Design, synthesis and study of mechanical behaviour of tough hydrogels and their multifunctional applications

Abstract

Polymer hydrogels show great potential for a wide range of applications, but the conventional hydrogels' poor mechanical properties severely limit their scope. In this regard, incorporating the energy dissipation mechanism into the hydrogel is considered an effective method to improve mechanical properties. However, coupling high strength and toughness with efficient recovery properties remains a major challenge. In this work, several hydrogels were synthesized from a facile one-step procedure. The physical polyacrylamide-chitosan (PAM-CS) hybrid gel shows huge improvements compared to the parent physical PAM gel. The improvements were based on the presence of PAM-CS inter chain H-bonding, which acted as a sacrificial bond and dissipated a large portion of applied energy. One of the major problems with hydrogels having sacrificial bonds is they suffer from poor recovery due to the slow reformation of the sacrificial bond. A dual cross-linked, poly(acrylamide-co-vinylimidazole)-M^{2+} (M: Ni, Zn) hydrogel was synthesized, where the strong chemical cross-linking holds the structure and highly dynamic imidazole-metal ion cross-links act as a sacrificial bond and dissipates energy. Due to the fast kinetics of imidazole-metal ion cross-links, after breaking, it rejoins quickly, leading to fast and efficient self-recovery within mins (96% dissipative energy recover at 200% strain in 1 min). Deviating from tedious traditional techniques to tailor the mechanical properties, the kinetics of the metal-ligand interaction was utilized for easier control of mechanical properties. Simply by controlling the kinetics, a wide range of mechanical properties having both soft (~ 1 MPa) as well as stiff (~ 39 MPa) hydrogels based on poly(methacrylamide-co-vinyl imidazole) were created. The ionic conductivity of the hydrogels was explored to prepare a highly sensitive resistive (gauge factor ~11 at 100% strain) and capacitive sensor electrolyte for a compressible supercapacitor. Another major problem with hydrogels is that the water inside the hydrogel freezes at subzero temperatures, resulting in loss of functional properties. Consequently, a proton donor-acceptor, poly(acrylamide-co-acrylic acid-co-vinylimidazole) hydrogel was developed. Due to strong H-bonding interactions with water molecules, the freezing tolerance of hydrogel improved, and mechanical properties were preserved at low temperatures. The hydrogel also shows good adhesiveness and conductivity. The hydrogels were used to prepare tactile sensors and employed as human motion sensors.

Keyword: Tough hydrogel, Mechanical properties, Self-healing, Tactile sensor, Compressible electrolyte, Self-recovery