Mechanical Strength and Optical Properties of LWC Wood-Containing Paper

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This study investigated optical and strength properties of light-weight coated (LWC) printing paper. Two different pigments, namely nanoclay and precipitated calcium carbonate (PCC) with rhombohedral particle shape, were used with acrylic styrene latex to coat base paper using a blade method. Strength properties such as: tensile, burst, and tear indices, stiffness and optical properties including brightness, yellowness, and opacity were measured. Surface topography was studied using atomic force microscopy (AFM). Comparison between the coated paper and the control sample demonstrated that surface of the paper coated with nanoclay was more uniform than the paper coated with PCC. Although there were no significant differences in terms of the strength of these paper samples, burst and tear strength were enhanced by up to 10 and 16% in some or all treatments, respectively. There was a slight increase in paper opacity with PCC because it has a narrower particle size distribution in comparison with that of nanoclay. Yellowness of the papers treated with nanoclay was degraded about 20% as compared to the control sample, while some small differences were also noticed in brightness and opacity of the papers.

Keywords: Atomic force microscope; Precipitated calcium carbonate; Nanoclay; Strength; Optical properties

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INTRODUCTION

Coating fills cavities, covers the surface of the base paper, increasing its smoothness considerably. Coated papers have certain advantages in comparison to uncoated papers, including decreased ink absorption, less dusting, and an increase in opacity, surface strength, and a possible increase in brightness. The extent of these changes depends on type and amount of various components (materials) of the coating, as well as coating equipment and finishing treatments (Lehtinen 2000). The end use performance of coated papers depends on the proper design of the coating structure. It is clear that pigment properties, including particle size, size distribution, and morphology, play essential roles in determining the coating structure and achieving enhanced optical and printing properties of the final products (Caner and Farnood 2006).

A large amount of research is currently being done in the field of nanoparticles, because of their potential application in various industries (Hamzeh and Rostampour 2008). Today, nanoclay particles hold a high rank amongst various nanofillers. This is because these particles are more likely to form different structures and thus affect properties of the product via the structure created (Tjong 2006). Different contents of clay and PCC are often used as pigments for coating the printing papers in order to improve their printability characteristics. These pigments currently provide substantial gloss in the range of visible light, as well as good brightness, an acceptable diffraction ratio, and a proper compatibility with other compounds used in typical paper coating processes. Generally speaking, PCC in a coating favors high porosity of the paper surface and may contribute to a better retention of ink molecules on the surface of paper (Donigian *et al*. 1999; Hladnik and Muck 2002; Lee *et al*. 2005; Nilsson and Fogden 2008; Vikman and Vuorinen 2004). Numerous studies have discussed modification of the precipitated calcium carbonate. They have mainly focused on application of the PCC as a filler in the papermaking process, in combination with mineral compounds such as calcium chelate (*e.g.*, sodium hexamethaphosphate), weak acids like phosphoric acid, sodium silicate, and zinc chloride (Shen *et al*. 2009; Zhao *et al*. 2004), and organic materials such as starch, cellulose derivatives, ketene, xanthan wax, artificial water-soluble polymers, surfactants, and polymeric latex (Shen *et al*. 2009; Zhao *et al*. 2004). Both particle size and particle morphology can be modified for enhanced performance in terms of brightness and opacity.

Atomic force microscopy (AFM) is used to examine various materials, including glass, metals, polymers, semiconductors, and biomaterials. This technology is being developed rapidly. AFM is a nondestructive means of studying various surfaces and can be used for materials such as cellulose and paper (Zou *et al*. 2004; Baker *et al*. 1997). This research was implemented to investigate mechanical strength and optical properties of the wood-containing coated printing paper with different loadings of PCC and nanoclay in acrylic styrene latex.

MATERIALS AND METHODS

Mechanical base printing paper with a 70-g/m^2 grammage was procured from Mazandaran Wood and Paper Co. This base paper was produced from hardwoods and had the following specifications: 7.5% moisture, 69% brightness, 86% opacity, 10% ash content, and 1.5 g/m^2 starch.

The nanoclay Cloisite 30B (montmorillonite in Sodium form) was supplied by Southern Clay Products Company. Micronized PCC was procured from the Ahovan Company. Specifications of the mineral pigment of this coating are summarized in Table 1. Acrylic latex (SH-305) was procured from Simab Resin Company; it had a milky appearance with an anionic emulsion system, 50% content of solid particles, 300 to 900 centipoise viscosity, and a minimum film-forming temperature (MFFT) of 20 °C. The latex was mixed with the pigments in six formulations: 5 wt% nanoclay, 10 wt% nanoclay, and 20, 30, 40, and 50 wt% PCC (see Table 2). A mixture of the latex, pigment, and the other ingredients was obtained using a dispersing apparatus at a rotational speed of 1500 rpm for 10 min. Lightweight coating was applied using a blade coater on surface of the paper to create a thin film of 4 to 6 g/m^2.

Then the coated paper, which was restrained to avoid its distortion, was exposed to 80 °C temperature for 2 min. Controlling the amount of coating was done based on dry weight of the coating material per unit area of base paper.

Table 1. Specifications of the Mineral Pigment of the Coating

Component	Trade Name	Manufacturer	Density (g/cm^2)	Weight Percent (%)	Particle Size (µm)	Shape	Brightness (%)
Nanoclay	Cloisite-30B	Clay Products	1.98	5,10	10%<2 50%<6 90%<13	Plate	75
Precipitated Calcium Carbonate	Aragonite	Neka Sang	2.82	20-50	5–6.5	Narrow	96.54

Table 2. Combinations of Different Ratios of Nanoclay, Precipitated Calcium Carbonate, and Acrylic Latex of the Coating

Sample code	Nanoclay (%)	Precipitated Calcium Carbonate (%)	Acrylic latex (%)
1	0	0	0
2	5	0	95
3	10	0	90
4	0	20	80
5	0	30	70
6	0	40	60
7	0	50	50

The AFM apparatus of Ara Pazhouhesh Company (Iran) was utilized to examine topography and surface features of the paper. The following standard tests were done to determine the strength and optical properties of this paper:

- Tear strength: SCAN P_{11}:73
- Burst strength: T403-Om91
- Tensile strength: T240-Om92
- Stiffness: T240-Om92
- Optical Properties: T452-Om98

Data analysis was performed using SPSS statistical software in terms of one-way analysis of variance. The average values were compared and classified using the Duncan test at a confidence level of 99%.

RESULTS AND DISCUSSION

Paper Topography

The tapping technique was adopted to investigate the surface of the coated papers with AFM. Figure 1 shows coated paper surfaces with 10% nanoclay and 50% PCC, respectively. It was observed that the nanoclay-coated paper samples were coated more uniformly than the PCC-coated samples. The greater specific surface area of the nanoclay and the different shape of its particles (plate-like) from those of PCC (with a narrow particle size distribution (psd)) may be reasons for this observation. Moreover, differing rheologies of the latex coating formulations with nanoclay and PCC is another reason for the different surface heterogeneities which are obtained in coating of these two materials (Kasmani *et al*. 2013).

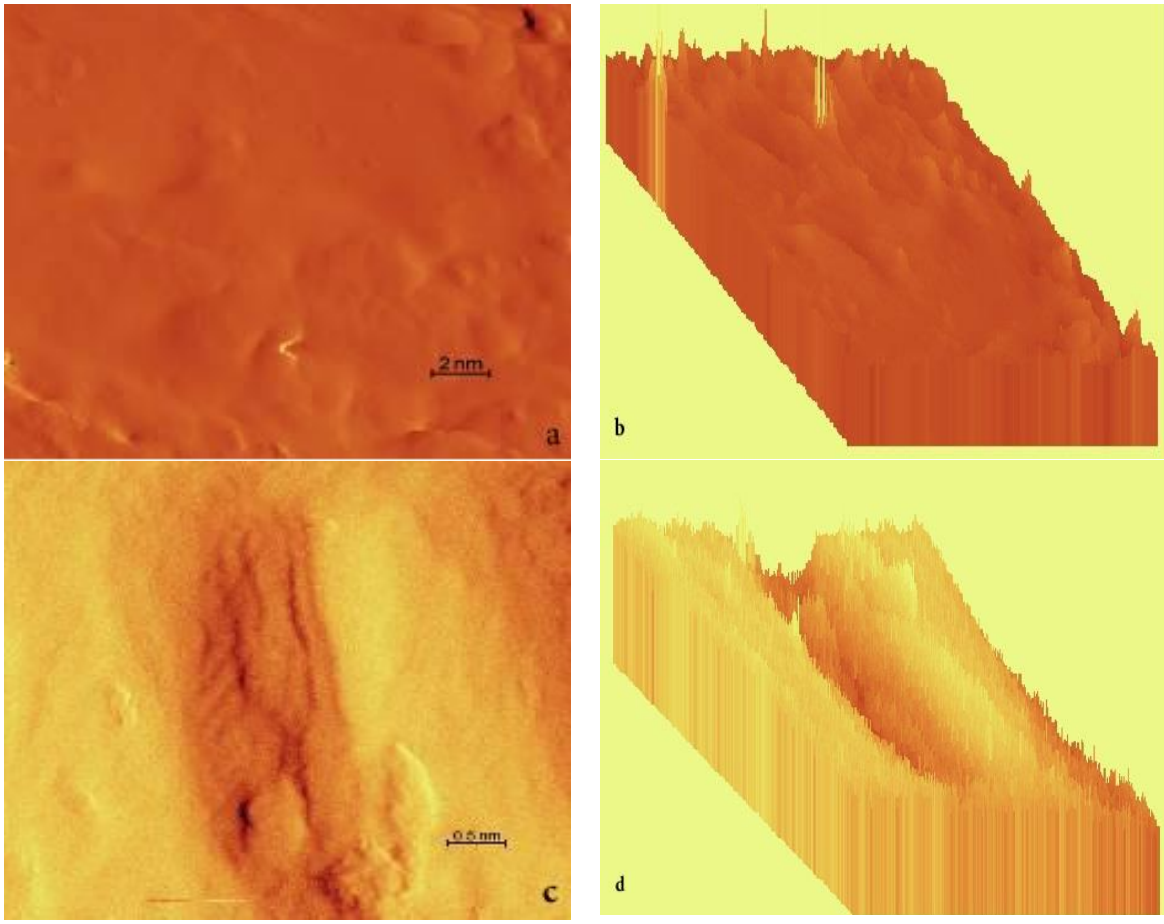

Fig. 1. Coated paper AFM figure. (a) Surface of paper coated with 10% nanoclay and Acrylic latex, (b) 3D shapes of paper coated with 10% nanoclay and Acrylic latex, (c) Surface of paper coated with 50% PCC and Acrylic latex, (d) 3D shapes of paper coated with 50% PCC and Acrylic latex

Strength Properties

The results of studying the strength and optical properties of the coated papers are illustrated in Figs. 2 to 8. Figure 2 shows that the minimum and maximum average tear strengths were associated with the papers coated with 10% nanoclay and 20% PCC, respectively. Variance analysis revealed that there was no statistically significant difference between the values of the tear strength from the seven samples under study here at a 99% confidence level (Fig. 2).

It can be inferred from Fig. 3 that the minimum and maximum average burst strengths belonged to the control samples and the papers coated with 50% PCC, respectively. Variance analysis showed that, statistically speaking, there was no significant difference between the values of the burst strength from the seven samples examined at a 99% confidence level (Fig. 3) Duncan's new multiple range test at a 1% significance level demonstrated that the values of burst strength were categorized under the same group.

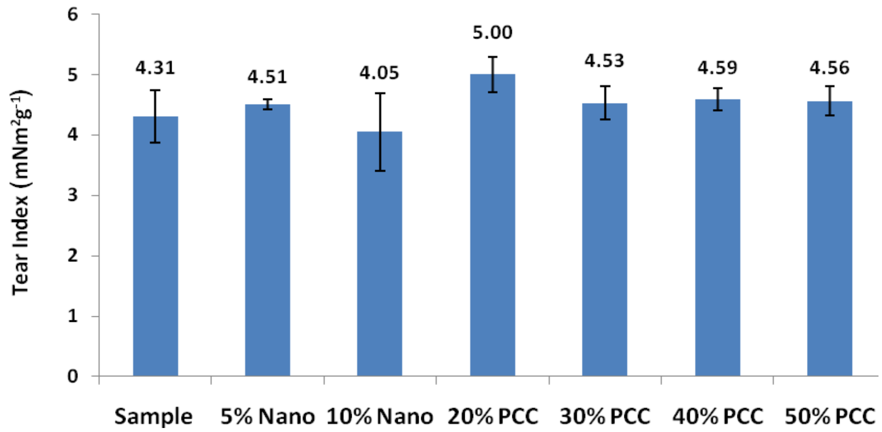

Fig. 2. Comparison of average tear strength of the control and coated samples

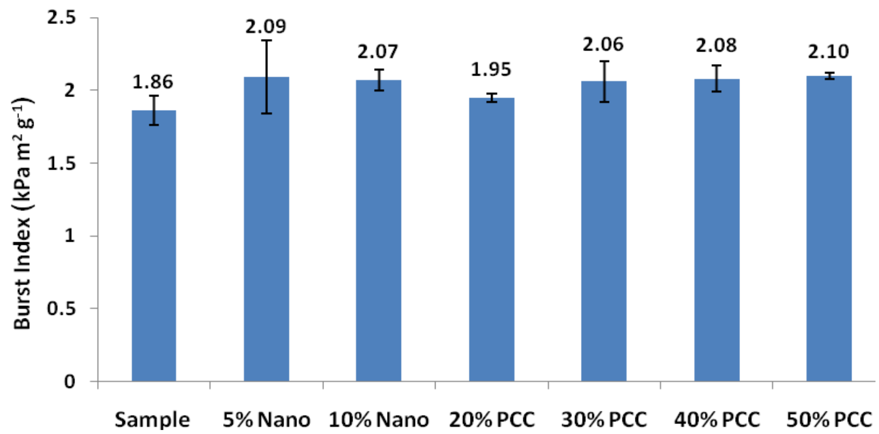

Fig. 3. Comparison of average burst strength of the control and coated samples

Figure 4 shows that the maximum average tensile strength was for the papers coated with 30% PCC, whereas the minimum average tensile strength was reported for those coated with 10% nanoclay. Variance analysis showed that there was no significant difference between the values of the tensile strength from the seven samples at a 1% confidence level (Fig. 4).

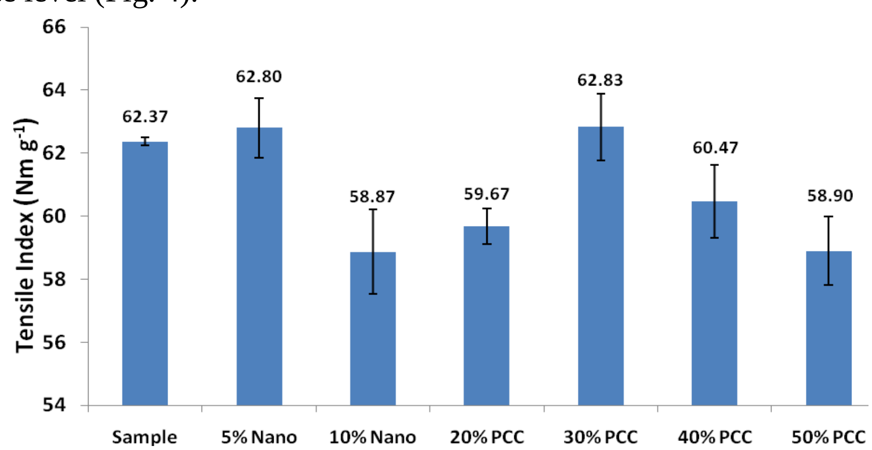

Fig. 4. Comparison of average tensile strength of the control and coated samples

Figure 5 shows that the maximum average stiffness occurred in the control sample, while the minimum average stiffness was for the samples coated with 40 and 50% PCC. Variance analysis revealed that, statistically, values of the stiffness were significantly different among the seven samples under study at a 1% confidence level. Duncan's new multiple range test at a 1% significance level demonstrated that the coated papers were categorized in two different groups (Fig. 5).

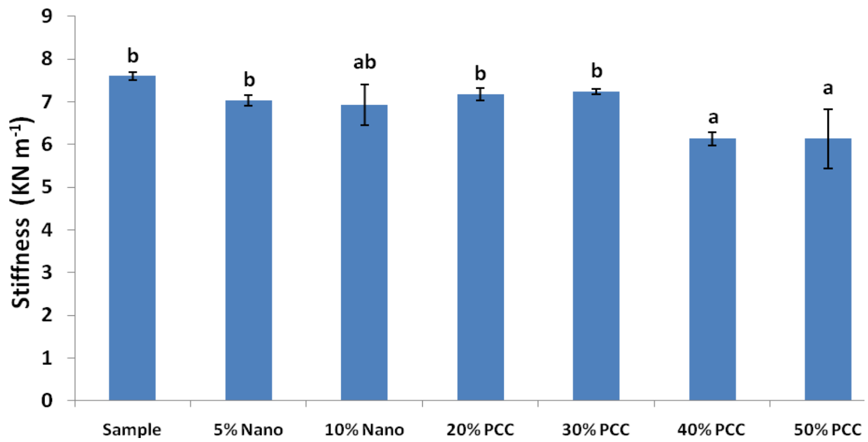

Fig. 5. Comparison of average stiffness of the control and coated samples (small letters indicate statistically indistinguishable classes for Duncan ranking of the averages values at a confidence interval of 99%.)

Comparison of the main strengths of the paper, including tensile, burst, and tear strengths, showed that although there were no significant differences between their average values, the tear strength improved up to 16% in the paper coated with 20% PCC. Meanwhile, the burst strength was enhanced up to 10% in all of the treated samples.

Stiffness is of great importance in some types of the printing paper, particularly copy paper, as this type of paper passes through several rolls. The requirements for this property are different depending on application of a specific printing method. Paper that is too stiff or not stiff enough causes problems such as improper feeding or delivery of paper to subsequent parts of the printer machine (Afra 2006). A comparison between the results of this characteristic revealed that there was no significant difference between the control sample and the experimental papers, except for those treated with 40 and 50% PCC.

The addition of fillers has been shown to adversely affect many strength properties of the paper due to the direct interference of the filler with the bonds between the fibers. Generally speaking, the adverse effects on the strength will be more significant when the size of the filler particles is smaller. Plate-like filler particles like clay have rather undesirable effects on the strength properties of nanocomposite in comparison with the particles of irregular shapes, such as PCC. To compensate for the undesirable effects of these fillers, cationic starch is used as a dry additive (Mirshokraei and Sadeghifar 2007).

Optical Properties

A previous research study reported very little influence of the coating color application solids on optical properties (Kröber *et al.* 2004). Figure 6 shows that the greatest effect of yellowness belonged to the treatment with a 40% PCC coating, whereas the smallest yellowness effect was related to the samples coated with 10% nanoclay. Variance analysis showed that there is no statistically significant difference between the values of yellowness from the seven samples under study at confidence level of 99% (Fig. 6).

Figure 7 indicates that the greatest opacity was for papers which were treated with 50% PCC, while the least opacity was for the control sample. One-way variance analysis implies that there is no statistically significant difference between the values of opacity from the seven samples under study at the confidence level of 99% (Fig. 7). The narrower particle size distribution of the PCC pigment has also resulted in a higher opacity of the coated sheet. The increased opacity of the PCC pigment is due to the higher light scattering coefficient, due to the narrower particle size distribution which gives a higher opacity than the nanoclay (Fig. 8) (Kröber *et al.* 2004).

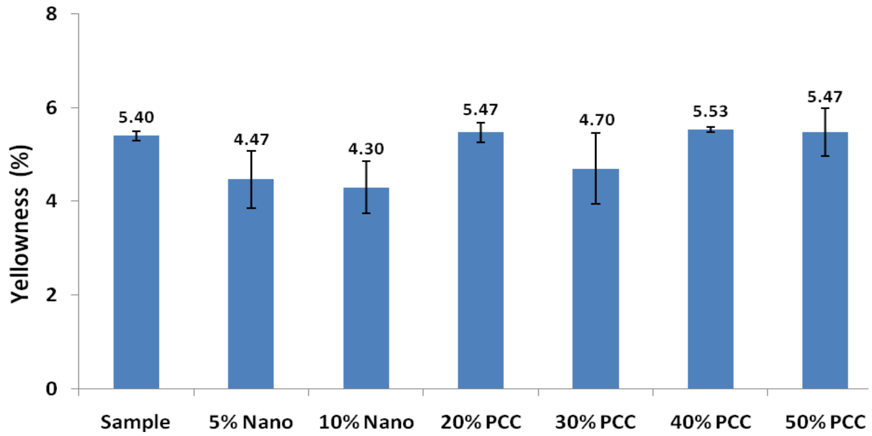

Fig. 6. Comparison of average yellowness of the control and coated samples

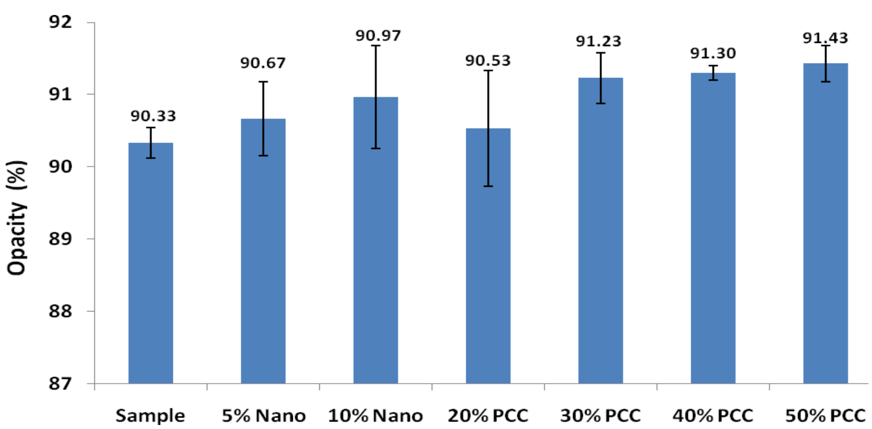

Fig. 7. Comparison of average opacity of the control and coated samples

Figure 8 shows that the minimum and maximum values of brightness are related to the samples coated with 20% PCC and the control samples, respectively. One-way variance analysis revealed that there was no statistically significant difference between the values of the brightness from the seven samples under study at the confidence level of 99% (Fig. 8).

The solid content of the coating resulted in minor or no visible effect on brightness of the final paper (Kröber et al. 2004). Nanoclays are smaller than the wavelength of visible light, so they typically have little optical effect, according to another report (Schut 2006).

Printed papers containing mechanical pulps tend to become yellowed after a certain period of time. Therefore, one-time coating of the paper is able to improve this feature while avoiding the photo yellowness. To summarize, coating seems the most effective process to challenge the yellowness effect. Comparing the results of this characteristic also showed that introduction of nanoclay will reduce the yellowness of the paper and probably increase the time required for yellowness to occur.

Comparison of the other optical properties of the papers, namely opacity and brightness, indicates that there were negligible differences between the coated papers, despite some difference between the treated samples and the control sample. It is obvious that the polymeric materials with high brightness can be used in the coating, while up to 10% titanium dioxide can also be added (Lehtinen 2000).

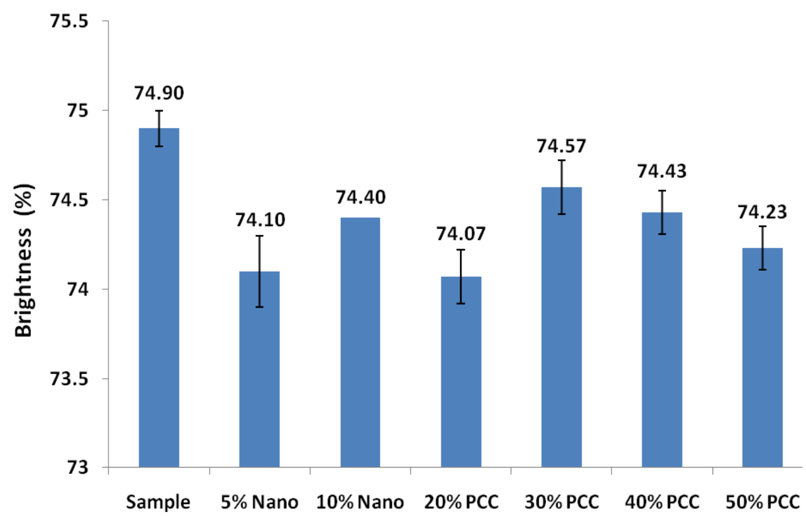

Fig. 8. Comparison of average brightness of the control and coated samples

CONCLUSIONS

1. A comparison between properties of the coated paper and those of the control sample demonstrated that the surface of the paper coated with nanoclay was more uniform.
2. There were no significant differences between the strength properties of the papers, except for tear and burst strength. The burst strength was enhanced by up to 10% in most of the coated samples, and the tear strength was improved by up to 16% in the paper sample coated with 20% of PCC.
3. Paper opacity slightly increased with PCC loading. This was due to the higher light scattering coefficient resulting from the narrower size distribution of the PCC particles, which led to a higher opacity in comparison to the nanoclay. The particle size of nanoclay is less than the wavelength of visible light, so it may not increase opacity or brightness.
4. The yellowness of the papers treated with nanoclay was decreased by about 20% as compared to the control sample, and there were some differences between brightness and opacity values of the coated samples in comparison with the control sample.

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