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Study on antibacterial activity of O-carboxymethyl chitosan sodium salt and spinnability of O-carboxymethyl chitosan sodium salt/cellulose polyblends in N-methylmorpholine-N-oxide system

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ABSTRACT

O-carboxymethyl chitosan sodium salt (NaCMCh), which has good antibacterial activity and solubility in N-methylmorpholine-N-oxide (NMMO) after being treated by sodium hydroxide solution, was blended with cellulose NMMO/H_2O solution to study the spinnability. The effect of molecular weight on antibacterial activity and solubility was discussed. The optimal range of molecular weights is from 8×10^4 to 1.9×10^5. The rheological properties of NaCMCh/cellulose polyblends in steady-shear were investigated. The results are presented using appropriate master curves for the temperature and concentration effects. The flow behavior index of the polyblends increase with increasing temperature and NaCMCh content. Apparent viscosity and zero-shear viscosity decrease, but the critical shear rate increases due to the addition of NaCMCh. The polyblends with NaCMCh display a lower structural viscosity index. Finally, the fibers were successfully spun using the lyocell process with NMMO/H_2O and the fibers with NaCMCh exhibit good mechanical properties and moisture absorption.

1. Introduction

Chitosan has a wide range of applications in various fields, such as biomedical, food and chemical industries (Jiang, Kumbar, Nair, & Laurencin, 2008; Kofuji et al., 2005; Liu & Yao, 2002; Senel & McClure, 2004). Chitosan is a copolymer of glucosamine and N-acetylglucosamine units linked by 1–4 glucosidic bonds, which can be obtained by N-deacetylation of chitin, a major component of the shells of crustacean such as crab, shrimp, and crawfish (Pillai, Paul, & Sharma, 2009; Rinaudo, 2006; Romoren, Thu, & Evensen, 2002).

Owing to its antibacterial activity and low reactivity with the skin, chitosan and its derivatives have been used in antibacterial next-to-skin fabrics (Davarpanah, Mahmoodi, Arami, Bahrami, & Mazaheri, 2009). In parallel, there is an increased interest in preparing chitosan/polymer blends for different applications (Luo, Yin, Khutoryanskaya, & Khutoryanskiy, 2008; Molinaro, Leroux, Damas, & Adam, 2002; Zhao, Mitomo, & Yosh, 2008). A lot of work therefore has been done with blends of chitosan and cellulose, which is a favorite undergarment material because it is not hazardous to the human body and its high moisture retention promotes comfort. Since both chitosan and cellulose possess similar structure with β-glycosidic linkages, we expect that cellulose will be miscible with chitosan so that antibacterial activity of chitosan can be introduced into cellulose fiber (Urreaga & Orden, 2006). The main difference is the primary amino groups at most of the C-2 positions in chitosan, in place of the hydroxyl groups of cellulose. Most of the characteristic properties of chitosan are due to the high content of primary amino groups, which are responsible for several easy and site-selective methods of chemical modification (Kumar, Bristow, Smith, & Payne, 2000; Twu, Huang, Chang, & Wang, 2003).

The preparation of the fiber was carried out through the viscose process, a traditional process based on a metastable cellulose derivative (cellulose xanthogenate) (Finger & Pakshver, 1990; Suzuki, 1994). However, both the carbon disulfide used in the viscose process and the hydrogen sulfide generated are harmful. In order to replace the viscose process, new processes have been developed to produce cellulose fibers from cellulose solvents, e.g., LiCl/N,N-dimethylacetamide (DMAc) (Kim, Frey, Marquez, & Joo, 2005) or N-methylmorpholine-N-oxide (NMMO)/H_2O (Kim, Kim, Kang, Marquez, & Joo, 2006; Liu & Bai, 2006), which are environmentally friendly. In particular, the lyocell process by NMMO solution is technically feasible and has been widely used for

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industrial production. The fibers made from this process are characterized with good physical properties, mechanical stability and biodegradability.

On the other hand, the poor solubility of chitosan in water limits its application. To solve this problem, chemical modification of chitosan is required and lots of derivatives have been synthesized. In our previous study, a chitosan derivate, ethyletheramine chitosan (EACS) was prepared via a novel procedure, which exhibited good antibacterial activity and solubility in NMMO/H_2O. Then the rheological behavior of EACS/cellulose polyblends from NMMO/H_2O solution was investigated. The results show that the spinnability of EACS/cellulose polyblends is improved compared with cellulose solutions and O-carboxymethylated chitosan (O-CMCh)/cellulose polyblends (Liu, Chen, & Pan, 2007). Finally, we successfully spun the hybrid antibacterial fibers containing EACS over 2 wt% (wt% = EACS/cellulose) that showed strong antibacterial activity and good mechanical properties (Xie, Liu, & Chen, 2007; Zhuang, Liu, Li, Cheng, & Kang, 2008).

In addition, O-carboxymethyl chitosan sodium salt (NaCMCh) (Zhuang, Liu, Cheng, & Kang, 2006) was synthesized and treated in our laboratory. The results show that it not only has satisfactory antibacterial activity but also ideal solubility in NMMO/H_2O after being treated with sodium hydroxide solution. This new discovery would promote industrialization of lyocell process using NMMO/H_2O due to mature synthetic process of O-CMCh and NaCMCh (Li, Zhuang, Liu, Guan, & Yao, 2002). So in this paper, the solubility in NMMO/H_2O and antibacterial activity against *Escherchia coli* (*E. coli*) of NaCMCh with various molecular weights were explored to obtain the optimum molecular weight. In addition, understanding the rheological properties of a solution will provide fundamental knowledge relevant to spinnability (Chen, Sun, & Zhang, 2004). Thus, NaCMCh was blended with cellulose NMMO/H_2O solution, and corresponding polyblends were prepared. The rheological behavior of NaCMCh/cellulose polyblends with various NaCMCh contents was investigated. Finally, the hybrid lyocell fiber was spun using the NMMO process to verify the feasibility of manufacturing the antibacterial lyocell fiber.

2. Experimental

2.1. Materials

Cellulose was obtained from the Tianjin Rayon Factory (Tianjin, China). Its degree of polymerization (DP) was 670, which was determined in a cupriethylene diamine solution at 25 °C (Isogai & Atalla, 1991). Chitosan ($M_n = 1.08 \times 10^6$), a commercial material supplied by Zhejiang Ao-Xing Biotechnology Co. Ltd. (Zhejiang Province, PR China), was depolymerized via γ-irradiation degradation to a series of low molecular weight samples. The number-average molecular weight of the irradiated chitosan was determined by GPC. The gel size was 5 μm, the eluent was 0.2 N CH_3COOH/0.2 N CH_3COONa, and the flow rate was 1 ml/min at 30 °C. The concentration of the chitosan solution was 1 wt%.

The deacetylation degree (DD) of chitosan, measured by potentiometric titration, was 0.85. N-methylmorpholine-N-oxide (NMMO) solution (50 wt%) was purchased from BASF Co. Ltd., Germany. Other reagents such as sodium hydroxide, chloroacetic acid, hydrochloric acid, methanol were of analytical grade and used as received. *E. coli* was supplied by Degradation Laboratory Nankai University, Tianjin, China.

2.2. Preparation and characterization of NaCMCh

To synthesize NaCMCh, 15 g of chitosan and 9 g of monochloroacetic acid were suspended in 150 mL of a sodium hydroxide solution (42 wt%). The system was reacted at 0 °C for 48 h and then the pH was adjusted to 8.0 with hydrochloric acid. After filtration, the solid product was washed with methanol twice, and then dried in an oven at 40 °C. The degree of substitution determined by pH titration was 0.86 (Wan, Khor, & Wong, 1996).

2.3. Solubility in NMMO/H_2O

10 g NaCMCh was dissolved in 20 mL sodium hydroxide solution (5 wt%) and the solution mixture was stirred for 1 h. After being filtered, the product was dispersed in 90 g NMMO/H_2O at 90 °C, and stirred for 12 h. Sediment was separated and washed with acetone, then dried in an oven under a vacuum. The solubility was defined as (*Sa*): $Sa\% = [(10 - W_1)/10] \times 100$, where W_1 represents the weight of sediment (g). The experiment was carried out three times and the average was reported.

2.4. Antibacterial activity of NaCMCh

Antibacterial activity of NaCMCh against *E. coli* was evaluated by an optical density method. A representative bacteria colony was picked off, placed in a nutrient broth (peptone 1%, beef extract 0.5%, NaCl 0.5%, distilled water 98%, pH 7.0–7.2) and incubated at 37 °C for 24 h. The culture medium was diluted with autoclaved nutrient broth in order to adjust its optical density (OD) to 0.2 at 610 nm, which was ready for antibacterial test. According to this test, the smaller the OD of the medium is, the higher the antibacterial activity of the tested material is.

Then 0.2 mL fresh bacteria liquid was inoculated to the culture medium (10 mL) with 2 mL NaCMCh solution (2 wt%) and incubated in a shaking bed (150 rpm) at 37 °C for 24 h. During incubation, the turbidity of the medium was measured at 610 nm with an UV spectrophotometer (Unico UV-2000, Shanghai, China). The measurement was repeated six times.

2.5. Preparation of cellulose solution and polyblends

10 g cellulose was pulverized and dipped in 200 mL of NMMO/H_2O (50%), followed by stirring for 1 h at 50 °C to make cellulose swelling sufficiently. Then the solution was heated to 110 °C, and stirred for 1 h in vacuum until the content of H_2O reduced to 13.3 wt% (wt% = H_2O/(NMMO/H_2O)) (Rosenau, Potthast, Sixta, & Kosma, 2001). Finally, the cellulose was filtered and dissolved in NMMO/H_2O completely under stirring.

NaCMCh polyblends were prepared as follows: 5 g NaCMCh powder ($M_n = 1.9 \times 10^5$) was dissolved in 10 mL of a sodium hydroxide solution (5 wt%) and the solution mixture was stirred for 1 h. After being filtered, the product was added into cellulose NMMO/H_2O solution under violent stirring to obtain polyblend. NaCMCh contents were fixed to 1% and 3% with respect to cellulose and the total macromolecular concentration was 15 wt% to NMMO/H_2O.

2.6. Rheological measurement

The rheological properties of cellulose NMMO/H_2O solution and NaCMCh polyblends were performed on the REOLOGICA Stresstech revolving rheometer (cone-plate diameter 30 mm and cone angle 1°). Rheological measurements were carried out at different temperatures.

2.7. Preparation of NaCMCh/cellulose fibers

According to the method above, NaCMCh/cellulose polyblends were synthesized and dissolved NMMO/H_2O to give a total concentration of 15%. Then *n*-propyl gallate (1 wt% of cellulose) was

Table 1
The influence of M_n on the solubility of NaCMCh in NMMO/H_2O.

M_n	8×10^3	2×10^4	5.1×10^4	8×10^4	1×10^5	1.9×10^5	2.7×10^5	5.8×10^5	8.4×10^5
Solubility (mg/ml)	84.2	62.1	59.4	50.5	48.6	42.3	16.8	Insoluble	Insoluble

added as an antioxidant. The fiber was made by spinning the co-solution through the dry jet-wet spinning process on a laboratory spinning machine. The machine used a 6-orifices spinneret with dimensions of a diameter (D) 0.1 mm and capillary length (L) 1 mm ($L/D = 10$). The air gap was set at 200 mm and extrusion flow rate was 30 m/min. The spinning temperature was 100 °C. Distilled water was used as a coagulation bath at room temperature. Mechanical properties of the fibers were measured using YG001A at the strain rate of 20 mm/min at the room temperature. Moisture absorption was determined on dried samples kept at 20 °C and 65% R.H. for 2 days. The average values were calculated from 15 trials.

3. Results and discussion

3.1. Solubility in NMMO/H_2O

To a great extent, the introduction of $-CH_2-COOH$ group destroys the intra- and inter-molecular hydrogen bonding of chitosan. Therefore, the water solubility of O-CMCh clearly increased compared with unmodified chitosan (Park, Park, & Park, 1986), but it was still insoluble in NMMO/H_2O. Interestingly, NaCMCh can be dissolved in NMMO/H_2O after being treated with a small amount of sodium hydroxide solution. Because molecular weight is the most crucial factor for the solubility, NaCMCh with various M_n were synthesized to investigate the effect of M_n on the solubility of NaCMCh in NMMO/H_2O.

Table 1 shows that NaCMCh with M_n ranging from 8×10^3 to 2.7×10^5 can be soluble in NMMO/H_2O. Especially, the solubility of NaCMCh reaches 84.2 mg/ml which is the biggest value when M_n is 8×10^3. Besides, NaCMCh cannot be soluble in solvent with M_n above 5.8×10^5. The good solubility of NaCMCh in NMMO/H_2O is attributed to the decrease of intermolecular interactions, such as van der Waals forces, the lower the molecular weight, the lower the intermolecular attraction forces (Kubota, Tatsumoto, Sano, & Toya, 2000). As a result, the decreasing solubility of NaCMCh with high molecular weight is probably because of the high molecular weight itself.

According to the result from the latter antibacterial experiment, when M_n ranges from 8×10^4 to 1.9×10^5, the antibacterial performance of NaCMCh improves. Therefore, the optimal range of M_n of NaCMCh, used as antibacterial agent, is from 8×10^4 to 1.9×10^5.

3.2. Antibacterial activity of NaCMCh

The antibacterial activity of NaCMCh with M_n ranging from 2×10^4 to 8.4×10^5 was studied. Fig. 1 shows the curves of the optical density (OD) versus the culture time for NaCMCh against *E. coli*. According to the curves, the antibacterial activity of NaCMCh increases when M_n increases from 2×10^4 to 1.9×10^5, but decreases at M_n above 1.9×10^5.

Sudarshan et al. observed that the growth inhibitory activity of chitosan notably increased with lengthening of the polymer (Sudarshan, Hoover, & Knorr, 1992). Also, the antibacterial function of amino-polysaccharides is generally ascribing to the $-NH_2$ group along the chain, so the above trend can be explained as follows: when the M_n is under 1.9×10^5, the antibacterial activity of chitosan increases with increasing of the $-NH_2$ content (in other words, with increasing M_n) (Liu, Guan, & Yang, 2001). Nevertheless, the intrinsic flexibility of the chain molecule is also improved with increasing molecular weight which reduces the number of the available antibacterial groups. So, when the M_n exceeds about 1.9×10^5, the antibacterial activity of chitosan decreased with increasing M_n. The two opposing factors affect the antibacterial activity of the polysaccharides, and the antibacterial activity peak mentioned above appears when the two factors reach a certain balance (Zhuang, Liu, Li, Guan, & Yao, 2004).

The results from our previous research demonstrate that the antibacterial activity of chitosan increases when M_n of chitosan ranges from 5×10^3 to 9×10^4 and decreases from M_n 9×10^4 to 1.08×10^6 (Liu et al., 2001). Obviously, NaCMCh has similar trend with chitosan. Meanwhile, they both have only one antibacterial activity peak where they possess the best antibacterial activity in the curves. However, the peak appears when M_n is 1.9×10^5 for NaCMCh, and 9×10^4 for chitosan.

The improvement of the balance point on molecular weight for NaCMCh can be attributed to the introduction of $-CH_2-COO^-$ group to form intramolecular hydrogen bonding which weaken the flexibility of the chains and prevent the chains from curling contributing to improve the number of the available antibacterial groups. Therefore, the appearance of the antibacterial peak is postponed for NaCMCh until a new balance reaches where M_n goes up to 1.9×10^5.

3.3. Rheological measurement

Appropriate rheology is essential for spinning. Many factors, such as additive and temperature, may affect the rheological property of the spinning solution. Based on above experiments, NaCMCh with M_n of 1.9×10^5, which has the best antibacterial activity and fairly good solubility in NMMO/H_2O, were blended with cellulose NMMO/H_2O solution for the rheological study.

3.3.1. Effect on the flow curve

It was reported that cellulose NMMO/H_2O solution was characterized as a power-law fluid (Blachot, Chazeau, & Cavaille, 2002). Thus, the shear stress (τ) and shear rate ($\dot{\gamma}$) of the solution obey the following equation: $\tau = \eta\dot{\gamma}^n$, where η represents viscosity at a shear rate $\dot{\gamma}$ of one and n is the flow behavior index. When n was less than one, the power-law fluid shows non-Newtonian shear-thinning behavior (Li, Zhuang, Liu, Guan, & Yao, 2003; Rosenau, Hofinger, Potthast, & Kosma, 2003).

When NaCMCh is added into the cellulose NMMO/H_2O solution, the power-law curve is preserved. As shown in Fig. 2, the $\dot{\gamma}$ range of 0.1–10 s^{-1} is selected. In this region plots of $\log \tau$ vs. $\log \dot{\gamma}$ are close to linearity. The slope of the straight line represents the flow behavior index (n) of the fluid. The n value in three fluids at different temperatures is shown in Table 2. Comparing with 1 wt% and 3 wt% NaCMCh/cellulose, the flow behavior index of cellulose solution is the lowest at all the experimental temperatures. 3 wt% NaCMCh/cellulose polyblend gives the highest flow behavior index. An increasing flow behavior index shows that the spinning solution is closer to a Newtonian fluid which contributes to the improvement of spinnability. So the addition of NaCMCh benefits spinning.

3.3.2. Effect on apparent viscosity

Apparent viscosity (η_a) can be calculated as follows: $\eta_a = \tau/\dot{\gamma}$. The apparent viscosity curves as functions of shear rate, selected temperatures and concentrations are presented in Fig. 3. All the curves have similar shapes which show a low-shear rate Newtonian

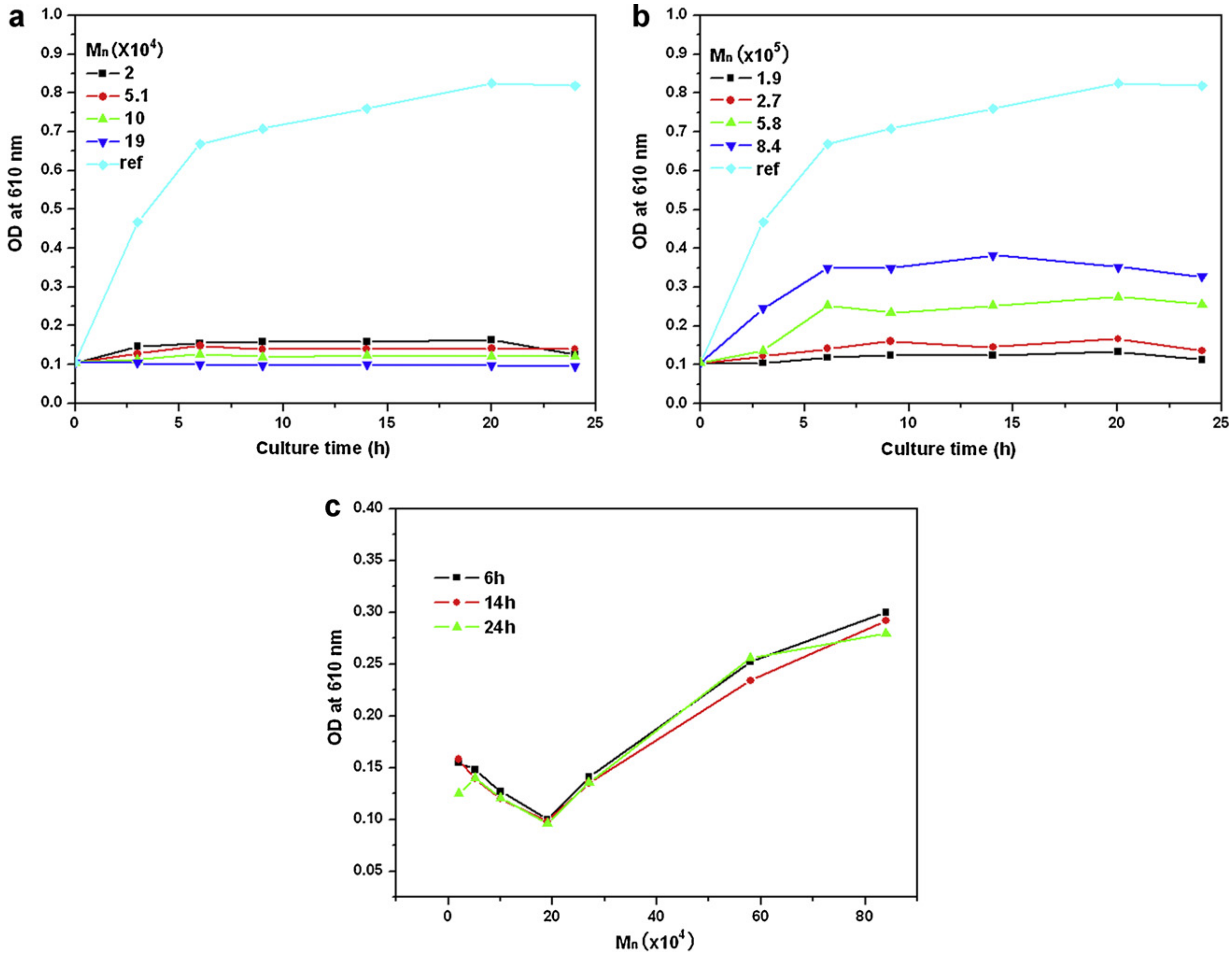

Fig. 1. The antibacterial activity of NaCMCh with various M_n. NaCMCh with M_n ranging (A) from 2×10^4 to 1.9×10^5; (B) from 1.9×10^5 to 8.4×10^5; (C) from 2×10^4 to 8.4×10^5 at different time.

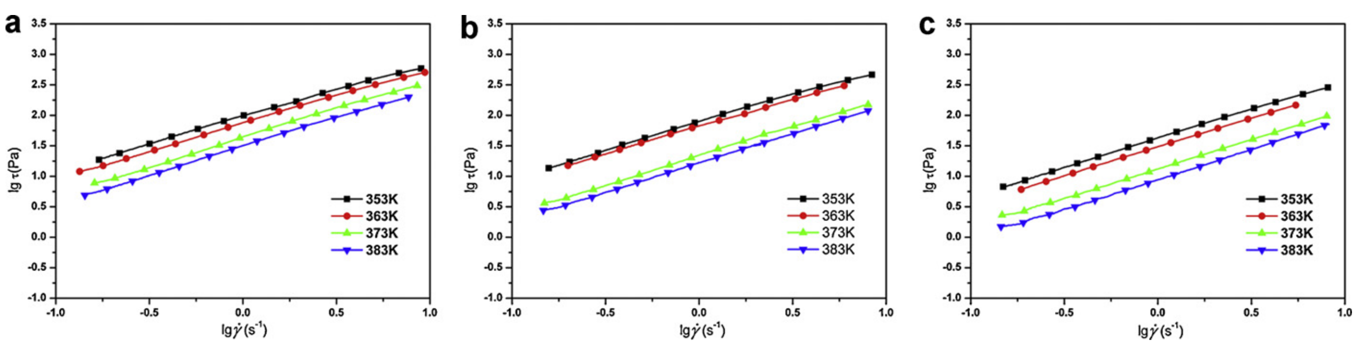

Fig. 2. Logarithmic stress ($\log \tau$) vs. logarithmic shear rate ($\log \dot{\gamma}$) curves for the three fluids with various NaCMCh contents: (a) with cellulose solution; (b) with 1% NaCMCh; (c) with 3% NaCMCh.

Table 2
Results of power-law equation fitting of the polyblends.

	Temperature											
	353 K			363 K			373 K			383 K		
NaCMCh (%)	0	1	3	0	1	3	0	1	3	0	1	3
n	0.75	0.78	0.79	0.76	0.78	0.82	0.81	0.83	0.84	0.81	0.84	0.86

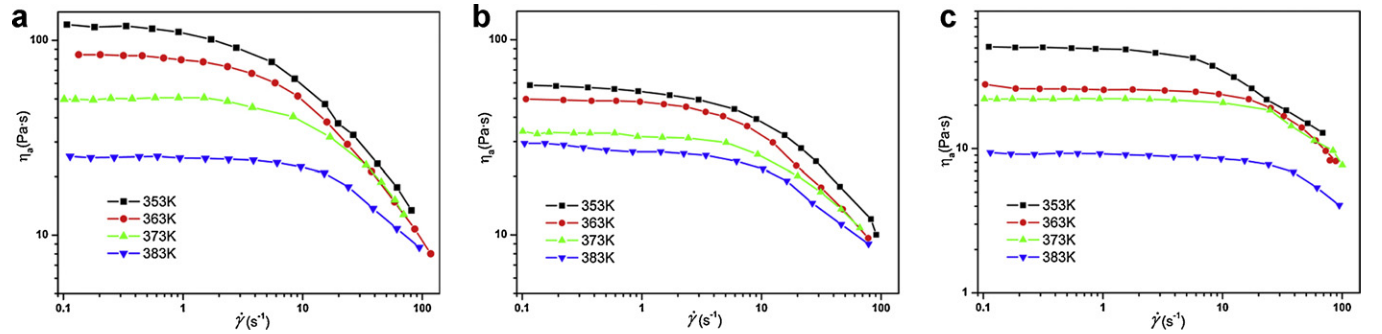

Fig. 3. Apparent viscosity (η_a) vs. shear rate ($\dot{\gamma}$) curves for the three fluids with various NaCMCh contents: (a) with cellulose solution; (b) with 1% NaCMCh; (c) with 3% NaCMCh.

Table 3
η_0 (Pa s) and $\dot{\gamma}_{cr}$ (s^{-1}) values of the spinning dopes.

	0%		1%		3%	
	η_0 (Pa s)	$\dot{\gamma}_{cr}$ (s^{-1})	η_0 (Pa s)	$\dot{\gamma}_{cr}$ (s^{-1})	η_0 (Pa s)	$\dot{\gamma}_{cr}$ (s^{-1})
353 K	107.15	2.95	59.36	5.77	52.03	7.15
363 K	79.43	5.37	50.04	5.97	28.63	17.58
373 K	50.12	8.71	33.81	7.37	22.43	22.50
383 K	24.55	11.22	23.34	12.31	9.67	25.64

plateau and a high-shear rate non-Newtonian region. It is of benefit to choose a suitable shear rate for spinning. So, from the angle of the shear rate, one can select the initial stage of the apparent viscosity platform to spin (Liu et al., 2007).

In Fig. 3, for the NaCMCh concentration studied, the viscosity can be decomposed into two regions: a region at low-shear rate where the material has a constant viscosity and a region where increasing shear rate causes the viscosity to decrease. Increasing NaCMCh content results in a viscosity which is less dependent on shear rate. Increasing the temperature increases the critical shear rate ($\dot{\gamma}_{cr}$) at which the polyblend no longer behaves as a Newtonian fluid. At high-shear rates, a non-Newtonian region is observed which is almost independent of the temperature.

Table 3 shows the zero-shear-rate viscosity (η_0) and critical shear rate ($\dot{\gamma}_{cr}$) of the fluids containing different contents of NaCMCh at different temperatures. Obviously, with increasing temperature, the apparent viscosity and zero-shear-rate viscosity of the three fluids decrease, meanwhile, critical shear rate increases leading to larger Newtonian plateau. Especially, experimental results indicate that NaCMCh has significant effect on the rheological behavior of the cellulose solution, including two aspects: one is reducing the zero-shear-rate viscosity and apparent viscosity, the other one is increasing critical shear rate and expanding the first Newtonian region of the solution. The results from Table 3 demonstrate that increasing the NaCMCh content has the same effect on the rheological behavior of the solution as raising the temperature.

3.3.3. *Effect on structural viscosity*

The structural viscosity ($\Delta\eta$), defined as follows: $\Delta\eta = -(d\log\eta_a/d\sqrt{\dot{\gamma}})\times 100$, is another important parameter of the spinning solution. It can be used to characterize the structuralization of a spinning solution, which represents number of instant physicocrosslinking sites in the cellulose solution (Dong, 1981). These crosslinking sites may counteract the orientation of macromolecules during the spinning process and thus affect the fiber quality. The lower $\Delta\eta$ of a spinning solution, the better spinnability and fiber quality are achieved (Chen et al., 2004).

Fig. 4 displays the curves of $\Delta\eta$ vs. $\sqrt{\dot{\gamma}}$ for the NaCMCh/cellulose fluids with various NaCMCh contents at different temperatures. Because all three fluids are shear-thinning fluids, their $\Delta\eta$ are always above zero. The cellulose solutions with NaCMCh have a lower $\Delta\eta$ than pure cellulose solution. Also, the 3 wt% NaCMCh/cellulose fluid has the lowest $\Delta\eta$, suggesting the better spinnability and fiber quality. The addition of NaCMCh obstructs the entanglement of the cellulose macromolecule chains, and decreases the intermolecular force at some extent. Therefore, the instant quasi-network structure is partially destroyed which can be also proved by following mechanical performance analysis of the fibers.

3.4. *Physical and mechanical properties of the fiber*

Mechanical properties of the blend fibers are shown in Table 4. Although the addition of a small amount of NaCMCh may interfere with the orientation and crystallization of cellulose, the mechanical properties of the fibers with NaCMCh are not so strongly affected

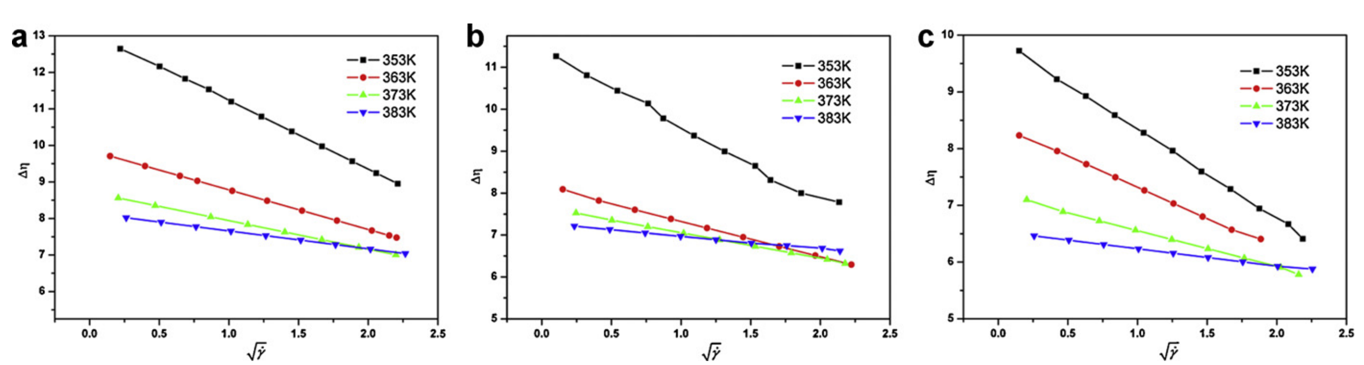

Fig. 4. Structural viscosity ($\Delta\eta$) vs. square root of shear rate ($\sqrt{\dot{\gamma}}$) curves for the three fluids with various NaCMCh contents: (a) with cellulose solution; (b) with 1% NaCMCh; (c) with 3% NaCMCh.

Table 4
Properties of antibacterial lyocell fibers.

	Samples no.		
	1	2	3
NaCMCh content (%)	0	1.0	3.0
Linear density (cN dtex^{-1})	17.5	19.2	19.7
Dry tensile strength (cN dtex^{-1})	3.38	3.18	3.02
Dry elongation at break (%)	18.7	18.9	19.0
Wet tensile strength (cN dtex^{-1})	3.31	3.19	3.02
Wet elongation at break (%)	18.9	19.1	19.3
Moisture absorption (%)	76.7	81.9	83.9

by the concentration of NaCMCh. Tensile strengths in the dry and wet condition of the fibers show a continuous minor decrease with the increasing content of NaCMCh, meanwhile, the modified fibers with NaCMCh show slightly higher elongation. Moreover, moisture absorption increases with NaCMCh content which may contribute to improve the comfortability of the textiles obtained.

4. Conclusion

The spinnability of O-carboxymethyl chitosan sodium salt/cellulose polyblends in NMMO system was investigated in this paper. The results show that NaCMCh has a good solubility in the NMMO/H_2O after being treated by a small amount of sodium hydroxide solution. The antibacterial performance and solubility test of NaCMCh indicate that both of them are influenced by the molecular weight. Antibacterial activity of NaCMCh increases when M_n increases from 2×10^4 to 1.9×10^5, but decreases at M_n above 1.9×10^5. And the solubility decreases with the increase of the molecular weight in the range of 8×10^3 to 2.7×10^5. The optimal range of molecular weights is from 8×10^4 to 1.9×10^5. Furthermore, the rheological behavior of NaCMCh/cellulose polyblends in NMMO/H_2O was examined. Cellulose NMMO/H_2O solution is characterized as a power-law fluid. When NaCMCh is added to the cellulose solution, the power-law curve is preserved. The flow behavior index (n) of polyblends with different NaCMCh contents rise along with the increase of the temperature. Moreover, a higher content of NaCMCh can result in a larger flow behavior index. Apparent viscosity and zero-shear viscosity decrease while critical shear rate increases with the addition of NaCMCh. The same effect could also be achieved by raising the temperature. In addition, the polyblends with NaCMCh display a lower structural viscosity index ($\Delta\eta$) than that of the cellulose solution. Hence, the improvement of spinnability can be attributed to the addition of NaCMCh. Through the polyblend of NaCMCh and cellulose in NMMO/H_2O, the antibacterial lyocell fibers were successfully spun. The fibers show acceptable mechanical properties and moisture absorption, which is expected to find much application for its good antibacterial activity and biodegradability.

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