Mo- and W-Fiber Reinforced SiCN Ceramic Matrix Composites: First Results

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Overview

- Introduction and motivation
- Properties of Mo- and W-fibers
- Manufacture of Mo/SiCN and W/SiCN composites
- Mechanical properties of composites
- Microstructure and phase analysis of composites
- Summary and outlook

Introduction and motivation

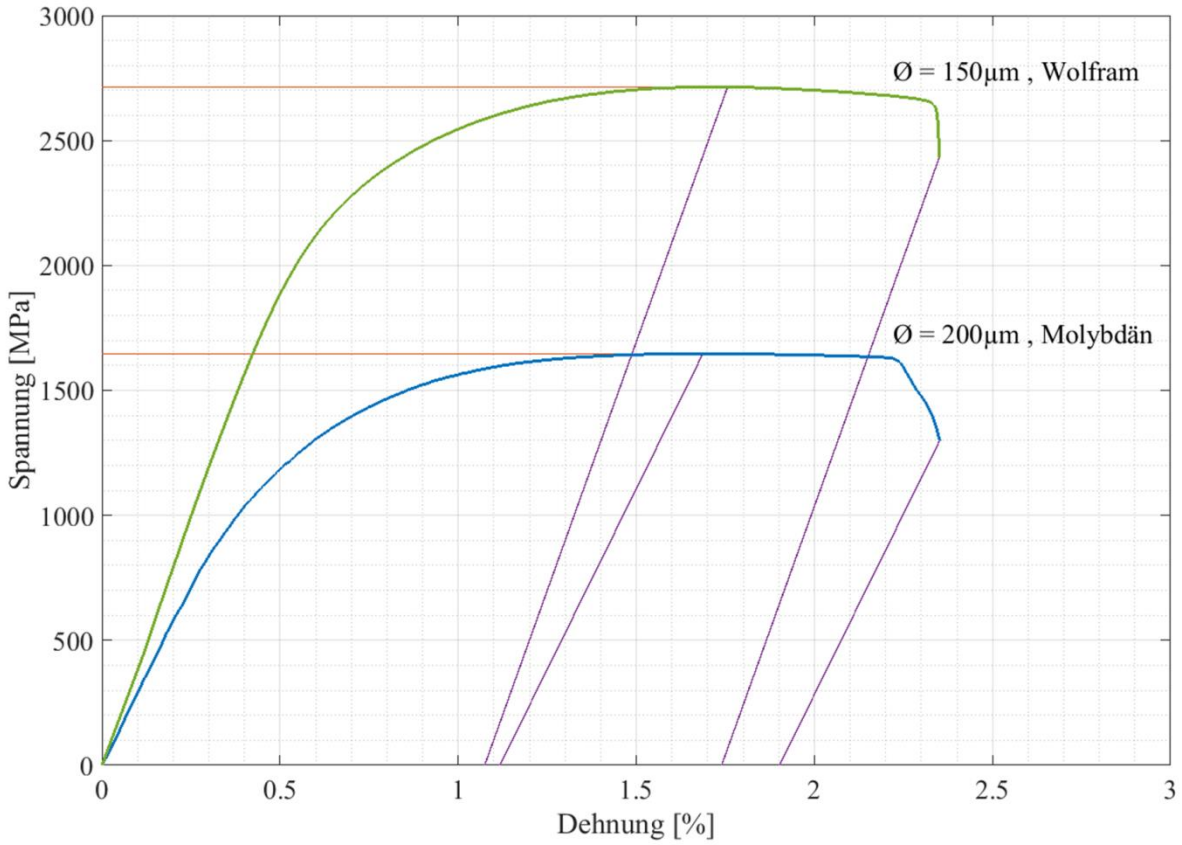
- Monolithic ceramics are brittle, have high stiffness and low elongation to break, but show catastrophic failure when overloaded
- Ceramic fiber reinforced ceramic matrix composites show graceful failure when overloaded, but still have low elongation to break (compared to metals)
- Metal fiber reinforced ceramic matrix composites are very little known, however, could be interesting due to higher elongation to break of metallic fibers
- Ceramic matrices are more oxidation and corrosion resistant as well as light-weight compared to molybdenum and tungsten

Physical and mechanical properties of Mo- and W-fibers

Fiber type		Tungsten BSD-OG-102045280100	Molybdenum MOA-B6144601XX42
Manufacturer		Osram	Osram
Diameter	µm	150	200
Density	g/cm³	19.250	10.220
Yield strength	MPa		1207±5
Tensile strength	MPa	2774±29 [Riesch2017]	1647±1
Tensile modulus	GPa		287±2
Fracture strain	%		1.9±0.1
Reduction in area	%	37±3 [Riesch2017]	70.2±0.2
K content	ppm	70-80	150-200

Tensile testing of single Mo- and W-fibers

a)



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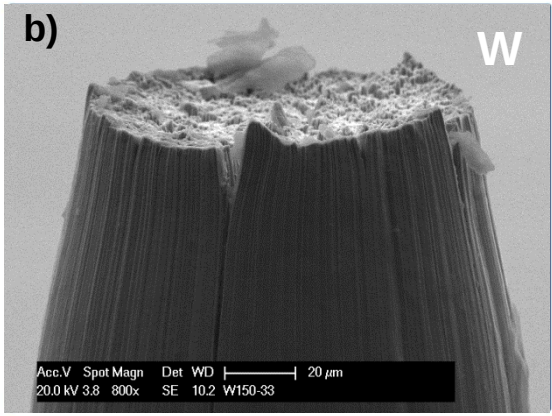

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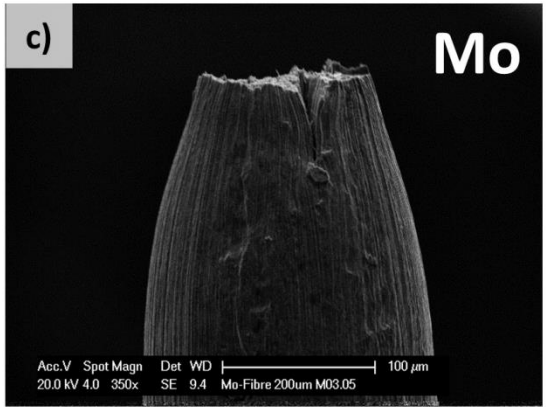
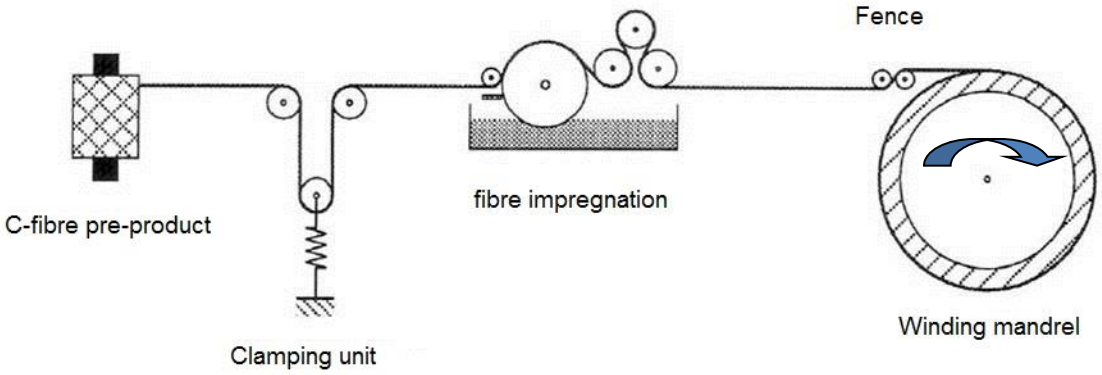
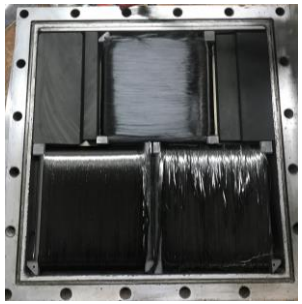
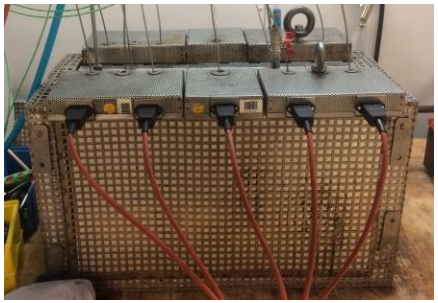


Preform Manufacture – Dry Filament Winding







Raw materials and equipment:

- Mo- or W-fibers
- Filament winding machine controlling winding speed and angle
- Graphite mandrel equipped with Teflon tape
- Precursor PSZ10 (polysilazane resin) for RTM infiltration
- Steel mould for RTM infiltration and curing under pressure

Manufacture of Mo- and W-fiber ceramic matrix composites

Polymer Infiltration und Pyrolyse (PIP)

Polymer Infiltration

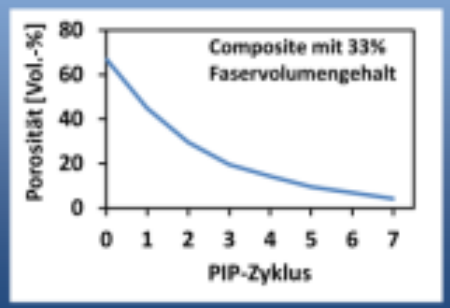
SiCFK

Infiltration der Faserpreform mit Polysilazan und Vernetzung
T = 260°C, p = 20 bar, N_2

Pyrolyse

SiC/SiCN

Pyrolyse des SiCFK
Polysilazan-Matrix → SiCN-Matrix
T = 1300°C, N_2



mehrere Zyklen zur Verringerung der Porosität

Liquid Silicon Infiltration (LSI)

Polymer Infiltration

SiCFK

Infiltration der Faserpreform mit Phenolharz und Vernetzung
T = 150°C, p = 20 bar, N_2

Pyrolyse

SiC/C

Pyrolyse des SiCFK
Phenoplast-Matrix → C-Matrix
T = 1450°C, N_2

Silicierung

SiC/SiC

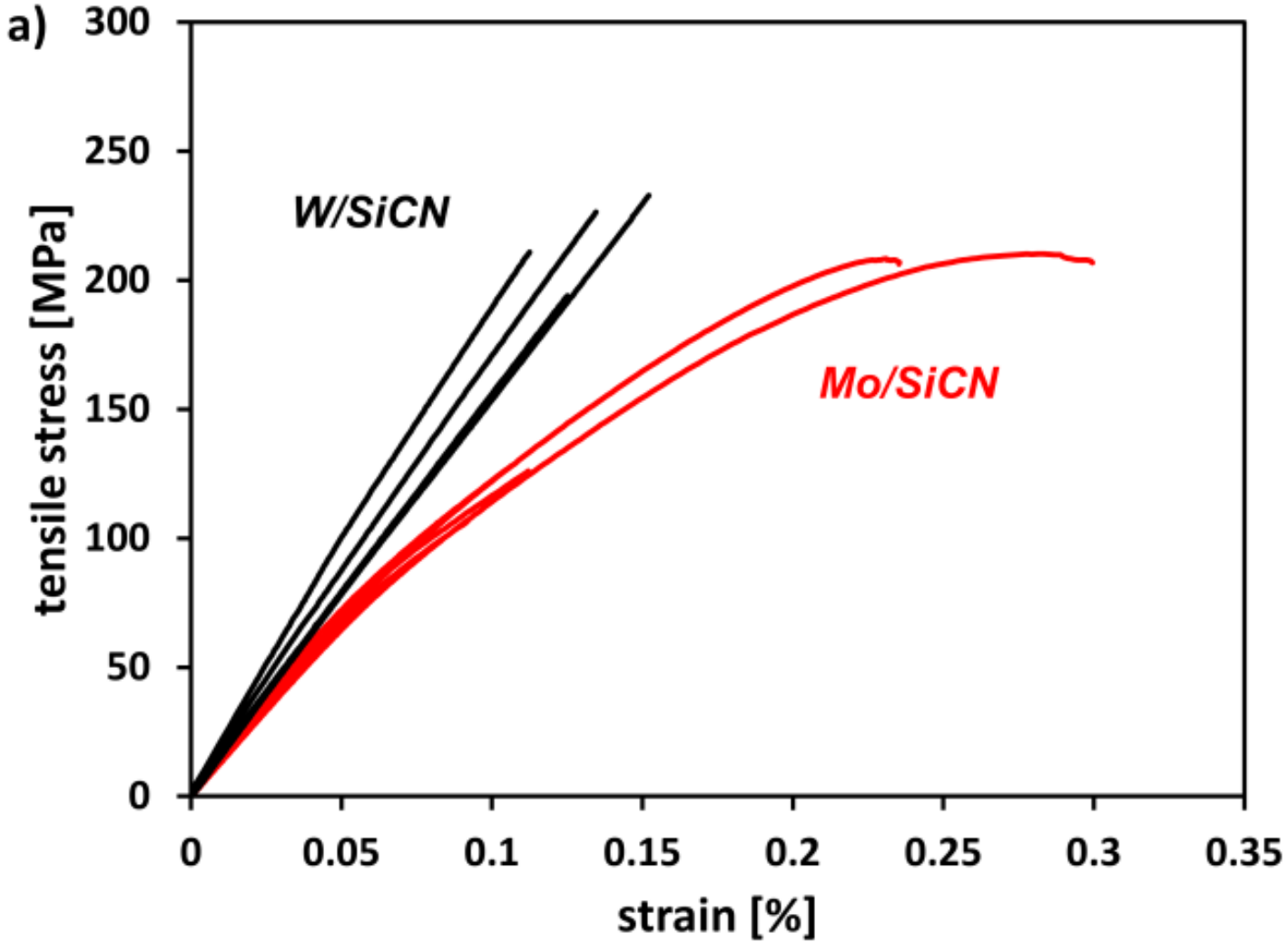
Infiltration des SiC/C mit Silicium
C-Matrix → SiC-Matrix
T > Schmelzpunkt von Si, Vakuum

Properties of Mo/SiCN and W/SiCN composites

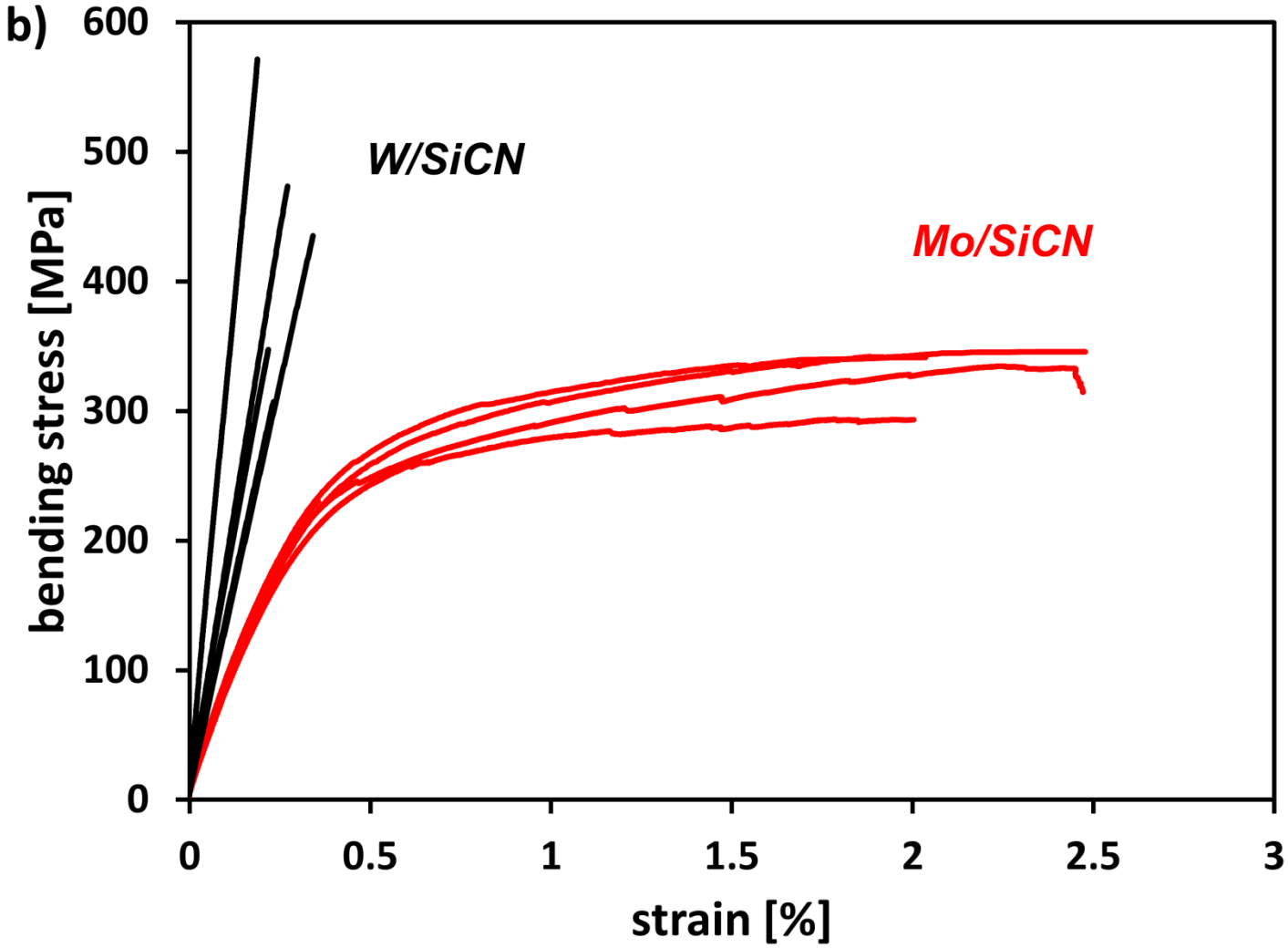
Composite type		W/SiCN	Mo/SiCN
Fiber volume content	%	25 (33*)	30
Tensile strength	MPa	206±27	156±50
Tensile modulus	GPa	172±19	144±7
Tensile fracture strain	%	1.26±0.18	1.64±0.86
Bending strength	MPa	427±105	312±50
Bending modulus	GPa	193±89	90±6
Bending fracture strain	%	0.24±0.08	2.02±0.93
Density	g/cm^3	7.72	4.44
Porosity	Vol.-%	6.86	10.07
Density (calculated)	g/cm^3	6.38 (7.74)	4.44

*calculated by asuming 2.30 g/cm^3 for density of SiCN

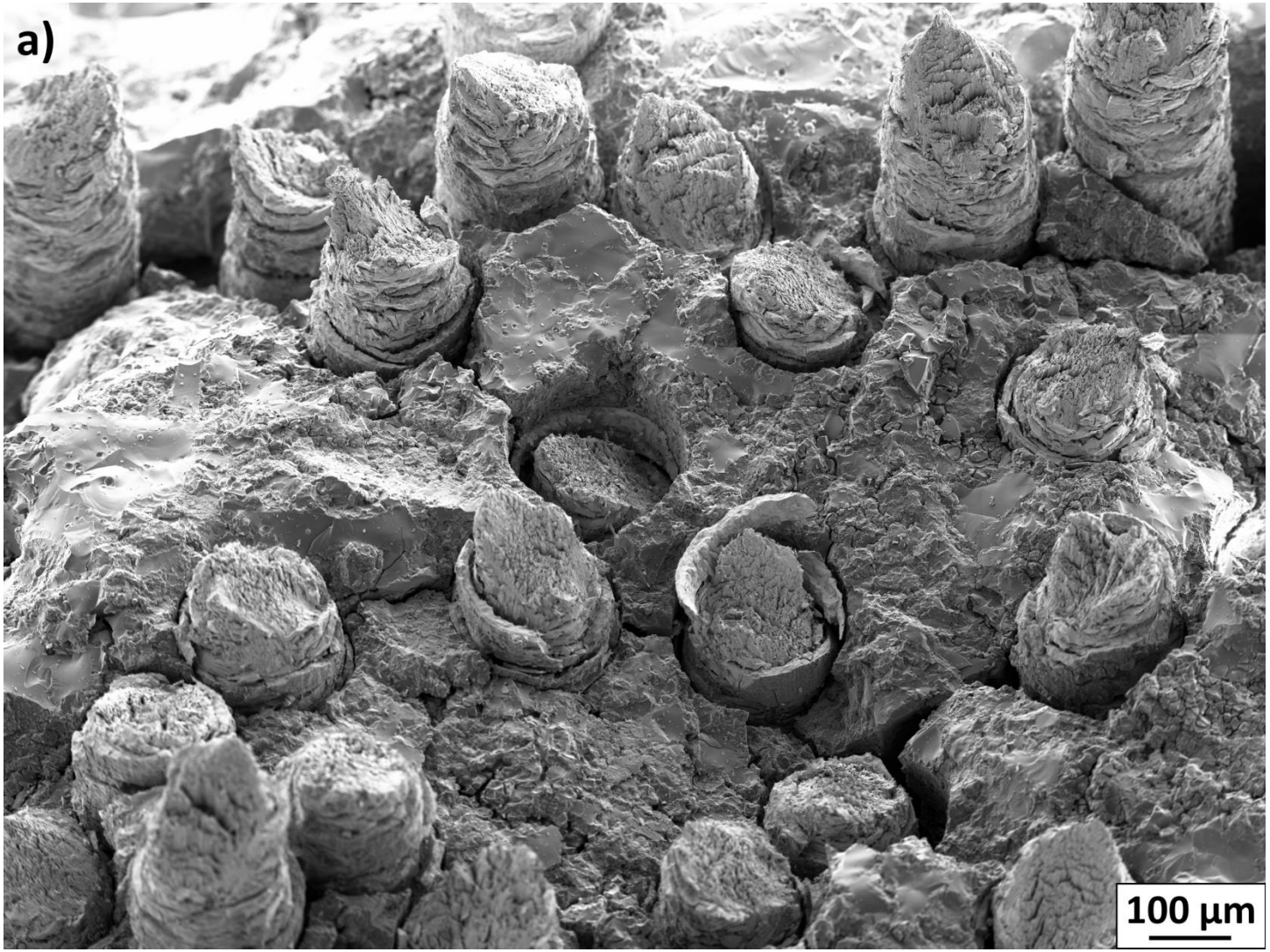
Tensile testing of Mo/SiCN and W/SiCN



Bending testing of Mo/SiCN and W/SiCN



Microstructure of Mo/SiCN (I)



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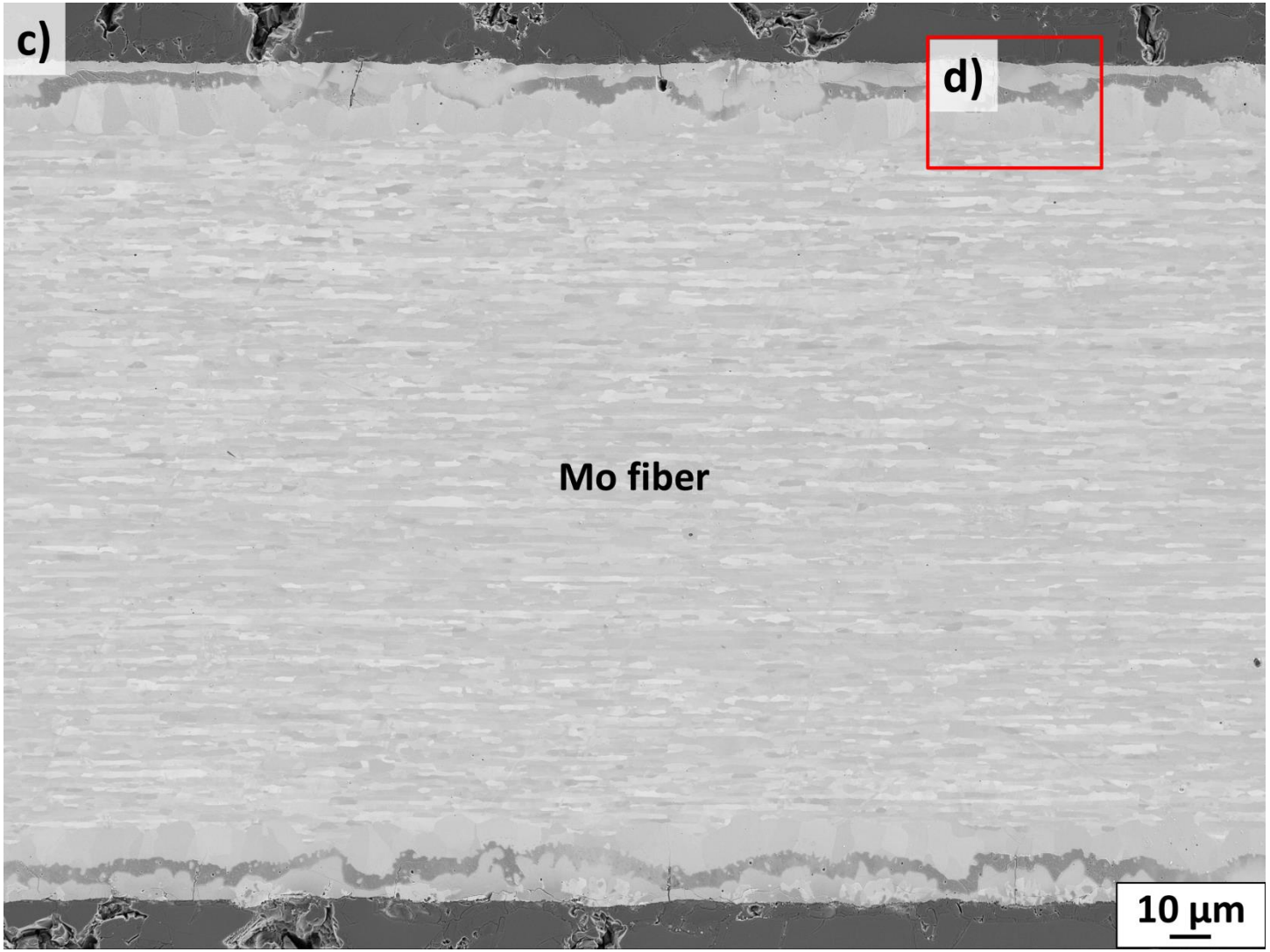
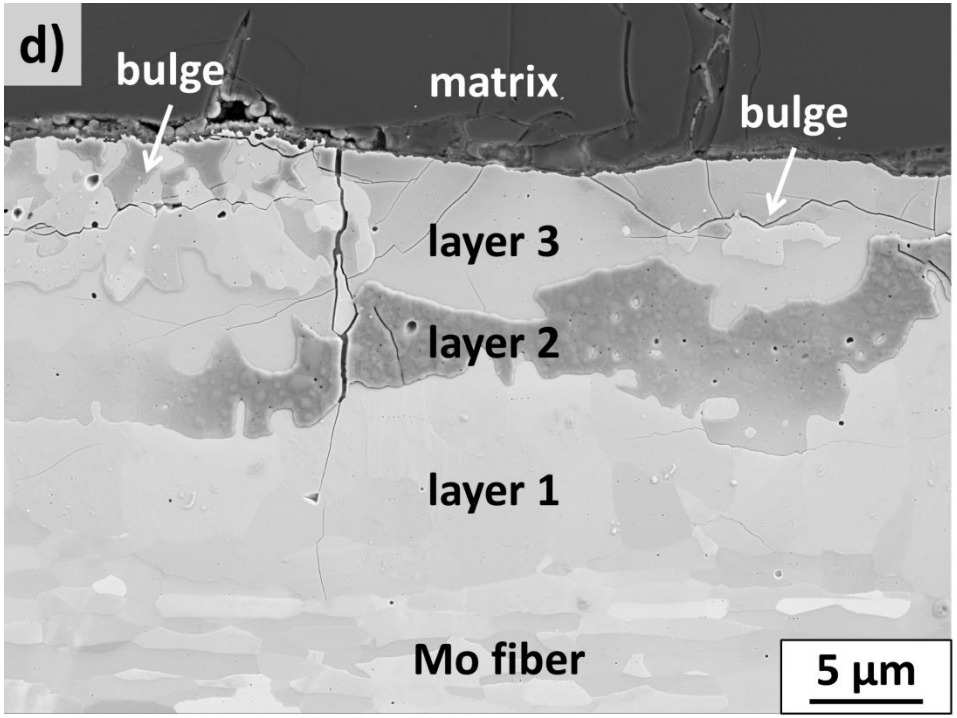
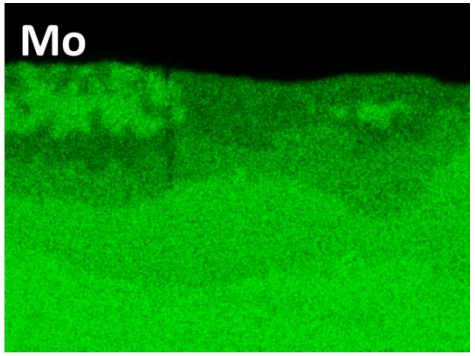
Microstructure of Mo/SiCN (II)

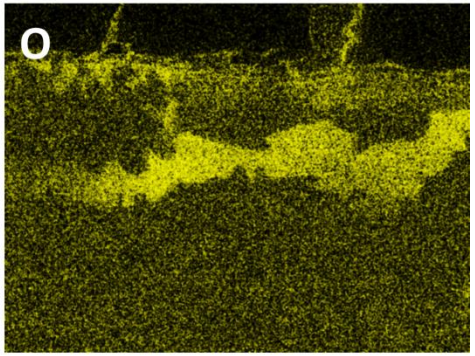
Microstructure of Mo/SiCN (III)

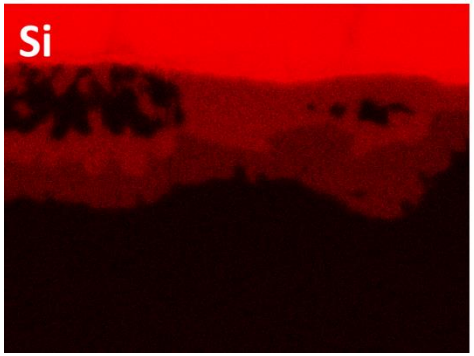


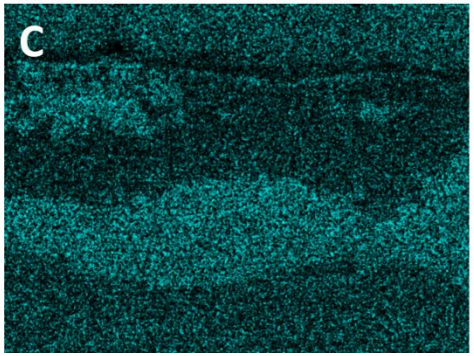
Microstructure and EDX-analysis of Mo/SiCN

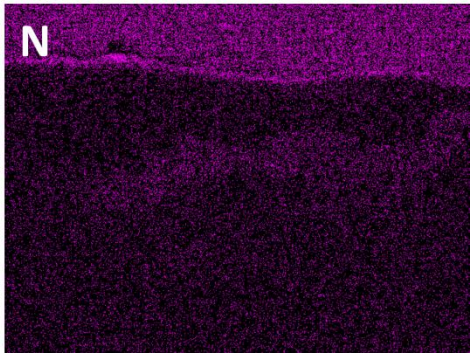




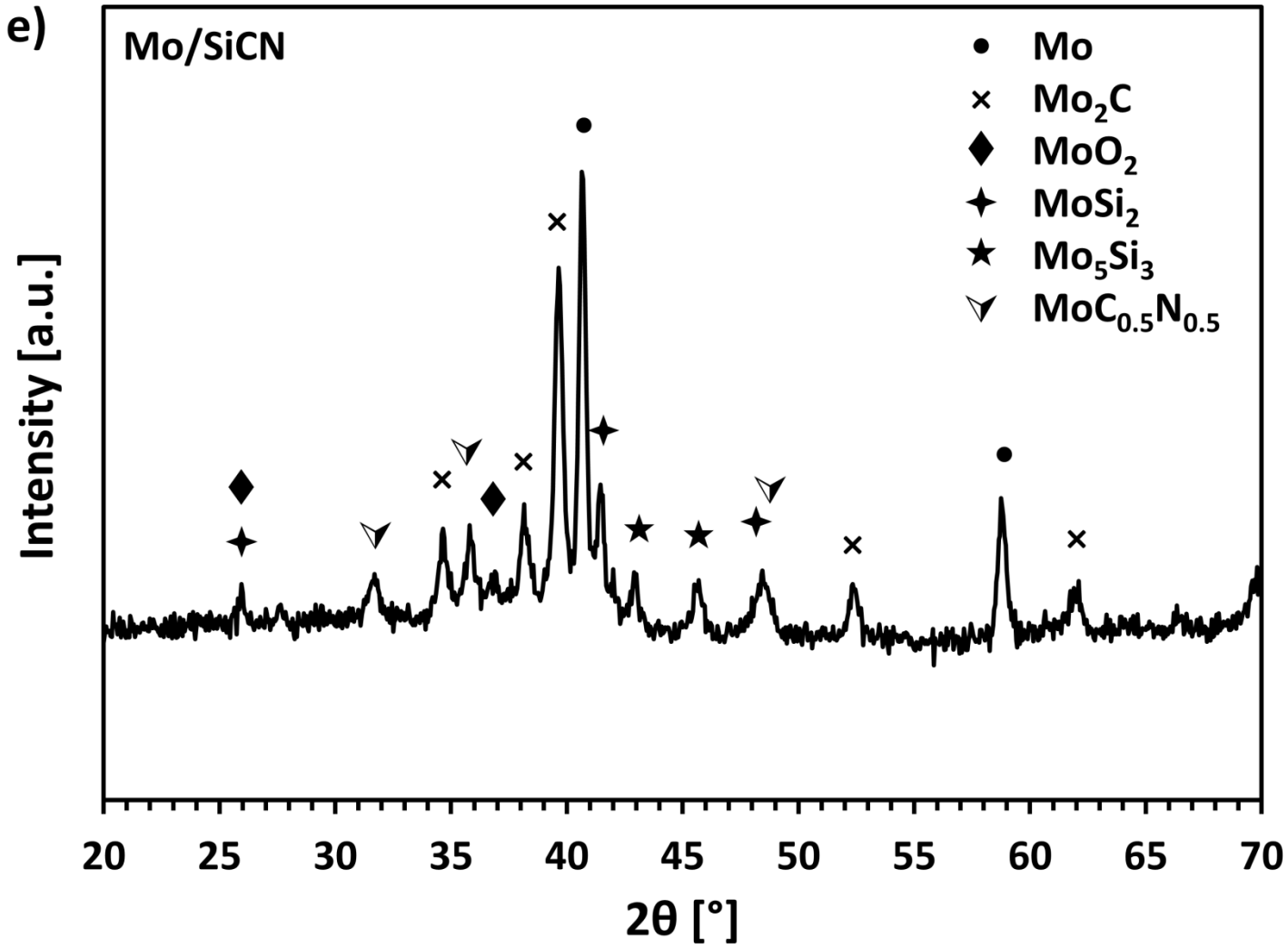






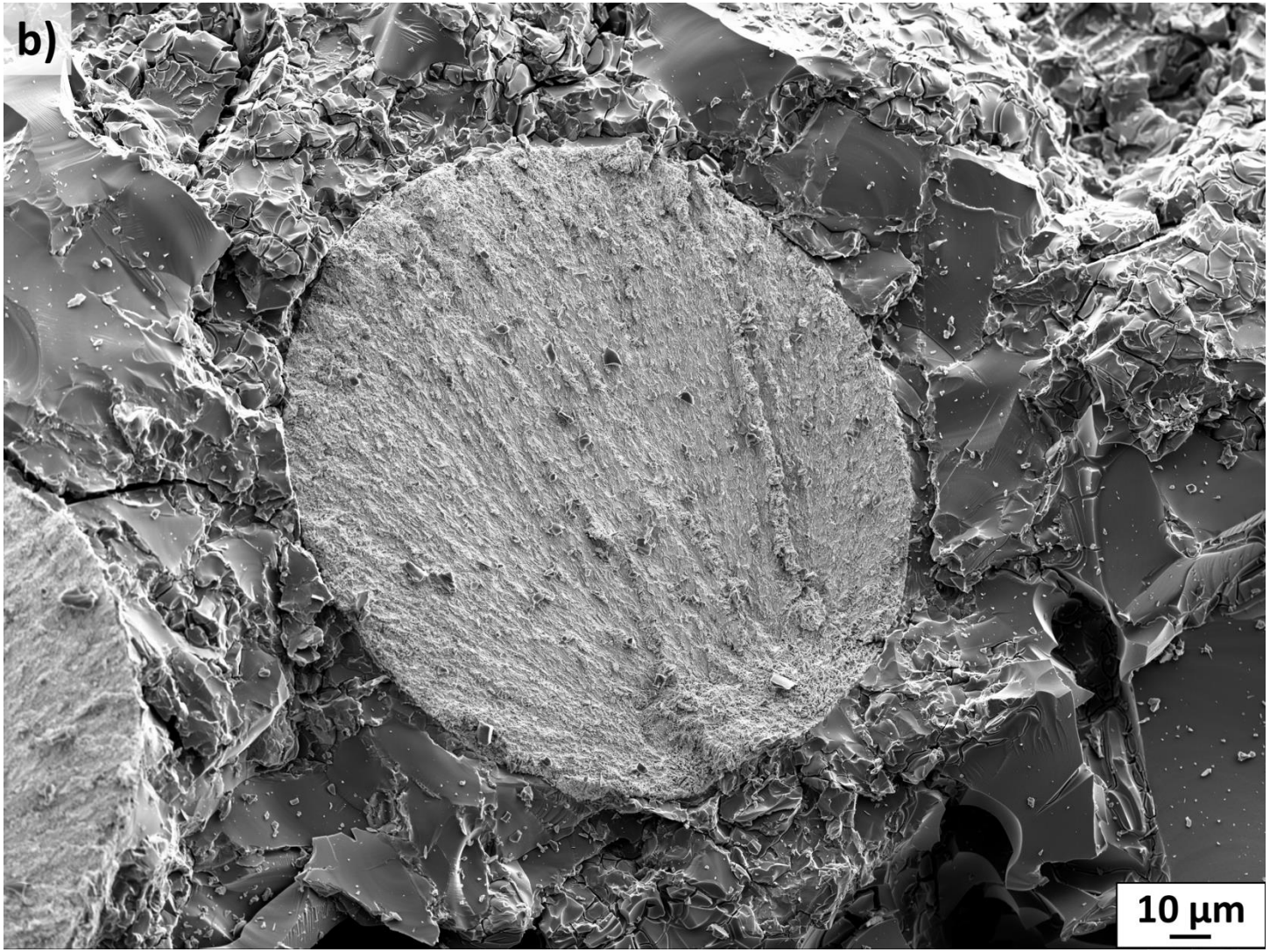


XRD-analysis of Mo/SiCN

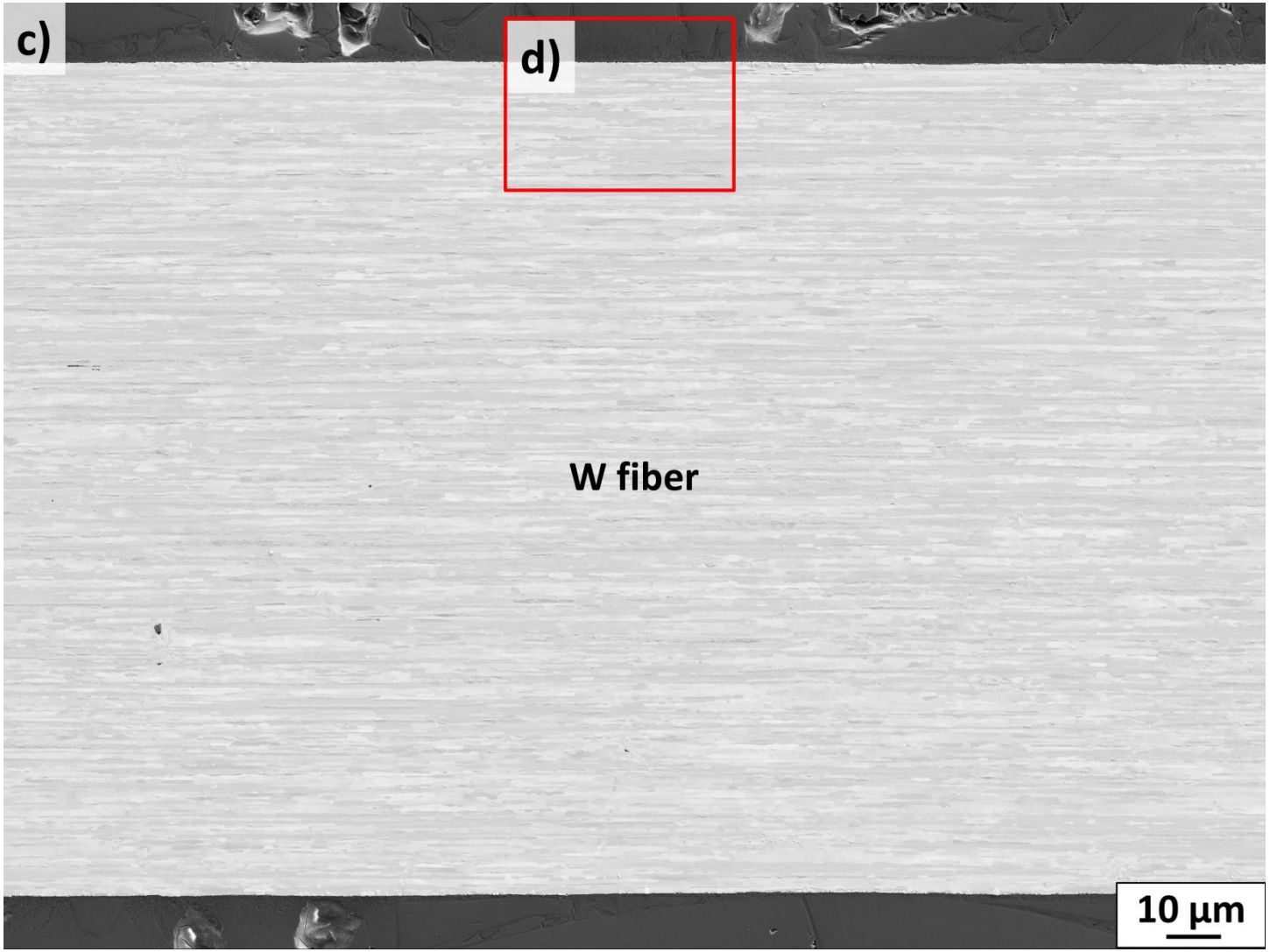


Microstructure of W/SiCN (I)

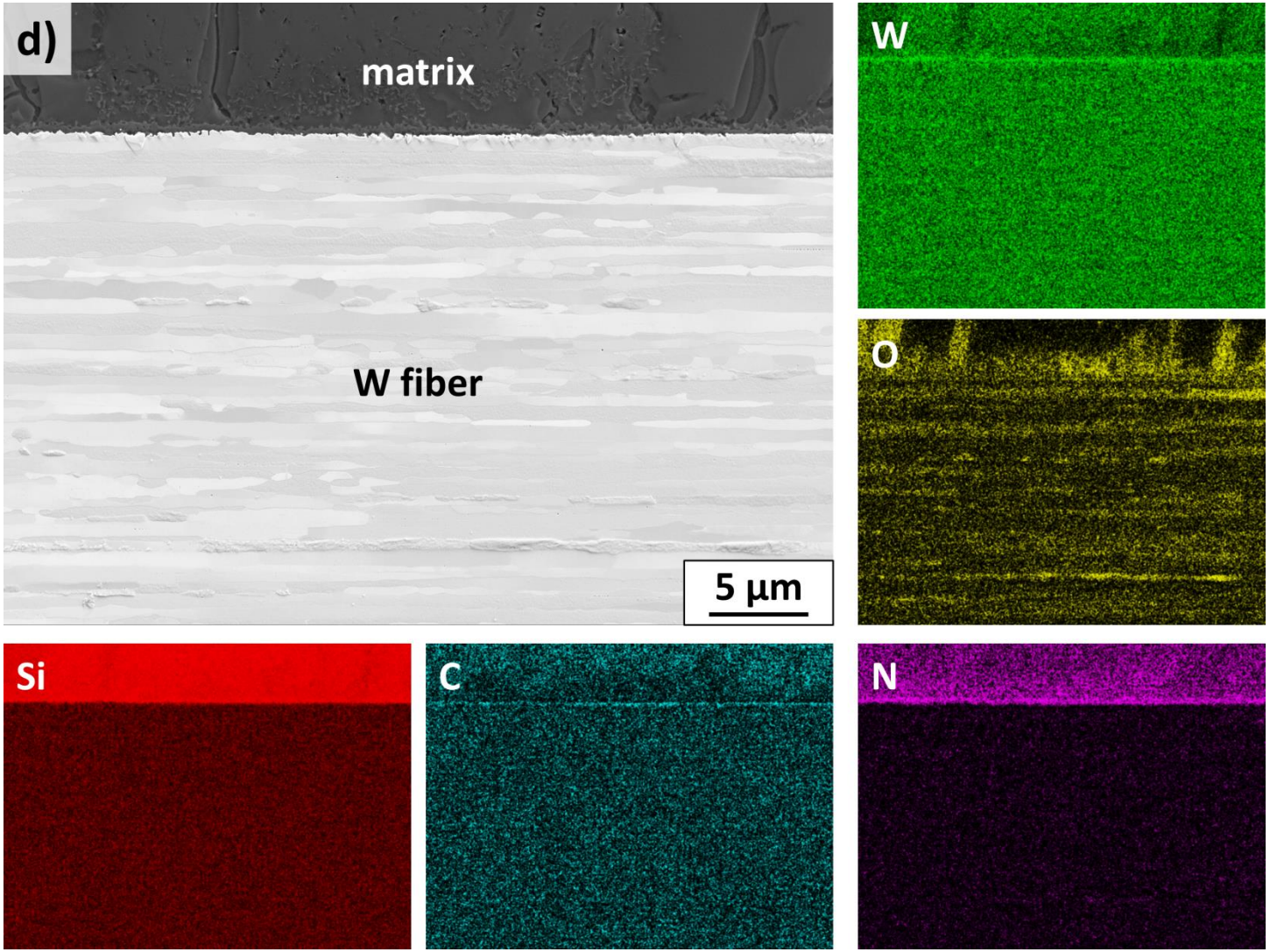
Microstructure of W/SiCN (II)



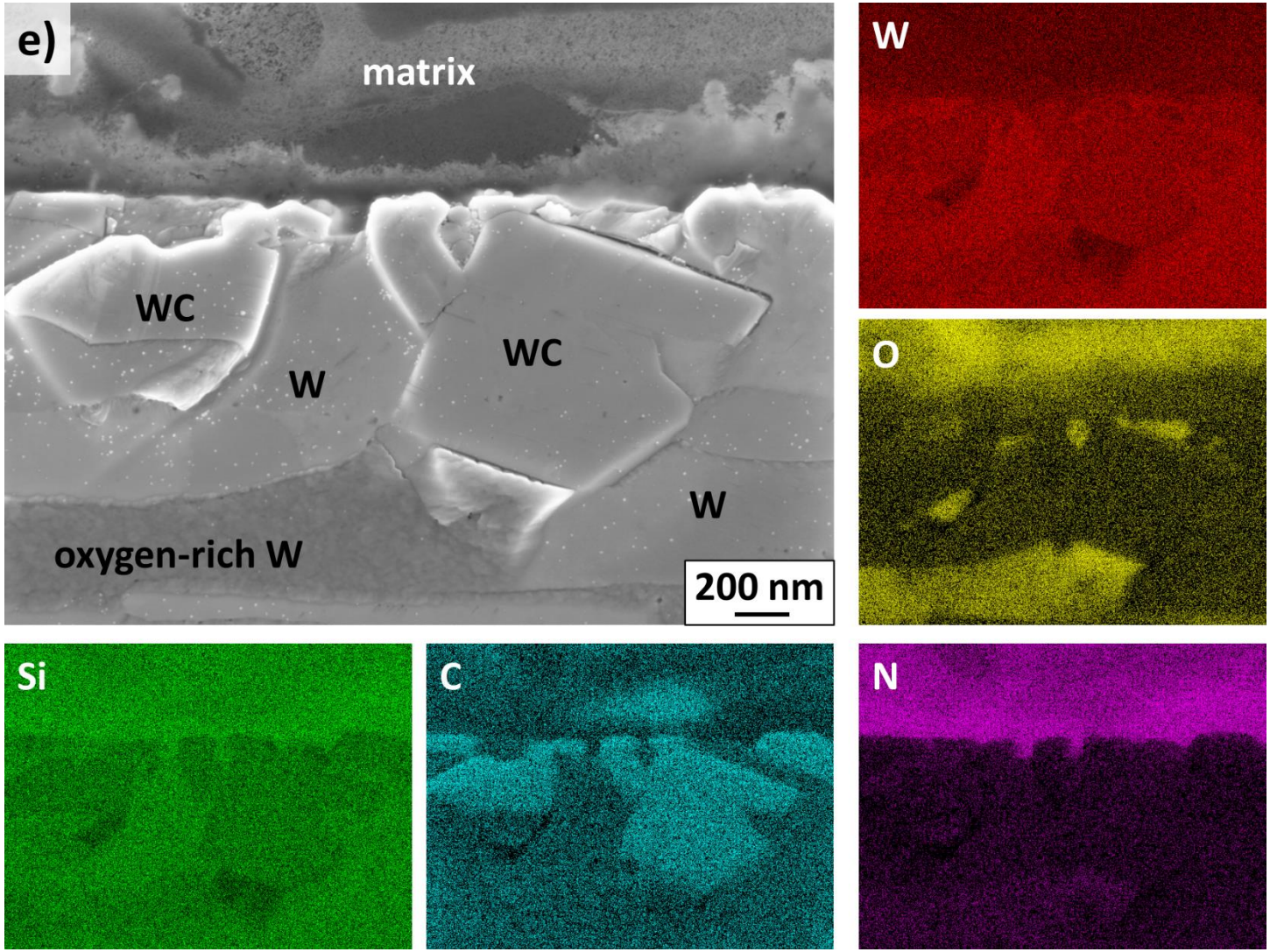
Microstructure of W/SiCN (III)



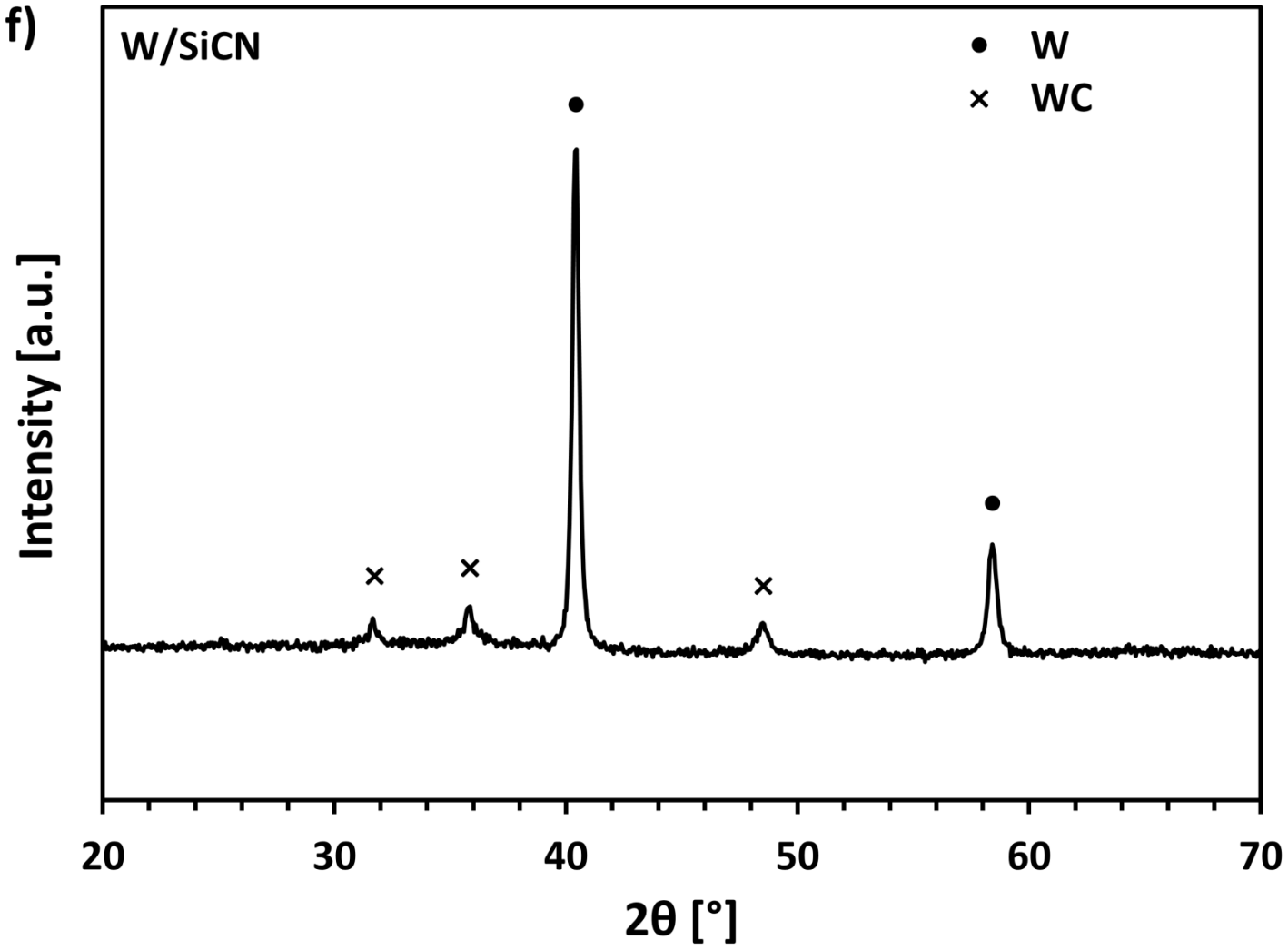
Microstructure and EDX-analysis of W/SiCN (I)



Microstructure and EDX-analysis of W/SiCN (II)

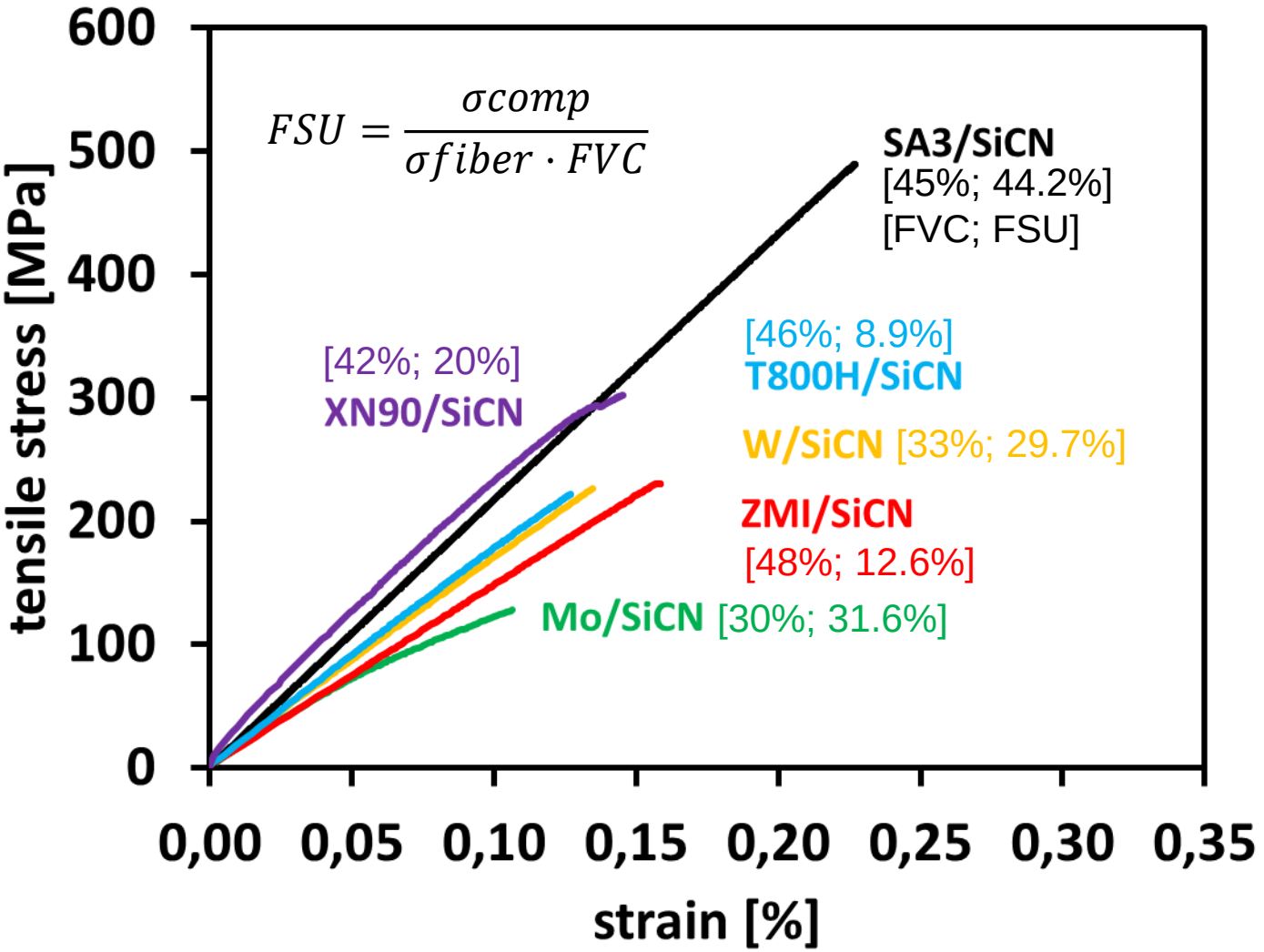


XRD-analysis of W/SiCN



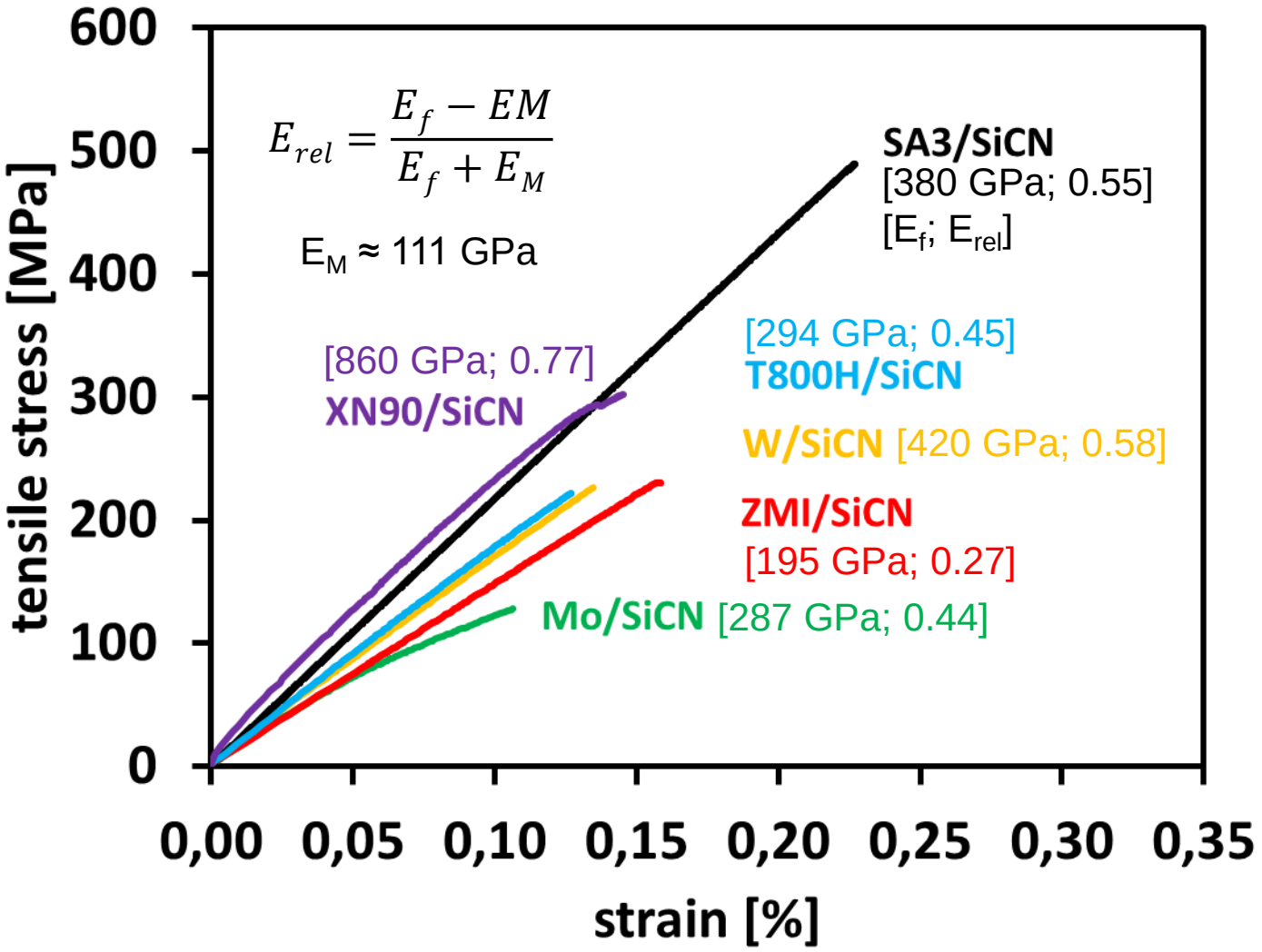
Tensile testing of various UD-fiber reinforced SiCN I

[FVC: fiber volume content; FSU: fiber strength utilisation]

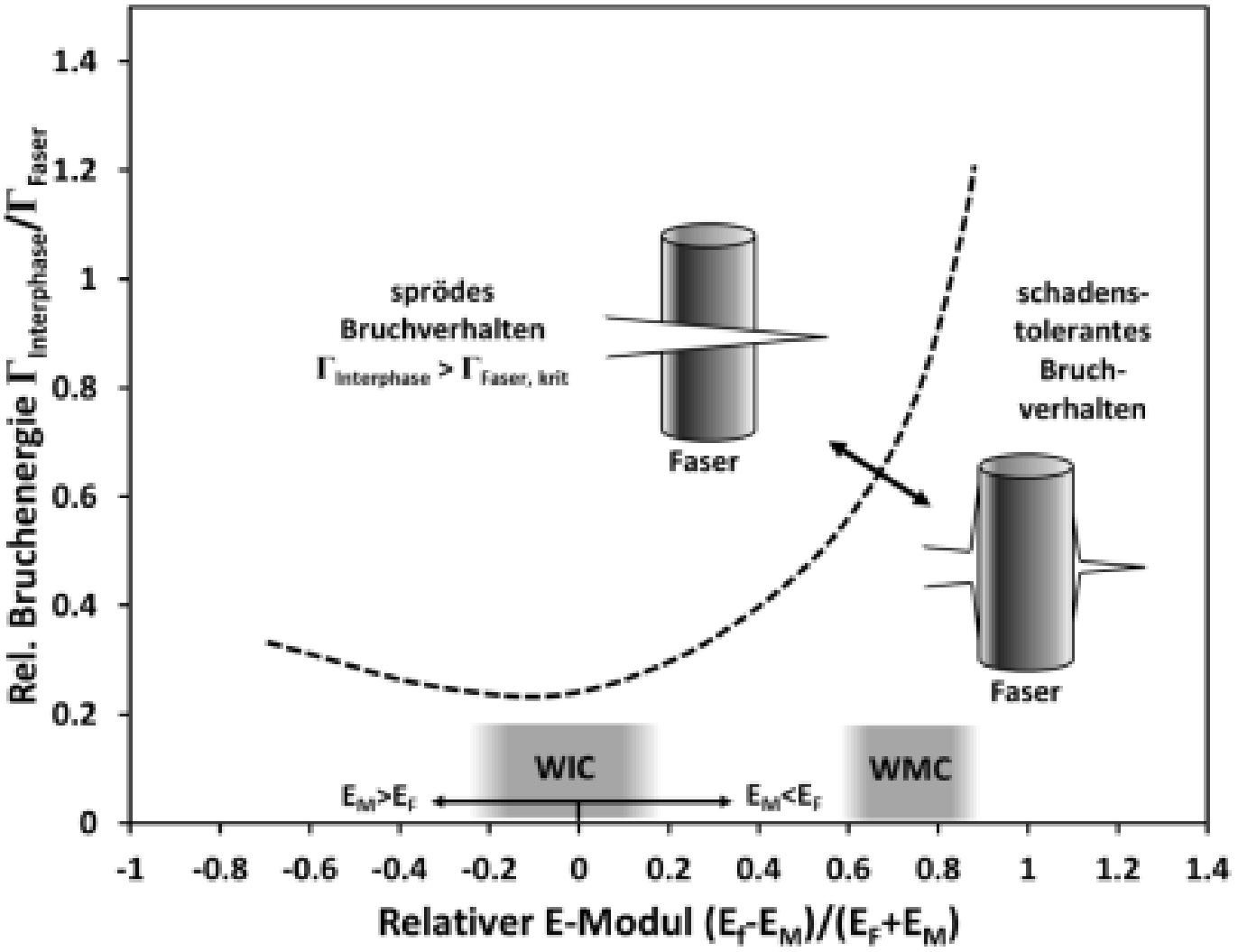


Tensile testing of various UD-fiber reinforced SiCN II

[E_f: Young's modulus of fiber; E_{rel}: relative Young's modulus of fiber and matrix]



Damage-tolerant and brittle fracture behaviour of CMCs
(Concept of He and Hutchinson)



Summary and outlook I

- Mo- and W-fiber reinforced CMCs can be easily manufactured by polymer infiltration and pyrolysis at 1300 °C (PIP)
- Mo/SiCN and W/SiCN composites are light-weight in comparison to Mo/Mo and W/W composites
- Mo/SiCN and W/SiCN show increased elongation at break compared to CMCs
- Mo/SiCN and W/SiCN can be considered as WMCs and thus need no weak interphase
- Microstructural and phase analyses have shown that Mo- and W-fibers are still present and thermally resistant in the SiCN matrix even at 1300 °C

Summary and outlook II

- Microstructural and phase analyses have shown that Mo- and W-fibers suffer from surfacial attack, mainly by C
- Applying a coating as reaction barrier (e.g. Y_2O_3) should provide further improvement in mechanical properties
- New applications are feasible due to:
  - increased elongation at break
  - good tensile and fracture strength
  - high stiffness
  - high thermal conductivity
  - low thermal expansion
  - high thermal shock resistance
  - anisotropic behaviour of composite according to tailor-made design