Bridging Natural Principles and Material Science: Advances in Lithomimetic-Inspired Polymeric Multi-Material Composites

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Abstract

The tailored design of material structures to meet the stringent demands of modern engineering applications has long been a focal point in materials science. Among the diverse strategies available within the extensive toolbox of materials design, lithomimetics (1) emerges as a novel and underexplored paradigm for polymeric materials, drawing inspiration from the complex patterns and structures naturally formed in the Earth's lithosphere. These structures, often featuring zig-zag or wave-like patterns, are characteristic elements recurring across various mineral types. The self-organization processes driven by extreme temperatures and pressures in the Earth's crust create these patterns, offering valuable inspiration for potential material design guidelines.

Recent studies, such as that by Waly et al. (2), have demonstrated the potential of wave-like "*lithomers*" - a fusion of lithomimetics and polymers - to surpass biomimetic straight-layered configurations in performance. These lithomers exhibit improved structure-property relationships, particularly in fracture toughness (damage tolerance) and stiffness, due to their complex architectures. These improvements are primarily attributed to the complexity and architecture of the structures. By incorporating soft interlayers within a hard matrix, the material inhomogeneity effect (3) can be harnessed to arrest crack propagation and enhance damage tolerance. Furthermore, the intricate geometry of the structures promotes mechanical interlocking, frictional effects, and increased shear stiffness within the soft layers, thereby contributing to improved initial stiffness of the overall system.

This study addresses two primary objectives. First, it seeks to optimize structural designs to enhance structure-property relationships. Through a combination of simulations and laboratory experiments, key parameters such as radii, amplitudes, frequencies, and layer thicknesses were analyzed, revealing their intricate interdependencies. This approach led to critical design guidelines and identified structural variants that outperform traditional straight-layered systems in damage tolerance and stiffness.

The second objective is the development of scalable fabrication methods for these structures, moving beyond additive manufacturing to mimic characteristics of the Earth's lithosphere. While such structures have been successfully fabricated in metals using specialized techniques like high-pressure torsion (4), no conventional polymer-based processes currently exist. To bridge this gap, a rotational mixer was developed, enabling the production of complex structures under high pressure, elevated temperatures, and relative motions analogous

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to geological processes. These fabricated structures demonstrated improved mechanical and fracture properties in testing compared to conventional designs.

Although still in their infancy, lithomers offer a promising avenue for advancing design principles in polymeric multilayer systems. Rather than serving as direct blueprints, they should be viewed as sources of inspiration for improving mechanical performance in materials. Additionally, they offer a versatile platform for innovating fabrication processes and refining existing methods, always aiming to meet the growing demands of modern applications.

References

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