The Improvement of the Opacity and Printing Strength of Fancy Paper Overlaid Plywood

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ABSTRACT

The purpose of this study is to investigate the opacity and printing strength of MG paper overlaid plywood. The printing strength of ink on MG paper can be evaluated effectively by a formula $E^{*2} = [(L^*)^2 + (a^*)^2 + (b^*)^2]^{1/2}$ that we proposed. Higher E value indicates good printing strength of ink-on-paper. We also assess the real color of translucent printed MG paper with a formula CIE $\triangle E^*$ (color difference between a pile of same paper to be opaque and fancy paper laminated board). In addition, the color difference on paper surface caused by the color of wood-based board (bottom) can be evaluated by a formula of Pc. No. Generally, an acceptable appearance quality of fancy boards is $\triangle E^* < 2.0$ and small Pc.No. value.

The experimental results showed that Japan-made MG papers –J1, J2 and J3 have better printing strength and gloss than that of Taiwan-made paper (T1). The reason for this was that Taiwan-made paper has poor printing strength and low gloss, which might be correlated to the fiber compositions in paper. Higher printing strength can be seen for short fiber containing handsheets when comparing to that of handsheets. Nonetheless, low-freeness sheets gives better printing strength than that of high-freeness sheets. High-opacity MG paper gives good opacifying effect to the fancy paper laminated wood-based boards. Comparing the surface color of 2 kinds of fancy paper laminated boards, paperboard T1 laminated with high-opacity fancy paper showed slight color difference. The same results can be seen for ?? g/m^2 handsheets. Higher-opacity Acacia and Eucalyptus bleached sulfate pulps (short fiber) gives higher opacifying effect on the plywood when comparing to Northan pine and Radiata pine sulfate pulps(long fiber). The former ones also showed small color differences when comparing the color differences between the color of fancy paper and laminated paper board. Additionally, the color of bottom plywood can't be shown through for the high-opacify surface paper adhered to. Besides, the PC No of the base paper laminated board is small as well. Apparently, we can add colorants to the binders for the manufacture of various handsheets (30 g/m^2) with various pulp mix ratios to increase the opacity of paperboards to certain extents. When we using yellow and brown binders in paper laminated board, the color difference between Acacia and Eucalyptus handsheets overlaid boards decreasing to 2.0 (acceptable $\triangle E^* < 2.0$, hard to discern), but not much improvement for Northern and Radiata pines. Definitely, show-through defects can be discernible for lower opacity papers. In general, admirable printing strength of fancy paper by which glued to plywood can be made with high-opacity paper and colored binders techniques.

Keywords: MG paper, fancy plywood, binder, opacity, printing strength.

INTRODUCTION

The demand for the manufacture of fancy paper overlaid plywood in Taiwan has increased greatly [1]. In the preparation of fancy paper overlaid plywood, its process is precisely the same as that used in the plywood manufacturing (see Figure 1). In the manufacturing of fancy paper overlaid plywood process, an opaque and smooth fancy paper is required for the coverage of dark wood color underneath and the admirable printability. One-side glossy opaque low grammage ca 30 g/m^2 made in Taiwan has some defects such as: uneven summerwood and springwood morphology, color difference in sapwood and heartwood, stain on wood surface and resin penetration ofwhich make uneven color on wood surface [2-6]. Although color variations do not influence the strength of fancy paper overlaid plywood, it results in unpleasing appearance and poor printability to some extents. Usually a low basis weight ca 30 g/m^2 fancy paper has poor opacifying power, so the color matching and consistent-color fancy paper overlaid plywood can't be attained easily.

The purpose of this study examined the cause of poor opacifying power of low grammage fancy paper and the methods taken to minimize the problem.

EXPERIMENTAL

Materials and Treatment

Taiwan-made T1 (basis weight: 30.5g/m^2) and Japan-made Machine glazed papers J1 32.0g/m^2, J2 31.1g/m^2, J3 30.1g/m^2 are used as fancy paper. Radiata pine and Eucalyptus bleached kraft pulps are purposed from Arauco pulp mill, Chile; Northern bleached kraft pulp made in Canfor Prince George pulp mill, Canada; Acacia bleached kraft pulp made in P.T. Tel pulp mill, Indonesia. Medium Density Fiberboards are imported from Malaysia. The densities of yellowish sample FB-A and brown FB-B are 0.67 g/cm^3 and 0.71 g/cm^3 respectively. 5730 white (viscosity: 20000-25000 cps, solid content: 45.03%), 5730L yellow (viscosity: 15000-20000 cps, solid content: 44.92%) and 5730L brown (viscosity: 15000-20000 cps, solid content: 4.66%), high polymers (PVAc) made in Nanpoa Resin Inc. Taiwan are used as binders (pH: 3-5) for gluing MG paper with fiberboards together. Meicky Printing Mill supplied blue ink (solid content: 15.48%) and red ink (solid content: 14.80%).

Opacity, brightness, gloss, CIE color of paper samples and handsheet preparation are determined and prepared respectively in accordance with TAPPI related standards.

Printability (expressed as ΔE*) of ink on fancy paper overlaid plywood's surface is examined by the following formula we proposed :

$$\Delta E^* = [(L^*)^2 + (a^*)^2 + (b^*)^2]^{1/2}$$

Where L*,a*,b* are the color difference between printed area and unprinted area backed by glued fiberboard. PC.NO values indicated the brightness difference before and after gluing on board's surface, higher value means less opacifying power of MG paper on boards.

RESULTS AND DISCUSSION

Opacity vs. Density

Table 1 shows fundamental properties of four commercial MG papers. As the density of paper increases, the optical contact increases and the opacity decreases. When bonding occurs between fibers, the light can pass through one fiber to another without passing through air, and thus no scattering occurs at these points; which is known as optical contact. A smooth paper can be obtained by calendaring that gives a flat surface. Although dense paper gives smooth paper surface, which is beneficial to paining in fancy paper overlaid plywood manufacturing. However, a lower opacity may be resulted as seen in Table 1.

Ink Absorption of Commercial MG Papers

Data calculated from a formula $(L^{*2} + a^{*2} + b^{*2})^{1/2}$ that we proposed can be regarded as the determination of coloring strength of various inks as seen in Table 2 & 3. A good relationship exists between the ink absorption of paper and the color strength of ink on paper surface. The figures in Table 2 & 3 show that coloring strength varies with ink types and no relationship exists between coloring strength and its gloss. Interestingly, paper sample J3 shows similar L* values of 47 as that of J1 and J2, but gives the highest gloss of 35.20%. In other words, it may be affected by paper sample J3's good ink holdout. The gloss after printing in Table 4, which was obtained in a laboratory run on commercial papers using red and blue inks, shows the effect of vehicle in ink. The increase in printed gloss of J1, J2 and J3 with blue ink may be due to vehicle, sizing degree and paper structure. Lower ink gloss clearly shows the aforementioned factors affecting the ink absorption of paper T1 to some extents sizing degree.

Color Differences between Varying Fancy Paper Laminated Boards

Table 5 shows that slight decrease in the opacity of fancy paper overlaid fiberboard, due to the decrease in its corresponding scattering coefficient. Paper sample T1 with increased grammage (30 g/m^2 → 45 and 45 g/m^2) leads to improved opacity. It is obvious that due to the increase in scattering power. If it is assumed that no others changes are made when the grammage is changed, the scattering coefficient will remain constant and the scattering power (sW) will be directly proportional to the weight [7].

It is assumed that slight color differences (ΔE*: 1.50 and 1.46) will exist when an opaque fancy paper (T1-45G (basis weight: 45 g/m^2) and T1-50G (basis weight: 50g/m^2 in Table 6) laminated on different fiberboards with varying colors. The PC. NO. of them (5.99 and 6.40) shows the same trend (smaller) than other samples. In other words, opaque fancy paper can be obtained by increasing basis weight. It you look at these samples, the acceptable color differences can be found for the ΔE < 2.0 and PC. NO < 20 ones. In choosing a paper for its opacifying effect, it is wise to choose one with a high scattering coefficient (s value). Papers with high absorption coefficients (k values) also increase the opacity, but they reduce the brightness (Table 7)

Pulp Mix Ratios vs. Opacity

Figure 2 shows the various pulp mix ratios (Northern Pine and Radiata pine + Acacia and Eucalyptus = 100/0, 50/50 and 0/100) of 30 g/m^2 handsheets give different opacity results. Hardwood pulps – Eucalyptus and Acacia pulps – produce papers of higher opacity than bleached softwood pulps – Northern pulp and Radiata pulp- possibly because fiber coarseness and its void structure. Perng indicated that the coarsenesses of hardwood and softwood fibers are 0.07-0.12 mg/m and 0.15-0.75mg/m respectively [8]. It may be as a general rule that the higher mix ratio of hardwood from which the paper is made, the higher opacity of the paper.

Colored Binders vs. Opacity of Fancy Papers Overlaid Plywood

We select 2 long-fiber pulps (Northern and Radiata bleached pulps) and 2 short fibers (Eucalyptus and Acacia bleached pulps) to investigate the effects of their properties on the opacity of fancy paper overlaid plywood. Table 8 shows that hardwood handsheets have higher opacity than that of softwoods for the same basis weight (30 g/m^2). Figure 2 shows that decreased lightness can be seen after the application of 3 kinds of glues (white, yellow and brown) adhesives on fiberboards. The lightness differences (ΔL*) between fiberboards A & B were increased for white glue application and decreased for brown and yellow ones. In general, the binders applied on boards' surface can make a homogeneous colored surface and decreased their color difference (board A vs. board B). Interestingly, when using brown glue, the lower-opacity Radiata pine bleached handsheet shows lower color difference (< 2.0) as that of higher-opacity hardwood handsheets, the reason needs to be further studied (Table 9).

Table 10 shows that lower color difference (< 2.0) can be obtained for hardwood bleached handsheets glued with brown and yellow ones, in addition, their PC. NO. (12.88-26.37) are lower than that of softwood ones (41.70-57.79). Acacia one is the best one and followed by Eucalyptus; Northern pine & Radiata pine can't meet our requirement (Δ E < 2.0 and PC.NO < 20).

CONCLUSIONS

Using low basis weight (30g/m^2) MG paper made from hardwood bleached kraft pulps backed by adding brown dyes to white PVAc resins reduced uneven surface color together with increased opacifying power of paper simultaneously. In other words, most of the absorption power of low-basis paper is derived from additives or from noncellulosic materials (dyes and residual lignin). The opacity of paper will increase with the increase in absorption power; therefore, very small quantities of dye in white glue will greatly increase the absorption power of paper. The opacifying power of MG paper on fiberboards can be assessed objectively by formula $\Delta E^* = [(L^*)^2 + (a^*)^2 + (b^*)^2]^{1/2}$ we proposed in this study.

REFERENCE

1. Su, W.S. and Lien, J.C., Raw materials and market analysis in Taiwan, R &D Report Industry Bureau, Taiwan (1995).
2. Kuo, L.S., Optical of paper, Workshop of Taiwan Papermaking Industry, (1986).
3. Wang, H. *et al.*, Effect of dyes on the opacity of paper, Pulp & Paper Monthly, Aug. (2):15-23 (1982).
4. Kuo, L.S. *et al.*, The opacity of white envelope, Taiwan Forestry Science, 12(1):53-59 (1997).
5. Kuo, L.S., Effect of the interaction of yellow dyes with fiber and additives on the opacity of papers – emphasis on the effect of basis weight on opacity with some mathematical formulae, Dissertation of the Dept of Forestry, National Taiwan University (1984).
6. Kollmann, F.P.F. and Wilfred A.C., Principle of wood science and technology, Vol. I, Solid wood, p. 105 (1976).
7. Casey, J.P., Pulp and Paper Chemistry and Chemical Technology, 3rd edition, Vol. III, p. 1879 (1981).
8. Perng, Y.S., The characteristics of chemical pulps and its application, Taiwan TAPPI J. 3(2):1-12, (1999) (Chinese edition).

Table 1 Fundamental properties of 4 commercial MG papers

Paper samples		T 1	J 1	J 2	J 3
Basis weight (g/m^2)		30.54	31.95	31.08	30.13
Caliper (mm)		0.044	0.043	0.041	0.036
Density (g/cm^3)		0.69	0.75	0.76	0.84
Air resistance (sec/100mL)		24.94	23	17.7	41.36
Sizing (sec)	WS	5.52	5.62	6.23	5.26
	FS	5.66	5.19	5.21	5.76
TAPPI Brightness (%)		88.77	84.62	81.04	87.82
Gloss (%, 75°)	WS	28.54	20.47	25.5	30.30
	FS	5.88	5.85	7.5	8.5
TAPPI Opacity (%)		63.28	61.32	56.57	57.42
Tensile strength (kgf/15mm)	MD	2.74	2.39	3.55	3.06
	CD	2.31	1.66	2.32	2.02
Burst strength (kgf/cm^2)		1.33	1.18	1.33	1.40

Table 2. CIE L*a*b* and coloring strength of blue ink on 4 commercial MG papers

Papers	L*	a*	b*	$(L^{*2}+a^{*2}+b^{*2})^{1/2}$	Gloss (%, 75°)
T1	45.70	-10.30	-29.92	55.59	24.98
J1	47.85	-12.03	-29.37	57.42	23.78
J2	47.24	-11.01	-27.31	55.67	27.72
J3	47.65	-10.99	-28.07	56.38	35.20

Table 3. CIE L*a*b* and coloring strength of red ink on 4 commercial MG papers

Papers	L*	a*	b*	$(L^{*2}+a^{*2}+b^{*2})^{1/2}$	Gloss (%, 75°)
T1	44.58	41.02	13.65	62.10	23.93
J1	45.28	39.30	12.06	61.16	22.73
J2	44.71	36.37	11.10	58.69	25.00
J3	45.14	37.56	11.55	59.85	28.00

Table 4. Variations of CIE L*a*b* and gloss for 4 commercial MG papers before and after printing

		Unprinted				Blue ink			
		L*	a*	b*	Gloss (%, 75°)	L*	a*	b*	Gloss (%, 75°)
T1	**Wire side**	**79.61**	**-0.48**	**-1.02**	**28.54**	**45.70**	**-10.30**	**-29.92**	**24.98**
Felt side	*79.81*	*-0.49*	*-1.02*	*5.88*	*56.21*	*-8.30*	*-20.50*	*5.03*	
J1	**Wire side**	**78.45**	**-0.53**	**-0.60**	**20.47**	**47.85**	**-12.03**	**-29.37**	**23.78**
Felt side	*78.64*	*-0.53*	*-0.59*	*5.85*	*57.09*	*-9.37*	*-20.61*	*5.34*	
J2	**Wire side**	**75.63**	**-0.49**	**-0.60**	**25.50**	**47.24**	**-11.01**	**-27.31**	**27.72**
Felt side	*75.62*	*-0.51*	*-0.5*	*7.50*	*53.62*	*-8.91*	*-20.62*	*7.06*	
J3	**Wire side**	**76.60**	**-0.50**	**-1.04**	**30.30**	**47.65**	**-10.99**	**-28.07**	**35.20**
Felt side	*76.44*	*-0.49*	*-1.05*	*8.50*	*56.84*	*-7.72*	*-18.47*	*7.98*	
		Unprinted				**Red ink**			
		L*	a*	b*	Gloss (%, 75°)	L*	a*	b*	Gloss (%, 75°)
T1	**Wire side**	**79.61**	**-0.48**	**-1.02**	**28.54**	**44.58**	**41.02**	**13.65**	**23.93**
	Felt side	79.81	-0.49	-1.02	*5.88*	*52.89*	*29.15*	*5.04*	*5.17*
J1	**Wire side**	**78.45**	**-0.53**	**-0.60**	**20.47**	**45.28**	**39.30**	**12.06**	**22.73**
	Felt side	78.64	-0.53	-0.59	*5.85*	*50.45*	*31.59*	*6.03*	*5.36*
J2	**Wire side**	**75.63**	**-0.49**	**-0.60**	**25.50**	**44.71**	**36.37**	**11.10**	**25.00**
	Felt side	75.62	-0.51	-0.5	*7.50*	*50.51*	*27.38*	*4.98*	*7.10*
J3	**Wire side**	**76.60**	**-0.50**	**-1.04**	**30.30**	**45.14**	**37.56**	**11.55**	**28.00**
	Felt side	76.44	-0.49	-1.05	*8.50*	*52.87*	*26.30*	*4.17*	*8.10*

Table 5 Optical properties of 4 commercial MG papers

Papers		T1	J1	J2	J3	T1-45G	T1-50G
Basis weight (g/m^2)		30.54	31.95	31.08	30.13	44.58	49.49
TAPPI Brightness (%)		88.77	84.62	81.04	87.82	88.10	87.88
TAPPI Opacity (%)		63.28	61.32	56.57	57.42	72.79	75.34
TAPPI Opacity' (%)		61.71	60.33	55.48	55.78	71.99	73.65
460nm	k, cm^2/g	2.04	2.94	3.19	1.84	2.26	2.38
	s, cm^2/g	138.69	127.65	105.88	111.68	201.59	224.92
	k', cm^2/g	2.71	3.78	4.46	2.93	3.12	2.99
	s', cm^2/g	129.66	121.98	100.25	103.97	192.89	208.34
580nm	k, cm^2/g	1.22	1.31	1.82	0.96	1.13	1.13
	s, cm^2/g	127.91	118.51	98.90	103.55	186.64	208.44
	k', cm^2/g	1.56	1.84	2.57	1.62	1.54	1.47
	s', cm^2/g	119.71	112.87	93.52	96.18	178.38	191.42

Table 6. The color differences of 4 commercial MG papers laminated on fiberboards A and B

Papers/Boards		L*	a*	b*	(A-B)△E*	PC. NO.
T1	A	83.30	1.93	3.89	2.70	13.63
	B	81.78	1.25	1.76		14.31
J1	A	82.01	2.14	4.67	2.95	16.06
	B	80.04	1.59	2.54		17.75
J2	A	79.77	2.74	5.92	3.18	21.48
	B	78.17	1.96	3.28		22.01
J3	A	80.64	2.65	5.45	3.71	20.31
	B	77.81	2.12	3.11		24.04
T1-45G	A	86.96	0.98	2.50	1.50	7.01
	B	86.14	0.56	1.32		7.26
T3-50G	A	87.73	0.86	2.31	1.46	5.99
	B	86.80	0.45	1.26		6.40

Table 7. Fundamental properties of 4 handsheets

Pulps (mL CSF)	Northern pine 350	Radiata Pine 350	Eucalyptus 450	Acacia 450
Basis weight (g/m^2)	30.43	30.09	30.08	30.28
Caliper (mm)	0.0423	0.0469	0.0492	0.0548
Density (g/cm^3)	0.72	0.64	0.61	0.55
Air resistance (sec/100mL CSF)	7.24	5.58	2.17	1.42
Brightness (%)	83.06	85.15	86.96	88.72
TAPPI opacity (%)	43.04	40.76	55.62	66.29
Wet-opacity (%)	25.25	24.58	29.50	28.86

Table 8. △E* values of fiberboards A and B after using 3 glues to laminate 4 handsheets

Pulps(mL CSF)	△E value between board A and board B		
	White glue	**Yellow glue**	**Brown glue**
Northern pine (350)	4.43	3.42	3.18
Radiata pine (350)	4.67	3.19	1.56
Eucalyptus (450)	3.11	1.81	1.65
Acacia (450)	2.31	1.04	1.00

Table 9. △E* and PC. NO. values of fiberboards A and B after using 3 glues to laminate with 4 handsheets

Paper (mL CSF)	Fiberboard	**White glue**		**Yellow glue**		**Brown glue**	
		△E*	PC. NO.	△E*	PC. NO.	△E*	PC. NO.
Northern pine (350)	**A**	4.43	30.76	3.42	44.36	3.18	41.70
	B		35.81		39.43		52.99
Radiata pine (350)	**A**	4.67	33.07	3.19	44.96	1.56	55.59
	B		39.36		43.00		57.79
Eucalyptus spp. (450)	**A**	3.11	17.45	1.81	23.66	1.65	23.62
	B		19.68		22.32		26.37
Acacia spp. (450)	**A**	2.31	10.15	1.04	12.30	1.00	12.88
	B		11.71		11.67		14.23

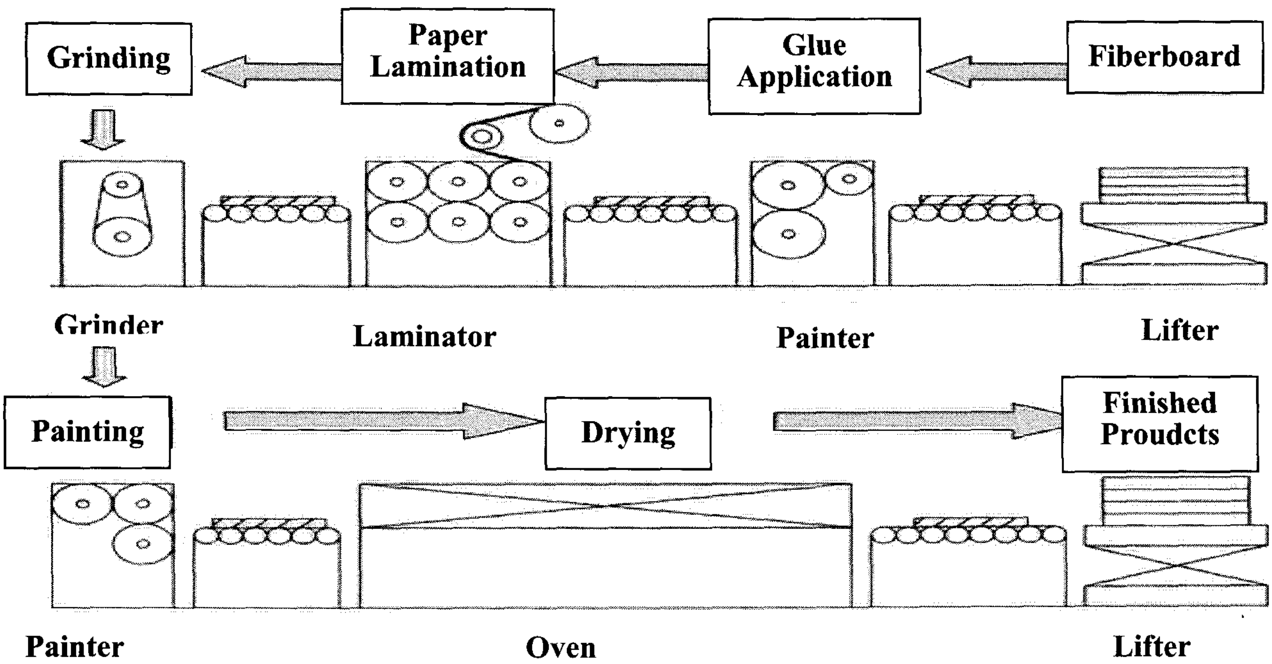
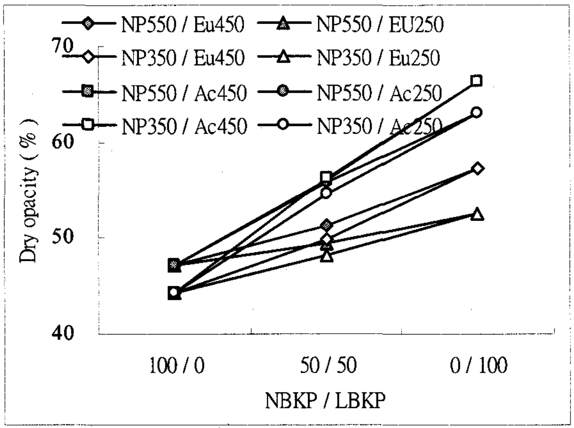
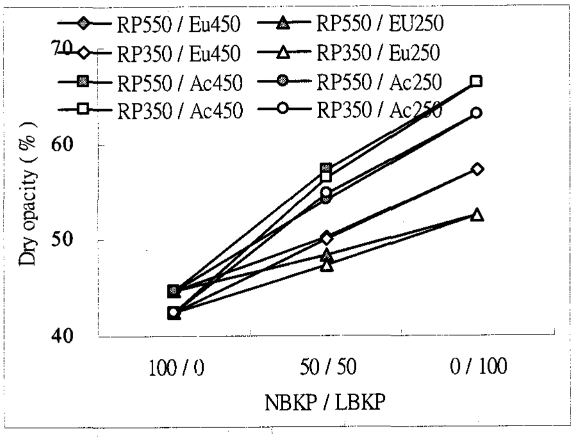


Fig. 1 Flow Chart of the preparation of fancy paper overlaid plywood



(a) Northern pine / Eucalyptus & Acacia



(b) Radiata pine / Eucalyptus & Acacia

Fig. 2 Effects of furnish on the dry opacity of handsheets