Mechanical testing of joints processed by electro-plating technology for brazing of divertor components

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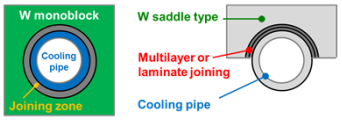
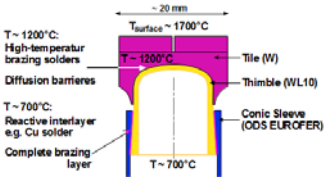
Motivation

Reliable and adapted joining of components is a general challenge in divertor development, independently of design type and cooling medium water or gas.
High heat flux testing showed that brittle phase formation and missing wetting are general risks in brazing divertor components. Thus, successful brazing needs innovative technologies to overcome such lacks. Electroplating has the feature to generate layers acting as barriers, active interlayers or as brazing alloys. The operation conditions imply to select metals from the transition elements. Electrochemical behavior of the elements allows plating for some elements (e.g. Cu, Ni, Fe or Pd) from aqueous electrolytes. Thus, technological relevance in industrial processing will be high. The path towards this goal requires development of electroplating technology, characterization of the joints and mechanical qualification.



Joint types for He or water cooled divertor design

W – W, W – steel, W - Cu or stainless steel with functional / structural behavior



Electroplating for joining

Tools and filler development for adapted joints

Removal of surface scales and activation for electroplating

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

Etching by H_2SO_4 - HCl - H_2O 10g, 20ml, 80ml 50°C, 5 min currentless

Etching by HNO_3 - HF - H_2O Ratio 20/3/77 50°C, 30 s currentless

Development of brazing technology depends on several factors as metallurgical behavior of filler components in correlations to W or steel joining parts, melting points and chemical behavior. Appropriate brazing needs surface cleaning and activation, interlayers for improved filler behavior and adapted processing steps due to the unique properties of tungsten.

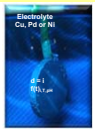
Interlayers for improved wetting

1.3 M $Ni(SO_3NH_2)_2$
T = 52 °C, pH = 3.5,
i = 10 mA/cm²
D = 12 µm / h

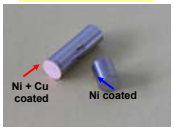
Pd electrolyte (AMI DODUCO)
T = 40°C
i = 4 - 8 mA/cm²
pH = 7.5

- Water based electrolyte
- Organic electrolytes
  - EMIM-Cl (Ethyl-Methyl-Imidazolium-Cl)
  - PC (Propylencarbonat

Electroplating Evaluation of parameters



Electroplated parts with interlayers and filler



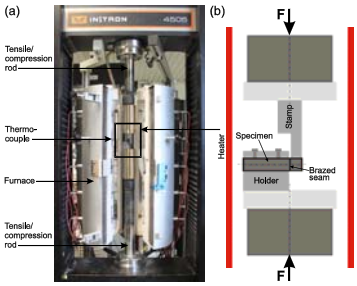
Brazed samples for shear testing

Type of joints
Tungsten
Eurofer
Stainless steel

Brazing Temp.: 1150°C
Brazing Time: 1 - 10 min
Type: Moving into hot zone

Qualification of joints by electroplating

Shear testing of joints



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

The microstructural analyses pointed out, that interlayers (Ni, Pd) and filler metal (Cu) can be electroplated on tungsten, Eurofer and stainless steel in adjustable thickness and well adherent quality. Cross sections of brazing zones showed homogeneous gap filling indicating good thermal and mechanical bonding.

Shear testing was chosen as the first mechanical qualification step to qualify the processed joints due to the simplest sample preparation and testing configuration.

Testing conditions:

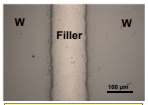
Sample size:	Diameter 8 mm
Temperature range:	RT to 600°
Atmosphere:	Air
During heating:	Preloading of 0.03 kN
Displacement rate:	0.01 mm/s

Typical behavior of samples during shear testing

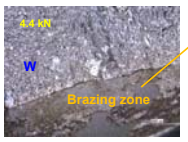
Tungsten	Stainless steel	Eurofer	Tungsten aged
As brazed Testing at RT Cracking of W-rod due to high DBTT of W	As brazed Testing at RT Bending of samples No failure up to < 9 kN	As brazed Tested at 450°C Failure in the braze by shearing/sliding	Annealed at 700°C, 215 h Cracking in brazing zone Similar behavior for testing at elevated temperatures

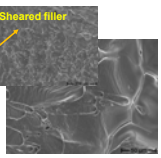
Microstructural features of sheared samples

Reactions of filler metal, functional layers and work piece



W parts brazed with Ni-Cu at 1150°C, Ar, 5 min.





W - W joints at RT
Main failure in W-rod with propagation of crack into filler

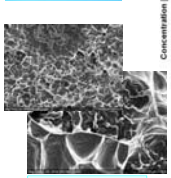
Brazing zone shows ductile behavior

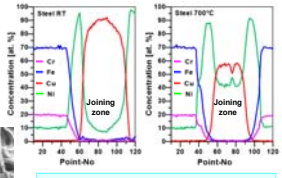
Impact of aging on Eurofer and stainless steel joints

Conditions of tested samples
Brazed at 1150°C, 5 min, Ar
- As joined
- Aged at 700°C, 215 h
- Aged at 700°C, 1002 h

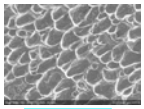
Aging of joints in glass tubes

CT analyses of joints





After shear testing



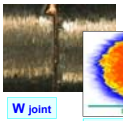
Shear testing of Eurofer as joined

Shear testing of Eurofer aged 215 h at 700°C

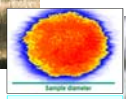
Impact of ageing
- Microstructure unchanged
- Homogenization of filler
- No defects generated by ageing
- No brittle phase formation in contact zone filler base material

Shear testing

Tungsten and Eurofer as joined



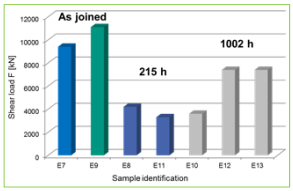
W joint

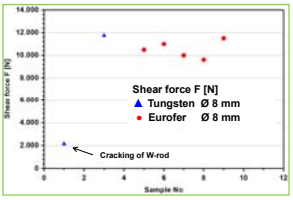


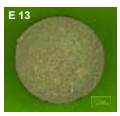
Testing at RT

Ultrasonic view of brazing zone

Impact of aging and quality







X-Ray tomography of tested samples and cracked zone

Mechanical behavior vs. testing conditions and temperature

Sheared brazing zone Eurofer, 450°C Oxidized after cracking

Alloy / Shear force [kN]	RT	450°C	Aged, 700°C, 215 h	Aged, 700°C, 1002 h
Tungsten	11.8	3.3	2.7	-
Stainless steel	> 9 bending	5.8	9.1	7.8
Eurofer	11.5	5.2	4.2	7.4

W joint shear tested at 450°C

Mapping of Cu

- Shear strength is similar for all three brazing combinations
- Softening at elevated test temperature as expected
- At 450°C about 40% of strength of RT value are remaining

Conclusions

The performed investigations show that electroplating is an alternative processing technology in the fields of the joining and coating of fusion relevant materials and components.

- **Homogeneous and well-adherent layers were successfully deposited on tungsten, Eurofer and stainless steel by electroplating**
- **Mechanical testing was performed in the temperature range RT to 600°C**
- **At RT Eurofer samples failed at high strength (L ≈ 230 N/mm²)**
- **Aging at 700°C showed diffusion in brazing zone but no significant weakening**
- **Mechanical strength still present at elevated temperature**
- **At 459 °C failure of W-W joints appear as expected in the braze**
- **Brazed steel parts by deposited Cu-Ni layers revealed strength behavior comparable to joints fabricated by common technology**

Acknowledgment

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