Mechanical Characterization of Electrochemically based W – Cu Joints for low Temperature Heat Sink Application

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Motivation

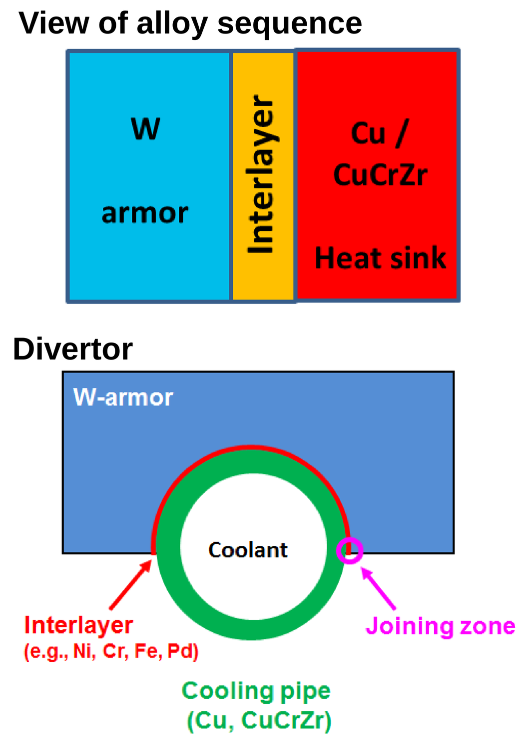
Joining of the armor material tungsten to copper components, which will act as low temperature heat sinks in divertor application, is a challenging process and showed lacks due to their restricted miscibility and alloyability.

Electroplating has the feature to generate layers acting as active interlayers which can overcome such lacks. The interlayers must have the ability to react with both alloys W or Cu.

This work was performed to demonstrate that joints can be processed applying the electrochemical plating tool and bonding.

The joints were qualified by thermomechanical testing for the demonstration of future applicability in fusion development.

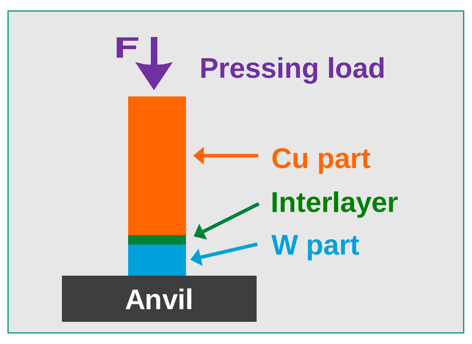
Application of electroplating technology for joining low temperature heat sinks



Joints processed by electroplating

Tools and plating development for adapted joints

Layout of sample processing for brazing of components



The development of joining technology by electroplating consists of the two main parts :

- Electroplating
- Joining by diffusion bonding

Pd was selected as interlayer metal to improve reactions. Electroplating from aqueous electrolytes was performed similarly to Cu or Ni plating with a current density of 8 mA/cm² and pH value of 7 to 8.

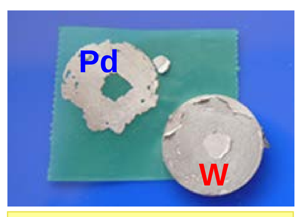
Surface conditioning and electroplating of interlayers

Surface conditioning

Etching by $K_3[Fe(CN)_6]$ * KOH

Pd plating on tungsten

Adherent layer on W

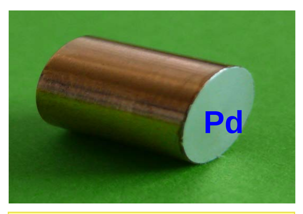


Spalling risk due to hydride formation

Pd deposition from an ammonia complex

- T = 40°C,
- pH range of 7 to 8,
- i = 8 mA/cm²
- approx. 10 µm/h

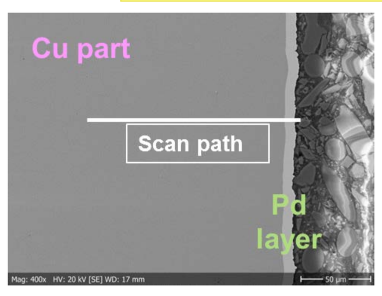
Pd interlayer on copper

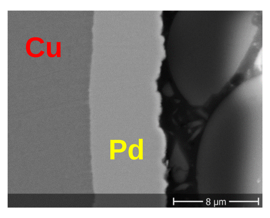


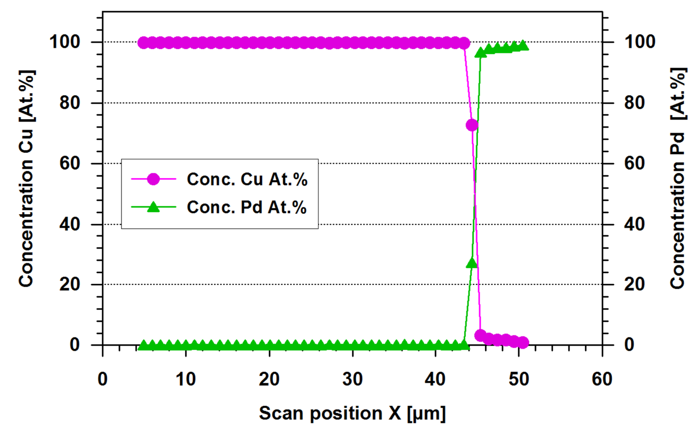
Adherent layer on Cu

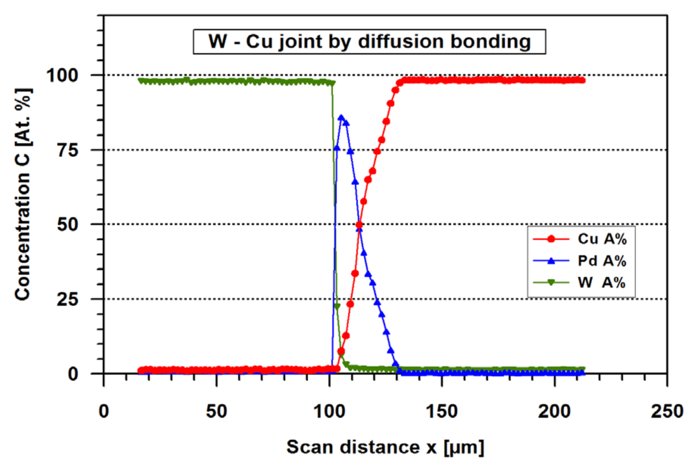
Characterization of plating layer and joined samples

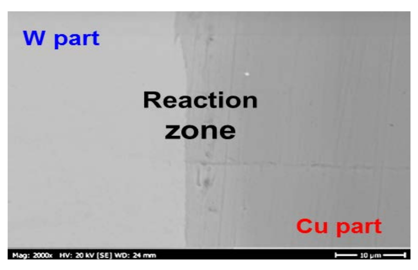
Pd coated part







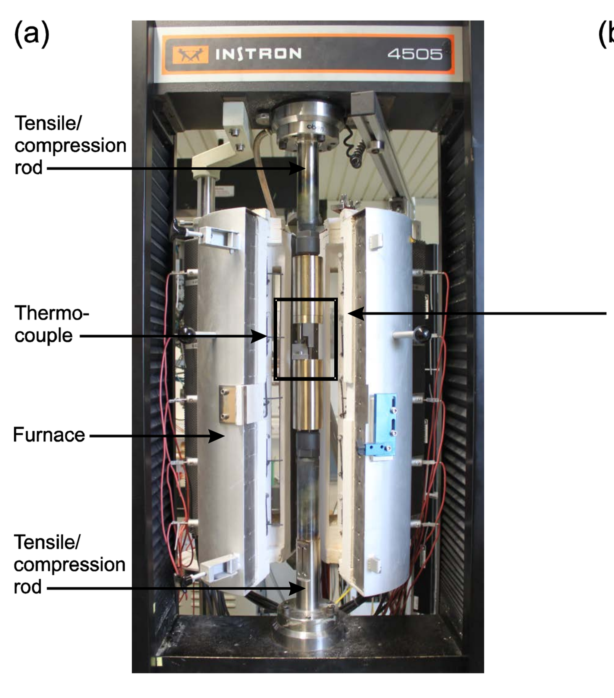


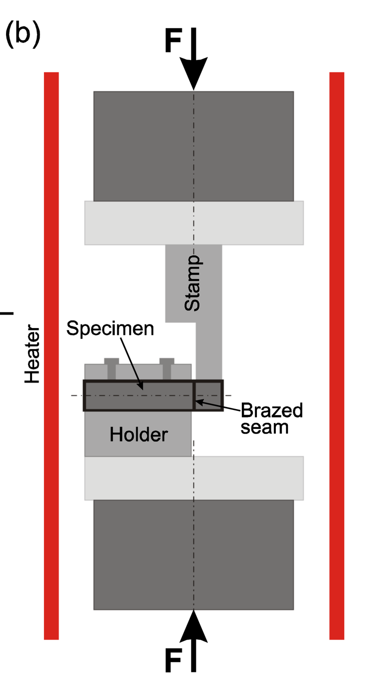


EDX line scan across W – Cu bonding zone

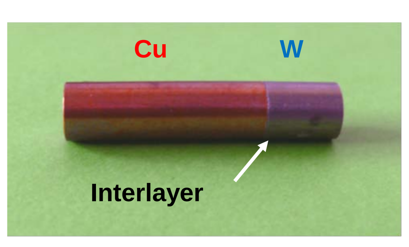
Mechanical characterization of joints

Shear testing of diffusion bonded samples





(a) Universal mechanical testing machine Instron 4505
(b) Schematic diagram of the experimental setup

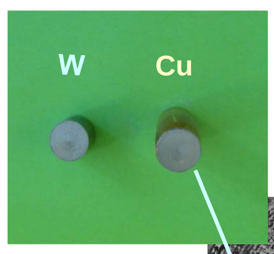


Testing conditions:

Sample size:	Diameter 8 mm
Temperature range:	RT
Atmosphere:	Air
During heating:	Preloading of 0.03 kN
Displacement rate:	0.01 mm/s

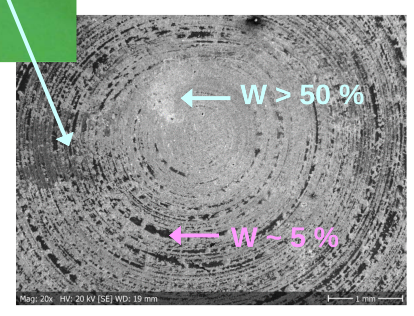
Mechanical behavior and characterization of joints

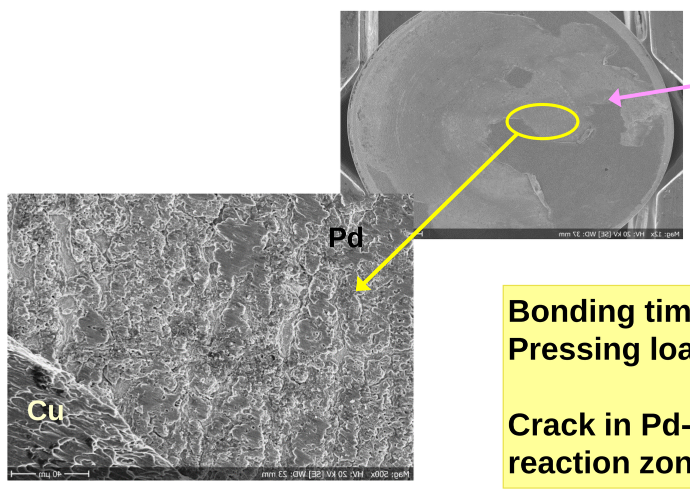
Behavior of joints bonded at 700°C vs bonding time

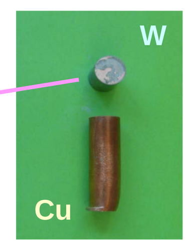


Bonding time: 1 hour
Pressing load: 7 Mpa

First reaction at cone ends





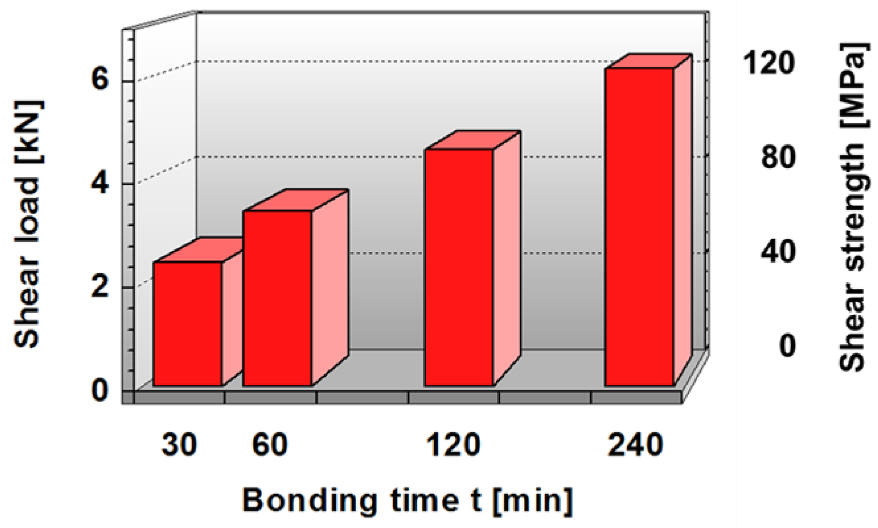


Bonding time: 4 hour
Pressing load: 7 Mpa

Crack in Pd-Cu reaction zone

Shear testing of W - Cu joints

Bonded at 700°C, 350 N



General behavior

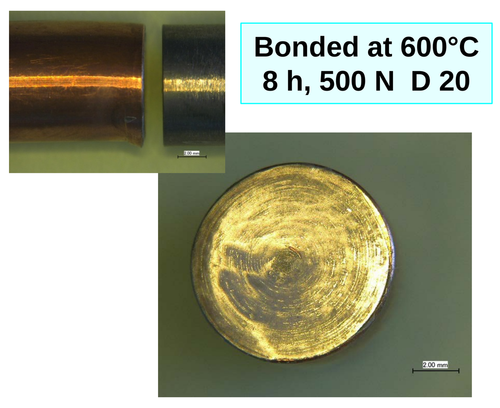
Sample	Time t [h]	Shear strength [MPa]	Bonding force F [N]	Temp. T [°C]
D 10	1	1	500 N	600°C
D 15	4	40	350 N	600°C
D 02	0.5	1	100 N	700°C
D 12	0.5	50	350 N	700°C

- Strength depends on T, t, F
- No spalling of Pd from W
- Shear strength comparable with conventional brazing values near 200 MPa

Bonded at 700°C
4 h, 350 N D 17

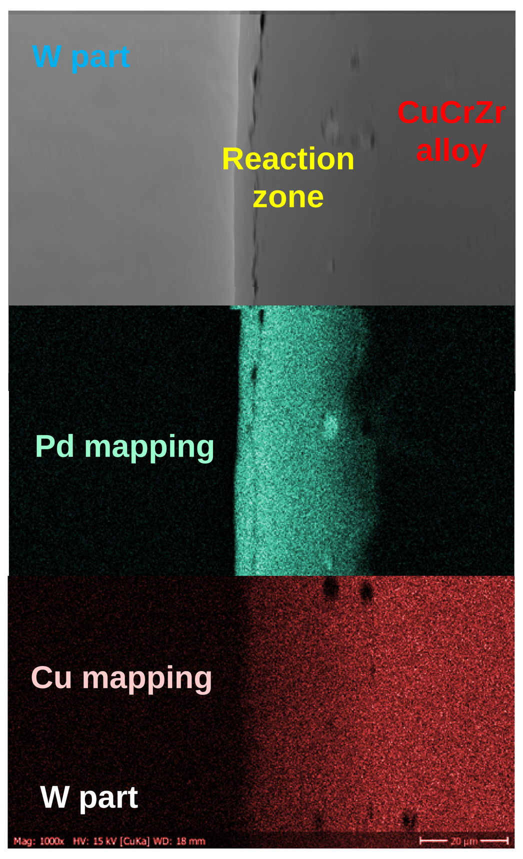
Bonded at 600°C

Sample	Time [h]	Load [N]	Strength [MPa]
D 19	4	350	40
D 22	8	350	51
D 23	4	500	47
D 20	8	500	63



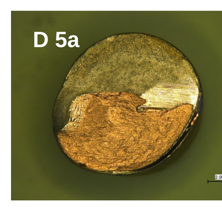
Bonded at 600°C
8 h, 500 N D 20

Behavior of W - CuCrZr joints

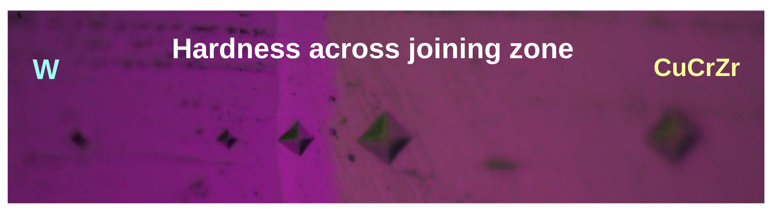


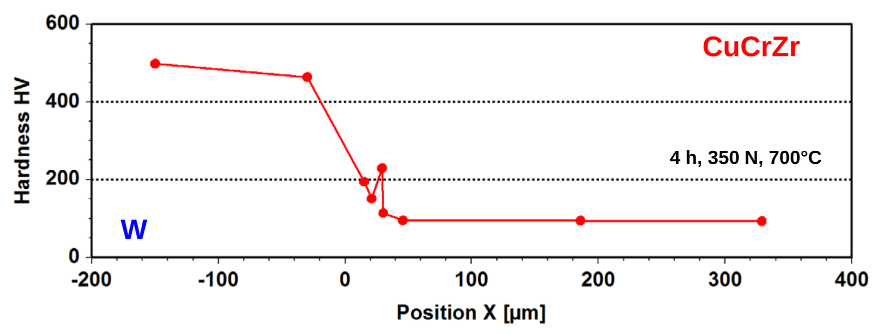
Bonded at 700°C, 4 h

Cracking under shear testing



Sample	Time	Shear strength	Temp.
D 1a	8 h	20 MPa	600°C
D 2a	2 h	1 MPa	700°C
D 3a	4 h	30 MPa	700°C
D 5a	8 h	90 MPa	700°C





Conclusions

The investigations showed that electroplating is an effective technology in the field of the joining of fusion relevant materials and components.

- Reactive Pd layers were successfully deposited on W, Cu and CuCrZr by electroplating to obtain improved bonding
- Pd reacted with both parts W and Cu / CuCrZr to be joined as expected
- Under industrial view Pd plating on Cu alloy instead on W is recommended
- Mechanical testing was performed at RT with shear strength of around 100 MPa
- Shear strength increased with bonding time
- W – CuCrZr joints showed lower strength compared to W –Cu joints
- The strength of CuCrZr may initiate microcracks due to expansion mismatch
- An additional layer of pure Cu between Pd and CuCrZr may be recommended

Acknowledgment

This work has been partly carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.