OPTIMIZATION OF HANDSHEET GREASEPROOF PROPERTIES: THE EFFECTS OF FURNISH, REFINING, FILLERS, AND BINDERS

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Internal addition of fluorochemical greaseproof agent was applied to furnishes of different fibers, filler, binder types, and loadings to examine their effects under different degrees of refining on the greaseproof indicators such as air resistance, water absorption, and the Kit values of the resulting handsheets. The results showed that more refining tended to produce a tighter textured paper which was more suitable for the greaseproof purpose. The Kit values of the resulting handsheets were found to correlate with a polynomial regression equation of the Gurley air resistance (A) of the paper with an equation of Kit no. = 2.51 + 0.064 A – 0.002 A^2. The results also showed that furnishes that blended northern softwood and *Eucalyptus* pulps at ratios from 25:75 to 75:25, depending on the strength requirements, had the best greaseproof performance. Among the fillers, sericite was superior to bentonite and PCC for contributing to greaseproof properties. However, filler loading exceeding 6.1% was undesirable. Soluble starch and polyvinyl alcohol were suitable binders for making greaseproof papers. Their dosages should be kept between 0.4 to 1.6%.

Keywords: Greaseproof paper; Fluorochemical greaseproof agent; Kit no.; Degree of refining; Sericite

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INTRODUCTION

Papers and boards having grease barrier functions are commonly called greaseproof container products. These products are mainly used in packaging fast food, baked goods, butter-containing foods, pet food, and occasionally they are used for certificate paper and labels. The functions must enable both oil repellency and oil resistance. Under different applications, certain other functions such as water resistance, air resistance, and wet- and dry-strengths must also be considered (Perng and Wang 2004; Chang and Deisenroth 1996).

Barrier properties to grease and oil can be achieved by applying either a coating or an internal addition of a fluorochemical, by laminating with a polyolefin film (such as PE or PP), by hot-wax treatment, or by sputter-coating with aluminum. Among the four methods, at the moment, the first two methods predominate (Perng and Wang 2004).

Wet end internal addition of the fluorochemical greaseproof agent entails sequential conflux of the chemical with retention aids, sizing agent, wet strength agent, *etc*., which then enters the headbox and forms sheets on paper machine wire. Surface application of the chemical entails using on-machine or off-machine coaters, size presses, or the water box-doctor blade of calender stacks to convert the already-formed base sheet and build a thin film on the surface. Often the fluorochemical is applied together with a starch or polyvinyl alcohol binder (Perng and Wang 2004; Chang and Deisenroth 1996). Although surface applications of fluorochemical can be expected to have better efficacies than internal addition, certain paper machines lack size press or coater, or in the case of paper molding industry, surface application would be impractical. In such cases the papermaker must rely on the mode of internal addition of a fluorochemical.

Perng and Wang (2006) investigated the use of a fluorochemical greaseproof agent in the preparation of molded paper products and found that softwood pulps performed better as the base paper furnishes than did the hardwood pulps. With the presence of aluminum ions in the system at concentrations > 30 mg/L, serious interference could occur. Often oil absorbance showed the same trend as the water absorbance. Over-sizing could also cause interference to fluorochemical performance and reduce the greaseproof efficacy. The study also found that a low-molecular weight highly cationic coagulant polymer followed by a high-molecular weight anionic flocculent polymer gave the optimal greaseproof and waterproof performance. Chang and Deisenroth (1996) discussed the chemical structures of various commercial greaseproof agents, the principle of their actions, and the related applications. Yang *et al.* (1999) compared a surface-coated fluorochemical greaseproof agent on filter paper and newsprint and found the latter required 10 times the dosage to reach the same degree of greaseproofing. About 40% of the increased dosage was consumed by the higher specific surface area of the mechanical pulp, and the other 60% was affected by the presence of solvent-extractable compounds (such as resins). The minimum effective coat weight of the fluorochemical greaseproof agent was 10 mg/m^2. By reducing the pitch content in wood pulp combined with the use of a hydrophobic modified starch, the necessary dosage of the fluorochemical could be reduced. Giatti (1996) described his experience at the Cartiere Cima S.p. A. mill on the internal addition and surface coating applications of manufacturing greaseproof paper. His furnishes consisted of three pulps: birch kraft pulp, pine kraft pulp, and fir sulfite pulp. The furnish was highly refined to make base paper with tighter texture, lower air resistance, and enhanced greaseproof quality. Wolford (1997) noted the production of greaseproof paper from the PM 10 of the Camas mill using internal addition at wet end and size press. The furnish they used, however, was not described. Wyser *et al.* (2002) developed a method for testing the degree of greaseproof for pet food packaging. Kjellgren and Engstrom (2005) noted in their paper on energy requirement and greaseproof properties, that blend ratio of furnish and degree of refining could be used to control the degree of greaseproofing, and that air resistance of the base paper is an indicator of the greaseproof degree. Under the same air resistance, a 100% sulfite pulp furnish produced base paper having better greaseproof properties than a 50%/50% blend of sulfite and kraft pulps, although the former had poorer tear resistance. Refining could improve the barrier properties, but it would require input of extra energy. Under a minimum energy input scenario, using calendar and/or coating could improve the barrier properties. Jonhed and Jarnstrom (2009) investigated the properties of hydrophobically-modified quaternary ammonium starch ethers for paper sizing. The results showed that contact angles on greaseproof paper decreased upon surface sizing as compared to unsized greaseproof paper, independently of pH and temperature.

Greaseproof paper showed no great difference between unsized substrates and substrates sized with starch at different pH. Goswami *et al.* (2008) utilized banana pulp fiber to produce greaseproof paper. At 80 °SR freeness, the pulp becomes hydrated and forms a jelly-like stock. The paper made from this hydrated pulp stock shows the characteristics of greaseproof paper with burst index 6.10 kPa m^2/g, tear index 7.00 mNm^2/g, and tensile index 51.2 N/mg with very good blister and oil resistibility. The physical strength properties of the paper may further be enhanced by incorporating 20% bamboo pulp beaten up to 85 °SR freeness and mixed with banana semi bleached pulp stock beaten up to 85 °SR freeness.

Perng *et al.* (2006) investigated the effects of applying fluorochemical by internal addition to furnishes which consisted of individual blends of two softwood pulps and three hardwood pulps refined to different degrees on the greaseproof indicators (air resistance, Kit values, and water absorption) of the resulting handsheets. The results indicated a positive correlation between the degrees of greaseproofing and air resistance of the paper. Softwood pulps tended to have higher water absorption than the hardwood pulps. The furnish that blended northern softwood pulp with eucalyptus pulp was most suitable for making greaseproof base paper.

The objectives of this study were to extend the above work and investigate the effects of an internal addition of fluorochemical greaseproof agent to pulp furnishes of the two softwood and three hardwood pulps individually blended at various ratios and refined to different degrees, with the addition of three fillers (PCC, bentonite, and sericite), and four binders (cationic starch, ethylated starch, soluble starch, and polyvinyl alcohol) on the final handsheet paper performances with regard to the main greaseproof indicators (air resistance, Kit value, and water absorption). Through this more comprehensive study, we hoped to find the optimal formulations for preparing greaseproof paper, as well as to discern factors influencing the greaseproof characteristics of the papers. The softwood pulps used were bleached northern softwood kraft pulp and bleached radiata pine pulp; the hardwood pulps included a bleached *Eucalyptus* pulp, a bleached mixed Indonesian hardwoods pulp, and a bleached *Acacia* kraft pulp.

EXPERIMENTAL

The study was conducted in three stages. In the first stage, we investigated the effects of individual pulp types (two softwood pulps and three hardwood pulps), as well as the degree of refining on the indicators of greaseproof performance. In the second stage, we employed a mill site furnishing principle to blend the softwood and hardwood pulps separately for a total of six combinations and investigated the effects of furnishes on the indicators of greaseproof performance. In the third stage, additionally, we added three fillers and four binders together with the fluorochemical greaseproofing agent to examine the combinatory effects on the indicators of greaseproof performance. The indicators of greaseproof performance are air resistance, the Kit value, and water absorption. The methods and apparatus used in the study were: Pulp freeness (TAPPI T227 om-99; Liensheng, Taiwan); handsheet property tests: grammage (TAPPI T410 om-95), air resistance (TAPPI T460 om-96, Gurley method; Liensheng, Taiwan), greaseproof Kit test (TAPPI T559 pm-96, oil kit test), water absorption (TAPPI T441 om-98, Cobb sizer; Toyoseike, Japan), and ash content (TAPPI T211 om-02 and TAPPI T413 om-02).

There were five experimental pulps: bleached northern softwood kraft pulp (long-fiber, from wood chips containing 5% Douglas-fir, 45 to 50% lodgepole pine, and 45 to 50% white spruce; Prince George Mill, Canfor, Canada); bleached radiata pine kraft pulp (long-fiber, Arauco, Chile); bleached *Eucalyptus* kraft pulp (short-fiber, Arauco, Chile); bleached *Acacia* kraft pulp (short-fiber, P.T. Tel, Indonesia); and bleached mixed Indonesian hardwoods pulp (short-fiber, Riau, Indonesia).

The three fillers used included: PCC (Chiada Chemicals, Tainan, Taiwan, particle size 6 μm）; sericite (Sungloss, particle size 14 μm; Sunmica Co., Taitung, Taiwan); and bentonite (Bayashi Chemicals, Japan; particle size: 90% < 200 mesh). The binders used were: cationic starch (Katex-H, Hsietai Chemicals, Kaohsiung, Taiwan); ethylated starch (PS-85, Hsietai Chemicals, Kaohsiung, Taiwan); soluble starch (Ishizu Seiki, Japan); and polyvinyl alcohol (BP 14, Changchun Chemicals, Kaohsiung, Taiwan).

Pulp refining in the laboratory was based on simulations of the mill site furnishing principles. A laboratory Valley beater (Liensheng, Taiwan) was used to refine the pulps. The softwood pulps were refined from their original freeness to both 550 and 350 mL CSF; and the hardwood pulps were refined from their original freeness to both 450 and 250 mL CSF.

Addition of wet end chemicals was also simulating the on-site practice with the following chemicals addition sequence and dosages: wet strength agent (Kymere 557, 0.4%; Hercules, Taiwan); a low-molecular weight highly cationic coagulant polymer (Nalco 7607, 0.3%, Taiwan); AKD size (Hercon 76, 0.3%; Hercules, Taiwan); fluorochemical greaseproof agent (FC-807, 0.12%; 3M Inc.); and a high-molecular weight anionic flocculent polymer (Nalco 625, 0.2%, Taiwan). Handsheet formation was based on the method of TAPPI T205 sp-95. The actual procedure was as follows:

1) Disintegrate the pulp with a standard disintegrator;
2) Add filler separately at 10, 15, and 20% dosages and/or binders (0~1.4%), and maintain stirring;
3) Adjust the pH of the furnish to 7.5 using Na_2CO_3 under continued stirring;
4) Add 0.40% of Kymene 557, stir for 60 s;
5) Add 0.35% Nalco 7607, stir for 60 s;
6) Add 0.30% Hercon 76, stir for 60 s;
7) Add 0.12% FC-807, stir for 60 s;
8) Add 0.20% Nalco 625, stir for 60 s;
9) Form handsheets of 60 g/m^2 using a standard sheet mold and air-dry overnight;
10) Condition the handsheets in a constant temperature and humidity room for > 3 h.
11) Proceed with indicators of greaseproof performance of handsheet tests.

For estimation of the experimental standard deviations, two sets were selected randomly and replicated, each of them once more. The results were used to calculate standard deviations. These two standard deviations were then pooled to provide an indication of the systematic standard deviation, with 2 degrees of freedom.

RESULTS AND DISCUSSION

Effects of Individual Pulp and Degrees of Refining on Greaseproof Indicators of the Handsheets

Air resistance

The influences of pulps and degrees of refining on the air resistance of the handsheets are shown in Fig. 1. The pooled standard deviations of pulp freeness and air resistance were 7.6 mL CSF and 3.1 s/100 mL air, respectively, with 2 degrees of freedom. Longer time in seconds means that the paper surface was smoother and less permeable. Thus, the higher the degrees of refining, the lower the pulp freeness, the tighter textured, and the higher the air resistance of the handsheets became. Under the same pulp freeness, softwood pulps had higher air resistance than the hardwood pulps, with the decreasing order of radiata pine, northern softwood, *Eucalyptus*, *Acacia*, and Indonesian hardwoods. The average cell wall thickness of the Indonesian hardwoods was 7.3 μm (Hillman, 1998), resulting in handsheets of very high bulk and coarse surface texture, hence the shortest time in air resistance. Apparently, refining was unable to modify the property of this pulp.

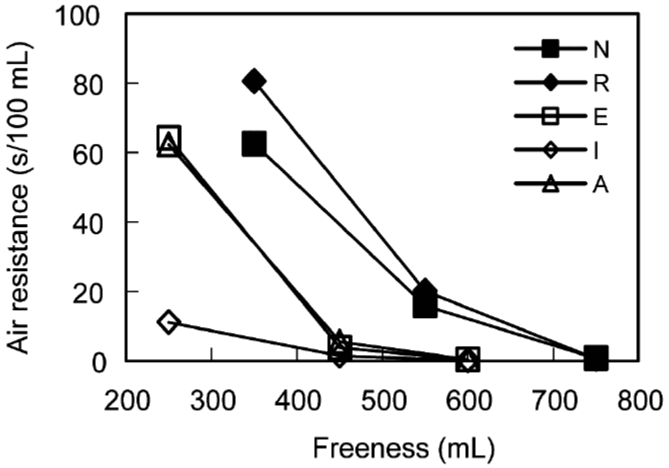


Fig. 1. Effects of freeness and pulps on the air resistance
N: northern softwoods, R: radiata pine, E: *Eucalyptus*, I: Indonesia hardwoods, A: *Acacia*

Kit values

Figure 2 shows the effects of pulps and degrees of refining on the greaseproof Kit values of the resulting handsheets. The pooled standard deviation of Kit value was 0.29, with 2 degrees of freedom. The higher the Kit value, the better the greaseproof property. Unrefined pulps generally produce papers with higher porosities and high air resistance. The papers had a more open structure and often with Kit values less than 1.0, and had no greaseproof efficacy. Along with the refining, pulp freeness decreased, air resistance increased, and the Kit values increased proportionally. Under the same freeness, softwood pulps had higher Kit values than the hardwood pulps, with the decreasing Kit order of radiata pine, northern softwood, *Eucalyptus*, *Acacia*, and Indonesian hardwoods.

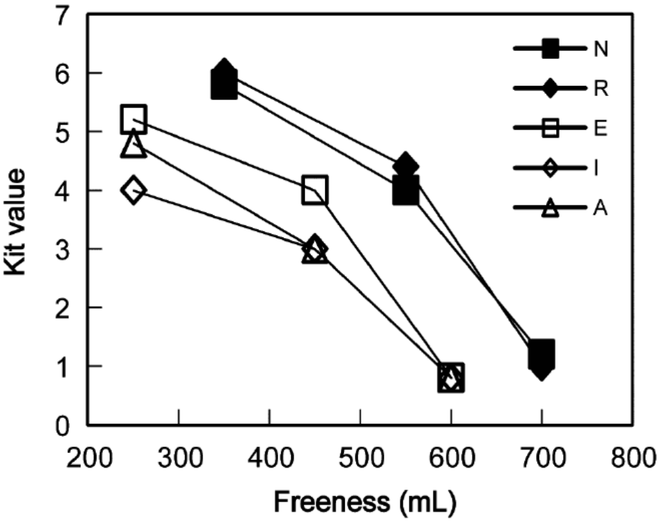


Fig. 2. Effects of freeness and pulps on the greaseproof property
N: northern softwoods, R: radiata pine, E: *Eucalyptus*, I: Indonesia hardwoods, A: *Acacia*

Water absorption

Influences of the pulps and degrees of refining on the water absorption property of the handsheets are shown in Fig. 3. The pooled standard deviation of water absorption was 0.66 g/m^2, with 2 degrees of freedom. Water absorption was represented by the Cobb size value. The lower Cobb value corresponded to high waterproof. The results indicated that the Cobb value increased with the increasing pulp refining. Under the same freeness, softwood pulps tended to have higher amounts of water absorption than those of the hardwood pulps. The decreasing order of pulp water absorption was: radiata pine, northern softwoods, *Acacia* ≈ *Eucalyptus*, Indonesian hardwoods.

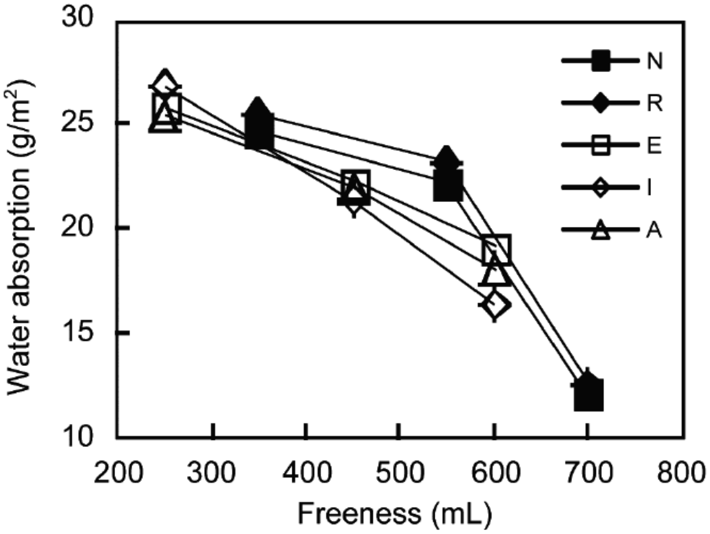


Fig. 3. Effects of freeness and pulps on the water absorption
N: northern softwoods, R: radiata pine, E: *Eucalyptus*, I: Indonesia hardwoods, A: *Acacia*

Effects of Blended Furnishes on the Greaseproof Indicators of the Handsheets

In compliance with the on-site practice, the two softwood pulps at 350 mL CSF were individually blended with the three hardwood pulps at 250 mL CSF for a combination of six sets. Within each set, different ratios of softwood/hardwood were included so as to investigate the effects of blended furnishes on the greaseproof indicators of the resulting handsheets.

Air resistance

The results of blended softwood/hardwood furnishes on the air resistance of the handsheets are shown in Fig. 4. The pooled standard deviations of pulp freeness and air resistance were 6.1 mL CSF and 2.5 s/100 mL air, respectively, with 2 degrees of freedom. The results indicated that along with more and more *Acacia* pulp proportions, furnishes tended to have higher air resistance. However, when *Acacia* pulp made up more than 50% of furnishes, air resistance reverted and became lower. Thus a furnish blending 50/50 of softwood/*Acacia* pulp had the highest air resistance (102 s/100 mL air). Blending *Eucalyptus* and Indonesian hardwoods pulps did not appear to benefit air resistance property. The coarse, thick-walled Indonesian hardwoods pulp, in particular, caused the air resistance to decrease along with its increased proportions in furnishes. Conceivably, it caused the paper structure to become looser and bulkier, and air can pass through the paper easier. The overall ranking in handsheet air resistance was: northern softwood/*Acacia*, radiata pine/*Acacia*, northern softwood/*Eucalyptus* ≈ radiata pine/*Eucalyptus*, radiata pine/Indonesian hardwoods, and northern softwoods/Indonesian hardwoods.

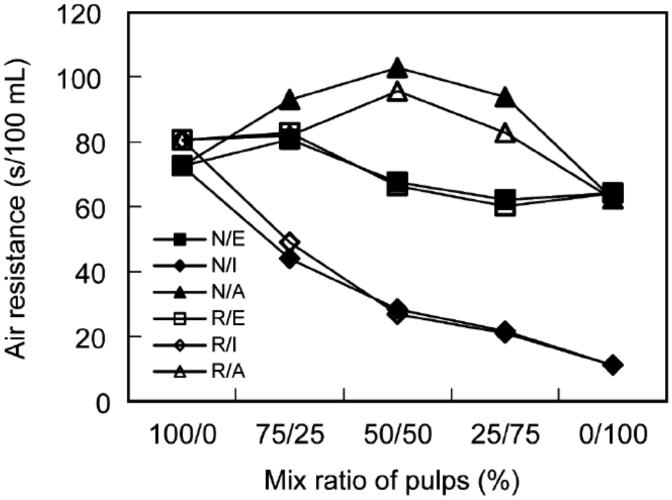


Fig. 4. Effects of furnishes on the air resistance
N: northern softwoods, R: radiata pine, E: *Eucalyptus*, I: Indonesia hardwoods, A: *Acacia*

The Kit values

Figure 5 shows the influence of blending softwood/hardwood pulps on the greaseproof Kit values of the resulting handsheets. The pooled standard deviation of Kit value was 0.35, with 2 degrees of freedom. The results indicated that blending 25% hardwood pulps (25 to 50% for the *Eucalyptus* pulp) to softwood pulps resulted in higher

Kit values. When more hardwood pulps were blended, however, the Kit values decreased. Thus, softwood pulps blended with *Eucalyptus* pulp gave the best Kit values. Blending with *Acacia* fared moderately, and yet blending with Indonesian hardwoods contributed little to the greaseproof characteristics. The overall ranking was: northern softwood/*Eucalyptus*, radiata pine/*Eucalyptus*, radiata pine/*Acacia*, northern softwood/ *Acacia*, and radiata pine/Indonesian hardwoods ≈ northern softwood/Indonesian hardwood.

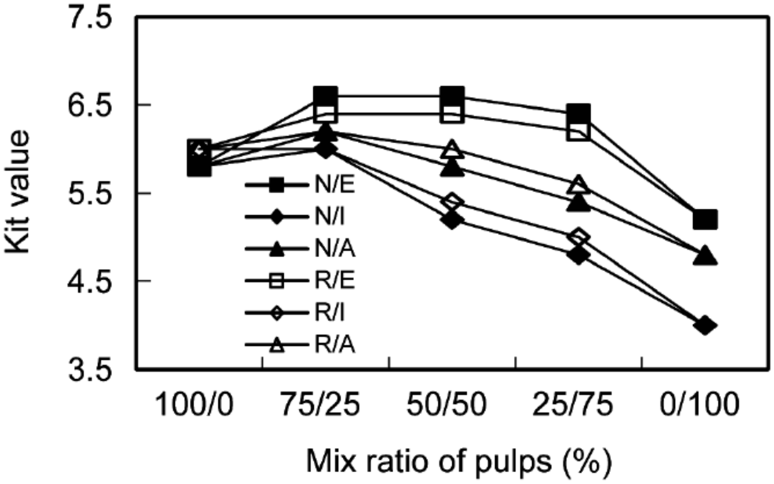


Fig. 5. Effects of furnishes on the greaseproofing property
N: northern softwoods, R: radiata pine, E: *Eucalyptus*, I: Indonesia hardwoods, A: *Acacia*

Water absorption

The effects of blending softwood/hardwood pulps at various ratios on the resulting handsheet water absorption are shown in Fig. 6. The pooled standard deviation of water absorption was 0.58 g/m^2, with 2 degrees of freedom. The results indicated that blending hardwood pulps to softwood reduced water absorption, *i.e.*, increased the water resistance.

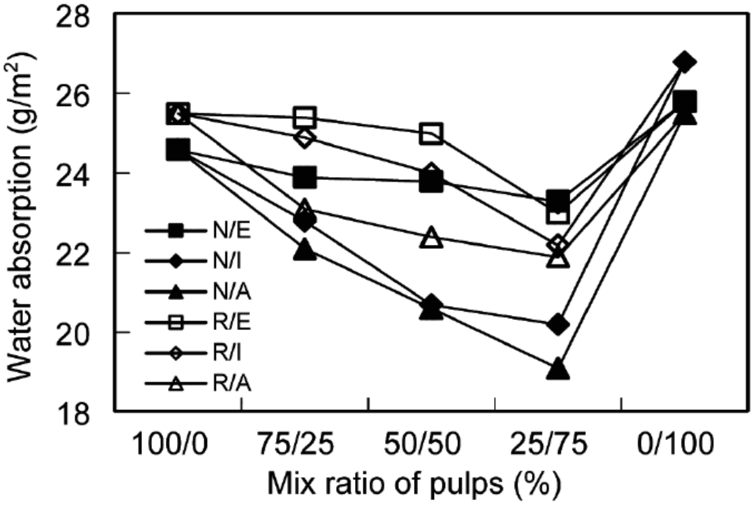


Fig. 6. Effects of furnishes on the water absorption
N: northern softwoods, R: radiata pine, E: *Eucalyptus*, I: Indonesia hardwoods, A: *Acacia*

The degree of water absorption decrease was largely proportional to the amounts of hardwood pulps. Individual pure hardwood pulps, however, had the highest water absorption values, greater than those of the softwood pulps (their freeness differed). When northern softwoods pulp was blended with *Acacia* pulp, the handsheets prepared from the furnish had the lowest water absorption; whereas the furnishes with *Eucalyptus* pulp were most water absorbent. The decreasing order of the blended furnishes was: radiata pine/*Eucalyptus*, radiata pine/Indonesian hardwoods, northern softwoods/ *Eucalyptus*, radiata pine/*Acacia*, northern softwoods/Indonesian hardwoods, and northern softwoods/*Acacia*.

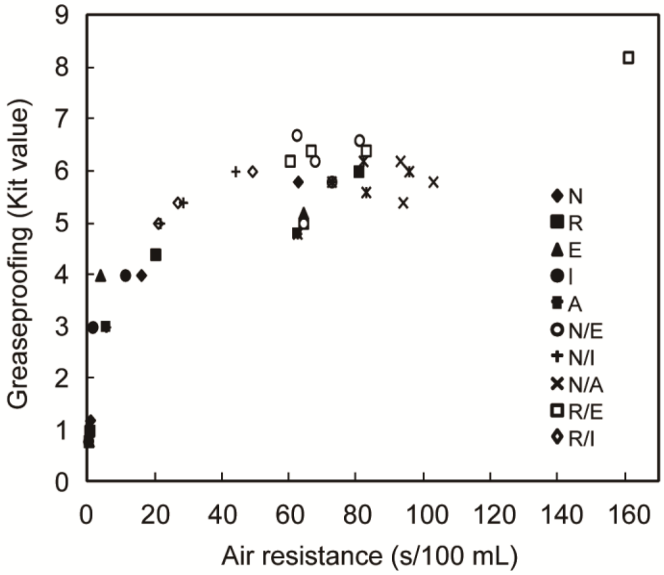


Fig. 7. Effect of air resistance on the greaseproof property
N: northern softwoods, R: radiata pine, E: *Eucalyptus*, I: Indonesia hardwoods, A: *Acacia*

Based on our results of the individual pulps and blended furnishes, a positive correlation between the Kit values and air resistance was discernible when these are plotted together as in Fig. 7. Thus, at a fixed greaseproof agent and wet end chemical regime, the Kit values that correlated to air resistance (A, s/100 mL) exhibited a polynomial relationship. The SPSS nonlinear regression then gave the following equation:

$$\text{Kits value} = 2.51 + 0.064\,A - 0.002\,A^2 \qquad R^2 = 0.73 \tag{1}$$

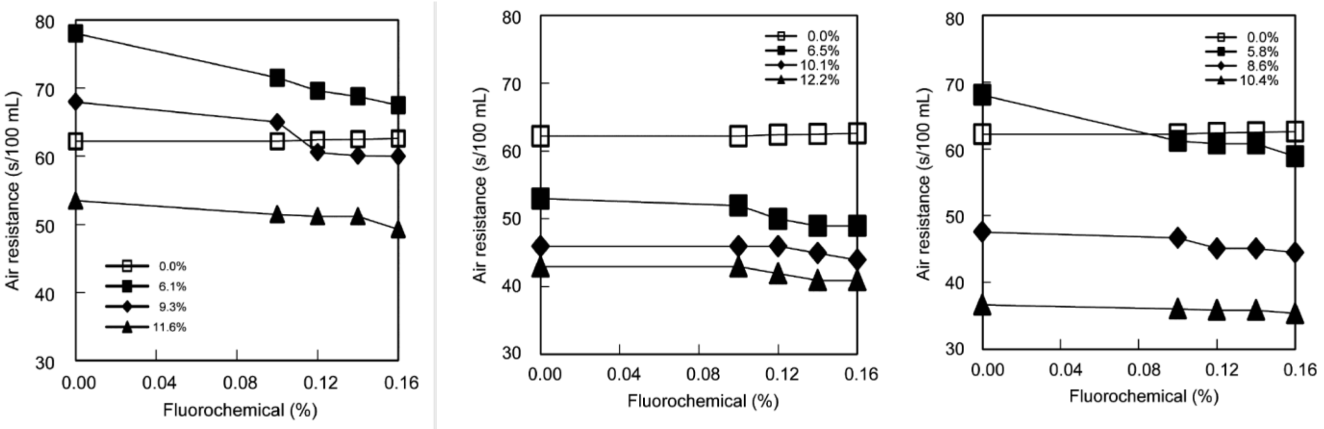
Although there appears to be a good correlation between the Kit value and air resistance of the handsheets, at air resistance of 70 s/100 mL air, several experimental sets showed substantial deviations. At the same smoothness values, most of the mixed pulp sets would have a Kit value higher than pure blends. We assume tentatively that at 70 s/100 mL air smoothness, the surface pore structures or sizes were such that the fluorochemical would be unable to form an effective layer with the hydrophobic ends of the molecular aligned and pointed outward. Mixed blend for the same reason might have fibers of different coarseness complementing each other and minimize the unfavorable pore structure/size, thus producing better greaseproof efficacies. The real reasons for the phenomena still require further investigation.

Effects of Filler Additions on the Greaseproof Indicators of the Handsheets

Although most commercial greaseproof paper products are unfilled, from the above correlation between the Kit value and degree of air resistance, fillers, particularly the platy type may help build a barrier to air flow and influence the greaseproof properties. Perng and Wang (2004) and Perng *et al.* (2008) applied a layered inorganic sericite mica powder as a wet end additive and found an enhanced first pass retention, better bulk, and air resistance in the resulting paper. In this study, we again selected sericite (platy, partially swelling), bentonite (platy, fully swelling), and PCC (rhombohedral shaped calcite) to examine the effects of incorporating them in the preparation of greaseproof handsheets (furnish: radiata pine (350 mL CSF) / *Eucalyptus* (250 mL CSF = 50%/50%). Filler loadings were 10, 15, and 20% with respect to dry pulp. Actual amounts of retained ash for the sericite, bentonite, and PCC were determined to be 6.1, 6.5, and 5.8% (for the 10% loading); 9.3, 10.1, and 8.6% (for the 15% loading), and 11.6, 12.2, and 10.4% (for the 20% loading), respectively.

Air resistance

The effects of adding each of the three fillers together with the fluorochemical greaseproof agent on the air resistance of the resulting handsheets are shown in Fig. 8. The pooled standard deviation of air resistance was 2.6 s/100 mL air, with 2 degrees of freedom. The results indicated that when unfilled, addition of the greaseproof agent did not affect air resistance of the handsheets. In the filler groups, however, an increase in the fluorochemical dosages tended to decrease the air resistance value. This phenomenon could be caused by the fluorochemical adsorbing onto filler particles or fiber surfaces forming hydrophobicity, which in turn affected the contacting points or faces between filler and fiber, leading to reduced air resistance.



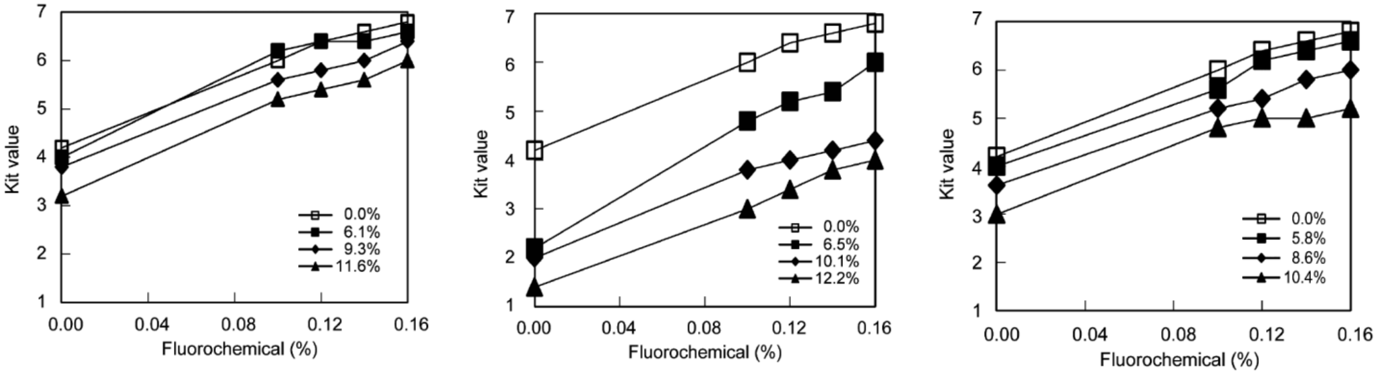
(A) Sericite (B) Bentonite (C) PCC

Fig. 8. Effects of fluorochemical and ash content on the air resistance

In the case of sericite, bentonite, and PCC, the addition of more fillers generally decreased the air resistance value. However, the sericite-treated group tended to have air resistance greater than the bentonite and PCC groups, which was consistent with the results of Perng and Wang (2004). The reason for the observation was not clear, perhaps in part because the platy mineral formed a stacked structure within the fiber network that blocked the flow paths of air. Bentonite is also a platy mineral of aluminum-silicate, however, it showed no synergistic effect with the fluorochemical agent. PCC, on the other hand, with its rhombohedral-shaped particle, may contribute to an increase in the porosity of paper at higher loadings, thus reduced air resistance.

The Kit values

Figure 9 shows the effects of incorporating the three fillers together with different dosages of the fluorochemical greaseproof agent on the Kit values of the resulting handsheets. The pooled standard deviation of Kit value was 0.38, with 2 degrees of freedom. The figure shows that adding fillers would decrease the Kit values, as fillers have intrinsic lipophilicity and will pick up grease or oil. Yet, for the sericite at ash loading of 6.1%, the Kit value had a similar trend as the control. Only at ash loading of 9.3 and 11.6% did it lag behind with the increasing ash content. We speculate that the layered structure of sericite interlaced with fibers was effective in forming a tightly adsorbed microparticle system in the paper sheet that acted as a barrier to the penetration of oil. Excessive amounts of the filler, however, might include numerous loosely bonded particles that were not helpful to the greaseproof property. Bentonite, although also a layered and more easily exfoliating filler, might have overly large particles, and its nature to swell in liquid might entrain water and allow excessive amount of fluorochemical to adsorb on its large specific surface areas. Thus, incorporation of bentonite might actually imbibe oil into the interstices, thus lowering the Kit value. This was consistent with the observation that along with an increase in bentonite ash content, the Kit value decreased precipitously. PPC, with its rhombohedral shape did not help to create a tight layered barrier structure. Thus, along with an increase in its retention, greaseproof quality decreased, although the decrease was not as serious as the handsheets incorporating bentonite.

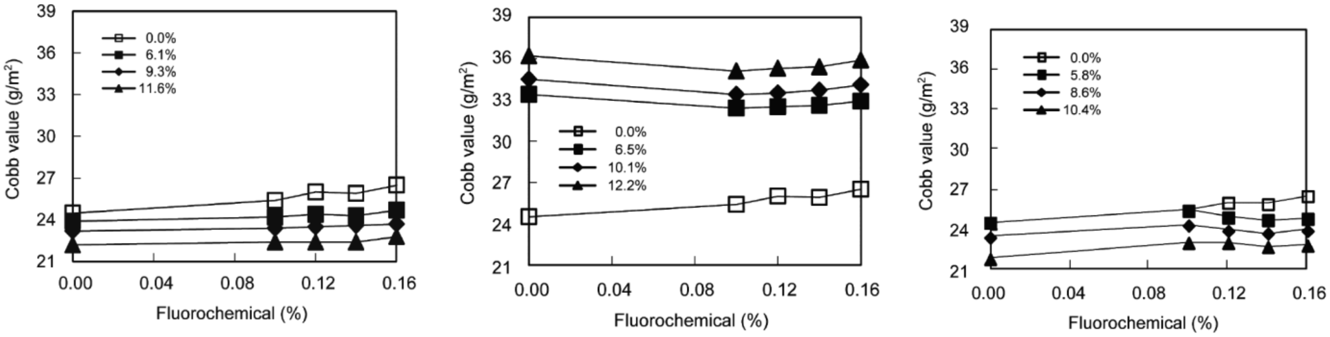


(A) Sericite (B) Bentonite (C) PCC

Fig. 9. Effects of fluorochemical and ash content on the greaseproof property

Water absorption

The influences of the filler content and fluorochemical dosages on the water absorption of handsheets incorporating them are shown in Fig. 10. The pooled standard deviation of water absorption was 1.0 g/m^2, with 2 degrees of freedom. The results indicated that adding sericite and PCC could lead to reduced water absorption along with an increase in ash retention. Bentonite, however, due to its swelling and water entraining capability, would cause the handsheets to absorb more water when the ash retention increased. Interactions between the fillers and the fluorochemical agent appeared to be relatively weak, causing only minor differences when the fluorochemical dosage changed. For the unfilled paper, increasing the fluorochemical dosage actually caused the handsheets to absorb slightly more water. With the presence of fillers, however, the reverse was true for the PCC and bentonite group, while sericite group showed a slight increasing trend with the fluorochemical dosage.



(A) Sericite

(B) Bentonite

(C) PCC

Fig. 10. Effects of fluorochemical and ash content on the water absorption

Effects of Adding Binders on Greaseproof Indicators of Handsheets

Currently, the commercial greaseproof paper often adds cationic starch in the wet end as a binder and retention aid (Chang and Deisenroth 1996; Giatti 1996; Wolford 1997). In our study, ethylated starch, soluble starch, and polyvinyl alcohol were tested to replace cationic starch, and their influence on the greaseproof indicators of the resulting handsheets were examined.

Air resistance

Effects of the binders on the air resistance of the handsheets are shown in Fig. 11. The pooled standard deviation of air resistance was 2.3 s/100 mL air, with 2 degrees of freedom. The results indicated that binder dosages were positively correlated to the air resistance of the handsheets. Soluble starch and ethylated starch showed similar trends; the former had slightly better air resistance than the latter. Polyvinyl alcohol did not perform as well with regard to air resistance but was still superior to that of cationic starch. The influence of binders on air resistance was probably related to the difference in their film-forming capability. Along with increased binder dosages, the film after drying probably became thicker and offered more resistance to the passage of air. Another possibility is that the soluble and ethylated starch had relatively weak cationic charges, which are less likely to interfere with the action of the anionic flocculent agent added, which causes the handsheets to have slightly better formation, hence a better air resistance performance.

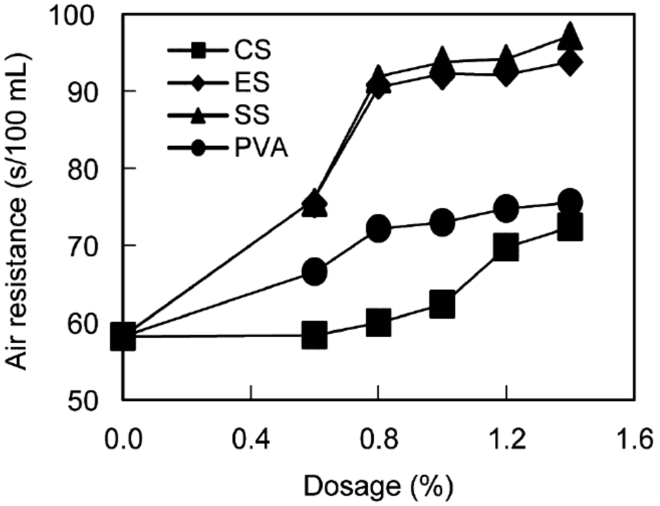


Fig. 11. Effects of binders on the air resistance
CS: cationic starch, ES: ethylated starch, SS: soluble starch, PVA: polyvinyl alcohol

The Kit values

The effects of binders on the Kit values of the resulting handsheets are shown in Fig. 12. The pooled standard deviation of Kit value was 0.16, with 2 degrees of freedom. The results showed that in general, the binder dosages were positively correlated with the Kit values of the handsheets. The Kit value in decreasing order was: cationic starch, ethylated starch, water soluble starch, and polyvinyl alcohol. When ethylated starch dosages exceeded 0.8%, the Kit values remained constant (6.2); the same happened to soluble starch at dosages above 1.2% (Kit value 6.2); whereas at polyvinyl alcohol dosages above 1.0%, the Kit value leveled off as well.

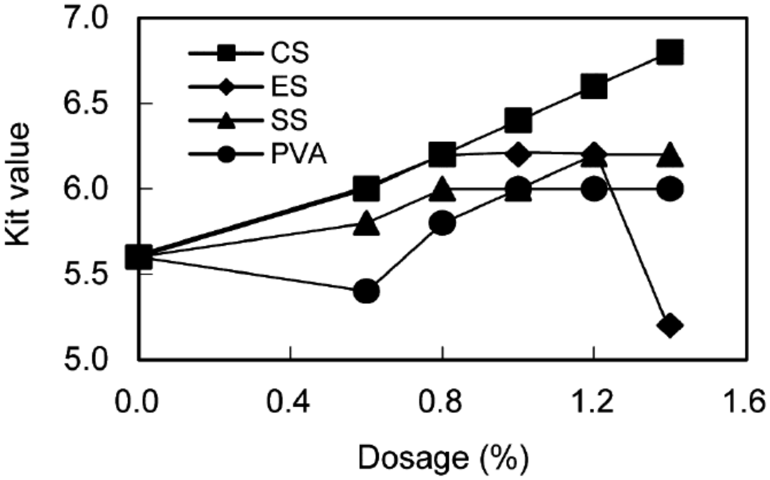


Fig. 12. Effects of binders on the greaseproof property
CS: cationic starch, ES: ethylated starch, SS: soluble starch, PVA: polyvinyl alcohol

Water absorption

Figure 13 shows the effects of adding binders on the water absorption of the resulting handsheets. The pooled standard deviation of water absorption was 0.24 g/m^2, with 2 degrees of freedom. Except for the ethylated group, an increase in binder dosages tended to decrease water absorption. Once polyvinyl alcohol is dried and forms films, it is soluble in water, hence incorporating it decreased water absorption. The other binders in decreasing capability to limit water absorption were: soluble starch, ethylated starch, and cationic starch. For the ethylated starch, however, an increase in dosage entailed an initial decrease and then increased water absorption.

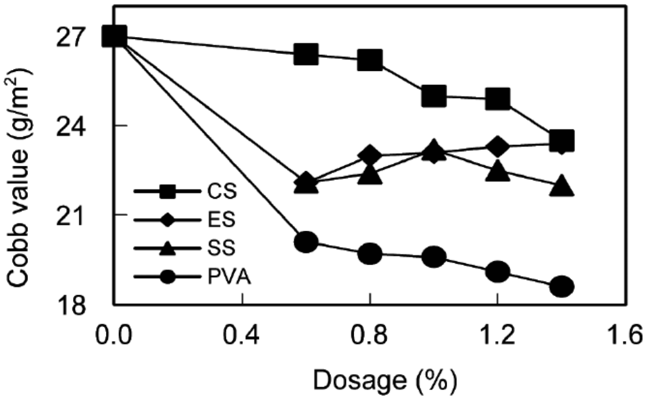


Figure 13. Effects of binders on the water absorption
CS: cationic starch, ES: ethylated starch, SS: soluble starch, PVA: polyvinyl alcohol

CONCLUSIONS

For individual pulps and degree of refining effects on the greaseproof indicators of the resulting handsheets, the softwood fibers had high air resistance, greater Kit values, and higher water absorption than did the hardwood fibers. Except for the higher water absorption, the thick-walled mixed Indonesian hardwood pulp tended to produce handsheets with the most open structure, hence the highest air permeability and the least Kit values. When individual softwood and hardwood pulps were blended at various ratios, the resulting furnishes often have modified performance in the greaseproof indicators. Blending of northern softwoods pulp with *Acacia* produced the least air permeable handsheets; the softwood-*Eucalyptus* blends had intermediate air resistance; and the softwood-Indonesian hardwoods blends produced the highest air resistance. For the greaseproof Kit values, however, the northern softwoods-*Eucalyptus* blend had the best performance; the softwood-*Acacia* blends were intermediate, and the softwood-Indonesian hardwoods blends were the poorest. As for water absorption of the mixed furnishes, radiata pine-*Eucalyptus* was the most absorbent; whereas the northern pine-*Acacia* blend was the least absorbent. A second order polynomial correlation between the Kit value and air resistance (A) was found to be:

$$\text{Kit value} = 2.51 + 0.064\ A - 0.002\ A^2$$

The experimental results suggested that furnishes consisting of northern softwoods pulp and *Eucalyptus* pulp at 75:25 or 25:75 ratios, depending on the strength requirement, were the most suitable for making greaseproof paper under the conditions examined. Sericite, a mica mineral, was more suitable for use in greaseproof paper, provided the ash content should be kept at a relatively low level of 6.1%. Cationic starch compared more favorably to impart greaseproof capability to handsheets than did ethylated and soluble starches, and polyvinyl alcohol. The dosages should be 0.4 to 1.6%, depending on the wet end requirement.

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