MAT-W&Walloys Monitoring Meeting,
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Functionally graded tungsten / EUROFER 97 joints for divertor applications

Thomas Weber, Jarir Aktaa

Activity (1):	Fabrication Process Development
Task:	Functionally graded tungsten / EUROFER 97 joints for divertor applications
WP:	WP10-MAT-WWALLOY-01-08/KIT/BS
Reporting Period:	February 2010 - June 2010
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Institution:	KIT

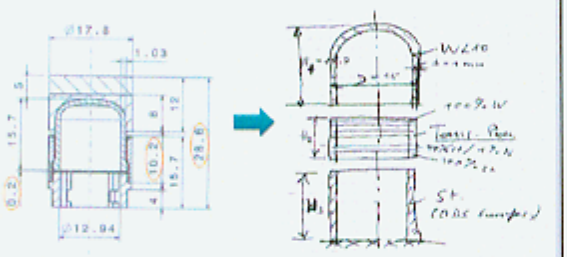
Objective

- Task:
  - Joining of tungsten-with steel-tubes
- Problem:
  - Thermal induced stresses
    - tungsten: $\alpha = 4.4\times10^{-6}$/K
    - steel: $\alpha = 12.0\times10^{-6}$/K

G. Kitz et al., Fusion Engineering and Design, 2009

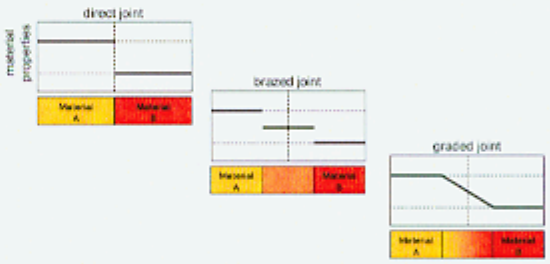
Norajitra et al., 21st IEEE/NPS Symposium on Fusion Engineering, 2005

Functionally graded tungsten/EUROFER97 joints

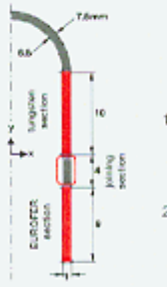


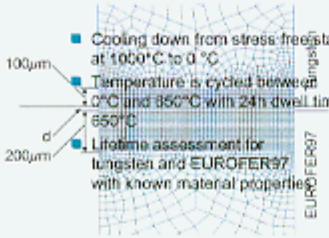
P. Norajitra, L. Boccaccini & J. Aktaa, KIT, Aug. 2005

Functionally graded materials (FGM)



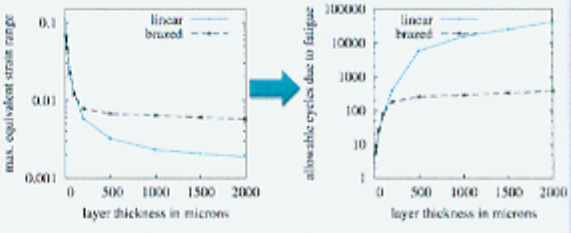
FEM-Simulation
Model description





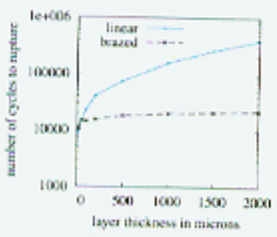
- 5 different meshes with $d/\mu m$=20, 200, 500, 1000, 2000
- Cooling down from stress-free state at 1050°C to 0 °C
- Temperature is cycled between 0°C and 650°C with 24h dwell time at 650°C
- Lifetime assessment for tungsten and EUROFER97 with known material properties

FEM-Simulation
Lifetime assessment for the EUROFER97 section



design criteria : Aktaa et al., FZKA 7309, 2007

FEM-Simulation
Lifetime assessment for the tungsten section



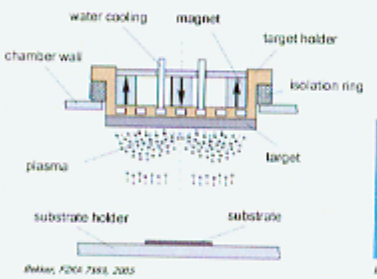
- Design criteria are going to be determined
- Probabilistic failure analysis will be performed based on measured Weibull parameters

Regge curve: ITER Material Properties Handbook, No. S 74 RE 1

Screening of fabrication methods

	Layer thickness	Gradation range	Vacuum	Feasibility
Vacuum Plasma Spraying	+	+	+	+
Magnetron Sputtering	-	+	+	+
Resistance Sintering under Ultra High Pressure	+	+	-	+
Conventional Sintering	+	+	+	-
Electro Deposition	-	-	+	•
Laser Cladding	+	+	-	•
Infiltration Method	+	-	+	•

Magnetron Sputtering
Fabrication principle of graded coatings



Bekker, FZKA 7368, 2005

- Segmented target
- Motion of substrate below target

Bauer, FZKA 6748, 2001

Magnetron Sputtering
Targets and substrates

Targets

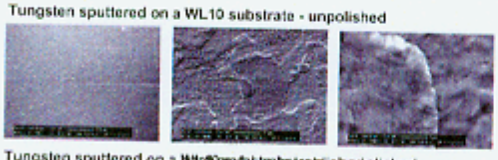
- WL10
  - Tungsten alloy with 1wt.% La_2O_3
  - Process parameters drifted during sputtering
- Tungsten
  - Pure tungsten >99.95%
  - Worked fine
- EUROFER97
  - Fe, Cr 9%, C 0.11%, Mn 0.4%
  - Worked fine

Substrates

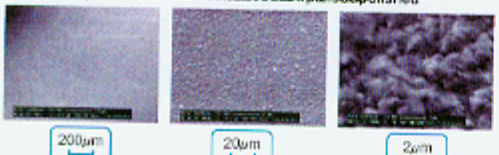
- Silicon
- Hard metal
- Tungsten
- WL10

Scanning electron microscope analysis
Surface morphology

Tungsten sputtered on a WL10 substrate - unpolished



Tungsten sputtered on a WL10 substrate - polished

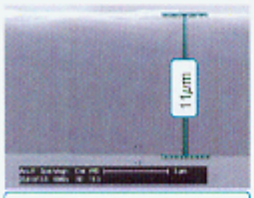


Scanning electron microscope analysis
Surface morphology

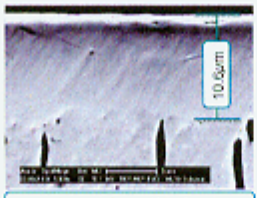
EUROFER97 sputtered on a tungsten substrate - unpolished

EUROFER97 sputtered on a tungsten substrate - polished

Scanning electron microscope analysis
Polished cross section

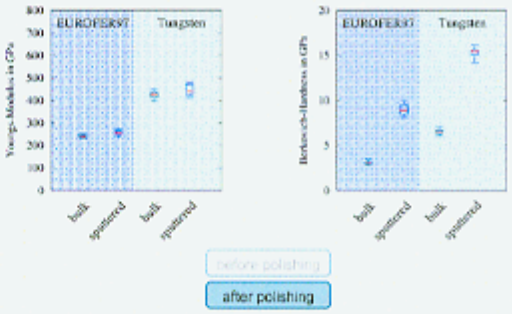


EUROFER97 on tungsten

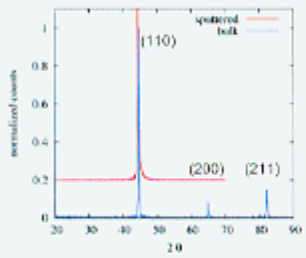


tungsten on WL10

Nanoindentation
Berkovich – 1 micron indentation depth

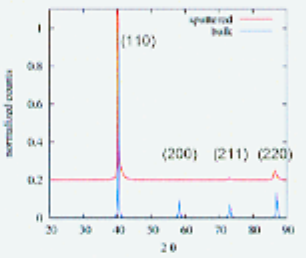


X-ray diffraction
Phases of EUROFER97



- only α-Fe phase found
- peak broadening indicates amorphous and/or nanocrystalline microstructure

X-ray diffraction
Phases of Tungsten



- only α-W phase found
- more phases (Fe_2W, Fe_7W_6, WC, W_2C) are expected after heat treatment of EUROFER97-tungsten coatings

Summary & Outlook

Performed Work (February 2010 - June 2010)
- Lifetime assessment of functionally graded tungsten/EUROFER97 joints
  → necessity of graded joints
- Successful deposition of EUROFER97 and tungsten on tungsten substrates by magnetron sputtering

Status of the whole task (level of achievements)
- Deposition of layers with different tunsten/EUROFER97 compositions on tungsten substrates started and first layers characterized

Summary & Outlook

Work planned for the next period
- Deposition and characterization of further layers with different tunsten/EUROFER97 compositions on tungsten substrates by magnetron sputtering
- Deposition and characterization of layers with different tunsten/EUROFER97 compositions on tungsten substrates by vacuum plasma spraying (VPS)
- Investigation of thermal stability of the microstructure at 700°C
- Fabrication of graded coatings on tungsten substrates by PVD and VPS

Work planned for WP 2011
- Diffusion bonding of graded coatings with EUROFER97
  → thermal stability of graded layers at diffusion bonding temperature?
- Investigation of resistance sintering under ultra high pressure (RSUHP) as an alternative method for realization of graded tungsten/EUROFER97 joints