



Thermal Shock Behaviour of Different Tungsten Grades under Varying Conditions

Oliver Marius Wirtz

Forschungszentrum Jülich GmbH
Institute of Energy and Climate Research (IEK)
Microstructure and Properties of Materials (IEK-2)

Thermal Shock Behaviour of Different Tungsten Grades under Varying Conditions

Oliver Marius Wirtz

Schriften des Forschungszentrums Jülich
Reihe Energie & Umwelt / Energy & Environment

Band / Volume 161

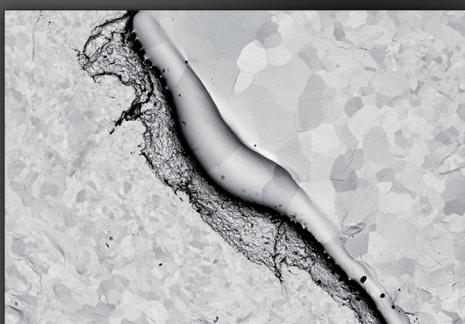
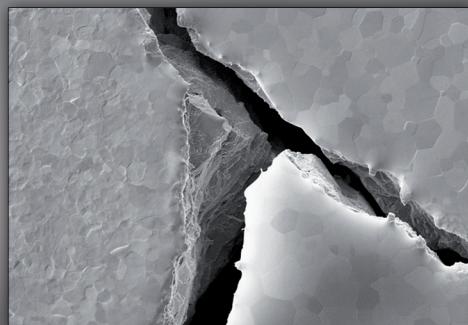
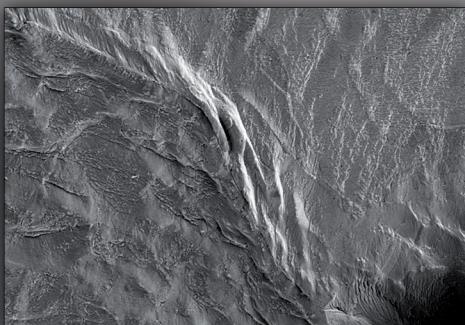
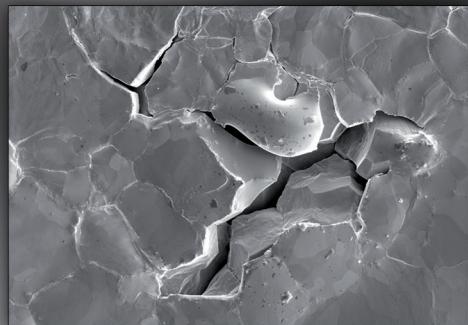
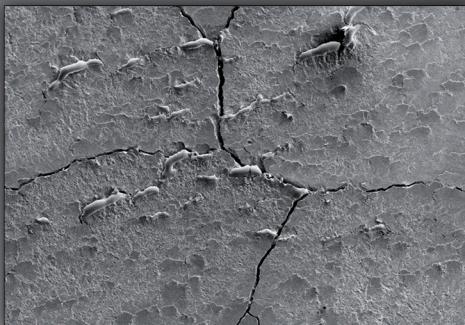
ISSN 1866-1793

ISBN 978-3-89336-842-6

Contents

1	Introduction	1
1.1	Nuclear fusion	1
1.2	ITER design and operation conditions	3
1.3	Plasma wall interaction	6
1.3.1	Energy deposition by thermal loads	7
1.3.2	Particle fluxes	8
1.4	Plasma facing materials	9
1.5	Induced material damages	12
1.6	Simulation of fusion relevant conditions	13
1.7	Scope of work	14
2	Test facilities and material characterisation methods	17
2.1	Mechanical properties	17
2.1.1	Tensile test	18
2.1.2	Impulse excitation method - Grindo Sonic	19
2.2	Thermal properties	21
2.2.1	Coefficient of thermal expansion - dilatometer	21
2.2.2	Specific heat capacity - differential scanning calorimetry	22
2.2.3	Thermal diffusivity - laser-flash method	23
2.3	Test facilities	25
2.3.1	JUDITH 1	25
2.3.2	Pilot-PSI	29
2.3.3	MARION	30
2.3.4	Nd:YAG laser	31
2.4	Post mortem analysis methods	33

2.5 Finite element method (FEM)	34
3 Thermal shock performance of different tungsten grades	35
3.1 Tungsten grades	35
3.1.1 Manufacturing and microstructure	35
3.1.2 Mechanical properties	44
3.1.3 Thermal properties	48
3.2 Experimental conditions	50
3.3 Simulation of temperature distributions	52
3.4 Results and discussion	55
3.4.1 Damage mapping	57
3.4.2 Investigation of thermal shock crack networks	71
3.4.3 Pulse number dependent thermal shock performance	77
3.4.4 Comparison of damages induced by laser and electron beam	79
3.5 Summary and conclusion	82
4 Influence of hydrogen on the thermal shock behaviour of tungsten	89
4.1 Tungsten grade	89
4.2 Experimental conditions	90
4.3 Results and discussion	93
4.4 Summary and conclusion	101
5 Overall conclusion and outlook	103
A Appendix: Hydrogen implantation in MARION	105
B Appendix: Tests at high temperatures in JUDITH 1	109
C Appendix: Detailed measurement results	113
C.1 Microstructure and density	113
C.2 Database for the calculation of the thermal conductivities	113
C.3 Arithmetic mean roughness of tungsten with different grain structures .	115
C.4 Crack parameters for tungsten with different grain structures	116
Bibliography	119



Energie & Umwelt / Energy & Environment
Band / Volume 161
ISBN 978-3-89336-842-6