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Polymer Physics Experiment Teaching Design - Taking the Preparation and Performance Research of Conductive Ion Gel as an Example

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Abstract: Polymer physics is a required course for materials majors. Promoting teaching with scientific research is an important way to improve the quality of teaching in colleges and universities. In this paper, ionic liquid was used as multifunctional components to prepare ion gels by photoinitiated polymerization of acrylamide and acrylic acid monomers, and the effect of the content of ionic liquids on the mechanical properties and ionic conductivity of ion gels was further investigated. This experiment can cultivate students' comprehensive experimental ability and in-depth understanding of the influence of polymer structure on performance. Through this experimental teaching reform, students can master knowledge principles and experimental skills, stimulate their enthusiasm for learning, and cultivate scientific thinking and scientific research innovation capabilities.

Keywords: Polymer physics; Experimental teaching; Mechanical property

1. Introduction

"Polymer Physics" is an important part of polymer science, which is a science that studies the relationship between polymer structure and performance. It is one of the important professional compulsory courses for polymer materials, materials science and engineering and related majors. It is the necessary theoretical knowledge before engaging in polymer material research and development. The content of polymer physics course is relatively abstract, and most students have difficulty learning it. Polymer physics experiments can transform abstract theoretical knowledge into the relationship between polymer structure and performance that students can understand more intuitively, which helps to systematically master the basic knowledge and basic principles of polymer physics and understand the relationship between structure and performance. In recent years, with the continuous deepening of teaching reform, integrating cutting-edge scientific research experimental results into teaching content, that is, organically combining scientific research with teaching, has received more and more attention [1]. Designing a comprehensive experimental teaching reform course that integrates cutting-edge scientific research results and applies advanced synthesis methods to prepare new functional materials will help broaden students' scientific horizons, improve experimental skills, stimulate learning enthusiasm, and cultivate scientific thinking and scientific research innovation capabilities.

Ion gel is a new type of gel material alongside polymer hydrogel and organogel. It is a soft composite material that uses ionic liquids with low volatility, antifreeze and thermal stability as dispersed phases to fill the polymer gel network [2]. It has shown great superiority in the fields of solid electrolytes, ionic skin, flexible devices and functional materials. Therefore, the content of ionic liquid is an important factor affecting the mechanical properties and ionic conductivity of ion gel [3]. This experimental design is based on a comprehensive experiment of conductive ion gel. By optimizing the dosage of ionic liquid, the effects of dispersed phase on the structure, mechanical properties and ionic conductivity of ion gel are explored. To this end, we introduced the "one-step rapid photoinitiated polymerization method" into the polymer synthesis experiment. The effects of the dosage of ionic liquid on the mechanical properties and ionic conductivity of ion gel were analyzed. The preparation and performance research of conductive ion gel, a cutting-edge scientific research experimental result, was designed into a comprehensive experiment, that is, the new scientific research results were fed back and integrated into teaching, realizing the interactive combination of scientific research practice and teaching practice.

2. Experimental principle

The design principle of ion gel is to fill ionic liquids with low volatility, good chemical stability, and high ionic conductivity into a flexible polymer matrix. Among them, acrylamide (AM) and acrylic acid (AA) monomers have good chemical stability. Using double-bonded

AM and AA as comonomers, flexible copolymers (P(AM-co-AA)) can be quickly obtained by photoinitiated free radical polymerization. In addition, hydrophobic ionic liquid ([EMIM][TFSI]) with low viscosity was selected as dispersed phases, plasticizers and electrolyte salts.

3. Experimental section

3.1 Preparation of ion gels

2 mL AM monomer, 0.5 mL AA monomer, photoinitiator (20 μL) and different contents of (0, 1.0, 1.5 and 2.0 mL) were fully mixed to form a uniform precursor solution. Then, the precursor solution was poured into a polytetrafluoroethylene mold (2.0 cm × 1.5 cm) and photoinitiated polymerization was carried out under 365 nm, 20 W ultraviolet light for 10 min to obtain ion gels with different ionic liquid contents.

3.2 Mechanical properties test

A universal mechanical testing machine (Shimadzu AGS-x 100N) was used to perform stress-strain tensile tests on ion gels. The tensile rate was 100 mm min^{-1}.

3.3 Ionic conductivity test

Aluminum foil with wires attached to both sides of the ion gel was used, and then the electrochemical workstation (CHI660D) was used to test its bulk resistance (R_b) using the AC impedance technology. The ionic conductivity of the ion gel is calculation by formula [4]: $\sigma = d/(R_b \times A)$, where σ is the ionic conductivity; A and d are the area and thickness of the ion gel, respectively.

4. Results and analysis

4.1 Mechanical properties of ion gels

As shown in Figure 1, the mechanical properties of the ion gel can be adjusted in a wide range by introducing and adjusting the content of the ionic liquid. The flexible copolymer (P(AM-co-AA)) without adding ionic liquid shows a very large tensile strength (189 KPa), but its elongation at break is only 325%. With the increase of the ionic liquid content, the tensile strength of the ion gel decreases and the elongation at break increases. When the content of the ionic liquid increases from 1.0 mL to 2.0 mL, the tensile strength decreases from 149 KPa to 76 KPa, while the elongation at break increases from 580% to 1037%. This is because the ionic liquid can act as a plasticizer in the ion gel. With the increase of the ionic liquid content, the free volume of the polymer chain segment increases, the mobility of the chain segment increases, and the interaction force between the molecular chains weakens, thereby reducing the stress and increasing the strain. On the other hand, when the content of ionic liquid continued to increase to 2.0 mL, the tensile strength of the ion gel further decreased by 23 KPa. This is because the high ionic liquid content caused the polymer chain to expand and dilute, resulting in a weakened tensile stress.

This result is a good explanation for the discussion of the effect of plasticizers on the movement of polymer molecular chains in polymer physics courses, that is, a certain amount of plasticizer can increase the activity space of polymer chains and improve the mobility of chains, thereby increasing the elongation at break of polymers and reducing tensile strength [5]. By examining the stress-strain curves of ion gels with different ionic liquid contents, students can more intuitively and better understand the relationship between polymer chain structure and performance, and deepen their understanding of theoretical knowledge.

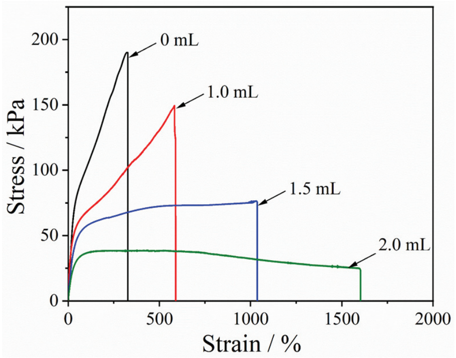

Figure 1. Stress-strain curves of ion gels with different ionic liquid contents.

4.2 Ionic conductivity of ion gels

Figure 2 shows the ionic conductivity of ion gels with different ionic liquid contents at room temperature (25 °C). The ionic conductivity of the flexible copolymer (P(AM-co-AA)) without the addition of ionic liquid is very low, only 0.02 S cm^{-1}. With the addition of ionic liquid, the ionic conductivity of the ion gel is significantly improved. When the ionic liquid content in the ion gel increases from 1.0 mL to 1.5 mL, its ionic conductivity increases rapidly from 0.1 S cm^{-1} to 0.18 S cm^{-1}. When the ionic liquid content continues to increase to 2.0 mL, the ionic conductivity of the ion gel increases sharply to 0.43 S cm^{-1}, indicating that the ionic conductivity is positively correlated with the content of ionic liquid. Ionic liquids can play multiple roles in ion gels as dispersed phases and conductive agents. With the increase of ionic liquid content, the free volume of polymer segments increases and the mobility of ionic increases.

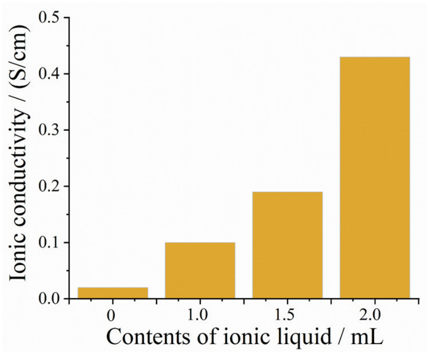

Figure 2. Ionic conductivity of ion gels with different ionic liquid contents.

5. Teaching suggestions

This experiment is a teaching experiment for the polymer physics course, which discusses the mechanical behavior, ionic conductivity and factors affecting tensile strength of typical polymer materials. This comprehensive experiment involves the chapters of polymer condensed structure, polymer plasticization, polymer mechanical behavior and electrical properties in the polymer physics course, and is very suitable as a teaching case. It is recommended to arrange it in the context of learning the basic knowledge of polymer physics courses, so as to deepen students' consolidation and understanding of theoretical knowledge.

The teaching time of this comprehensive experiment is recommended to be 6-8 hours, and the experiment should be carried out in groups of 3-4 people. Before the experiment begins, students are asked to preview and consult the materials before conducting group discussions, review the theoretical knowledges involved in the experiment and the test purpose of the experimental instruments, which exercise their independent thinking ability. After the experiment begins, the experiment is divided into two parts: the preparation of ion gel and the performance test. In addition, for the performance of ion gels, it is also possible to expand the test of its self-healing performance, adhesion performance, anti-swelling performance and stress sensing performance, so that students can further understand the wide application of polymer gels. How to arouse students' knowledge coherence, how to guide students' logical thinking on theoretical knowledge, stimulate students' learning interest, and cultivate students' scientific research thinking and experimental skills are the purpose of this experimental design.

References

[1] Tukhtamirzaevich, Mamadaliyev Adkhamjon. Interactive educational methods in teaching the subject of physicochemical properties of minerals, Scientific Impulse, 2023, 1(6): 1718-1725.

[2] Peng Hui, Yang Fan et al. Rapid radiation synthesis of a flexible, self-healing, and adhesive ionogel with environmental tolerance for multifunctional strain sensors. ACS Applied Materials & Interfaces, 2023, 15(44): 51763-51773.

[3] Ruan Qinqin, Yao Meng et al. Ionic liquid crystal electrolytes: Fundamental, applications and prospects, Nano Energy, 2023, 106: 108087.

[4] Tamate Ryota, Takeshi Ueki. Adaptive ion-gel: Stimuli-responsive, and self-healing ion gels, The Chemical Record, 2023, 23(8): e202300043.

[5] Fei Weihang, Wu Zishuo et al. Molecular mobility and morphology change of poly (vinyl alcohol)(PVA) film as induced by plasticizer glycerol, Journal of Polymer Science, 2023, 61(17): 1959-1970.