Improved Oil Resistance of Cellulose Packaging Paper by Coating with Natural Polymer Derived Materials

Feijie Wang[1], Liqiang Wang[1,*], Xinchang Zhang[1], Shufeng Ma[2]
[1] Jiangsu Provincial Key Laboratory of Food Advanced Manufacturing Equipment Technology, School of Mechanical Engineering, Jiangnan University, Wuxi, 214122, China
[2] School of Food Engineering, Jiangnan University, Wuxi, 214122, China
*Email: wlqcom@jiangnan.edu.cn

Abstract: Paper is widely used as food packaging due to its good mechanical strength and degradability. However, it has a relatively strong affinity for water and oil, which limits its application scope. In this work, we prepare two types of coated paper to investigate, the influence the air permeability and polarity on the oil resistance of the coated paper. The results showed that reducing the air permeability improved the grease resistance of the coated paper. High surface energy coatings also showed better oil resistance because of their higher content of polar components that resulted in a higher resistance to grease. The mechanical properties of the paper also improved after applying the coating. These natural derived materials offer an alternative to the fluoride-containing materials currently used in the market to improve the wettability of paper.

Keywords: coated paper · oil resistance · air permeability · polarity

Introduction

As the variety of foods containing grease is abundant, the types of oil-resistant materials used in food packaging has diversified in recent years. Environmental protection and safety issues continue to be important, and as a result, scholars have paid increasing attention to paper packaging materials (Coltelli et al. 2016; Johansson et al. 2012). Paper is a porous structure made from plant fibers that also have capillary phenomena, which result in underdeveloped greaseproof, air permeability, and moisture resistance properties in the paper products. Compounds such as PE (Rhim et al. 2006), EVOH (Zhang et al. 2001), and palm wax (Syahida et al. 2020) are often compounded with cellulose to reduce the porosity and wettability of paper materials and thereby improve their oil resistance. However, these composite papers lose some of their biodegradability and recyclability. Consequently, coating derived from biomass polymers have great research potential in food packaging applications.

Oleophobic materials have contact angle greater than 90°, and often are prepared by physical and chemical methods (Shiraki and Yokoyama 2020). The physical method is inspired by the "lotus leaf effect", and researchers try to recreate a regular, rough structure on the surface of the substrate by adding nano-fillers (Wang et al. 2014), preparing ordered porous structures (Zhang et al. 2015), and using composite paper support materials (Sundar et al. 2020). When an oleophobic materials comes in contact with grease, a layer of air is formed under the oil droplet due to the rough surface structure. The influence of the rough structure on the oleophobicity of the material can be characterized using the dynamic Cassie-Baxter model (Teisala and Butt 2019). The chemical method examines the effect of the surface chemistry on the oil resistance of the material. According to Young's equation, when the solid surface tension is much smaller than the liquid surface tension, it is difficult to wet the surface with the liquid. At present, fluorine-containing oil repellents often are used to reduce the surface energy of the substrate as fluorine-containing compounds repel both grease and water. The principle is that after the lipophilic groups in the fluorine-containing oil repellent combine with the hydroxyl groups in the paper fiber, the surface energy of the thermal trifluoromethyl group is low which protects the paper from being wetted by the liquid. Chemical deposition (Jin et al. 2011), coating (Fukuda et al. 2013), dipping (Zhou et al. 2013) and other processes are often used to prepare greaseproof paper. The Owens-Wendt model (Liu et al. 2018) can be used to analyze the effects of the surface energy on the wetting of the paper by grease. Both methods for creating oleophobic surfaces have certain drawbacks. Increasing the surface roughness can weaken the grease wetting on the paper, but is not suitable for paper products that require heat sealing. For example, most materials that that contain inclusions cannot be heat sealed because the increased surface roughness reduces the efficiency of the heat seal. Paper products coated with polylactic acid must have a smooth surface to have strong heat seal strength (Rhim and Kim 2009). In chemical methods, fluorine-containing oil repellents easily lower the surface energy, but these fluorides also are easily converted into perfluorooctane sulfonic acid (PFOS) and other harmful substances if they are heated. These harmful substances bioaccumulate in the human body and can trigger multiple chronic diseases (Cui et al. 2009).

The oil barrier material is based on forming a surface barrier on the paper to prevent grease penetration. Biomass oil-repellents are gradually being used in food packaging materials, but these coating have high surface energy and strongly adhere to grease. The grease quickly spread over the surface once it comes in contact with the materials. However, if the coating has excellent barrier properties, it can also achieve effective oil resistance. Paper is composed of porous microstructures from the crystalline long-chain polymers in cellulose. The irregular non-crystalline regions continuously destroy the crystalline regions. The fiber pores in the paper are dense and the fiber hydroxyl content is relatively high, consequently, the air permeability of paper is higher than other substrates (Yoo et al. 2012). Air permeability is a non-negligible index that determines the barrier properties of a material. Common biomass oil-repellent materials that reduce air permeability include proteins (Bordenave et al. 2010), chitosans (Kopacic et al. 2018) and alginate (Ham-Pichavant et al. 2005) among others. Although fluorine-containing oil repellents achieve good oleophobic performance, they have little effect on the porosity and air permeability of the substrate (Jiang et al. 2017). There are two ways to improve the barrier properties of paperboard: increasing the degree of the pulp beating or coating the paperboard with materials that act as outstanding barriers. Increasing the degree of pulp beating degree can shorten the fibers and reduce the porosity of the paperboard structure (Goswarni et al. 2008).Alternatively, Hassan (Hassan et al. 2016) used nanocellulose and chitosan nanoparticles to prepare barrier films on paperboard.

The addition of the nanochitosan particles reduced the air permeability of the film, and at the same time, enhanced the antibacterial and oil resistance of the film. Aulin (Aulin et al. 2010) used carboxymethyl nanocellulose to prepare coated paper. The air permeability of the coated paper was significantly reduced, and the resistance to castor oil and turpentine also greatly improved. Li (Li and Rabnawaz 2019) coated the surface of paper with chitosan, and good coverage reduced the porosity and improved the oil resistance of the paper.

Surface chemistry suggests that coatings with a lower surface energy are not easily wetted. Polar components are an important component of the total surface energy, and polar groups repel grease. For example, Tuominen (Noeske et al. 2004) attached LDPE and PP to the surface of paper, and then plasma and corona treated the surface. The air permeability of the resulting paper changed, the coating surface energy and the content polar content increased, and the oil resistance also improved. Ovaska (Ovaska et al. 2017) performed a corona treatment on hydroxypropyl starch coated paper. After a negative corona treatment, the polar content and oil resistance of the coated paper decreased. Fazeli (Fazeli et al. 2019) found that although the polarity decreased after corona treatment, the adhesion between the coating and the substrate increased.

Two kinds of carboxymethyl chitosan (CMCS) based biodegradable coated papers were prepared in this study, with a special focus on changing the oil resistance of the coated paper. We mainly studied the oil resistance of two kinds of coated paper prepared by either adding sodium carboxymethyl cellulose (CMC) or sodium alginate (SA). In particular, we explored the influence of the air permeability and surface polarity on the oil resistance of the coated paper. The main purpose of this work was to offer more experimental data to better understand the factors that affect oil resistance in paper and lay the foundation for future investigations.

Experimental

Materials

Carboxymethyl Chitosan (CMCS, degree of substitution ≥80%) with a viscosity of 10~80mPa·s，sodium alginate (SA, $(C_6H_7NaO_6)_n$) and sodium carboxymethyl cellulose (CMC) with a viscosity of 300~800mPa·s were purchased from Sinopharm Chemical Reagent Co., Ltd. White cardboard (quantity of 280g/m^2) was provided by Shanghai Young Sun Printing Co., Ltd. All the chemicals were chemical grade.

Preparation of greaseproof paper

Deionized water containing 1.5% (wt) CMC, 1.5% (wt) SA and 5% (wt) CMCS, was stirred continuously for 2 hours at 50°C. CMCS and CMC were mixed at a 1:1 ratio, and CMCS and SA were mixed at different ratios (CMCS:SA=1:0, 8:2, 6:4, 5:5, 4:6, 2:8, 0:1) to prepare the mixed solutions (Model of ZY-TB-B, Shandong Zhongyi Instrument Co., Ltd.). Grease-proof paper was prepared by coating the cardboard with the two mixed liquids using a coating machine. The coated papers were dried at 70°C for 180 seconds, and then placed in a controlled environment with a relative humidity of 50% and a temperature of 25°C for 24 hours.

Oil resistance tests

The standard TAPPI T559cm-12 often used in the paper industry was used to test the oil resistance of coated paper. A total of 12 test solutions containing different proportions of castor oil, toluene and n-heptane were prepared, thereby, dividing the greaseproof paper into 12 grades. The liquid was released from a height of about 13mm above the paper, and then quickly cleaned from the paper after 15 seconds to determine the level of the oil resistance. Each coated paper was tested 5 times. According to the stardard test method, an oil proof value of more than 5 met the defined requirements for oil-proof paper.

Contact angle measurements

A contact angle surface analyzer (Model JC2000D1, from Shanghai Zhongchen digital technic apparatus Co.,Ltd, China) was used to measure the water contact angle of the coated paper. Distilled water droplets with a volume of 5μl were placed on the samples, and each sample was tested ten times to determine the average value of the contact angle. The wetting of papers coated paper with the CMCS/CMC solutions with oil resistance values of 8 from the above tests was measured.

Air permeability measurement

According to GB/T 458 2008, the papers was cut into 60mm×100mm samples, and the air permeability value was measured using a paper and cardboard air permeability analyzer (Model J-TQY10, Sichuan Changjiang Papermaking Instrument Co., Ltd.) after treating the paper in a constant temperature and humidity box.

SEM analysis

The morphology of the coated paper was investigated by a SU1510 (Hitachi Ltd., Japan) scanning electron microscope (SEM) operating at 10kv high pressure to determine the uniformity and coverage of the coating.

Surface roughness measurement

The surface roughness was measured using an MFP-D (RETC, America) atomic force microscope (AFM) on samples that were cut into 2×2cm sections. The measurement area was 0.55×0.44cm^2. Intuitively, the roughness of the coating was reflected in the distance between the peaks and valleys in the images. The average roughness (Ra) was calculated from the images, and each sample was measured ten times to obtain the average.

Mechanical property measurements

According to the GB/T 22898-2008, the paper sample was cut into strips with a size of 15×100mm^2, and the tensile strength and elongation at break of the paper were measured using a universal electronic material testing machine (LRX Plus, LLOYD, UK). Each sample was tested three times and the average value was taken.

Results and discussion

Air permeability and oil resistance of the CMCS/CMC coated paper

Table 1 Air permeability and oil resistance of CMCS/CMC coated paper

Coated weight (g/m^2)	0	1.02	2.04	3.06	4.08	5.1	6.12
Air permeability (mL/min)^a	0.020±0.011	0.016±0.006	0.010±0.009	0.005±0	0.003±0	0.003±0	0.003±0
Kit no.	0	5	6	7	8	8	9

^{a}Mean±standard deviation

Table 1 shows the influence of the weight of the CMCS/CMC coating on the air permeability and oil resistance of the coated paper. Although the surface smoothness and barrier properties of cardboard were improved, the air permeability was still high. The selective gas permeability of the CMCS was outstanding, but strongly inhibited to O_2 and CO_2 permeation. As the coating weight increased from 1.02 g/m^2 to 4.08 g/m^2, the sample kit value gradually increased from 5 to 8, but the air permeability gradually decreased. The barrier properties of the composite film formed by the CMCS/CMC coatings to gas and grease varied with the coating weight. An increase in coating weight improved the relatively high air permeability of the base material, which was also seen in work by Park (Park et al. 2000). Experimental results by Ham-Pichavant (Ham-Pichavant et al. 2005) also showed that the oil resistance positively correlated with air permeability, and the kit no. did not change significantly with increasing coating weight. The air permeability reached the limit when the coating amount was over 4.08 g/m^2. After coating, the air permeability significantly reduced, and the oil resistance level of the paper greatly improved to meet the requirements of packaging paper.

Surface micromorphology

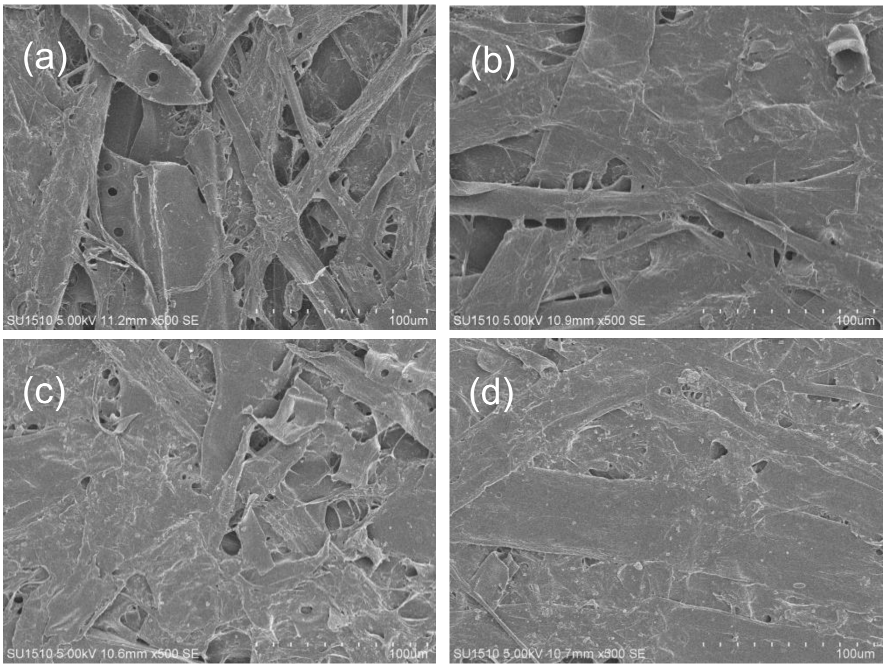

Figure 1 SEM image of **a** uncoated paper, **b** coated CMCS/CMC with 1.02 g/m^2, **c** coated with 3.06 g/m^2, **d** coated with 5.1 g/m^2

In order to observe the coating coverage of the base paper, SEM image of the paperboard surface were analyzed. It can be vividly seen from the images that the degrees of coverage were uneven. While the paperboard with a coating weight of 1.02 g/m^2 was covered by the coating, some uncoated fibers were still visible. When the coating weight reached 3.06 g/m^2, most of the fibers were covered, but the coating was not uniform. Increasing the coating weight to 5.1 g/m^2, the fibers and pores on the surface were fully covered, and the surface was flatter compared with base paper.

Wettability of the coated paper surface

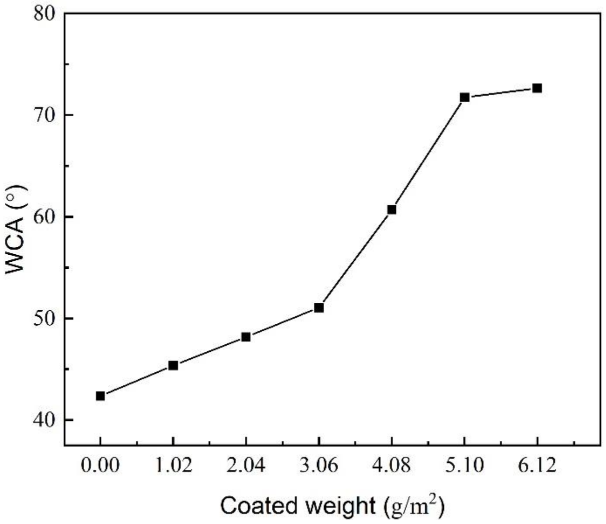

Figure 2 WCA of CMCS/CMC coated paperboard

As seen in Figure 2, the anti-wetting performance of the paper was enhanced after coating with a CMCS/CMC mixture. When the coating weight reached 5.1 g/m^2, the water contact angle (WCA) increased by nearly 30°. The formation of the composite film reduced the direct contact area between the paper fibers and water, and weakened the combined effects that lead to attraction between the fiber and water of the fiber's attraction to water. The water contact angle (CA) increased slowly with further increases in the coating weight, because the surface was already completely covered by the composite film, and the additional coating did not further affect the hydrophobicity.

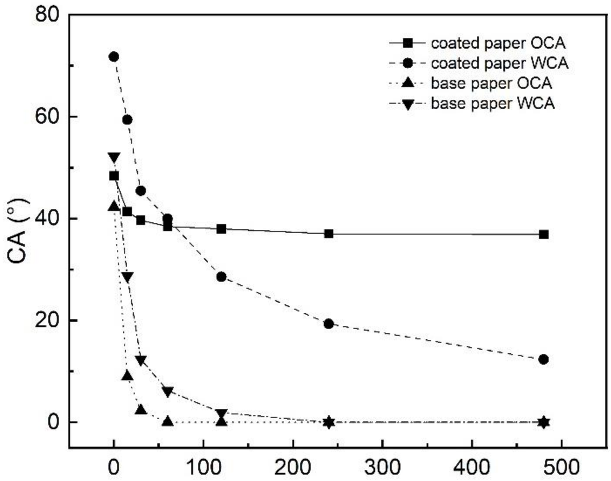

Figure 3 Wetting properties of CMCS/CMC coated paper and base paper

In order to further explore the dynamic anti-wetting properties of the coated and base papers, the changes in the water and oil CA were observed over time to better reflect the barrier effects of coated paper. The trend in the dynamic changes of the CA of the coated papers with different coating amounts was similar, therefore, the coated paper with a coating weight of 5.1 g/m^2 was studied further. It could be seen from Figure 3 that the oil contact angle (OCA) of the base paper quickly dropped to 0° within 60 second, and the wetting effect was stronger. However, the CA of the coated paper decreased rapidly within first 15 second, and then only gradually decreased with increasing time. The OCA stabilized around 40°, suggesting that the grease-wetting resistance of the coated paper was improved greatly, and the coating maintained good oil-repellent performance for a long time. The changes in the water contact angle (WCA) of the base paper and coated paper followed the same trends over time. After 240 seconds, the WCA of the base paper reached 0°, and the base paper was completely wetted. The anti-wetting behavior was enhanced after coating the base paper. At 0 second, the WCA of the base paper increased by 19.6°, but then decreased over time. The reason was that the composite film formed by the CMCS/CMC coating prohibited direct contact between the water molecules and fibers. However, the film also contained abundant hydrophilic hydroxyl and carboxymethyl groups, and hydrophilicity of the film was also comparatively strong. Over time, the water molecules gradually penetrated into the spaces between the fibers and were finally completely absorbed. Therefore, the CMCS/CMC coating not only imparted excellent oil resistance, but also prolonged the water wetting time. These results were consistent with the experimental results of Arancibia (Arancibia et al. 2016).

Mechanical properties of the CMCS/CMC coated paper

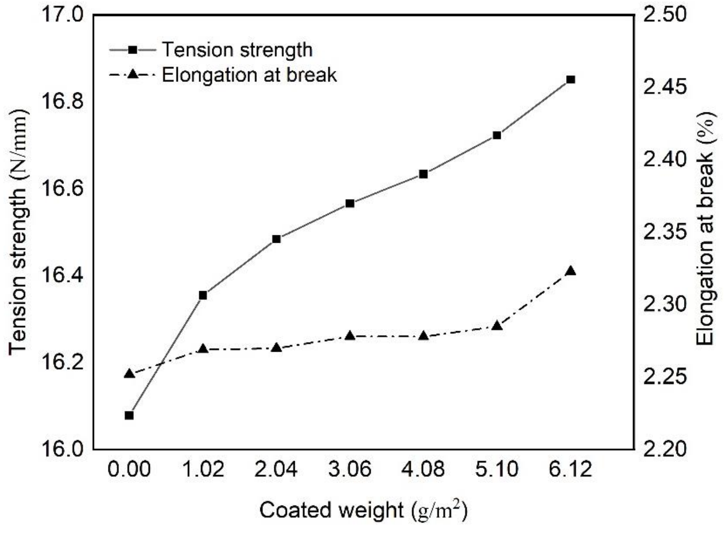

Figure 4 Mechanical properties of CMCS/CMC coated paper

In practical applications, processed paper must have sufficient strength to protect the contents. Therefore, changes in the strength of the paper after coating will affect its application range. Figure 4 shows the effect of the CMCS/CMC coating weight on the mechanical properties of paper. Mechanical strength is an important indicator of the paper packaging materials. Sufficient mechanical strength can reduce damage to the contents caused by external impact. As shown in figure 4, the tensile strength (TS) and elongation at break (E) of coated paper increased with increasing of coating weight. When the coating weight reached 6.12 g/m^2, the TS was maximum and E was much larger than the base paper. The TS of the coated paper was affected by the fiber structure and the external environment. The length of the fiber and the bonding force between the fibers had a greater impact on the TS. The coating solution possessed a certain viscosity. After the paper surface was coated with CMCS/CMC solution, the molecules penetrated the surface and blended with the fibers. After drying, the fiber surfaces and solute molecules were tightly bound, therefore, the surface strength and TS of the paper was enhanced. However, the coating liquid did not penetrate into all of the gaps of the paper, so only the extensibility of the surface layer was improved and the resulting E increased slowly.

Surface energy and oil resistance of CMCS/SA coated paper

The surface tension is the sum of the interaction forces between the molecules on the surface. The surface tension concept better explains the wetting phenomena in papers. The polar components of the solid surface layer have a certain degree of repellency to grease, and the wetting performance of paper is influenced by the surface tension. In order to explore the effect of surface tension changes in the wetting behavior of the paper, different amounts of SA were added into the CMCS coating solution. Young's equation (1) describes the relationship between the surface tension and the measured CA, but does not enough to reflect the influence of each component to the CA. Owens and Wendt proposed a new surface tension model based on formula (2) and (3), where γ_l represents the surface tension of the liquid, γ_s represented the surface tension of the solid, γ_s^d represented the dispersion force component of the surface tension, γ_s^h represents the pole component of the surface tension, and θ is the measured angle between solid and liquid. However, to use this model, the contact must be measured with two liquids with opposite polarities. Water and diiodomethane were selected as the probe liquids, and combined with equation (4) to calculate the dispersion force and the polar components. Equation (5) allows for the calculation of the contributions of the polar component on the surface tension.

Table 2 The polar component (γ_l) and dispersion force component (γ_l) of the surface energy (γ_l) in the test liquid

Liquid	γ_l^d（mN/m）	γ_l^h（mN/m）	γ_l（mN/m）
Water	21.8	51.0	72.8
Diiodomethane	48.5	2.3	50.8

$$\gamma_s = \gamma_{sl} + \gamma_l \cos\theta \tag{1}$$

$$\gamma_l = \gamma_l^d + \gamma_l^h \tag{2}$$

$$\gamma_s = \gamma_s^d + \gamma_s^h \tag{3}$$

$$1 + \cos\theta = 2\sqrt{\gamma_s^d}\left(\frac{\sqrt{\gamma_l^d}}{\gamma_l}\right) + 2\sqrt{\gamma_s^h}\left(\frac{\sqrt{\gamma_l^h}}{\gamma_l}\right) \tag{4}$$

$$X=\frac{\gamma_s^h}{\gamma_s}\times 100\% \tag{5}$$

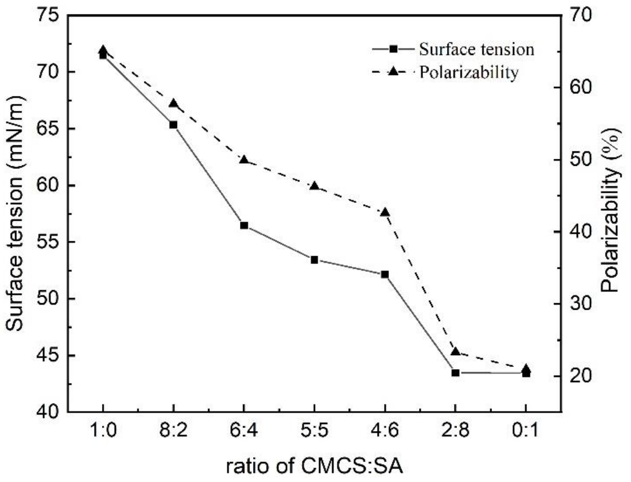

Figure 5 Surface tension and polarizability of the CMCS/SA coated paper

As revealed in Figure 5, different ratios of CMCS and SA led to different polar component contents in coating. The surface tension and polarizability of the coating decreased with the decreasing CMCS content. The addition of SA not only reduced the surface tension, but also improved the gas barrier properties of the coating. For example, after the solution was coated with a CMCS:SA ratio of 5:5, the surface tension was lower, the kit value was up to 7, and the air permeability reached the measurement limit of the equipment.

It can be seen from Young's equation that substances with a lower solid surface tension are less wettable. According to Table 3, as the ratio of the solution changed from 1:0 to 8:2, the surface tension reduced to 65.34 N/km, the air permeability reduced, and the oil resistance level rose to 8. The surface tension of the CMCS/SA coating with a ratio of 8:2 was much higher than the coating with a ratio of 2:8, but the oil repellency performance was significantly declined. Most greases have zero dipole moment and small electronic activity, so they appear non-polar. According to the principle of "similar polarity", the polar components in the coating were more resistant to the test solution. Therefore, for high surface tension coatings with higher polarizability, the polar components had a greater impact on grease the barrier properties.

The oil resistance of the coating with an 8:2 ratio was better than that of 1:0; however, it was not clear if the decrease in air permeability or greater polar content played a more critical role in determining the oil resistance. Therefore, paper with a coating weight of 1.02 g/m^2 and CMCS/SA coatings with a ratio of 8:2 and 0:1 were prepared to further explore the effects of high-polarity components on the anti-oil effects under this test condition. The results are shown in Table 4. Compared to the coated paper with a coating weight of 3.06 g/m^2 and a ratio of 1:0, the coated paper with a coating weight of 1.02 g/m^2 and a ratio of 8:2 had a higher air permeability, but the kit value was also high. Meanwhile, the coating with a ratio of 6:4 in Table 3 and with a ratio of 0:1 in Table 4 had the same air permeability, but the oil resistance performance was significantly different. Combining results in Figure 5 verified that the higher polar group content in the coating resulted in higher surface tension and the better oil resistant coating.

Table 3 Air permeability and oil resistance of CMCS/SA coated paper with a coating weight of 3.06 g/m^2

CMCS:SA	1:0	8:2	6:4	5:5	4:6	2:8	0:1
Air permeability (μm/Pa•s)	0.010	0.007	0.004	0.003	0.003	0.003	0.003
Kit no.	5	8	7	7	6	4	3

Table 4 Air permeability and oil resistance of CMCS/SA coated paper with a coating weight of 1.02 g/m^2

CMCS:SA	8:2	0:1
Air permeability (μm/Pa•s)	0.013	0.004
Kit no.	6	2

Surface micromorphology of CMCS/SA coated paper

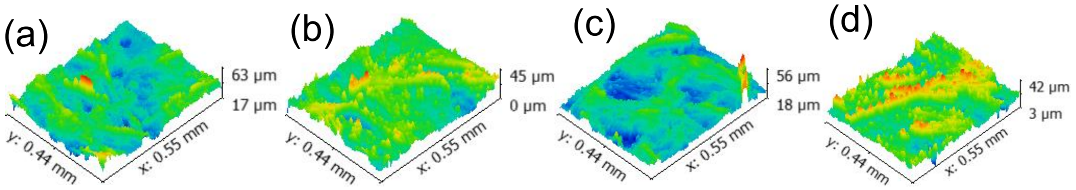

Figure 6 AFM image of CMCS/SA coated paper (**a**) with 1:0, (**b**) with 6:4, (**c**) with 5:5, and (**d**) with 0:1

The coating weight of the four samples was the same, and the solution coverage on the paper was ideal, so there was little difference in the microscopic state seen with the electron microscope. In order to further analyze the differences in the surface layers of the different coated papers, AFM was selected to observe the 3D morphology of the surface layers. The surface roughness is shown in figure 6 (a-d) after coating the papers with different proportions of the solutions. It was vividly found that the wave distance was within 80 μm. However, the surface roughness of the coated papers changed with increasing dosage of SA in the coating. The reason might be based on the following aspects: the fibers were relatively large, the surface of the cardboard was not smooth surface, and the roughness presently differently. After coating, film formed on the fibers had excellent replicability and was better than the original roughness of the cardboard surface. The solute molecules penetrated some gaps between the fibers and adhered to the fibers and surface. After drying, they had different effects on the surface roughness. As seen in Figure 7 the roughness of the coated paper did not show regular changes with the coating composition.

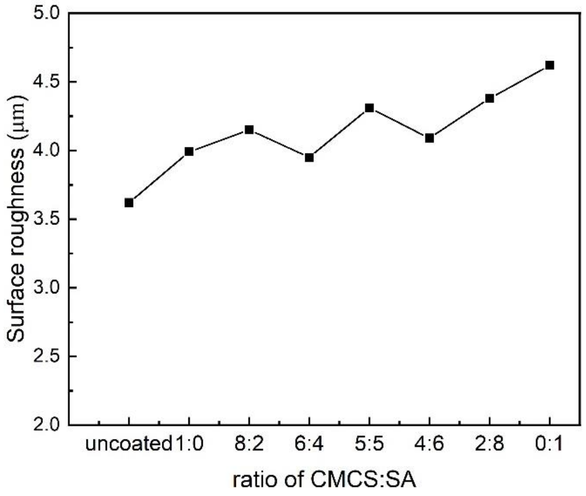

Figure 7 Surface roughness of CMCS/SA coated paper

Surface wettability of CMCS/SA coated paper

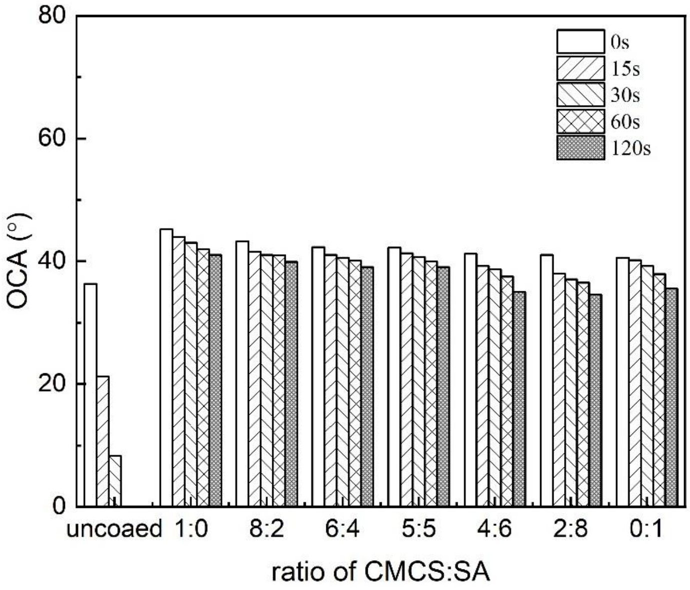

Figure 8 OCA of CMCS/SA coated paper

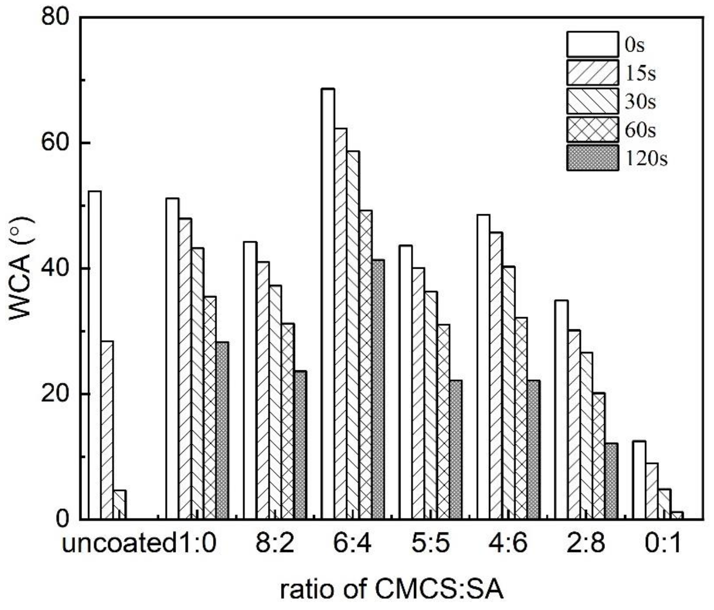

Figure 9 WCA of CMCS/SA coated paper

The dynamic changes of the OCA within a specified time reflect the oil resistance of the coated paper. It can be seen (Figure8) that the OCA of the various coated papers increased compared to the base paper. After 60 seconds, the base paper was completely wetted by grease, and the contact angle became 0°. Meanwhile the contact angle of the coated paper only decreased by 5° after 120 seconds, indicating that the coating formed a good barrier to grease. Within the same time, as the CMCS content in the coating decreased, the reduction of the OCA gradually increased, indicating that the oil resistance was better for the given period time.

The Figure 9 shows that the water resistance of the coated paper varied irregularly with the SA content in the coating, but no matter what kind of coating was used, the water-blocking performance of the paper improved. Although the WCA of the coated paper with a ratio of 0:1 was much smaller than the base paper, the water blocking time was prolonged, indicating that the water resistance of the paper improved regardless of the coating composition.

Due to the differences in the barrier properties, surface energies, and polar contents of the different coatings, the coated papers exhibited differences in their water and oil resistance. However, the changes in OCA and WCA reflected in the above figure are not consistent with the changes in barrier properties shown in Table 3. The impact of the barrier properties to grease and water was not a direct factor. After analyzing Figure 5, it was found that the surface tension and polarization rate of the coating gradually decreased. Most grease molecules are non-polar, while water molecules are polar due to their uneven charge distribution. The coatings presented here repelled grease but were hydrophilic. The barrier properties of the coated paper to grease first increased and then decreased, indicating that the surface tension and polarization mainly impacted the grease resistance of the coating. The roughness of the different coated papers was different (Figure7). Previous research suggested (Taguet et al. 2014) that more complex surface microstructures with WCAs over 90° was easier to wet, but materials with

WCAs less than 90° presented opposite phenomenon. The trends in moisture resistance of the coatings was similar to the trends in surface roughness. The surface roughness of the coated paper with a ratio of 0:1 was relatively high. Although the surface tension was small, it can be concluded from Figure 9 that the surface roughness had a greater effect on the water wettability than the surface tension, which was similar to conclusions reached by Azimi (Azimi and He 2020). Therefore, the surface roughness, surface tension, and polarization of the coating together affected the water and oil resistance of the coated paper.

Mechanical strength of the CMCS/SA coated papers

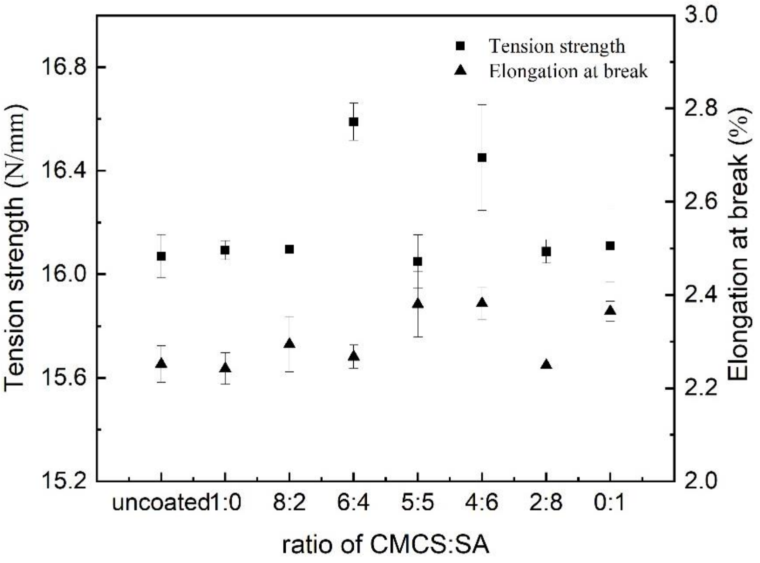

Figure 10 TS and E of CMCS/SA coated paper

The mechanical properties of coated paper were improved compared to the base paper (Figure 10). The viscosity of the solution was relatively high, and the bonding strength between the fibers was enhanced after coating penetrated into the pores. Both the CMCS and SA composition were experimental variables. The different CMCS and SA proportions in the coating, but E was relatively stable. When the composition ratio was 6:4, the TS reached a maximum value and the E was also better. Therefore, the various coatings improved the TS, but had little effect on the E of the paper.

Conclusion

Coating biomass compounds onto base paper has great development potential and application value in food packaging. This method abandons the application of traditional fluorine-containing materials, yet still meets the oil resistance level required for food packaging. The lower air permeability of the coating had a significant effect on the oil resistance of the coated paper, and the influence of the surface tension and polar content of the coating on the oil resistance of the coated paper could not be ignored. For hydrophilic materials, reducing the surface roughness was conducive to improving the hydrophobicity of the material. The mechanical properties of the coated papers were improved to a certain extent. Research and development into new coatings, preparation processes for creating coated paper and the reduction in coating costs still need to be studied further. Biomass materials also have good prospects in antibacterial resistance, and could be used to develop multifunctional environmentally friendly food packaging.

Author Contribution

F.W. and L.W. conceived the idea and supervised the research. F.W., X.Z. and F.M. contributed to the material preparation and characterization. F.W., F.M. and L.W conducted the property measurements. F.W. and L.W. contributed to the writing of the manuscript. All authors reviewed and commented on manuscript.

Notes

The authors declare no conflicts of interest.

Acknowledge

This work is supported by Special Funds for Fundamental Scientific Research Funds of Central Universities (JUSRP21115); Independent Research Project Funding Project of Jiangsu Key Laboratory of Advanced Food Manufacturing Equipment Technology (FMZ201902)

Reference

Arancibia C, Navarro-Lisboa R, Zuniga RN, Matiacevich S (2016) Application of CMC as Thickener on Nanoemulsions Based on Olive Oil: Physical Properties and Stability. International Journal of Polymer Science 2016 http://doi.org/10.1155/2016/6280581

Aulin C, Gallstedt M, Lindstrom T (2010) Oxygen and oil barrier properties of microfibrillated cellulose films and coatings. Cellulose 17:559-574 http://doi.org/10.1007/s10570-009-9393-y

Azimi A, He P (2020) Effect of gravity in the Cassie-to-Wenzel transition on a micropatterned surface. Mrs Communications 10:129-134 http://doi.org/10.1557/mrc.2019.160

Bordenave N, Grelier S, Coma V (2010) Hydrophobization and Antimicrobial Activity of Chitosan and Paper-Based Packaging Material. Biomacromolecules 11:88-96 http://doi.org/10.1021/bm9009528

Coltelli M-B et al. (2016) State of the Art in the Development and Properties of Protein-Based Films and Coatings and Their Applicability to Cellulose Based Products: An Extensive Review. Coatings 6 http://doi.org/10.3390/coatings6010001

Cui L, Zhou QF, Liao CY, Fu JJ, Jiang GB (2009) Studies on the Toxicological Effects of PFOA and PFOS on Rats Using Histological Observation and Chemical Analysis. Archives of Environmental Contamination and Toxicology 56:338-349 http://doi.org/10.1007/s00244-008-9194-6

Fazeli M, Florez JP, Simao RA (2019) Improvement in adhesion of cellulose fibers to the thermoplastic starch matrix by plasma treatment modification. Composites Part B-Engineering 163:207-216 http://doi.org/10.1016/j.compositesb.2018.11.048

Fukuda S, Chaussy D, Belgacem MN, Reverdy-Bruas N, Thielemans W (2013) Characterization of oil-proof papers containing new-type of fluorochemicals Part 1: Surface properties and printability. Appl Surf Sci 277:57-66 http://doi.org/10.1016/j.apsusc.2013.03.174

Goswarni T, Kalita D, Rao PG (2008) Greaseproof paper from Banana (Musa paradisica L.) pulp fibre. Indian J Chem Technol 15:457-461

Ham-Pichavant F, Sebe G, Pardon P, Coma V (2005) Fat resistance properties of chitosan-based paper packaging for food applications. Carbohydr Polym 61:259-265 http://doi.org/10.1016/j.carbpol.2005.01.020

Hassan EA, Hassan ML, Abou-Zeid RE, El-Wakil NA (2016) Novel nanofibrillated cellulose/chitosan nanoparticles nanocomposites films and their use for paper coating. Industrial Crops and Products 93:219-226 http://doi.org/10.1016/j.indcrop.2015.12.006

Jiang L, Tang ZG, Clinton RM, Breedveld V, Hess DW (2017) Two-Step Process To Create "Roll-Off" Superamphiphobic Paper Surfaces. Acs Applied Materials & Interfaces 9:9195-9203 http://doi.org/10.1021/acsami.7b00829

Jin H et al. (2011) Superhydrophobic and Superoleophobic Nanocellulose Aerogel Membranes as Bioinspired Cargo Carriers on Water and Oil. Langmuir 27:1930-1934 http://doi.org/10.1021/la103877r

Johansson C et al. (2012) RENEWABLE FIBERS AND BIO-BASED MATERIALS FOR PACKAGING APPLICATIONS - A REVIEW OF RECENT DEVELOPMENTS. Bioresources 7:2506-2552

Kopacic S, Walzl A, Zankel A, Leitner E, Bauer W (2018) Alginate and Chitosan as a Functional Barrier for Paper-Based Packaging Materials. Coatings 8 http://doi.org/10.3390/coatings8070235

Li Z, Rabnawaz M (2019) Oil- and Water-Resistant Coatings for Porous Cellulosic Substrates. Acs Applied Polymer Materials 1:103-111 http://doi.org/10.1021/acsapm.8b00106

Liu XW et al. (2018) Adhesion of liquid food to packaging surfaces: Mechanisms, test methods, influencing factors and anti-adhesion methods. J Food Eng 228:102-117 http://doi.org/10.1016/j.jfoodeng.2018.02.002

Noeske M, Degenhardt J, Strudthoff S, Lommatzsch U (2004) Plasma jet treatment of five polymers at atmospheric pressure: surface modifications and the relevance for adhesion. Int J Adhes Adhes 24:171-177 http://doi.org/10.1016/j.ijadhadh.2003.09.006

Ovaska SS et al. (2017) Corona Treatment of Filled Dual-polymer Dispersion Coatings: Surface Properties and Grease Resistance. Polymers & Polymer Composites 25:257-266 http://doi.org/10.1177/096739111702500402

Park HJ, Kim SH, Lim ST, Shin DH, Choi SY, Hwang KT (2000) Grease resistance and mechanical properties of isolated soy protein-coated paper. J Am Oil Chem Soc 77:269-273 http://doi.org/10.1007/s11746-000-0044-2

Rhim JW, Kim JH (2009) Properties of Poly(lactide)-Coated Paperboard for the Use of 1-Way Paper Cup. J Food Sci 74:E105-E111 http://doi.org/10.1111/j.1750-3841.2009.01073.x

Rhim JW, Lee JH, Hong SI (2006) Water resistance and mechanical properties of biopolymer (alginate and soy protein) coated paperboards. Lwt-Food Science and Technology 39:806-813 http://doi.org/10.1016/j.lwt.2005.05.008

Shiraki Y, Yokoyama H (2020) Novel hydrophobic and oleophobic surfaces using polyurethane with hydrogenated polyisoprene soft segment. Materials Today Communications 24 http://doi.org/10.1016/j.mtcomm.2020.101243

Sundar, Kumar A, Pavithra, Ghosh (2020) Studies on Semi-crystalline Poly Lactic Acid (PLA) as a Hydrophobic Coating Material on Kraft Paper for Imparting Barrier Properties in Coated Abrasive Applications. Prog Org Coat 145 http://doi.org/10.1016/j.porgcoat.2020.105682

Syahida SN, Ismail-Fitry MR, Ainun ZMA, Hanani ZAN (2020) Effects of palm wax on the physical, mechanical and water barrier properties of fish gelatin films for food packaging application. Food Packaging and Shelf Life 23 http://doi.org/10.1016/j.fpsl.2019.100437

Taguet A, Cassagnau P, Lopez-Cuesta JM (2014) Structuration, selective dispersion and compatibilizing effect of (nano)fillers in polymer blends. Prog Polym Sci 39:1526-1563 http://doi.org/10.1016/j.progpolymsci.2014.04.002

Teisala H, Butt HJ (2019) Hierarchical Structures for Superhydrophobic and Superoleophobic Surfaces. Langmuir 35:10689-10703 http://doi.org/10.1021/acs.langmuir.8b03088

Wang JQ, Li Y, Tian HY, Sheng JL, Yu JY, Ding B (2014) Waterproof and breathable membranes of waterborne fluorinated polyurethane modified electrospun polyacrylonitrile fibers. Rsc Advances 4:61068-61076 http://doi.org/10.1039/c4ra09129a

Yoo S, Lau SH, Krochta JM (2012) Grease Penetration and Browning Resistance of Pulpboard and Paperboard Coated with Whey Protein. Packaging Technology and Science 25:259-270 http://doi.org/10.1002/pts.977

Zhang AJ, Bai H, Li L (2015) Breath Figure: A Nature-Inspired Preparation Method for Ordered Porous Films. Chem Rev 115:9801-9868 http://doi.org/10.1021/acs.chemrev.5b00069

Zhang ZB, Britt IJ, Tung MA (2001) Permeation of oxygen and water vapor through EVOH films as influenced by relative humidity. J Appl Polym Sci 82:1866-1872 http://doi.org/10.1002/app.2030

Zhou H, Wang HX, Niu HT, Gestos A, Lin T (2013) Robust, Self-Healing Superamphiphobic Fabrics Prepared by Two-Step Coating of Fluoro-Containing Polymer, Fluoroalkyl Silane, and Modified Silica Nanoparticles. Adv Funct Mater 23:1664-1670 http://doi.org/10.1002/adfm.201202030