

Impact of high-yield pulp substitution on the brightness stability of uncoated wood-free paper

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ABSTRACT: Without any fillers and optical brightening agents (OBAs), 15%–20% substitution of high-yield pulps (HYPs) for the hardwood bleached kraft pulp (BKP) in a paper furnish can decrease the brightness stability significantly because HYP contains a large amount of lignin. However, using mineral fillers such as precipitated calcium carbonate (PCC) and OBA in a HYP-containing paper can essentially eliminate the negative effect of HYP substitution on the brightness stability of uncoated wood-free paper. During the commercial production of traditional wood-free paper products, which usually use both PCC and OBA, 15%–20% HYP substitution for the hardwood BKP will not have practical impact on the paper brightness stability. Results from commercial printing and writing paper production support the same conclusion.

Application: Papermakers can produce high-quality uncoated wood-free paper using high-yield pulp without affecting the brightness stability.

Increasingly, high-yield pulp (HYP) has been used in printing and writing paper grades due to its unique properties, including high bulk and high light-scattering coefficient. Technological advances in HYP manufacturing have made it practical to produce various grades of HYP with suitable strength and brightness for use in many value-added paper products, which had been made almost exclusively with fully bleached kraft pulps (BKP) [1–5]. However, HYP's tendency to yellow upon UV exposure has been a drawback to realizing the great potential of HYP application in printing and writing paper grades such as uncoated wood-free paper.

Mechanical pulp-based paper products like newsprint turn yellow and lose brightness readily under sunlight or office fluorescent light. Paper made from BKP is much more stable due to lower lignin content. In contrast, HYP has a pulp yield between 80%–90% and almost all the lignin from the wood raw material is preserved. The light-induced color reversion of lignin-rich mechanical pulp fibers is the main cause of the brightness loss of HYP-containing paper [6], although thermal yellowing and air pollution can also lead to paper discoloration to some degree [7–9]. Approaches to inhibit the light-induced yellowing of mechanical pulp, including lignin modification and addition of radical scavengers and/or UV absorber [10–20], have not yet been economically feasible in an industrial scale application because of the high cost of the chemicals and incompatibility with the papermaking process.

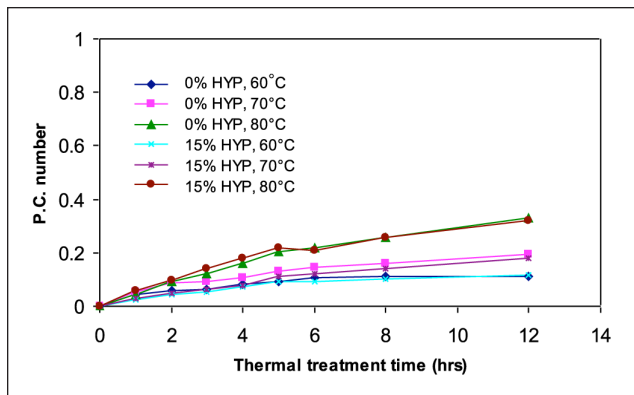
Pigment coating can effectively improve the brightness stability of mechanical paper [21, 22]. Yuan et al. [21] investigated the effect of HYP substitution on the brightness stability of coated paper. Those results showed that a 10%–20%

HYP substitution for hardwood BKP had negligible effect on the brightness stability because the coating layer can effectively protect HYP fibers from harmful UV radiation.

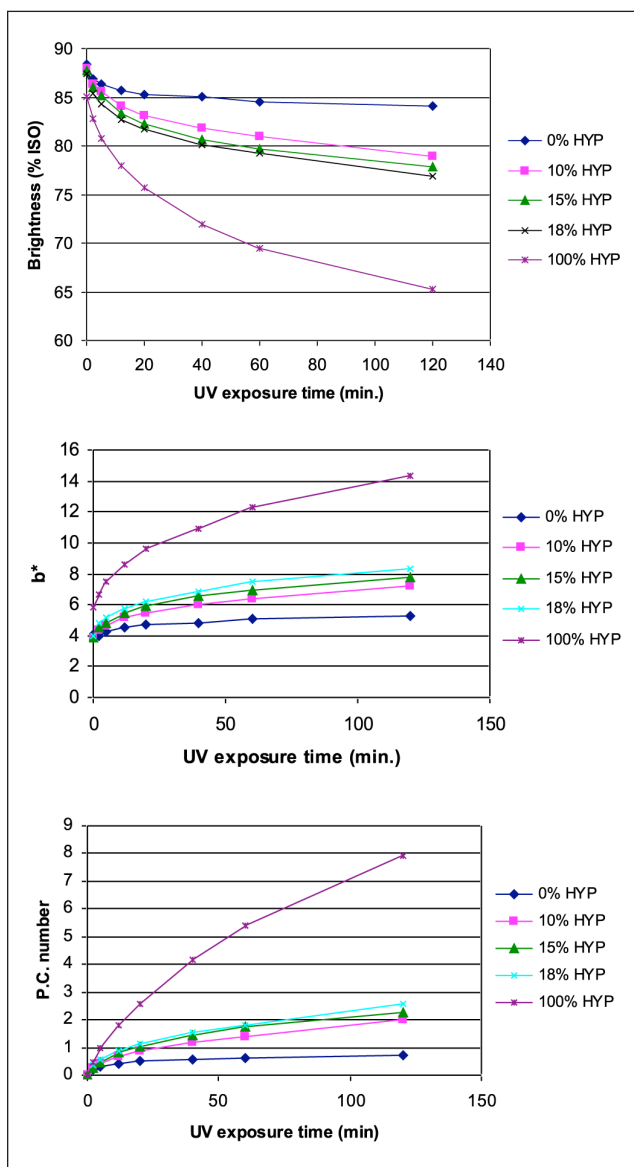
Mineral fillers, such as precipitated calcium carbonate (PCC), and optical brightening agents (OBAs) or fluorescent whitening agents (FWAs) are commonly used in the production of both coated and uncoated fine paper. The PCC particles with high light-scattering coefficient in uncoated paper may protect the HYP fibers by scattering off UV light. Because OBAs are UV absorbers, they can decrease the light-induced reversion of HYP-containing paper [23, 24]. Studies have shown that the combination of OBA and other additives can effectively improve the brightness stability of mechanical pulps [25, 26]. Recent studies have shown that OBA/FWA has good absorption on HYP fibers [24, 27, 28], and the presence of OBA can decrease the light-induced yellowing process for the HYP [29, 30]. Our aim was to determine the effect of HYP substitution on the brightness stability of high-quality wood-free paper, simulating the industrial conditions by including PCC and OBA in the papermaking process. The experimental variables included HYP substitution ratio, PCC charge, and OBA charge.

EXPERIMENTAL

A softwood bleached kraft pulp (SWBKP), a hardwood (eucalyptus) bleached kraft pulp (HWBKP), and an aspen high-yield pulp with 325 ml CSF and 85% ISO brightness, HYP 325/85, were obtained from a mill in Eastern Canada. The kraft pulps were refined in a PFI refiner to about 450 ml CSF. The HYP pulp was used without further refining. The control sheets (100% BKP) were prepared by using 30% SWBKP and 70% HWBKP at 1.2% consistency in a standard



1. Thermal reversion of HYP-containing paper at different temperatures.



2. Effect of HYP substitution rate on the light-induced brightness reversion of paper without PCC and OBA.

disintegrator for 15,000 revolutions, followed by the addition of wet-end chemicals in the order of 0.1% AKD (Hercules), 0.1% PEI (Aldrich), 0%–45% PCC (Specialty Minerals), and 0.05% CPAM (Percol 182, Ciba). Mixing occurred between the additions of chemicals. The mixture was then made into handsheets (TAPPI T 272-sp 08 “Forming handsheets for reflectance testing of pulp (sheet machine procedure)”). To prepare HYP-containing handsheets, HYP was used to replace the same amount of HWBKP, with SWBKP fixed at 30% and all other conditions unchanged; the same procedure was followed as for the control. The retention of the PCC filler was about 85%.

The light-induced brightness reversion of the handsheet samples was conducted in a standard NCE (Network of Centres of Excellence, University of Windsor, Windsor, ON, Canada) photoreactor with a radiation intensity of about 2.7 mW/cm² and a nominal wavelength of 350 nm. One minute of treatment under these conditions was found to be equivalent to about 100 h of exposure to the light radiation in a typical office environment. The photoreactor that had a ventilation fan in the back was placed in an air-conditioned room with constant temperature and humidity (23 °C, 50% RH). The thermal brightness reversion was conducted in an air-circulation oven to ensure temperature uniformity. The optical properties of the paper sheets before and after reversion were tested on a Technidyne TechniBrite™ Micro TB-1C brightness meter (Technidyne Corp., New Albany, IN, USA). The post-color (P.C.) number was calculated according to the following equations (Eqs. 1 and 2):

$$k/s = (1 - R_{\infty})^2 / 2R_{\infty} \quad (1)$$

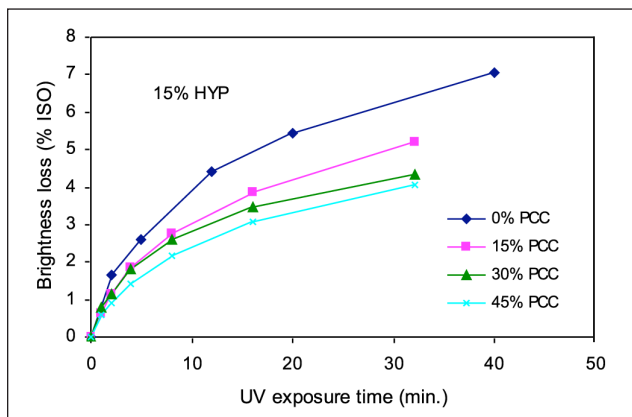
$$\text{P.C. number} = ((k/s)_{\text{after}} - (k/s)_{\text{before}}) \times 100 \quad (2)$$

RESULTS AND DISCUSSION

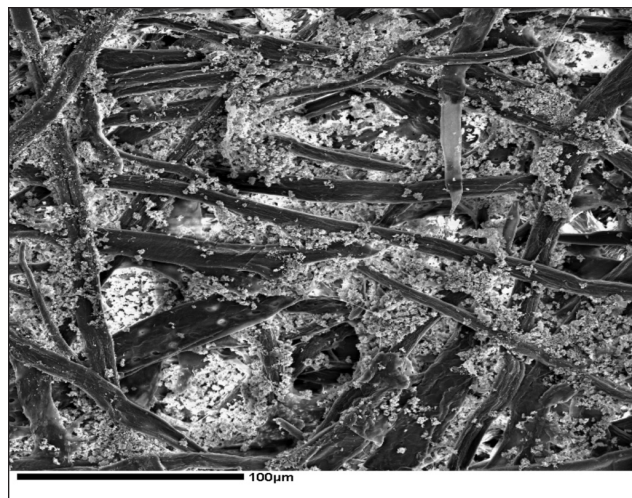
Effect of HYP substitution on thermal reversion

The thermal-induced brightness reversion of paper takes place during storage in dark, warm, humid conditions, or during the papermaking process where there may be higher than ambient temperature.

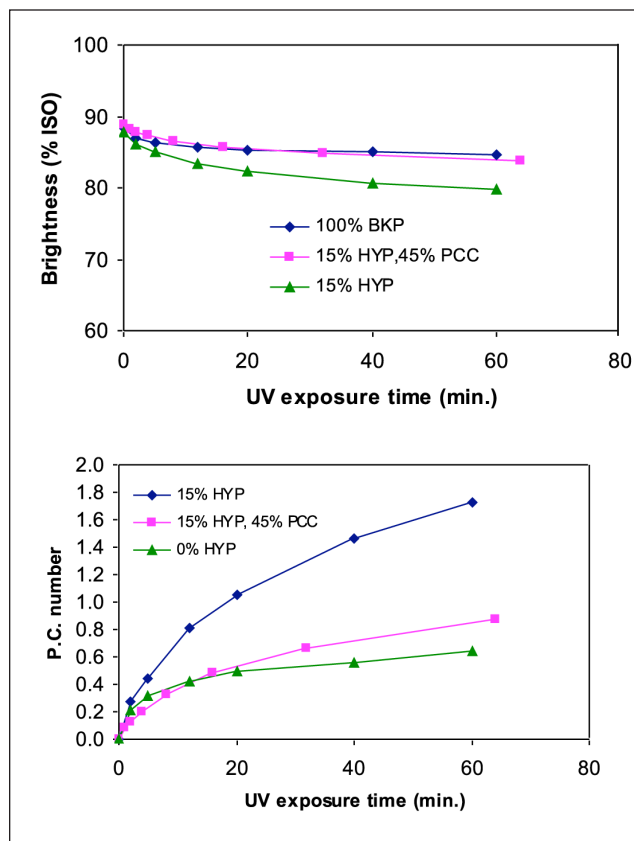
Figure 1 shows the effect of HYP substitution (15%) on the thermal reversion of paper sheets at 60 °C–80 °C. The difference in the P.C. number was caused by the temperature: the higher the temperature, the higher the P.C. number. On the other hand, a 15% HYP substitution had no effect on the thermal-induced brightness reversion at all three temperature levels studied. This is in agreement with a previous study that showed handsheets containing 18% aspen HYP had brightness stability similar to the 100% kraft sheet at 60 °C [6]. Zou et al. [31] reported that there was no significant change in the brightness of high-yield pulp over a period of 14 months at room temperature.



3. Effect of PCC dosages on brightness loss during the accelerated light-induced reversion (PCC retention was about 85%).



5. Scanning electron microscope picture of the HYP-containing sheet in the presence of PCC filler (30% SWBKP + 55% HWBKP + 15% HYP [Aspen 325/85], 45% PCC charge; PCC retention was about 85%).



4. Comparison of the brightness and P.C. number profiles of papers of different composition in the accelerated light-induced reversion (PCC retention was about 85%).

Effect of HYP substitution on light-induced brightness

Figure 2 shows the effect of HYP substitution, without the addition of PCC or OBA, on the brightness stability in an accelerated light-induced reversion test. The brightness stability decreased as HYP substitution increased. At 10%–15% HYP substitution, which is of commercial interest, the brightness reversion was significantly more in comparison with the control (with 0% HYP). Certainly this is attributed to the presence of lignin in HYP; the decreased brightness stability due to HYP substitution also has been observed by others [21].

Figure 2 also includes the yellowness index (b^*) of the paper sheets as a function of UV exposure time. The b^* increased as the HYP substitution increased, which is in agreement with the results on brightness loss. The results on P.C. in Fig. 2 again support the conclusions that the brightness stability of paper sheets decreased with the increase in the HYP substitution and that at 10%–15% HYP substitution, the paper brightness loss was significant in comparison with the control. Therefore, it is evident that HYP substitution causes more chromophores formation in the UV-induced yellowing process. All these results were obtained in the absence of PCC and other mineral fillers. However, in reality, fillers such as PCC and OBA are always used in the production of high-quality printing and writing paper.

Addition of PCC

In the production of high-quality uncoated printing and writing paper, PCC is commonly used to improve printability and optical properties such as opacity and brightness. Decreased production cost is another reason PCC is used. Fillers such as PCC have large specific surface area and can scatter UV light, as well as visible light, which may improve the brightness stability. For this reason, we determined the effect of PCC fillers on the brightness stability of paper sheets containing HYP.

Figure 3 shows that at 15% HYP substitution, the brightness loss of the paper sheets in the light-induced reversion process decreased significantly as the PCC charge increased from 0% to 45%. Figure 4 compares the brightness stability of the HYP-containing paper sheets with and without PCC filler to that of the HYP-free sample (100% BKP). At 45% PCC charge (equivalent to about 27% PCC content in the sheet), the paper sheet containing 15% HYP had a similar reversion curve as that of the HYP-free sheet. These results are different from those without PCC, and the

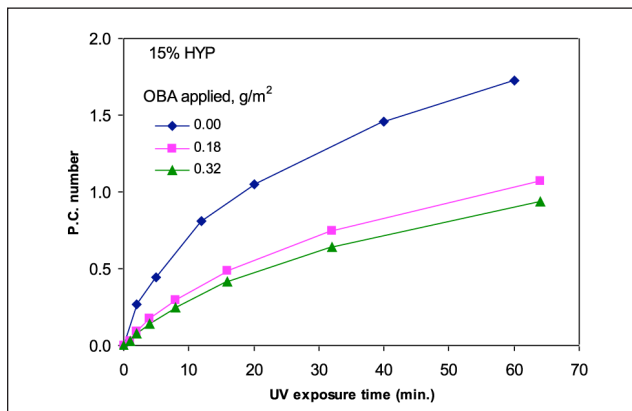
presence of these fillers makes the difference. The implication is that printing and writing papers with about 30% PCC filler content can have good brightness stability at 15% HYP substitution.

Figure 4 includes the P.C. number as a function of the UV exposure time for the same three paper sheets, namely, 15% HYP without PCC, 15% HYP with PCC, and the HYP-free sample. These results again support the conclusion that PCC is very effective in decreasing the brightness reversion due to the presence of HYP. It has been shown that pigment coating can significantly improve the brightness stability of HYP-containing paper [6]. With 12 g/m² coating, the brightness stability of the HYP-containing coated paper was similar to that of the 100% kraft coated paper [6]. When present in the paper sheet, the PCC particles adsorbed on HYP fibers can act as coating layers for the HYP fibers so that the harmful UV light is scattered off, protecting the lignin-rich HYP fibers from the UV-induced yellowing process. **Figure 5** shows the scanning electron microscope (SEM) image of a paper sheet made of 30% softwood BKP, 55% hardwood BKP, 15% aspen HYP, and 27% PCC (filler content in the sheet). It can be observed that (1) PCC filler particles are distributed well in the fiber network, and (2) only kraft fibers are visible while the HYP fibers are not, indicating that the PCC particles are covering the pulp fibers well and protecting the lignin-rich HYP fibers from the UV-induced yellowing process.

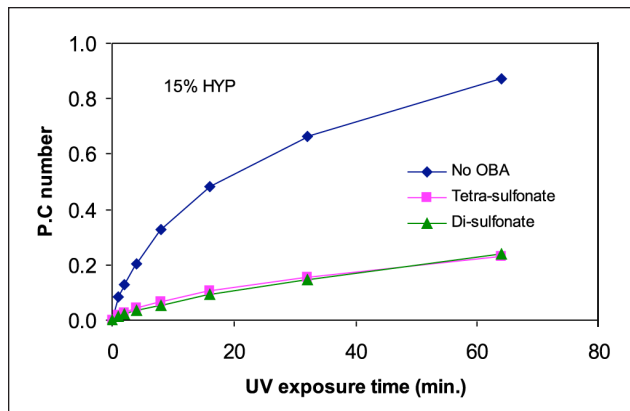
OBA effect on light-induced brightness reversion of uncoated paper

To improve the optical properties of printing and writing papers, OBAs or FWAs are commonly used in the pulp and paper industry. The OBAs are chemicals, applied at the wet-end of the papermaking process or at the size press, that absorb UV light and re-emit it as blue light to increase the paper brightness. They can act as an effective UV screener to protect HYP fibers from the harmful UV light [23, 24, 29, 30].

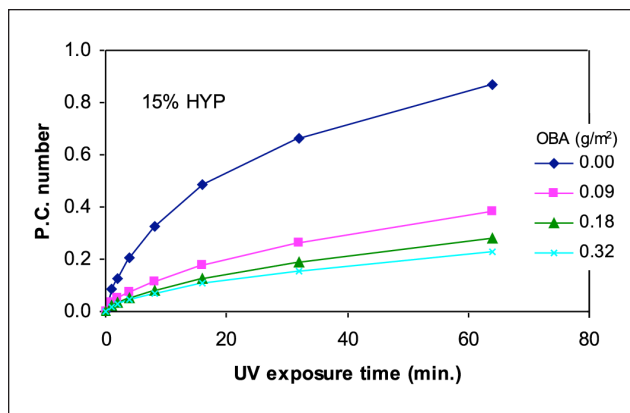
Figure 6 shows the results of improving brightness sta-



6. Effect of surface application of OBA on the UV-reversion of the HYP-containing paper without PCC filler.



7. Comparison of the effects of disulfonate and tetrasulfonate types of OBA on the P.C. number (45% PCC charge, 0.32 g/m² OBA).



8. Effect of OBA usages on the P.C. numbers (45% PCC charge, tetrasulfonate type of OBA).

bility of HYP-containing paper by surface application of OBA. Such a method was very effective in decreasing the light-induced reversion of the HYP-containing paper sheets even without PCC filler.

Combined effect of PCC and OBA

The combined effect of PCC filler addition and surface application of OBA can further decrease the light-induced brightness reversion of the HYP-containing paper. **Figure 7** shows that the surface application of OBA markedly decreased the brightness reversion of the HYP-containing paper that contained about 27% PCC filler. Figure 7 also shows that the disulfonate and tetrasulfonate types of OBA had a similar effect on the light stability of the HYP-containing paper. **Figure 8** shows the effect of OBA dosage on the brightness reversion of the HYP-containing paper: the higher the OBA dosage, the lower the P.C. number.

The surface application of OBA may not be practical for some mills. Therefore, we also determined if the wet-end addition of OBA can effectively decrease the light-induced brightness reversion of the HYP-containing paper. **Figure 9** shows that the wet-end addition of OBA not only in-

Sample	Before UV reversion				After UV reversion			
	% ISO	L*	a*	b*	% ISO	L*	a*	b*
0% HYP	101.90	93.67	2.2	-12.3	100.58	93.60	2.0	-11.5
10% HYP	102.00	93.60	2.1	-12.3	99.50	93.40	1.8	-11.0

I. Comparison of the optical properties of two commercial copy papers with or without 10% HYP before and after UV reversion (two UV lamps, 40 min).

creased the initial brightness significantly but also decreased markedly the light-induced brightness reversion of the paper that contained 10% HYP, in terms of both brightness loss and P.C. number when exposed to UV light. Figure 9 also shows that OBA and PCC had a synergistic effect in decreasing the P.C. number when compared with the control (without PCC and OBA); that is, the delta P.C. was larger when

dered the HYP-containing paper very low light-induced brightness reversion.

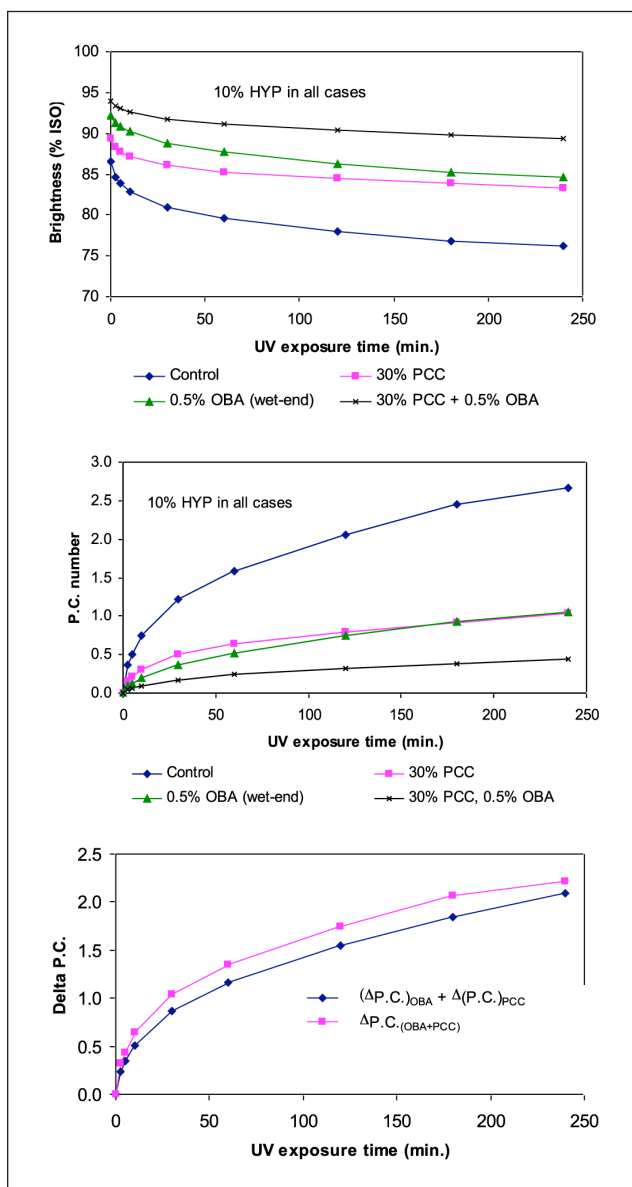
Table I shows the UV reversion results of two commercial copy papers that contained both PCC (about 27%) and OBA. The optical properties of the paper samples with and without 10% HYP were very similar both before and after the reversion, supporting the conclusion that the effect of 10% HYP substitution on brightness stability can be largely eliminated due to the presence of both PCC and OBA.

CONCLUSIONS

Substitution of 15% HYP for hardwood bleached kraft pulp had a negligible effect on the thermal stability of paper at 60 °C–80 °C. When PCC and OBA are not present, a 10%–15% HYP substitution can strongly decrease the brightness stability of paper upon UV light exposure due to the high lignin content of HYP fibers. When present in paper, PCC can significantly improve the brightness stability. This is attributed to the scattering effect of PCC so that harmful UV light has a decreased chance of contacting HYP fibers. The coverage of PCC fillers in HYP may also be responsible for the increased brightness stability. As a UV absorber, OBA is very effective in decreasing the UV-induced brightness loss for both surface and wet-end application. The combined effect of PCC filler and OBA application can essentially eliminate the negative effect of a 10%–20% HYP substitution on paper brightness stability in the light-induced reversion process. Our conclusions are supported by the results from commercial printing and writing paper with or without 10% HYP. **TJ**

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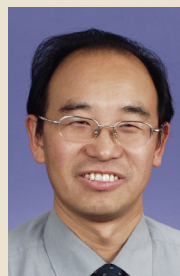
High-yield pulp (HYP) has unique properties that make it appealing for printing and writing paper grades but it can have a negative effect on the brightness stability of paper products because of the presence of lignin. In our previous work, we found that optical brightening agents (OBAs) can compensate for the brightness deficiency of HYP in printing and writing papers. In this study, we determined the combined effect of both precipitated calcium carbonate (PCC) and OBAs, both of which are commonly used in the production of printing and writing paper, to improve the brightness stability of paper sheets made with 10%–20% HYP.

The inherent tendency of HYP to yellow upon exposure to UV-containing light due to its high lignin content was a challenge to testing our hypothesis to improve the brightness stability of HYP-containing paper. Our solution was to use OBA as a UV absorber/brightener and PCC fillers for scattering light, both of which can protect the HYP fibers from the harmful UV radiation. We found that OBA and PCC have a synergistic effect in improving the brightness stability of HYP-containing paper.

With OBA and PCC, papermakers can use HYP to substitute hardwood kraft pulp to reduce cost and im-



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prove product qualities. In future work, we will explore more efficient ways to use OBAs to improve or stabilize the brightness and whiteness of HYP-containing paper.

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