Stress and Strain of Plant Polysaccharides Aerogels and Their Effects on Mechanical Properties

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Abstract—In order to verify the mechanical properties of plant polysaccharides aerogels, the polysaccharide aerogels were prepared by freeze-drying method. The aerogels were screened by raw material selection and mass ratio, and their mechanical properties were tested. The experimental results show that with the increase of starch content, the compression modulus increases gradually, and the elasticity decreases linearly with the increase of starch content. The main effect on the mechanical properties is that after the addition of polysaccharide macromolecules, they are entangled with KGM and gelatin skeleton molecules. The increase of concentration increases the interaction sites, and the intermolecular force increases.

1. INTRODUCTION

Plant polysaccharides aerogels have the advantages of strong adsorption, complete biodegradability and environmental friendliness. They are ideal materials for making cigarette filter rods and replacing traditional acetate filter rods, however, there are also shortcomings such as low strength and poor mechanical properties[1-6].

Aerogels are a class of high porosity gel porous materials, which are usually prepared by sol-gel process (Sol-Gel). The general synthesis process follows three steps: first, the gel containing liquid medium is formed in the solvent, then the gel is treated by aging, modification, and so on, and then through the supercritical drying, freeze-drying and the atmospheric drying technology developed in recent years, the liquid in the pores is formed[7-12]. The medium is made by replacing it with air. The unique three-dimensional nano network skeleton structure of aerogels makes the aerogels exhibit excellent physical and chemical properties. The aerogels synthesized by these precursors need complex and complicated post-processing technologies, including aging, surface modification, solvent replacement, etc[13-19]. After supercritical drying, the final sample has larger embrittlement, smaller failure compression strain and poor comprehensive mechanical properties[21-24]. Aerogels prepared by atmospheric drying have certain degree of improvement in brittleness, which provides a useful reference for improving the mechanical properties of materials. At the same time, aerogel is a low-density porous material similar to sponge and foam material. It has great difference in mechanical behaviour with solid materials.
2. EXPERIMENTAL

2.1. Preparation of samples
The preparation method of raw materials is as follows, weigh KGM, gelatin, starch and other raw materials according to a certain mass ratio, place gelatin and starch in a 250ml beaker, add 100ml distilled water, disperse evenly under normal temperature, place the beaker in a 90 ℃ water bath, stir and add KGM under 500 rpm, seal with a fresh-keeping film after adding to reduce water evaporation, After stirring for 5 minutes, adjust the speed to 1000 rpm. After stirring for 60 min, the 20ml syringe was injected into the cylindrical mold with inner diameter of 8mm at room temperature for gel, then transferred into the refrigerator at 4 degrees for aging molding. After 2 h, it was transferred to an ultralow temperature refrigerator for pre freezing. After the water was completely frozen, it was dried in a vacuum freeze dryer at -50 cold temperature and vacuum degree of 10 Pa (Fig. 1), and after 24 h, the plant polysaccharide gas could be obtained. Gel: Set & Match. Cut off both ends and trim them into a cylinder with a length of 120mm and a diameter of 7mm. After the moisture absorption reaches equilibrium in the constant temperature and humidity phase with a temperature of 25 ℃ and a humidity of 80%, put it into a sealed bag. At this time, the samples can be processed into filter rods in batches on the cigarette machine.

![Figure 1. Vacuum freeze dryer](image)

2.2. Mechanical properties
The effect of biodegradation on the mechanical properties of filter rod material was studied by texture analysis (TPA). Tms-pro texture analyzer of FTC company of the United States was adopted. The parameter settings are as follows: test speed is 60 mm/min, compression ratio is 30%, minimum force is 1N, and trigger type is automatic. The diameter of the sample is 7 mm and the height is 5 mm. The compressive strength and elasticity are obtained by secondary compression. The sample was compressed once, and the strain was taken as the abscissa and the stress as the ordinate. The compression modulus of the filter rod is obtained from the slope of the linear part of the initial test of the stress-strain curve. The significance of data was analyzed by DPS software.

3. RESULTS AND DISCUSSION
The composite aerogels were prepared by freeze-drying of KGM and gelatin simply. Although the aerogels with uniform and porous network structure could be obtained, their mechanical strength was poor and filtration efficiency was low. To improve the mechanical strength and pore structure was achieved by adding common potato starch.
TABLE 1. PLANT POLYSACCHARIDE AEROGEL RAW MATERIAL FORMULA

| Samples   | Additive (%) | KGM | Gelatin | Starch |
|-----------|--------------|-----|---------|--------|
| K1G2S0    | 1            | 2   | 0       |
| K1G2S1    | 1            | 2   | 1       |
| K1G2S2    | 1            | 2   | 2       |
| K1G2S3    | 1            | 2   | 3       |
| K1G2S4    | 1            | 2   | 4       |

Firstly, the mass ratio of KGM and gelatin in aerogel raw materials was determined to be 1:2. Starch with different contents was used to prepare the plant polysaccharide aerogel. The optimum amount of starch in aerogel was examined by testing its mechanical properties and filtration performance, observing its macroscopic and microscopic morphology.
Effect of starch content on the mechanical properties of composite aerogels was firstly analysed by texture analysis. The effect of different starch content on the mechanical properties of the composite aerogels is shown in Figure 2. From the stress-strain curves of Figure 2.a and Table 2, we can see intuitively that the amount of starch has great influence on the mechanical properties of aerogels. When no starch was added, the compression modulus of aerogel was 269.74 kPa. With the increase of starch content, the compression modulus increased gradually, and reached the maximum value of 1117.80 kPa when the starch content was 4%. The compressive strength of aerogels under 30% strain also showed the same trend, that is, with the increase of starch content, the compressive strength of aerogels increased linearly, that is, when the starch content increased from 0% kPa to 74.69 kPa, the 414.33 kPa of starch content increased to 349.64 kPa (Fig..C). On the contrary, the elasticity of aerogel decreased linearly with the increase of starch content, and decreased from 0.780 of starch content 0% to 0.503 of starch content (4% 2.d). This is because starch, as a polysaccharide macromolecule, is intertwined with KGM and gelatin skeleton molecules after joining the system.

TABLE 2. COMPRESSION MODULUS OF PLANT POLYSACCHARIDES AEROGELS WITH DIFFERENT STARCH CONTENTS AFTER EQUILIBRIUM

| Samples  | Compression modulus (kPa) |
|----------|---------------------------|
| K1G2S0   | 269.74 ± 1.763\(^a\)     |
| K1G2S1   | 470.12 ± 3.905\(^b\)     |
| K1G2S2   | 848.34 ± 5.074\(^c\)     |
| K1G2S3   | 983.85 ± 8.596\(^d\)     |
| K1G2S4   | 1117.80 ± 8.333\(^e\)    |

As the concentration increases, the sites of interaction increase, and the intermolecular forces increase, resulting in the improvement of the mechanical strength of aerogels. In addition, from 2.c and 2.d, the compressive strength of the gels decreased slightly and the elasticity increased slightly after the moisture equilibrium of the gels at 50% relative humidity. This is because the sample is porous structure, with uniform holes distributed inside. The sample contains a large number of hydrophilic groups. When it is in a certain humidity environment, it is easy to absorb water in the air, and the water molecules are inserted into the polymer molecular chain, which weakens the stress between the polymer molecules and increases the mobility of the molecular chain. When the sample is applied with external force, the molecular chain slips, thus Reduce the compressive strength and increase the resilience of the sample.

4. CONCLUSIONS
When no starch was added, the compression modulus of aerogel was 269.74 kPa. With the increase of starch content, the compression modulus increased gradually, and reached the maximum value of
1117.80 kPa when the starch content was 4%. The elastic properties of aerogels decreased linearly with the increase of starch content. The main effect on the mechanical properties was the entanglement of KGM and gelatin skeleton molecules after adding polysaccharide macromolecules. The increase of concentration increased the sites of interaction, and the intermolecular forces increased, resulting in the increase of mechanical strength of aerogels.

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