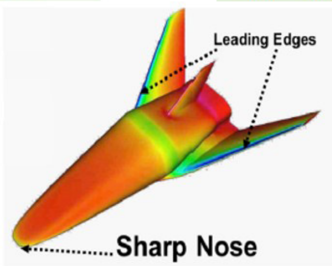
Development of engineering ceramics for variety of advanced structural applications via microstructural engineering using innovative processing routes

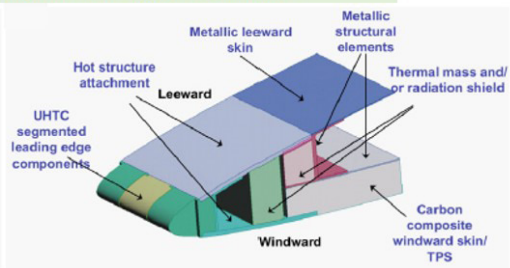
In addition to the more conventional applications, such as refractory linings of steel-making furnaces / ladles and pressurised chemical vessels, engineering ceramics, owing to their high stiffness, excellent thermal stability, relatively low density and corrosion resistance have a variety of applications as advanced structural materials in cutting tools, armor, wear resistant parts, etc. The excellent biocompatibility of ceramics (as compared to their metallic counterparts) in addition to the aforementioned properties, offer potential biomedical applications such as dental as well as hip and knee joint implants. Additionally, ultra-high temperature ceramics (UHTCs) such as TiB_2, ZrB_2, offering unique set of properties such as high melting point (>3000°C), hardness, elastic modulus and thermal shock resistance even at high temperatures, find applications in harsh atmospheres, such as those in space re-entry vehicles.

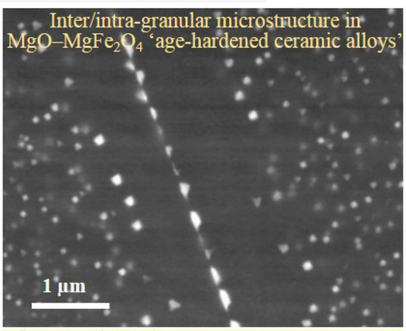
With respect to the engineering applications of ceramics and ceramic composites (and also ceramic 'alloys'), the major focus in our group at the High Temperature and Energy Materials Laboratory, IIT Bombay pertains to the defense and space applications. Some of the works are presently being carried out in collaboration with DRDO and ISRO laboratories.

Ceramics in hip-joint prostheses

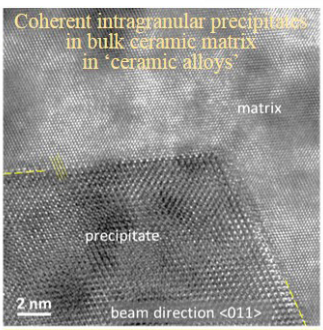
UHTCs in hypersonic (space) vehicles



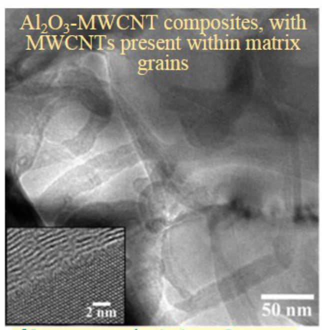




[Gurnani *et al.*; *J. Am. Ceram. Soc.* **99** (2016) 5]



[Gurnani *et al.*; *Philos. Mag. Lett.* **92** (2015) 285]



[Satam *et al.*; *J. Am. Ceram. Soc.* **99** (2016) 2905]

In more scientific terms, addressing concerns over inherent brittleness of these bulk ceramic materials and also possible degradation at high temperatures for some of the promising ceramic composites (such as carbon nanotube reinforced ceramics) are the major focus here.

The research involves adopting innovative processing routes to allow suitable microstructural engineering; thus providing solution to the aforementioned issues. Overall, we aim at understanding and engineering the processing-structure-property relationships, through critical analysis of the microstructural development and mechanical, physical and tribological properties of various particulate, as well as multi-walled carbon nanotube (MWCNT), reinforced ceramic composites.

In more specific terms, one of the major focuses has been on the improvement in fracture properties of bulk polycrystalline ceramics through MWCNT reinforcements, wherein the challenges associated with inhomogeneous MWCNT dispersion and distribution within the sintered matrix (*i.e.*, the usual aggregation at the grain boundaries of polycrystalline ceramic matrix) are addressed via development of innovative and facile wet chemical synthesis routes.

In addition to the superior properties rendered by the presence of MWCNTs within the matrix grains, as opposed to presence only at the grain boundaries, the overall oxidation resistance also gets significantly improved by such microstructure engineering (otherwise, MWCNTs at grain boundaries get oxidised fast). Use of MWCNTs with suitable oxidation resistant coatings are also being explored as reinforcements for still superior oxidation resistance; as needed for the ultra-high temperature applications in space shuttles and missiles.

All such innovations are performed with the processing route being still commercially feasible and scalable. Additionally, the researchers in our group are actively involved in exploration for developing bulk polycrystalline 'ceramic alloys' via solid-state precipitation, as a potential alternative for ceramic nanocomposites that possess significant processing challenges and microstructural in homogeneity. This would render high performance bulk ceramic-based materials better suited for a variety of engineering applications, ranging from refractories to healthcare.

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