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Development of high precision joints in particle accelerator components performed by vacuum brazing

L. Sánchez [a,*], D. Carrillo [a], E. Rodríguez [a], F. Aragón [a], J. Sotelo [b], F. Toral [a]

[a] Accelerator Technology Group, Technology Departament, CIEMAT. Av. Complutense 22 Madrid, Spain
[b] Joining Technologies Plant, AIMEN. C. Relva 27 Porriño (Pontevedra), Spain

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ABSTRACT

This paper resumes the study of the development of high precision joints performed by vacuum brazing as part of the fabrication of accelerating structures and other parts of particle accelerators. The study is focused on the selection of the most suitable parameters for carrying out high quality copper/copper and copper/stainless steel joints such as thermal cycle, filler material, filler grooves design, surface preparation, thickness of Ni plating and joint clearance. The joint characterization was carried out by means of microstructural (OM, SEM) and compositional (EDS) techniques and by leaking test.

1. Introduction

Vacuum brazing (Mathot, 2008) is one of the most common techniques to join accelerating structures (RF cavities) and other related components such as waveguides, flanges or vacuum connectors. In this process, the parts to be joined and the filler alloy are under vacuum and heated to a temperature where the filler melts and flows throughout the joint area by capillary action between the base materials (Ramani, 2005).

In the particle accelerators field, the copper/copper and copper/stainless steel (SS) joints are mainly performed by means of vacuum brazing (Pisent et al., 2004; Dykes et al., 1994; Takahashi et al., 1997), since this process has several advantages:

- Relative to ultra high vacuum conditions that are usually required in particle accelerators: minimum joint contamination, as vacuum brazing is a flux less joining technique. Moreover, the high vacuum during brazing removes oils and oxides more effectively than chemical cleaning.
- In connection with the tight tolerances and high precision required in the pieces: minimum piece distortion, as during brazing the pieces are static and the thermal gradients are low. Low thermal stress since the use of ductile fillers such as Ag/Cu or Ag/Cu/Pd alloys reduce the stress problem in the case of brazing materials with different thermal expansion coefficients (Vaidya et al., 2001).

It is well known that the characteristics of the brazed joints depend mainly on the base materials and the suitable filler selection, but not only. Other parameters such as thermal cycle, brazing temperature, time and vacuum level, joint clearance, surface preparation (cleanliness, roughness and plating) or the design and tolerances of the parts to be brazed are the same importance. This paper describes the study and optimization of Cu/Cu and Cu/SS joints in several components of particle accelerators, especially in RF cavities. The brazed pieces were studied via metallographic examination by means of Optical Microscopy (OM) and Scanning Electron Microscopy with Electron Dispersive Spectroscopy (SEM/EDX). In addition, Helium leaking test was also performed to obtain the vacuum tightness of the Cu/SS joints.

2. Experimental procedure

2.1. Base materials and fillers

The base material of the cavities was high purity oxygen free electronic grade copper (OFE Cu) with a content of impurities less than 40 ppm. It was supplied by Luvata in the form of extruded rods.

The connectors used for the water cooling circuit were supplied by Swagelok and produced in SS AISI 316 L with a composition (wt%) of <0.03 C, 16–18 Cr, 10–14 Ni, 2–3 Mo, <2.25 (Mn, P, S, Si and N), Fe bal.

Two Ag based filler alloys in form of wire were selected for brazing both Cu/Cu and Cu/SS joints:

- Ag/Cu eutectic alloy (72 Ag/28 Cu, wt%). Melting temperature 780 °C. Wire diameter of 1 mm, supplied by Castolin Eutectic.

* Corresponding author. Tel.: +34 914962555; fax: +34 913466260.
E-mail address: laura.sanchez@ciemat.es (L. Sánchez).

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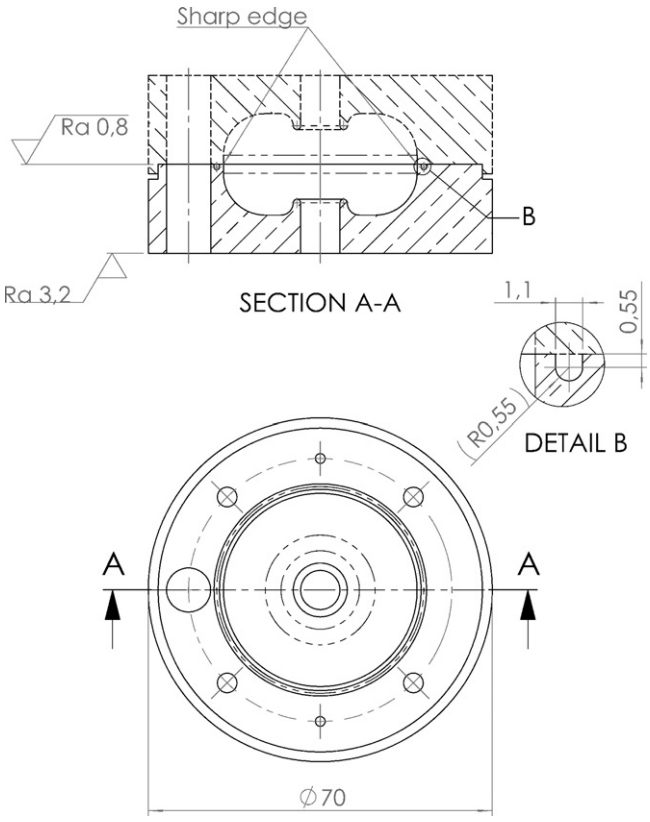

Fig. 1. Brazing surface and cross section of the cavity A (dimensions are in mm).

- Ag/Cu/Pd alloy Pallabraze 810 (68.5 Ag/26.5 Cu/5 Pd, wt%). Melting range 807–810 °C. Wire diameter of 0.5 mm, provided by Johnson Matthey.

2.2. Machining, surface preparation and cleaning procedure

2.2.1. RF cavities

The cavities (two high precision OFE Cu cups) were made by turning, drilling and milling operations using CNC machines. The cups were rough machined, stress relieved in air for 1 h at 220 °C and fine machined to obtain the final dimensions. Two different types of cavities were performed: the cavity A (one set) and the cavity B (two sets). In both cavities the roughness of the brazing surfaces was 0.8 μm (Ra) which has been used by other authors in the vacuum brazing of accelerating structures (Berra et al., 2000; Jensen, 2002).

2.2.1.1. Cavity A. Fig. 1 illustrates a diagram of the cross section and the brazing surface of the cavity A. It also shows two concentric grooves with a diameter of 1.1 mm where the filler was placed.

2.2.1.2. Cavity B (B1 and B2). In this case the brazing surface was designed after studying the results obtained in the cavity A: in order to avoid overflow of the brazing alloy, the diameter of the filler was reduced to 0.5 mm and the distance of the groves to the end of the cavity was increased as Fig. 2 shows.

2.2.2. Vacuum connectors

The vacuum connectors were of SS, and it is well known that an adherent chromia scale is formed on the surface, protecting the material against corrosion and high temperature oxidation (Meetham and Voorde, 2000). It is even stable at the brazing conditions and acts as a barrier for the filler wettability (Kozlova et al., 2008). In order to increase the surface wettability the SS must be plated by another metal such as nickel (Shein et al., 2003).

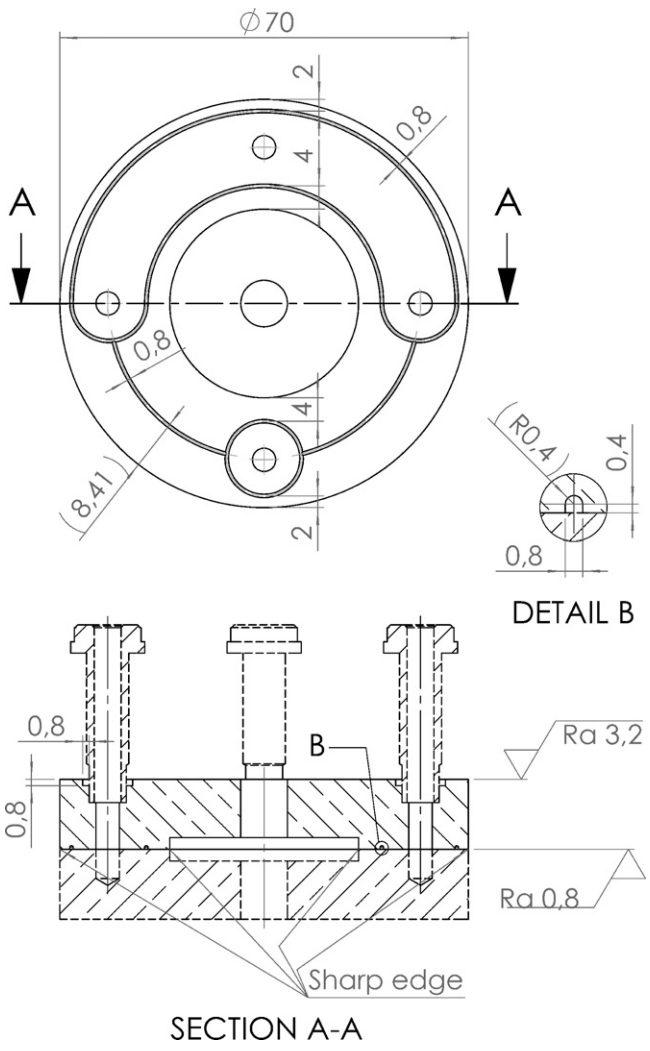

Fig. 2. Brazing surface and cross section of the cavity B and connectors for the cooling circuit (dimensions are in mm).

The connectors used in the cavity B1 were Ni plated by electroless, obtaining coating with a thickness about 20–30 μm. As will be discussed hereafter, the Cu/SS joint in the cavity B1 was not totally satisfactory, so the connectors of the cavity B2 were electroplated in a Wood's solution (Durney, 1984), obtaining a plating thickness about 3–4 μm. Finally, with the aim to evaluate the influence of the joint clearance in the quality of the brazed joints, this was adjusted to 5–25 μm, in agreement with the advice given by other authors (Ramani, 2005).

2.2.3. Cleaning procedure

The initial cleanness of the base materials is extremely important since the presence of contaminants or oxides prevents the wetting of the filler alloy. Cavities and connectors were cleaned using acid detergent in ultrasonic bath, rinsed with demineralised water and ethanol and final dried with filtered air.

2.3. Brazing procedure

Before brazing, the filler alloy was introduced into the grooves and the cavities were aligned by alumina tubes and fixed by molybdenum wire. In order to ensure capillary flow of the molten filler, a