Performance of electroplated and joined components for divertor application

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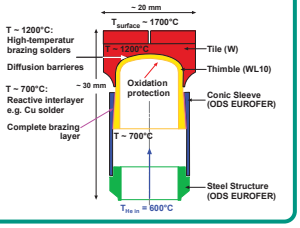
Motivation

Reliable and adapted joining of components W to W or W to steel is a general challenge in divertor development, independently of design type and cooling medium water or Helium.
Successful brazing needs innovative technologies as well as aligned interlayers to overcome un-alloying behavior and filler components to avoid dangerous brittle phase formation. 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. Electro-chemical behavior of the elements allows plating only for some elements (e.g. Cu, Ni, Fe or Pd) from aqueous electrolytes. Whereas other elements (e.g. W, Ta, Ti or V) need innovative aprotic (water-free) solvents like molten salts.

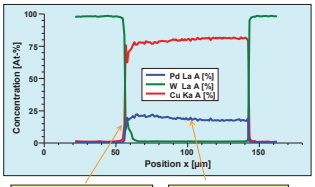
Joint types for He or water cooled divertor design

W - W
W – steel
with functional / structural behavior



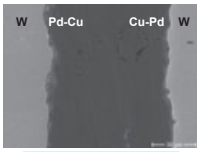
Pd-Cu layers and heat treatment

Reactions of filler metal, functional Pd layer and work piece



Pd - W interaction by diffusion of W towards Pd

Filler: Pd - Cu solid solution



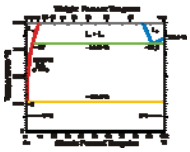
Pd-Cu layers on W after annealing at 1100°C / 10 min.

Brazing by electroplated Pd and Cu layers

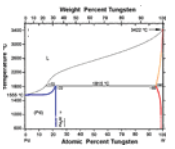
- Reactive interlayer of Pd reacts with W
- Pd is wetting W excellently
- Pd and Cu form homogeneous filler metal by diffusion
- Increase of re-melting temperature by diffusion above Cu melting

Element selection for joining and electroplating

Elements for fillers and metal deposition systems



No miscibility for Cu - W

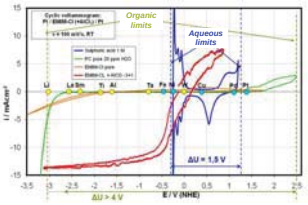


Interlayer with solubility range

Several factors as metallurgical behavior of filler components in correlations to W or steel joining parts, melting points and chemical behavior influence brazing development. Appropriate brazing temperature favor Cu as filler part, however, reactive interlayers are required. Additionally, common plating technique has to be adapted to e.g. W coating or completely new developed.

- Water based electrolyte
- Organic electrolytes

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



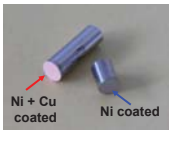
Cyclic voltammetry scans for determination of plating conditions

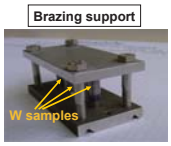
Mechanical characterization

Fabrication of samples for shear testing

Steel joining

W joining



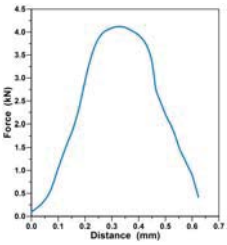


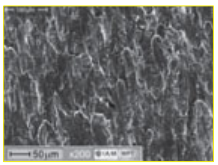
Deposition and joining conditions

- 10 µm Ni deposition on activated surface
- 90 µm Cu deposition as filler
- Brazing under Ar at 1100°C / 10 min.

Mechanical behavior of parts brazed by electroplating of layers

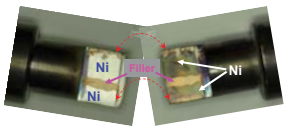
Steel joining





Cracking behavior

Insufficient clamping
Reactions and adherence

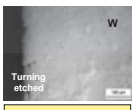


Brazing behavior

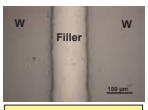
- Ni reacts with work pieces, well adherent
- Cu acts as filler and reacts with Ni interlayers
- Shear strength similar to conventional brazes
- Crack appears at weakest position in filler

Joining by Ni and Cu layers

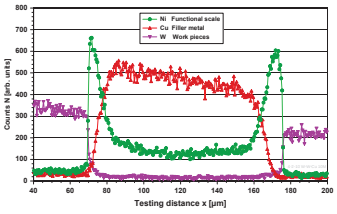
Processing of tungsten for joining by Ni and Cu



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



W parts brazed at 1100°C, Ar, 10 min.



Plating by Ni and Cu
Both exhibit wetting and interlocking

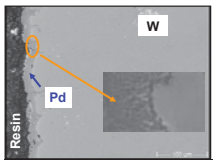
Brazing behavior

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

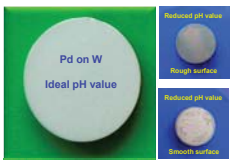
Electroplating of Pd

Palladium as interlayer for joining of tungsten

W discs plated by Pd and Pd and Cu layers



Coated tungsten after heat treatment 1100°C, 10 min.



Impact of deposition parameters

Palladium interlayer

- Tungsten and steel require activation
- Pd layers were successfully deposited
- Pd is more sensitive compared to Ni
- Stress accumulation can appear in Pd

Electrolyte: Basic Pd amino complex

Deposition parameters:

T = 40 °C, pH = 7 – 7.8
i = 2 - 8 mA/cm²

Rate: D ~ 10 µm/h

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 or Eurofer by electro-plating
- 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
- Mechanical testing was included into the qualification of joints fabricated by applying electroplating
- Brazed steel parts by deposited Cu-Ni layers revealed strength behavior comparable to joints fabricated by common technology

Acknowledgment

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