



Sustainable Waste Management in Materials Science

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Poster

Sustainable solution for poly(3-hydroxybutyrate-co-3-hydroxy hexanoate) recycling by foaming using supercritical CO₂

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Poly(3-hydroxybutyrate-co-3-hydroxyhexanoate) (PHBHHx), also referred to as PHBH or P(3HB-co-3HHx), is a biodegradable and biocompatible polyhydroxyalkanoate (PHA) produced by microorganisms through fermentation of renewable carbon sources. The incorporation of 3-hydroxyhexanoate (3HHx) units into the PHB backbone reduces crystallinity and melting temperature while improving flexibility, toughness, and processability compared with highly crystalline PHB. The properties of PHBHHx can be tailored by controlling the 3HHx content, making it attractive for applications ranging from biodegradable packaging to biomedical materials and tissue-engineering scaffolds. Its biodegradability, biocompatibility, and tunable mechanical properties have stimulated considerable interest in PHBHHx-based films, composites, porous structures, and medical devices [1].

Supercritical carbon dioxide (scCO₂) is an environmentally attractive physical foaming agent for biopolymers, as it can dissolve in polymer melts, act as a plasticizer, reduce processing temperature and generate cellular structures through pressure-induced nucleation and expansion. The technology enables the production of lightweight, porous biopolymer materials with tunable morphology and properties, including foams based on PLA, PHB and other biodegradable polyesters. From a recycling perspective, scCO₂-assisted foaming may provide an attractive route for upgrading recycled biopolymers and polymer waste into higher-value porous materials, while avoiding conventional chemical blowing agents and potentially compensating for some loss of material performance associated with reprocessing. The integration of scCO₂ foaming with mechanical recycling therefore offers potential for developing more circular processing routes for biopolymer waste [2].

In the present study, an attempt was made to foam poly(3-hydroxybutyrate-co-3-hydroxyhexanoate) (PHBHHx) using supercritical carbon dioxide (scCO₂) as a physical foaming agent. The polymer was initially injection molded to obtain compact specimens, which were subsequently subjected to a foaming process under scCO₂ at controlled pressure and temperature conditions. This two-step processing approach was employed to investigate the feasibility of inducing cellular structures in preformed PHBHHx specimens. The resulting foamed materials were characterized in terms of their cellular morphology and overall porosity to evaluate the effectiveness of the scCO₂ foaming process.

Acknowledgments

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Plenary lecture 4 – Wednesday, 23.09, 09:15-10:00

Oral presentation

Nature has no waste - rethinking materials design through living systems

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Keywords: Bioinspired materials design; Engineered living materials; Circular economy; Building materials.



The built environment is a major consumer of resources and a significant generator of waste across its entire lifecycle, from raw material extraction and manufacturing to construction, operation, and demolition [1]. In parallel, rapid global urbanisation is accelerating material demand and intensifying the production of waste across multiple sectors. These overlapping pressures position the construction industry at the center of the transition toward circular and sustainable systems [2]. Addressing this challenge requires a fundamental rethinking of waste, not as an endpoint, but as a resource within continuous material cycles.

In natural systems, waste does not exist. Biological processes operate through closed-loop cycles in which by-products are continuously transformed into resources, enabling efficiency, resilience, and regeneration [3]. This lecture will explore bioinspired approaches to materials design, drawing on organisms and ecosystems that represent circularity through growth, decay, and reuse. These principles have informed the development of materials and processes that reinterpret waste streams, industrial by-products, agricultural residues, and other forms of biomass, as valuable inputs for new material systems [4]. In architecture and materials science, such strategies have contributed to the emergence of bio-based and waste-derived materials that reduce reliance on virgin resources [5]. However, while bioinspired approaches translate selected principles from nature into engineered solutions, they largely remain passive. Recent advances in synthetic biology, microbiology, and materials science are enabling a transition beyond biomimicry toward engineered living materials (ELMs), in which living organisms are embedded directly within the material structure. These systems introduce metabolic activity into materials, allowing them to transform, regenerate, and interact dynamically with their environment [6]. In this context, waste streams can be actively processed and valorised within the material itself, opening new possibilities for circular material flows.

This transition is explored through several research initiatives. The ARCHI-SKIN project investigates fungal biofilms as living architectural coatings that can grow on and adapt to building surfaces, offering protective and regenerative functionalities while utilising available substrates. The REMEDY project expands this approach through the development of microbial living inks and “archibiome tattoos,” enabling the bespoke integration of designed microbial communities into architectural surfaces for functions such as bioremediation and environmental regulation. Extending these concepts further, the LIVEMAT project explores the creation of fully integrated living composite materials that combine abiotic scaffolds with algae, cyanobacteria, and fungi. These materials are capable of performing functions such as carbon sequestration, photosynthesis, and waste transformation, positioning them as active participants in material cycles rather than passive components. Together, these approaches outline a shift from viewing materials as static products to understanding them as dynamic systems embedded within broader ecological and technological cycles [7]. Building envelopes and material assemblies can be reimagined as active interfaces that not only minimise waste but also contribute to its transformation and reuse. This perspective aligns with emerging concepts of regenerative design, circular economy, and biologically integrated architecture. By bridging architecture, materials science, and life sciences, this work contributes to a new paradigm in which materials are designed to participate in continuous cycles of production, transformation, and regeneration. While challenges remain in terms of scalability, durability, and regulatory integration, engineered living materials offer a compelling pathway toward a built environment that reflects the fundamental principle observed in nature: waste is not eliminated, but continuously redefined as a resource.

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