National Institute of Technology Rourkela

Synopsis Seminar

Seminar Title	: Processing, Microstructure and Fracture Behaviour of Biomimetic All-ceramics Composites with 4-Levels of structural hierarchy
Speaker	: Soumavo Sikder (Rollno : 517cr1001)
Supervisor	: Arindam Paul
Venue	: Seminar Room, Ceramic Engineering Department
Date and Time	: 11 Jul 2025 (10.45 AM)
Abstract	: Bio-inspired nacre-like composites with lightweight and high toughness can be envisaged as next-generation high-performance structural composite materials, due to its unique &lsquobrick-and-mortar&rsquo architecture. This study explores the integration of two widely used ceramic materials Al_2O_3 (brick phase) and ZrO_2 (mortar phase) through an unconventional processing route involving freeze casting followed by single-step spark plasma sintering (SPS).The biomimetic alumina-zirconia (AZ) composites with 2 levels of structural hierarchy were consolidated (>98% dense) at 1300-1425 ^oC with 50 MPa pressure. The hierarchical &lsquobrick-and-mortar&rsquo microstructure, akin to nacre, exhibited strength of 270 MPa, fracture toughness at crack initiation (K_{IC}) and during stable crack growth (K_{JC}) as 5.2 and 13.5 MPa&radicm respectively. The progressive failure of the bioinspired *all-ceramic* composites occurs by stable crack propagation with fracture energy almost 10 times higher than alumina (main constituents), an unusual and remarkable behaviour for a material exclusively composed of brittle constituents. An exclusive strategy was employed to increase both strength and toughness of nacre-mimetic AZ composites by introducing SiO_2-CaO liquid phase sintering aid (LP), to produce 3rd level of structural hierarchy. The addition of LP played a critical role in significant improvement of both strength and K_{IC} to 470 MPa (~75% increment) and 6.7 MPa&radicm (~24% increment) respectively as compared to level-2 composites. Further, an additional level of structural hierarchy (level-4), similar to &lsquobrick-bridge-mortar&rsquo architecture of natural nacre, was created by incorporating submicron size alumina particles in the layered AZ-LP. This addition yields an extraordinary increase of K_{IC} to 8.5 MPa&radicm (~30% increase than level-2). The strong interfaces between alumina platelets developed due the liquid-phase sintering aid (LP) and stress-induced phase transformation of tetragonal to monoclinic zirconia (denoted as *intrinsic toughness*) are attributing for remarkable strength and K_{IC} for level-3 and 4 hierarchies. The positive influence of LP addition is offset by 25% reduction of K_{JC} to 10 MPa&radicm, mainly due to less crack deflection (termed as *extrinsic toughness*) as layered interfaces disappeared between platelets. The intrinsic and extrinsic toughness are also uniquely isolated for each level of structural hierarchy. Finally, by optimizing the hierarchical architecture from micro to macroscopic level, the structural performance of the synthetic nacre is found to be superior to that of natural nacre and many other engineering materials (illustrated in the form of Ashby map).