Computer Aided Development of Light Weight, High-temperature Ceramic Matrix Composites (CMCs) for Gas-turbine Engines

by

Rohan Galgalikar

Department of Mechanical Engineering, Clemson University

Ph.D.

Advisor, Professor Mica Grujicic

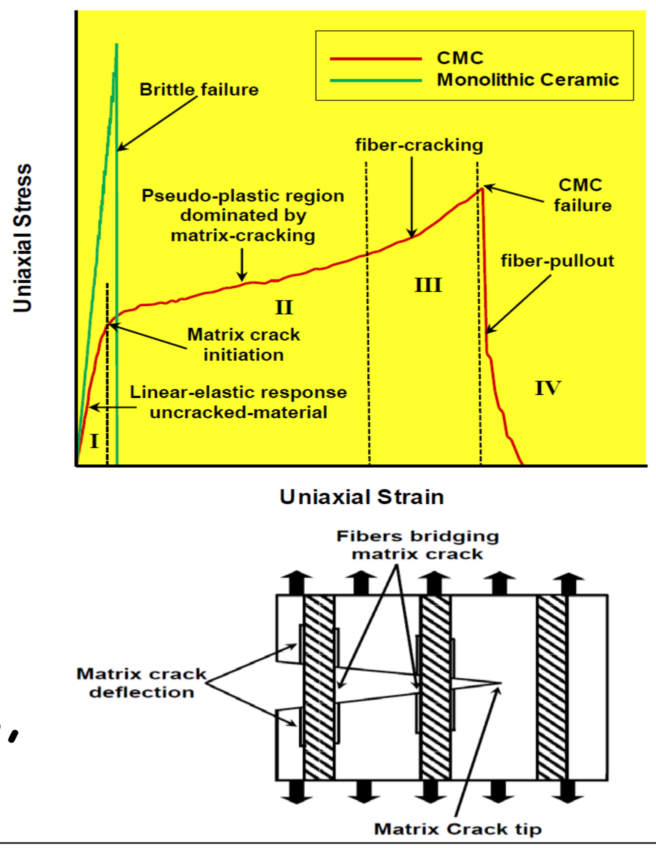
Motivation

Current gas-turbine engines, manufactured from nickel and cobalt based superalloys , have reached their maximum efficiency limits. These gas-turbines are being operated within 50°C of the material melting points, needing significant internal cooling of components. However, it is imperative to increase their operating temperatures to improve cycle efficiency and reduce emissions. Hence the Ceramic Matrix Composites (CMCs) are beginning to replace the superalloys in gas turbines.

Thus far, development of CMCs has been predominantly experimental, which is costly and time consuming. A computer aided model is developed here to predict microstructure-property relationship for the CMCs. This model will provide predictive capabilities to complement the experimental efforts, thereby reducing future CMC development cost and time.

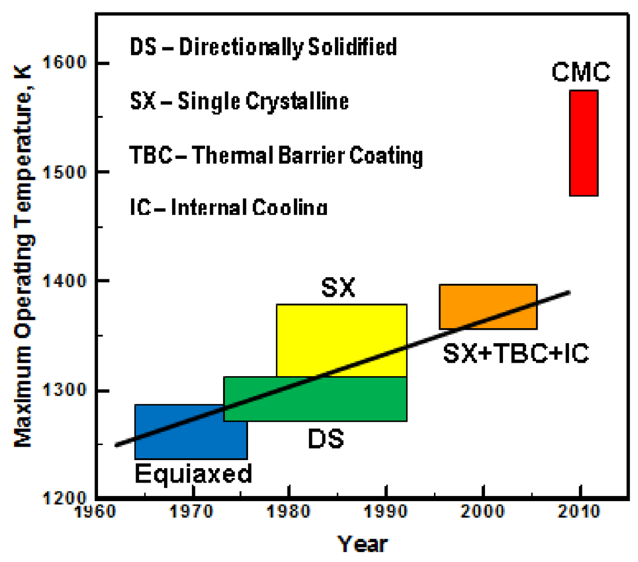
What are CMCs?

- Tough composites made from brittle monolithic ceramic constituents: SiC fiber, with BN coating embedded in SiC Matrix.
- Ductile/non-brittle behavior achieved by the weak matrix-coating bond, leading to matrix crack deflection around fibers
- The intact fibers bridge the matrix cracks, preventing abrupt composite failure.



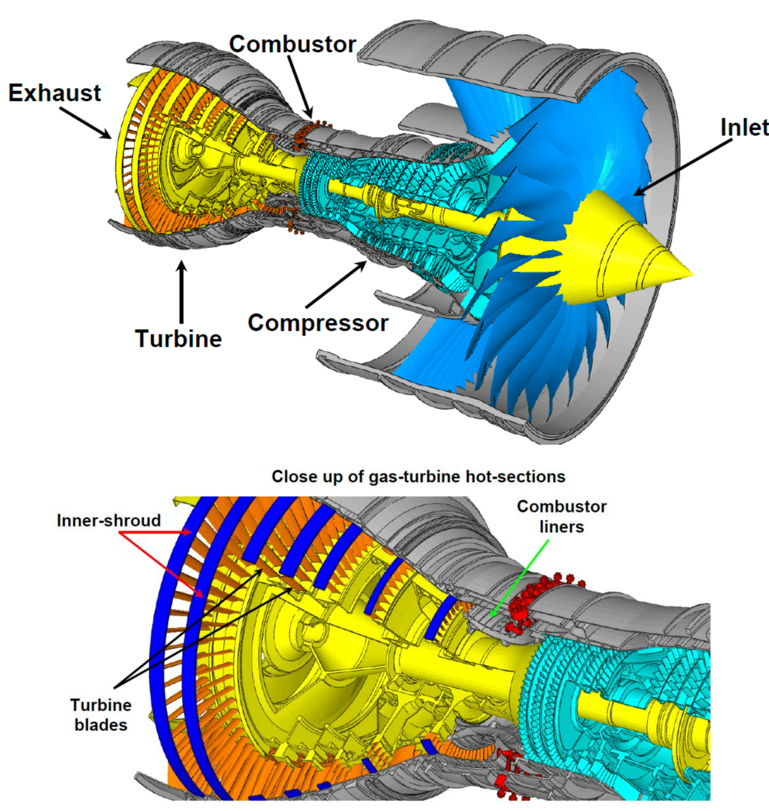
What advantages do they offer?

- SiC/SiC CMCs melt around 2800°C while super alloys melt close to 1300°C.
- CMCs, will thus drastically increase engine-operating temperatures.
- It means, higher efficiency and lower emissions.
- Density of SiC is about 1/3 that of typical superalloy.
- Hence , CMCs will increase the power-to-weight ratio, critical for aviation gas-turbines.
- Thus CMCs are light weight material which exhibit metal-like ductile behaviour along with ceramic-like excellent high temperature strength-retention.

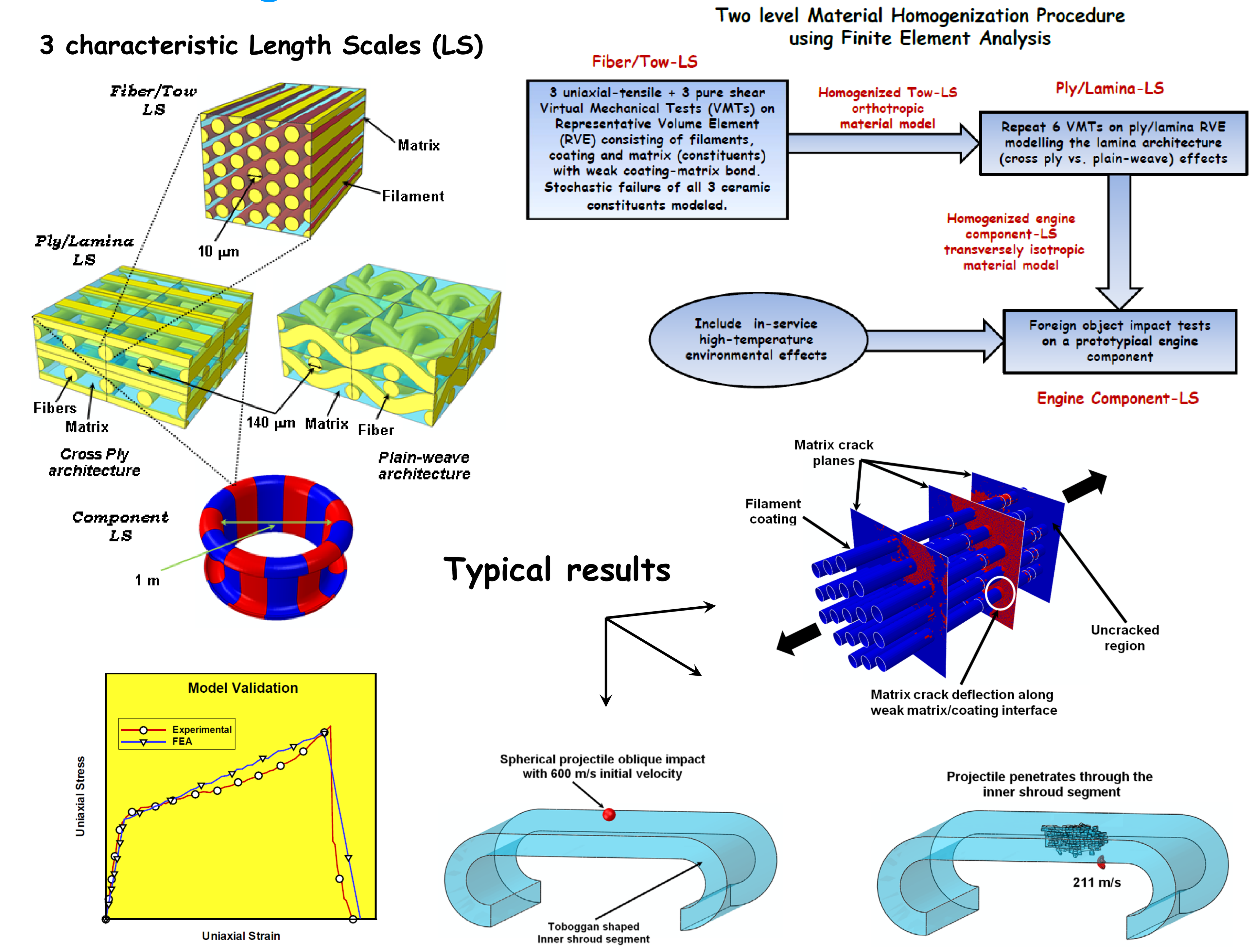


Location of CMC components in gas-turbines

- Currently targeted for use in hot-sections, i.e. turbine & combustor sections of gas-turbines.
- Being a new class of material, only stationary components, i.e. inner shroud and combustor liners which experience low in-service loads , are presently made from CMCs.
- The inner shroud reduces blade-tip clearance to minimize loss of combustion gases. It also acts as a heat shield for the turbine casing.



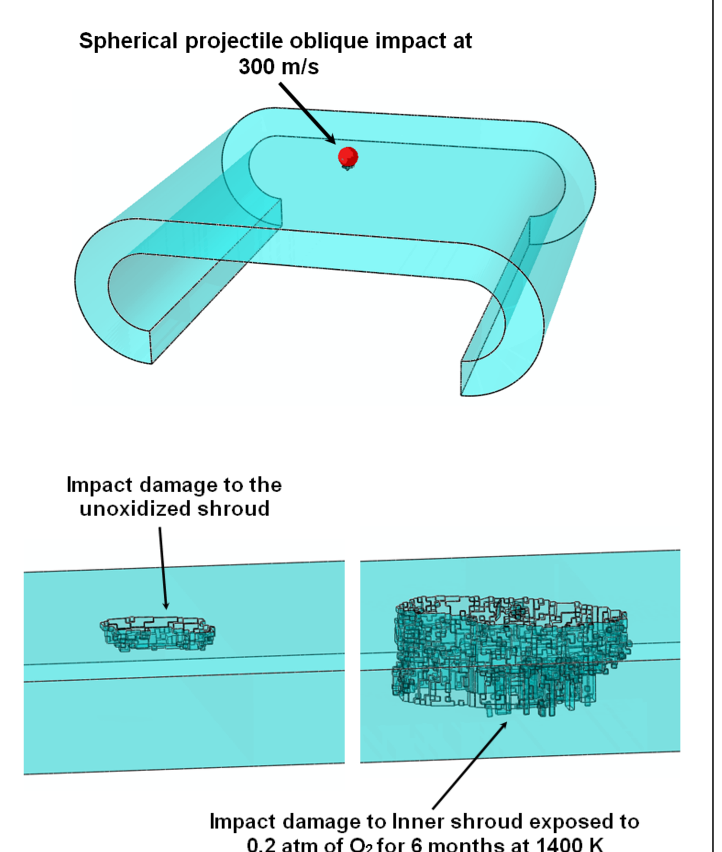
Multi-length scale material model derivation



In-service material degradation effects

The high temperature thermo-mechanical effects are included by making the CMC component scale properties functions of the nature, duration and extent of exposure.

No.	Environmental effect	Constituent property affected	CMC property affected
1.	Prolonged high temperature exposure without mechanical load or oxidation	Fiber strength and stiffness degradation due to grain growth and porosity evolution	Ultimate tensile strength (UTS) flow stress and stiffness reduction
2.	Prolonged high temperature exposure to mechanical load without oxidation	Fiber-to-matrix load transfer due to fiber/matrix differential creep with potential matrix cracking	First matrix cracking strength reduction with potential stiffness degradation
3.	Prolonged high temperature exposure to dry oxidation in presence of matrix cracks	Oxygen ingress through matrix cracks, oxidation of fibers resulting in their strength degradation.	UTS, flow stress reduction
4.	Prolonged high temperature exposure to wet oxidation without mechanical load	Oxygen and water vapor ingress through matrix cracks, oxidation and volatilization of fibers resulting in their accelerated strength degradation.	UTS, flow stress reduction



Commercial benefits and future of CMCs

- Once the stationary components are successfully deployed in aviation and land-based turbines, the cycle efficiency is expected to increase by 2% and 75% reduction in NO_x, CO and unburnt hydrocarbon emissions.
- This translates to annual fuel savings of about $700 million for a fleet of 500 aircrafts.
- In future, moving components, e.g. blades and shafts, which experience high in-service stresses will be made from CMCs, contributing to higher operating temperatures, lighter engines generating even bigger profits.

Concluding remarks

A multi-length scale computational model is developed for predicting microstructure-property relationships for CMCs. This model will complement future experimental design efforts by providing predictive capabilitites to reduce development time and cost.

For more information, please contact
Rohan Galgalikar at (rgalgal@g.clemson.edu)