Effects of Fiber Characteristics on the Greaseproofing Property of Paper

YUAN-SHING PERNG[*], EUGENE I-CHEN WANG[†], LAN-SHENG KUO[‡], YU-CHUN CHEN[§]

[*]Associate Professor, Dept. of Environmental Engineering, Da Yeh University

[†]Sr. Researcher & Division Chief, Division of Wood Cellulose, Taiwan Forestry Research Institute

[‡]Professor, Dept. of Environmental Resources Management, Overseas Chinese Institute of Technology

[§]Business Representative, Bayer Taiwan Co.

Dept. of Environmental Engineering, Da Yeh University, 112 Shanjiau Rd., Datsuen, Changhua 515, Taiwan.

e-mail: ysperng@mail.dyu.edu.tw.

ABSTRACT

Grease barrier food containers are commonly used for packaging of fast food, cooked food, and food in general. Greaseproofing is also used for certificate paper and label paper etc. Different pulp raw materials, due to their different fiber morphology and chemical compositions, produce papers of varying characteristics. We used optical photomicroscopy and fiber analysis data to evaluate fiber morphology and traits under various beating conditions in order to understand which pulp raw materials produced superior greaseproofing property when a fluorinated greaseproofing agent was added internally.

The experiment studied 9 species of pulps, including 2 softwood (northern pine and radiata pine) bleached kraft pulps which were beaten to 550 and 350 mL CSF, respectively; 3 hardwoods (eucalypts, acacia, mixed Indonesian hardwoods) bleached kraft pulps which were beaten to 450 and 250 mL CSF, respectively; and nonwood fibers of reed, bagasse, and abaca. A fluorinated greaseproofing chemical at 0.12% dosage with respect to dry pulp was added to each pulp preparation and formed handsheets. A total of 67 sets of handsheets were prepared, and their basis weights, thickness, bulks, opacities, wet opacities, air resistance, water absorption and degrees of greaseproofing were measured for an overall evaluation of pulp and freeness on greaseproofing papers.

The experimental fiber length, coarseness and distribution characteristics and the greaseproofing results suggest that softwood pulps (radiate pine > northern pine) were superior to hardwood pulps (eucalypts > acacia > mixed Indonesian hardwoods). The unbeaten pulps gave papers with high porosities and nearly devoid of greaseproofing property. Greaseproofing is proportional to air resistance. Among the nonwood fibers, bagasse had the best greaseproofing property, followed by reed and abaca was the poorest. With regards to waterproofing property, hardwood pulps (mixed Indonesian hardwoods > acacia > eucalypts) were better than softwood pulps (northern pine > radiate pine). Among the Nonwood fibers, reed had the highest waterproofing property, and it was followed by abaca, while bagasse had the poorest waterproofing characteristic. In summary, bleached kraft northern pine, eucalypts and reed pulps were best suited for making greaseproofing papers, Freeness of the pulps should be kept at 200~280 mL CSF for optimal performance.

Keywords：fluorinated greaseproofing chemicals, greaseproofing, fiber properties, coarseness, freeness

INTRODUCTION

The main characteristics of a grease barrier food container entail oil repellency, and oil resistance. These can be achieved through 1) coating with a fluorochemical; 2) laminating with several polyolefins, such as PE and PP; 3) hot wax treatment; 4) laminating with aluminum foil. Among these, the first two are the mainstay of marketplace. In their application, water resistance, air permeability, wet strength and wet opacity properties should also be considered.

Application of fluorochemical greaseproofing agent can be either wet-end internal addition or surface coating at post-conversion. Wet-end internal addition entails adding fluorochemical, retention aid, sizing agent, and wet strength resin together in headbox, before formation of the paper on the forming wire. Surface coating at the converting stage involves using on-line or off-line coater, size press, or waterbox doctor blades of calender stack to apply a thin film of fluorochemical on base sheet. The fluorochemical is often added together with starch or polyvinyl alcohol (PVOH) in the latter cases.

Chang and Ted reviewed in detail the structures and greaseproofing principles of commercially available greaseproofing fluorochemicals [1]. Yang et al. tested fluorochemical surface coating on newsprint and found that the least amount of the chemical should be 10 mg/m^2. Lowering pitch content and using hydrophobically modified starch could reduce the amount of fluoro-chemical required [2]. Giatti described the internal addition and size press application of greaseproofing agent at the Cartiere Cima S. p. A. mill [3]. Wolford described his experience of applying fluorochemical greaseproofing agent internally at PM 10 of the Camas mill [4]. Wyser et al. developed a method of testing greaseproofing properties for pet food packaging [5]. Perng and Wang investigated the application of fluorochemical to molded paper products and found that softwood pulp had better greaseproofing and waterproofing properties than did the hardwood pulps; also, when aluminum ion in white water exceeded 30 ppm, the higher the aluminum content, the greater the interference on grease- proofing was; grease absorption of the paper showed the same tendency as water absorption; and oversizing interfered with fluoro-chemical and lowered greaseproofing values. Molded paper products have production wet-end chemistry mechanism akin to a cylinder former and by adding low molecular weight strong cationic coagulant and high molecular weight anionic flocculent in sequence the most optimal greaseproofing property was achieved [6]. Kjellgren and Engstrom utilized mill statistical data to show that all sulfite pulp of low freeness had the least energy demand; while a 50:50 mix of sulfite/sulfate furnish had the poorest barrier property. Refining could improve the barrier property but requiring extra energy. Under the least energy input condition, calendaring and surface coating were the best means of enhancing barrier properties [7].

EXPERIMENTALS

We collected wood fibers: 2 varieties of bleached softwood (northern pine and radiate pine) kraft pulps, each beaten to freeness of 550 and 350 mL CSF; and 3 varieties of bleached hardwood (eucalypts, acacia, and mixed Indonesian hardwoods) kraft pulps, each beaten to freeness of 450 and 250 mL CSF. Nonwood fibers of reed, bagasse and abaca pulps were also prepared. In addition, base pulp from a domestic greaseproofing paper mill was also included. To these pulps, 4 treatments were devised with no chemical was added; all chemicals except the fluorochemical was added; all chemicals except AKD sizing agent were added; and all chemicals were added. Fluorochemical addition was fixed at 0.12% with respect to dry pulp. The treated pulps were formed into handsheets for a total of 67 sets, 16 sheets to a set. Then the basis weight, thickness, bulk, opacity, wet opacity, air resistance, water absorption and greaseproofing property of the handsheets were measured in order to evaluate the effects of pulps and freeness on the greaseproofing property of the handsheets.

The fluorochemical greaseproofing agent we used were FC-807 from the 3M Inc., dosage was 0.12% to dry pulp.

The manipulated variables of this experimental series included: wood fiber blend (100% softwood; 100% hardwood, and 30% softwood and 70% hardwood); a low molecular weight strong cationic coagulant (Nalco 7607, 0.35% to dry fiber); AKD sizing agent (Hercules, Hercon 76, 0.30% to dry pulp); and a high molecular weight anionic flocculent (Nalco 625, 0.20% to dry pulp). Their effects on greaseproofing and waterproofing properties of the handsheets were evaluated. The softwood pulp used was northern pine from Canfor (750 mL CSF) and the hardwood pulp was eucalypts from Arauco (650 mL CSF).

Paper molding operation was batchwise, using a standard British sheet mold to simulate. The handsheet forming procedure was in accordance with the TAPPI T 205 sp-95, and entailed the following:

1) Pulp was disintegrated using a standard disintegrator; 。
2) Add Na_2CO_3 to adjust pulp suspension to pH 7.5, kept stirring;
3) Add 0.15~0.35% Nalco 7607, stirring for 60 s;
4) Add 0.19~0.45% Hercon 76, stirring for 60 s;
5) Add 0.10~0.14% FC-807; stirring for 60 s;
6) Add 0.15~0.35% Nalco 625, stirring for 60 s;
7) Form handsheets of basis weight 60 gsm using a standard sheet mold, dry overnight.;
8) Condition the handsheets in a constant temperature and humidity room for at least 3 h. Proceed with the tests for oil and water absorption.

Oil absorption test used the hot Mazola oil test, 1 mL of corn oil heated to 110℃ was dropped on the handsheet and the oil penetration observed for 20 min. The amount of oil absorbed was recorded; and the value was converted to percentage of the original oil mass been absorbed. The water absorption was tested using the hot water test 1 mL of 83℃ distilled water (containing 5.0% of lactic acid) was dropped on the handsheet and the water penetration was observed for 20 min. The amount of water absorbed was recorded; and the value was converted to percentage of the original water mass being absorbed.

RESULTS AND DISCUSSION

1. Fiber morphology and analysis

Beating, grinding and refining impart fibers with fibrillation, collapsing and shortening actions. The degree of beating should match the property requirements of the end products in order for the papermaking fiber to produce products having suitable attributes. The pulp fibers used in this study were subjected to fiber analysis using a Kajanni FS200 unit at the Taiwan Pulp and Paper Co. lab. The results of the analysis are shown in Table 1. Softwood fibers are all longer than the hardwood one, with ranking of northern pine > radiate pine > mixed Indonesian hardwoods > eucalypts > acacia. Coarseness (mg/m) of the fiber follows the same order. For the nonwood fibers, abaca was the longest and baggase the second, reed was the shortest. Coarseness of the nonwood fiber had the order of bagasse > abaca > reed.

Along with the increasing beating, proportion of fines increases, hence the number of fibers in an unit mass increases. Hardwood pulps all had higher distribution factors than the softwood ones (acacia > mixed Indonesian hardwoods > eucalypts > northern pine > radiata pine). Among the nonwood fibers reed had the highest number of fibers per unit mass and it was followed sequentially by bagasse and abaca.

Comparing the fiber morphology, among the softwood pulps, northern pine had longer than thinner fibers; radiate pine had shorter and thicker fibers and the former had higher distribution factor. Among the hardwood pulps, eucalypts had the best overall characteristics. And for nonwood fibers, reed pulp had the best overall fiber characteristics. Due to the low porosity tolerance of a greaseproofing paper, for individual fiber types, northern pine, eucalypts and reed were most suitable to serve as raw materials for making greaseproofing paper.

The mill pulp collected from a domestic greaseproofing paper mill, despite of its low freeness of 200 mL CSF, still retained a fair fiber length and had coarseness and distribution factor somewhere between the softwood and hardwood pulps. We judge that the pulp was composed of a softwood and hardwood blend. Mill refining also showed different actions than the beating with a lab valley beater and tended to have relatively greater fibrillation than cutting effects.

Regardless of beaten or not, softwood fibers were longer and coarser than the hardwood ones. Along with increasing degree of beating, pulp freeness lowered and fibrillation, cutting and collapsing effects on the fiber increased, causing fibers to be shorter, thinner and smaller in dimensions. The mixed Indonesian hardwood pulp had long and coarse fibers among the hardwood pulps, the acacia pulp had short and thin fibers and the eucalypts pulp was intermediate in those characteristics. The abaca pulp had the longest fiber among nonwood fibers while bagasse and reed pulps had similar lengths.

2. Effects of pulps and freeness on the greaseproofing property of paper

We fixed the dosages of the wet-end additives and divided pulps into 4 treatments which were respectively (a) control group (without any additive); (b) with wet strength agent, AKD sizing agent, cationic starch, and a dual retention aid system (without the fluorochemical greaseproofing agent); (c) with wet-strength agent, cationic starch, fluorochemical greaseproofing agent and a dual retention aid system (without the AKD sizing agent); and (d) with wet-strength agent, cationic starch, fluorochemical greaseproofing agent and a dual retention aid system (all wet-end additives included); so as to understand the effects of pulp types and freeness on the greaseproofing property of the resulting handsheets.

The effects of pulp types and freeness on the greaseproofing property of handsheets are shown in Fig. 1. Softwood pulp (northern pine > radiata pine) handsheets had better greaseproofing than the hardwood ones (eucalypts > acacia > mixed Indonesian hardwoods). For unbeaten pulps, the sheets had numerous pores and practically no greaseproofing to speak of. Along with increased beating and lowering of pulp freeness, greaseproofing value markedly increased. The mill pulp from a domestic greaseproof paper mill had freeness of only 200 mL CSF, hence a greaseproofing Kit value of 8.2, indicating that the lower the freeness, the denser the formed sheets and the less likely for organic solvent or oil/grease to penetrate them. Comparing the (b), (c) and (d) treatment groups, one found that adding AKD sizing caused sheet to be tighter, and enhanced greaseproofing values. Combining AKD and fluorochemical raised greaseproofing value the most. Addition of fluorochemical tended to reduce the influence of pulp freeness on greaseproofing property (slope reduced). Greaseproof values were proportional to the air resistance. Among the nonwood fibers, bagasse had the best greaseproofing values and it was followed by reed pulp and the abaca was the least greaseproofing.

The effects of pulp types and freeness on waterproofing properties are shown in Fig. 2. Under identical pulp freeness, addition of AKD (b and d groups), lent hardwood handsheets to have better waterproofing properties than did the softwood handsheets; i.e. with less water uptake (mixed Indonesian hardwood > acacia > eucalytps > northern pine > radiata pine). Along with the increasing degree of beating, pulp freeness lowered, and despite of a denser sheet, waterproof value decreased probably due to increased fines that increased specific surface area of the sheet, leading to insufficient AKD coverage, or that AKD reacted preferentially with the fine fractions which were poorly retained. Conversely, without the AKD addition, since hardwood pulps contain vessels and numerous lumens that lent a higher waterproofing value for softwood pulps (northern pine > radiata pine) than the hardwood ones. Along with decreasing pulp freeness of softwood, the sheets became denser and less tendency to imbibe water. Comparing the (b) and (d) groups, as fluorochemical agent attaches to the fiber surfaces it lowered the chance of AKD sizing interacting with the hydroxyl group on fiber which led to reduced waterproofing value, this was particularly notable for the low freeness pulps. Comparing the (a) and (c) groups, because fluorochemical had oil and water repellency which also reduces water uptake. The mill pulp, due to its low freeness exhibited high water absorbency and high oil resistance. Among the nonwood fibers, reed pulp had the highest waterproofing value, it was followed by abaca, and bagasse had the least waterproofing.

The effects of pulp types and freeness on the air resistance of handsheets are shown in Fig. 3. Softwood pulps (northern pine > radiata pine) had higher air resistance than the hardwood ones (eucalypt ≒ acacia >> mixed Indonesian hardwoods). The last pulp had especially thick cell walls that formed bulkier sheets, hence exhibited very low air resistance. The lower the pulp freeness, the denser the sheet and the less air permeable it became. Comparing groups (b), (c) and (d), shows that adding wet-end chemicals generally reduced air resistance of the sheets. This was presumably due to the effect of the high molecular weight anionic flocculent added. AKD sizing had the effect of increasing sheet air resistance, whereas the fluorochemical agent reduced inter-fiber bonding strength and led to decreased sheet air resistance. The mill pulp from a domestic greaseproofing paper maker had low freeness of 200 mL CSF, and hence an air resistance value of 160.8 s/100 mL. Among the nonwood fibers, bagasse had the highest air resistance, reed the next and abaca had the poorest air resistance. Air resistance and greaseproofing property of paper had positive correlation, and for both, the lower the freeness, the better the performance was.

CONCLUSIONS

Based on our fiber analysis of the fiber length, coarseness and distribution characteristics of various pulps and the greaseproofing experiments, softwood pulps (northern pine > radiata pine) had better greaseproofing values using the same treatment as the corresponding hardwood pulps (eucalyptus > acacia > mixed Indonesian hardwoods) did. Unbeaten pulps yielded papers with numerous pores and had practically no greaseproofing to speak of. Greaseproofing property of paper had a positive correlation with the air resistance property. Among the nonwood fibers, bagasse had the best greaseproofing value, reed the next and abaca the worst. With regard to waterproofing property, the order was reversed with hardwood pulp (mixed Indonesian hardwoods > acacia > eucalypts) having superior waterproofing values than the softwood pulps (northern pine > radiata pine); for nonwood fibers, reed pulp had the best waterproofing value, abaca the next and bagasse the worst. With respect to air resistance of paper, softwood pulps (northern pine > radiata pine) had higher values than the hardwood pulps (eucalypts ≒ acacia >> mixed Indonesian hardwoods); for nonwood fibers, bagasse pulp had the best air resistance, reed the next and abaca the worst. Overall, we found northern pine and eucalypts bleached kraft pulp to be most suitable for making greaseproofing paper products. For nonwood fibers, reed pulp was the best. Optimal pulp freeness was in the 200 to 280 mL CSF range.

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Table 1. Fiber analysis results of the experimental pulps

Code	Pulp name	Freeness mL, CSF	Fiber length mm	Fiber coarseness mg/m	Fiber distribution 10^6 fibers/g
N-700	Northern pine BKP	700	2.44	0.202	2.01
N-550		550	2.09	0.186	3.05
N-350		350	1.90	0.185	3.13
R-700	Radiata pine BKP	700	2.34	0.251	1.64
R-550		550	1.99	0.256	2.52
R-350		350	1.75	0.241	2.97
E-600	Eucalypts BKP	600	0.75	0.084	10.2
E-450		450	0.63	0.088	12.6
E-250		250	0.61	0.095	12.8
A-700	Acacia BKP	600	0.66	0.077	13.3
A-450		450	0.53	0.080	18.2
A-250		250	0.40	0.079	25.7
I-600	Mixed Indo-	600	0.93	0.129	7.09
I-450	nesian hw.	450	0.72	0.128	10.3
I-250	BKP	250	0.58	0.118	13.2
L	Reed	627	0.82	0.128	9.17
G	Bagasse	555	0.92	0.166	7.18
M	Abaca	608	2.65	0.131	5.88
U-200	Mill pulp	200	1.04	0.127	7.07

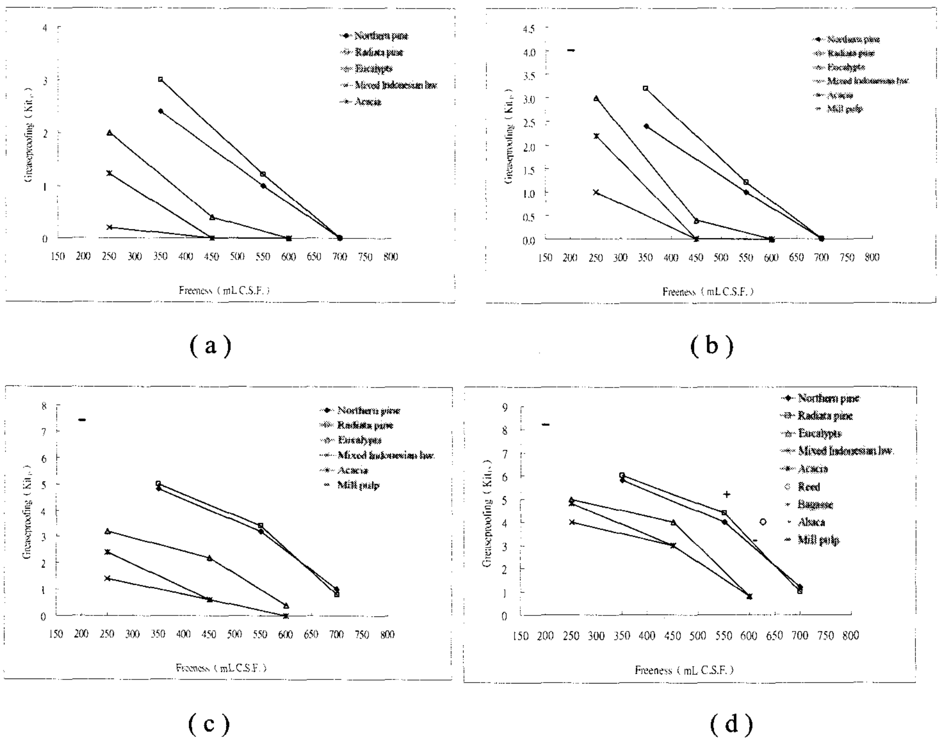

Fig. 1. Effects of pulp types and freeness on the greaseproofing property of paper:

(a) Control (no wet-end chemical addition; (b) All chemicals except the fluorochemical agent;
(c) All chemicals except the AKD sizing; (d) All chemicals added.

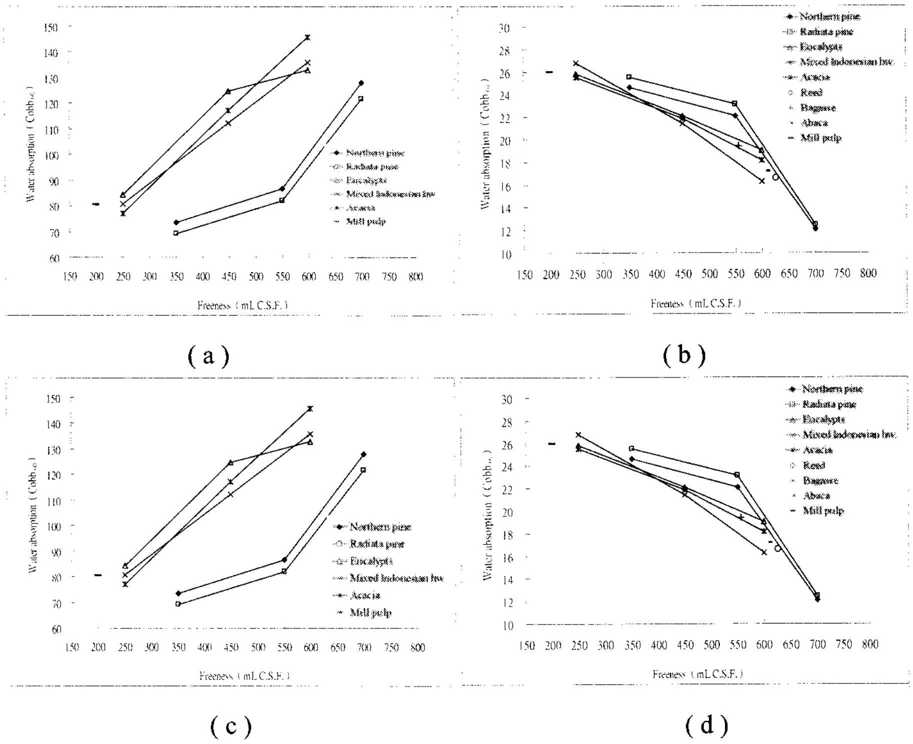

Fig. 2. Effects of pulp types and freeness on the water absorption property of paper.

(a) Control (no wet-end chemical addition; (b) All chemicals except the fluorochemical agent;

(c) All chemicals except the AKD sizing; (d) All chemicals added.

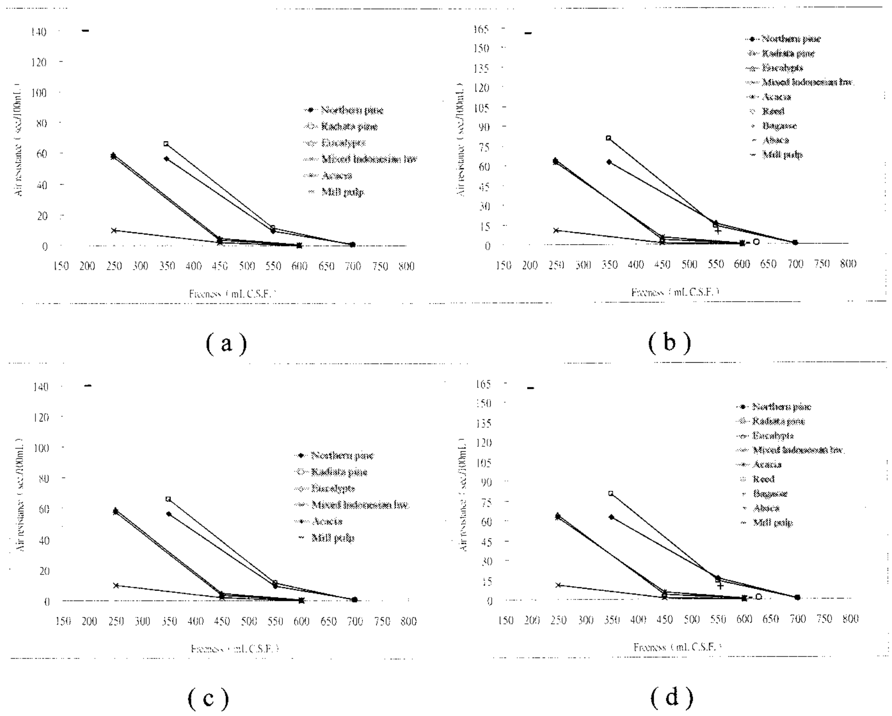

Fig. 3 Effects of pulp types and freeness on the air resistance property of paper.

(a) Control (no wet-end chemical addition; (b) All chemicals except the fluorochemical agent;

(c) All chemicals except the AKD sizing; (d) All chemicals added.