Proceedings of the Canadian Society for Mechanical Engineering International Congress
32nd Annual Conference of the Computational Fluid Dynamics Society of Canada
Canadian Society of Rheology Symposium
CSME-CFDSC-CSR 2025
May 25–28, 2025, Montréal, Québec, Canada

MIMICKING NATURE: IMPROVING CERAMIC COMPOSITE PERFORMANCE WITH MICRO-PATTERNED INTERFACES

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ABSTRACT

Ceramics are known for their exceptional mechanical properties, making them highly attractive for advanced engineering applications. However, their inherent brittleness and limited energy absorption capacity pose significant challenges for broader utilization. Inspired by natural armors such as nacre and seashells—biological composites that combine brittle ceramic-like substances with soft, ductile materials to achieve remarkable resilience—this study investigates bioinspired architected ceramics. Specifically, the research employs Alumina as the hard, brittle component and Surlyn (an ionomer) as the soft, ductile component to replicate the microstructural synergy seen in natural armors.

The primary focus of this study is to bridge a critical knowledge gap concerning the role of the soft component's volume fraction in influencing interfacial properties. By mirroring the microstructures of natural protective systems, this research investigates the impact of interface micro-patterning between Alumina and Surlyn. Advanced ablation machining techniques utilizing ultra-short pulsed picosecond lasers were employed to engrave diverse, high-precision micro-patterns onto the surface of Alumina. These patterns were designed to enhance interfacial performance by promoting improved adhesion and energy dissipation under mechanical stress.

A series of rigorous experimental tests, including single-lap joint, double-lap joint, and three-point bending tests, were conducted to evaluate the interfacial behavior of the composite structures. The results demonstrate that an increased volume fraction of Surlyn contributes to greater plastic deformation at the interface, effectively maintaining adhesive failure while enhancing the system's overall toughness. Furthermore, the introduction of laser-engraved micro-patterns significantly altered the failure mode. While the unpatterned interfaces exhibited adhesive failure, the micro-patterned interfaces shifted to cohesive failure. This transition resulted in a substantial enhancement of interfacial mechanical properties, with the interfacial shearing strength increasing by up to 65% and energy absorption improving by approximately 110%.

These findings underscore the transformative potential of microstructural design in improving the mechanical performance of ceramics. By leveraging bioinspired principles, this study highlights the ability to engineer advanced composite materials that combine high strength with superior toughness and energy absorption. The insights gained from this work not only advance the understanding of interfacial mechanics in architected ceramics but also provide a promising pathway for the development of next-generation materials for protective applications, inspired by the elegance and efficiency of natural systems.