Conductive Hydrogels with Superior Mechanical Properties

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1. Introduction

Hydrogels can absorb and retain a significant amount of water, which makes them have a number of promising properties such as biocompatibility and environmental friendliness [1,2], responsiveness to external stimuli [3,4], adhesion [5], and biodegradability [6]. Especially, the hydrogels that exhibit both mechanical and electrical properties have received particular attention recently. Mostly this type of hydrogel has been obtained by employing the interactions between monofunctional carboxylic groups and multivalent metal ions such as Fe^{3+}. However, there are some limitations in their mechanical properties such as low tensile strength [7] and modulus [8], as well as low compression properties [9].

To overcome these limitations, we have developed novel hydrogels which have a combination of superior mechanical and good electrical properties by exploiting the ionic interactions between bifunctional carboxylic groups and multivalent Fe^{3+} ions. Due to their strong ionic bonding and simultaneously breaking and reforming ability upon deformation, the equilibrium hydrogels also exhibit rapid self-recovery properties at room temperature.

2. Hydrogel synthesis

To prepare the hydrogels, firstly the prescribed amount of *N*-acryloyl glutamic acid (AGA), acrylamide (AAm) monomers and thermo–initiator, ammonium persulfate (APS), were dissolved in deionized water by sonication to form homogeneous solution. Then the solution was deaired for 5 min with nitrogen gas and transferred into a reaction chamber for polymerization at 60 ^oC for 12 h. After that the as–prepared hydrogels were cooled down room temperature, taken out of the reaction chamber, and subsequently immersed in $FeCl_3$ solution for 24 hours for Fe^{3+} loading. Finally, the gels were kept under water for 24 h to remove excess Fe^{3+} ions. The shape of hydrogels is shown in Fig. 1.

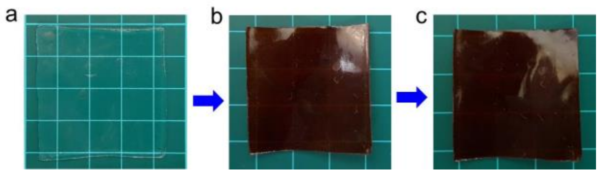

Fig.1 (a) As-prepared hydrogel; (b) Hydrogel after soaking in 0.1M Fe^{3+} for 24 h; (c) Water-equilibrium hydrogel.

3. Mechanical and electrical properties

For evaluating mechanical properties, the tensile stress and strain properties of these hydrogels including as-prepared hydrogel, hydrogel after soaking in 0.1 M Fe^{3+} solution, and equilibrium hydrogel were determined by using Universal Test Machine (Model TO-100-1C). In testing process, the initial length was set at ~12 mm and the deformation speed was set at 500% per minute. Based on the obtained results, the two best composition hydrogels were selected for further investigation such as fracture energy, compressive properties, and self-recovery properties. The best composition equilibrium hydrogels can exhibit over 30 MPa of Young's modulus, 10 MPa of strength,

~10 kJ m^{-2} of fracture energy, ~60 MPa of compressive strength at 98 % strain, and rapid self-recovery at room temperature.

For investigating the electrical properties, the hydrogels resistance was measured. Then their resistivity and conductivity were calculated. Moreover, the dielectric constant of the hydrogels was also determined. The results indicated that, the hydrogels exhibit not only superior mechanical properties, but also good electrical conductivity and dielectric constant.

4. Conclusions

With a combination of superior mechanical and good electrical properties, our developed hydrogels have great potential for applications such as load–bearing materials, soft robotics, flexible electrical devices and sensors.

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