Joining of HHF components applying electroplating technology

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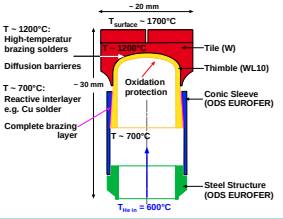
Motivation

Independently on divertor design and used cooling medium helium or water reliable and adapted joints of armor material and structural components are a general challenge in divertor development.
Adapted interlayers and fillers are needed for successful brazing of tungsten and steel components to create long-term stable joints and to resolve dangerous brittle phase formation or to overcome un-alloying behavior. In the past electroplating showed to generate layers acting as barriers, active interlayers or as brazing alloys. Transition elements (e.g. Cu, Ni, Fe or Pd) can be deposited from aqueous electrolytes and joints were reproducibly fabricated. After general demonstration of the applicability characterization and mechanical testing are now dominating the development of joining by electroplating technology.

Joint types for He or water cooled divertor design

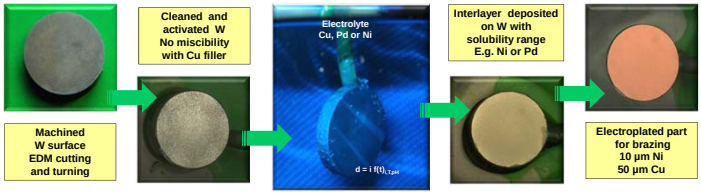
W - W
W – steel
with functional / structural behavior



Electroplating for joining

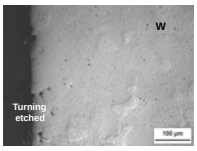
Elements for fillers and processing steps

Joints for divertor application should work for brazing W to W and W to steel at temperatures up to 1200 and 700° C, respectively. The brazing development depends on several factors as metallurgical behavior of filler components in correlations to W or steel as, e.g., melting points and chemical behavior additionally influence brazing development. Appropriate brazing temperature favors Cu as filler part. However, reactive interlayers are required and, additionally, common plating technique has to be adapted for W coating or completely new developed.

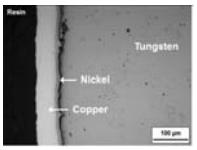


Joining by interlayers of Ni or Pd and filler Cu

Characterization of electroplated parts and joints

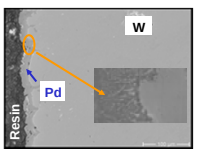


Tungsten surface activation by $K_3[Fe(CN)_6]$ * KOH



Tungsten plated by Ni and Cu
Both exhibit wetting and interlocking

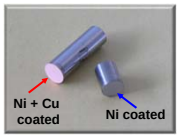
Electrolyte: 1.3 M $Ni(SO_3NH_2)_2$
Deposition parameters:
T = 52 °C, pH = 3.5
i = 10 mA/cm²
Rate: D = 12 µm/h

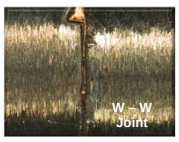


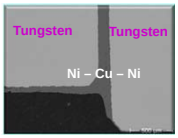
Pd coated tungsten after heat treatment 1100°C, 10 min.
Reaction of active interlayer

Electrolyte: Pd amino complex
Deposition parameters:
T = 40 °C, pH = 7 – 7.8
i = 2 - 8 mA/cm²
Rate: D ~ 10 µm/h

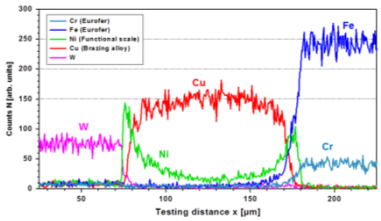
Processed tungsten or Eurofer steel samples for mechanical testing







Behavior of interlayers and filler metal for joining of tungsten to Eurofer steel



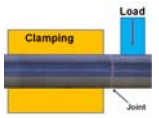
Brazing behavior

- W has to be activated for well adherent layers
- Reactions between W – Ni – Cu and W – Pd – Cu emphasize brazing ability
- High grade of reproducibility and straightforwardness
- Ni – Cu proven as (model) brazing system

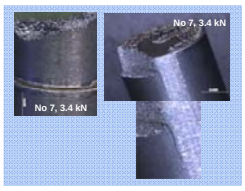
Mechanical characterization

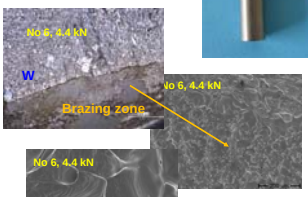
Shear testing of W - W and Eurofer - Eurofer joints

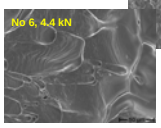
Testing configuration

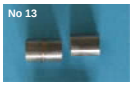


Features of W samples tested at RT

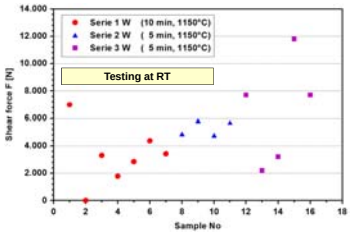




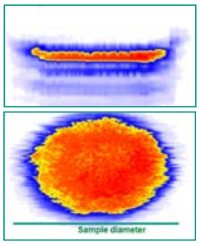




Shear strength of W joints



NDT of W-W joint

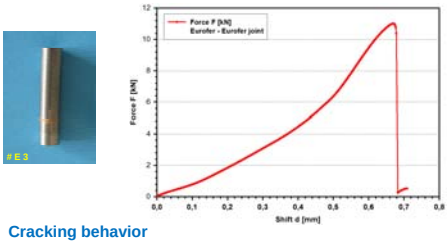


Mechanical testing of W-W joints

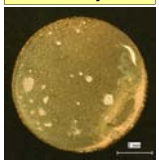
- Wetting of W is excellently
- Cracking occurred in W bulk not in brazing zone
- Shear forces observed of 12 kN at 0.5 cm² surface
- Quality of joint has to be controlled (ultrasonic testing)
- Braze showed ductile behavior

Features of Eurofer samples tested at RT

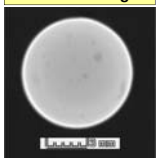
Shear strength



Crack in joint



CT of joint before shear testing



Cracking behavior

- Brazing zone is weak position for Eurofer joints
- Most of crack is in filler
- Shear strength similar to 'strong' W-W joints
- NDT by CT (X-Ray) indicates weak points

Conclusions

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

- Homogeneous and well-adherent layers were successfully deposited on tungsten or Eurofer by electroplating
- Filler composition can be determined by process parameters, e.g., deposition time
- Interlayers of Ni or Pd plated on W ensured real joint connections with metallurgical reaction applying Cu as main filler component
- Qualification of joints successfully performed by shear testing
- Brazed tungsten and steel parts by deposited Cu-Ni layers revealed strength behavior comparable to joints fabricated by common technology
- Testing at elevated temperatures necessary (ductile range of W)
- Qualification of aged joints has to be included into characterization process
- NDT of joints is recommended especially towards analyzing aged joints

Acknowledgment

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