Fabrication Strategies of Cellulose Nanocrystal-based Hydrogel

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DOI: 10.32629/aes.v5i1.1848

Abstract: In this paper, the preparation, properties and applications of cellulose nanocrystal (CNC)-based hydrogels are presented. The paper first introduces the characteristics and research significance of CNC, then introduces the principles, advantages and disadvantages of the two preparation methods, then introduces the various performance evaluation methods and indexes of the hydrogel, and finally introduces the current status and prospects of the hydrogel's application in various fields. This paper also presents future research directions and suggestions.
***Keywords*:** cellulose nanocrystals, hydrogel, preparation method, performance evaluation, application field

1. Introduction

Hydrogel is a kind of polymer material containing a large number of water molecules, which has many excellent properties, but also has some disadvantages. Cellulose nanocrystals (CNC) is a kind of nanostructures extracted from natural cellulose, which is an ideal nano-strength reinforcing agent with the properties of high strength and high stiffness, etc. CNC-based hydrogel is a kind of hydrogel prepared by compositing the CNC with other polymer materials, which has the excellent performance and broad application prospect. In this paper, the preparation method, performance evaluation and application areas of CNC-based hydrogels are summarized.

2. The preparation method of cellulose nanocrystals

Cellulose nanocrystals (CNCs) are nanomaterials with many excellent properties that can be used as nanoenhancers. CNCs can be prepared from natural cellulose by physical, chemical, and biological methods, which have their own principles, advantages and disadvantages, and scope of application, which affect the shape, size, structure, and surface of CNCs. Physical method: The physical method involves the separation of cellulose macromolecular chains by external forces to obtain nanoparticles with a crystalline structure. Chemical method: Chemical method is the method of hydrolyzing or oxidizing cellulose macromolecule chains with chemical reagents such as acids, bases, oxidants, etc., to obtain nanoparticles with crystal structure. Biological method: biological method is to use microorganisms or enzymes and other biological catalysts to hydrolyze or oxidize the cellulose macromolecular chain, to get the nanoparticles with crystal structure.

3. The preparation of cellulose nanocrystal-based hydrogels

Cellulose nanocrystal (CNC)-based hydrogel is a hydrogel compounding CNC with other polymers, which has good mechanical, water absorption, water retention and functional properties and can be applied in many fields. The methods used to prepare CNC-based hydrogels are physical cross-linking and chemical cross-linking, which have an effect on the network structure and cross-linking effect of the hydrogels. The following is the introduction and comparison of these two methods.

Physical cross-linking method: Physical cross-linking method is to use the physical force of CNC itself to form the hydrogel network, without adding cross-linking agent or catalyst. The advantages of physical cross-linking method are simple preparation, environmental protection, non-toxic, and can maintain the original properties of CNC. The disadvantage of physical cross-linking method is that the hydrogel stability is poor, easily affected by temperature, pH or ionic strength and so on, and uncross-linking or contraction. Physical cross-linking method is suitable for the preparation of CNC-based hydrogels with high purity, high crystallinity, high biocompatibility and biodegradability.

Chemical cross-linking method: Chemical cross-linking method uses an external cross-linking agent or catalyst to react with the functional groups of CNC to form a stable covalent or ionic bonded hydrogel network. The advantage of chemical crosslinking method is that the hydrogel has high strength, toughness, stability and functionality, and can be adapted to different environments. The disadvantages of the chemical cross-linking method are that it is complicated to prepare, time-consuming and energy-consuming, and may be harmful, which may damage the structure and properties of CNC. The chemical cross-linking method is suitable for the preparation of CNC-based hydrogels of different shapes, sizes, functions and properties.

4. Properties and applications of cellulose nanocrystal-based hydrogel

Cellulose nanocrystal-based hydrogel is a kind of hydrogel prepared by compositing cellulose nanocrystals (CNC) with other polymer materials, which has excellent mechanical properties, water absorption, water retention and functional properties, and it can show a broad application prospect in many fields. Below the author will introduce you the properties and applications of cellulose nanocrystal-based hydrogels.

Properties: The properties of cellulose nanocrystal-based hydrogels mainly depend on the content of CNC, morphology, size, surface functional groups, and interactions with other polymer materials. Generally, CNC can improve the hydrogel's properties in terms of water absorption, water retention, mechanical properties, biocompatibility and biodegradability as follows:

Water absorption: Water absorption refers to the degree of volume expansion of hydrogel after absorbing water, and is closely related to the network structure of hydrogel.CNC can increase the porosity and permeability of hydrogel, thus improving its water absorption. However, too high CNC content may cause the network structure of the hydrogel to be too compact, thus reducing its water absorption. Therefore, the content and distribution of CNC need to be optimized according to different application requirements.

Water retention: Water retention refers to the ability of a hydrogel to maintain its shape and function after the loss of water, and is closely related to the cross-linking density and cross-linking efficiency of the hydrogel.CNC can enhance the cross-linking density and cross-linking efficiency of the hydrogel, thus improving its water retention. However, too high cross-linking density and cross-linking efficiency may lead to excessive stiffness of the hydrogel, thus reducing its water retention. Therefore, it is necessary to optimize the cross-linking method and conditions of CNC according to different application requirements.

Mechanical properties: Mechanical properties refer to the elasticity, toughness and strength of hydrogels when subjected to external forces, and are closely related to the network structure and crosslinking density of hydrogels.CNC can enhance the network structure and crosslinking density of hydrogels, thus improving their mechanical properties. However, too high network structure and cross-linking density may lead to excessive brittleness of the hydrogel, thus reducing its mechanical properties. Therefore, it is necessary to optimize the CNC morphology, size and surface functional groups according to different application requirements .

Biocompatibility: Biocompatibility refers to the ability of a hydrogel to interact with living organisms without adverse reactions or side effects, and is closely related to the composition, structure, and surface properties of the hydrogel.CNC, a naturally sourced, biodegradable, and non-toxic and non-hazardous nano-materials, can enhance the biocompatibility of hydrogels. However, CNCs from different sources, preparation methods and modifications may affect the organisms to different degrees. Therefore, the safety and effects of CNC on organisms need to be evaluated according to different application requirements .

Biodegradability: Biodegradability refers to the ability of a hydrogel to be broken down into harmless substances by biological factors, such as microorganisms or enzymes, in the natural environment, and is closely related to the composition, structure, and surface properties of the hydrogel.CNCs are biodegradable nanomaterials, which can enhance the biodegradability of hydrogels. However, CNC-based hydrogels with different crosslinking methods and conditions may have different biodegradation rates and mechanisms. Therefore, the biodegradability of CNC-based hydrogels needs to be adjusted according to different application requirements .

APPLICATIONS: Cellulose nanocrystal-based hydrogels can play an important role in a number of fields due to their excellent properties and functionalities, as follows:

Food packaging: food packaging refers to the materials used to protect, preserve and transport food, which requires good moisture-proof, oxygen-proof, bacteria-proof and anticorrosion functions, as well as biodegradable and non-toxic and harmless properties, etc. CNC-based hydrogels can be used as a new type of food packaging materials because they have the advantages of high water absorption, high water retention, high biocompatibility and high biodegradation, which can effectively extend the shelf-life of food and reduce the risk of food degradation. It can effectively extend the shelf life of food, reduce food waste, and also reduce the pollution of the environment.

Biomedicine: Biomedicine refers to materials used for the diagnosis, treatment and prevention of human or animal diseases, and requires good biocompatibility, bioactivity, drug carrier ability, stimulus responsiveness, and other functions, as well as controlled release and traceability, etc. CNC-based hydrogels can be used as a new type of biomedical materials because they have high water absorption, high water retention, high mechanical properties, high biocompatibility and high biodegradability, which can effectively extend the shelf life of foodstuffs and reduce the waste of foodstuffs, as well as reduce environmental pollution. They can effectively mimic the structure and function of human tissues and promote tissue regeneration and repair because of their high water absorption, high water retention, high mechanical properties, high biocompatibility, and high biodegradability, etc. They can also be used as carriers for drugs or genes to achieve controlled release and traceability.

Energy electronics: Energy electronics refers to the use of electronic technology to convert, control and store energy in the field, requiring good electrical conductivity, electrochemical stability, capacitance or photoelectric conversion efficiency and other functions, as well as flexible and wearable characteristics.

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