Einsatz nicht-oxidischer keramischer Faserverbundwerkstoffe in Triebwerken

Bernd Mainzer, Martin Frieß, Dietmar Koch

DLR Stuttgart
Institut für Bauweisen und Strukturtechnologie
Keramische Verbundstrukturen
Pfaffenwaldring 38-40
70569 Stuttgart



Motivation – Das GE LEAP und GE9X Triebwerk

Das LEAP Triebwerk

- Investitionen für CMC Entwicklung: >1 Mrd. USD
- Jedes LEAP hat 18 CMC shrouds
- 15% Treibstoffeinsparung, verglichen mit dem Vorgänger CFM56-7BE
- 9500 Bestellungen
- Für Airbus A320neo (2016) und Boeing 737MAX (2017)



CFM International LEAP

Das GE9X Triebwerk:

- CMCs für Brennkammer- und Hochdruckturbinen-Sektion
- 700 Bestellungen
- Für Boeing 777X (2020)

Warum CMCs?

- Höhere Effizienz durch verringerten Kühlluftbedarf
- Verringerung des Triebwerkgewichts

Entwicklung von zwei SiC-faserverstärkten CMCs am DLR:

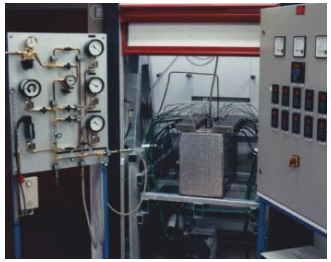
- SiC/SiCN über PIP-Verfahren
- SiC/SiC über LSI-Verfahren



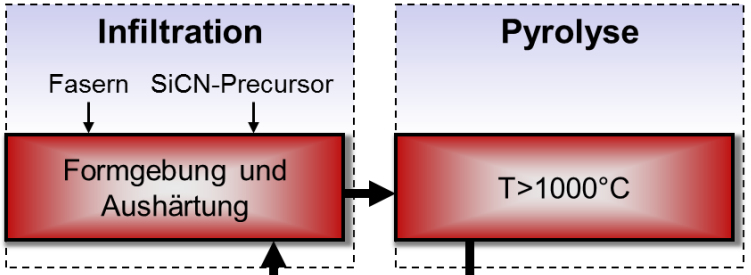
Polymer Infiltration und Pyrolyse (PIP) am DLR





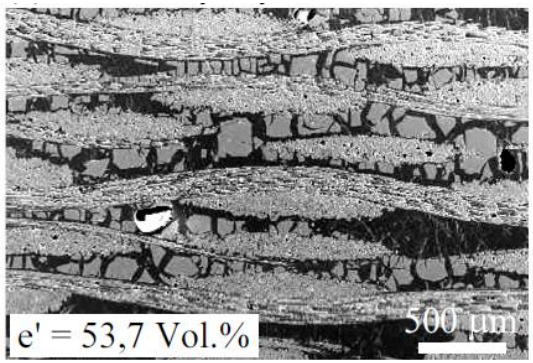




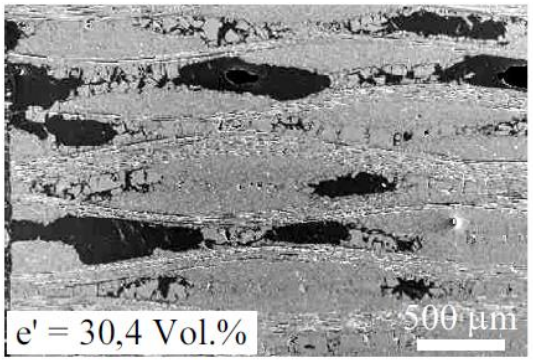


Nachinfiltrations-zyklen zur Verringerung der Porosität

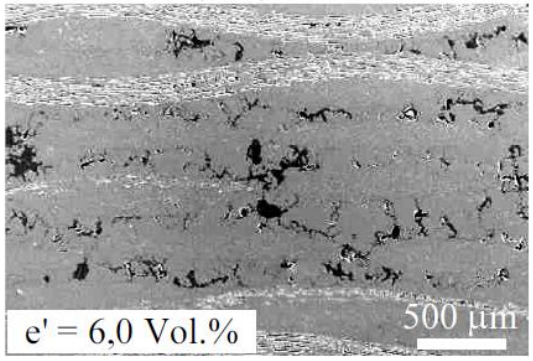
1. PIP Zyklus



4. PIP Zyklus

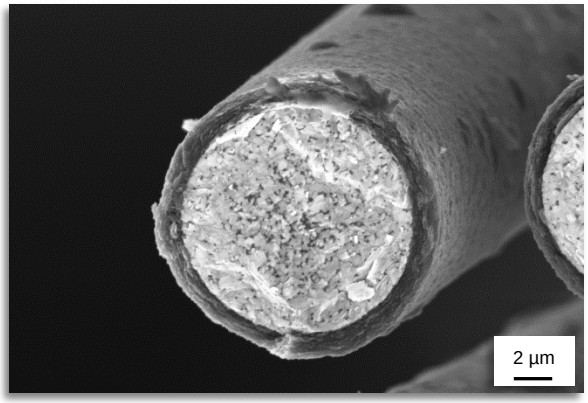


9. PIP Zyklus

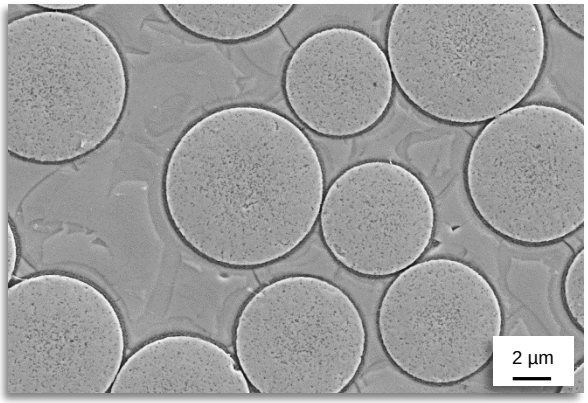




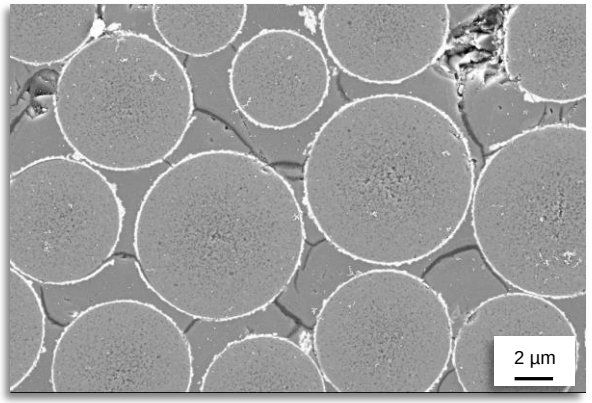
Mechanische Eigenschaften PIP-SiC/SiCN



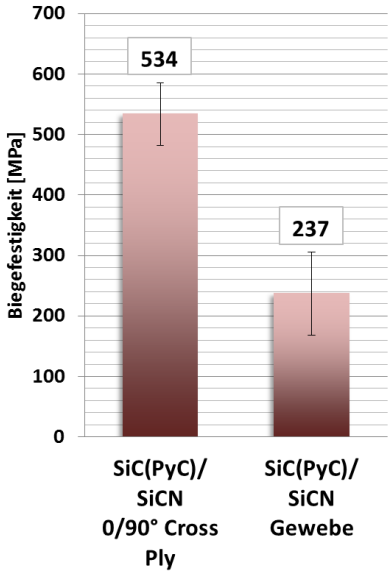
Tyranno SA3 mit PyC-Beschichtung

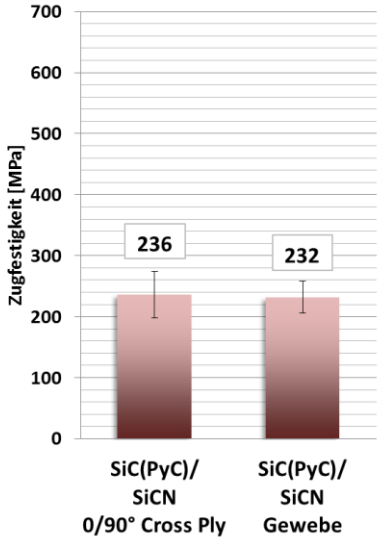


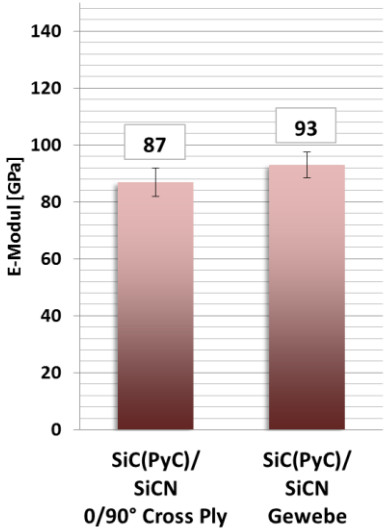
SiC_{PyC}/SiCN Komposit



SiC_{LaPO4}/SiCN Komposit



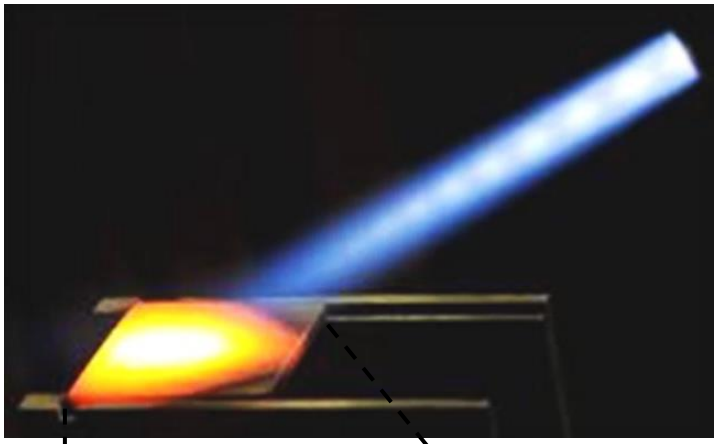




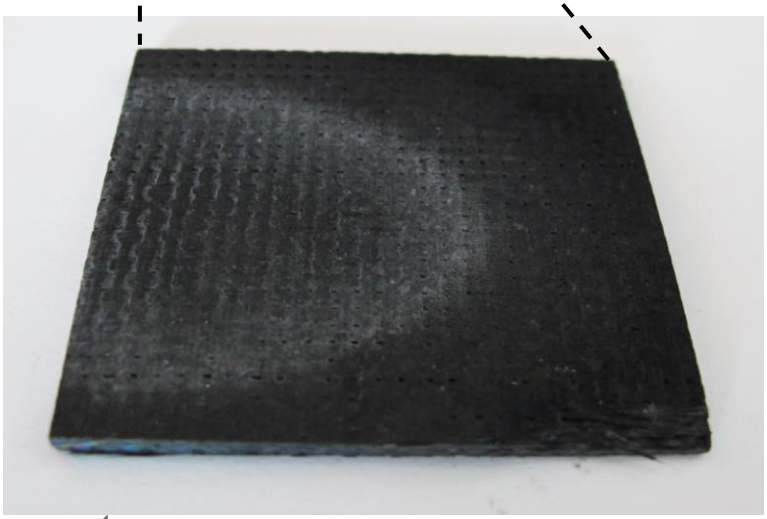
- Tyranno SA3 Fasern
- 33% Faser-volumengehalt
- PyC Faser - beschichtung



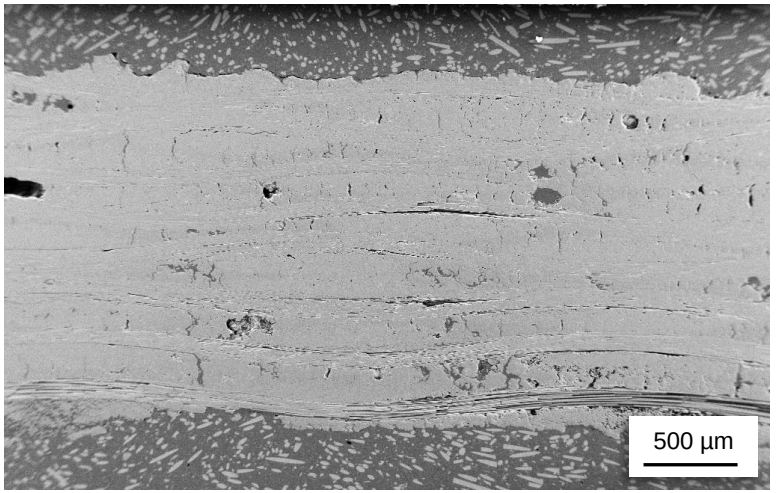
HVOF Tests (High Velocity Oxygen Fuel)



EADS Innovation Works



3 mm



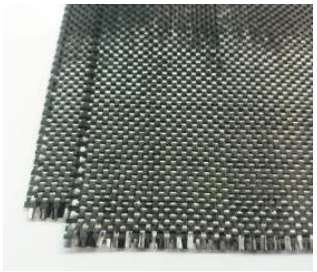
Querschnitt nach Test

SiC_{PyC}/SiCN
1700 °C, 4h, Kerosinflamme

Δm/m [%]: -3,3%

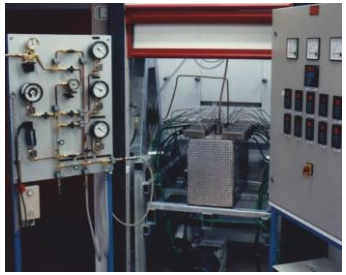


Flüssigphasensilicierung (LSI) am DLR





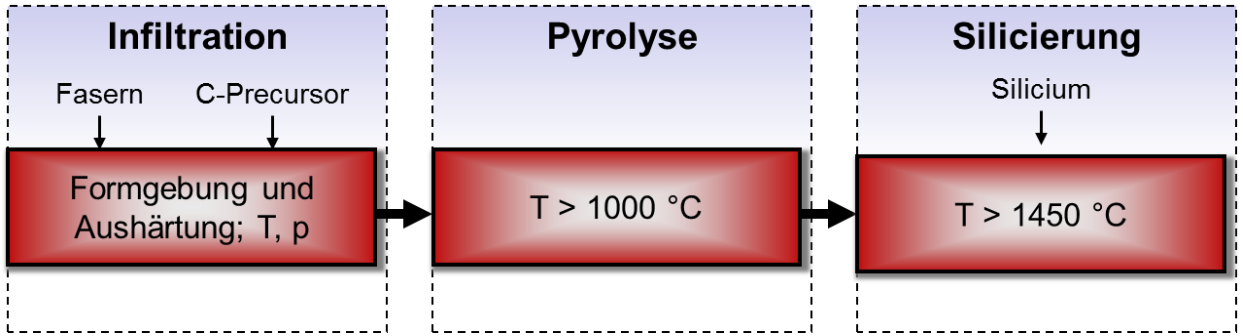
Tyranno SA3





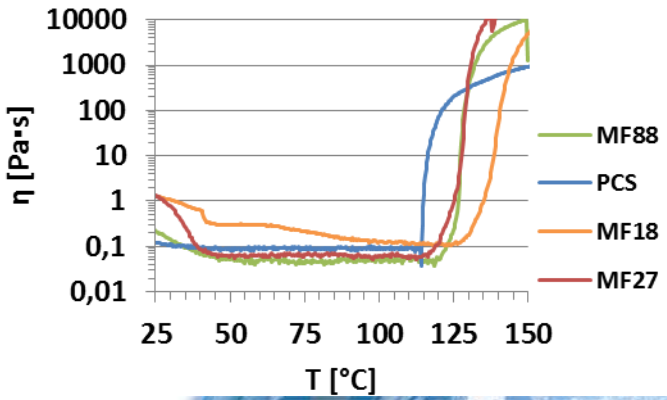
Si-Granulat







SiC/SiC Platte 150x90mm



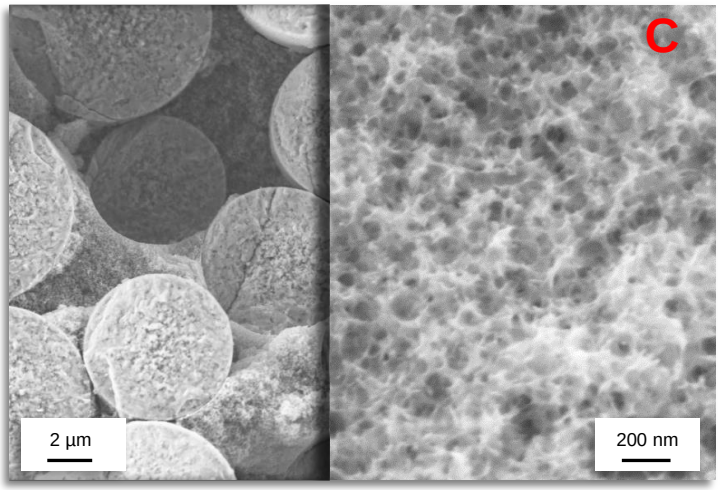
Zielsetzungen

- Stöchiometrische SiC-Matrix
- Entwicklung einer geeigneten Faserbeschichtung

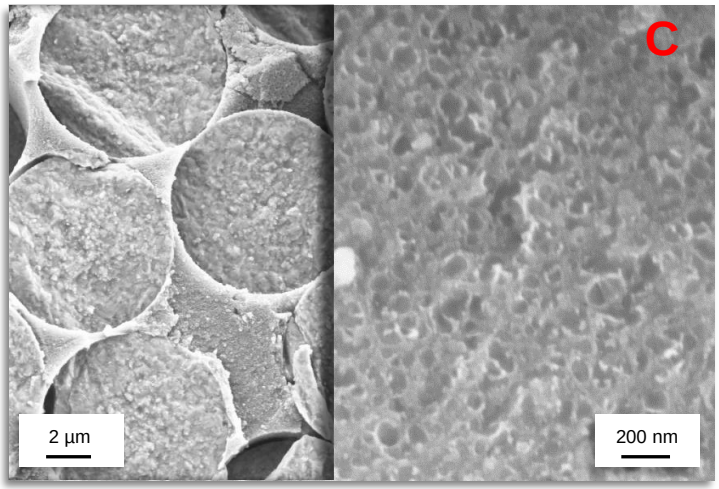


Matrixentwicklung – C-Matrix

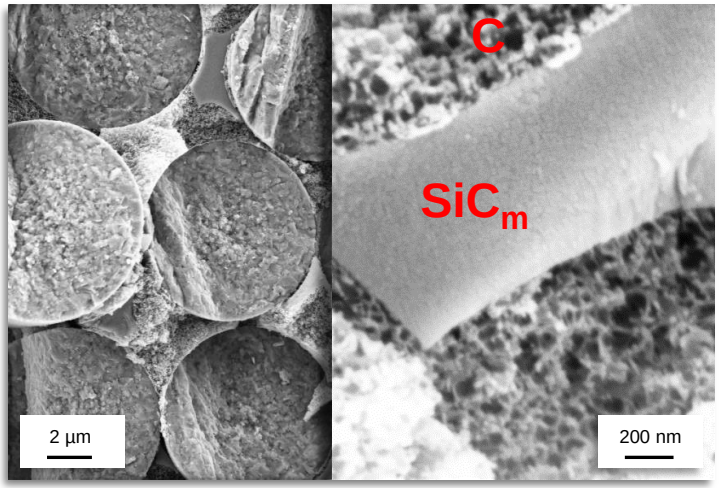
MF88



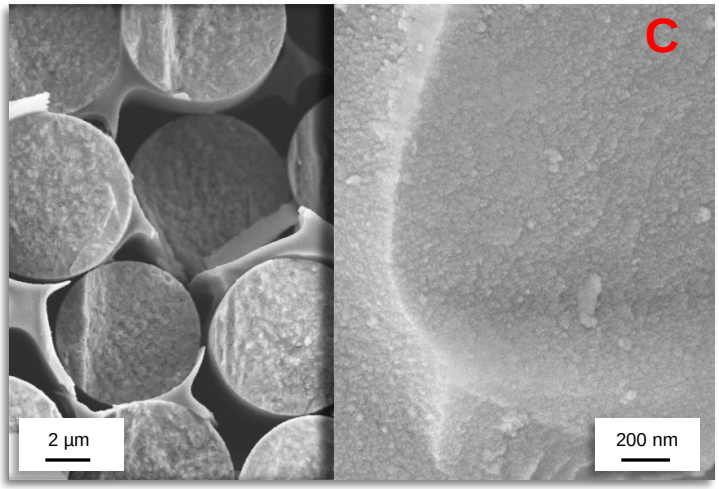
MF27



PCS+
MF88

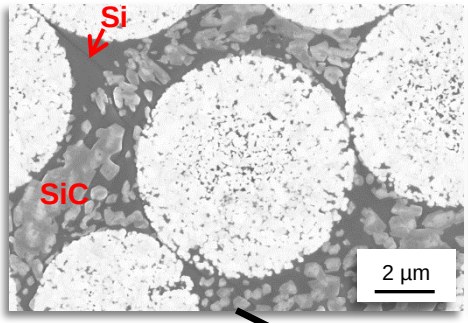


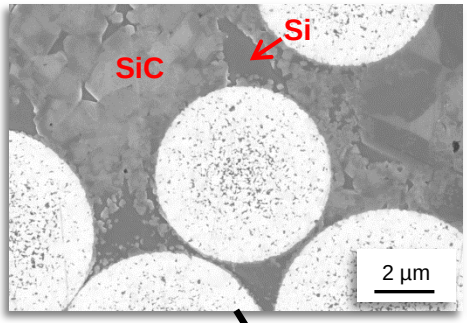
MF18

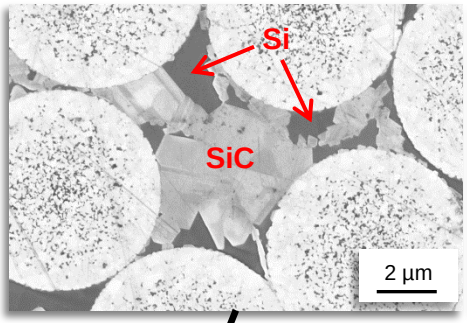


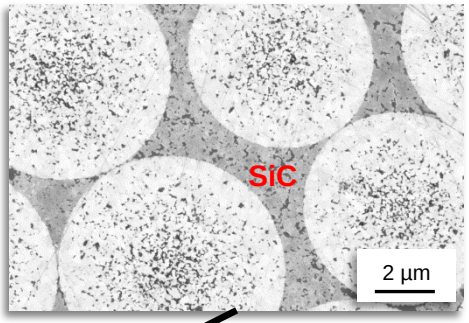


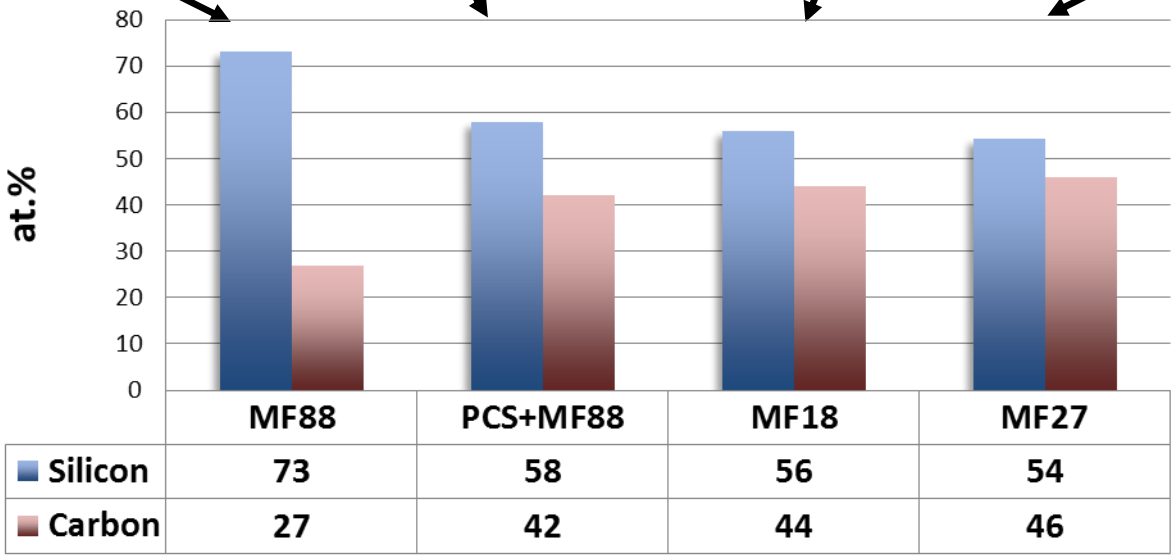
Vergleich Matrixkonvertierung









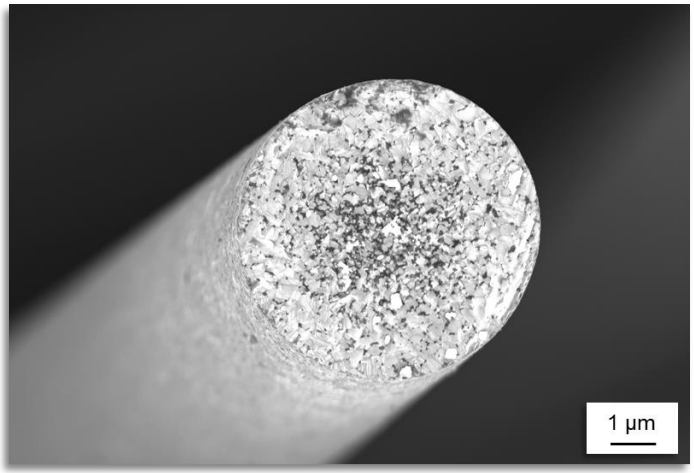


	MF88	PCS+MF88	MF18	MF27
Silicon	73	58	56	54
Carbon	27	42	44	46

- SiC-Gehalt der Matrix und SiC-Morphologie über C-Precursor steuerbar

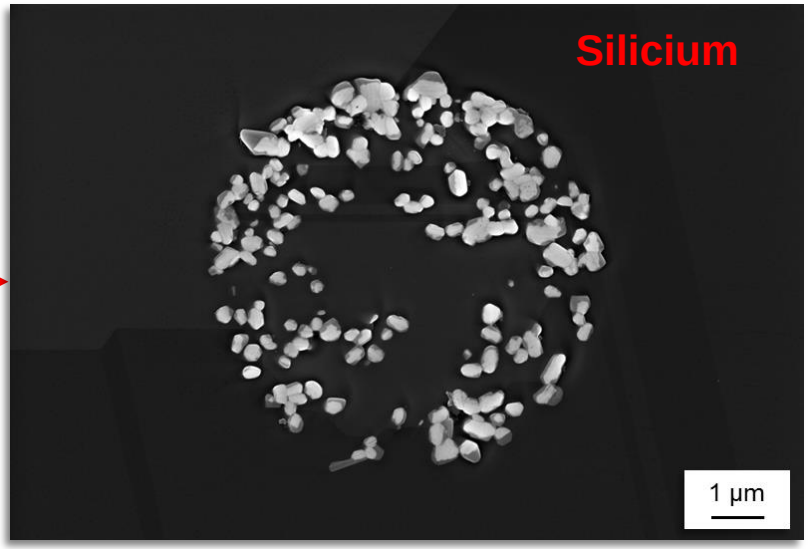


Faserbeschichtungen für LSI-SiC/SiC Komposite



LSI

T>1450°C

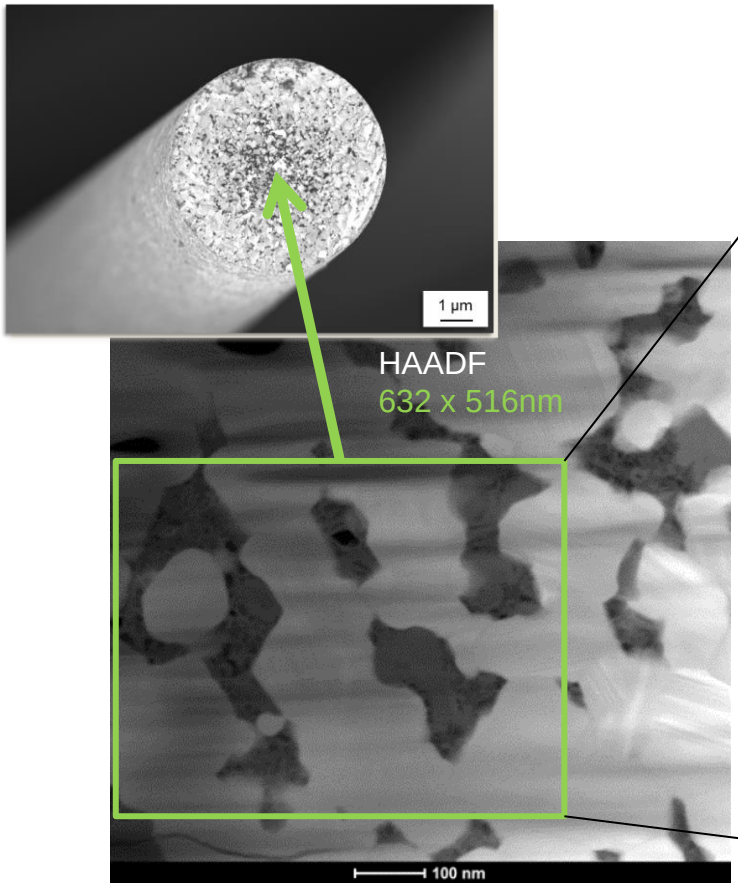


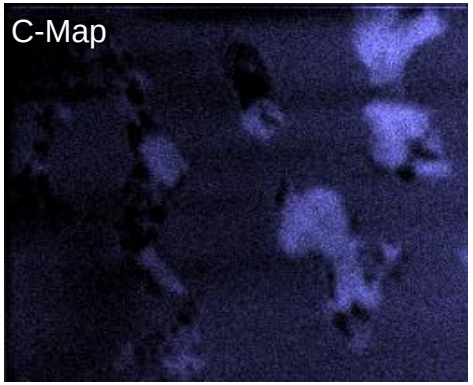
Worst case scenario -> Zerstörte SiC-Faser durch Si-Angriff

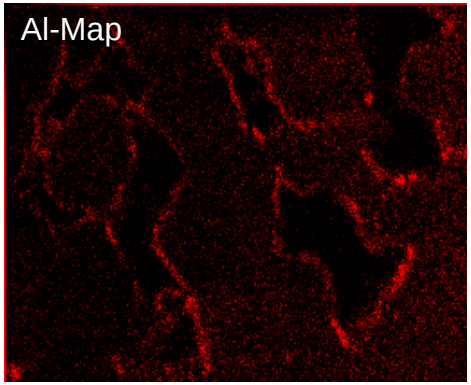
- Zerstörung der Faser durch Auflösung und Präzipitation an größeren SiC-Kristalliten außerhalb der Fasern (Ostwald Reifung)

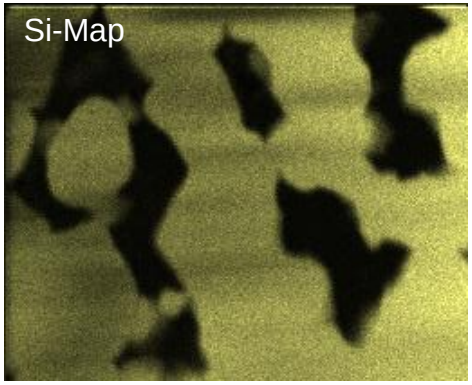


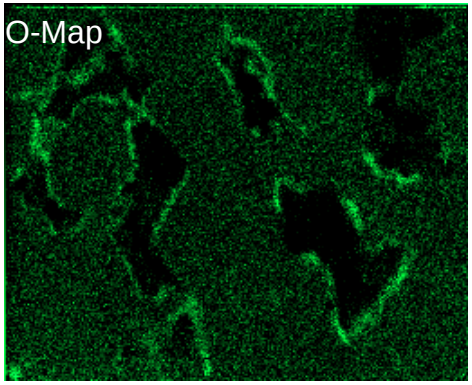
Aufklärung des Si-Angriffs auf SA3-Faser











Kelm, Watermeyer, DLR-WF

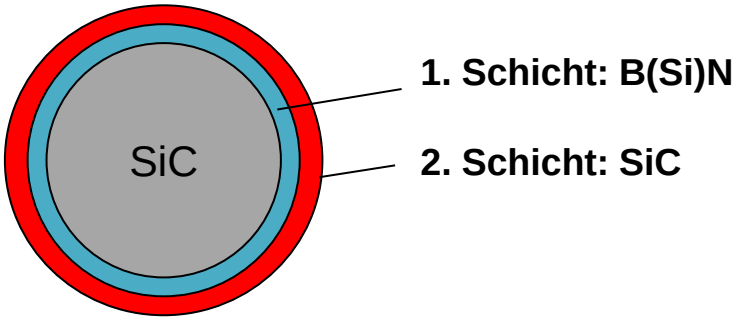
- Extrem kohlenstoffreicher Kern in der Faser
- Auflösung von Kohlenstoff bei Kontakt mit flüssigem Silicium
- In Konsequenz: Schutzbarriere gegen Silicium notwendig

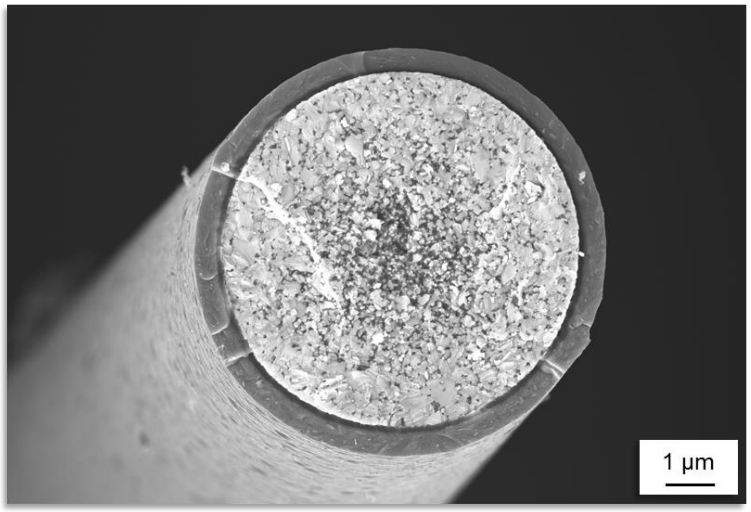


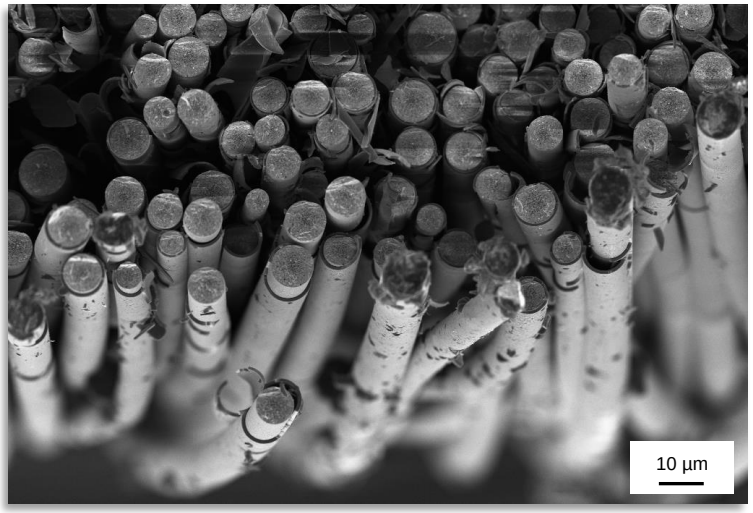
BSiN/SiC Faserbeschichtung

Eine Faserbeschichtung für LSI-SiC/SiC Komposite benötigt drei Funktionen:

1. Schutz der Faser vor flüssigem Silicium
2. Schwaches Faser/Matrix Interface zur Schaffung energiedissipierender Effekte (Rissablenkung, Faser-Pullout) für gesteigerte Schadenstoleranz
3. Oxidationsresistenz

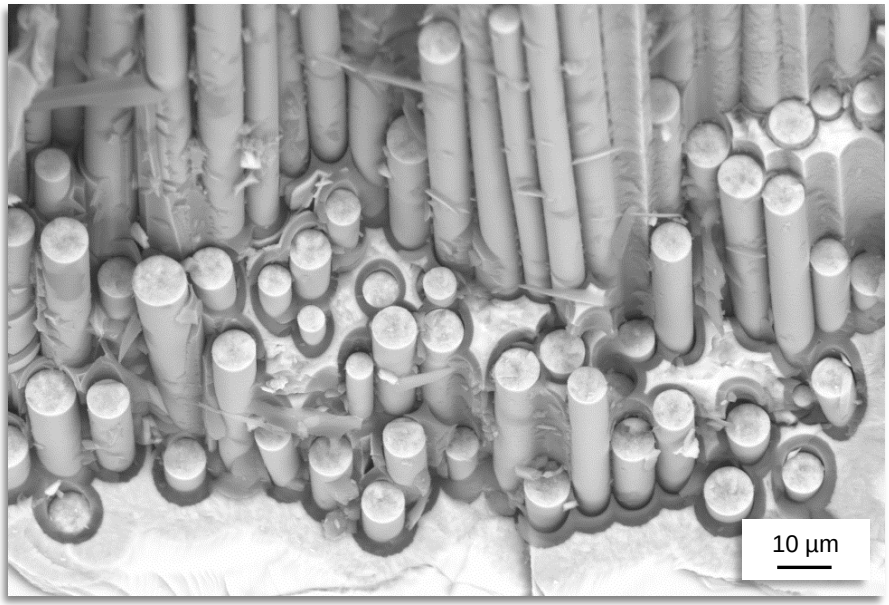




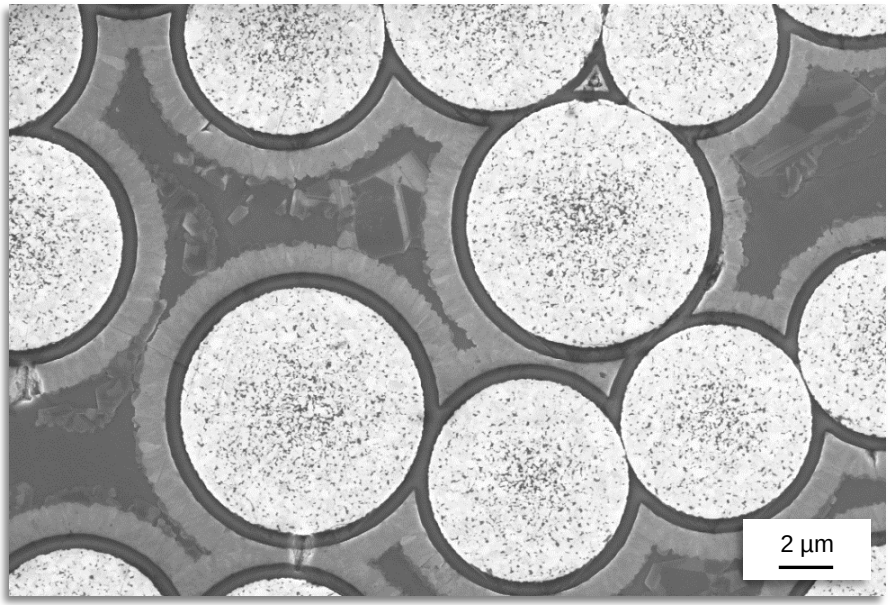




Mikrostruktur SiC/SiC Komposit mit BSiN/SiC Faserbeschichtung



Bruchfläche LSI-SiC/SiC

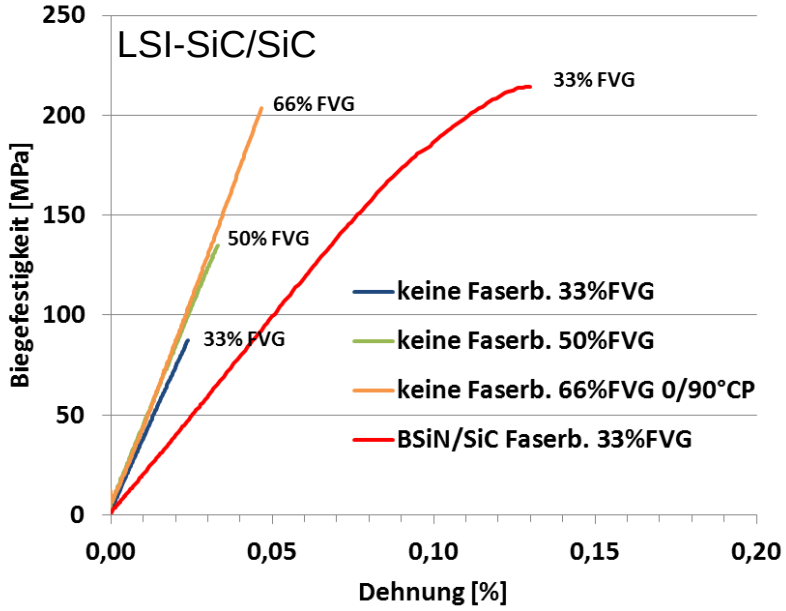


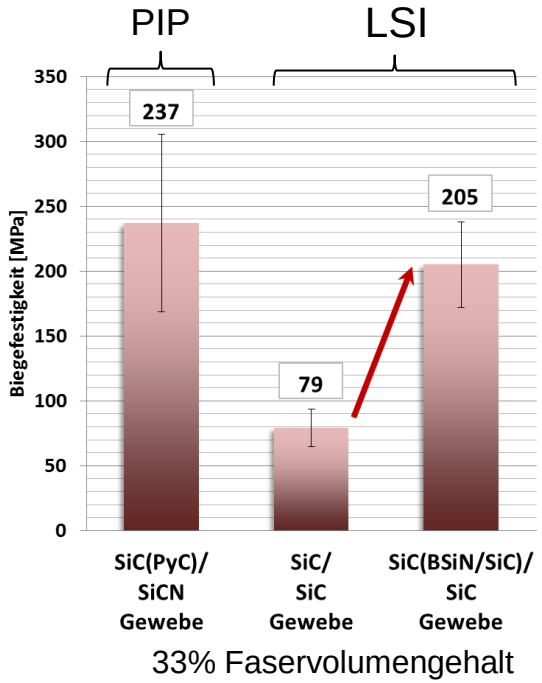
Schliff LSI-SiC/SiC

- Schadenstolerantes Bruchverhalten
- offene Porosität < 2 Vol.% durch LSI-Verfahren



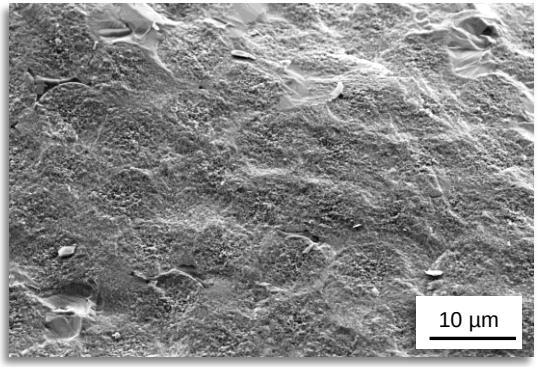
Einfluss der Faserbeschichtung auf das Versagensverhalten

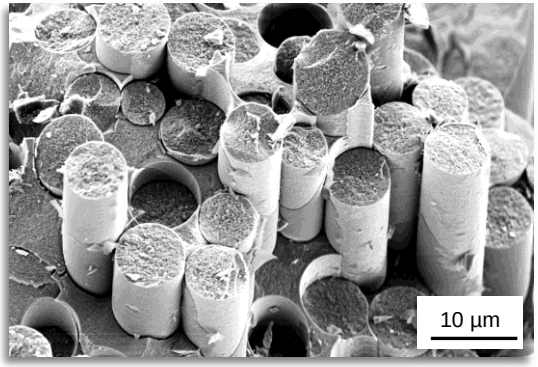




33% Faservolumengehalt

Bruchfläche LSI-SiC/SiC ohne Faser-beschichtung

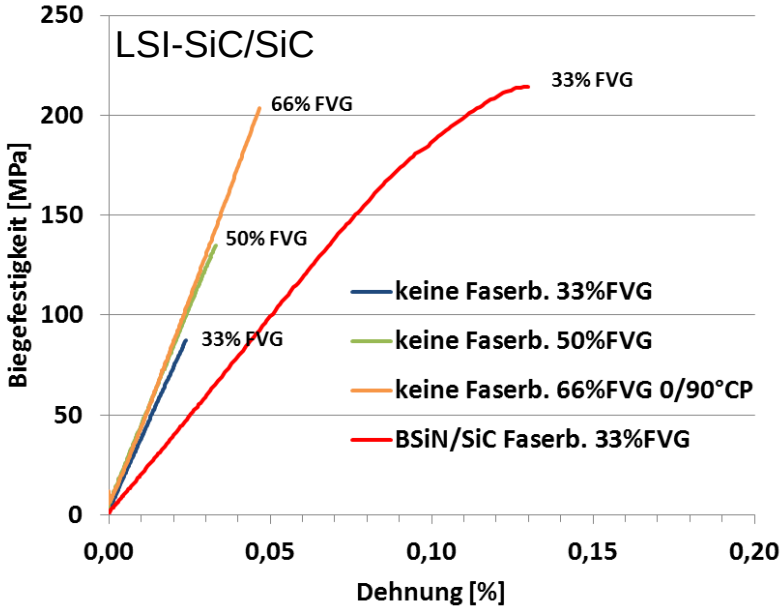


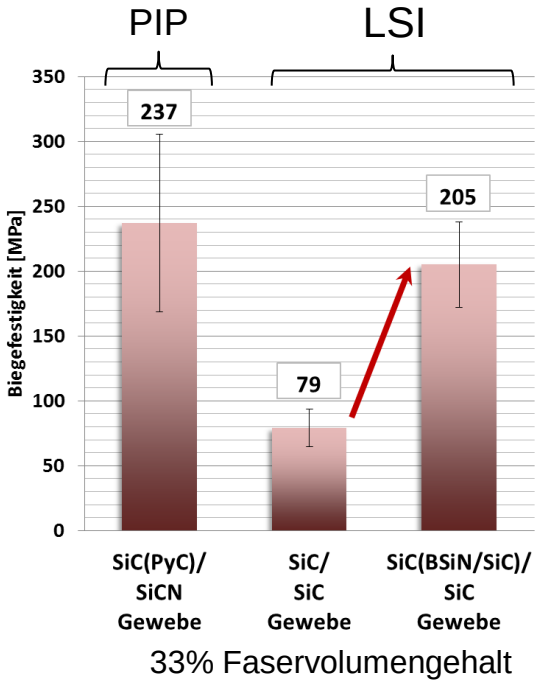


Bruchfläche LSI-SiC/SiC mit CVD-BSiN/SiC Faser-beschichtung



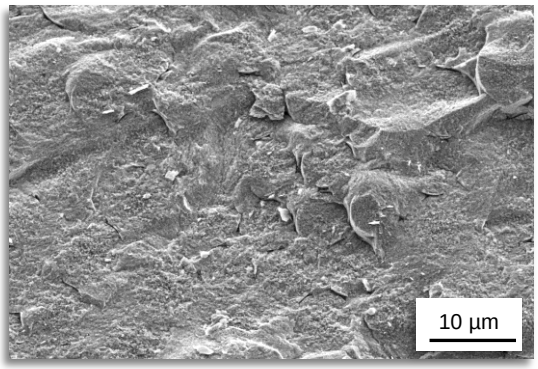
Einfluss der Faserbeschichtung auf das Versagensverhalten

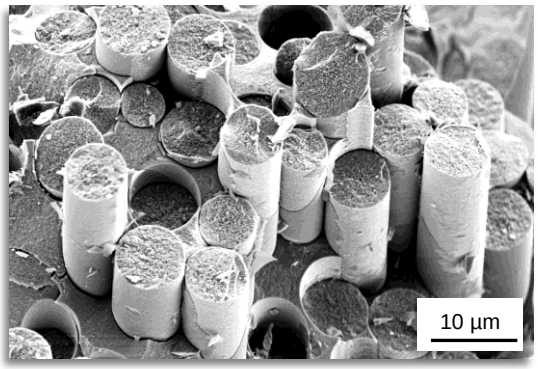




33% Faservolumengehalt

Bruchfläche LSI-SiC/SiC mit PyC Faser-beschichtung

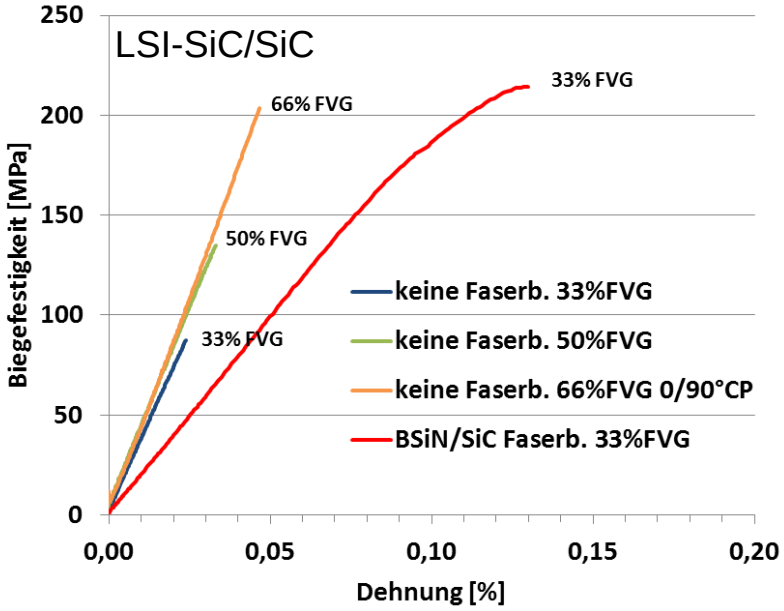


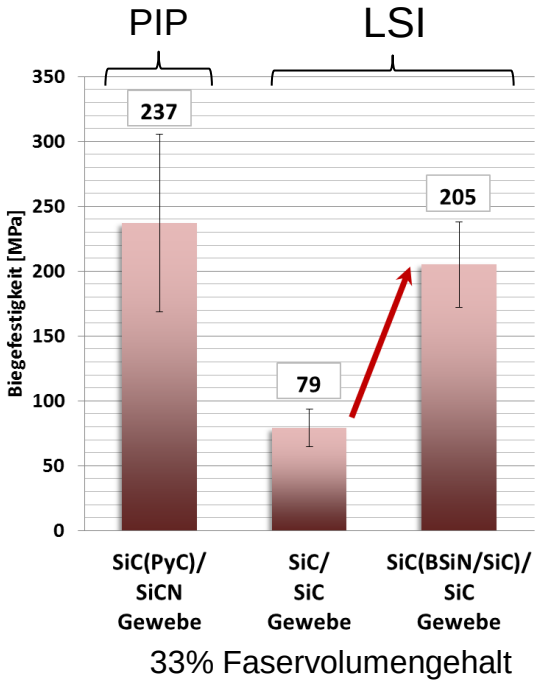


Bruchfläche LSI-SiC/SiC mit CVD-BSiN/SiC Faser-beschichtung



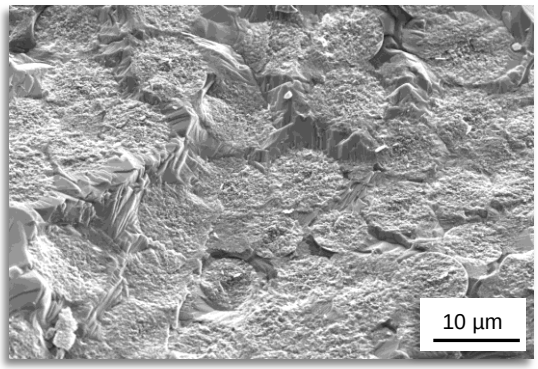
Einfluss der Faserbeschichtung auf das Versagensverhalten

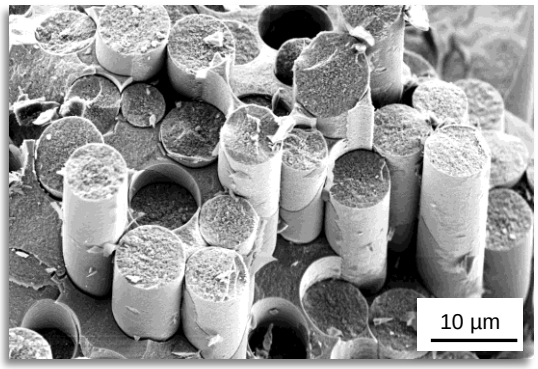




33% Faservolumengehalt

Bruchfläche LSI-SiC/SiC mit dip-coating BN/SiC Faser-beschichtung

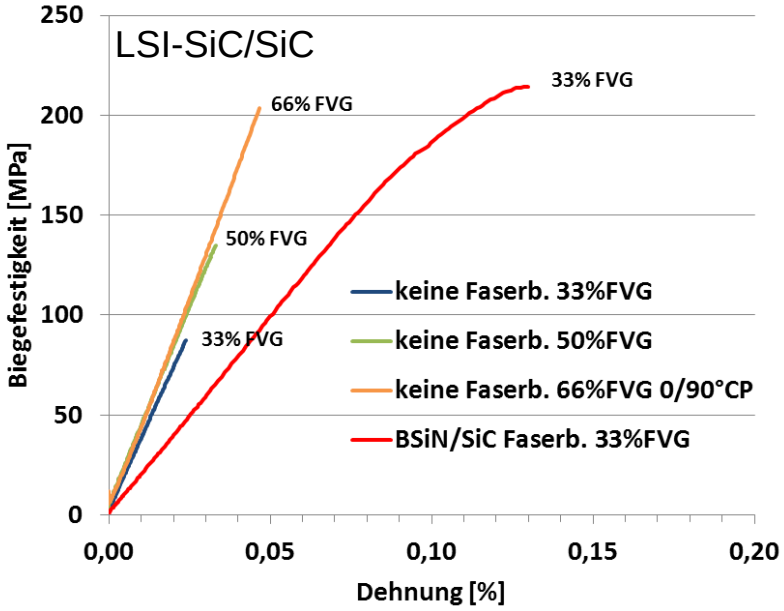


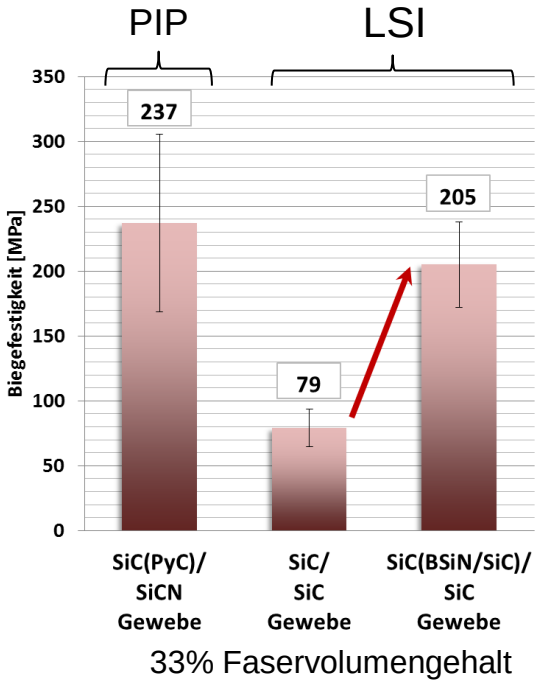


Bruchfläche LSI-SiC/SiC mit CVD-BSiN/SiC Faser-beschichtung



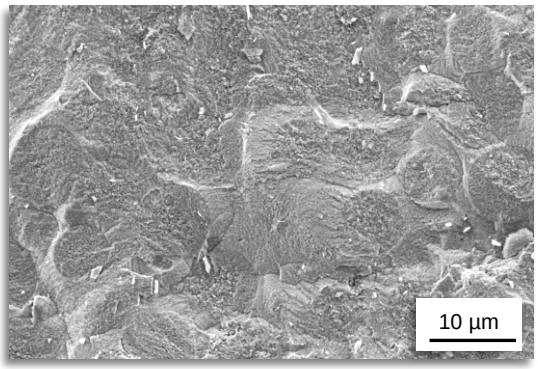
Einfluss der Faserbeschichtung auf das Versagensverhalten

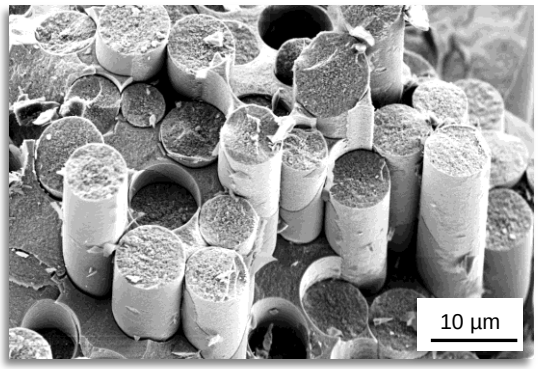




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Bruchfläche LSI-SiC/SiC mit TiB_2 Faser-beschichtung

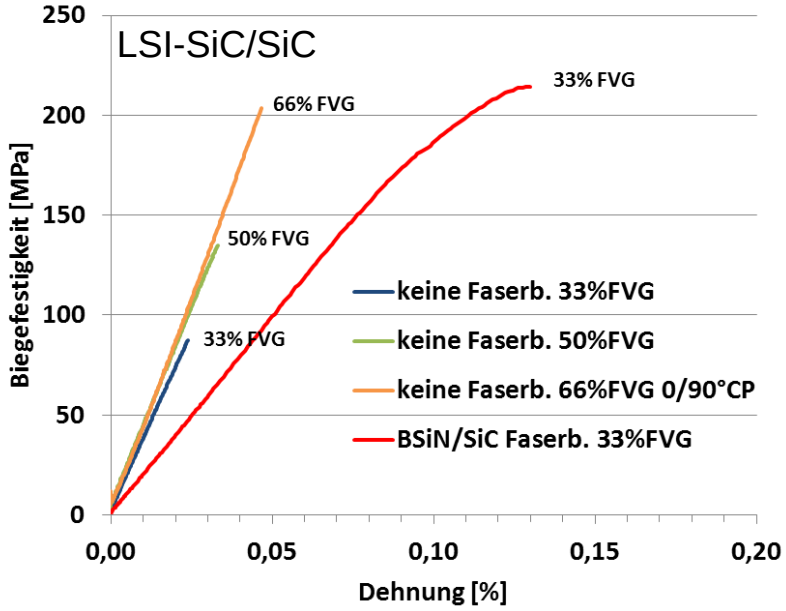


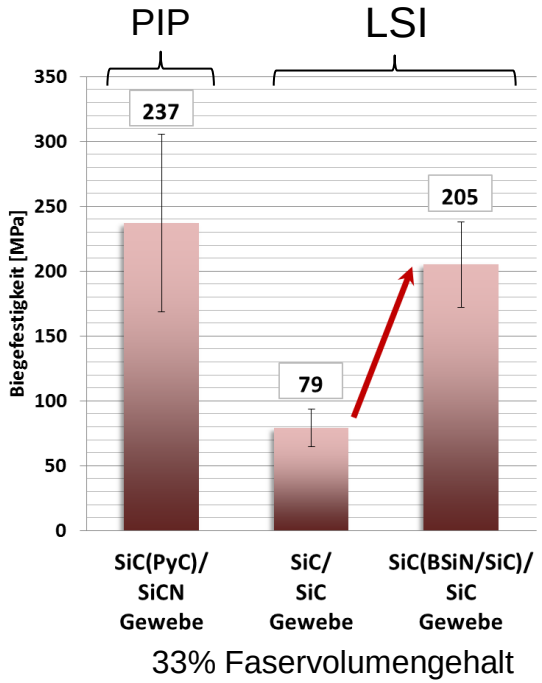


Bruchfläche LSI-SiC/SiC mit CVD-BSiN/SiC Faser-beschichtung



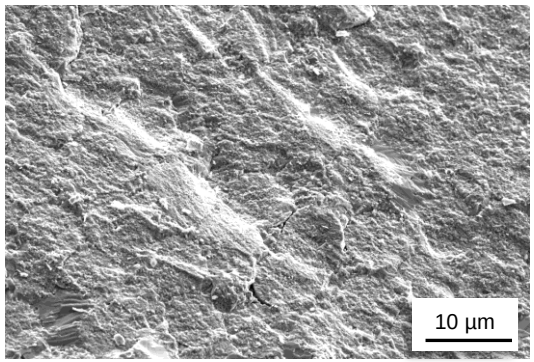
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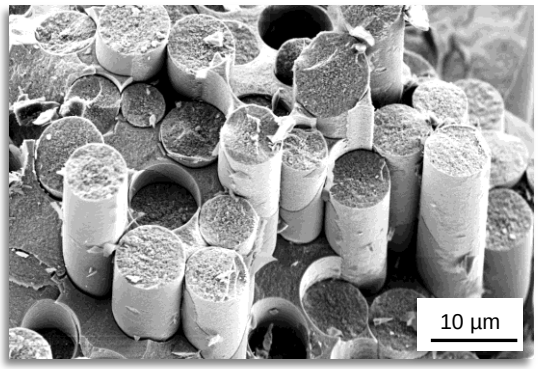




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Bruchfläche LSI-SiC/SiC mit Y_2O_3 Faser-beschichtung

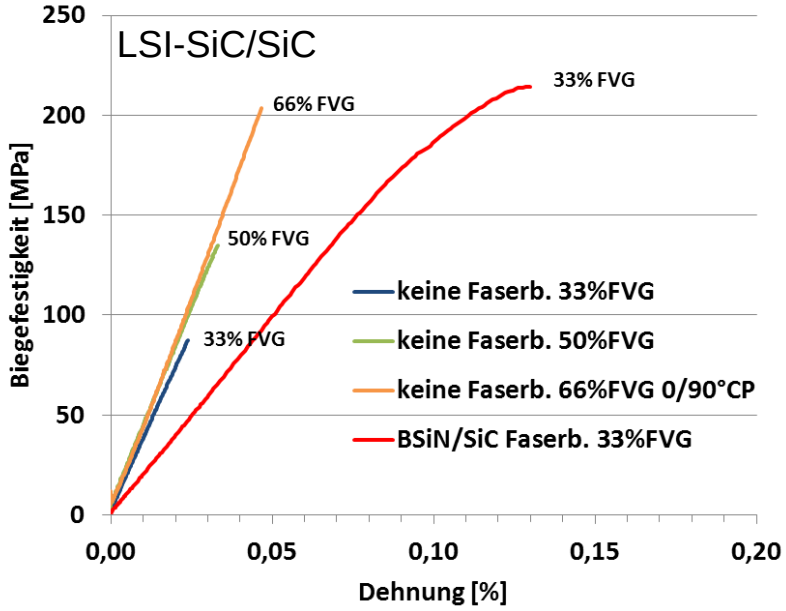


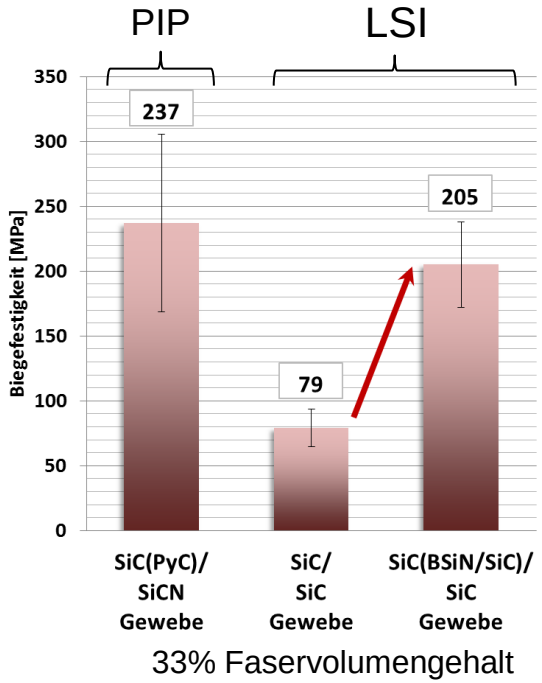


Bruchfläche LSI-SiC/SiC mit CVD-BSiN/SiC Faser-beschichtung



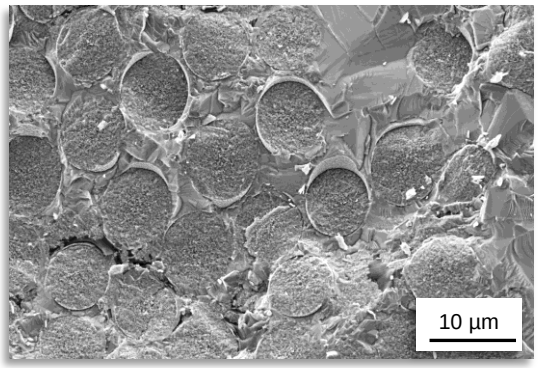
Einfluss der Faserbeschichtung auf das Versagensverhalten

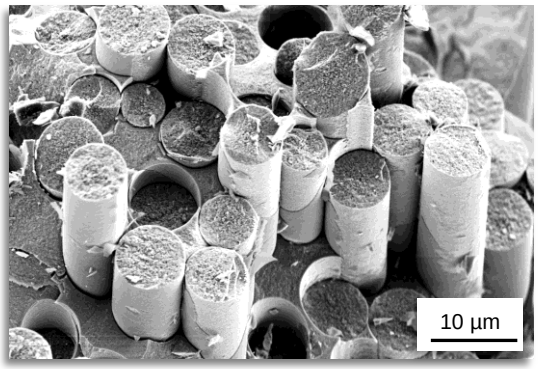




33% Faservolumengehalt

Bruchfläche LSI-SiC/SiC mit SiN_x Faser-beschichtung





Bruchfläche LSI-SiC/SiC mit CVD-BSiN/SiC Faser-beschichtung



Zusammenfassung

- Zwei auf SiC-Fasern basierte Verbundwerkstoffe werden am DLR für Anwendungen im Triebwerk entwickelt:

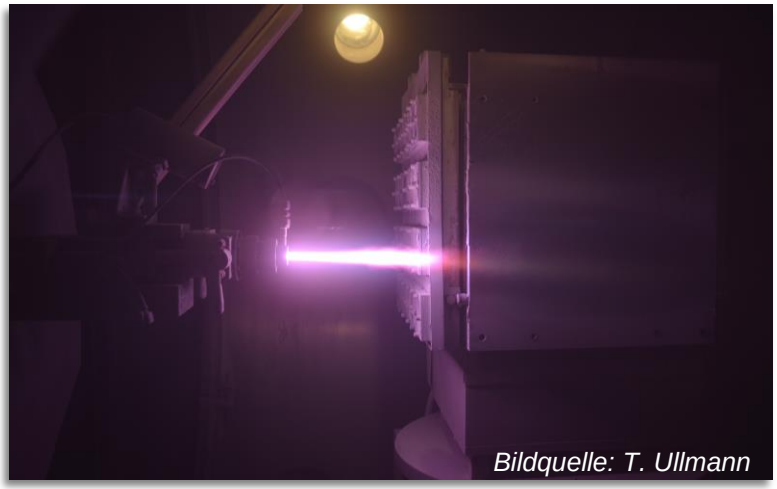
  SiC/SiCN (**PIP-Verfahren**) und SiC/SiC (**LSI-Verfahren**)

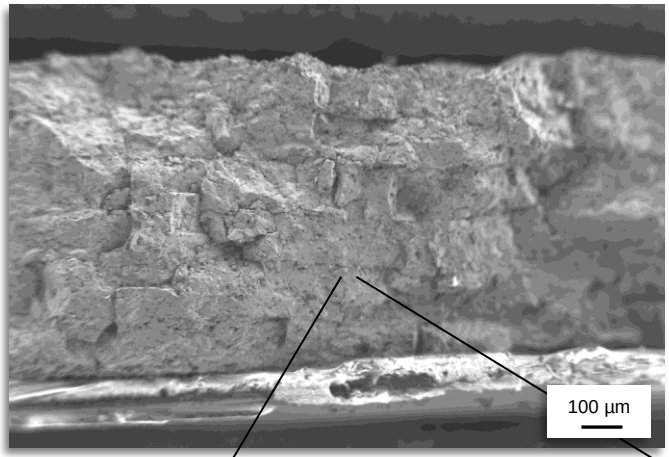
- Der **PIP**-SiC/SiCN Verbundwerkstoffe zeigt Eignung für Brennkammerbedingungen

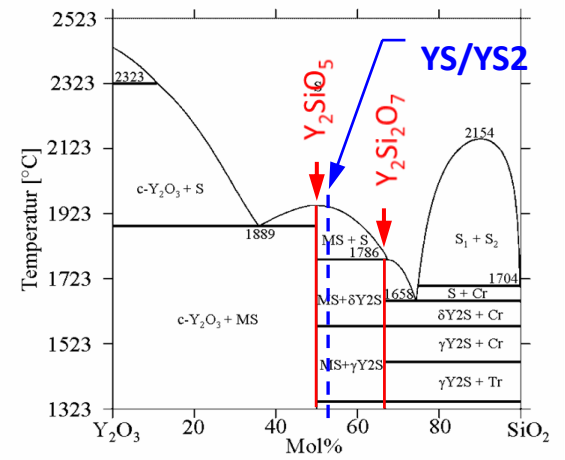
- Der erste schadenstolerante DLR **LSI**-SiC/SiC Verbundwerkstoff wurde entwickelt



Ausblick: Entwicklung von EBCs für PIP- und LSI-Werkstoffe

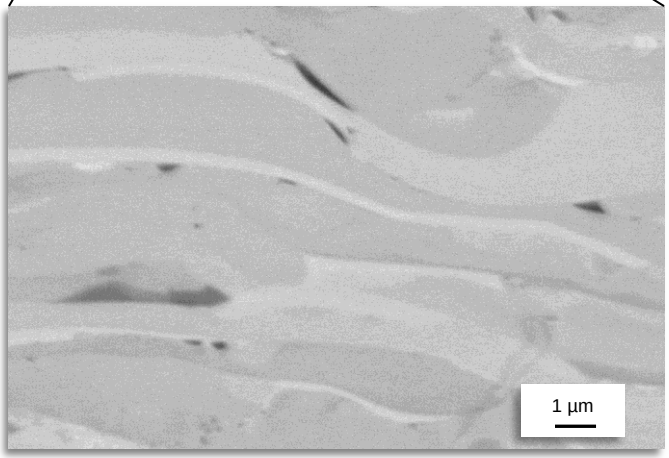








LPPS – Yttriumsilikat Schicht





Vielen Dank für die Aufmerksamkeit

