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Recycled Paper Cellulose Aerogel Synthesis and Water Absorption Properties

Jingduo Feng[1, a], Son T. Nguyen[1, b], Hai M. Duong[1, c*]

[1]Material Laboratory, Department of Mechanical Engineering, National University of Singapore,9 Engineering Drive 1, Singapore 117576

[a]verafeng1988@gmail.com,[b]mpents@nus.edu.sg,[c]mpedhm@nus.edu.sg

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Abstract: By applying sodium hydroxide/urea and a sample freeze drying method, we successfully synthesized green cellulose aerogel from paper waste for the first time. We adjusted the cellulose concentration from 1.5 percents to 4 percents in the initial hydrogel. They yielded densities changing from 0.03-0.1 g/cm^3.The absorption capacities varied from 9 to 20 times of their own weight. To investigate the water absorption capacity in relationship with the initial chemical dosage, we changed the input amount of urea and sodium hydroxide, which is the first study ever. The thermal conductivity of the 2 percents sample ranged from 0.029-0.032 W/mK. Besides, the material has a high potential to be used in diaper industry as it is biodegradable which is better than most super absorbent polymers.

Introduction

Most diapers in market are composed of super absorbent polymers, which are not biodegradable. Averagely a baby needs more than 5,000 diapers before it is potty-trained [1]. Adult diapers are also requested in large amount every day. Huge amount of diapers is consumed daily in this world. Nowadays, as super absorbent polymer is not biodegradable. The used diapers waste large amount of land to store them. Our paper gives a potential alternative of traditional diapers-Cellulose aerogel, which with high absorbent capacity (almost 20 times) and also biodegradable can be used to replace the non-biodegradable super absorbent polymer. Cellulose aerogel can be derived from paper. Only United States alone used 85.5 million tons of paper per year [2]. This huge amount of used paper needs to be recycled and functions as useful material to prevent waste. Our group converts the recycled cellulose to cellulose aerogel. Aerogel is porous material with more than 90 percents pores in the volume. Most aerogel are silica or carbon aerogel. Cellulose aerogel is a new material.

Materials and Chemicals

Sodium hydroxide, urea, and ethanol are purchased from Sigma-Aldrich. Commercial recycled cellulose fibers are donated by Insul-Dek Engineering Pte. Ltd., Singapore.

Synthesis Procedure

For standard sample, urea (13.7 wt%, 5.025g) and sodium hydroxide (1.9 wt%, 0.725g) were dispersed in DI water (30g), which is dispersed by a magnetic stir. Recycled cellulose (2 wt%, 0.75g) was added to the transparent solution, pre-cooled in ice/water bath for 10 minutes, then sonication for 10 minutes. Thereafter, the solution was placed in refrigerator for more than 24 h to allow gelation of the solution. After the solution was frozen, it was then thawed at room temperature and then followed by immersing into ethanol (99 vol %) for coagulation for two days. After coagulation, solvent exchange was carried out by immersing the gel in de-ionised (DI) water for 2 days. The sample was then frozen in a freezer at – 18 ℃ for 24 h. After that, freeze drying is carried out for 2 days with a ScanVac CoolSafe 95-15 Pro freeze dryer (Denmark) to obtain the desired aerogel. Other samples were prepared by the same method by varying one component of the standard sample. Detail refers to the Table 1.

TABLE 1 PARAMETERS USED IN MORPHOLOGY CONTROL OF CELLULOSE AEROGEL

Group 1	cellulose amount	cellulose concentration
G1_015	0.5444[g]	1.50%
standard	0.75[g]	2%
G1_03	1.1057[g]	3%
G1_04	1.4896[g]	4%
Group 2	urea amount	urea concentration
G2_10	3.4972[g]	10%
standard	5.025[g]	13.76%
G2_15	5.5544[g]	15%
G2_20	7.8688[g]	20%
Group 3	NaOH amount	NaOH concentration
G3_015	0.5448[g]	1.50%
standard	0.725[g]	1.90%
G3_025	0.9173[g]	2.50%
G3_03	1.1064[g]	3%

Characterization

Thermal conductivity measurement.

C-Therm TCi Thermal Conductivity Analyzer (C-Therm Technologies, Canada) was used to measure the thermal conductivity of the aerogel.

Water absorption test.

This test was carried out in DI water, followed by modified ASTM D570-98 standard, refer to Figure.1.

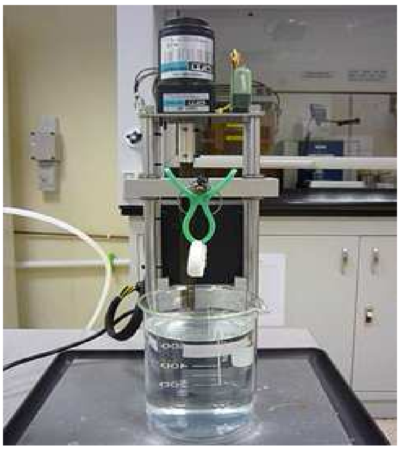

Figure 1 The setting of water absorption test

Results and Discussion

The thermal conductivity of the standard sample was 0.03 $Wm^{-1}K^{-1}$. It is comparable to silica aerogels (0.026 $Wm^{-1}K^{-1}$) and wool (0.03-0.04 $Wm^{-1}K^{-1}$) [3].

TABLE 2 CELLULOSE CONCENTRATION AFFECTS WATER UPTAKE RATIO AND POROSITY

Sample No	Dry Weight [g]	Wet Weight [g]	Water uptake Ratio	Porosity	Density [g/cm^3]
G1_015	0.3928	8.3431	20.24	0.984	0.03
Standard	0.7280	13.4140	17.43	0.978	0.04
G1_03	0.8976	12.3885	12.80	0.970	0.05
G1_04	2.4507	24.4634	8.98	0.935	0.10

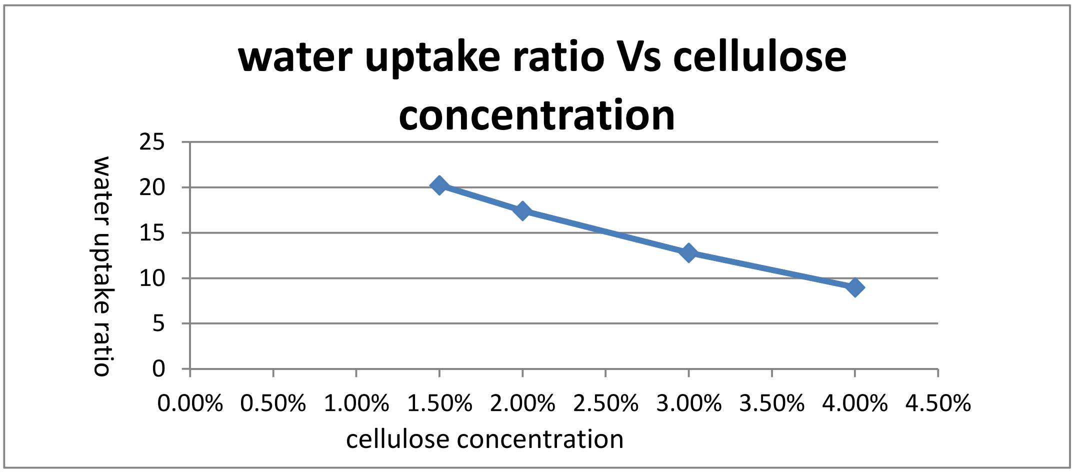

Figure 2 The water uptake ratio change with cellulose concentration

Cellulose concentration varies from 1.5% to 4%, while the water uptake ratio drops from 20 to 9. Their relationship is quite linear. By increasing cellulose content in one sample, the density of the solution is also increased, but the structure of the aerogel is more compacted. Hence, the porosity is decreased (see Table 2), resulting in less space for water molecular being taken in. As the result, Water uptake ratio linear decrease with an increase cellulose concentration, referring to Figure. 2.

TABLE 3 UREA AMOUNT AFFECTS WATER UPTAKE RATIO AND POROSITY

Sample No	Dry Weight [g]	Wet Weight [g]	Water uptake Ratio	Porosity
G2_10	0.6712	14.1073	20.02	0.978
standard	0.7280	13.4140	17.43	0.978
G2_15	0.7532	14.5129	18.27	0.975
G2_20	0.6985	13.1829	17.87	0.978

Urea forms urea hydrate in the solution. Urea hydrate helps prevent cellulose molecule come near to each other. Hence, urea restrains the formation of hydrogen bond among cellulose. The experiment results about water up take ratio are without much difference in this group. It may be caused by the urea amount that plays an insignificant role about porosity. However, the porosity is not as the same as the water up take ratio results suggest, referring to Table 3. It is may be due to measure errors, as the porosity is calculated by weight divided by volume. Volume is derived from diameter and height of the cellulose samples, and then determined by cylinder volume calculation formula. The diameter is determined by the average of three readings. Errors may be generated in the process, as the sample is not exactly cylindrical shape. However, we could see all the data are the same in the first two digits regards to porosity.

Part of sodium hydroxide can be bound to cellulose, which improves the dissolve of cellulose. More sodium hydroxide causes less hydrogen bonding among cellulose, which leads to less porosity and thus less water uptake ratio, referring to Table 4. However, when sodium hydroxide changes from 2.5 percents to 3 percents, the water uptake ratio does not drop further. It is due to 2.5 percents of sodium hydroxide is the maximum amount needed to bound with cellulose. More sodium hydroxide will not further the reaction.

TABLE 4 SODIUM HYDROXIDE AMOUNT AFFECTS WATER UPTAKE RATIO AND POROSITY

Sample No	Dry Weight [g]	Wet Weight [g]	Water uptake Ratio	Porosity
G3_015	0.5925	11.9001	19.08	0.983
standard	0.7280	13.4140	17.43	0.978
G3_025	0.7639	12.6251	15.53	0.974
G3_03	0.7066	11.3263	15.03	0.976

Summary

Our group successfully synthesized recycled cellulose aerogel from paper waste. The newly developed material is with high absorption capacity. Sodium hydroxide amount and cellulose concentration alter the water uptake ratio of cellulose aerogel greatly, while urea amount do not play a significant role in the water uptake ratio.

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