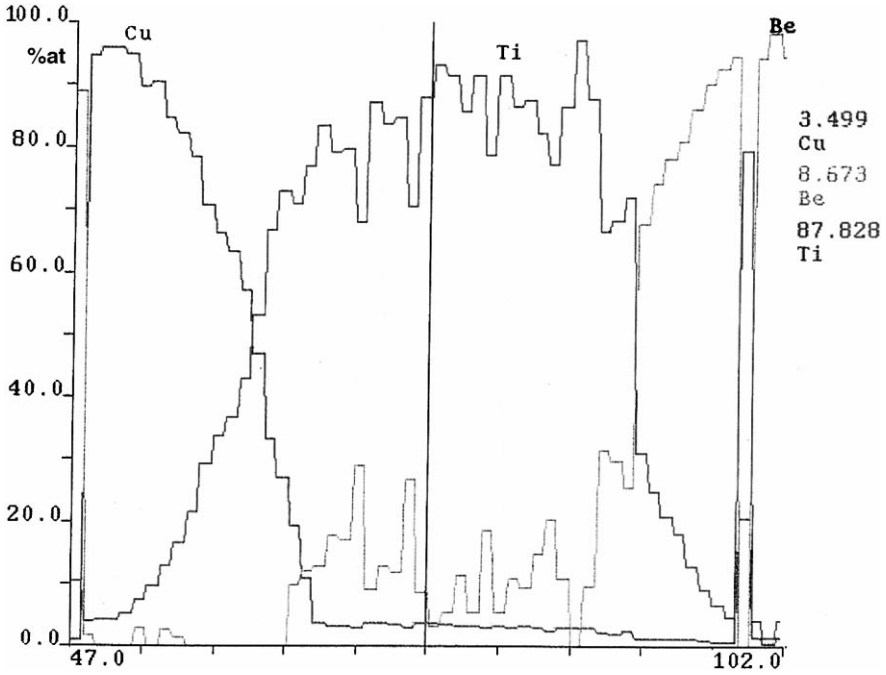


Fig. 4. X-microprobe profile through the junction (the distance between two marks on the $x$-axis is 11 µm).

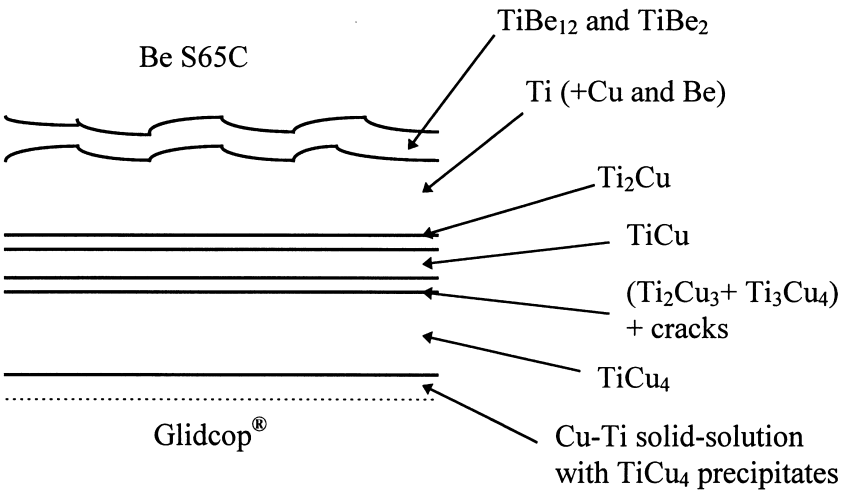


Fig. 5. Schematic phase structure interpretation of the Be/Glidcop® joint.

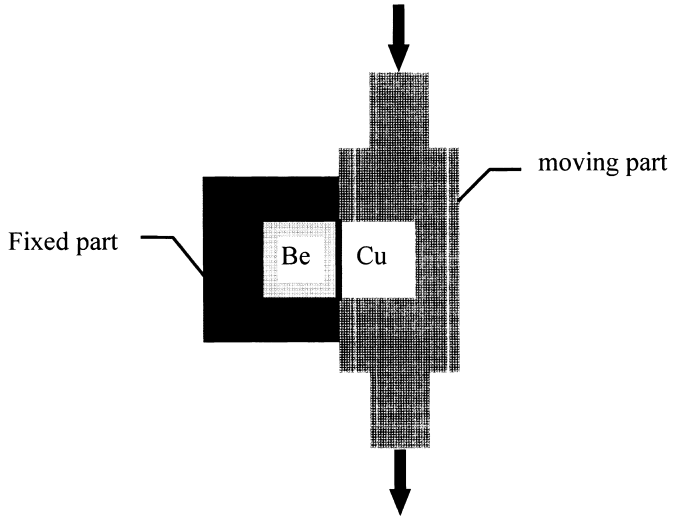


Fig. 6. Principle of the shear test apparatus.

## 5. Conclusion

Titanium interlayer may be used for the fabrication of beryllium/Glidcop® joint. Several regular intermetallic layers are present at the joint after the joining process. Two hot isostatic pressing bonding cycles have been tested. The higher rupture shear stress was obtained with the HIPB performed at 850°C and 120 MPa followed by a gradual cooling down to room temperature. The rupture shear stress is about 108 MPa: that is 50% of the rupture shear stress for Glidcop®. In the present study, only the metallurgical point of view was considered. The residual stress at the joint will be evaluated in the future with finite element modelling. This joining technique was successfully used for the fabrication of two mock-ups: one with a large Be plate and the other one with Be tiles [9,10].

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