This research investigates the mechanics of complex aerospace material systems designed for extreme environments. Ceramics and ceramic matrix composites (CMCs) provide highly sought-after capabilities including the potential to withstand extreme temperatures and heat fluxes, severe oxidation and mechanical stresses. Two important material systems form the basis of the scope for this effort: i) thermal barrier coatings (TBCs) on Ni-superalloys that have enabled dramatic increases in turbine temperatures exceeding 1100°C; and ii) ceramic matrix composites that have shown capability and promise for hypersonic applications beyond 1300°C. Understanding the mechanical and material properties of these ceramics as they evolve with temperature and load requires in-situ measurements under realistic representative environments, and from these measurements life expectancy and failure mechanisms can be more completely elucidated.

A multi-variable study was designed and conducted to compare the influence and effect of external thermal loading, applied tensile loading, and internal coolant flow on thermal barrier coatings. Synchrotron measurements, including 2D diffraction, radiography imaging, and three-dimensional computed tomography, were employed to investigate mechanical behavior under realistic representative service loading.

The investigation was conducted to determine the influence and magnitude of internal flow cooling, external applied force loading, and thermal exposure in cyclical application. Lattice strains for the axial and radial direction were resolved for the YSZ top coat layer and the internal thermally grown oxide scale. The findings revealed that during sufficiently high axial loading the strain condition for both the thermally grown oxide and top coat layers may be reversed in direction, and demonstrated how the internal flow and applied mechanical loading produce opposing effects while showing the magnitude of each variable. This reversal of the strain direction is known to contribute to the failure mechanics in the system. This discovery shows that with increased internal cooling to critical zones that experience higher mechanical loads, it is possible to tune the response of the system and prevent the reversal from compressive to tensile strains (in the axial direction). The impact of the results has the potential to be used in design for enhanced durability of the multi-layer coatings.

Ceramic Matrix Composites were investigated for the influence of micro-structure and the role of processing on the mechanics of the system. Isolation techniques of the all alumina composite by means of synchrotron diffraction and tomography presented a novel non-destructive method for evaluating the constituent's properties and evolution. The study successfully revealed how variations in grain size and elastic modulus result in a complex strain state. Further tomographical analysis identified system mechanics, including how to improve the durability of the inter-laminar strength of environmental barrier coatings interface.

Together the research conducted has contributed to the aerospace high temperature materials’ community, and the experimental work taken strides to provide validation and support future numerical simulation for developing better lifetime modeling. Resulting high temperature mechanics’ information has the potential to enhance the design of aerospace components for substantial increases in durability.

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