Progress in Developing ITER and DEMO First Wall Technologies at SWIP

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Outlines

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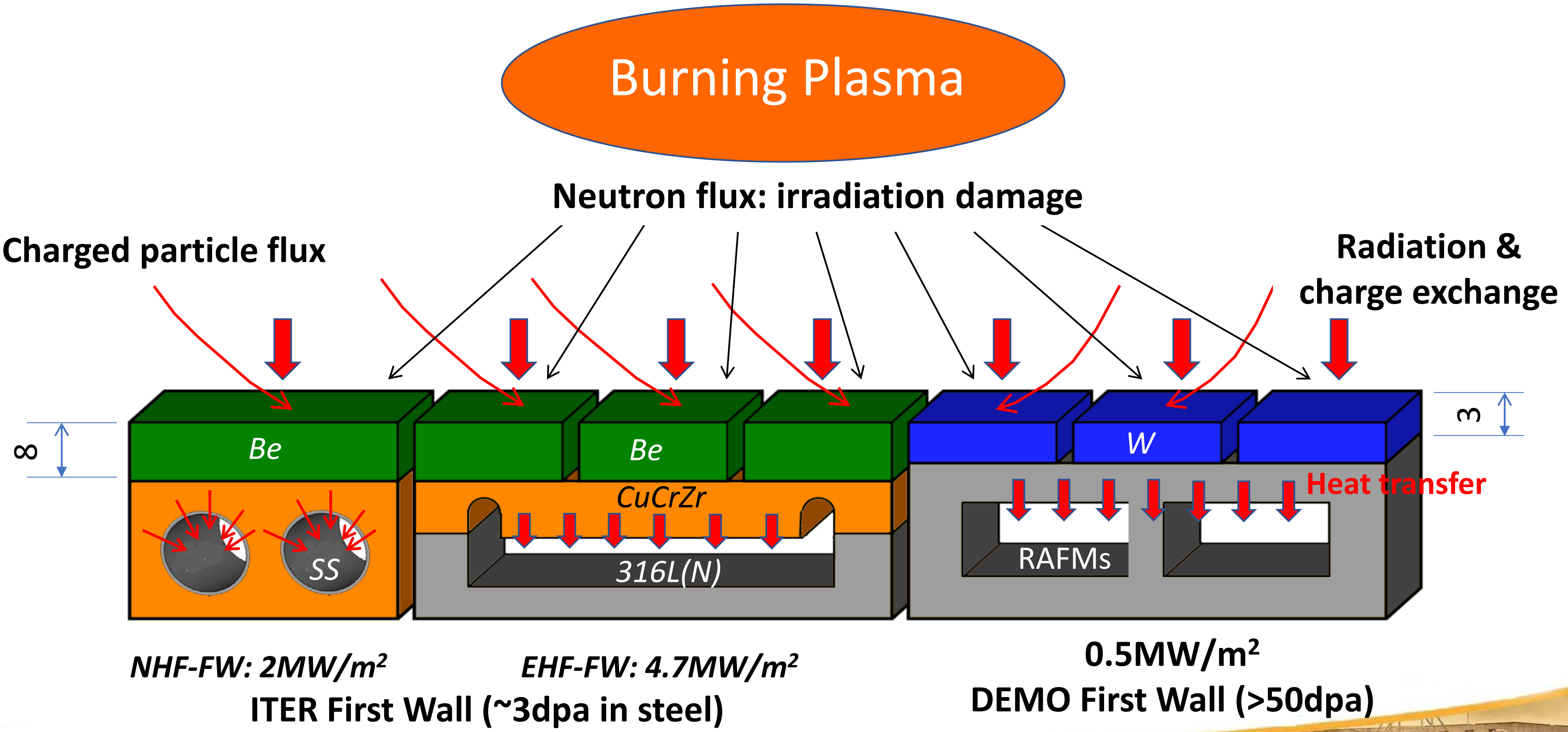
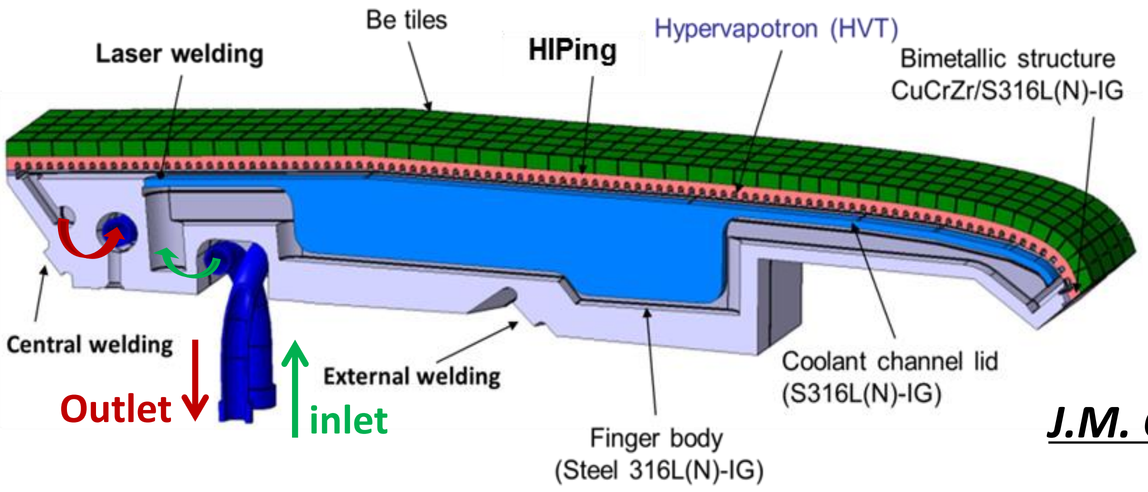
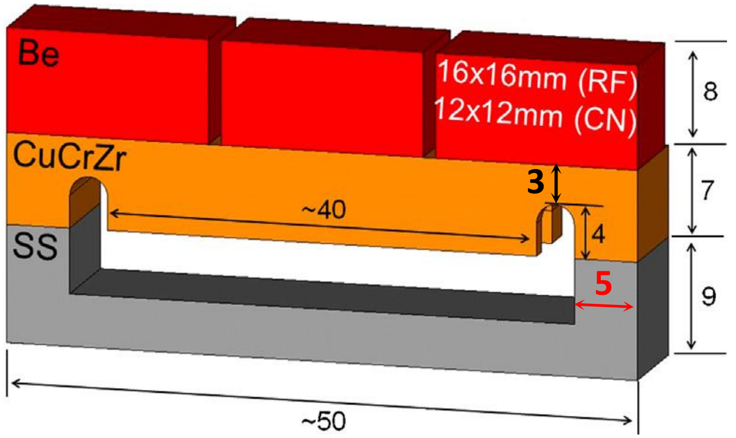
2. Improving ITER FW thermal fatigue performance
    2.1. Design optimization to reduce thermal strain
    2.2. Improving Be/CuCrZr bonding
    2.3. Strengthening CuCrZr/316L(N) bonding
    2.4. Improving CuCrZr alloy property
    2.5. Verify by high heat flux test
3. W/RAFM steel bonding for CFETR FW
4. Summary

First wall in operation



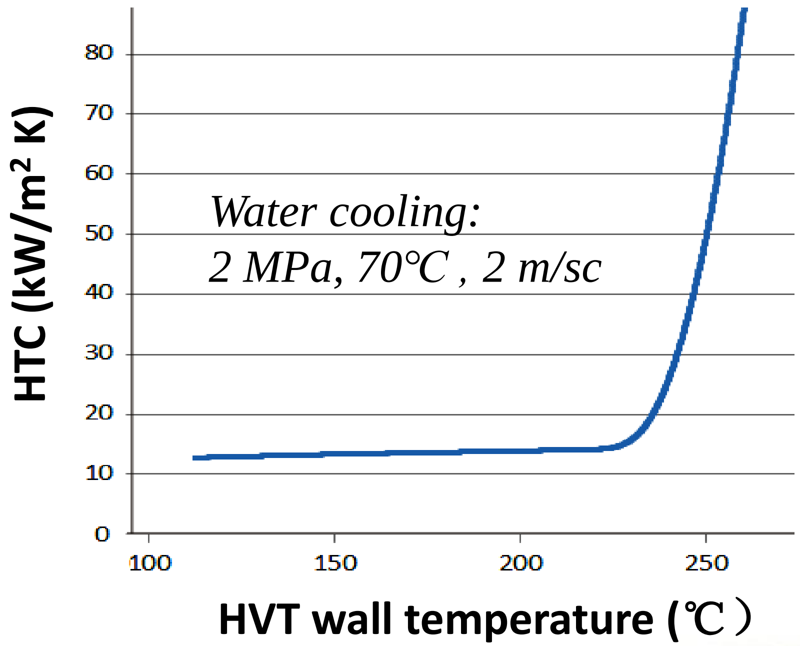
Thermal behavior of ITER Enhanced Heat Flux FW

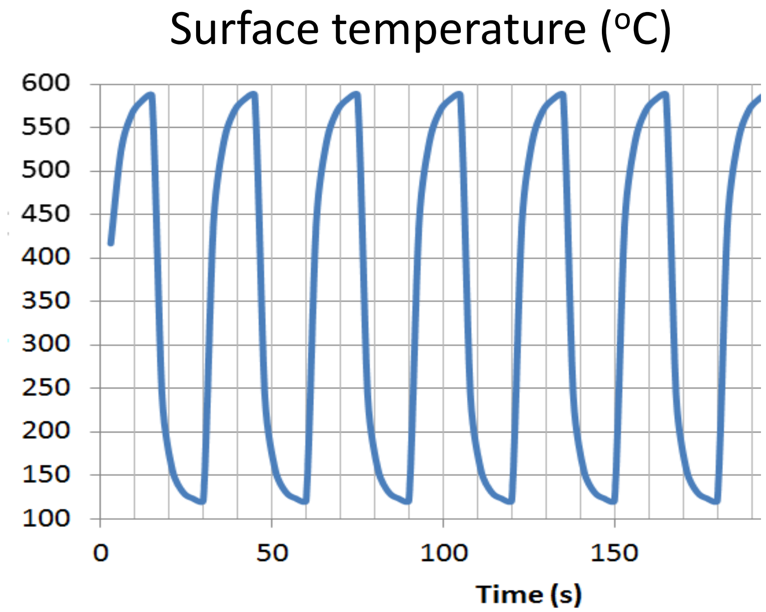




G. Perez / Fus Eng & Des, 89 (2014) 1324-1329.

J.M. Chen, FEC-26, Poster





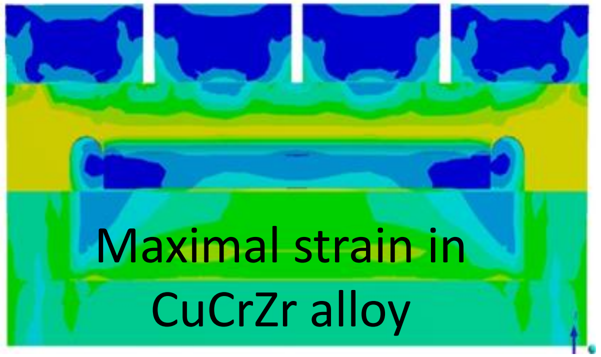
4.7MW/m², 15s on/off

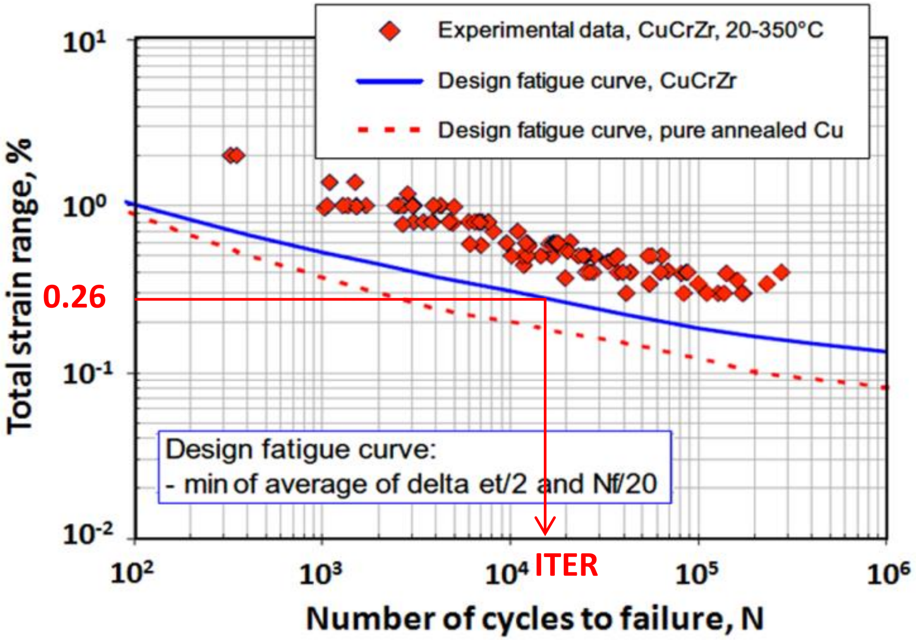
Thermal fatigue is a major concern for the design.

ITER EHF FW – Thermal fatigue issue

- ✓ Assessable thermal fatigue life of CuCrZr and 316L(N) by analysis
- × **Unpredictable Be/CuCrZr/316L(N) joint interface.**
- × **Test showed thermal fatigue damage of HVT channel & Be tile detachment.**

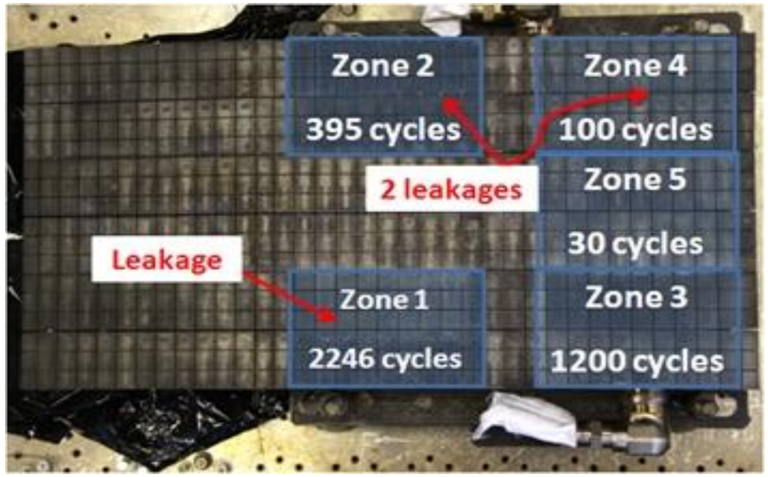
ITER requires FW a fatigue life of 15,000 cycles





V. Barabash / JNM 367–370 (2007) 21-32

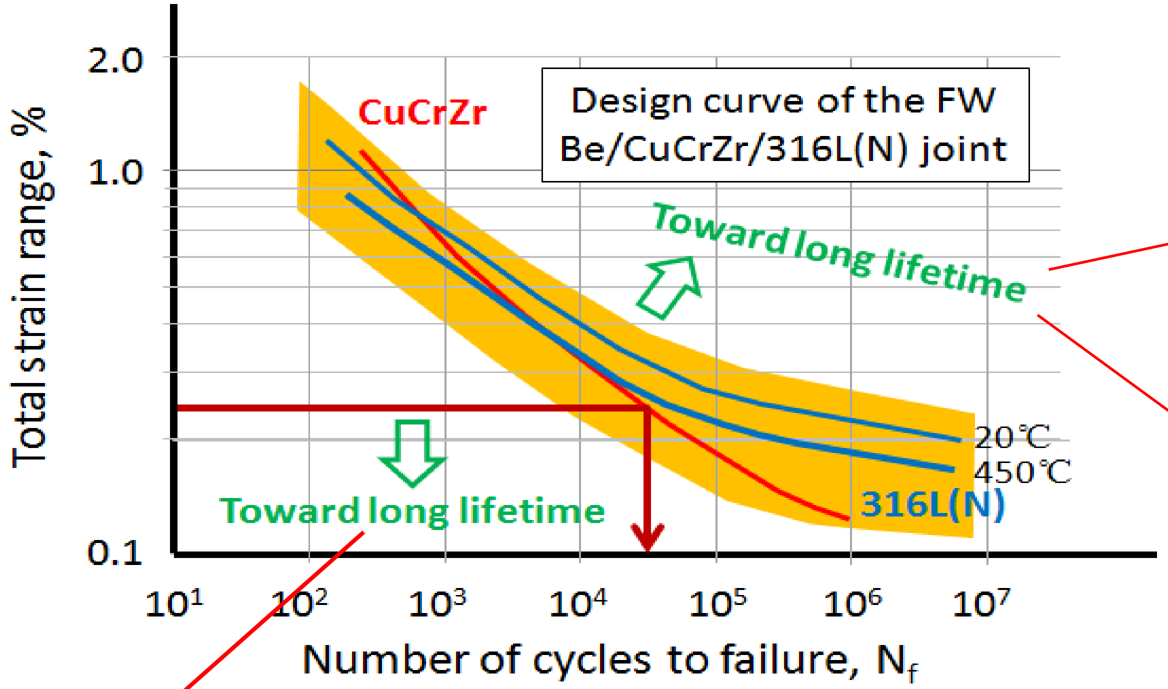
Be tile detachment

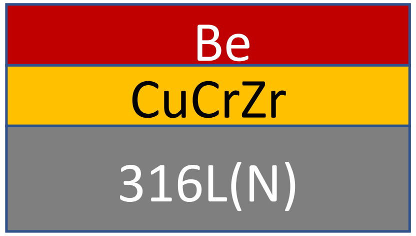


Water leak at 4.7MW/m^2

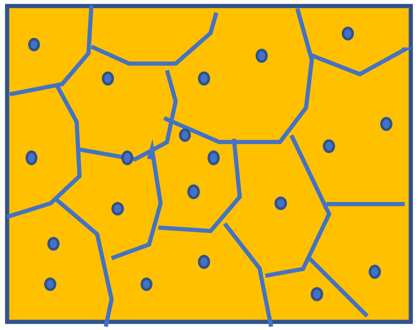
R. Eaton / BIPT-66, Apr 2016

2. Improving ITER FW thermal fatigue performance

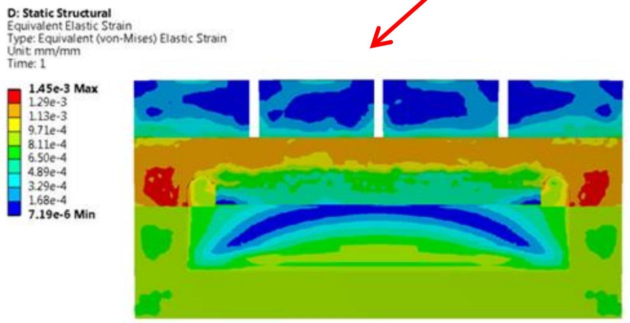




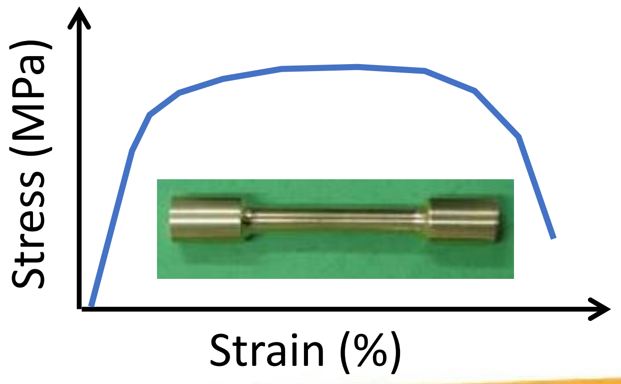
(2) Improving Be/Cu/SS bonding
Fatigue crack may initiate from interface defect.



(3) Improving material properties
Small grain size & high tensile strength

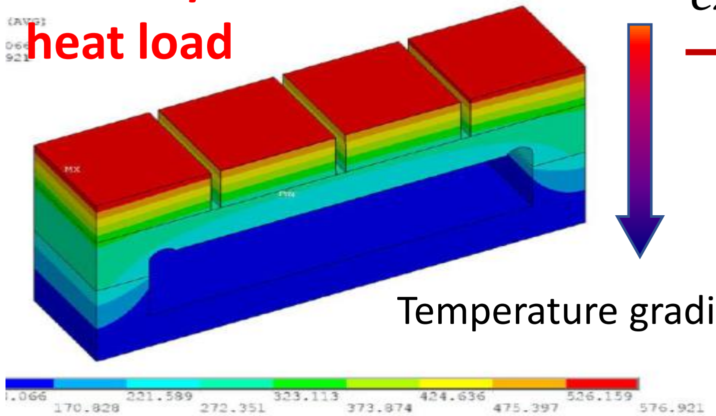


(1) To reduce the thermal stress by design optimization

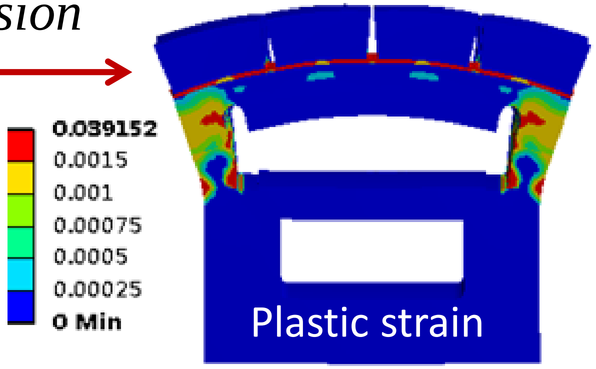


2.1 Design optimization to reduce thermal strain

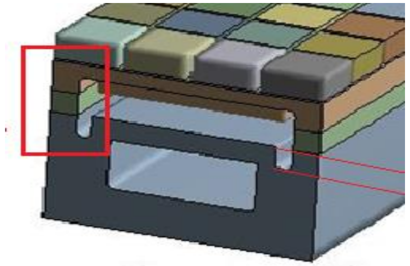
4.7MW/m² surface heat load

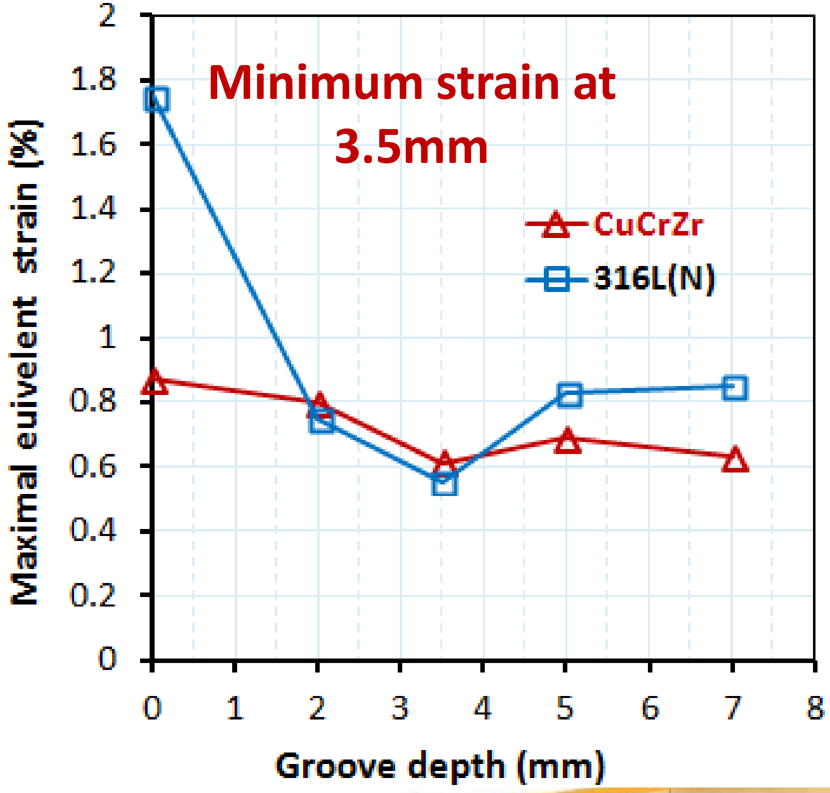


Surface expansion

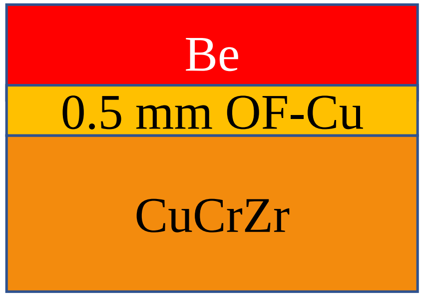


To reduce strain in HVT side wall





To reduce strain at Be/CuCrZr interface



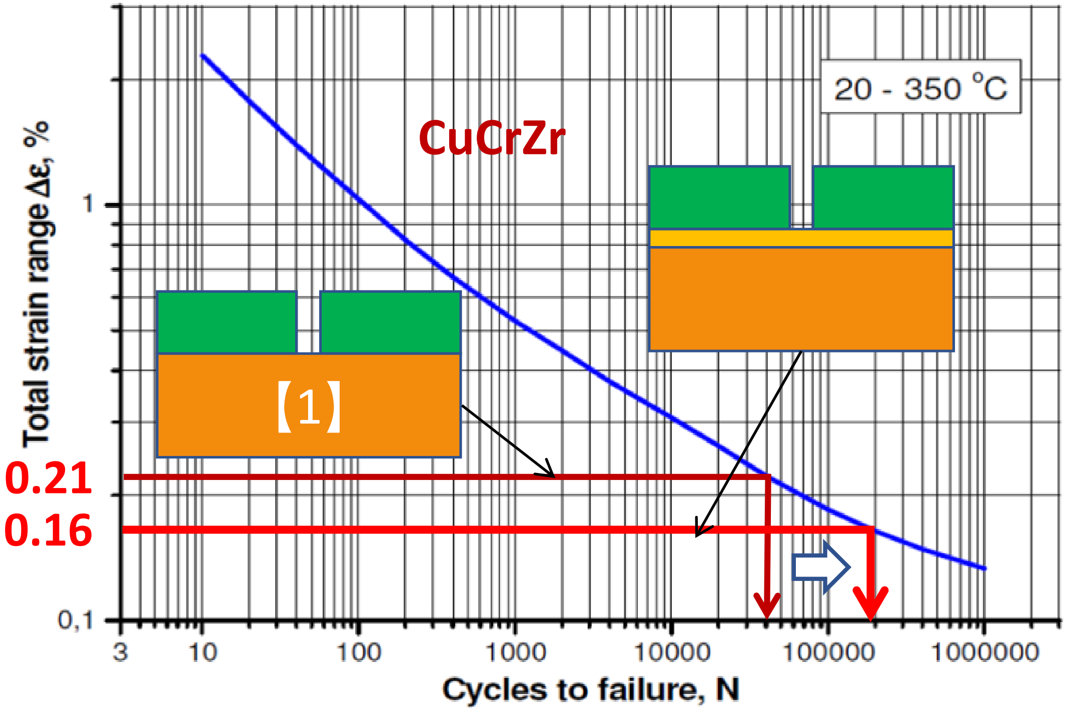
(1) Adding a groove at the HVT channel bottom

(2) Adding a 0.5mm OF-Cu layer between Be and CuCrZr heat sink

Thermal fatigue life increase by one order

✓ Effect of 0.5mm OF-Cu interlayer

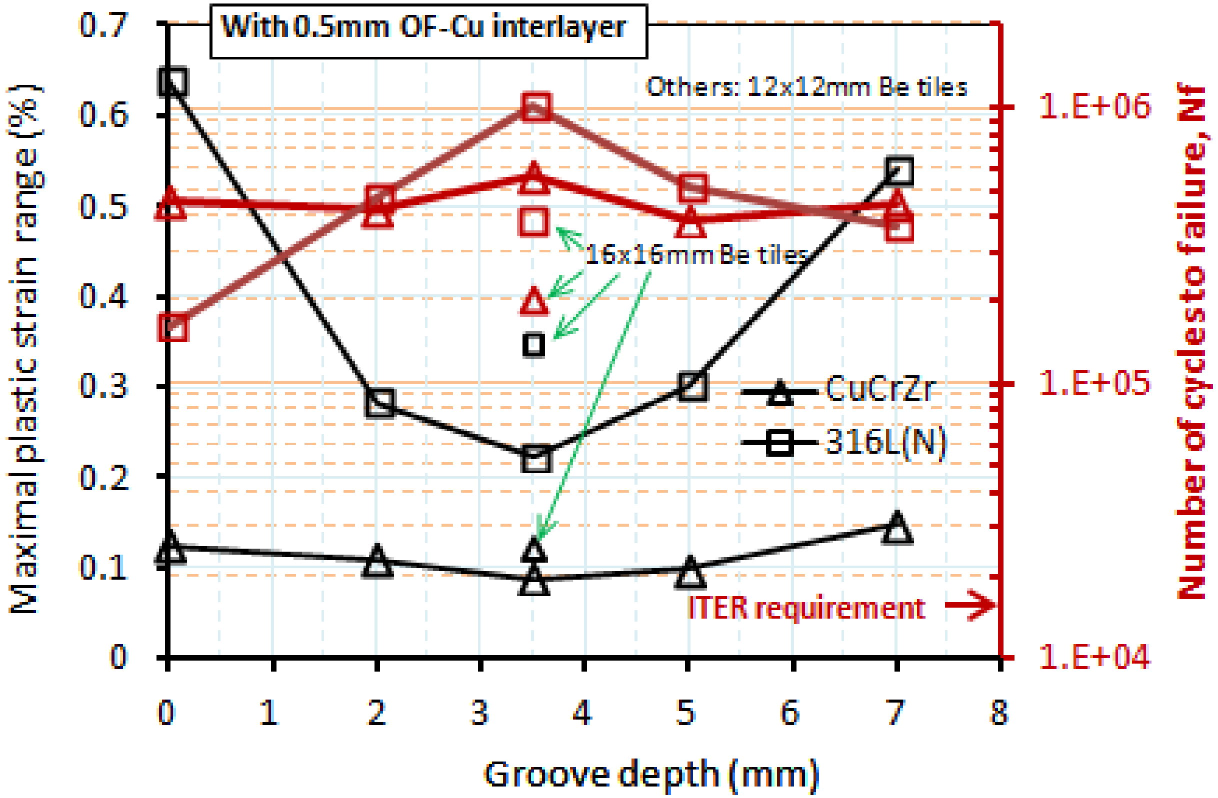
For FW with 16x16mm Be tile



Fatigue life: 4×10^4 [1] → 2×10^5 cycles

【1】D. GLAZUNOV, ITER BIPT-68, ITER_D_TL78R4

✓ Effect of HVT groove depth & Be tile size



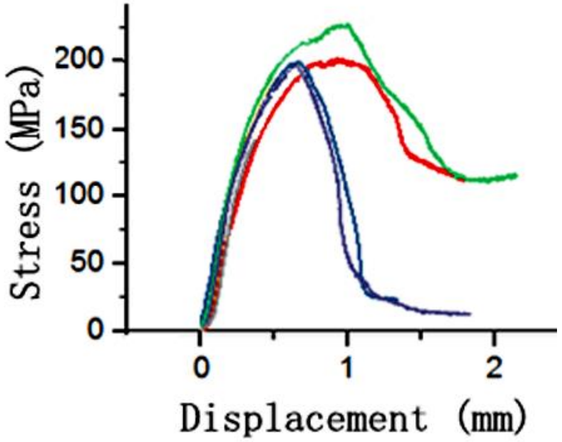
12x12mm Be tile: fatigue life > 5×10^5 cycles.
Large Be tile up to >16x16mm is acceptable.

2.2 Improving Be/CuCrZr HIP bonding

（1）Adding a 0.5mm thick OF-Cu accommodation layer

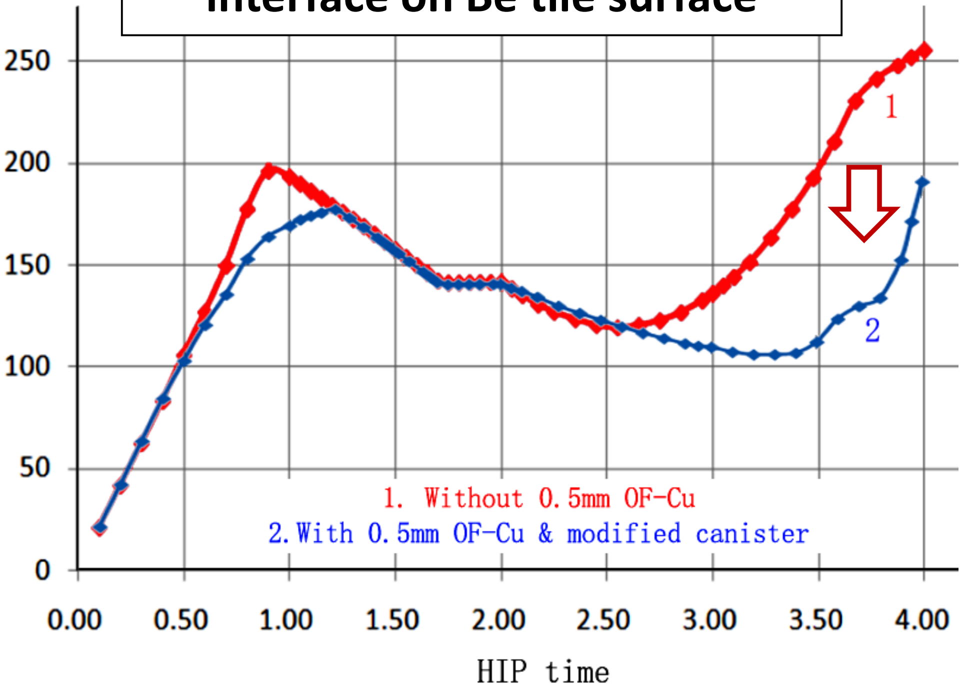
- Significant reduction of residual stress.
- Achieving >90% defect-free EHF FW (previously 0).

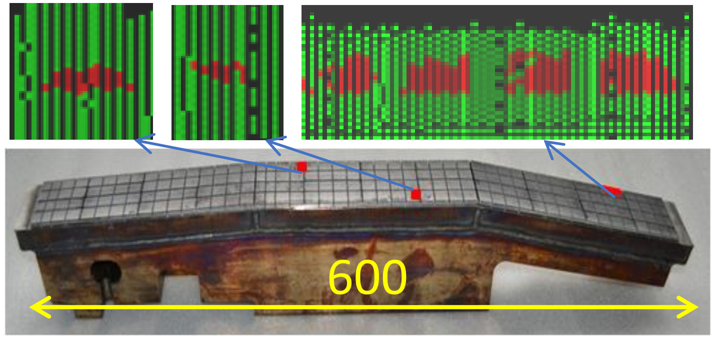
HIP: 580℃/150MPa/2h



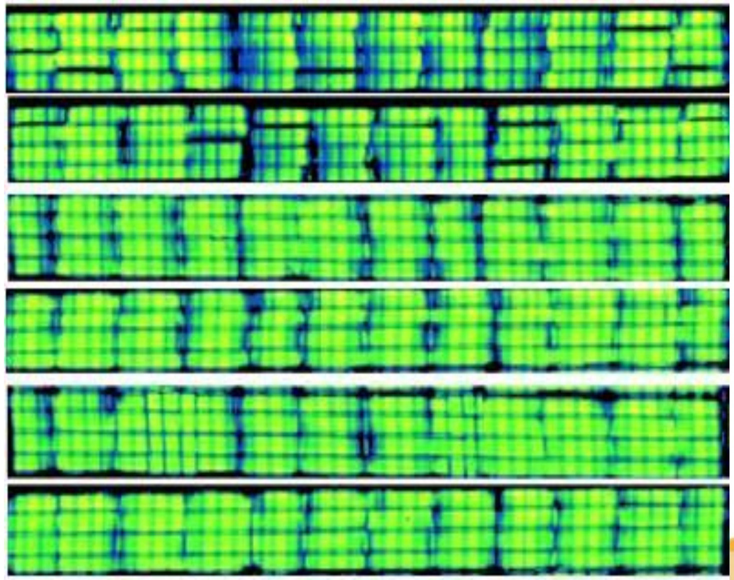
Shear strength: > 190 MPa

Thermal stress (MPa) at Be/Cu interface on Be tile surface





Adding 0.5mm OF-Cu ⇩ Success rate to 90%

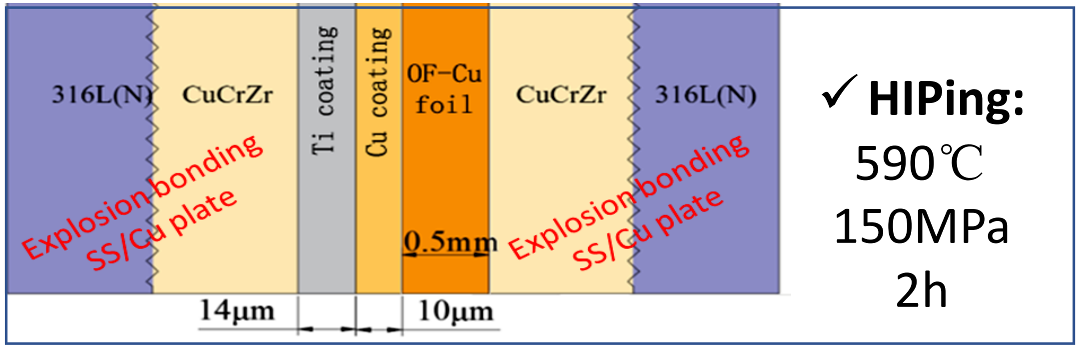


Perfect Be/CuCrZr bonding without Cu coating layer

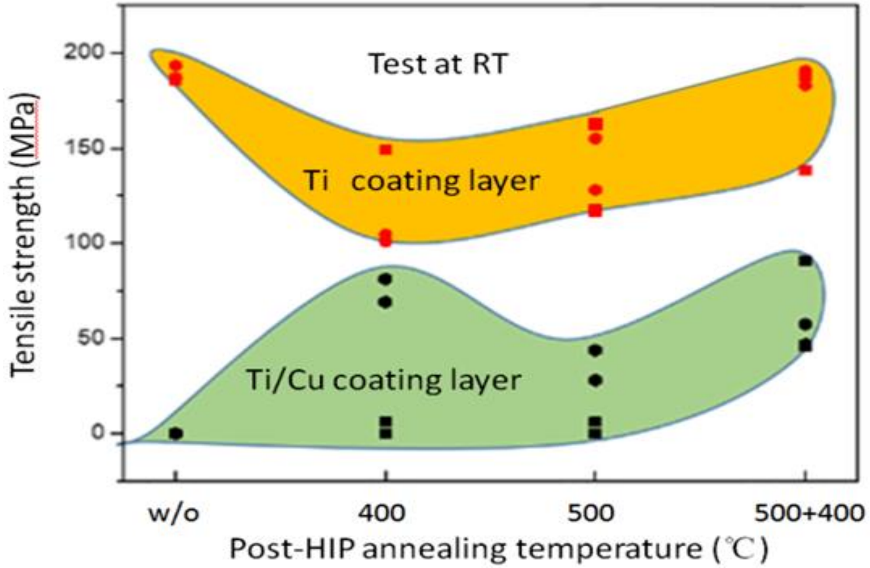
（2）Removing the interfacial Cu coating

- Significantly higher bonding strength.
- No crack at Ti/CuCrZr interface forever.

Cu coating accounts for the 10% failure.

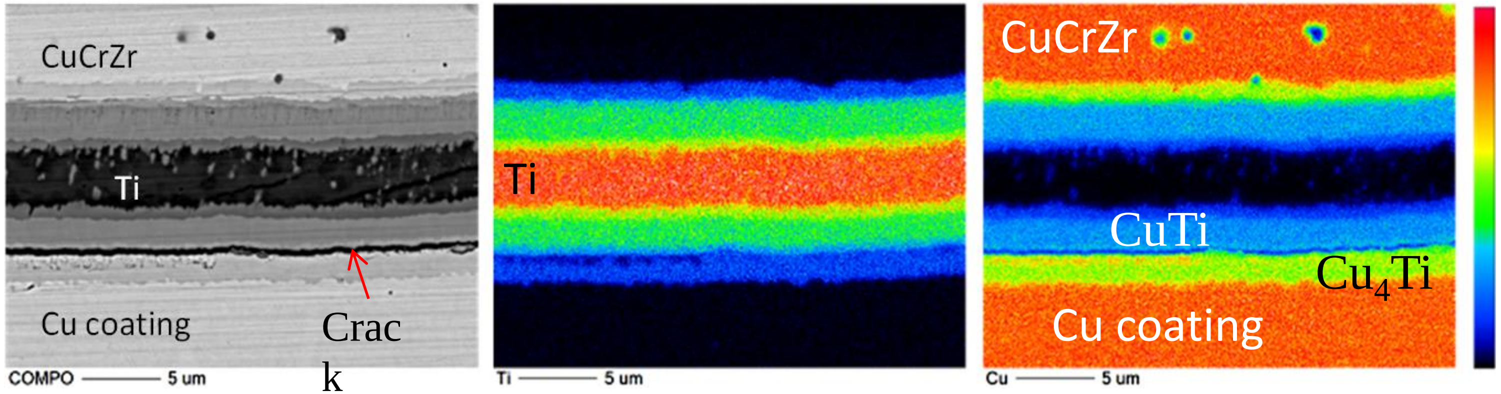


Removing Cu coating



Crack at Ti/Cu coating interface

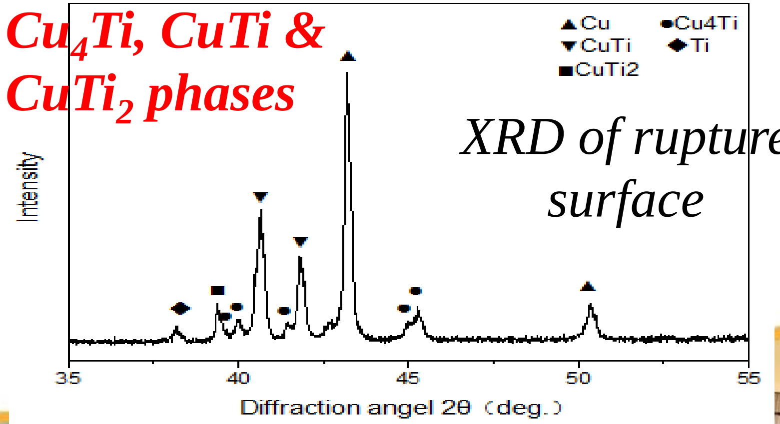
Cu coating thickening Cu_4Ti layer



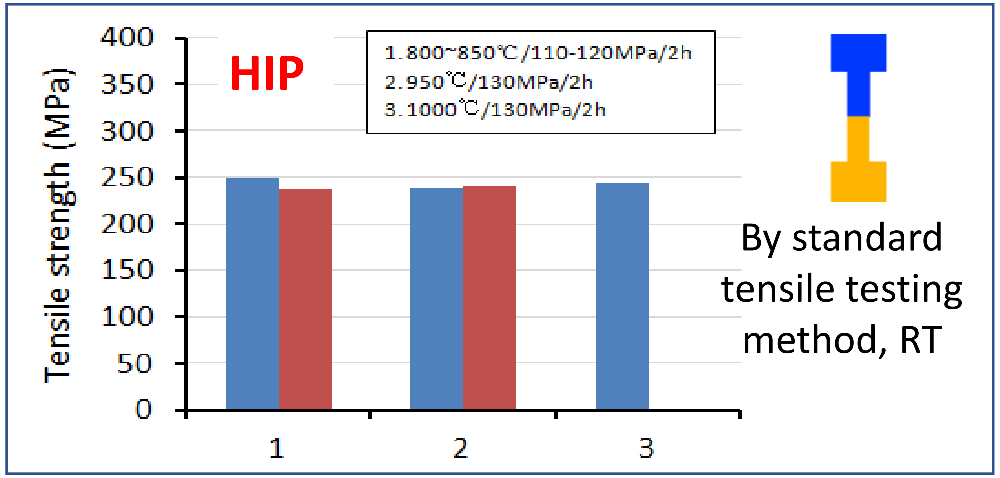
SEM image

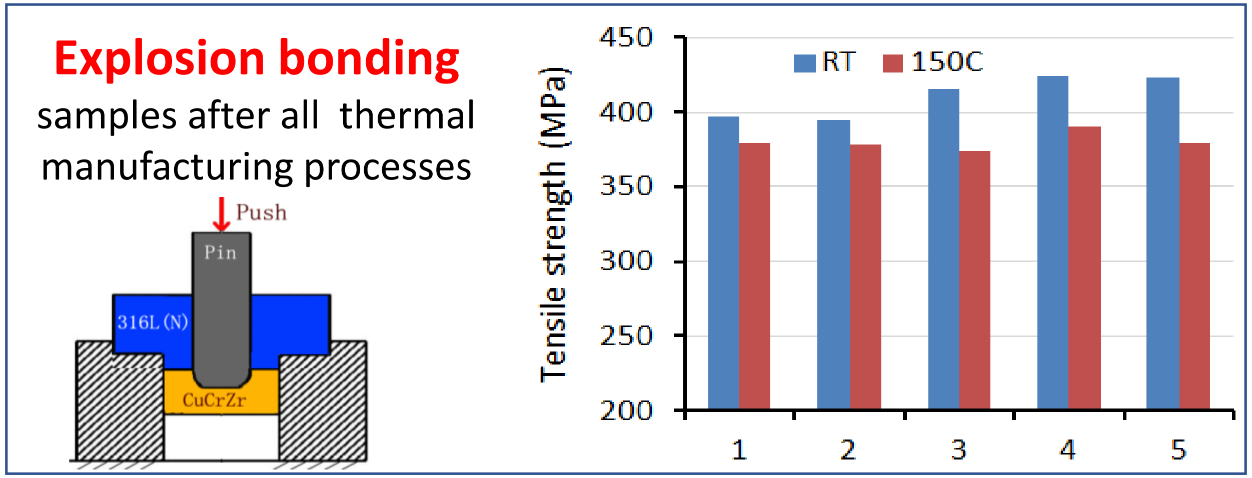
Ti/Cu interface--EPMA image

Cu_4Ti, CuTi & $CuTi_2$ phases



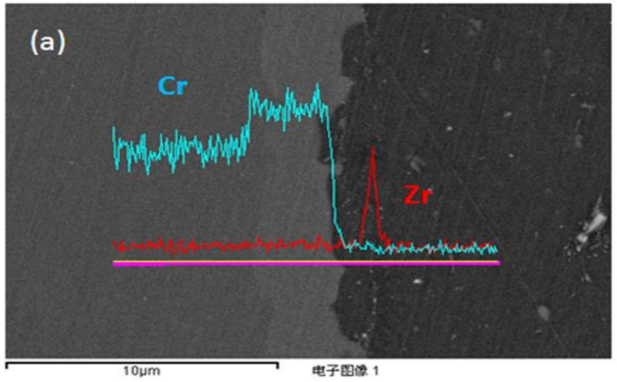
2.3 Strengthening CuCrZr/316L(N) bonding by > 60%



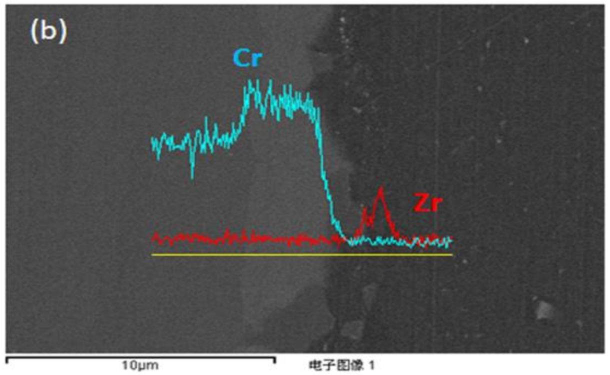


- However, Zr and a Cr/Mo segregation layers along interface, may weaken the bonding, shall be further addressed.

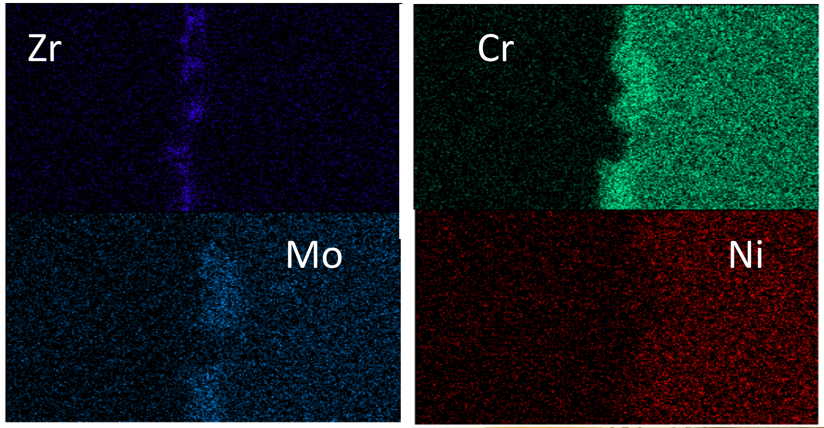
P.H. Wang, et al, SOFT-29, Poster



As received HIP joint



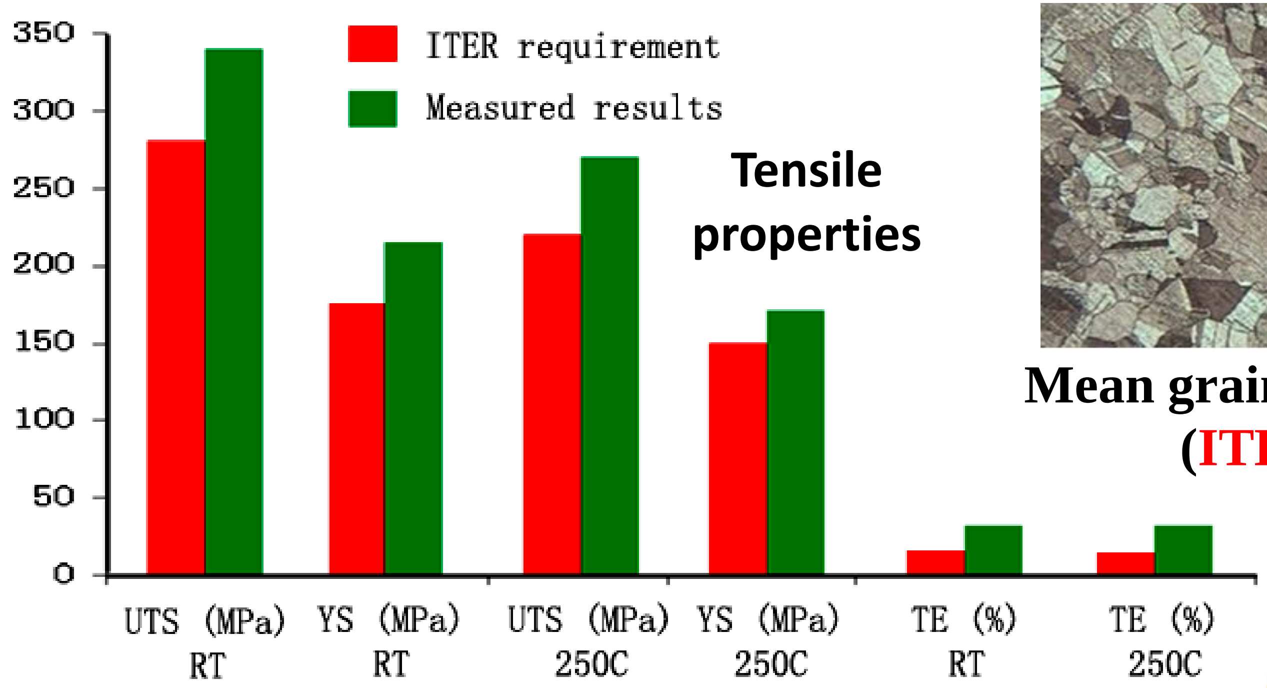
After 580℃/150 MPa/2 h HIP

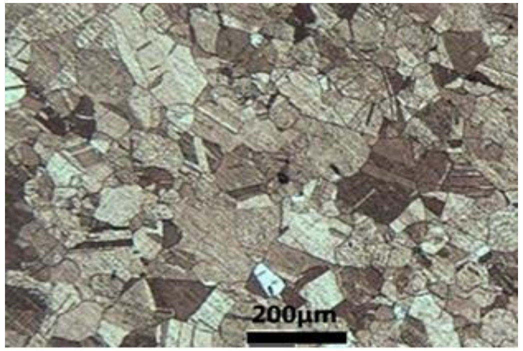


2.4 Better CuCrZr than ITER requirement

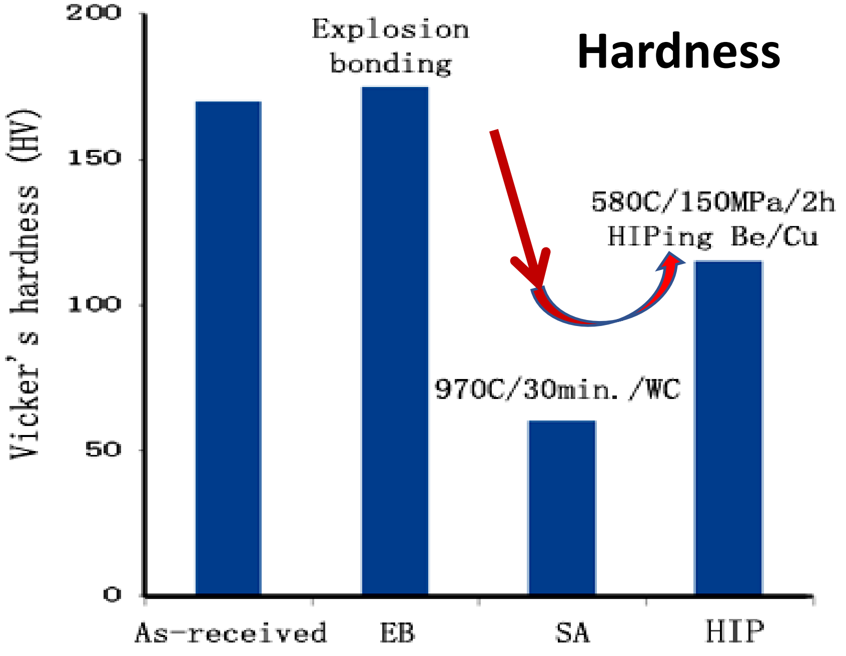
Eliminating HIP joining SS/Cu at elevated temperature,
Higher strength and smaller grain size

- CuCrZr alloy in 50%CW and 475/3h aging state
- Explosion bonding Cu/SS, followed by SA (970℃/30min)
- HIP bonding Be/Cu treatment: 580℃/150MPa/2h.



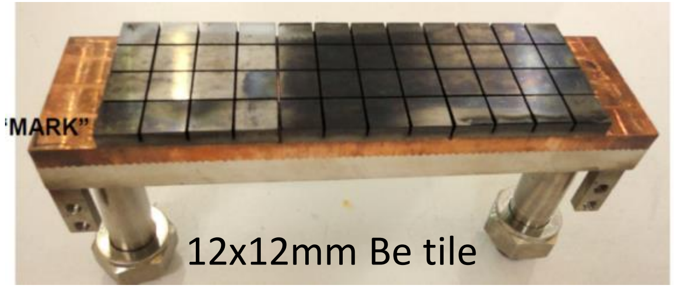


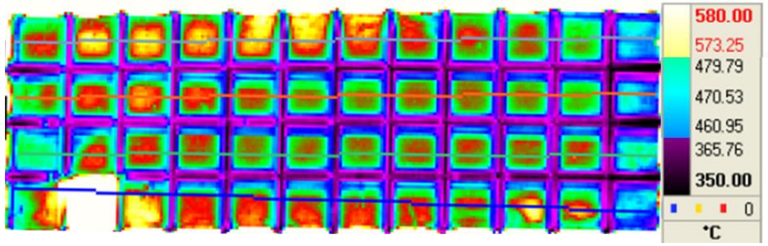
Mean grain size: 98μm (ITER<200 μm)



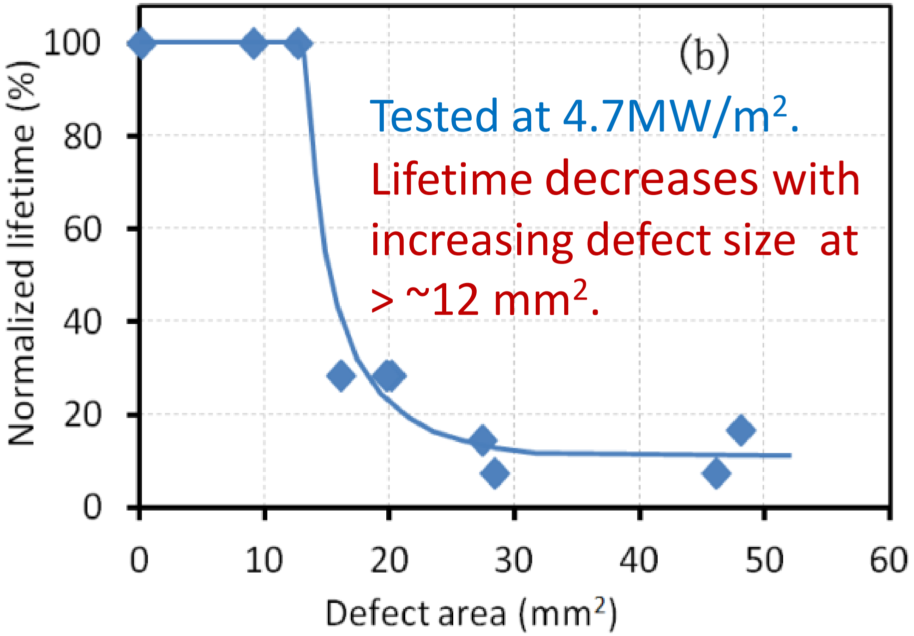
2.5 Verify by HHF test_ big effect of Be/Cu defects

- Previous test showed acceptable 12x12mm Be tile for old design.
- Artificial defects by carbon painting on Be surface before Be/Cu HIP joining.
- **Acceptable defect: ≤ Φ4 or 3x3mm.**





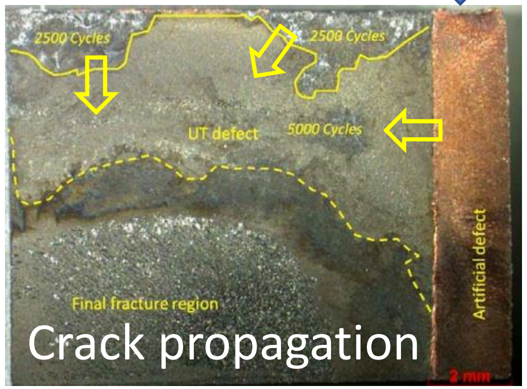
Overheating at 1100th cycle

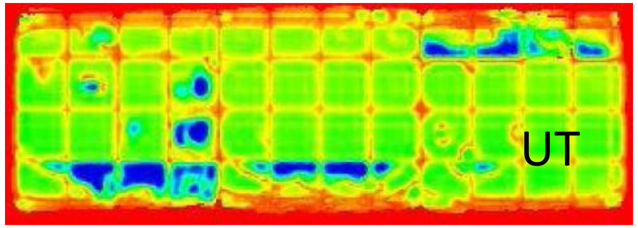


High heat flux (HFF) Testing

- ✓ *2 Mpa/2 m.s^{-1}/ 70℃ water cooling*
- ✓ *4.7 MW/m^2 for 5000 cycles*

2x12mm artificial defect



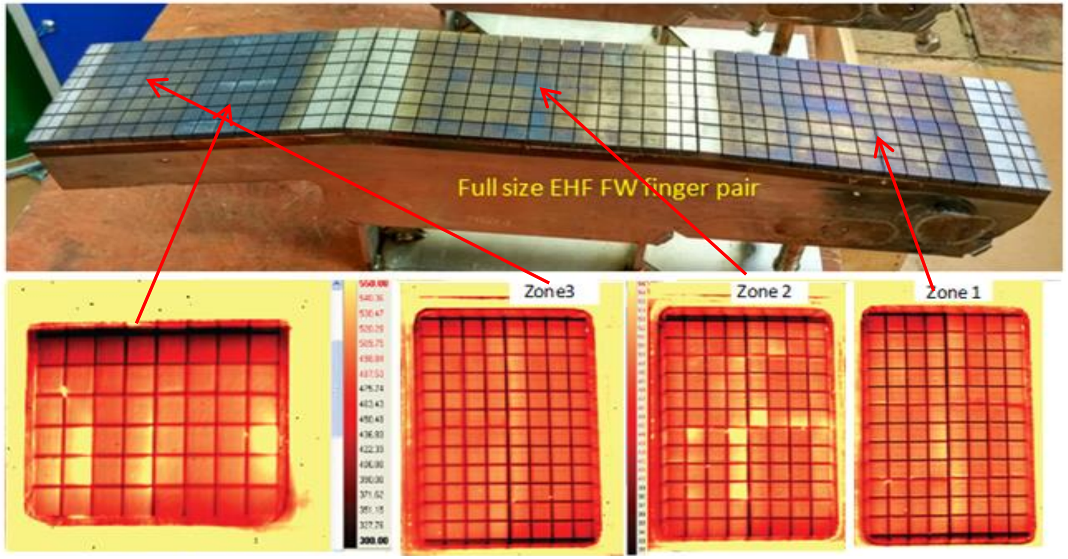


J.M. Chen et al, ISFNT-12, Poster

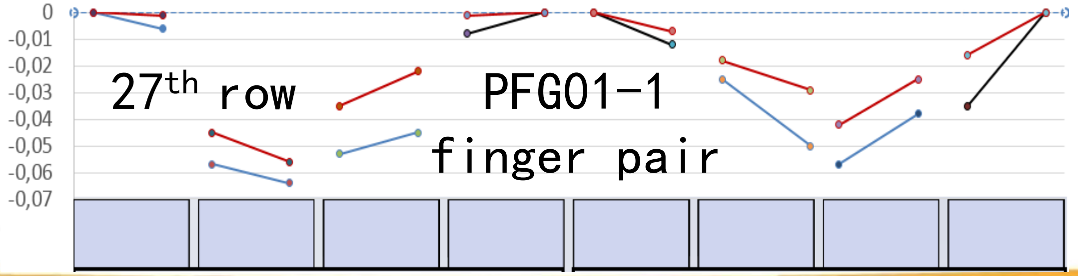
Successful HHF test of full-size FW fingers

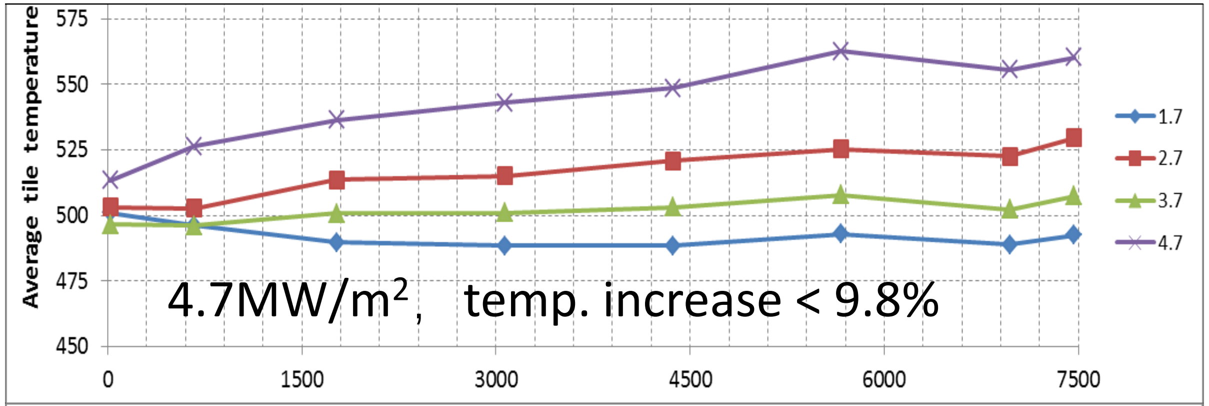
With modified design

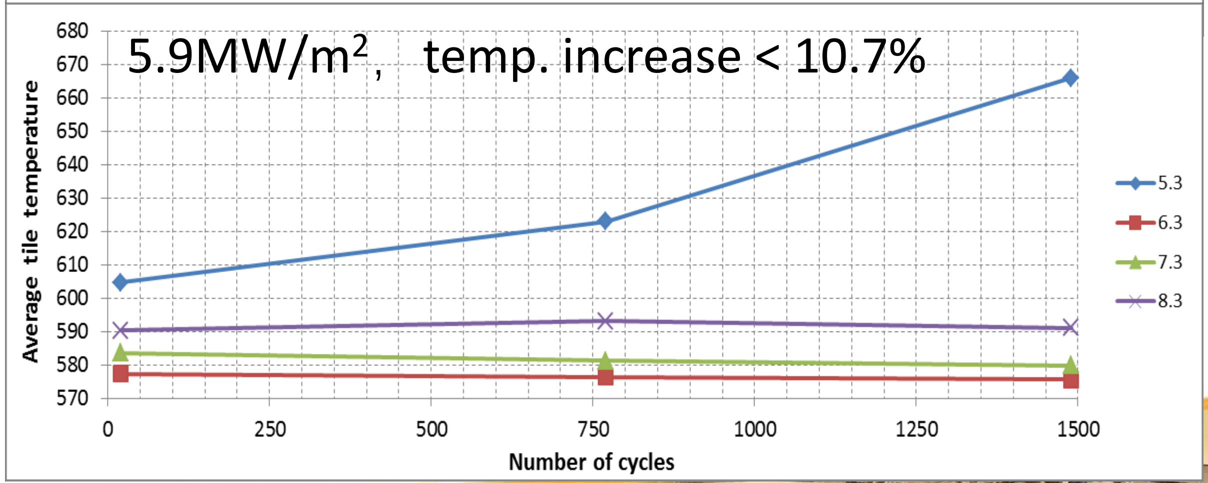
- 7500 cycle @4.7MW/m^2 + 1500 cycle @5.9MW/m^2.
- < 24% in local temperature variation and <11% temperature rising.
- Perfect finger pairs, < 20 μm deformation and < 3.4×10^{-11} Pa.m^3/s He leakage.



5.9MW/m^2 at 1490th cycle 4.7MW/m^2 at 7470th cycle

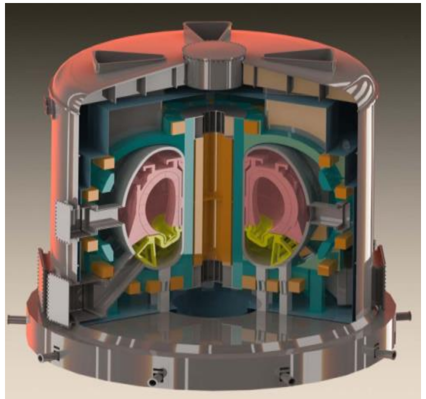




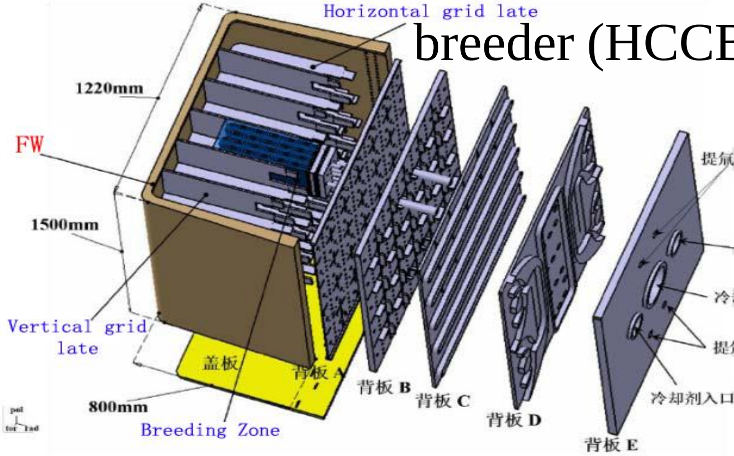


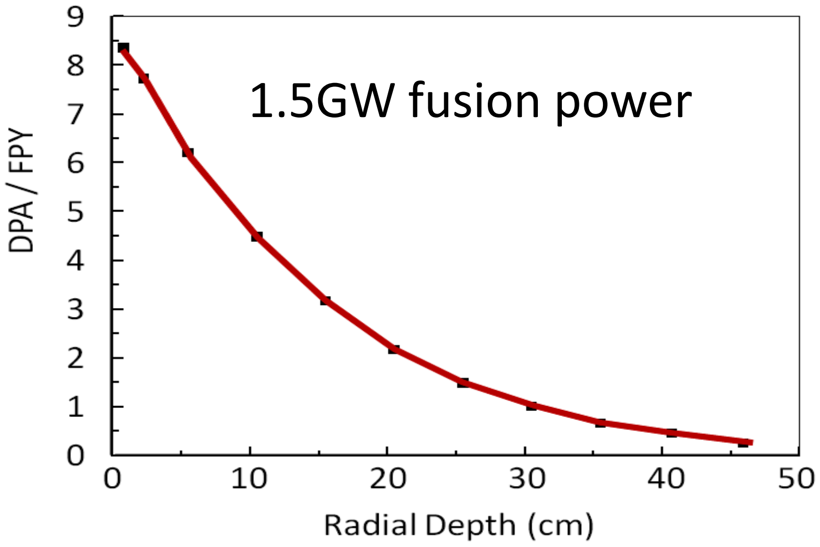
CFETR first wall progress

Preliminary design phase



Helium cooled ceramic breeder (HCCB) blanket

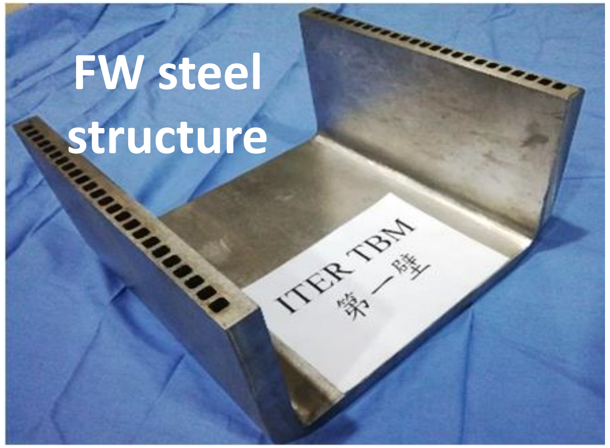




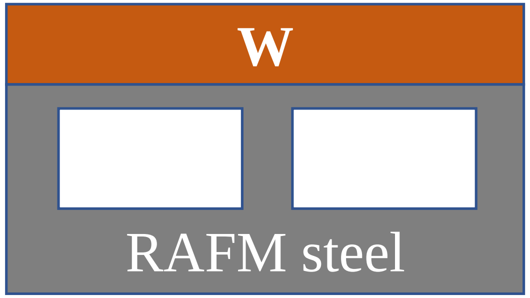
Y.X. Wan, Nucl. Fusion, 57 (2017)

HCCB blanket parameter

Parameters	HCCB
Heat Flux, Avg.	0.5 MW/m^2
Neutron Wall Loading	2 MW/m^2
Plasma facing mater.	W alloy
Structural Material	ODS RAFMs
Breeder	Li_4SiO_4
Neutron Multiplier	Be
He Coolant Temp.	300/550 ^oC
He Coolant Pressure	12 MPa



X.Y. Wang, et al, FEC-27, Oral, FTP/1-6

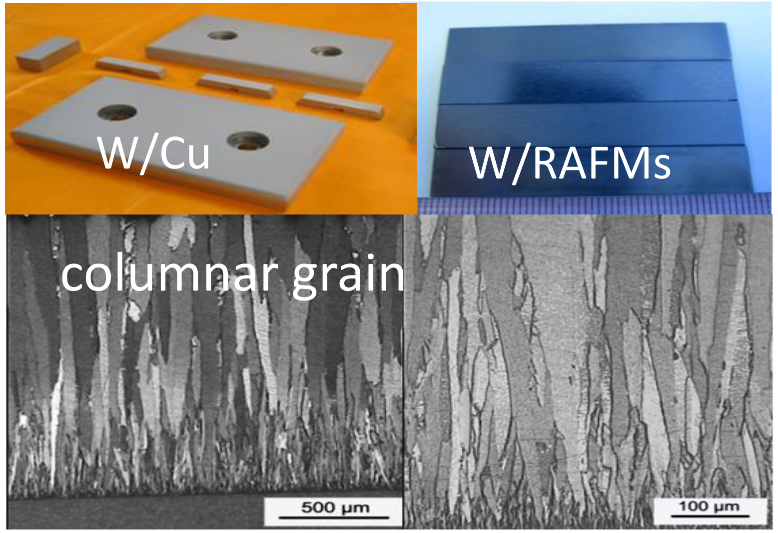


FW

Candidate technologies:
CVD-W, Brazing & HIP,
Low activation design.

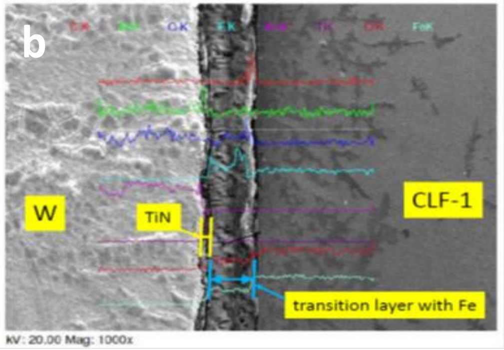
Activities on CVD W/RAFM steel

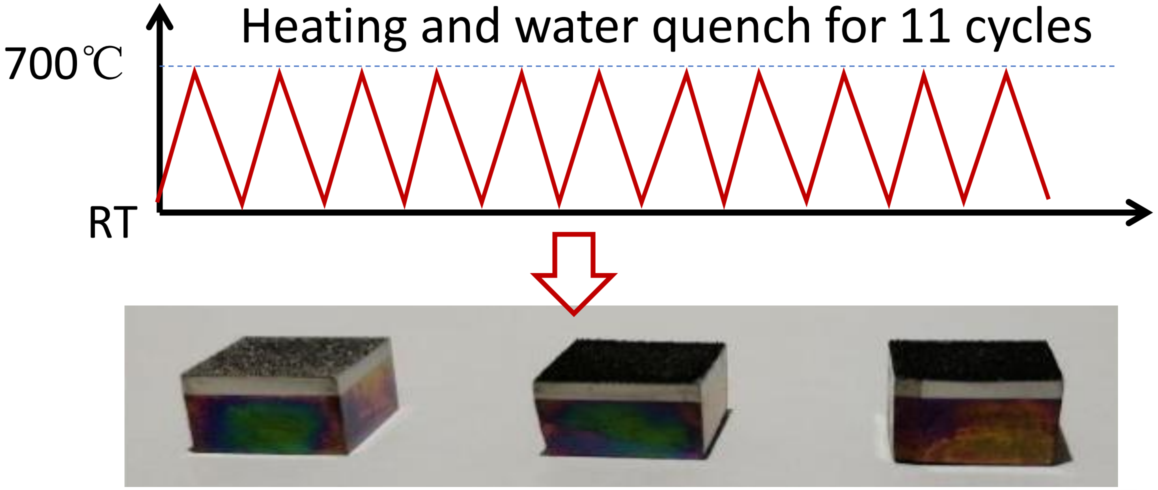
- Fast CVD W up to 0.5mm/h: dense, columnar structure with high thermal conductivity.
- Fast CVD-W + CVD TiN coating (as T permeation barrier) on RAFMs developed.



Deposition rate	0.3-0.5 mm/h
Purity	99.9999%
Thermal conduct.	>180 W.m/K
density	>99%

X. Liu et al, FEC-25, Oral



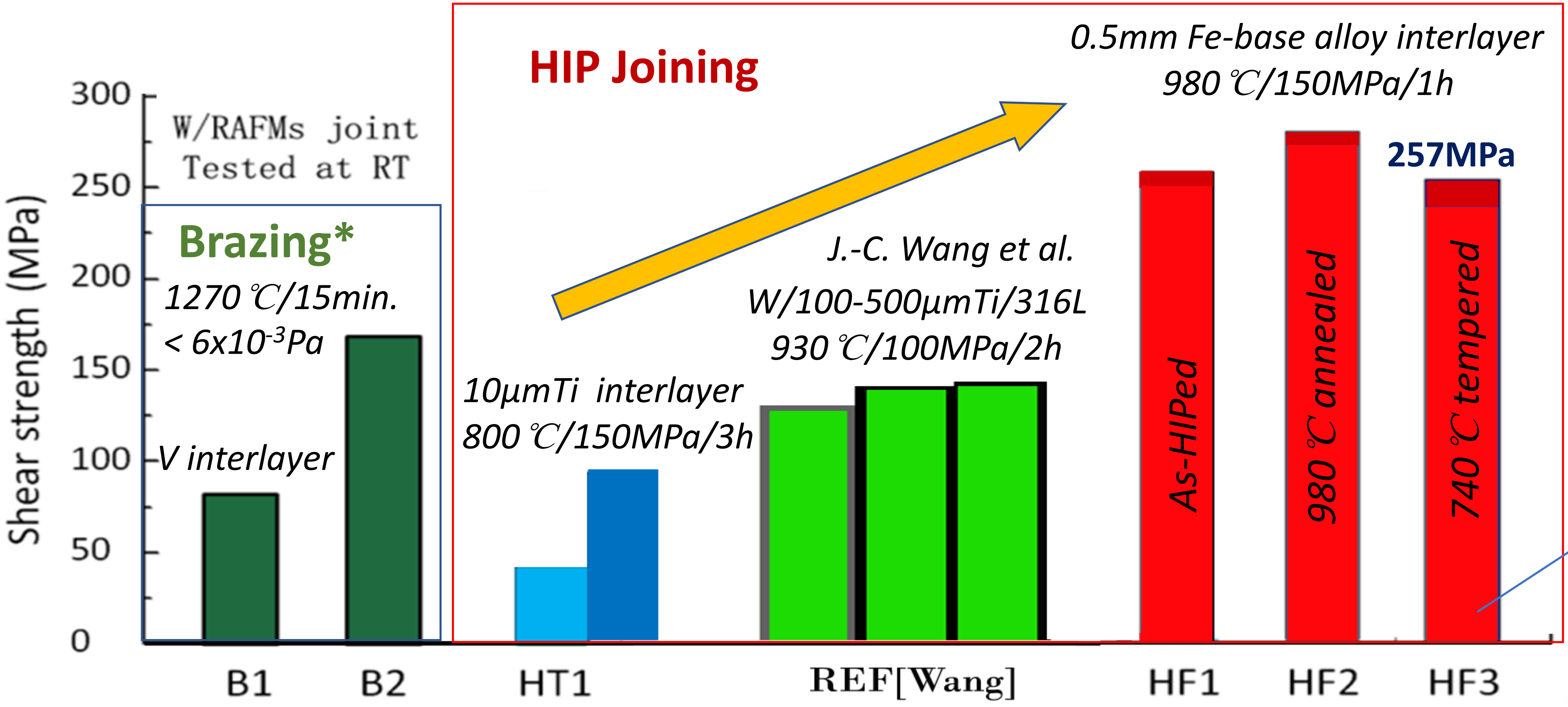


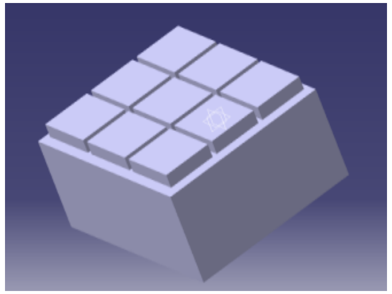
L.Z. Cai et al, FEC-27, Poster, FIP/P1-38

Activities on brazing and HIP Joining W/RAFM steel

ITER-grade W tiles (3mm) and CLF-1 RAFM steel

Results: HIP joints show promising bonding, strongly depending on interlayer metals.





Shear tested sample

* Fe63.5Cr11.5Si8.3B16.7 (at%) amorphous filler

4. Summary

1. Measures for improving thermal fatigue life of ITER EHF FW were investigated and verified by test.
2. One order increase in fatigue life may allow the using of larger Be tiles in the new FW design, and shall be further verified by test.
3. Strong effect of Be/CuCrZr interface defect on thermal fatigue life of the ITER EHF FW. A thick OF-Cu interlayer is a good solution for defect-free joint.
4. Better CuCrZr properties by explosion bonding instead of HIP bonding CuCrZr/316L(N) joints. Cr and Zr elements segregation maybe an issue and shall be assessed further.
5. Good progress in developing the W/RAFM steel joints for CFETR FW. Further study is required for optimizing the technologies and for high heat flux test evaluation.

Thanks for Your Attention!