ELECTRON BEAM WELDING AND BRAZING CHARACTERIZATION FOR SRF CAVITIES

N. Valverde Alonso *, S. Atieh, I. Aviles Santillana, S. Calatroni, O. Capatina, L. Ferreira, F. Pillon, M. Redondas Monteserín, T. Renaglia, K. Schirm, T. Tardy, A. Vacca,
CERN, Geneva, Switzerland

INTRODUCTION

In the framework of the SPL R&D effort at CERN, development design efforts study the joining of dissimilar metals: bulk niobium for the superconducting RF cavities and stainless steel (316LN) or titanium alloys (Ti-6Al-4V and Nb55Ti) for the cryostats. Joining techniques of electron beam welding (EBW) and vacuum brazing are particularly important for these applications. These processes have been used in the accelerator community and developed into generally accepted "best practice". Studies were performed to update the existing knowledge, and comprehensively characterise these joints via mechanical and metallurgical investigations using modern available technologies. The developed solutions are described in detail, some currently being applied uniquely at CERN.

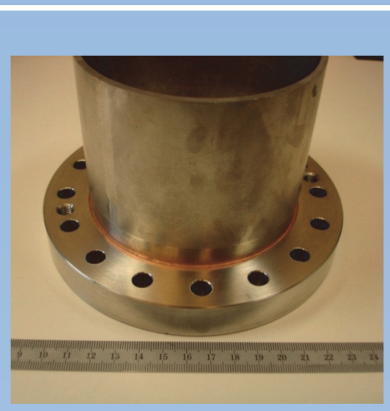
One of the main objectives of the SPL R&D effort at CERN is to develop 704 MHz bulk niobium β=1 elliptical cavities operating at 2 K with an accelerating gradient of 25 MV/m and to test a string of four cavities in a cryo-module. The 5-cell cavities are made up of bulk niobium (RRR>300) and are equipped with SS flanges. The half-cells are shaped by spinning and assembled together with the cut-off tubes via EB welding

VACUUM BRAZING Niobium to Stainless steel

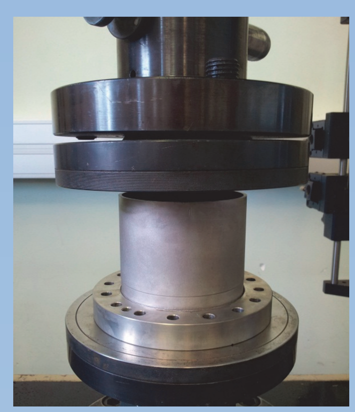
The niobium cavity is equipped with stainless steel flanges, connected to the niobium body by vacuum brazing. Three different campaigns of tests have been carried out to study the suitability of this joint for the SPL cavity at CERN.

Validation campaign 1:

- Ultrasonic examination
- Leak test
- Thermal shock liquid N_2 (x5)
- Ultrasonic examination
- Leak test
- Electropolishing (200 µm)
- HT (600°C/24h)
- Electropolishing (20 µm)
- Leak test
- Ultrasonic examination
- Thermal shock liquid N_2 (x5)
- Ultrasonic examination
- Leak test
- Shear test (30 KN)
- Leak test
- Ultrasonic examination
- Assembly test
- Metallographic examination
- SEM assesment + EDS
- Fractography

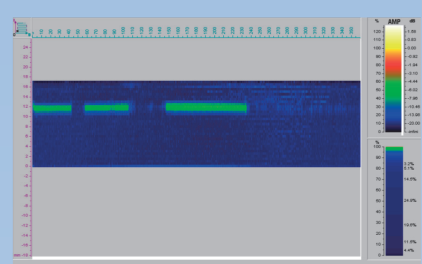


Brazed sample-test 1. Nb tube brazed to SS flange with Cu as filler metal

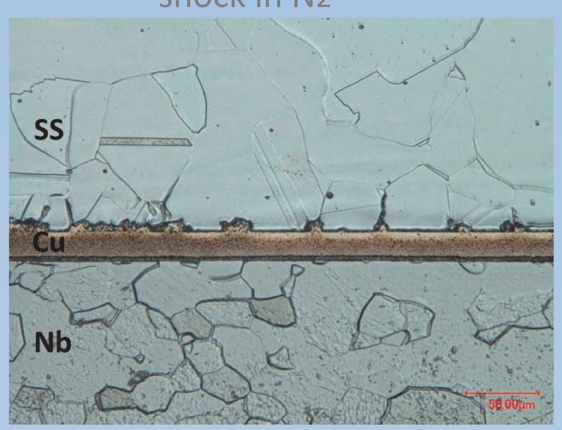


Brazed sample during shear test

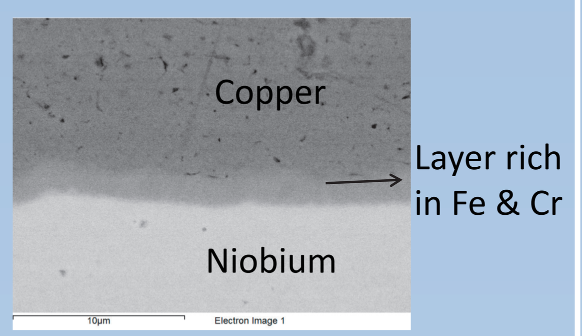
Brazed sample during thermal shock in N2



Ultrasonic examination of the brazed joint



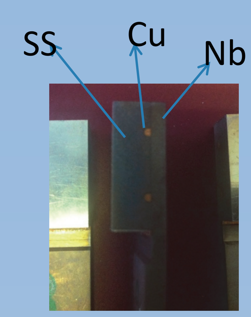
Metallographic observation of the brazed joint



SEM image of the interface Nb-Cu Backscattered detector image

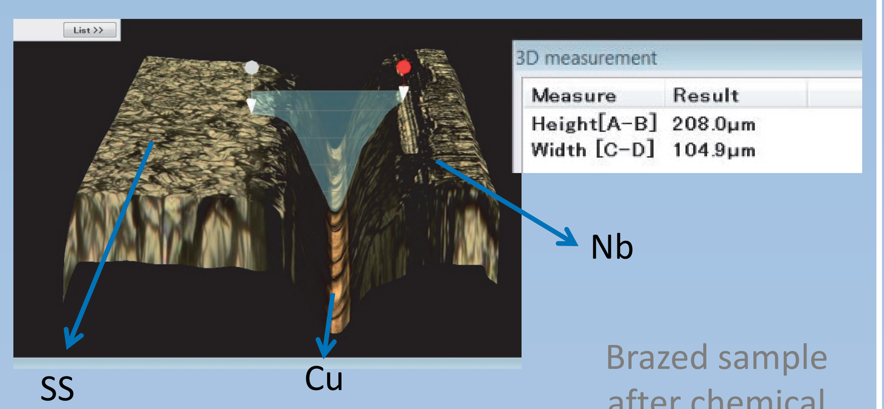
Validation campaign 2:

to study the behaviour of the brazed joint when submitting the assembly to a chemical polishing treatment (40% HF, 60% HNO_3, 85% H_3PO_4 (1:1:2)).

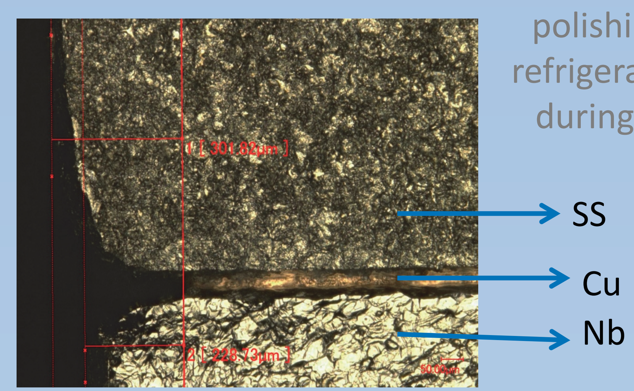


Brazing sample-test 2. SS plate brazed to SS plate with Cu as filler metal

Samples 1-5 → Bath refrigerated (12°C-15°C).
Samples 6-10 → Bath non refrigerated: (21°C-25.4 °C)



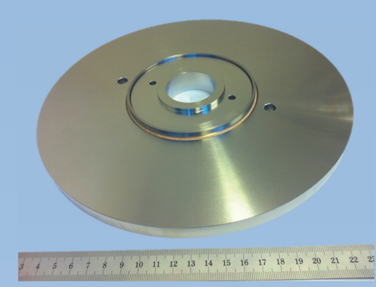
Brazed sample after chemical polishing. Non refrigerated bath during 20 min



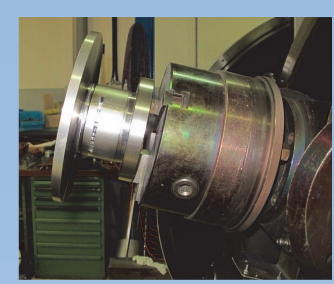
The bath removed ~ 300 µm of Cu
The bath attacks more the Nb than the SS

Validation campaign 3:

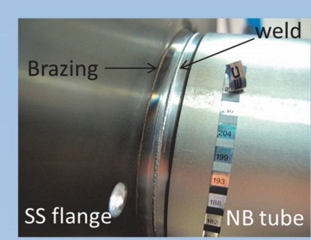
to study if the heat produced during EB welding could deteriorate a brazed joint situated in the vicinity of the EB weld. For this campaign we have carried out the brazing of a stainless steel flange to a niobium tube and then we have EB welded a niobium tube to the previous assembly.



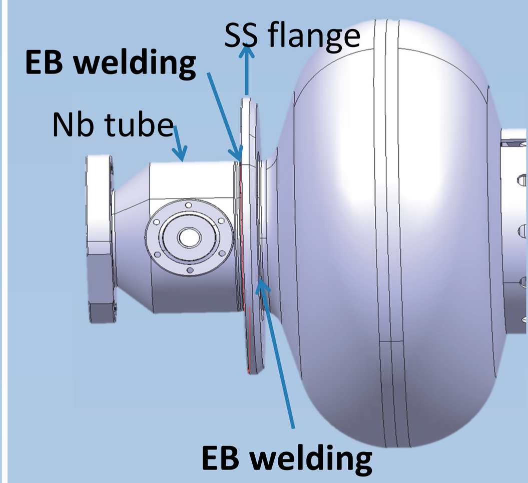
SS flange brazed to Nb tube with Cu as BFM



EB welding a Nb tube to the brazed piecee. The weld is located 4.5mm from the brazedjoint



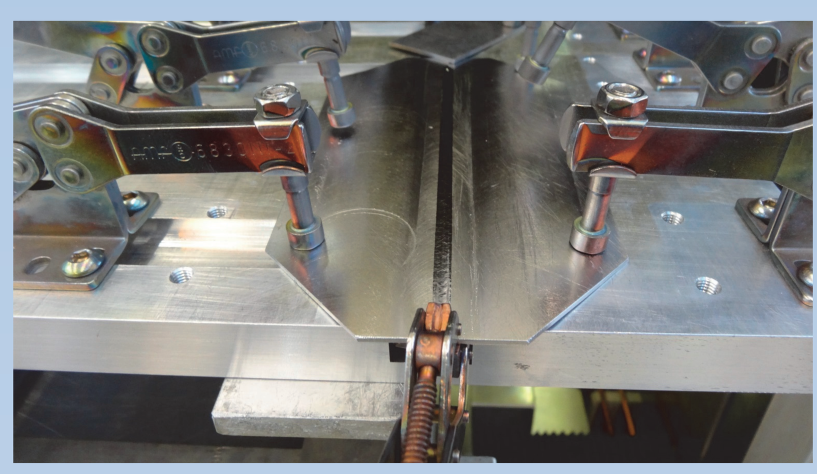
Sample after EB welding



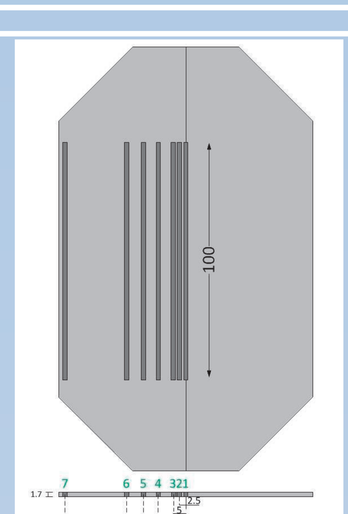
SPL cavity with the cryostat connection flange

EFFECT OF EBW VACUUM LEVEL ON RRR VALUE

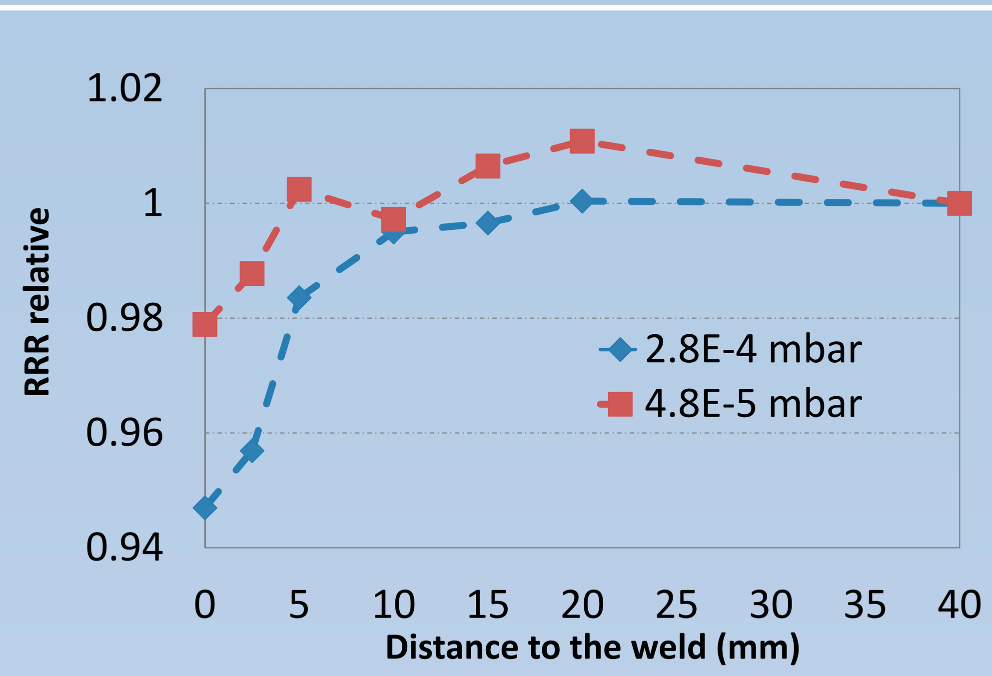
As welding under vacuum better than $5x10^{-5}$ mbar is recommended for welding SRF cavities, such an EBW machine was commissioned at CERN 2 years ago. Welding tests have been performed on it at $4.8x10^{-5}$ mbar (60kV, 12 mm/s, 45 mA) and on a second welding machine at $2.8x10^{-4}$ mbar (60 kV, 12 mm/s, 37 mA) to confirm that the degradation of RRR during welding depends on vacuum level.



NB sample after EB welding



Sketch of the position from where RRR samples were subtracted



The graph shows the RRR of each sample relative to the RRR at 40 mm from the weld seam (reference). There is a slight reduction of the RRR value in the weld area in both cases, always less than 5 %. As expected, the reduction of the RRR is lower when welding in the $5x10^{-5}$ mbar vacuum range.

EBW OF DISSIMILAR METALS

In SRF cavities it is common to find Nb – Ti, Nb-NbTi, Ti-NbTi transitions mainly because the cryostat is normally fabricated in titanium. Three different electron beam welding transitions have been characterized:

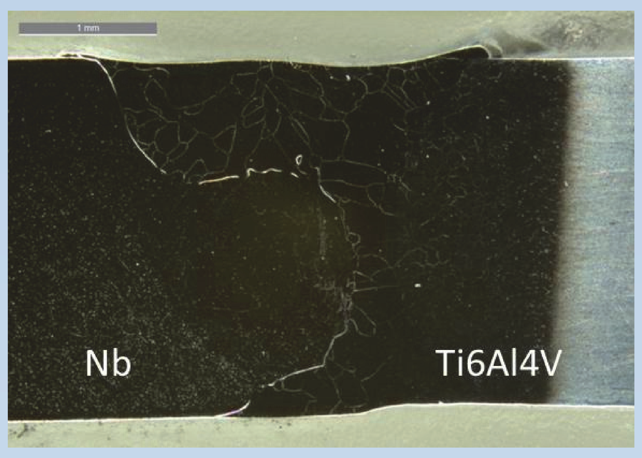
- Nb to Nb55Ti alloy
- Nb55Ti alloy to Ti grade 5 (TI6Al4V)
- Nb to Ti grade 5 (Ti6Al4V)

Results presented are after heat treatment (600ºC/24h)

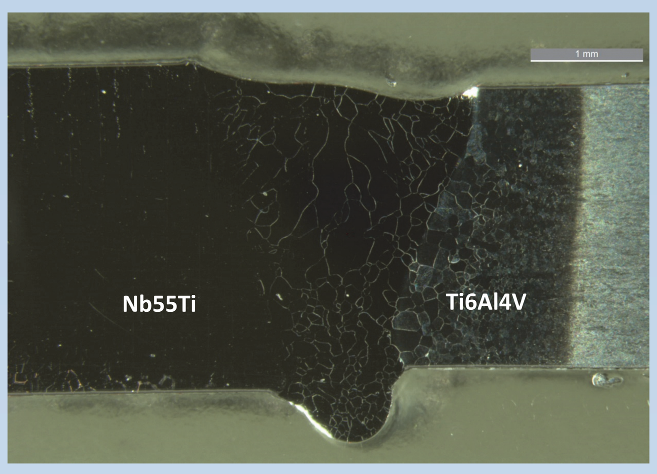
Despite the fact that niobium and titanium have total solubility, the large difference in melting temperatures and thermal conductivity makes a challenge performing a correct weld of these dissimilar metals.

Welding parameters :

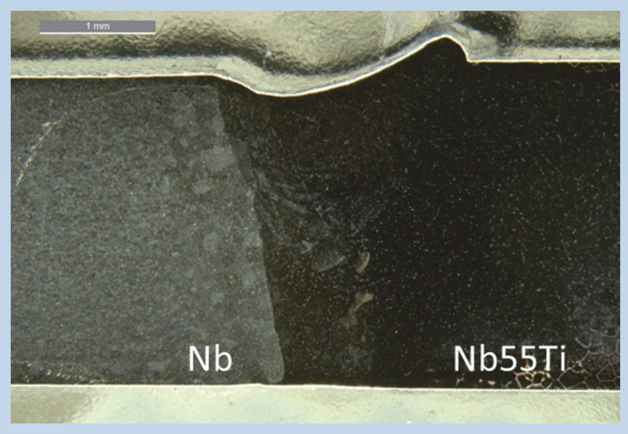
	Nb-Nb55Ti	Nb-Ti 6Al4V	Ti6Al4V-Nb55Ti
Beam potential	60 kV	60 kV	60 kV
Beam current	34 mA 15 mA tacking	33 mA 18 mA tacking	18 mA 12 mA tacking
Offset	0.5 mm in Nb	0.4 mm in Nb	0.3 mm in Nb55Ti
Speed	16.7 mm/s	16.7 mm/s	12 mm/s



Macrograph of the EB weld
Nb – Ti6Al4V



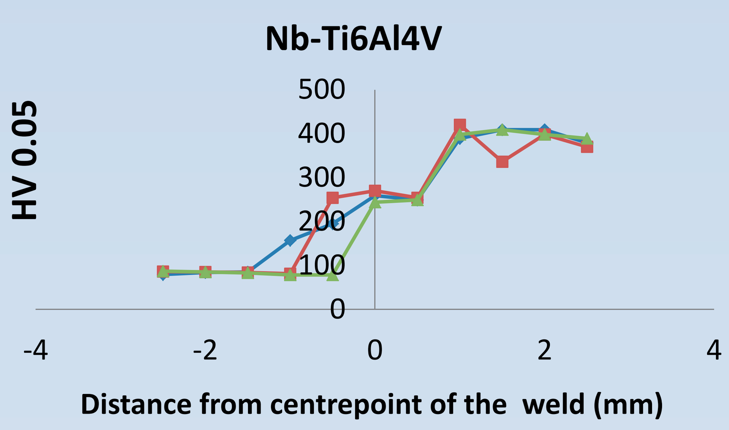
Macrograph of the EB weld
Nb55Ti – Ti6Al4V



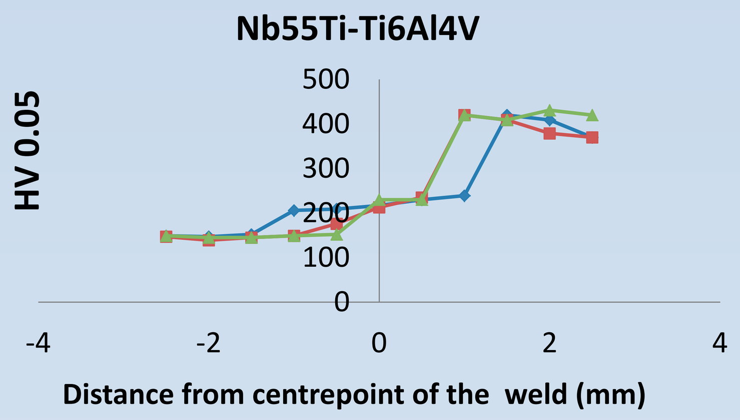
Macrograph of the EB weld
Nb-Nb55TI

Tensile tests results of the EB welds Nb-NB55Ti and Ti6Al4V-Nb55Ti :

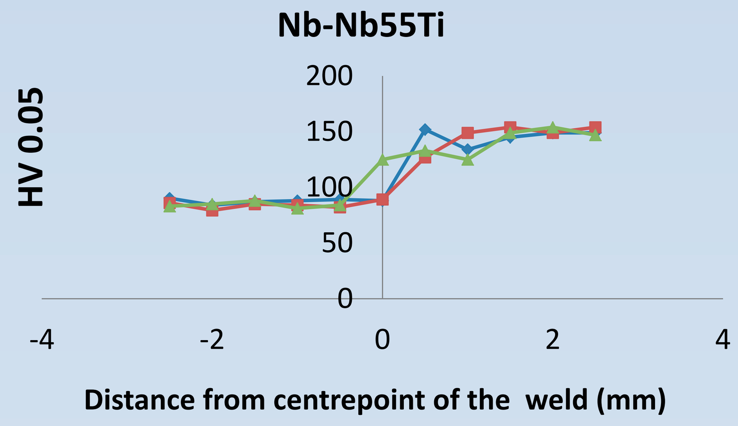
	Nb-Nb55Ti	Ti6Al4V-Nb55Ti
UTS [Mpa]	219 ± 4	488 ± 10
A%	30.5	19.4
Broke in	Nb	Nb55Ti



Hardness profle across the weld Nb-Ti6Al4V



Hardness profle across the weld Nb55Ti-Ti6Al4V



Hardness profle across the weld Nb-Nb55Ti

*nuria.valverde@cern.ch