Journal of Polymers and the Environment (2025) 33:301–322
https://doi.org/10.1007/s10924-024-03416-0

ORIGINAL PAPER

Recent Advances in Vitrimers: A Detailed Study on the Synthesis, Properties and Applications of Bio-Vitrimers

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Accepted: 26 September 2024 / Published online: 10 October 2024

Abstract
Nowadays, thermoset polymers stand out as notable composites, but the surge in global thermoplastic production has raised concerns due to the non-recyclability of these composites, leading to an increase in landfill waste. In response to these challenges, researchers are investigating innovative approaches to enhance thermosetting materials, focusing on the modification of crosslinking agents responsible for forming a covalently bonded network. Vitrimers offer a promising solution by enabling re-processability while maintaining favourable thermo mechanical properties and solvent resistance. Although many current vitrimers use synthetic polymeric molecules from fossil-based sources, there is a growing interest in bio-based vitrimers. While still in early development, these bio-based alternatives leverage biomass for creating durable polymers, aligning with the goal of establishing a circular economy. This review has been designed to highlight the use of covalently modified networks to produce advanced synthetic and bio-based vitrimer composites with diverse applications, contributing to the development of sustainable materials for the next generation through the use of recyclable resources and renewable feedstocks in polymer network synthesis. This review also explores vitrimers, examining their unique characteristics and addressing current limitations hindering their widespread adoption as recyclable materials with superior performance.

Keywords Bio-Vitrimer · Polymers · Sustainable development · Material science · Covalent adaptable networks

Introduction

Plastics are likewise durable materials that frequently withstand oxidation, dampness, and biodegradation. Generally, plastic materials have been mainly divided into two types: thermosets and thermoplastics. Thermoplastics, including polyethylene, polyethylene terephthalate, polystyrene, and poly-vinyl chloride, exhibit the ability to undergo melting and reprocessing at higher temperatures because of the intermolecular interactions present in their linear polymeric chains [1, 2]. In contrast, thermosets, like melamine resins, silicone resins, epoxy resins, and urea-formaldehyde, can't be easily recycled because of complex covalent crosslinks, and shortly before melting, the polymer generally breaks down. Therefore, efforts are being made to create new plastics that have the strength and durability of thermosets but can also be pre-processed at the end of their useful lives. This would contribute to the growth of a circular economy in which outdated items are recycled or utilized as feedstock. In recent years, a novel category of polymers known as vitrimers has arisen as a means to attain a balance between thermosets and thermoplastics, as depicted in Fig. 1. These vitrimers are considered to be "smart" polymers [3]. Indeed, vitrimers are multi-use, re-processable polymer networks that are irreversibly crosslinked, resistant to solvents, and plastically flowable at high temperatures [4,

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