

COST REDUCTION STUDIES OF DECORATIVE LAMINATES

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Barrier paper, which is made of bleached absorbent kraft pulp, is a significant layer of decorative laminates, since it controls the see-through of brown color of saturating kraft paper and its opacifying effect usually is achieved by a heavy loading of TiO₂. The TiO₂, due to its very small particle size, passes between the cellulosic fibers and drains into the white water. To overcome this problem, papermakers try to use various retention aids for improving overall retention of TiO₂, but agglomeration of TiO₂ causes a decrease in light scattering efficiency of TiO₂. During the subsequent saturation operation, the air in the voids is replaced by melamine formaldehyde, which has a refractive index close to that of cellulose. As a result, the sheet becomes translucent and poses 'see through' problem. Keeping this in view, anhydrous magnesium silicate is used as an extender with TiO₂ because it effectively increases the overall filler retention, sheet brightness, opacity. The dispersed aqueous slurry of anhydrous magnesium silicate forms fine gel that entraps TiO₂ in the wet web and prevents removal of fines and fillers. The addition of 25% TiO₂, 7% micronized soapstone powder, 8% anhydrous magnesium silicate, 1% melamine formaldehyde, and 0.1% sodium hexametaphosphate was found to improve the overall retention by 65.25% and to cut the manufacturing cost by US\$ 546.00 per tonne of pulp without affecting the product quality.

Keywords: Anhydrous magnesium silicate; Titanium dioxide; Decorative laminates; Barrier paper; Cost reduction

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INTRODUCTION

Indian Pulp and paper companies are facing diverse problems such as a shortage of fibrous raw materials, high manufacturing costs, declining price of the end-product, and soaring environmental costs, so they cannot match the costs of final products *vis-a-vis* those manufactured by leading paper manufacturers of the developed nations. One way to increase their profit margin is by switching from the manufacture of traditional papers (writing and printing grades) to high value-added quality papers like magnetic ink character recognition (MICR) paper (Dutt et al. 2001), wax match paper (Dutt et al. 2002), electrical insulation paper (Dutt et al. 2003a), padding paper (Dutt et al. 2003b), alkali resistant paper (Dutt et al. 2003c), pictorial circuit board base paper (Dutt et al. 2003d), abrasive base paper (Dutt et al. 2003e), azure laid ledger paper (Dutt et al. 2003f), mulberry paper (Dutt et al. 2004a), dark brown Turkish umber (DBTU) paper (Dutt et al. 2004b), titanium dioxide loaded poster paper (Dutt et al. 2004c), automobile

and industrial filter paper (Dutt et al. 2005a), paper cups base paper (Dutt et al. 2005b), seed germination paper (Dutt et al. 2005c), and tea bag paper (Dutt et al. 2007). Another possible alternative is to cut the production cost by augmenting the activities through in-house research and development.

A decorative laminate contains numerous layers, each having its own function. Each layer is impregnated by resin, mostly melamine formaldehyde, which is cured to form an inert, hard composite with the fiber structure of the paper. The highly visible use of the laminates, as working tables, crockery, cupboard fronts, or floor sets of very high demand on the appearance of the laminate, which must be cleaned, have the correct light-resistant shade and surface structure, and be resistant to wear and scratching. The base of decorative laminate contains 4 to 5 layers of unbleached absorbent kraft paper. Each sheet is saturated, by capillary action, either with melamine formaldehyde or urea formaldehyde resins before lamination in such a way so that it may retain 40% resins of the total weight of the finished sheet (TAPPI Useful Method F. 3U “Water absorbency of paper board: immersion method”). Likewise, 4 to 5 layers of barrier paper are applied on each other after impregnation with resins. In barrier paper, one key barrier property is the opacity, because the barrier layer controls the see-through of brown color. The optical requirements generally can be achieved by a heavy loading of TiO_2 (Kwoka 1992). In addition, ivory base paper can be used to apply a fancy pattern to the sheet, which is then impregnated with resin before lamination (Volz et al. 1973/1974). Finally, overlay paper is being used as top layer to give wear resistance to the decorative laminate. After the impregnation step, the laminate is cut into sheets and pressed together in a high-density press, with separating plates between the laminate boards. A very high-pressure, about 3000 lb/in^2 between 150 to 250 °C, is applied on the decorative laminate, which is cushioned on both sides by padding paper (Dutt et al. 2003d). The pressure and temperature is enough to press out any gases contained in the laminate, which thus becomes a solid, nonporous structure.

The high opacity of the barrier layer is achieved by using TiO_2 , which has spherical shape, mean particle size near 0.3 (rutile) or 0.4 μm (anatase) and maximum refractive index among commonly available fillers, i.e. anatase 2.55 and rutile 2.76 (Laufmann 2006). A major problem in the realization of a TiO_2 -filled sheet is the tendency of the very small TiO_2 particles to pass between the cellulosic fibers and down in to the white water due to its poor retention (Kwoka 1990). The economics of this situation forces the paper makers to add any of the numerous well-known retention aids. With such retention aids it is feasible to retain in the sheet as much as 90% of the filler material. Unfortunately, this also causes flocculation or aggregation of the TiO_2 particles (Blazer and Lane 1975; Kwoka 1993). Although an opacity of 99% is attained initially, during the subsequent saturation step the air in the sheet is replaced by resin having a refractive index approximately the same as that of cellulose. As a result, the barrier layer becomes more translucent, the only significant remaining opacity being that which is imparted by any added filler. Pigments such as calcined clay, alumina trihydrate, and precipitated amorphous silica are used as TiO_2 extenders because they effectively increase the sheet brightness and opacity and mitigate the manufacturing cost by reducing the amount of TiO_2 that is required in order to get target optical properties (Houle et al. 1990). Keeping this in view, the cost of barrier paper, one of the layers of decorative

laminates, can be mitigated by partially replacing expensive titanium dioxide with anhydrous magnesium silicate, a TiO₂ extender, without sacrificing the quality of barrier paper.

EXPERIMENTAL

Pulp Collection, Stock Preparation and Laboratory Handsheets Evaluation

Screened chips of eucalyptus, veneer waste of poplar, and bamboo mixed in the ratio of 15:80:05 were cooked by the kraft pulping process using 16% active alkali (as Na₂O), sulfidity 20%, time from ambient temperature to 162 °C (max temp) 120 min, time at max temp 75 min, digester pressure 7.5 kg/cm², and liquor to wood ratio 2.8:1 to get a kappa number of 16 and screened pulp yield of 48%. O₂ delignification produced a pulp of brightness 42% (ISO) and kappa number 8 using O₂ pressure 3 kg/cm², reaction time 90 min at 90 °C. The pulp was bleached by a CEPHH bleaching sequence to produce a pulp brightness of 85% (ISO) and viscosity 9.2 cps using total chlorine demand of 6%. The pulp was beaten in a laboratory Hollander type beater (TAPPI T200 sp-01 “Laboratory beating of pulp [Valley beater method]”) at a beating level of 30 °SR. Likewise, softwood pulp (brightness 89%) was beaten at 30 °SR separately and then blended in different ratios. Laboratory handsheets of 70 g/m² were prepared (T 205 sp-02 “Forming handsheets for physical tests of pulp”). Both the pulps were evaluated for brightness (T 452 om-02 “Brightness of pulp, paper, and paperboard [directional reflectance at 457nm]”), opacity (T 519 om-02 “Diffuse opacity of paper [d/0 paper backing]”), grammage (T 410 om-02 “Grammage of paper and paperboard [weight per unit area]”), tear index (T414 om-98 “Internal tearing resistance of paper [Elmendorf-type method]”), tensile index (T494 om-01 “Tensile breaking properties of paper and paperboard [using constant rate of elongation apparatus]”), burst index (T403 om-97 “Bursting strength of paper”), ash content (T 413 om-02 “Ash in wood, pulp, paper and paperboard: combustion at 900°C”), porosity, and COP (T 462 om-01 “Castor-oil penetration test for paper”) as per TAPPI standard test methods (Anonymous 2007), and water klemm (TAPPI Useful Method F. 3U “Water absorbency of paper board: immersion method”). The results are reported in Table 1.

In order to study the effect of alum on fines and filler retention, imported softwood and mixed hardwood pulps were blended in different ratios, as stated in Table 2 and mixed with TiO₂ and micronized soapstone in a beater without load in the presence of 0.1% sodium hexametaphosphate. Thereafter, the beater was emptied into a bucket and adjusted to a pH of 6.5 with non-ferric aluminum sulfate (Table 2).

In a 2nd set of experiment (Table 3), imported softwood and mixed hardwood pulps were blended in the ratios of 0:100, 100:0, and 50:50 and different ratios of TiO₂ and micronized soapstone fillers were added in a beater without load in the presence of 0.1% sodium hexametaphosphate and non-ferric aluminum sulfate to for adjusting a pH level of 6.5. For wet strength, 1.0% (based on the weight of total furnish) of a melamine formaldehyde resin was added (Table 3).

In a 3rd set of experiment (Table 4), a pulp blend having imported softwood and mixed hardwood pulps (50:50) was mixed with different ratios of TiO₂, micronized

soapstone, and anhydrous magnesium silicate (AMS) with dispersing agent sodium hexametaphosphate (0.1%) and 1% melamine formaldehyde resin in a beater without load, and a pH level of 6.5 was maintained with non-ferric aluminum. AMS and non-ferric alum (microparticulate retention aids) were used to improve the retention of fillers.

In all the cases, the laboratory-made handsheets of 70 g/m² were prepared on a Mesmer automatic sheet former and evaluated for brightness, opacity and ash. Finally, the economy of barrier obtained by partial replacement of TiO₂ with anhydrous magnesium silicate was studied.

RESULTS AND DISCUSSION

Table 1 presents the properties of bleached mixed hardwood and imported softwood pulps. There are two important properties for barrier paper, i.e. water klemn and castor oil penetration (COP). The water klemn property is related to absorption of melamine formaldehyde resin mixture by barrier paper during the saturation step. COP is related to the tendency of barrier paper to retain melamine formaldehyde by the fiber structure. An optimum value for COP and water klemn can be obtained by varying the degree of refining, blending of short fibred pulp with long fibred pulp, and filler dosing. The strength properties of a pulp blend can be predicted very closely if the two pulps are beaten separately before combining simply by obtaining a weighted average of the strength properties at the two freeness levels (Packham and May 1959). A pulp blend having beaten hardwood and softwood pulps in the ratio of 50:50 is found suitable to give water klemn and COP for barrier paper.

Table 1. Properties of Bleached Mixed Hardwood and Imported Softwood Pulps

Sl. No.	Particulars	Bleached mixed hardwood pulp	Bleached imported softwood pulp
1.	Initial beating level, °SR	18±1	13±1
2.	Final beating level, °SR	30±1	30±1
3.	Ash, %	2.2	0.32
4.	Basis weight, g/m ²	70	70
5.	Burst index, kPam ² /g	2.75	7.25
6.	Tensile index, Nm/g	45.08	100.94
7.	Tear index, mNm ² /g	4.9	9.2
8.	Brightness, % (ISO)	84	89
9.	Opacity, %	87	86
10.	Water klemn (4 min), mm	31	42
11.	COP at 35 ±1°C, s (TS/WS)	14/11	11/8

Table 2 reveals the effect of papermakers' alum (aluminum sulfate) on fines and fillers. The pH of the pulp after bleaching is alkaline. When pH was adjusted to 6.5 with alum, in the case of the mixed hardwood pulp, the ash contents increased from 2.2 to 2.8% and ash contents in case of imported softwood from 0.32 to 1.03%. In a furnish composition containing mixed hardwood and imported softwood pulps in the ratio of

50:50 and loaded with 30% TiO₂ and 10% micronized soapstone, alum enhanced ash contents from 12.1 to 25.48% compared to the control, and the alum had little effect on the flocculation of the filler and fiber suspension.

Davison and Cates (1975) and Stratton and Swanson (1981) showed that a significant role is played by surface charges and zeta potentials with respect to retention and drainage phenomena. The improvement in retention is due to effect of surface charges when alum is used (Allen and Yaraskavitch 1991; Horn and Melzer 1975; Ström and Kunnas 1975). Maximum retention is associated with an addition rate that achieves zeta potential near to zero (Hubbe 2005).

Table2. Effect of Alum on Retention of Fines and Fillers and Improvement on Opacity

Furnish composition, %		^{a,b} Alum, %	^a Filler, %		Initial pH of stock	Laboratory made handsheet		
Mixed Hardwood pulp	Softwood Pulp %		TiO ₂	Micronized Soapstone, (95 %, ISO)		Brightness, %	Opacity, %	*Ash, %
100	—	—	—	—	8.0	83.9	83.53	2.2
100	—	0.5	—	—	6.3	82.9	84.31	2.8
—	100	—	—	—	7.9	87.9	87.93	0.32
—	100	0.5	—	—	6.5	86.72	88.12	1.03
50	50	—	30	10	7.4	88.23	91.3	12.1
50	50	0.5	30	10	6.5	86.90	97.98	25.48

*=% ash of total added fillers, a= oven dry pulp basis, b= alum added to attain a pH level of 6.5

Likewise, with 100% mixed hardwood pulp, the total ash content, brightness, and opacity increased with increasing TiO₂ filler from 20 to 40% (oven dry pulp basis) (Table 3). When TiO₂ was replaced by 5 and 10%, respectively, of micronized soapstone powder, there was an increase in ash content with a slight drop in brightness. The same pattern was obtained in the case of 100% imported softwood pulp. A furnish composition having mixed hardwood and imported softwood pulps in the ratio of 50:50, 30% TiO₂, 10% micronized soapstone powder, non-ferric alum to attain a pH of about 6.5, and 1% melamine formaldehyde showed maximum retention of filler 21.48% of the total quantity of added filler.

Obviously, decorative laminate manufacturers require 98 to 99% opacity, 87 to 90% (ISO) brightness, and 25% ash in paper. It is observed that during manufacturing of decorative laminates, the retention of TiO₂ filler is very poor due to its small particle size. However, the retention of TiO₂ can be improved by using retention aids. Unfortunately, this causes agglomeration of the TiO₂ particles and reduction in their scattering efficiency. If we use potassium polyvinyl sulfate (retention aid), agglomeration of TiO₂ filler causes a 7.18% drop in opacity during the saturation step, contributing to the see-through problem. In order to combat see-through in barrier paper, TiO₂ is partially replaced with anhydrous magnesium silicate during the manufacturing process (Table 4). Table 4 shows the effect of anhydrous magnesium silicate on the retention of TiO₂, micronized soap stone in decorative laminates. The overall retention of TiO₂ at pH 6.5 was 54.05%. When TiO₂ was partially replaced with 5% micronized soapstone and 10% anhydrous magnesium silicate, the overall ash retention was improved to 64.13%. Further, overall filler retention was improved to 65.25% when TiO₂ was replaced with

Table 3. Effect of Filler Loading and Furnish Composition on Brightness, Opacity, and Ash Contents

Furnish composition, %		^a Filler, %		^b Initial pH of stock	Brightness, % (ISO)	Opacity, %	*Ash in paper, %
Mixed hardwood pulp	Imported Softwood pulp	TiO ₂	Micronized soapstone, (95 %, ISO)				
100	–	20	–	6.5	83.32	95.43	10.2
100	–	25	–	6.5	84.16	96.10	12.8
100	–	30	–	6.5	85.43	96.54	15.6
100	–	40	–	6.5	86.10	97.48	18.8
100	–	35	05	6.5	85.32	96.87	20.9
100	–	30	10	6.5	85.13	96.73	22.2
–	100	20	–	6.5	87.39	93.01	9.4
–	100	25	–	6.5	87.69	94.72	11.67
–	100	30	–	6.5	87.57	94.89	14.81
–	100	40	–	6.5	88.21	95.87	16.03
–	100	35	05	6.5	88.78	94.94	18.71
–	100	30	10	6.5	88.36	94.87	20.13
50	50	40	0	6.5	87.83	96.58	20.01
50	50	35	5	6.5	87.02	96.01	19.67
50	50	30	10	6.5	86.88	96.99	21.48
50	50	25	15	6.5	86.20	96.87	20.04

* = percent ash of total added fillers, a = oven-dry pulp basis, b = pH is adjusted with non-ferric alum, pulp furnish contains 0.1% sodium hexametaphosphate, and 1.0% melamine formaldehyde on oven-dry pulp basis

Table 4. Effect of Anhydrous Magnesium Silicate on Retention of Ash

Sl. No.	^a Filler, %			^b Initial pH of stock	Brightness, % (ISO)	Opacity, %	Ash in paper, %	% ash retained of fillers added
	TiO ₂ , %	Micronized soapstone, % (ISO)	AMS					
1.	40	–	–	6.5	88.92	98.76	21.62	54.05
2.	35	05	–	6.5	87.91	98.62	22.72	56.80
3.	35	–	05	6.5	89.53	98.21	23.52	58.80
4.	30	–	10	6.5	89.42	98.10	24.88	62.20
5.	25	–	15	6.5	89.00	97.48	25.25	63.13
6.	30	05	05	6.5	88.53	98.61	23.05	57.63
7.	25	05	10	6.5	88.48	98.78	25.65	64.13
8.	25	10	05	6.5	87.94	97.87	24.84	62.10
9.	20	10	10	6.5	87.63	97.99	23.90	59.75
10.	32	–	08	6.5	88.20	97.37	23.50	58.75
11.	25	07	08	6.5	88.25	99.05	26.10	65.25
12.	25	15	–	6.5	–	98.52	–	–
13.	25	15	PVS	6.5	–	91.34	–	–

a = oven dry pulp basis, b = pH is adjusted with non-ferric alum, pulp furnish contains 0.1% Na hexametaphosphate, and 1.0% melamine formaldehyde on oven dry pulp basis, * = sheet impregnated with melamine formaldehyde resin, potassium polyvinyl sulfate 2kg per tonne of pulp

7% micronized soapstone and 8% anhydrous magnesium silicate. Microparticulate retention aids improve retention, drainage, and formation. When these retention aids are added to a pulp slurry, small, tight flocs form and adsorb to the furnish components. The

microparticles effectively lock the suspended and dissolved solids in the sheet with the fibers and filler (Ovenden et al. 2000).

Table 5 reveals that laboratory-made handsheets achieved a brightness of 88.25% (ISO), opacity 99.05%, overall retention in paper 65.25%, water klemn (4 min) 30 mm, castor oil penetration value (COP) ^{TS/WS} 29/32 s, Bendsten air porosity 720 mL/s, wet strength 160 g/cm, opacity after saturation with melamine formaldehyde (40% melamine formaldehyde resin of the weight of paper) 94.20%, and it met the specifications prescribed by Indian decorative laminate manufacturers. The paper did not exhibit a see-through problem after saturation with melamine formaldehyde. Keeping the cost of other variables constant, the cost of filler per tonne of decorative laminates is US\$ 1772.00 per tonne of pulp in present practice, while the cost of filler by partially replacing TiO₂ with micronized soapstone and anhydrous magnesium silicate is US\$ 1226.00 per tonne of pulp. The cost reduction per tonne of decorative laminates is about US\$ 546.00 tone of pulp. The cost reduction data are given in Appendix-A.

The beneficial effects of the soapstone addition may be partly attributed to a reduction in optical crowding, an effect that reduces overall light scattering when the high refractive index TiO₂ particles are able to agglomerate together. Such agglomerates provide less opportunity for light scattering, an effect that is roughly proportional to the interfacial area between phases having a strong contrast in refractive index. By contrast, when TiO₂ particles are mixed with another mineral of much lower refractive index (e.g. soapstone particles), the combination will tend to retain a higher ability of scatter light, even when the particle are mutually agglomerated and when air spaces become filled with resin.

Table 5. Properties of Laboratory Made Handsheets

Sl. No.	Parameters	Results	Specifications prescribed by Indian Decorative Laminate Manufactures
1.	Basis weight, g/m ²	70.10	–
2.	Brightness, % (ISO)	88.25	–
3.	Opacity, %	99.05	–
4.	*Opacity, %	94.10	–
5.	Over all filler retention, %	65.25	–
6.	Water klemn (4 min), mm	30	25-29
7.	COP at 35 ±1°C, s TS/WS	29/32	20-35 (avg)
8.	Porosity (Bendsten), mL/min	720	600-800
9.	Wet strength, g/cm	160	150

A pulp blend ratios of mixed hardwood and imported softwood 1:1, pulp beating level 30 °SR, TiO₂ 25%, micronized soapstone 7%, anhydrous magnesium silicate 8%, 1% melamine formaldehyde, 0.1% sodium hexametaphosphate, with opacity evaluated after impregnation with melamine formaldehyde

CONCLUSIONS

Non-ferric alum at pH 6.5 helped in retaining TiO₂ filler and fines. A furnish composition having mixed hardwood and imported softwood pulps at 1:1 ratio, beaten at

30 °SR separately and mixed with 25% TiO₂, 7% micronized soapstone powder, 8% anhydrous magnesium silicate, 1% melamine formaldehyde, and 0.1% sodium hexametaphosphate yielded a brightness of 88.25% (ISO), opacity 99.05%, overall retention in paper 65.25%, water klemm (4 min) 30 mm, castor oil penetration value (COP)^{TS}/_{WS} 29/32 s, Bendsten air porosity 720 mL/s, wet strength 160 g/cm, and opacity after saturation with melamine formaldehyde (40% melamine formaldehyde resin of the weight of paper) 94.2%. The resulting barrier layer exhibited see-through. The partial replacement of TiO₂ with micronized soapstone powder and anhydrous magnesium silicate showed a net savings in manufacturing cost by US\$ 546.00 per tonne of pulp.

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APPENDIX: COST REDUCTION STUDIES

A. The cost of filler in present practice at mill-A.

Titanium dioxide filler per tonne of pulp = 400 kg
Total cost of TiO₂ fillers = 400 x 4.43= US\$ 1772.00
@4.43US\$/kg of TiO₂

B. The cost of filler with partial replacement of titanium dioxide with micronized soapstone and anhydrous magnesium silicate

Titanium dioxide filler per tonne of pulp = 250 kg
Cost of TiO₂ fillers = 250 x 4.43= US\$ 1107.50
Micronized soapstone filler per tonne of pulp = 70 kg
Cost of TiO₂ fillers = 70 x 0.55= US\$. 38.50
@0.55US\$/kg of micronized soapstone

Anhydrous magnesium silicate per tonne of pulp = 80 kg
Cost of anhydrous magnesium silicate fillers = 80 x 1.00= US\$. 80.00
@1.00 US\$/kg of anhydrous magnesium silicate

Total cost in case of A = US\$ 1772.00 per tonne of pulp

Total cost in case of B = US\$ 1226.00 per tonne of pulp

Net savings = US\$ 546.00 per tonne of pulp

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