Preparation of Be/Cu modules and their high heat flux tests in China

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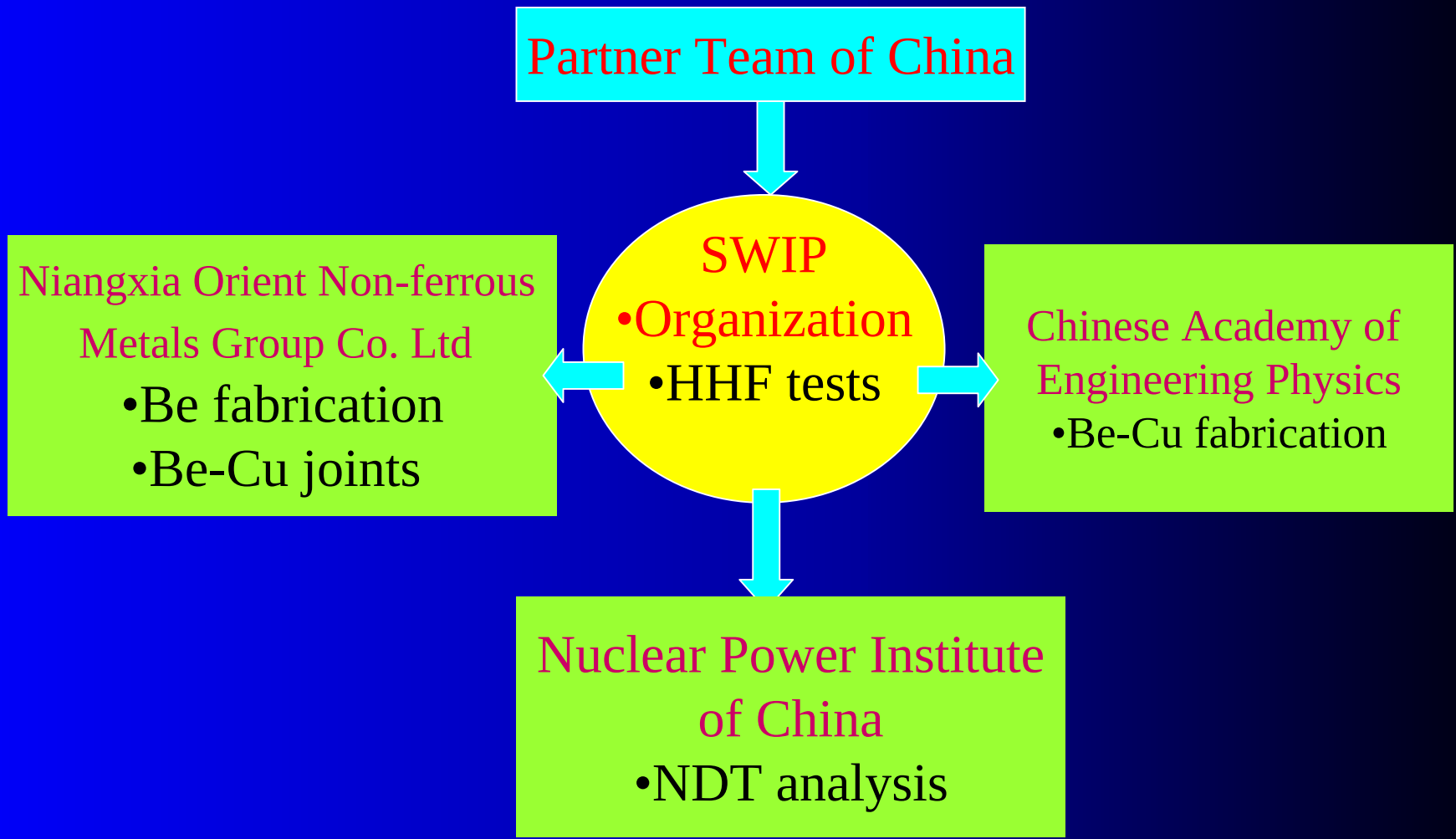
Outline

- Introduction
- Organization and cooperation
- Fabrication of the Be/Cu joints by HIP
- Mechanical properties of the joints
- Effect of post-HIPing heat treatment
- Microstructure of the interface
- High Heat Flux Tests (including NDT by Supersonic wave)
- Summary

1. Introduction

- The present study is based on the agreement with ITER-IT (ITA 16-10) “testing and fabrication of Be/Cu mock-up for qualification”.
- The work is divided into three phases, (1) small specimen for HIP parameter selection; (2) Middle size mock-up fabrication (2 Be tiles); (3) larger size mock-up (4 Be tiles) fabrication and test for qualification.
- Now we are at the end of Phase 1 and will start Phase 2 very soon.
- Several mock-ups in cylinder shape were fabricated and the corresponding tests were nearly finished.
- Some results will be given here.

2. Organization and cooperation



3. Fabrication of Be/Cu joints by HIP

- Material:

(1) **Be**: Chinese Be of 98.5% in purity was used now and the improvement of Chinese Be for ITER requirements was conducted.

(2) **Cu alloy**: CuCrZr (0.46%Cr, 0.084%Fe, 0.041%Mg, 0.35%Sn)

DS-Cu (0.6%Al_2O_3 in mass)

(3) **Interlayer**: Ti, AlSiMg and AlSi foils; ~5μm PVD coating.

AlSiMg: 11.89%Si, 1.5%Mg, in mass.

AlSi: 7%Si in mass.

- Microstructure analysis by SEM, AES, OM
- Tensile/shear strength measurement at RT.
- HHF tests and NDT inspection.

Pre-treatment before HIPing

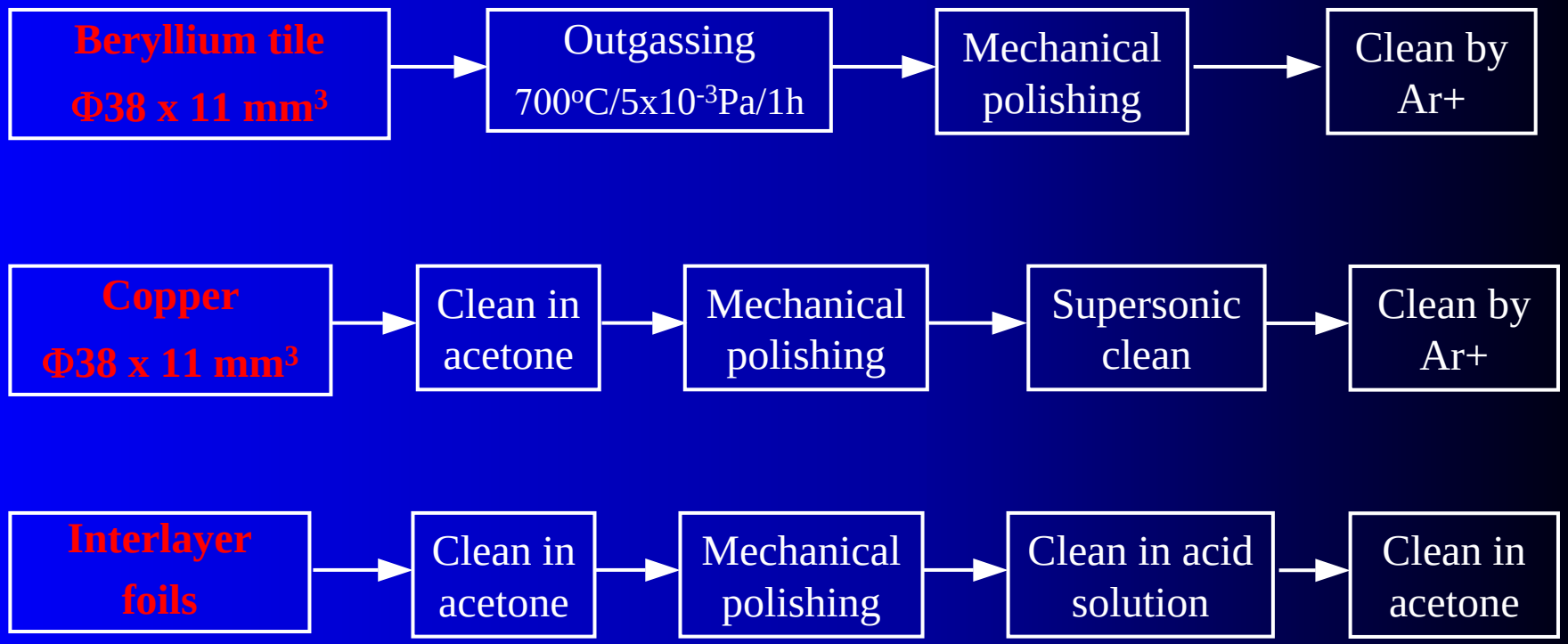


Table 1 Parameters for the Be/Cu HIP joining

No.	Coating (μm) of Pre-HIP				Interlayer (μm)	HIP Condition (°C/Mpa/Hr)	Can Mater.**	Result*** **A: Attached F: Failed**
	Be side	Cu side						
	Al	Al	Ti	Cu				
I	5	5	5	5	A*-50~100	555/140/2	L2	F[1]
II	5	5			A-100	535/140/2	L2	A
III	5			5	A-50 + Al-50+Ti-100	540/140/2	L2	A
IV	5					620/140/2	SS1/SS2	F[2]/A
V				5		620/140/2	SS2	A
VI					Ti-100	850/140/2	SS2	A
VII					Ti-100	730/140/2	SS1	F[2]

*Here A: AlSiMg; **L2: 1.5mm thick Al, SS1: 1.5mm thick 1Cr18Ni9Ti and SS2: 1mm thick 00Cr17Ni14Mo2;

[1] Failed due to the reaction of can material with Be; [2] Failed due to swell of the can while no leak was detected.

Table 1 Parameters for the Be/Cu joining --continue

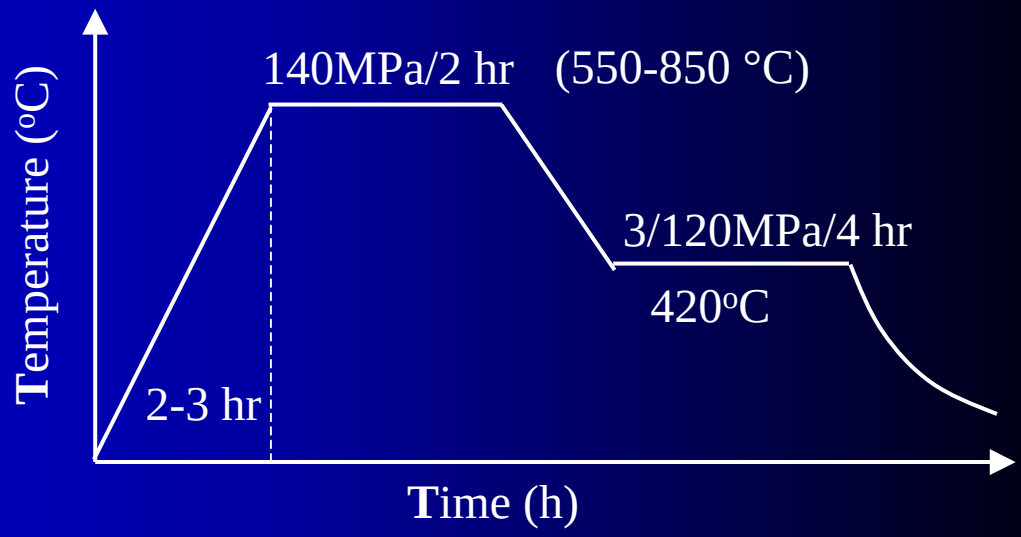
No.	Coating (μm) of Pre-HIP				Interlayer (μm)	HIP Condition (°C/Mpa/Hr)	Can Material	Result*** **A: Attached F: Failed**
	Be side	Cu side						
	Al	Al	Ti	Cu				
VIII					Ti-50	850/120/2	LCS*	A
IX					Ti-50	800/120/2	LCS	A
X					Ti-50	700/120/3	LCS	A
XI					AlSi-100	550/70/2	LCS	F**

*LCS: Low Carbon Steel; **Failed due to low HIP pressure.

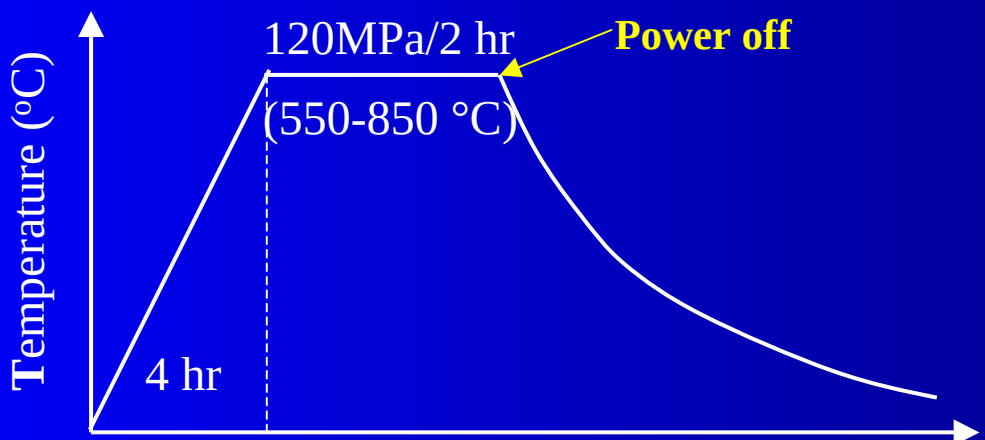
***RESULT: **Bad joint for all samples with DS-Cu.**

HIPing process

(1) I-VII specimen



(2) VIII-XI specimen



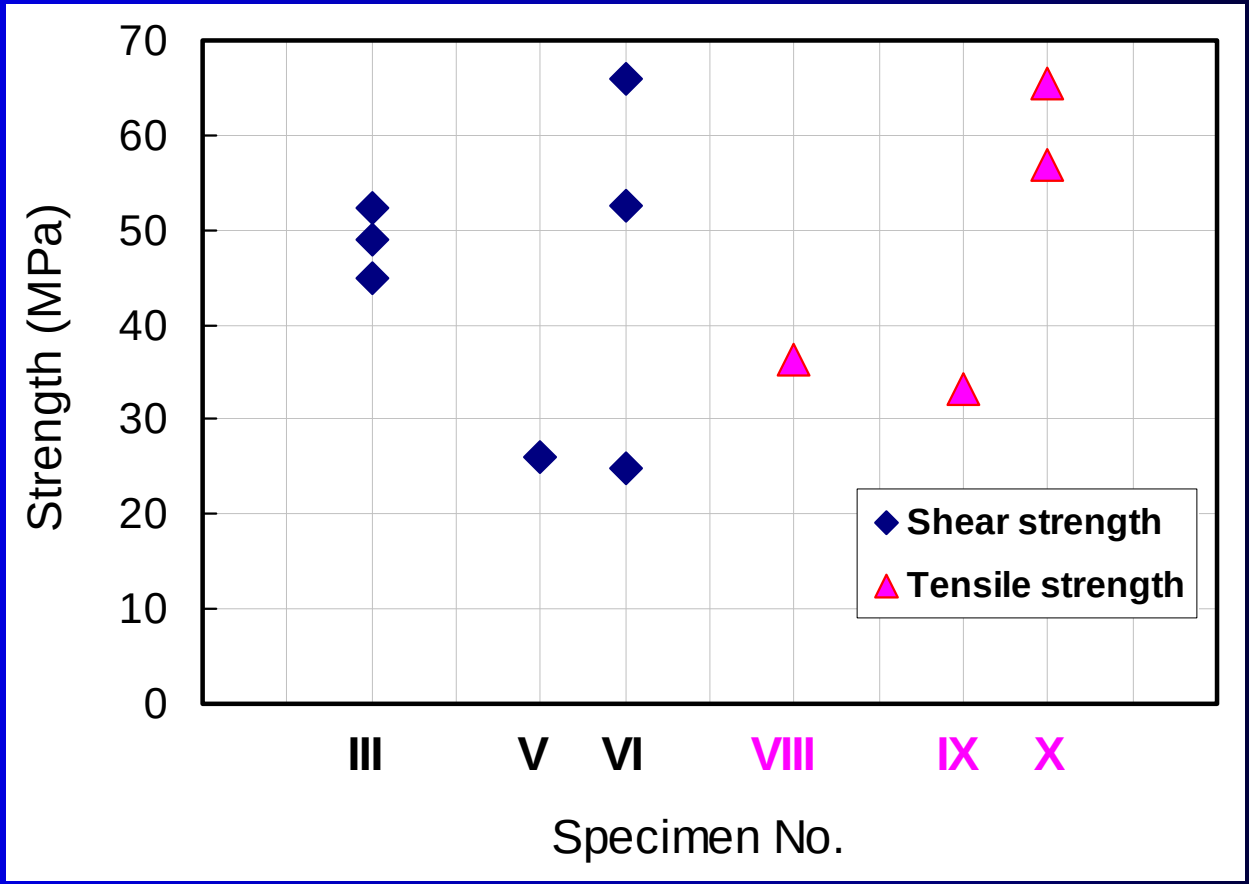
Φ40~60

Be

CuCrZr

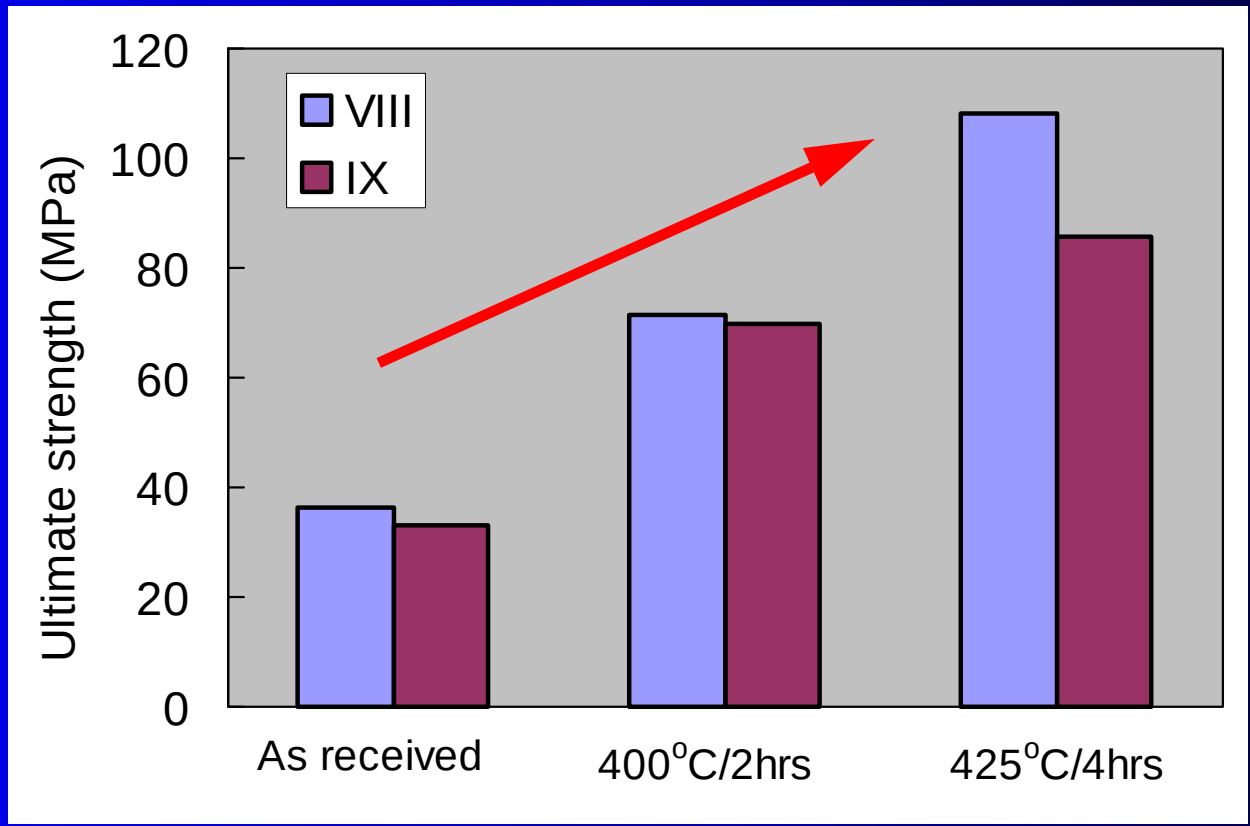
SS

4. Mechanical test results



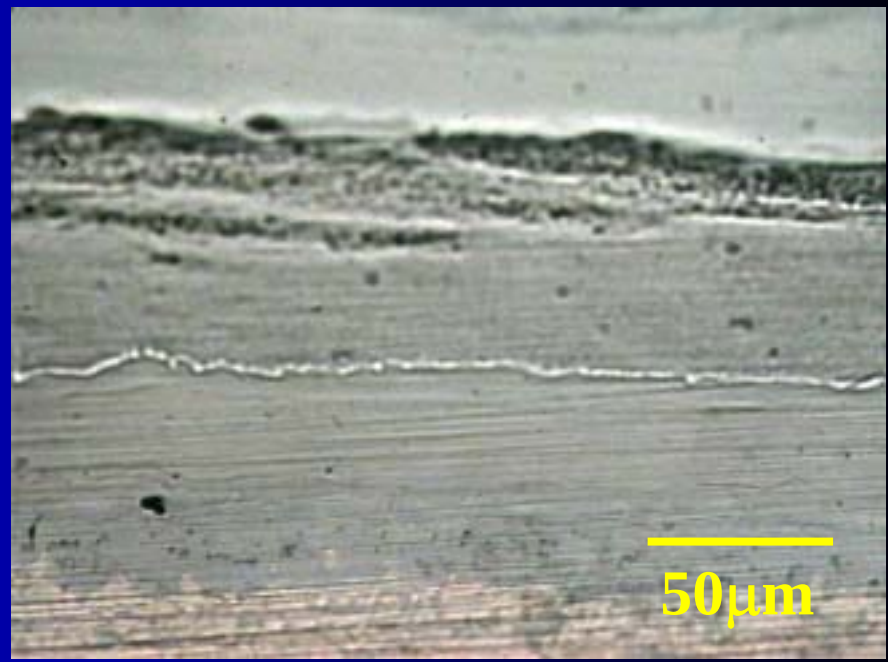
The data shows certain scattering, indicating some regions were not properly joined or inhomogeneity of the interface.

5. Effect of post-HIP heat treatment



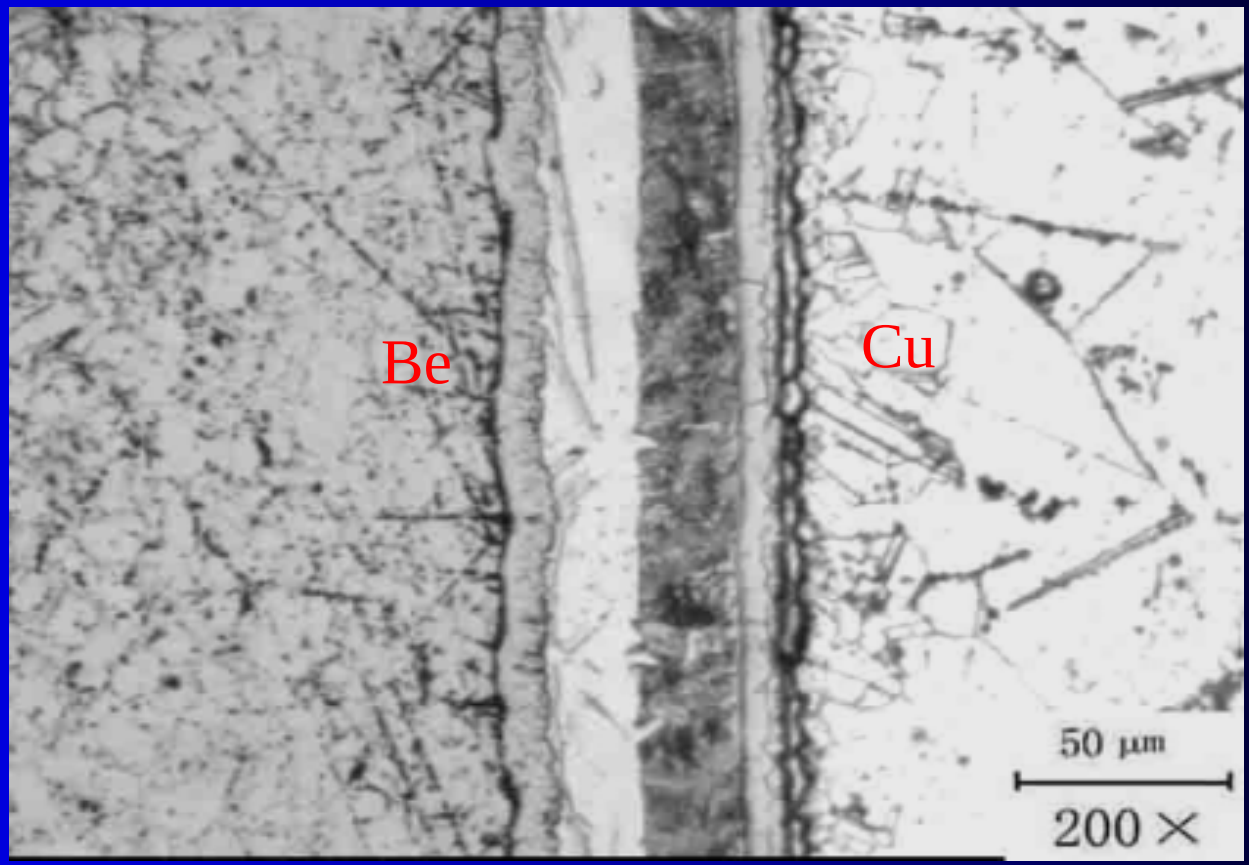
The heat treatment is active to increase the joining strength due to the release of the residual stress.

Be/Ti/DS-Cu



With the post-annealing, the joint appears good. Otherwise, the two parts detached.

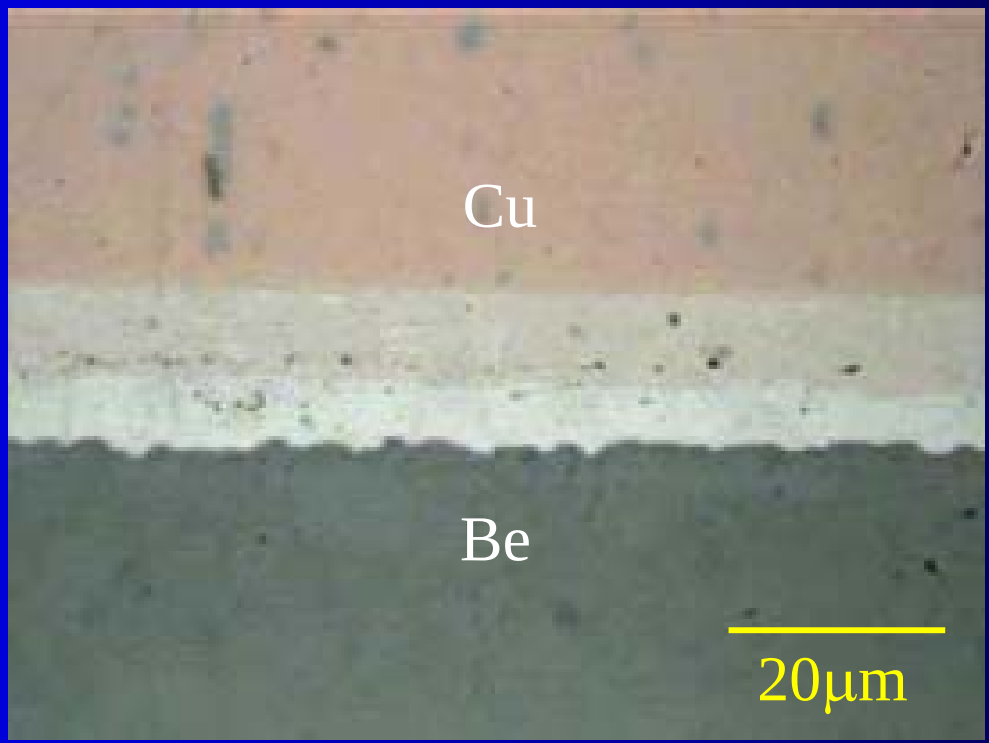
6. Microstructure of the interface



Specimen No.: VIII: Be + Ti foil + CuCrZr

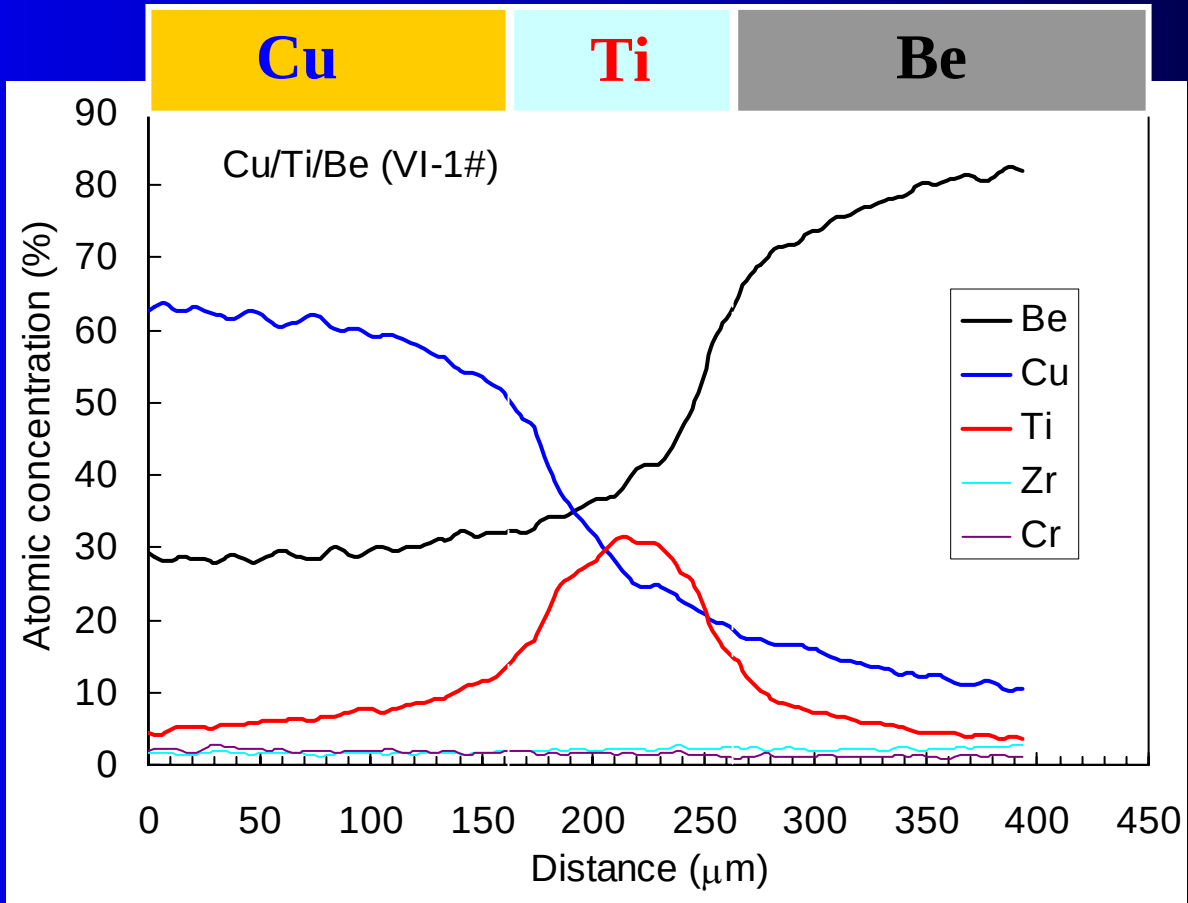

800x
Be
Specimen No.: VIII
Cu

No.V specimen: Be + 5μm Cu on CuCrZr

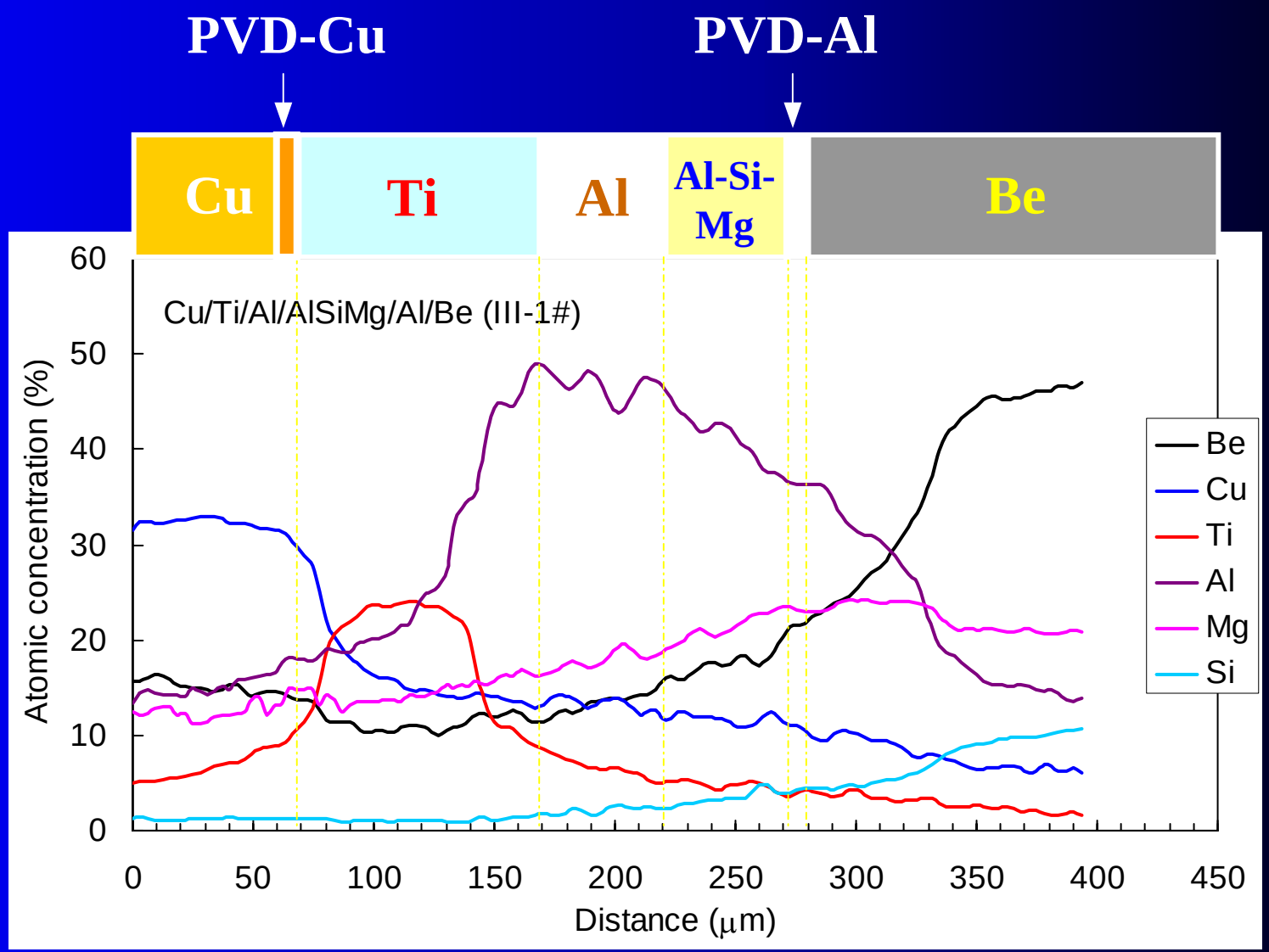


No Crack was observed, but the shear strength is low (26MPa)

Element distribution across the interface



Gently transition of the elements, indicates sufficient diffusion during the HIPing and good metallurgical bonding between the materials.

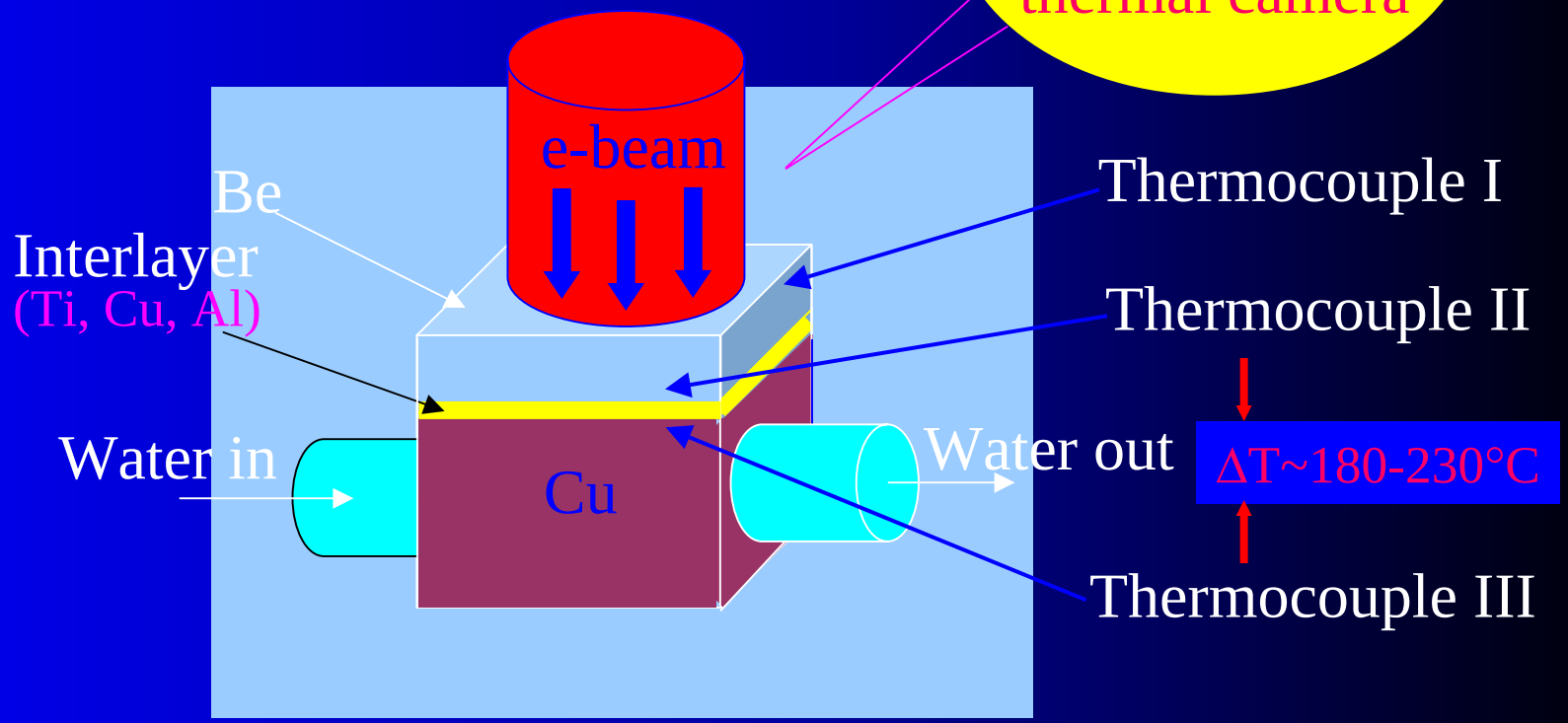

PVD-Cu
PVD-Al
Cu
Ti
Al
Al-Si-Mg
Be
Cu/Ti/Al/AlSiMg/Al/Be (III-1#)
Atomic concentration (%)
Distance (μm)
0
10
20
30
40
50
60
0
50
100
150
200
250
300
350
400
450
Be
Cu
Ti
Al
Mg
Si

6. Heat load test

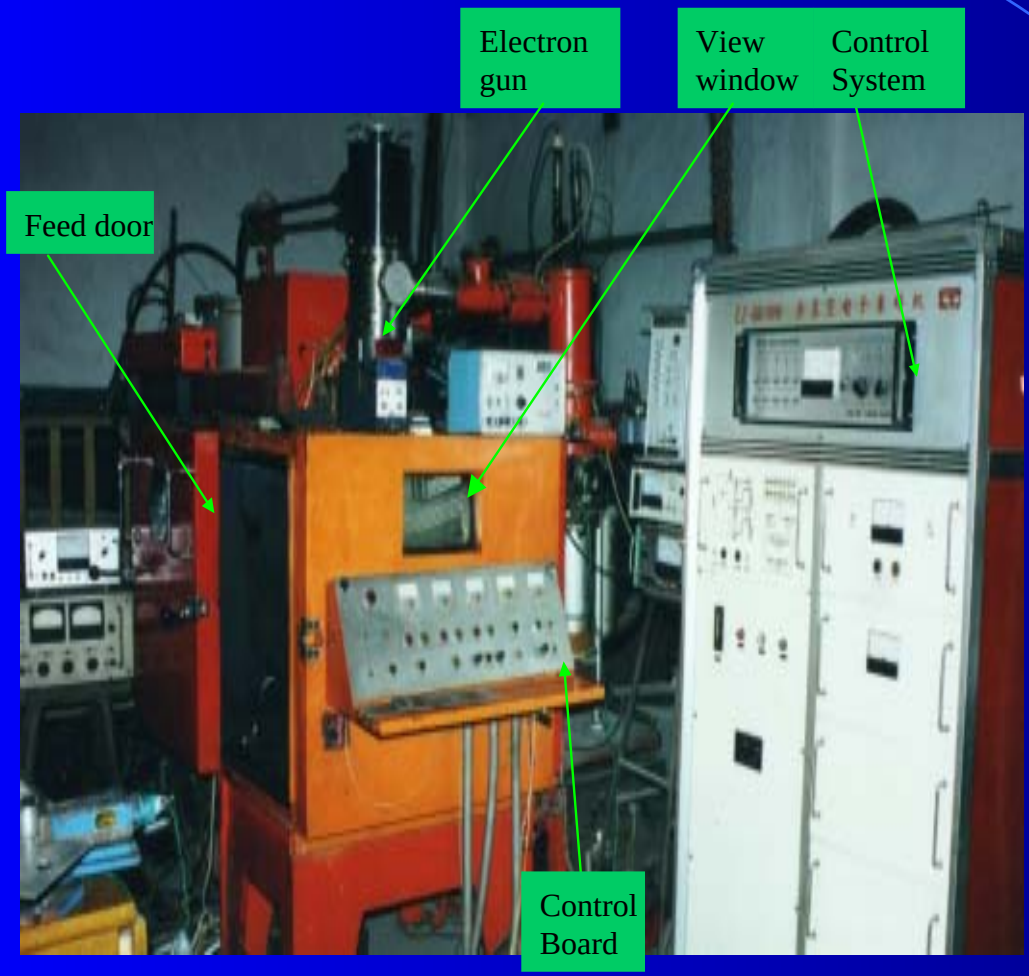
Experimental arrangements of HHF tests of Be/Cu joints

Power density: 2-8 MW/m^2
Pulse duration: 10-15s

View by optical pyrometers or thermal camera



Photographs of HHF testing facility and specimen



Power: 6 KW
Profile: Gaussian
Spot Size: ~ϕ20mm
Sample Size: 20-40×20-40mm

Primary results of HHF tests

Sample	Description	Power density	Pulse time/interval	Surface temperature	Cycle number
I	Be/Ti/Cu (Film)	4 MW/m^2	15s/15s	400-450 °C	500
II	Be/Ti/Cu (Film)	4 MW/m^2	15s/15s	450-500 °C	350
III	Be/(Al/AlSiMg/Cu)/Cu (Coating +Film)	4 MW/m^2	15s/15s	400-450 °C	800
IV	Be/(Ti/Cu)/Cu (Film+coating)	4 MW/m^2	15s/15s	380-420 °C	950

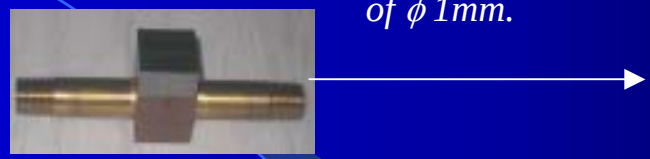
HHF tests of other samples are in progress

Non-destructive test (before HHF tests)

Specimens Supersonic wave inspection

Standard sample

Be/Cu--No.1#



Be/Cu--No.2#

Be/Cu--No.3#

Be/Cu--No.4#

7. Summary

1. The work for qualification of the first wall panel fabrication for ITER has being conducted. The organization and cooperation networks have been established and some excited progress has been achieved although big challenge is still on the way.
2. Small-size Be/Cu joints by HIPing has been carried out. To avoid or reduce the formation of brittle intermetallic phase, several kinds of interlayer materials have been tested. Both mechanical properties and HHF tests showed that the joint with Ti foils and the one with multi-layer interface of AlSiMg alloy, and Al, Ti thin coated on both Be and CuCrZr respectively were promising.
3. Shear or tensile strength of the joints is among 30 to 65MPa, approximately. Post-HIPing annealing could increase the strength significantly.
4. Bond Be to DS-Cu seems to be more difficult than that to CuCrZr. Post-HIPing annealing might be a way to get a good bonding for the case of DS-Cu.

Thanks for your attentions!