



ENGINEERING
DEPARTMENT

PS Booster magnets Task Force

Today's understanding of the failure modes

- Summary of the inspections carried out to date
- Illustration of the experimental approach
- First outcomes, commonality of phenomena
- Next steps

Meeting 1 – 21.03.2023 – Subtask-2: Analysis and understanding of the failure modes

Stefano Sgobba and Ana Teresa Perez

[EDMS_2866091](#)

Summary of the inspections carried out to date

- Sample #1: Non-leaking joint from PSB main **quadrupole** operated during 50 years
- Sample #2: Non-leaking joint from PSB main **quadrupole** commissioned and operated only 2 weeks in 2022
- Sample #3: Non-leaking joint from PSB bending **dipole** installed until LS2 from another supplier

Experimental approach

- Sequence of non-destructive examinations by computed microtomography (CT)
- Aiming at judging (qualitatively) the overall soundness of the brazed joint, identify possible incipient leak paths and select the cutting planes
- Followed by destructive examinations, microscopic observations and microanalysis

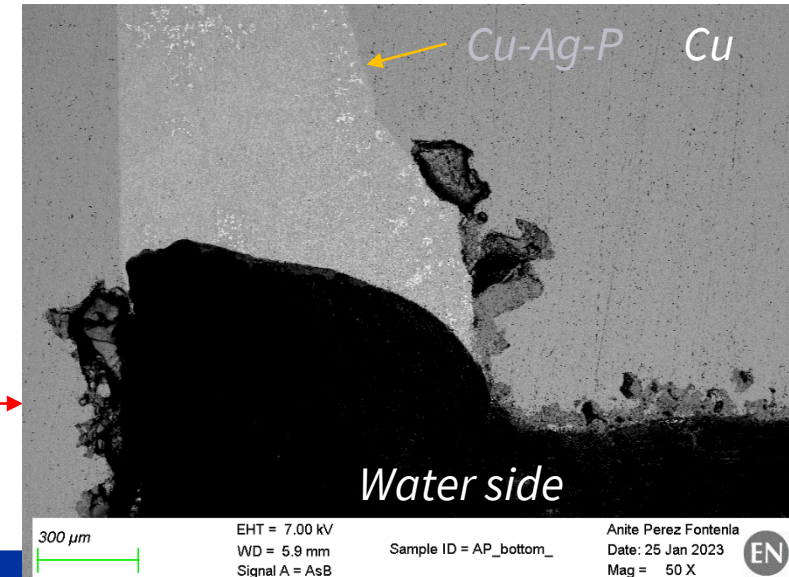
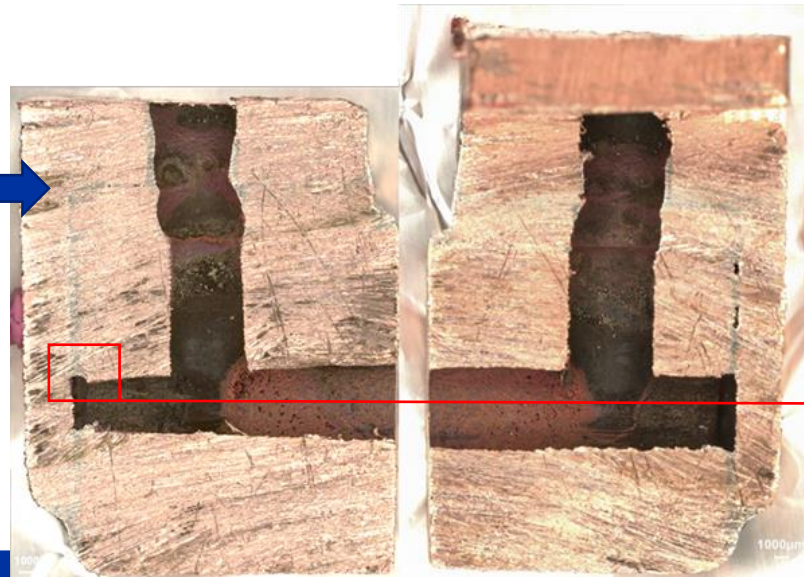
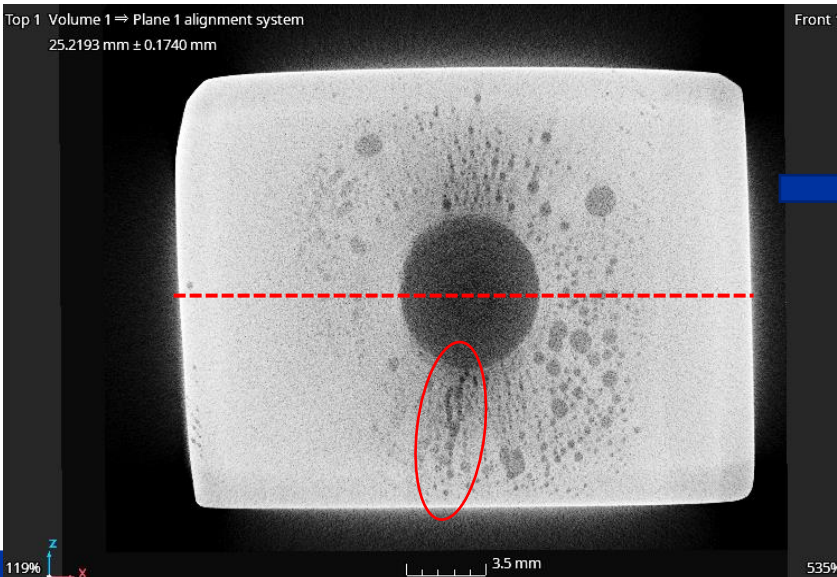
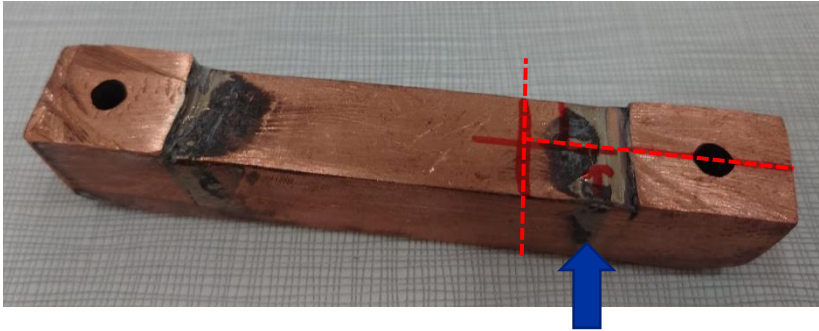
**Sample #1: Non-leaking joint
From PSB main quadrupole
50 years in service
EDMS 2817755**

Inspection procedure:

1. NDT → Definition of the cutting plane/s based on CT results
2. Dry cutting → To avoid exogenous contamination
3. Chemical analysis and microscopic examination
4. Mechanical polishing → To assess the brazed interfaces status

Summary of observations:

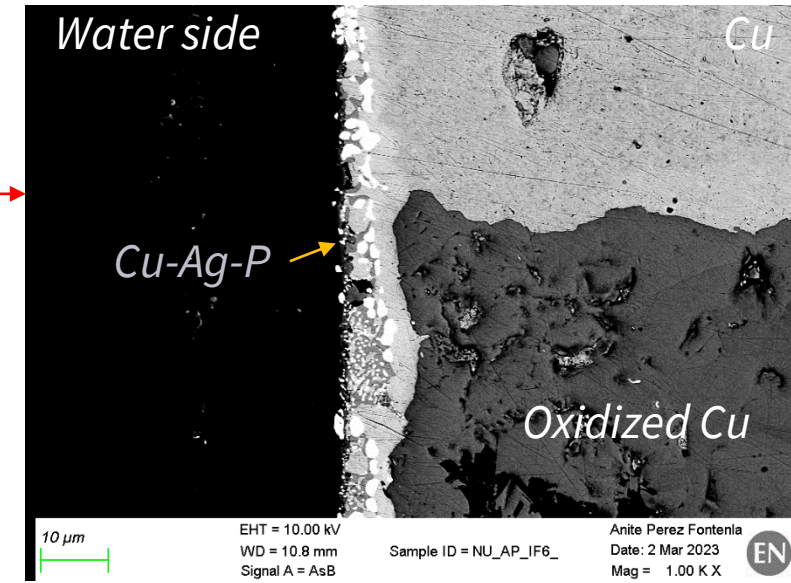
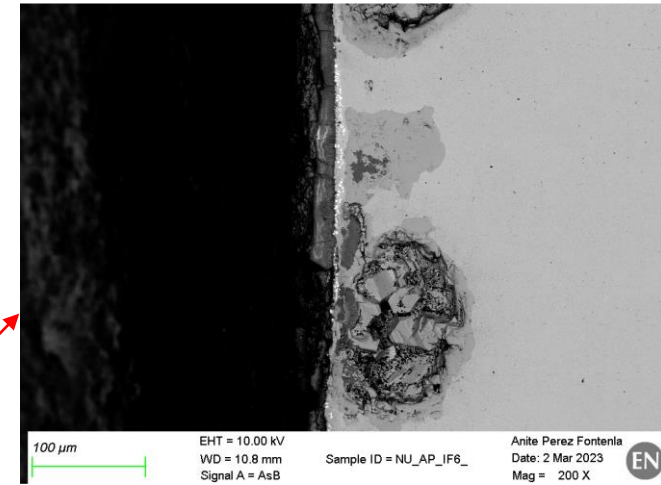
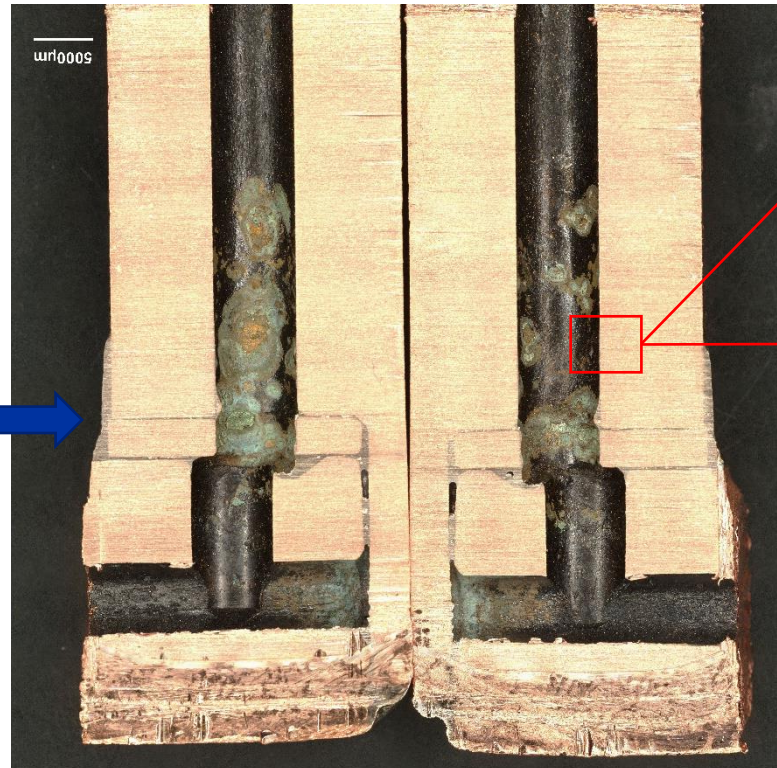
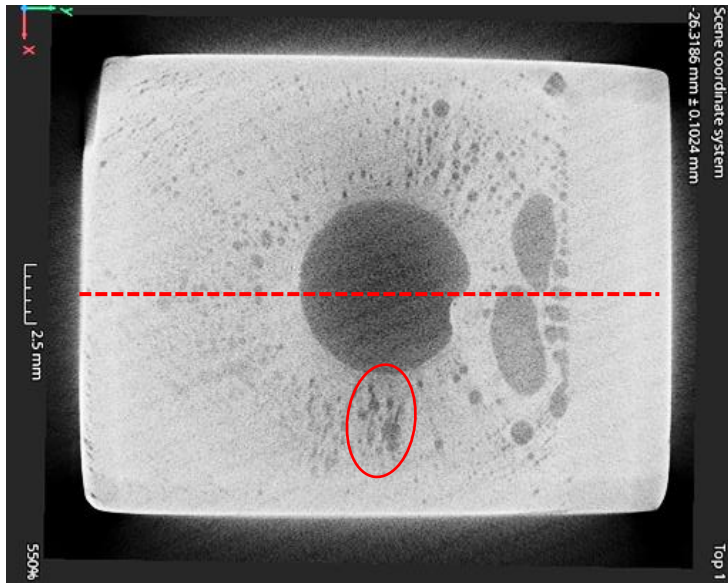
1. NDT (voxel size= 21 μm)
 - Brazing interfaces present numerous cavities and discontinuities
 - Radially aligned features are clearly visible
2. Chemical analysis:
 - Cu-Ag-P braze metal is confirmed and Cd traces (?) were detected punctually
 - S is univocally present locally on the corrosion products (up to 5.5 wt. %)
3. Microscopic examination:
 - The bulk Cu is attacked and large gaps are visible at the vicinity of the brazing alloy
 - The oxidation of the Cu phase within the braze material varies depending on the area
 - It is likely that the Cu has been selectively corroded due to galvanic corrosion phenomena



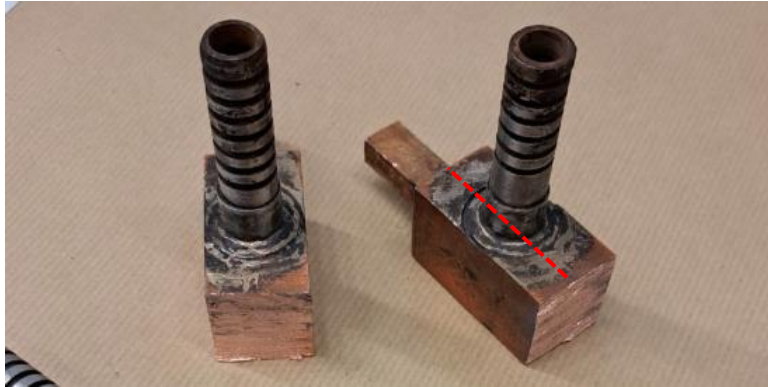
**Sample #2: Non-leaking joint
From PSB main quadrupole
2 weeks in service (2022)
EDMS 2855110**

Summary of observations:

1. NDT (voxel size= 21 μm):
 - Brazing interfaces present numerous cavities and discontinuities
 - Radially aligned features are slightly visible
2. Chemical analysis:
 - Traces of “S” well below 1 wt. % \rightarrow much lower than samples that have been in service for longer periods
3. Microscopic examination:
 - Same type of corrosion phenomena
 - Lower progression

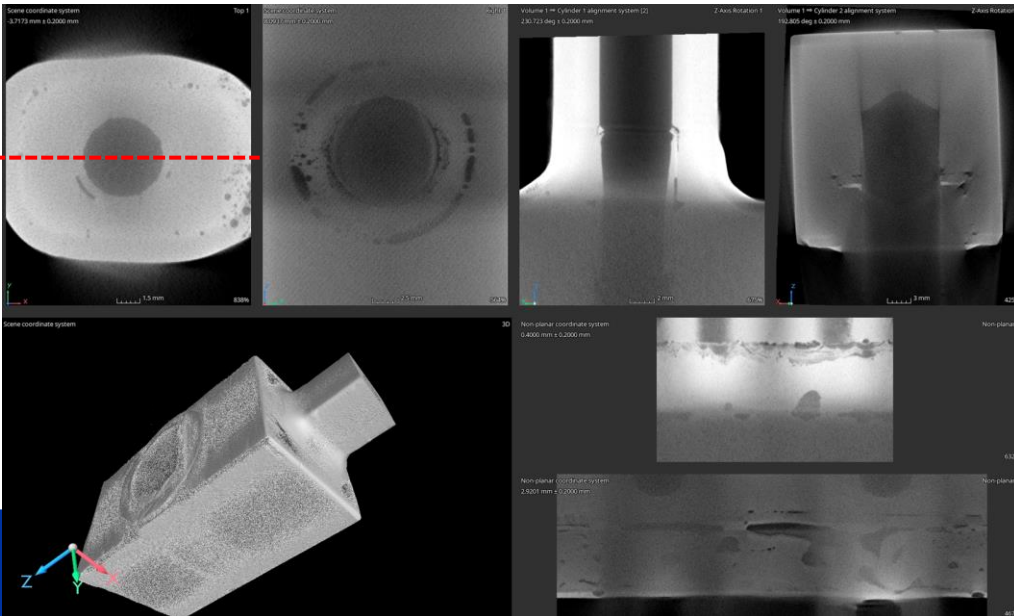
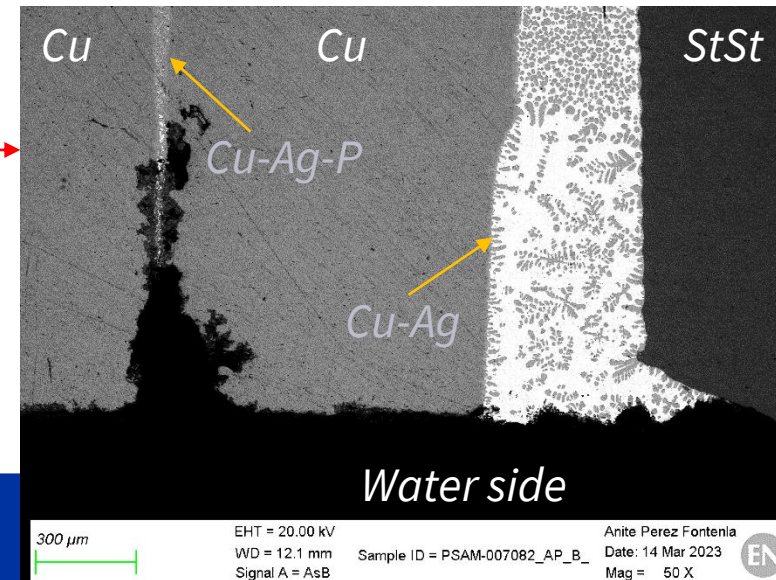
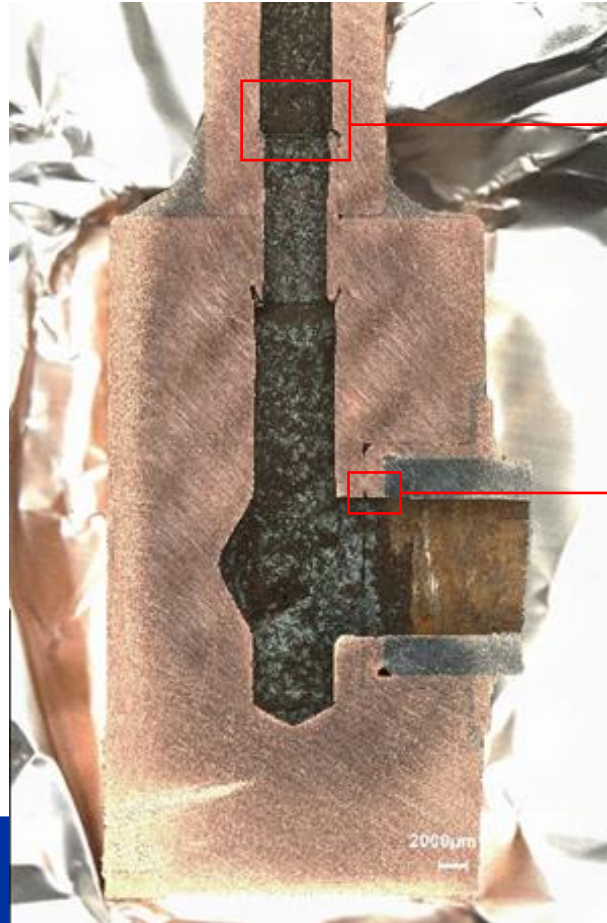


Sample #3: Non-leaking joint From PSB bending dipole Installed until LS2 EDMS under preparation



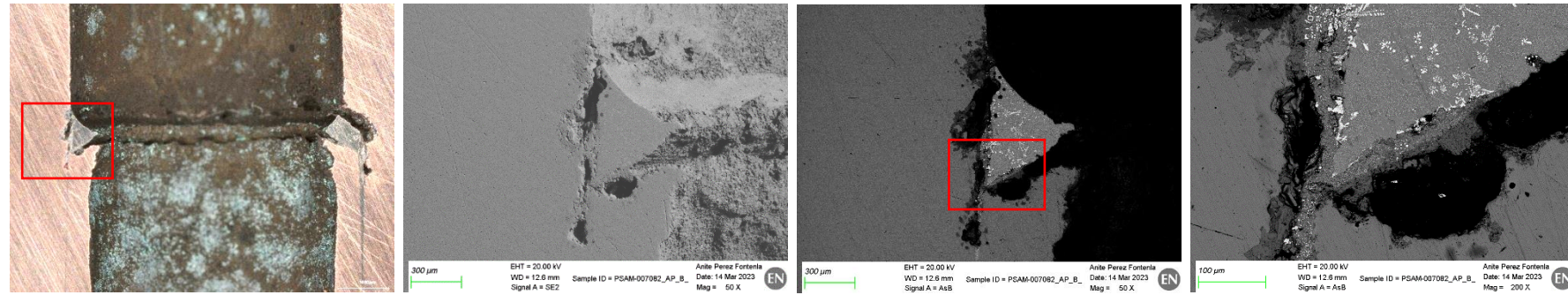
Summary of observations:

1. NDT (voxel size= 40 μm):
 - Brazing interfaces present numerous cavities and discontinuities
2. Chemical analysis:
 - "S" (up to 5.5 wt. %)
3. Microscopic examination:
 - Same corrosion phenomena
 - Cu-Cu joints (Cu-Ag-P brazing) highly affected
 - Cu-StSt joint (Cu-Ag brazing) less affected



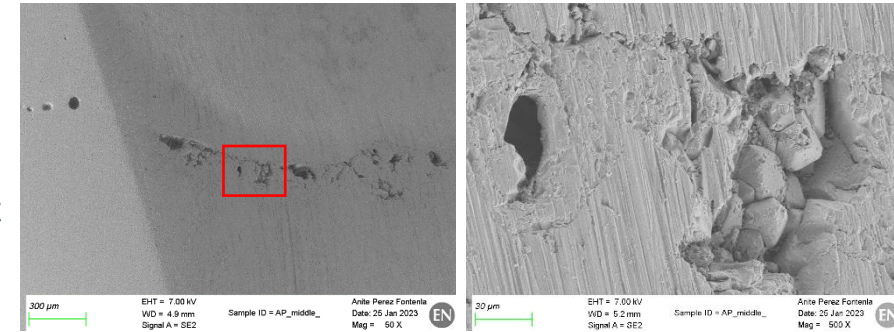
Summary

- The state of various non-leaking brazed joints from the PSB cooling circuit were investigated via NDT and microscopic means;



What was observed?

- Corrosion selectively attacks Cu at the interface with the braze and the Cu within the braze metal;
- As corrosion progresses, the Cu grain structure is revealed and in some sites a large gap is formed;
- Phenomena practically not visible associated to Cu-Ag braze alloy used to join the Cu with StSt;
- Evidence of “S” within the corrosion products is confirmed in higher or lower (traces) amount depending on service time. The origin of the “S” contamination is unclear for the moment;



What is known?

- Examples of Cu-Ag-P brazed joints presenting similar corrosion were found in papers about transformers and tap water ducts. In those cases sulphide-containing species in the water was reported as the main cause of the attack;
- Brazed joints fabricated from a high-Ag filler, that contained no “P”, exhibited no corrosion when exposed to the same sulphide environment;
- Material providers state in their technical data sheets the suitability of the Cu-Ag-P braze for the Cu-Cu joints but remark the importance to avoid exposure to “S” compounds;
- Effect of T on corrosion rate measured for several environments

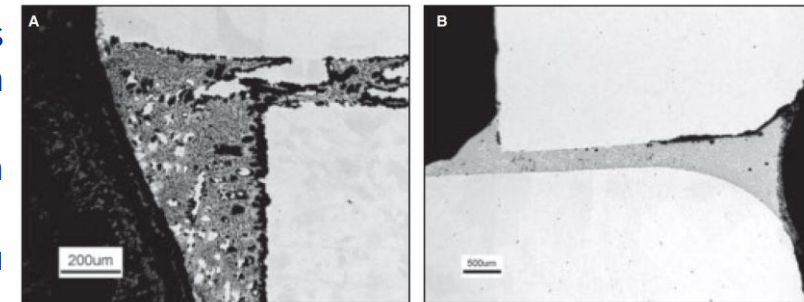


Fig. 4 — Cross-sectional views of damaged brazed joints. A — Severe interfacial attack and attack within the braze; B — severe interfacial attack from the air side with limited interfacial and braze metal attack from the water passage.

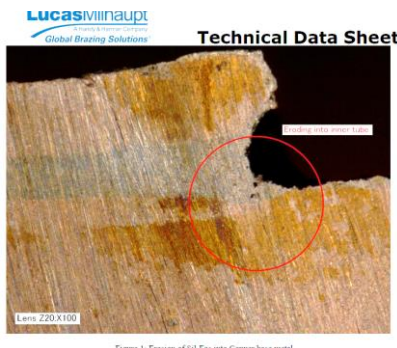
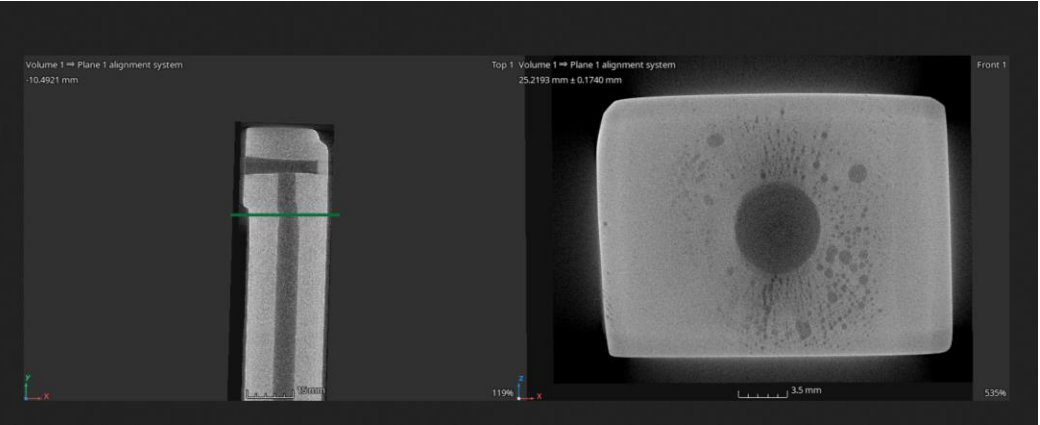


Figure 1 Erosion of Si-Foil into Copper base metal

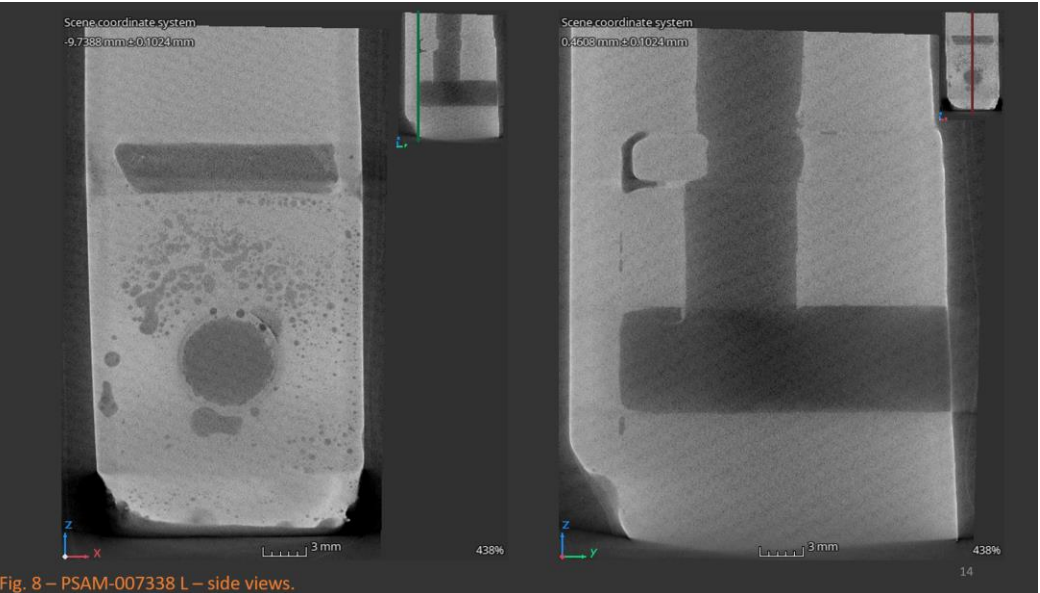
Poor quality of the brazed joints

- Aggravating factor?

Sample #1



Additional samples (tests ongoing)



Sample #2

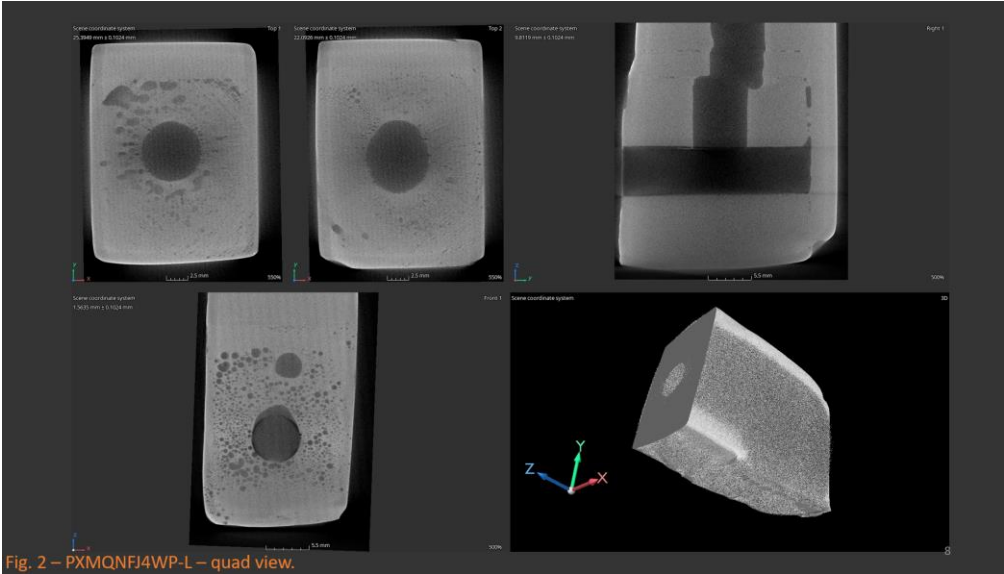


Fig. 2 – PXMQNFJ4WP-L – quad view.

Sample #3

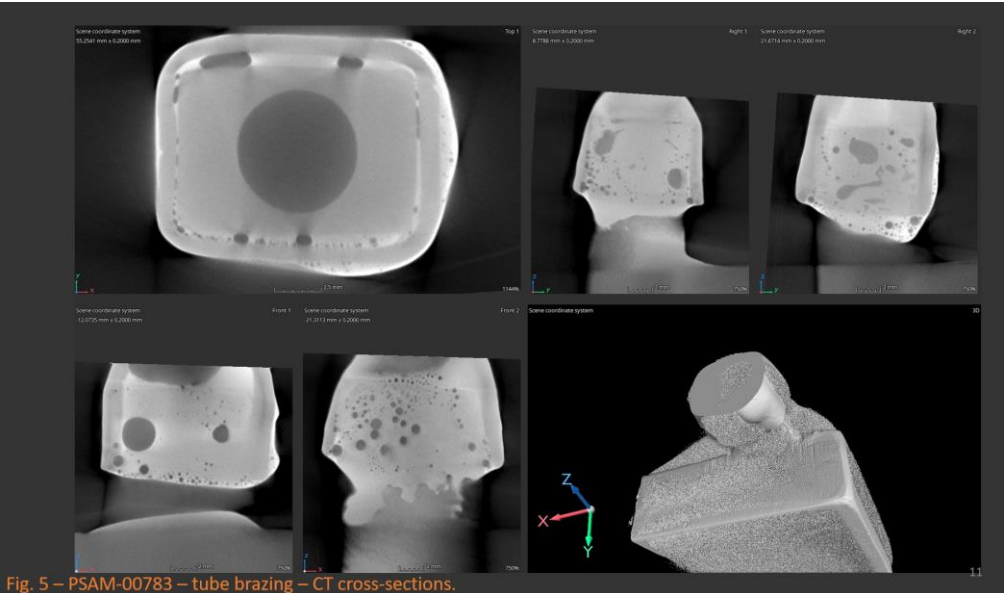


Fig. 5 – PSAM-00783 – tube brazing – CT cross-sections.

Summary

Sample #1



Sample #2



Sample #3



	Sample #1	Sample #2	Sample #3	Additional samples
Sample from	PSB main quadrupole	PSB main quadrupole	PSB bending dipole	PSB main quadrupole
Time in service	50 years	2 weeks	Until LS2	Until LS2 ??
Status	Non-leaking			
Interface aspect	Bulk Cu selectively attacked			-
Sulphur content	Up to 5.5 wt. %	Below 1 wt. %	Up to 5.5 wt. %	-
CT reports	<u>2817755</u>	<u>2824484</u>	<u>2825737</u>	<u>2847250</u>
Microscopy reports		<u>2855110</u>	Under preparation	-

Additional samples

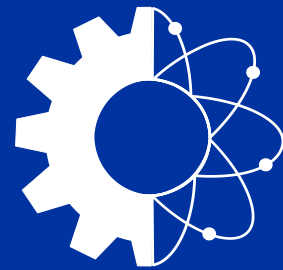


First outcomes, commonalty of phenomena

- Selective corrosion of the Cu at the interface with the braze metal
- As above, of the Cu-rich phases within the braze metal
- Galvanic effects, crevice corrosion phenomena
- Effect of the filler
- Aggravating factors: sulphide-induced events?
- Poor quality of the brazed joints

Next steps:

- Three additional non-leaking samples from main quadrupole already inspected by CT;
- Cutting and microscopic inspection will follow with identical procedure to gain understanding of the corrosion mechanism and have more statistics about the joints state



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