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Roberts 307

Material Properties of Ureolytically Induced Calcium Carbonate Composites

Polymers utilized in adhesive applications commonly derive from petrochemical sources and release volatile organic compounds (VOCs) during application. The accumulation of these VOCs indoors can pose risks to human health. To counter these concerns, biopolymers offer a potential non-toxic and sustainable alternative to synthetic polymers. However, biopolymers often exhibit limited physical stability and mechanical performance. To enhance the stability and adhesive capabilities of biopolymers, the addition of a mineral phase can be employed to create biopolymer-mineral composites.

This study focused on the production of such composites through the ureolytically induced precipitation of calcium carbonate in the presence of guar gum (GG) or soy protein (SP). The ureolysis process was initiated by either the ureolytic bacterium *Sporosarcina pasteurii* or jack bean urease. The resulting composites were designated as ureolytically induced calcium carbonate composites (UICCs). Optimization of the adhesive strength of these composite adhesives involved varying calcium and cell (or enzyme) concentrations. The adhesive strength of UICCs was found to be significantly higher, up to 2.5 to 6 times, compared to that of the biopolymers alone. Durability testing of the UICCs was conducted under different immersions (24 hours and 7 days), relative humidities (50% and 80% RH), and temperatures (-20°C, 100°C, and 300°C). The UICCs demonstrated improved adhesive strength compared to biopolymers alone, maintaining their performance in moderate humidities and temperatures ranging from below freezing to room temperature after 7-day exposures.

Additionally, the impact of biopolymers on the nanoscale material properties of UICCs was evaluated by inducing calcium carbonate precipitation in the presence of Bovine Serum Albumin (BSA), a model protein. Nanoindentation analysis revealed that the nanoscale moduli of the mineral precipitates were notably reduced in the presence of BSA. Furthermore, mineral precipitates produced in the presence of BSA exhibited high resistance to inelastic deformation, indicating an improved resistance to brittle fracture—a favorable characteristic for load-bearing applications. Atomic force microscopy investigations showed that BSA introduced structural variations and moduli gradation in biominerals, resembling the heterogeneities observed in biogenic and geologic minerals. These findings demonstrate the influence of organics on the nanoscale structure and material properties of calcium carbonate precipitates. The prospect of controlling microscale material properties of biominerals using organic additives offers opportunities for enhanced microscale control and increased toughness at the macroscale, particularly in engineering applications such as construction, binders, and adhesives.

Overall, the incorporation of mineral phases into biopolymers yields composite materials with superior adhesive strength and enhanced durability compared to biopolymers alone. Furthermore, introducing organic additives, such as BSA, improves toughness at the macroscale and potentially enables the fine-tuning of material properties at the nanoscale. These advancements present exciting possibilities for the development of safer, more sustainable adhesives suitable for a wide range of applications.