Vitrimers: from Molecular Design to Composites Materials

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Covalent adaptable networks (CANs), and particularly vitrimers, have emerged as a promising class of thermoset materials capable of combining high mechanical performance with reprocessability, repairability, and extended service lifetime. Among the various dynamic chemistries available, disulfide exchange reactions are especially attractive due to their efficiency under relatively mild conditions and their compatibility with high-performance polymer networks.

In this research, we demonstrate how the precise molecular design of dynamic epoxy networks enables control over vitrimer behavior across multiple length scales, from molecular exchange mechanisms to macroscopic material performance. We investigate how both the chemical structure of the curing agent and the introduction of phase-segregated domains govern exchange kinetics, network rearrangement, and ultimately the thermal and mechanical properties of the resulting vitrimers.

Building on this molecular-level understanding, we extend this design strategy to fiber-reinforced composite materials, where dynamic network chemistry offers new opportunities to overcome the traditional limitations of thermoset composites. By integrating adaptable disulfide-based matrices into structural composites, we demonstrate the possibility of combining high mechanical performance with advanced functionalities such as repairability, reprocessability, and enhanced durability. This multiscale approach highlights how rational molecular engineering of vitrimer networks can enable the development of next-generation sustainable composite materials, bridging the gap between fundamental chemistry and advanced engineering applications.