Studies on Particle Board (XI)

Studies on Overlaid Particle Board (2)

The influence of physical properties of some Japanese particle boards and high pressure decorative laminates on the stability of overlaid boards

By

Mutsumi IWASHITA[(1)] and Andrew M. STASHEVSKI[(2)]

Introduction

Problem of particle board overlaying becomes more important each year with the increasing amount of particle board finding the consumer market in Japan. Since its early days in the early fifties particle board production has risen from 68,000 m^2 in 1953 to 12,200,000 m^2 in 1966. Estimated production for 1967 will reach 14,000,000 m^2.

A considerable proportion of particle boards will be overlaid with high pressure decorative laminates to provide improved surface conditions for uses where heat and moisture resistance and resistance to corrosive action of chemicals is required. Chief uses for particle boards overlaid with high pressure laminates will be found in furniture and shopfitting industries, and also in the manufacturing of electrical goods, office partitions and numerous other applications.

Although today this type of product has an established market, because of its good physical properties and attractive appearance which can be changed easily to suit particular taste and application, the manufacturer and consumer are often troubled by undesirable dimensional instability problems which cause table tops to bow and wardrobe doors to warp, thus leaving the product open to criticism.

Observations of industrial practices both in Japan and Australia led the authors to believe that basically dimensional instability is caused by lack of symmetry in most of the commercial constructions i. e. the high pressure decorative laminate overlay is not counterbalanced on the other face, or is counterbalanced by some dissimilar sheet material. This practice is of course dictated by economic considerations.

To produce high pressure decorative laminates is costly, as melamine resin is comparatively expensive and the percentage of sheet rejects in the course of manufacture is high.

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(1) Chief, Wood Improvement Laboratory, Wood Improvement Section, Wood Technology Division, Government Forest Experiment Station, Meguro, Tokyo, Japan.

(2) Member of the staff, Plywood and Gluing Section, Division of Forest Products, C. S. I. R. O., Melbourne, Victoria, Australia.

A. M. STASHEVSKI was a foreign specialist under Japanese Scientific and Technical Award by Science and Technics Agency at Government Forest Experiment Station from February 1 to October 31, 1963.

Decorative laminates are therefore much more expensive than ordinary phenol based laminates used in the electrical industry.

High pressure decorative laminates, being laminates incorporating two types of resin and many types of paper, have very specific properties corresponding to their assembly technique and materials, which are very difficult if not impossible to duplicate. So far it has been impossible to manufacture a cheaper sheet material which would be suitable to counterbalance stresses produced by high pressure decorative laminates in a laminated assembly during moisture content changes experienced in daily life.

It has been further observed that distortions occurring in laminated commercial products and resulting from construction unbalance vary both in intensity and frequency, and that this can be often related to the physical properties of individual boards and sheets used in manufacture of the articles[1)2)3)].

It has occurred to the authors, therefore, that before suitable methods to restore balance could be developed, it is necessary to examine the physical properties of commercially available particle boards and high pressure laminates sheets and relate these properties to the distortions resulting in unbalanced constructions.

Computing the distortion of decorative laminates overlaid particle board

Particle board is an isotropic material in the board surface direction, while decorative laminates are anisotropic due to the paper used as raw materials. In the analysis of distortion it is therefore necessary to consider these laminated boards as anisotropic bodies. Since it is difficult to analyse anisotropic bodies, the authors considered only one direction of the material, based on the simple beam theory.

If inner stress, which is caused by swelling or shrinkage, goes beyond the elastic limit, permanent set occurs. Again, since it is difficult to calculate the distortion beyond the elastic limit, this analysis is confined within the elastic limit.

Plastic laminates overlaid particle board is shown in Fig. 1.

When the laminated board absorbs moisture and when these two sheets are not glued, each sheets swells freely as shown in Fig. 2.

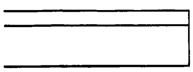


Fig. 1

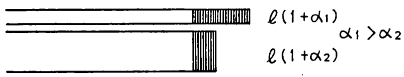


Fig. 2

But when these sheets are glued and cannot warp freely, the length of the laminated board changes to $l\ (1+x)$ and compressive force P_1 is applied on the decorative laminates having bigger swelling ratio α_1, tensile force P_2 is applied on the particle board having smaller swelling ratio α_2 (Fig. 3).

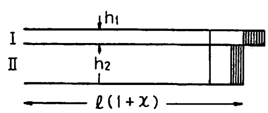


Fig. 3

Assuming that Young's modulus of the laminates and particle board are E_1 and E_2 respectively ($E_1 > E_2$), strain of elongation occasioned by swelling of each member is as follows :

$$\alpha_1 m_1 - \frac{P_1}{E_1 h_1 b} = \alpha_2 m_2 + \frac{P_2}{E_2 h_2 b} \quad \cdots\cdots(1)$$

where m_1, m_2 are moisture change of the laminates and particle board respectively, b is width of beam.

Since P_1 and P_2 should be balanced, these are $P_1=P_2=P$. Therefore, the above equation is changed to

$$\alpha_1 m_1-\alpha_2 m_2=P\left(\frac{E_1h_1+E_2h_2}{E_1h_1E_2h_2}\right)\frac{1}{b}$$

Consequently, the stress occasioned by swelling is

$$P=\frac{(\alpha_1 m_1-\alpha_2 m_2)E_1h_1E_2h_2b}{E_1h_1+E_2h_2} \qquad \cdots\cdots(2)$$

And then, the moment occasioned by the stress P is

$$M=P\left(\frac{h_1}{2}+h_2-\eta\right)+P\left(\eta-\frac{h_2}{2}\right)$$

$$=P\cdot\frac{H}{2} \qquad \cdots\cdots(3)$$

where, $H=h_1+h_2$, η is distance from neutral line as shown in Fig. 4. Substituting P of eq. (3) with eq. (2),

$$M=\frac{(\alpha_1 m_1-\alpha_2 m_2)E_1h_1E_2h_2b}{E_1h_1+E_2h_2}\cdot\frac{H}{2} \qquad \cdots\cdots(4)$$

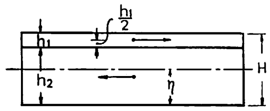


Fig. 4

On the other hand, the curvature of elastic curve within elastic limit is shown as follows:

$$\frac{M}{\Sigma EI}=\frac{1}{\gamma} \text{ or } M=\frac{\Sigma EI}{\gamma}$$

where, I is the moment of inertia of area, γ is the radius of curvature.
Integrating the above equation,

$$M=\frac{bE_2}{\gamma}\int_{-\eta}^{h_2-\eta}y^2dy+\frac{bE_1}{\gamma}\int_{h_2-\eta}^{H-\eta}y^2dy$$

$$=\frac{b}{3\gamma}[E_2(h_2^3-3h_2^3\eta+3h_2\eta^2)+E\{H^3-h_2^3-3\eta(H^2-h_2^2)+3\eta^2(H-h_2)\}] \qquad \cdots(5)$$

From eq. (4) and eq. (5),

$$\frac{1}{\gamma}=\frac{3H(\alpha_1 m_1-\alpha_2 m_2)E_1h_1E_2h_2}{2(E_1h_1+E_2h_2)[E_1(H^3-h_2^3)+E_2h_2^3-3\eta^2(E_2h_2+E_1h_1)]} \qquad \cdots\cdots(6)$$

When the laminated board is bent, the neutral line is transferred and the strains in any position are proportional to the distance from the neutral line. When this strain is multiplied by YOUNG's modulus, the bending stress can be obtained. Therefore, the distribution of bending stress is as shown in Fig. 5. This means that the bending stress is also proportional to distance from the neutral line.

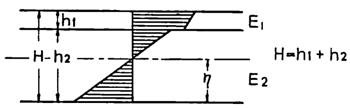


Fig. 5

Since compressive stress should be identical with tensile stress, the following equation can be obtained:

$$\frac{1}{2}E_2\frac{(h_2-\eta)}{\gamma}\cdot(h_2-\eta)+\frac{1}{2}\left[E_1\frac{(H-\eta)}{\gamma}+E_1\frac{(h_2-\eta)}{\gamma}\right]=\frac{1}{2}E_2\frac{\eta}{\gamma}\cdot\eta$$

Then,

$$\eta=\frac{E_1(H^2-h_2^2)+h_2^2E_2}{2(E_1h_1+E_2h_2)} \qquad \cdots\cdots(7)$$

When, $h_1=t$

$h_2=ct$, $\qquad H=t+ct=t(1+C)$

$E_1=E$

$E_2=aE$

Eq. (6) is

$$\frac{1}{\gamma}=\frac{3(t+ct)(\alpha_1 m_1-\alpha_2 m_2)Et\cdot aE\cdot ct}{2E(t+act)[E\{(t+ct)^3-(ct)^3\}+aE(ct)^3-3\eta^2Et(1+ac)]} \cdots\cdots (6)'$$

Eq. (7) is

$$\eta=\frac{t(1+2c+ac^2)}{2(ac+1)} \cdots\cdots (7)'$$

From eq. (6)′ and eq. (7)′,

$$\frac{1}{\gamma}=\frac{6(1+c)(\alpha_1 m_1-\alpha_2 m_2)a\cdot c}{(1+6ac^2+4ac+4ac^3+a^2c^4)t} \cdots\cdots (8)$$

On the other hand, when the deflection of distorted laminating board is y, and the span is B,

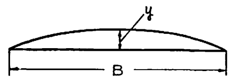


Fig. 6

$$\frac{1}{\gamma}=\frac{8y}{B^2}$$

Therefore

$$y=\frac{1}{\gamma}\cdot\frac{B^2}{8} \cdots\cdots (9)$$

From eq. (8) and eq. (9),

$$y=\frac{3}{4}\cdot\frac{ac(1+c)^2\cdot(\alpha_1 m_1-\alpha_2 m_2)}{1+4ac+6ac^2+4ac^3+a^2c^4}\cdot\frac{B^2}{(t+ct)} \cdots\cdots (10)$$

As can be seen from the equation (10), the conditions for decreasing the distortion of the plastic laminates overlaid particle board exposed to high or low humidity are as follow: (i) $\alpha_1 m_1=\alpha_2 m_2$, (ii) Young's modulus ratio a is high, (iii) thickness ratio c is high, and (iv) span B is small.

The condition (i) would seem to be impossible, but at least the tendency (plus or minus) of the distortion could be expected from the relation between $\alpha_1 m_1$ and $\alpha_2 m_2$. It is necessary for the condition (ii) that particle board having higher Young's modulus be combined with plastic laminates having low Young's modulus relatively. For the condition (iii) the thickness of particle board should be increased and the thickness of plastic laminates should be decreased. The condition (iv) is to make the span smaller, but the span as well as the thickness of particle board and plastic laminates are constant in this experiment.

Therefore, this study was carried out to investigate the influences of the combination of individual moisture change, swelling, shrinkage and Young's modulus in particle board and plastic laminates on the distortion of plastic laminates overlaid particle board.

Physical properties of particle board and plastic laminates

As can be seen from the equation (10) given above, flatness of an unbalanced particle board and plastic laminate construction is affected by such factors as hygroscopic movement, Young's modulus in tension and equilibrium moisture content of each of the components.

Study of these factors was therefore considered necessary to obtain a better understanding of the problem and to gain quantitative data for possible design of assemblies with known and predetermined degree of distortion.

Furthermore, from the practical viewpoint, it was considered important to determine the rate at which the individual component materials are likely to absorb and desorb moisture.

A similar approach was used by B. G. Heebink[3] who has also studied free dimensional movement due to moisture of elasticity in tension, vapor transmission rate and equilibrium moisture content of particle board and decorative laminates.

In this study the above-mentioned factors for the distortion of composite board were investigated by using several kinds of typical particle board and decorative laminates in Japan for the purpose of basic data of mathematical study.

Experimental procedure

1. Experimental material and preparation of specimen

The description of all boards and code letters are shown in Table 1. The materials used in this study were obtained from commercial stocks in the market. The selection of suitable samples of decorative laminates presented some difficulties because the construction of the sheets and particularly the ratio of paper impregnated with phenolic and melamine resin could vary quite considerably depending on the colour and the pattern of the printed paper.

After some initial tests it was decided to use three basic types of printed paper—plain white, wood grain print, and fancy pattern print, as usually applied to kitchen-type furniture. Moreover, as different construction in decorative laminates are produced by manufacturers, the products of three typical manufacturers were used for specimens.

Eight brands of particle board, representing all types of boards produced in Japan at the

Table 1. Experimental material

Type of material	Manufacturer's code letter	Description	Thickness (mm)	Specific gravity
Decorative laminates	AP	Plain white print	1.66	Approximately 1.4
	AG	Wood grain print	1.63	
	AF	Fancy print	1.64	
	BP	Plain white print	1.55	
	BG	Wood grain print	1.55	
	CP	Plain white print	1.46	
	CG	Wood grain print	1.57	
	CF	Fancy print	1.65	
Backing sheet laminates	D	Made by A manufacturer	1.59	
	E	Made by B manufacturer	1.30	
	F	Made by C manufacturer	1.77	
Particle boards	G	Three-layer board	19.99	0.62
	H	do.	20.13	0.66
	I	do.	19.57	0.62
	J	do.	20.25	0.57
	K	Continuous-layer board	20.22	0.57
	L	Mono-layer veneer overlaid board with cross band (5-ply)	20.15	0.52
	M	Mono-layer veneer overlaid board without cross band (3-ply)	20.07	0.64
	N	Extrusion type board with veneer crossband	21.02	0.56

(Note) A, B, C. Decorative laminate. Manufacturer's code letter.
G, H, I, J, K, L, M, N. Particle board. Manufacturer's code letter.
Size of materials: 91 cm × 91 cm

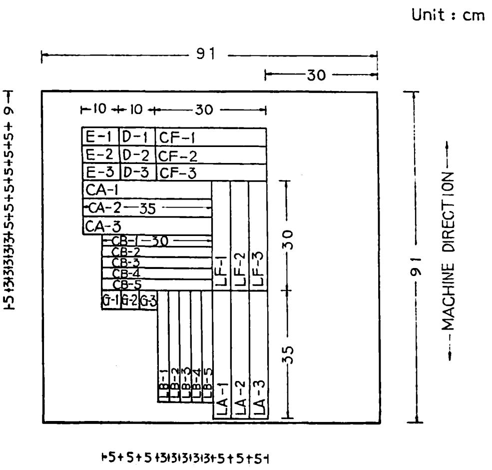
Table 2. Physical properties of particle board

Properties \ Specimens		G	H	I	J	K	L	M	N
Board thickness (mm)		19.99 (0.12)	20.13 (0.14)	19.57 (0.15)	20.25 (0.37)	20.22 (0.09)	20.15 (0.09)	20.07 (0.08)	21.02 (0.15)
Specific gravity		0.62 (0.02)	0.66 (0.02)	0.62 (0.02)	0.66 (0.02)	0.57 (0.02)	0.52 (0.06)	0.64 (0.02)	0.56 (0.06)
Moisture content (%)		9.3 (0.59)	9.1 (0.77)	10.6 (0.49)	9.1 (0.78)	9.4 (1.15)	9.7 (0.67)	9.7 (0.55)	8.6 (0.48)
Bending strength (kg/cm²)	L	187.9 (19.8)	193.5 (24.6)	235.1 (21.0)	210.4 (27.3)	115.2 (17.1)	213.8 (35.2)	385.3 (42.4)	253.2 (7.7)
	C	171.6 (22.6)	182.6 (48.8)	287.2 (27.2)	214.2 (10.0)	105.6 (18.3)	234.3 (13.1)	114.8 (8.0)	82.6 (3.2)
YOUNG's modulus in bending ×10⁴ (kg/cm²)	L	2.5 (0.31)	2.6 (0.06)	3.6 (0.21)	2.9 (0.16)	1.9 (0.05)	3.2 (0.24)	4.4 (0.33)	3.7 (0.54)
	C	2.4 (0.22)	2.7 (0.23)	4.2 (0.09)	2.9 (0.22)	1.7 (0.15)	2.9 (0.29)	1.8 (0.11)	1.7 (0.15)
Tensile strength parallel to surface (kg/cm²)	L	65.5 (3.8)	74.5 (13.4)	85.9 (12.0)	74.2 (14.2)	36.5 (4.1)	72.0 (9.3)	132.0 (9.5)	125.9 (29.7)
	C	61.7 (6.8)	65.8 (13.6)	94.7 (9.9)	71.5 (9.4)	34.3 (5.9)	104.5 (19.8)	54.5 (5.5)	25.2 (10.7)
YOUNG's modulus in tension parallel to surface ×10⁴ (kg/cm²)	L	1.5 (0.17)	2.0 (0.17)	2.1 (0.13)	2.0 (0.36)	1.3 (0.05)	2.0 (0.21)	3.2 (0.14)	1.8 (0.19)
	C	1.8 (0.27)	1.9 (0.19)	2.8 (0.13)	1.8 (0.35)	1.1 (0.2)	1.8 (0.2)	1.8 (0.21)	1.4 (0.16)
Tensile strength perpendicular to surface (kg/cm²)		1.25 (0.21)	3.01 (0.27)	3.87 (0.45)	3.87 (0.79)	1.14 (0.44)	3.07 (0.49)	5.39 (0.61)	9.9 (1.19)
Wood screw holding power (kg)		36.1 (4.0)	48.6 (3.7)	53.2 (5.0)	50.9 (5.4)	32.6 (4.2)	35.4 (5.8)	49.9 (5.3)	35.4 (4.4)
Water absorption (%)		83.5 (2.8)	67.2 (2.0)	60.4 (3.5)	67.2 (2.9)	90.0 (1.9)	78.4 (6.5)	36.8 (2.9)	76.1 (11.3)
Thickness swelling (%)		17.4 (0.7)	17.7 (0.9)	8.6 (1.0)	17.3 (1.7)	16.3 (1.0)	13.3 (1.1)	9.2 (0.8)	2.2 (0.5)

Remark: ( ) Standard deviation.

time of this study, were used and they included some mono-layer boards, which, because of their physical properties, are usually overlaid with face veneers. The general properties of the board specimens are shown in Table 2.

Specimens were cut from the sheets or board which were delivered to the laboratory in approximately 90 cm × 90 cm squares. Method of cutting and dimensions of all types of specimen are shown in Figs. 7～8.



Code letter
L : Machine direction
C : Across machine direction
A : Bending
B : Tensile strength parallel to surface
D : Tensile strength perpendicular to surface
E : Wood screw holding power
F : Dimensional change & moisture change
G : Water absorption
1～3 : Specimen replication number

Fig. 7 Specimen cutting diagram for particle boards.

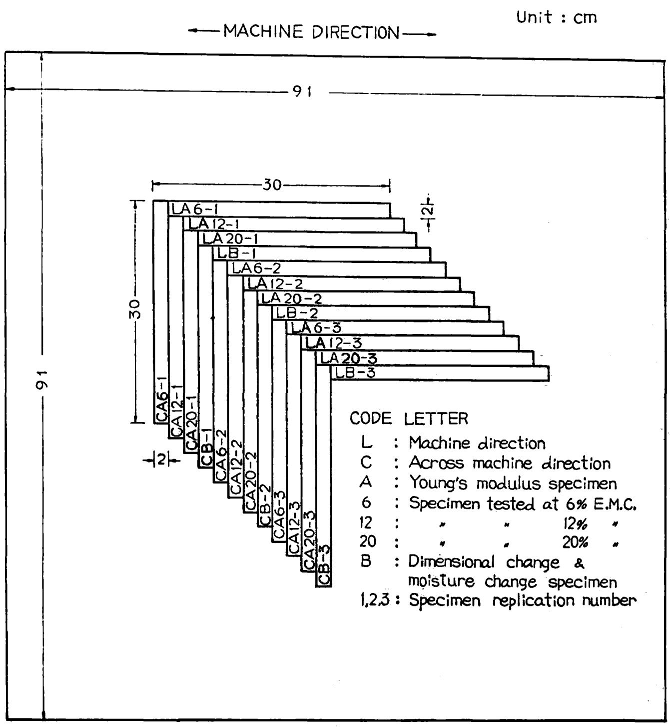


Fig. 8 Specimen cutting diagram for decorative laminates.

2. Humidifying condition

All specimens were conditioned to constant weight in a room at 20°C, 65 percent relative humidity for about one month prior to commencement of the experimental work. Conditioning to specified moisture contents was conducted in special rooms under conditions shown in Table 3. During conditioning the specimens were resting freely on shelves so that their movement was unrestrained.

Table 3. Test exposure conditions for physical and mechanical properties

Title of test		Exposure conditions: Temperature (°C)	Exposure conditions: Relative humidity (%)	Exposure conditions: EMC in wood (%)	Method of controlling relative humidity	Type of test specimens
Free dimensional movement due to moisture change	(1)	20	65	12	Air conditioning	Particle board & decorative laminate
	(2)	24	90	20		
	(3)	32	68	12		
	(4)	35	32	6		
Modulus of elasticity in tension		24	90	20	do.	Decorative laminate
		20	65	12		
		35	32	6		
		20	65	12	do.	Particle board
Initial moisture sorption and desorption rate	(1)	20	65	12	do.	Particle board & decorative laminate
	(2)	24	90	20		
	(3)	20	65	12		
Moisture content		105			Oven dry	

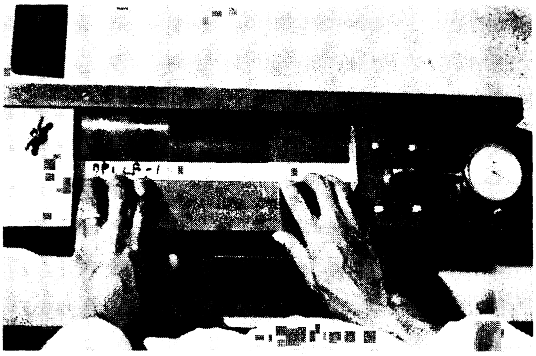


Fig. 9 Measuring method of linear dimensional change in decorative laminates.

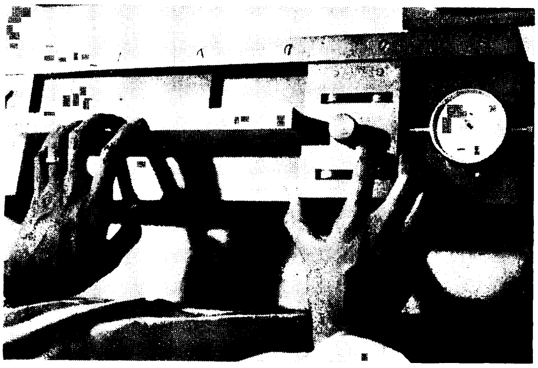


Fig. 10 Measuring method of linear dimensional change in particle board.

3. **Testing procedure**

(a) Measurement of linear dimensionol changes: The change in length of specimens exposed to various relative humidity conditions was determined using special apparatus incorporating a dial indicator as proposed by ASTM D 1037-56T (Figs. 9～10). Minimum readings in indicator were 1/100 mm. The sizes of test specimen are 2 cm by 5 cm by 30 cm in particle board and 1.6 mm by 2 cm by 30 cm in decorative laminates. The longitudinal distance from one side of specimen to another was measured with this dial indicator. Swelling was represented with linear swelling (based on 12% EMC) per 1 per cent moisture content change at the time when the specimen was exposed from 12% EMC to 20% EMC humidity condition (as shown in Table 3, for instance, 12% EMC represents symbolically the psychrometric conditions which is 20°C, 65% R. H. or 32°C, 68% R. H. by means of the equilibrium moisture content of wood for them).

Actual equilibrium moisture contents of these materials are different from that of wood. Shrinkage was represented with linear shrinkage (based on 20% EMC) per 1 per cent moisture content change at the time when the specimen was exposed from 20% EMC to 6% EMC. Three replications were used for each direction of specimen (the machine direction and across the machine direction).

(b) Measurement of thickness dimensional changes: The change in thickness of specimens exposed at the various relative humidity conditions was measured using micrometer. Mean value of three point in longitudinal direction of specimen was taken for the measurement of one replication. Minimum readings on micrometer were 1/100 mm. The same test specimen as linear dimensional stability was used.

(c) Measurement of modulus of elasticity in tension of decorative·laminates: The tensile test on decorative laminates was made in accordance with JIS Z 2112 (1957). Size of test specimens were rectangle 2 cm by 30 cm. Specimens' deformations were measured with a Martins one-mirror system deflection meter. The magnification was five hundred-times. The modulus of elasticity was only determined from the load deformation ratio. Six replications were tested for each of the test variables, including the machine and across the machine direction.

(d) Measurement of tensile properties parallel to surface of particle board: The tensile test on particle board was also made in accordance with JIS Z 2112 (1957). Size and shape of test specimens are shown in Fig. 11. Specimen deformations were measured with a Martins two-mirror system deflection meter. The magnification was one thousand-times. The modulus of elasticity was determined from the load deformation ratio, and the strength was also determined from maximum load. Ten replications were tested for each of the test variables including the machine and across the machine direction. After testing, the data of six specimens were selected by shape of destruction in specimens.

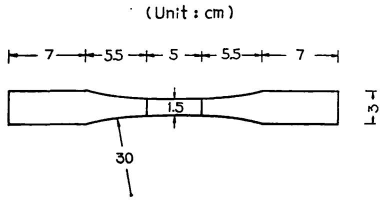


Fig. 11 Tensile test specimen for particle board parallel to surface.

(e) Measurement of initial moisture sorption and desorption rate: To determine the moisture sorption and desorption rate of each of the specimens strictly, mean diffusion coefficients of moisture sorption and desorption processes are evaluated from half time measurements[4]. In this experiment, however, only for the purpose of considering the distortion process qualitatively, the initial moisture sorption and desorption rates were evaluated from the moisture content change during initial 24 hours of moisture sorption and desorption processes in swelling and shrinkage specimens mentioned above.

Results and discussion

1. Equilibrium moisture content

The equilibrium moisture content values (shown in Tables 4~5) were determined from six dimensional stability specimens of each condition. Among those, the moisture content values in 12% EMC and 20% EMC were obtained by approaching the relative humidity conditions from dry side, and the values in 6% EMC were obtained by approaching from wet side. Therefore, no information was obtained on the effect of hysteresis.

The equilibrium moisture contents of particle boards, in general, were slightly lower than those of solid wood in each exposure condition. The reason why the values of the specimen L and M in 20% EMC were slightly lower than that of other particle board specimens depends

Table 4.　Basic properties

Manufacturer's code letter		Thickness (mm)	Specific gravity	Moisture content (%)		
				6% EMC(6)	12% EMC	20% EMC
G	L(1)	19.99(0.12)	0.62(0.02)	4.6	9.3(0.6)	15.1
	C(2)					
H	L	20.13(0.14)	0.66(0.02)	4.7	9.1(0.8)	15.1
	C					
I	L	19.57(0.15)	0.62(0.02)	5.0	10.6(0.5)	14.8
	C					
J	L	20.25(0.37)	0.66(0.02)	4.7	9.1(0.8)	15.5
	C					
K	L	20.22(0.09)	0.57(0.02)	4.4	9.4(1.2)	15.6
	C					
L	L	20.15(0.09)	0.52(0.06)	4.3	9.7(0.7)	14.0
	C					
M	L	20.07(0.08)	0.64(0.02)	4.9	9.7(0.6)	13.8
	C					
N	L	21.02(0.15)	0.56(0.06)	4.5	8.6(0.5)	15.0
	C					

Note: (1) Parallel to the machine direction.
(2) Across the machine direction.
(3) Swelling in percentage per 1% moisture content from 12% EMC to 20% EMC.
(4) Shrinkage in percentage per 1% moisture content from 20% EMC to 6% EMC.

Table 5.　Basic properties

Manufacturer's code letter		Thickness (mm)	Moisture content (%)			Swelling
			6% EMC	12% EMC	20% EMC	Thickness
AP	L	1.66	4.0	6.7	9.2	1.43
	C					0.82
AF	L	1.64	3.6	5.8	8.7	1.03
	C					0.78
AG	L	1.63	3.6	6.3	8.8	1.13
	C					0.81
BP	L	1.15	4.1	6.9	10.6	1.04
	C					0.64
BG	L	1.55	3.7	7.5	11.7	1.18
	C					0.81
CP	L	1.46	3.2	5.4	8.2	0.98
	C					0.39
CF	L	1.65	3.7	6.3	9.2	0.82
	C					0.28
CG	L	1.57	3.6	6.0	9.4	1.05
	C					0.49
D	L	1.59	3.9	6.7	9.6	1.00
	C					1.32
E	L	1.30	3.3	7.8	13.5	0.95
	C					0.86
F	L	1.77	3.0	6.0	9.4	0.90
	C					0.81

of particle baord.

Swelling(%/%)(3)		Shrinkage(%/%)(4)		Modulus of elasticity ×10⁴(kg/cm²) 12% EMC	Remark
Thickness	Length	Thickness	Length		
0.68	0.03 0.03	0.45	0.03 0.04	1.5 (0.2) 1.8 (0.3)	Three-layer board
0.68	0.03 0.03	0.47	0.04 0.04	2.0 (0.2) 1.9 (0.2)	do.
0.59	0.03 0.03	0.44	0.03 0.03	2.1 (0.1)*(5) 2.8 (0.1)	do.
0.69	0.03 0.02	0.45	0.04 0.03	2.0 (0.4) 1.8 (0.4)	do.
0.55	0.03 0.03	0.68	0.03 0.03	1.3 (0.1) 1.1 (0.2)	Continuous layer board
0.90	0.02 0.02	0.51	0.02 0.03	2.0 (0.2) 1.8 (0.2)	Veneer overlaid board with crossband
0.56	0.02 0.04	0.45	0.02 0.04	3.2 (0.1)* 1.8 (0.2)	Veneer overlaid B. without crossband
0.06	0.04 0.02	0.25	0.04 0.03	1.8 (0.2)* 1.4 (0.2)	Extrusion board

(5) Significant at 5% level between L and C direction.

(6) 6% EMC, 12% EMC and 20% EMC represents symbolically the psychrometric conditions shown in Table 3.

of decorative laminates

(%/%)	Shrinkage (%/%)		Modulus of elasticity ×10⁴ (kg/cm²)		
Length	Thickness	Length	6% EMC	12% EMC	20% EMC
0.02 0.08	0.84 0.88	0.05 0.13	18.7(0.2) 11.4(0.2)	17.9(0.6) 11.0(0.2)	15.8(0.5) 9.2(0.4)
0.02 0.04	0.73 0.82	0.05 0.11	16.4(0.4) 12.1(0.2)	15.6(0.6) 11.1(0.4)	13.1(0.4) 9.3(0.2)
0.02 0.06	0.72 0.85	0.05 0.12	16.5(0.3) 11.9(0.2)	15.7(0.3) 11.2(0.5)	13.7(0.1) 8.6(0.7)
0.01 0.03	0.90 1.02	0.04 0.09	16.3(0.7) 12.4(0.4)	14.7(0.3) 10.5(0.4)	12.0(0.5) 8.4(0.3)
0.01 0.03	0.98 1.03	0.034 0.08	17.1(0.3) 12.1(0.2)	14.6(0.6) 9.8(0.2)	11.9(0.2) 8.0(0.2)
0.03 0.04	0.77 0.90	0.05 0.10		14.7(0.5) 10.9(0.2)	
0.01 0.04	0.90 0.90	0.05 0.09	15.8(0.3) 12.4(0.2)	15.4(0.5) 11.3(0.3)	12.8(0.2) 9.3(0.4)
0.01 0.04	0.85 0.89	0.05 0.09		15.0(0.5) 16.3(0.2)	
0.02 0.08	0.85 0.87	0.05 0.12		16.2(1.3) 10.6(0.7)	
0.004 0.02	0.86 0.87	0.03 0.07		13.4(0.3) 9.0(0.1)	
0.01 0.05	0.86 0.86	0.04 0.08		14.3(0.9) 10.8(0.3)	

on the influence of overlaid veneer in the specimens.

Plastic laminates attained lower equilibrium moisture content than particle board. It seems that the influence of phenolic resin layer in plastic laminates is strongly in evidence.

When the specimen laminated by the materials having different equilibrium moisture contents is exposed in a certain humidity condition, the moisture content changes in each layer are apparently different, and this could be one of the important causes by which the specimen is distorted.

2. **Swelling**

The particle board specimen, except for the specimen M and N, had about the same linear swelling change in both the machine direction (L direction) and across the machine direction (C direction). The specimen M and N showed anisotropic property in the cause of anisotropy of veneer for overlay. The specimen N had a very low thickness swelling. This is because of the fact that since this particle board is manufactured by means of the extrusion process, the orientation of particle in this board is different from other particle board. The specimen L showed a slightly higher thickness swelling in spite of low specific gravity of board. The reason is not yet clear.

The linear swelling of decorative laminates was affected by anisotropy of base paper, and consequently lower in L direction than C direction. According to NEMA Standard, although the testing method of linear dimensional stability is different, the dimensional change in L direction of decorative laminates is about one-half of C direction. In this measurement, therefore, it seems that the linear swelling in C direction is too high. The difference in linear swelling of decorative laminates among the manufacturers was recognized to some extent.

Table 6. Swelling and shrinkage in length of particle board

Manufacturer's code letter		Swelling		Shrinkage	
		Moisture change 12% EMC～20% EMC (%)	($\alpha_2 m_2$) 12% EMC～20% EMC (%)	Moisture change 12% EMC～6% EMC (%)	($\alpha_2 m_2$) 12% EMC～6% EMC (%)
G	L	5.8	0.174	4.7	0.141
	C		0.174		0.188
H	L	6.0	0.180	4.4	0.176
	C		0.180		0.176
I	L	4.2	0.126	5.6	0.168
	C		0.126		0.168
J	L	6.4	0.192	4.4	0.176
	C		0.128		0.132
K	L	6.2	0.186	5.0	0.150
	C		0.186		0.150
L	L	4.3	0.086	5.4	0.108
	C		0.086		0.162
M	L	4.1	0.082	4.8	0.096
	C		0.164		0.192
N	L	6.4	0.256	4.1	0.164
	C		0.128		0.123

Table 7. Swelling and shrinkage in length of decorative laminates

Manufacturer's code letter		Swelling		Shrinkage	
		Moisture change 12% EMC～ 20% EMC (%)	$(\alpha_1 m_1)$ 12% EMC～ 20% EMC (%)	Moisture change 12% EMC～ 6% EMC (%)	$(\alpha_1 m_1)$ 12% EMC～ 6% EMC (%)
AP	L	2.5	0.050	2.7	0.135
	C		0.200		0.351
AF	L	2.9	0.058	2.2	0.110
	C		0.116		0.242
AG	L	2.5	0.050	2.7	0.135
	C		0.150		0.324
BP	L	3.7	0.037	2.8	0.140
	C		0.111		0.252
BG	L	4.2	0.042	3.8	0.129
	C		0.126		0.304
CP	L	2.8	0.084	2.2	0.110
	C		0.112		0.220
CF	L	2.9	0.029	2.6	0.130
	C		0.116		0.234
CG	L	3.4	0.034	2.4	0.120
	C		0.136		0.216
D	L	2.9	0.058	2.8	0.140
	C		0.232		0.336
E	L	5.7	0.023	4.5	0.135
	C		0.114		0.315
F	L	3.4	0.034	3.0	0.120
	C		0.170		0.240

Almost all decorative laminates specimens in L direction had a higher thickness swelling than that in C direction. It would seem that, since the specimen in C direction shows a higher linear swelling when it swells, the swelling in thickness direction may be decreased by greater stresses exerted towards the longitudinal direction (C direction). HEEBINK[3] has also recognized the phenomenon that, when the specimen in L direction swells, although it increases the length at first, it shrinks slightly at the last stage of swelling. And he has explained that this phenomenon is caused by greater stresses exerted with the swelling in C direction, like a rubber band stretched.

In general, particle board, as compared with decorative laminates, shows a higher or the same linear swelling in L direction and a lower linear swelling in C direction. As mentioned in the paragraph on equilibrium moisture content, in the case of comparing the actual swelling, it is necessary to consider the difference of moisture content change. From Table 4 and 5, the actual linear swelling and shrinkage of both materials are found by considering the moisture content change of each specimen, as shown in Tables 6 and 7. For instance, the moisture content change of the particle board (G) and decorative laminates (AP) from 12% EMC to 20% EMC are 5.8% and 2.5% respectively. Therefore, the actual linear swelling of the particle board G is 0.174 % both in L and C direction. The decorative laminates AP is 0.050 % in L direction and 0.200 % in C direction.

When the tendency of distortion in laminated board is considered by the combination of both materials in the equation (10), the following relation: $m_1\alpha_1 < m_2\alpha_2$ in both L and C, or $m_1\alpha_1 < m_2\alpha_2$ in L direction and $m_1\alpha_1 > m_2\alpha_2$ in C direction, are expected. Consequently, it seems that the distortion of board will show a cup type with the decorative laminates as the concave side, or saddle type.

3. **Shrinkage**

Particle board had almost the same linear shrinkage in both L and C direction, except for the specimens M and N like the linear swelling. Extrusion board N showed a very low thickness shrinkage, as compared with the other specimens.

Decorative laminates had a much higher linear shrinkage in C direction than that in L direction. In the case of L direction, the difference in linear shrinkage of decorative laminates among the manufacturers was hardly recognized, whereas in the case of C direction, the difference among the manufacturers or brands was somewhat recognized. Consequently, decorative laminates in C direction had an excessive higher linear dimensional movement; therefore, it is still worthwhile to consider their causes.

Under actual use of decorative laminates in laminating, since the length of decorative laminates is about 1～2 m in both L and C direction, the stress exerted in each direction with swelling and shrinkage may be restraining each other during the sorption and desorption process. Therefore, it seems that too much change of length in C direction is restrained with less change in L direction, and that the length in C direction actually may be not so significantly changed as swelling and shrinkage obtained by slender test specimen in C direction. However, HEEBINK[3] has investigated the effect of size of test specimen on the linear dimensional stability by using the test specimens of 7/8 inch (L direction) by 22 inch (C direction) and 6 inch (L direction) by 22 inch (C direction), and stated that sheet size of the decorative laminates specimens has little or no influence on the amount of dimensional movement of the laminate. The conclusions drawn from small-sized samples of decorative laminates, therefore, can give accurate information about large sheets.

Also, in this experiment, to determine the influence of these relationships, the linear dimensional change in L and C direction was measured simultaneously

Table 8. Longitudinal swelling and shrinkage of decorative laminates observed on 30 cm × 30 cm specimen

Manufacturer's code letter		Swelling (%/%)	Shrinkage (%/%)
AP	L	0.02	0.05
	C	0.08	0.14
AF	L	0.02	0.05
	C	0.04	0.11
AG	L	0.02	0.05
	C	0.06	0.12
BP	L	0.02	0.05
	C	0.04	0.09
BG	L	0.01	0.04
	C	0.04	0.09
CP	L	0.02	0.05
	C	0.06	0.11
CF	L	0.01	0.05
	C	0.05	0.10
CG	L	0.01	0.05
	C	0.04	0.09
D	L	0.02	0.05
	C	0.08	0.12
E	L	0.01	0.03
	C	0.04	0.07
F	L	0.02	0.04
	C	0.06	0.09

with square test specimen 30 cm by 30 cm. The results obtained are as shown in Table 8. As compared with the value obtained from the specimen 2 cm by 30 cm, little or no influence of size of test specimens on the linear dimensional change was recognized. Consequently, although the finding evidencing that decorative laminates in C direction have an excessive linear dimensional change could not be obtained, for instance during sorption process, the phenomenon of decorative laminate shrinking slightly at the last stage of swelling after it increases the length at first is recognized, and such being the case it may be considered that the dimensional movement in L direction is somewhat affected by the greater movement in C direction.

Considering the tendency of distortion in laminated board during desorption as applying to the combination of both materials in the equation (10), since decorative laminates in C direction have a maximum linear swelling in any combination of both materials, it seems that the distortion of board in C direction will happen towards the concave side of decorative laminates, while the distortion of board in L direction will happen towards the different side, depending on the linear swelling of both materials laminated.

4. **Modulus of elasticity in tension**

Particle boards had nearly the same modulus of elasticity in both L and C direction, except for the specimens I, M and N. Since the specimen I is a three-layer board, practically it must be an isotropic body along the surface. If particle spreading machine is mechanically stable in the manufacturing process, however, the particle mattress might become rather an anisotropy in particle orientation, because the particle mattress is so even that the level of particle mattress is not corrected after spreading. It can also be seen from the bending properties as shown in Table 2 that the specimen I has an anisotropic property. The large differences observed in boards M and N can be explained by the effect of crossband veneer which provide higher tensile property along the grain direction. The difference in modulus of elasticity of particle board among the manufacturers was recognized somewhat, but it is impossible to compare strictly among those on account of having different specific gravity. The influence of moisture content due to the relative humidities was not investigated, because according to HEEBINK[3], the relative humidity exposure conditions have little effect on the modulus.

Decorative laminates, which were affected by anisotropy of base paper, usually had higher modulus of elasticity in L direction than that in C direction. The specimen A, as compared with other specimens, showed somewhat higher modulus, therefore it can be expected from the equation (10) that the board overlaid by the specimen A will have big distortion. Since the backing sheet D was the sheet which the surface melamine layer of the decorative laminates AP was removed by sanding, it showed almost the same modulus as AP. On the contrary, other backing sheets had somewhat low modulus.

As for the influences of moisture content due to the exposing conditions on modulus of elasticity of decorative laminates, there were significant differences between 20% EMC and the others.

Decorative laminates have approximately ten times higher tensile values than particle board. Considered from the modulus of elasticity aspect in both materials by the equation (10), the less modulus the particle board has and the more modulus the decorative laminate has, the more distortion occurs in the board laminated by both materials. Therefore, it can be expected that the board having combination between the particle board G or K and the decorative laminates A will have a big distortion.

5. Initial moisture sorption and desorption rate

When decorative laminates overlaid particle board absorbs or desorbs moisture from both side simultaneously, if both materials have a different moisture sorption and desorption rate without relation to linear swelling and shrinkage, the overlaid board warps at the initial stage of exposure. For instance, distortion of board will occur at first towards the material having a higher initial moisture sorption rate as the concave side, but if the material has lower linear swelling, finally the distortion of board will change the direction to the opposite side. In the case of desorption, distortion of board will also occur at first towards the materials having a higher initial moisture desorption rate as the concave side, but if the material has lower linear shrinkage, finally the distortion of board will change the direction to the opposite side. To consider the distortion process in such an initial stage of sorption and desorption, rates of initial moisture absorption and desorption were measured. The results obtained are given in Table 9.

Table 9. Ratio of initial moisture sorption and desorption

Manufacturer's code letter	Initial moisture sorption rate 12 % EMC～20 % EMC (%/day)	Initial moisture desorption rate 20 % EMC～12 % EMC (%/day)
G	1.8	2.2
H	1.7	2.1
I	1.3	1.8
J	1.7	2.1
K	2.1	3.4
L	1.9	2.7
M	1.5	1.6
N	1.9	2.4
AP	0.3	0.85
AF	0.2	0.75
AG	0.45	0.9
BP	0.65	1.08
BG	0.85	1.75
CP	0.2	0.7
CF	0.3	0.88
CG	0.25	0.78
D	0.4	0.95
E	1.50	2.80
F	0.6	1.15

The particle boards showed in general a much greater rate of both sorption and desorption than the decorative laminates. Between the manufacturers of particle board, there were no significant differences. Between the manufacturers of decorative laminates and backing sheet, the specimen B, E and F had a greater rate of both sorption and desorption than the others. Especially it is characteristic that the backing sheet E has a greater rate of both sorption and desorption, and a lower linear swelling in spite of having a higher equilibrium moisture content in high humidity condition.

Consequently, it can be expected that the laminated board having combination between the particle board which has a lower linear dimensional change and a greater rate of both sorption and desorption, and the decorative laminates which has a higher linear dimensional change in C direction and a lower rate of both sorption and desorption, will turn about the direction of distortion in the stage between initial and final of both sorption and desorption.

The distortion of decorative laminates overlaid particle board

It is possible to compute by means of the equation (10) the distortion of overlaid board which consists of each component at the time of moisture sorption and desorption in a two-layer simple beam and the basic data of each material. As mentioned above, however, it seems that since these components, especially decorative laminates, are actually an orthotropic plate, the computing value may be different from the actual distortion. In this chapter the overlaid specimens were prepared by using the materials in almost the actual scale. The distortion of the overlaid specimens were measured during exposure at various humidity conditions and compared with the computing value, in order to obtain the basic data for manufacturing process of non-warping overlaid board.

Experimental procedure

1. **Preparation of specimen**

The materials used were selected from the materials shown in Table 1. Four brands of particle board, two brands of plain white decorative laminates (AP, BP), two brands of wood grain print decorative laminates (AG, BG), two brands of fancy print of decorative laminates (AF, CF) and two brands of backing sheets (D, E) were used. The overlaying combination of these materials is given in Table 10.

Table 10. Test specimens used in overlay

Particle board		Decorative laminate
Three layer board	G	AP, AG, BP, BG, AP-D*, BP-E*
	I	AP, AG, AF, BP, BG, CF
Veneer overlaid board	(With crossband) M	AP, AG, BP, BG
	(Without crossband) L	AP, AG, BP, BG

* Laminating backing sheet on back side as comparison.

2. **Overlaying condition**

When particle board is overlaid with decorative laminates, it is necessary to decrease water delivery due to adhesive as much as possible so as to decrease the distortion of the board immediately after overlaying. In this experiment, therefore, enriched type urea resin adhesive (Uloid 22, 67% solids, 42 p-20°C viscosity) was used, and ten parts of wheat flour and 2.5 parts of 20% ammonium chloride were added to 100 parts of urea resin. One hundred g/m² of the adhesive was coated to each surface with rubber roller (Total quantity 200 g/m²).

In laminating, cold pressing was used, because, if the hot pressing is used, distortion occurs immediately after pressing on account of difference of thermal expansion of both materials. The pressure of press was 5 kg/cm² and the pressing time 24 hours.

3. **Exposure condition**

To investigate the distortion of overlaid board in moisture sorption and desorption, an

Table 11. Test exposure conditons for overlaid specimens

Exposure procedure	Exposure conditions: Temperature (°C)	Relative humidity (%)	EMC in wood (%)	Method of controlling relative humidity
1	20	65	12	Air conditioning
2	24	90	20	do.
3	32	68	12	do.
4	35	32	6	do.
5	32	68	12	do.

identical specimen was exposed at one cycle of moisture sorption and desorption as shown in Table 11.

4. **Measurement of distortion**

The distortion of the overlaid specimen was measured by the method as follows: In regard to period of measurement, the distortions were measured immediately after overlaying, and then after conditioning at 12% EMC (basic point). During the period of one exposure condition, the distortions were measured at first every 2 or 3 days, then almost every 7 days and finally at saturating point which was concluded by means of measuring the weight of the overlaid specimen simultaneously.

(a) Preparation of measurement (Fig. 12): In this measurement, nine measuring points were taken upon the face of decorative laminates side as shown in Fig. 12. When the laminated specimen warped towards the decorative laminates as the concave side, a positive mark of distortion was used.

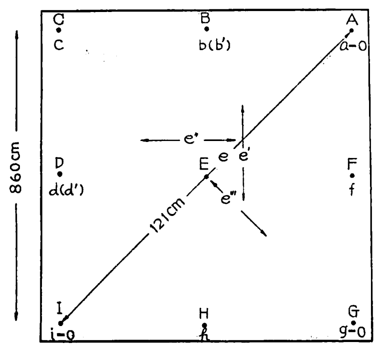


Fig. 12 Measuring point of deflection on decorative laminates overlaid particle board.

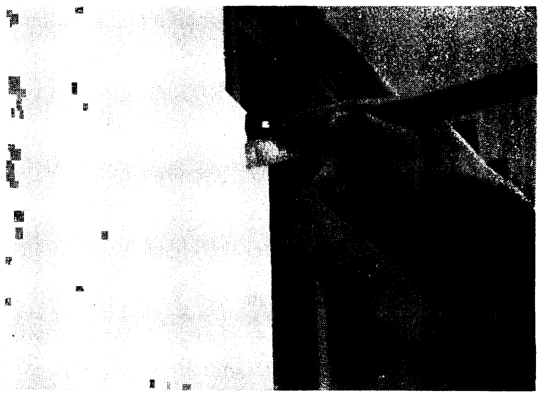


Fig. 13 Preparation of measurement in deflection (1).

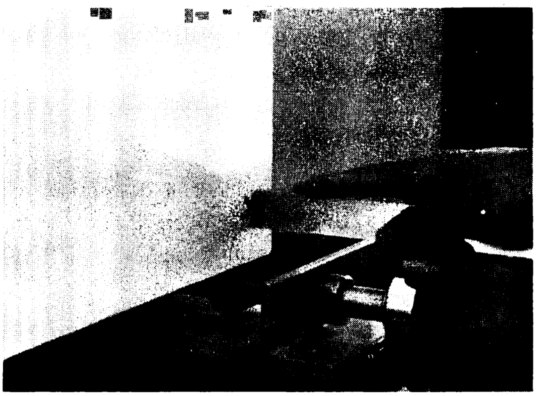


Fig. 14 Preparation of measurement in deflection (2).

At the beginning, point A was fixed by arm of the pole. An optional point on ruler (for instance $a = 3$ cm) which was set up at the point A was brought together with vertical line of cross hair line of transit compass (Fig. 13). Then, after the ruler was fixed at the point G, until 3 cm point on the ruler was brought together with the vertical line of transit compass, the point G was transferred in front and the rear (Fig. 14). Finally, the same procedure for the point I as the point G was taken. Consequently, a plane parallel to the vertical line of cross hair line of the transit compass is formed by the three points A, G and I.

(b) Measurement of deflection: Thus, reading the distance from 3 cm point on the ruler which has been set up at any point on the surface of overlaid board, the distance in its point

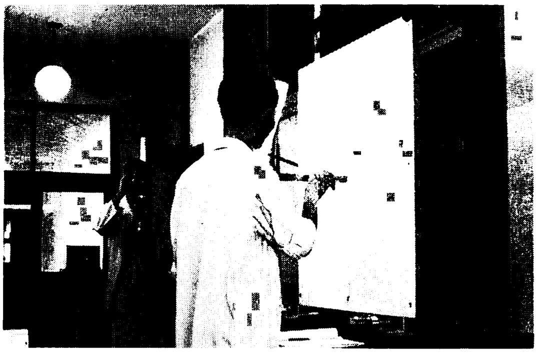


Fig. 15 Measuring method of deflection in decorative laminates overlaid particle board.

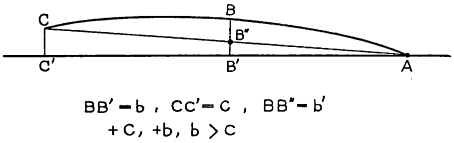


Fig. 16 Example for computation of deflection.

from the standard plane can be seen (Fig. 15). Consequently, changing the reading (a, g, i) in the three points A, G and I to zero, i. e. according to reducing 3 cm from the readings, the distance from the standard plane (A-G-I plane) can be seen, as shown by the marks of b, c, d, e, f and h respectively. For instance, as illustrated in Fig. 16, to say that the measurement b in the point B is positive and larger than the measurement c in the point C is to say that the overlaid board underwent distortion towards the decorative laminates as the concave side. And to say that the measurement c in the point C is not zero is to say that the board underwent twisting. The measurements f and h are directly the deflection of A-F-D and D-H-I, and since the point C is not fixed in the case of twist occurring, the measurements b and d are not the deflection of A-B-C and C-D-I. They must be obtained by computing as explained below. Besides, the measurement e is directly the deflection of A-E-I, but when c is not zero, the measurement e can not be used for the deflection of B-E-H, D-E-F and C-E-G.

(c) Computing method of average deflection: If b', d', e', e'' and e''' are respectively defined as the unknown deflection of A-B-C, C-D-I, B-E-H, D-E-F and C-E-G mentioned above, and if these deflections are assumed to be quite small,

$$b'=b-\frac{c}{2},$$

$$d'=d-\frac{c}{2},$$

$$e'''=e-\frac{c}{2},$$

$$e'=e-\frac{b'+h}{2},$$

$$e''=e-\frac{d'+f}{2}.$$

Thus, the average deflections in L and C direction are respectively shown with the mean value of three deflections in both directions.

$$\text{L direction}\quad \frac{d'+e'+f}{3}\cdot\frac{100}{86}(\%),$$

$$\text{C direction}\quad \frac{b'+e''+h}{3}\cdot\frac{100}{86}(\%),$$

where span is 86 cm.

Moreover, the twist is illustrated with the difference of the deflection in diagonal of the board specimen to span,

$$\text{Twist}=\frac{e-e'''}{121}\times 100(\%)$$

Table 12. Average deflection of distortion due to

Specimen code No.	Assembly condition		Combination of the machine direction	Immediately after overlaying		
	D. L.	P. B.		L[3]	C[4]	Twist
7	A P	G	Perpendicular[2]	0.06	−0.02	−0.01
8	A P	G	do.	0.06	−0.01	0.07
5	A G	G	Parallel[1]	0.04	0.04	0.03
6	A G	G	Perpendicular	0.01	−0.03	0.03
1	B P	G	Parallel	−0.02	−0.08	0.02
2	B P	G	Perpendicular	0.02	0.01	−0.01
3	B P	G	Parallel	−0.03	0	0.01
4	B G	G	do.	−0.02	−0.10	0
11	A P—D	G		−0.04	−0.05	0.01
12	A P—D	G		0	0	0
9	B P—E	G		0	0.01	−0.03
10	B P—E	G		−0.02	0.01	−0.01
19	A P	I	Parallel	0.02	0	0
20	A P	I	Perpendicular	0.03	0	0
21	A P	I	do.	0.09	0.06	−0.04
23	A G	I	do.	0.12	−0.02	−0.04
24	A G	I	do.	0.08	0.01	−0.07
13	A F	I	Parallel	0.04	0.05	0
14	A F	I	Perpendicular	0.06	−0.01	0
22	B P	I	do.	0.08	0.03	−0.01
17	B G	I	do.	0.03	−0.03	0.02
18	B G	I	do.	0.03	−0.03	0
15	C F	I	do.	0.03	−0.02	−0.03
16	C F	I	do.	0.07	0.01	−0.02
29	A P	M	Parallel	0.02	0.01	0
30	A P	M	do.	0.08	0.01	−0.02
31	A P	M	do.	0.07	0.02	−0.03
27	A G	M	do.	0	0.03	−0.01
28	A G	M	do.	0.08	0.02	−0.01
32	B P	M	Perpendicular	0.03	−0.07	0.04
33	B P	M	Parallel	−0.02	−0.21	0.02
25	B G	M	do.	−0.05	−0.05	−0.03
26	B G	M	do.	−0.05	−0.05	0
35	A P	L	do.	0.02	−0.02	−0.01
36	A P	L	do.	−0.03	0	0
37	A G	L	do.	0	−0.13	−0.02
42	A G	L	do.	0.02	0.01	−0.01
34	B P	L	do.	0.01	−0.02	−0.01
41	B P	L	do.	0.20	−0.07	−0.05
38	B G	L	do.	0.02	−0.08	−0.02
39	B G	L	do.	−0.01	−0.09	−0.05
40	B G	L	Perpendicular	0.02	−0.01	−0.01

Remark :

(1) The machine direction of decorative laminates is parallel to the machine direction of

(2) Above combination is perpendicular.

(3) The machine direction of overlaid decorative laminates.

(4) Across the machine direction of overlaid decorative laminates.

(5) Computed value of deflection.

(6) Effective deflection.

change of exposure condition (%)

12% EMC			20% EMC					
L	C	Twist	Weight change	L-direction		C-direction		Twist
					Compu.[5] value		Compu. value	
0.13	−0.11	−0.04	4.5	0.79	0.73	0.07	−0.13	−0.03
0.08	−0.01	0.04	3.6	0.83		0.11		0.05
0.04	−0.05	0.04	3.9	0.53	0.71	0.17	0.12	0.05
0.03	−0.09	0.04	4.2	0.57		0.03		0
0	−0.01	0.04	5.6	0.64		0.35		0
0.01	−0.05	−0.03	6.7	0.84	0.76	0.31	0.31	−0.08
−0.05	−0.08	0.06	5.8	0.53		0.33		0.05
−0.02	−0.02	0.02	5.3	0.66	0.72	0.25	0.23	0.10
−0.02	0.01	0.04	0.6	0.01	—	0.02	—	−0.02
−0.02	−0.03	−0.04	1.2	0.05	—	−0.07	—	−0.03
0.02	0.02	−0.C2	1.8	−0.02	—	0.05	—	−0.03
−0.07	−0.03	−0.04	3.0	−0.02	—	−0.06	—	0
0.08	0.08	0	4.4	0.32	0.56	−0.01	−0.31	−0.03
0.07	0.01	0	3.9	0.52	0.40	−0.09	−0.35	0
0.08	0.08	−0.04	4.7	0.39		−0.07		−0.07
0.14	−0.02	−0.02	4.0	0.34	0.39	−0.22	−0.11	−0.05
0.13	0.05	−0.07	4.0	0.34		−0.23		−0.07
0.06	0	0	3.9	0.27	0.27	0.06	0.04	−0.01
0.08	−0.06	−0.02	4.7	0.45	0.33	−0.07	0.05	0.02
0.06	0.02	0	4.7	0.33	0.46	−0.09	0.07	−0.07
0.06	−0.03	0.04	4.4	0.37	0.39	−0.09	0	0.04
0.09	0	−0.02	4.7	0.26		−0.14		−0.01
0.13	0.01	−0.04	4.3	0.48	0.47	0.02	0.05	−0.02
0.20	−0.01	0	2.9	0.44		0		0.01
0	0.11	0.02	3.8	0.20		0.23		−0.03
0.09	0.09	0.04	3.7	0.27	0.16	0.14	−0.18	0.06
0.14	0.08	0	2.9	0.11		0.51		−0.04
−0.03	0.02	−0.02	4.5	0.13	0.15	0.11	−0.07	−0.09
0.05	0.05	0	4.1	0.20				−0.12
0	−0.01	0.01	4.2	0.71	0.69	−0.16	0.11	0.20
−0.06	−0.13	0	4.2	0.03	0.20	0.27	0.26	0
−0.09	−0.01	−0.04	5.0	−0.03	0.18	0.28	0.17	−0.09
−0.02	−0.01	0	3.8	0.11		0.16		−0.06
−0.01	−0.03	−0.02	5.5	0.13	0.21	−0.13	−0.59	0.04
0.01	0.03	0	4.9	0.11		−0.02		−0.04
0	−0.06	−0.02	3.8	−0.03	0.20	−0.37	−0.31	−0.14
0.01	0.01	0.02	5.7	0.03		−0.22		−0.12
0.05	0.02	0	4.5	0.20	0.26	−0.06	−0.12	0.04
−0.02	−0.08	−0.02	5.8	0.35		−0.17		0
−0.01	0.02	0	4.7	0.30		−0.22		0.02
0.02	−0.01	0	4.6	0.20	0.24	−0.20	−0.19	0.02
0.06	0.02	0.04	5.3	0.11		0.11		0

three-layer board or fiber direction of overlaid veneer.

Table 12

Specimen code No.	12% EMC Weight change	L	C	Twist	6 % Weight change	L-direction	Effect.[6] deflec.	Compu. value
7	0.9	0.43	0.27	0.02	− 4.8	0.09	−0.34	−0.33
8	− 0.6	0.32	0.30	0.07	− 6.5	−0.08	−0.40	
5	− 0.6	0.23	0.19	0.03	− 5.3	0.06	−0.17	−0.04
6	0.1	0.35	0.14	0.06	− 4.7	−0.06	−0.41	−0.32
1	0.1	0.19	0.14	0	− 4.5	−0.07	−0.26	−0.01
2	1.0	0.19	0.11	0	− 5.1	−0.08	−0.27	−0.29
3	0.7	0.15	0.15	0.02	− 4.4	−0.14	−0.29	−0.01
4	0	0.22	0.27	−0.03	− 5.0	0.15	−0.07	−0.07
11	− 0.4	0.03	0.09	0.02	− 2.2	0.10	0.07	—
12	0.6	−0.01	−0.01	−0.02	− 1.8	−0.13	−0.12	—
9	− 0.1	−0.08	−0.03	−0.02	− 2.2	0.01	0.09	—
10	1.5	−0.07	−0.05	−0.03	− 1.1	0	0.07	—
19	0.9	0.11	0.07	−0.02	− 2.7	−0.09	−0.26	−0.19
20	0.2	0.16	0.02	0	− 3.2	−0.12	−0.28	−0.18
21	0.2	0.14	0.06	−0.07	− 3.5	−0.13	−0.27	
23	0.2	0.03	−0.06	−0.06	− 3.4	−0.09	−0.12	−0.17
24	0.7	0.14	−0.07	−0.05	− 3.3	−0.01	−0.15	
13	0.5	−0.02	−0.08	−0.01	− 4.8	−0.23	−0.21	−0.33
14	0.2	0.05	−0.12	0	− 4.0	−0.23	−0.28	−0.31
22	0.3	0.06	−0.03	−0.01	− 3.5	−0.08	−0.14	−0.15
17	0.3	0.09	−0.08	−0.01	− 3.4	−0.01	−0.10	−0.21
18	0.8	0.09	−0.08	−0.01	− 3.1	−0.02	−0.11	
15	− 0.1	0.19	0.01	0.01	− 3.3	−0.07	−0.26	−0.20
16	− 0.8	0.17	−0.02	0.02	− 4.8	−0.12	−0.29	
29	0.4	0.34	0.84	0.07	− 3.3	0.35	0.01	
30	0.3	0.27	0.73	0.07	− 3.7	0.43	0.16	0.21
31	− 0.2	0.33	0.43	0.05	− 4.7	0.99	0.66	
27	1.3	0.22	0.57	−0.05	− 3.4	0.37	0.26	0.20
28	0.7	0.24	0.43	−0.05	− 3.7	0.42	0.18	
32	0.1	0.59	0.03	0.18	− 5.0	0.63	0.04	−0.31
33	0.7	0.06	0.38	0.01	− 3.7	0.31	0.25	0.22
25	1.8	0.01	0.67	−0.11	− 3.4	0.20	0.19	0.17
26	− 0.6	0.12	0.66	−0.01	− 3.9	0.32	0.20	
35	0.2	0.12	0.16	0	− 4.6	0.31	0.19	0.16
36	1.0	0.21	0.13	0.02	− 4.1	0.41	0.20	
37	− 0.3	0.03	−0.06	−0.05	− 4.4	0.27	0.24	0.16
42	1.5	0.08	−0.08	−0.08	− 3.9	0.38	0.30	
34	0.5	0.23	0.30	0.07	− 4.6	0.43	0.20	0.19
41	0.5	0.24	0	0	− 4.6	0.37	0.13	
38	− 0.1	0.27	0.16	0	− 5.9	0.41	0.14	
39	0	0.22	0.18	0.06	− 4.7	0.38	0.16	0.12
40	1.0	0.21	0.21	0.03	− 4.0	0.48	0.27	−0.19

(Continued)

EMC				12% EMC			
C-direction			Twist	Weight change	L	C	Twist
	Effect. deflec.	Compu. value					
1.17	0.90	1.15	−0.02	−0.7	0.32	0.41	0.03
1.09	0.79		0.17	−0.5	0.23	0.32	0.08
0.86	0.67	0.76	0.06	−1.3	0.13	0.28	0.03
0.72	0.58	1.02	0.02	−0.2	0.15	0.24	0
0.35	0.21	0.36	0.05	0	0.08	0.12	0
0.55	0.44	0.63	0.02	−0.1	0.13	0.17	0.05
0.50	0.35	0.36	0.01	0	0.05	0.15	0.04
0.86	0.59	0.65	0.08	0	0.30	0.36	0.05
0.23	0.14	—	0.07	−0.9	0.02	0.13	−0.03
0.08	0.09	—	0.01	−0.8	−0.05	0.01	−0.02
0.07	0.10	—	0.05	−0.7	−0.09	−0.06	−0.02
0.12	0.17	—	0	1.0	−0.06	−0.05	−0.02
0.72	0.65	0.85	0	0.5	0.05	0.21	−0.02
0.80	0.78	0.93	0.07	−0.4	0.09	0.23	−0.02
0.60	0.54		−0.08	−0.5	0.16	0.12	−0.08
0.46	0.52	0.81	0	−0.5	0.03	0.01	−0.07
0.56	0.63		0.02	−0.3	0.06	0.07	−0.06
0.11	0.19	0.35	−0.02	−1.3	−0.01	0.02	−0.02
0.24	0.26	0.39	0.01	−0.9	0.06	0.05	0
0.42	0.45	0.51	0.04	−0.3	0.02	0.03	−0.04
0.52	0.60	0.71	0.03	−0.2	0.12	0.14	0.01
0.48	0.56		−0.01	0.1	0.07	0.06	0.02
0.35	0.34	0.35	0.06	−0.2	0.09	0.15	−0.02
0.30	0.32		−0.01	−1.5	0.12	0.07	0
2.28	1.44		0.03	0.6	0.21	0.99	−0.04
2.10	1.37	0.86	0.04	0.5	0.33	0.87	0
0.76	0.33		0.04	−0.2	0.34	0.54	−0.01
1.69	1.12	0.72	−0.04	0.3	0.16	0.73	−0.07
1.56	1.13		0	0.2	0.23	0.61	−0.06
0.61	0.58	0.71	0.19	−0.2	0.34	0.05	0.19
1.00	0.62	0.34	0	−0.1	0.09	0.42	−0.02
1.63	0.96	0.62	−0.12	0.6	0.01	0.85	−0.13
1.78	1.12		0.06	−0.2	0.13	0.86	−0.07
0.99	0.83	1.00	−0.07	0.1	0.15	0.31	−0.02
1.07	0.94		0.11	0.4	0.27	0.23	0.02
0.65	0.71	0.86	0.03	−0.4	0.01	0.01	−0.03
0.83	0.75		−0.02	0.4	0.11	0.11	−0.02
1.15	0.85	0.49	0.07	0.5	0.27	0.41	0.06
0.65	0.65		0.02	0.4	0.18	0.12	−0.06
0.94	0.78	0.77	0.03	−0.6	0.29	0.25	−0.02
0.91	0.73		0.02	−0.8	0.21	0.29	0.05
0.92	0.71	1.06	0.08	0	0.24	0.38	0

$$=\frac{e-(e-c/2)}{121}\times 100$$

$$=\frac{c}{2}\cdot\frac{100}{121}(\%)$$

Consequently, the twist in this case shows the relative situation of the point C to the standard plane AGI.

Results and discussion

1. Distortion immediately after overlaying and during conditioning at air dry condition

Almost all laminated specimens immediately after overlaying and during conditioning at 12% EMC condition had much less distortion than that during sorption and desorption process, as shown in Table 12. This means that if moisture added by the adhesive in laminating is decreased as far as possible, the laminated board has little distortion even in the case of unbalanced construction of one side overlaying. Although weight changes due to the moisture movement from immediately after overlaying to conditioning at 12% EMC condition were not mentioned in Table 12, the specimens during this period had little weight change. Therefore, if the moisture movement does not occur within the laminated board, it seems that the distortion is not increased during the same exposure condition even in the case of one side overlaying. Besides, no influence of difference of the brand in both materials and its combination on the distortion of the laminated board was recognized.

2. The influence of the brands of decorative laminates and particle board on distortion process due to change of exposure condition

Six specimens out of 42 were used for measurement of distortion throughout the process: Four decorative laminates one side overlaid board (two replication of a brand of three-layer board I and two brands of veneer overlaid boards M, L) and two replication of decorative laminates overlaid board with backing sheet (three-layer board G) for comparison. For all the remaining specimens, the distortions saturated in every exposure condition were measured. The results obtained are as shown in Fig. 17 to 22 and Table 12.

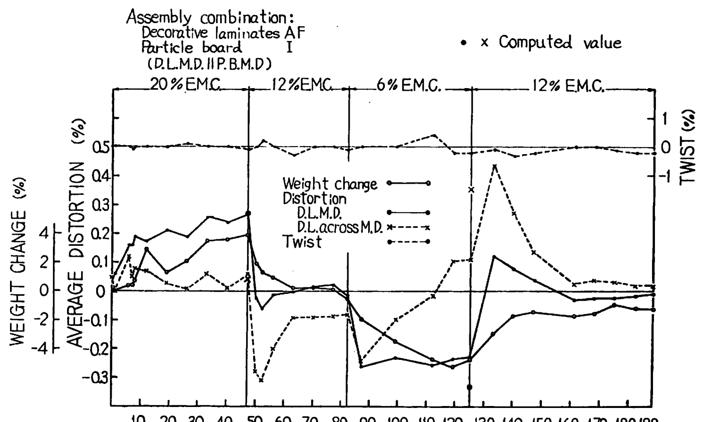


Fig. 17 Distortion process of decorative laminates overlaid particle board exposed to high and low humidity condition.

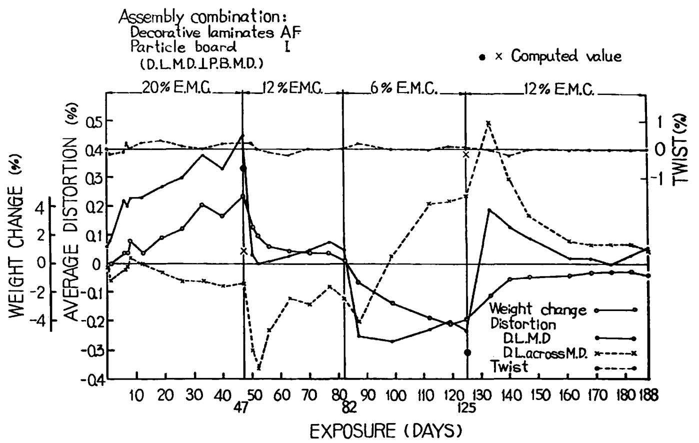


Fig. 18 Distortion process of decorative laminates overlaid particle board exposed to high and low humidity condition.

(a) **Process of distortion**

Distortion during processes, especially when specimens were exposed at 20% EMC humidity condition, showed a complicated behaviour due to a subtle difference of combination between decorative laminates and particle board. Namely, although Figs. 17 and 18 show the distortion processes of the specimens which are laminated by the same brand of material respectively (AF-I), in the former the machine directions of both materials are parallel to each other, in the latter the machine directions of both materials are perpendicular to each other. The particle board (I) in this case is a three-layer board and has the same swelling and shrinkage in both L and C direction as shown in Table 4, but it seems that since the machine direction of both materials were perpendicular to each other in Fig. 18, the swelling in C direction brought about a subtle difference, and consequently the distortion in C direction showed the different processes. Figs. 19 and 20 show the distortion processes of the veneer overlaid board

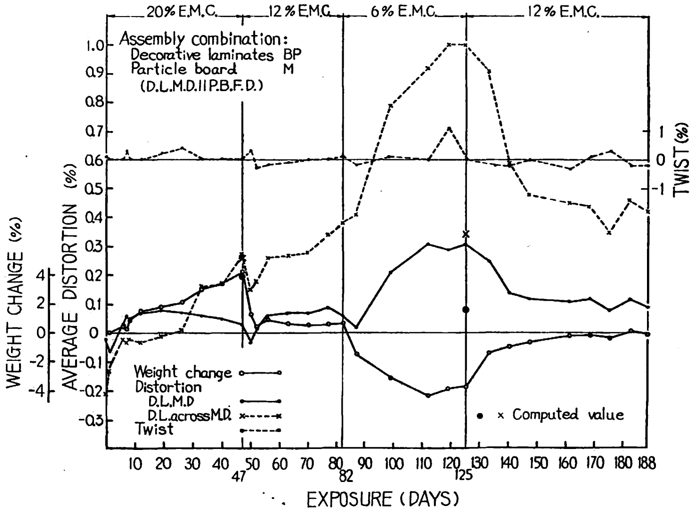


Fig. 19 Distortion process of decorative laminates overlaid particle board exposed to high and low humidity condition.

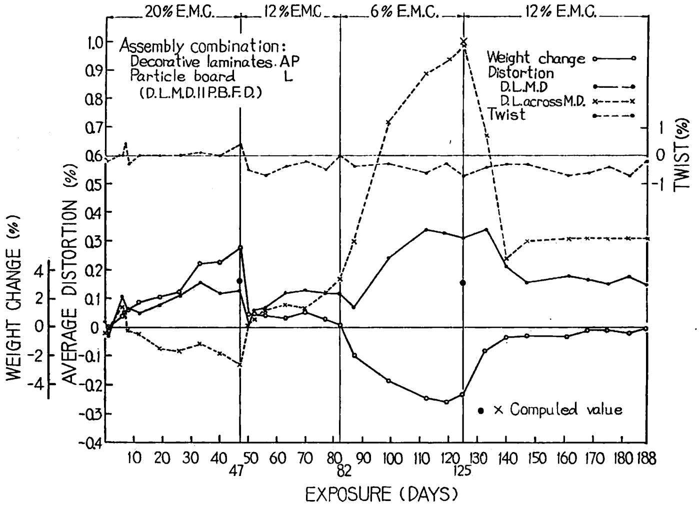


Fig. 20 Distortion process of decorative laminates overlaid particle board exposed to high and low humidity condition.

laminated by the decorative laminates (BP-M, AP-L). From these figures, it can be seen that the particle board L with cross band veneer has an isotropic swelling and modulus of elasticity; on the other hand, the particle board M shows the orthotropic properties on account of being without cross band veneer.

Besides, since particle board has a higher initial moisture sorption and desorption rate than decorative laminates (Table 9), even if the decorative laminates have higer swelling in especially C direction, the laminated specimen has once warped towards the decorative laminates as the concave side (plus side in figure), but finally the distortion of the specimen tends to change the direction to the opposite side. This phenomenon conducts the distortion process to confusion.

In the desorption process, on the other hand, the laminated specimen tends to warp temporarily towards particle board as the concave side at the initial stage of exposure condition change, due to influence of particle board having higher moisture desorption rate. Finally, however, the distortion of the specimen tends to change the direction to the opposite side, due to influence of decorative laminates having higher shrinkage, especially in C direction (Figs. 19 and 20). As shown in Figs. 17 and 18, however, since it happens occasionally that the distortion in L direction remains warping towards the particle board as the concave side, the distortion process seems to be affected by the combination of shrinkage of the material.

From the viewpoint of both the distortion process mentioned above and the basic properties such as swelling of materials, when the two-layer material laminated by components with different swelling and shrinkage are exposed under different humidity condition, it is evident that the two-layer material is sure to warp. If the laminated material is subject to distortion, however, when the resultant strain in the material is within elastic limit, the distortion almost recovers at the time when the humidity condition returns to the beginning state. On the other hand, the laminated board which showed big distortion at the higher or lower humidity condition suffered permanent strain within the board, and therefore considerable distortion remained, even when the humidity condition returned to the beginning state.

(b) **Direction of distortion**

As mentioned in the foregoing chapter, tendency (positive or negative) of the distortion in two-layer board can be expected from the equation (10) and the swelling or the shrinkage shown in Tables 6 and 7. Therefore, relevant to the swelling or the shrinkage of each material, the relationship between the measured value and the computed value of the distortion was discussed here as applying to moisture sorption and desorption separately.

(i) **The distortion depending on the difference of swelling of individual materials under high humidity condition.**

As can be seen from Tables 6 and 7, decorative laminates always show the relation which is $\alpha_1 m_1 (L) < \alpha_1 m_1 (C)$; and the swelling $\alpha_1 m_1 (L)$ is the smallest among the others including the swelling of particle board, except for only one brand of the decorative laminate. In the three-layer particle board G, H and I, the continuous layer board K and the veneer overlaid board (with cross band veneer) L showed an isotropic swelling, when they are combined with the decorative laminates, hence

1) If the decorative laminate in across the machine direction has a higher swelling than the particle board in both directions, the following relations are given.

$$\alpha_1 m_1 (L) < \alpha_2 m_2 (L) = \alpha_2 m_2 (C) < \alpha_1 m_1 (C)$$

Therefore

$\alpha_1 m_1 (L) - \alpha_2 m_2 (L) < 0$ The decorative laminate side is concave in L direction (positive in measurement)

$\alpha_1 m_1 (C) - \alpha_2 m_2 (C) > 0$ The decorative laminate side is convex in C direction (negative in measurement)

The combinations which belong to this equation are AP-G (7, 8), AP-L (19, 20, 21), AG-I (23, 24), BG-I (17, 18), CG-I, AP-K, AP-L (35, 36), AF-L, AG-L (37, 42), BP-L (34, 41), BG-L (38, 39, 40), CP-L and CG-L. Among those combinations, however, the direction of the distortion in No. 7, 8, 37 and 40 were not consistent with the measured value.

2) If the decorative laminate in across the machine direction has a lower swelling than the particle board in both directions, the following relations are given.

$$\alpha_1 m_1 (L) < \alpha_1 m_1 (C) < \alpha_2 m_2 (L) = \alpha_2 m_2 (C)$$

Therefore

$\alpha_1 m_1 (L) - \alpha_2 m_2 (L) < 0$ The decorative laminate side is concave in L direction (positive in measurement)

$\alpha_1 m_1 (C) - \alpha_2 m_2 (C) < 0$ The decorative laminate side is concave in C direction (positive in measurement)

The combinations which belong to this equation are AF-G, AG-G (5, 6), BP-G (1, 2, 3) BG-G (4), CP-G, CF-G, CG-G, AF-H, AG-H, BP-H, BG-H, CP-H, CF-H, CG-H, AF-I (13, 14), BP-I (22), CP-I, CF-I (15, 16), AG-K, BP-K, BG-K, CP-K, CF-K and CG-K. Excepting for No. 14, 22, the direction of the distortion in those combinations were consistent with the measured value.

On the other hand, the particle boards which showed an anisotropic swelling are the three-layer board J and the veneer overlaid board M, N. The three-layer board J and the veneer overlaid board with crossband N show the relation which is $\alpha_2 m_2 (L) > \alpha_2 m_2 (C)$ and the veneer overlaid board without crossband M shows the relation which is $\alpha_2 m_2 (L) < \alpha_2 m_2 (C)$. When they are combined with the decorative laminates, since the decorative laminate always shows the relation which is $\alpha_1 m_1 (L) < \alpha_1 m_1 (C)$,

A. In the case of $\alpha_2 m_2 (L) > \alpha_2 m_2 (C)$ (Ex. J, N).

1) If the decorative laminate in C direction has a higher swelling than the particle board in both directions, the following relations are given.

$$\alpha_1 m_1 (L) < \alpha_2 m_2 (C) < \alpha_2 m_2 (L) < \alpha_1 m_1 (C)$$

Therefore

$\alpha_1 m_1 (L) - \alpha_2 m_2 (L) < 0$ The decorative laminate side is concave in L direction.

$\alpha_1 m_1 (C) - \alpha_2 m_2 (C) > 0$ The decorative laminate side is convex in C direction.

The combination which belongs to this equation is only AP-J within this study. In this case, even if the machine directions of particle board and decorative laminates intersect perpendicularly, this tendency is not changed.

2) If the decorative laminate in C direction has a lower swelling than the particle board in both directions, the following relations are given.

$$\alpha_1 m_1 (L) < \alpha_1 m_1 (C) < \alpha_2 m_2 (C) < \alpha_2 m_2 (L)$$

Therefore

$\alpha_1 m_1 (L) - \alpha_2 m_2 (L) < 0$ The decorative laminate side is concave in L direction.

$\alpha_1 m_1 (C) - \alpha_2 m_2 (C) < 0$ The decorative laminate side is concave in C direction.

The combinations which belong to this equation are AF-J, BP-J, BG-J, CF-J, CP-J, AF-N, BP-N, BG-N, CF-N and CP-N. In this case, also, even if the machine directions of particle board and decorative laminates intersect perpendicularly, this tendency is not changed.

3) If the decorative laminate in C direction has higher swelling than the particle board in C direction and a lower swelling than the particle board in L direction, the following relations are given.

$$\alpha_1 m_1 (L) < \alpha_2 m_2 (C) < \alpha_1 m_1 (C) < \alpha_2 m_2 (L)$$

Therefore

$\alpha_1 m_1 (L) - \alpha_2 m_2 (L) < 0$ The decorative laminate side is concave in L direction.

$\alpha_1 m_1 (C) - \alpha_2 m_2 (C) > 0$ The decorative laminate side is convex in C direction.

The combinations which belong to this equation are AG-J, CG-J, AP-N, AG-N and CG-N. In this case if the machine directions of particle board and decorative laminate intersect perpendicularly, the following relations are given.

$\alpha_1 m_1 (L) - \alpha_2 m_2 (C) < 0$ The decorative laminate side is concave in L direction.

$\alpha_1 m_1 (C) - \alpha_2 m_2 (L) < 0$ The decorative laminate side is concave in C direction.

B. In the case of $\alpha_2 m_2 (L) < \alpha_2 m_2 (C)$ (Ex. M), according to the difference of the respective swelling of the decorative laminates and the particle board in the same machine directions, the following three relations are given.

1) $\alpha_1 m_1 (L) < \alpha_2 m_2 (L) < \alpha_2 m_2 (C) < \alpha_1 m_1 (C)$

Therefore

$\alpha_1 m_1 (L) - \alpha_2 m_2 (L) < 0$ The decorative laminate side is concave in L direction.

$\alpha_1 m_1 (C) - \alpha_2 m_2 (C) > 0$ The decorative laminate side is convex in C direction.
The combination which belongs to this equation is only AP-M (29, 30, 31), but the actual distortion in C direction occurs towards the decorative laminate as the concave side.
In this case, even if the machine directions of particle board and decorative laminate intersect perpendicularly, this tendency is not changed.
2) $\alpha_1 m_1 (L) < \alpha_2 m_2 (L) < \alpha_1 m_1 (C) < \alpha_2 m_2 (C)$.
Therefore

$\alpha_1 m_1 (L) - \alpha_2 m_2 (L) < 0$ The decorative laminate side is concave in L direction.

$\alpha_1 m_1 (C) - \alpha_2 m_2 (C) < 0$ The decorative laminate side is concave in C direction.

The combinations which belong to this equation are AG-M (27, 28), AF-M, BP-M (33), BG-M (25, 26), CF-M and CG-M. Excepting for No. 25 in L direction, the direction of the distortion in those combinations were consistent with the measured value.
In this case, if the machine directions of particle board and decorative laminate intersect perpendicularly, the following relations are given.

$\alpha_1 m_1 (L) - \alpha_2 m_2 (C) < 0$ The decorative laminate side is concave in L direction.

$\alpha_1 m_1 (C) - \alpha_2 m_2 (L) > 0$ The decorative laminate side is convex in C direction.

The combination which belongs to this equation is BP-M (32) and the direction of the distortion was consistent with the measured value.
3) Besides, in the case of the particle board having the smallest swelling in L direction as only one example.

$\alpha_2 m_2 (L) < \alpha_1 m_1 (L) < \alpha_1 m_1 (C) < \alpha_2 m_2 (C)$

Therefore

$\alpha_1 m_1 (L) - \alpha_2 m_2 (L) > 0$ The decorative laminate side is convex in L direction.

$\alpha_1 m_1 (C) - \alpha_2 m_2 (C) < 0$ The decorative laminate side is concave in C direction.

The combination which belongs to this equation is CP-M. In this case, if the machine directions of particle board and decorative laminate intersect perpendicularly, the following relations are given.

$\alpha_1 m_1 (L) - \alpha_2 m_2 (C) < 0$ The decorative laminate side is concave in L direction.

$\alpha_1 m_1 (C) - \alpha_2 m_2 (L) > 0$ The decorative laminate side is convex in C direction.

(ii) **The distortion depending on the difference of shrinkage of individual materials under low humidity.**

The specimens which had been exposed under high humidity condition at first were exposed under low humidity condition after exposing under 12% EMC condition, and since the distortion and the moisture content of the specimens exposing under low humidity condition were affected by the previous process, they could not start from zero point in low humidity condition, as shown in Fig. 17 to 20. On the other hand, since the computing value of distortion took a form which the specimens started from 12% EMC condition, the difference between measured value and computed value already had occurred when the specimens started to be exposed at low humidity condition (6% EMC). Therefore, in order to compare the measured value with the computed value, the following effective deflection (*ED*) was used.

$$ED = AD - ID$$

where *AD* is the deflection which occurred at the end of exposure period, *ID* is the deflection which had occurred at the beginning of exposure period. Even in the case of the effective deflection, however, it seems to be unavoidable to have a certain degree of error more or lees, because the adjustment of the moisture content change at the beginning of exposure period was not considered.

The decorative laminate shows the relation which is $\alpha_1 m_1(L) < \alpha_1 m_1(C)$ in shrinkage as well as swelling. The particle boards which showed an isotropic shrinkage were H, I in three-layer board and K in continuous-layer board. When they are combined with the decorative laminates,

1) If the decorative laminate in L direction has a lower shrinkage than the particle board in both directions, the following relations are given.

$$\alpha_1 m_1(L) < \alpha_2 m_2(L) = \alpha_2 m_2(C) < \alpha_1 m_1(C)$$

Therefore

$\alpha_1 m_1(L) - \alpha_2 m_2(L) < 0$ The decorative laminate side is convex in L direction (negative in measurement).

$\alpha_1 m_1(C) - \alpha_2 m_2(C) > 0$ The decorative laminate side is concave in C direction (positive in measurement).

The combinations which belong to this equation are AP-H, AF-H, AG-H, BP-H, BG-H, CP-H, CF-H, CG-H, AP-I (19, 20, 21), AF-I (13, 14), AG-I (23, 24), BP-I (22), BG-I (17, 18), CP-I, CF-I (15, 16), CG-I, AP-K, AF-K, AG-K, BP-K, BG-K, CP-K, CF-K and CG-K. Compared with the measured value for the particle board I, the direction of the distortion in those combinations was quite consistent.

2) For the other combination of shrinkage, the following relations are expected in an isotropic particle board.

$$\alpha_2 m_2(L) = \alpha_2 m_2(C) < \alpha_1 m_1(L) < \alpha_1 m_1(C)$$

$$\alpha_1 m_1(L) < \alpha_1 m_1(C) < \alpha_2 m_2(L) = \alpha_2 m_2(C)$$

According to the measured value of shrinkage of the isotropic particle board used in this study, however, these relations were not found.

On the other hand, the particle boards which showed an anisotropic shrinkage are G, J in three-layer board and L, M and N in veneer-overlaid board. They show the relations which are $\alpha_2 m_2(L) < \alpha_2 m_2(C)$ or $\alpha_2 m_2(L) > \alpha_2 m_2(C)$. When they are combined with the decorative laminates, since the decorative laminates always show the relation which is $\alpha_1 m_1(L) < \alpha_1 m_1(C)$, $\alpha_1 m_1(C)$ is largest among the others including the shrinkage of particle board.

A. In the case of $\alpha_2 m_2(L) < \alpha_2 m_2(C)$.

1) If the decorative laminate in L direction has a lower shrinkage than the particle board in L direction, the following relations are given.

$$\alpha_1 m_1(L) < \alpha_2 m_2(L) < \alpha_2 m_2(C) < \alpha_1 m_1(C)$$

Therefore

$\alpha_1 m_1(L) - \alpha_2 m_2(L) < 0$ The decorative laminate side is convex in L direction (negative in measurement).

$\alpha_1 m_1(C) - \alpha_2 m_2(C) > 0$ The decorative laminate side is concave in C direction (positive in measurement).

The combinations which belong to this equation are AP-G (7, 8), AG-G (5, 6), AF-G, BP-G (1, 2, 3), BG-G (4), CP-G, CF-G and CG-G. Compared with the measured value (effective deflection), the direction of the distortion in those combinations were quite consistent. In this case, even if the machine directions of particle board and decorative laminates intersect perpendicularly, this tendency is not changed.

2) If the decorative laminate in L direction has a higher shrinkage than the particle board in L direction, the following relations are given.

$$\alpha_2 m_2 (L) < \alpha_1 m_1 (L) < \alpha_2 m_2 (C) < \alpha_1 m_1 (C)$$

Therefore

$\alpha_1 m_1 (L) - \alpha_2 m_2 (L) > 0$ The decorative laminate side is concave in L direction.

$\alpha_1 m_1 (C) - \alpha_2 m_2 (C) > 0$ The decorative laminate side is concave in C direction.

The combinations which belong to this equation are AP-L (35, 36), AF-L, AG-L (37, 42), BP-L (34, 41), BG-L (38, 39), CP-L, CF-L, AP-M (29, 30, 31), AF-M, AG-M (27, 28), BP-M (33), BG-M (25, 26), CP-M, CF-M and CG-M. The direction of the distortion in those combinations were quite consistent with the measured value.

In this case, if the machine directions of particle board and decorative laminates intersect perpendicularly, the following relations are given.

$\alpha_1 m_1 (L) - \alpha_2 m_2 (C) < 0$ The decorative laminate side is convex in L direction.

$\alpha_1 m_1 (C) - \alpha_2 m_2 (L) > 0$ The decorative laminate side is concave in C direction.

The combinations which belong to this equation are BG-L (40) and BP-M (32). The directions of the distortion in these case were not consistent with the measured value. This means that as the machine directions of particle board and decorative laminate were intersected perpendicularly in laminating, the movements of each material in C direction which shows a high shrinkage were restricted by each other, then normal shrinkage could not occur, and consequently the tendency of the distortion in computing value was not consistent with the measured value.

B. In the case of $\alpha_2 m_2 (L) > \alpha_2 m_2 (C)$, the following classifications are given by the difference between $\alpha_2 m_2 (C)$ and $\alpha_1 m_1 (L)$.

1) If the particle board in C direction has a lower shrinkage than the decorative laminates in L direction, the following relations are given.

$$\alpha_2 m_2 (C) < \alpha_1 m_1 (L) < \alpha_2 m_2 (L) < \alpha_1 m_1 (C)$$

Therefore

$\alpha_1 m_1 (L) - \alpha_2 m_2 (L) < 0$ The decorative laminate side is convex in L direction.

$\alpha_1 m_1 (C) - \alpha_2 m_2 (C) > 0$ The decorative laminate side is concave in C direction.

The combinations which belong to this equation are AP-J, AG-J, BP-J, AP-N, AG-N, BP-N, BG-N and CF-N. In this case if the machine directions of particle board and decorative laminates intersect perpendicularly, the following relations are given.

$\alpha_1 m_1 (L) - \alpha_2 m_2 (C) > 0$ The decorative laminate side is concave in L direction.

$\alpha_1 m_1 (C) - \alpha_2 m_2 (L) > 0$ The decorative laminate side is concave in C direction.

2) If the decorative laminate in L direction has a lower shrinkage than the particle board in C direction, the following relations are given.

$$\alpha_1 m_1 (L) < \alpha_2 m_2 (C) < \alpha_2 m_2 (L) < \alpha_1 m_1 (C)$$

Therefore

$\alpha_1 m_1 (L) - \alpha_2 m_2 (L) < 0$ The decorative laminate side is convex in L direction.

$\alpha_1 m_1 (C) - \alpha_2 m_2 (C) > 0$ The decorative laminate side is concave in C direction.

The combinations which belong to this equation are AF-J, BG-J, CP-J, CF-J, CG-J, AF-N, CP-N and CG-N. In this case, even if the machine directions of particle board and decorative laminates intersect perpendicularly, this tendency is not changed.

Consequently, it is generally concluded that the tendency of the computed value in distortion coincides with the measured value, but exceptionally some computed values were not coinsistent with the measured value in the tendency of distortion. The causes of the error which may be considered are as follows:

(1) If the machine directions of particle board and decorative laminates were intersected perpendicularly in laminating, the movements of each material in C direction which were expected (to be a high shrinkage) were restricted by each other, and consequently the error in direction of the distortion occurred.

(2) In the case of the combination between the decorative laminate AP and any kind of particle board, the same errors were always recognized. Although the swelling of the decorative laminate AP in C direction was high in the case of measuring by test specimen, it is conceivable that when the decorative laminate was laminated to particle board, it could actually have less change than that of test specimen on account of restraint of small dimensional change in particle board. Therefore the error occurred in the direction of the distortion. In this case the absolute value of the deflection was somewhat apart from the computed value.

(3) In the moisture content change, a difference between the test specimen of dimensional change and the distortion specimen occurred. It seems that the error in distortion of several examples was caused by this difference of the moisture content change.

These results indicate that if the decorative laminate differs even in the case of the same brand of particle board in the laminating combination, the tendency of distortion is changed by the difference of relative combination in swelling or shrinkage, and that if the particle board differs even in the case of the same brand of decorative laminate, the tendency of distortion is also changed by the different combination of swelling or shrinkage. Therefore, although it has not been assumed that the direction of the distortion shows a certain tendency in laminating without knowledge of the individual basic data, it may be considered that the laminated board which shows the distortion has not a groundless way of distortion respectively.

(c) **Absolute value of distortion**

As can be seen from the equation (10) in Chapter II, the absolute value of the distortion in laminated two-layer board is affected by the difference of the swelling or shrinkage $\alpha_1 m_1 - \alpha_2 m_2$, the YOUNG's modulus ratio a, the material thickness ratio c and the span B. In this study, however, c and B are not changed, therefore, the absolute value of the distortion is affected by $\alpha_1 m_1 - \alpha_2 m_2$ and a. The difference of the swelling or shrinkage especially, as mentioned previously, influences the direction as well as the absolute value of the distortion. In considering these abilities which exert an influence on the absolute value, with the combination of the measured value in the decorative laminates and the particle board, the ratio of maximum to minimum in $\alpha_1 m_1 - \alpha_2 m_2$ is about 100:1 (Table 8). On the contrary, the ratio of maximum to minimum in the YOUNG's modulus ratio is about 4:1 (Tables 4 and 5). The extent of influence of $\alpha_1 m_1 - \alpha_2 m_2$ on the absolute value of distortion is stronger than that of a. Therefore, even in the consideration of the absolute value of the distortion, $\alpha_1 m_1 - \alpha_2 m_2$ was also used.

(i) **The distortion under high humidity condition.**

The distortion during this period was not remarkably at variance with the computed value. The laminated board which was combined with the decorative laminate AP, however, in spite of being higher swelling in C direction of AP, seemed to actually have less change than that of test specimen on account of restraint of small dimensional change in particle board. The combinations which belong to this error were No. 7, 8, 19, 20, 21, 29, 30, 31, 35 and 36. The above tendency was more or less recognized throughout these combinations.

In addition to the above tendency, the other errors of distortion which were caused by the error of moisture content change were recognized (No. 25, 37).

(ii) **The distortion under low humidity condition.**

As mentioned previously, since the distortion as well as the moisture content change during this period could not start from zero point, the measured value of the distortion could not be compared with the computed value which was formed starting from zero point. On account of evaluating the absolute value of the distortion due to the combination of the materials, therefore, the effective deflection mentioned previously was used. In the case of the absolute value of distortion as well as the direction of distortion, however, it seems to be unavoidable to have some degree of error more or less, because the adjustment of the moisture content change at the beginning of this exposure period was not considered, and the distortion is affected by the stress which has occurred before this exposure period within the laminated board.

1) The error depending on the phenomena which did not show the actual shrinkage.

In spite of being higher shrinkage in C direction of the decorative laminate AP, the laminated board which was combined with AP seemed to actually have less change than that of test specimen on account of restraint of small dimensional change in particle board, as was the case under high humidity condition (No. 7, 21 and 31).

2) The error depending on the combination which the machine directions of each material were combined at right angles.

The laminated boards which were combined with the particle board G and I (No. 3, 4, 5, 16, 17 and 23 in Table 11) had generally less actual distortion than the computed value, excepting the above-mentioned special case (AP). The distortion of these specimens showed saddle type on account of tension of big shrinkage in L direction of particle board. On the other hand, specimen Nos. 26, 34 and 38 showed a cup type distortion in which the decorative laminate side was concave, because of small shrinkage in L direction of the particle board. Consequently, it seems that the actual distortion was accelerated by shortage of factor which restrains the shrinkage in C direction of the decorative laminates. This might be a sign indicating that the movement in L direction of the laminated board is affected by the movement in C direction and phenomenon which occurred by means of analyzing the distortion in every direction as a simple beam.

(d) **Twist**

As mentioned previously, the twist in this study illustrates the relative situation of the point C to the standard plane AGI (Fig. 12). When the value of the twist is zero, it is implied that the four points ACIG on the board are within a plane. When the value of the twist is not zero, the sign (positive or negative) implies at which side of the AGI plane the point C is situated. In the case of positive, for instance, the point C situates in the particle board side.

According to the results measured, as shown in Table 12, the twist was generally not remarkable, and it was also not found that the twist was affected by the combination of the materials and the exposure condition. But a bigger twist seems to be unavoidable if the machine direction of the decorative laminate is combined at right angles with the machine direction of the particle board which has an evident anisotropy such as the veneer-overlaid board L without crossbanding.

(e) **The influence of the backing sheet.**

Laminating of the backing sheet to the back of the decorative laminates overlaid board is to make both sides of laminated board balance in dynamics and moisture sorption or desorption in using the lower cost materials. For this reason, three kinds of backing sheet used in this study seemed to be appropriate materials. Since the backing sheet D is a sheet which the surface of the ordinary decorative laminates was whittled, it is acknowledged that the physical properties are similar to the original decorative laminate (Tables 5 to 7). On the contrary, although E and F are real backing sheets, they have also physical properties resembling those of the ordinary laminates respectively. When the backing sheet is laminated at a back side, therefore, it may not be expected that the laminated board will have a big distortion.

In this study, compared with the test results of distortion of one side overlaid board mentioned previously, the distortion of the specimens AP-G-D and BP-G-E were measured in the same testing condition. The results obtained are as shown in Figs. 21 and 22 and Table 12. The distortion in this case was not theoretically analyzed, because of three layers, but, since the value of swelling and shrinkage were almost similar to that of the surface materials respectively, as can be seen in Table 7, they had quite small absolute values of the distortion

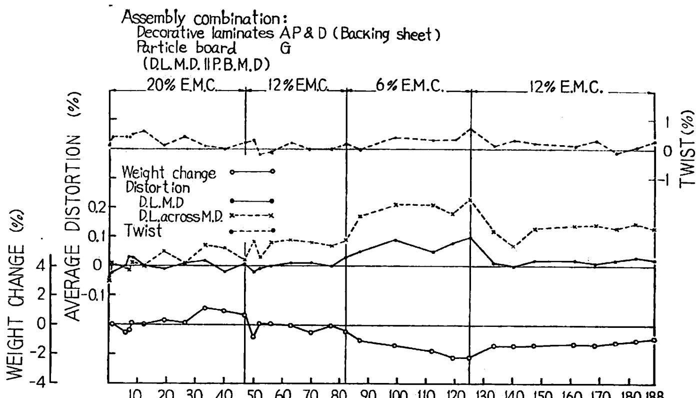


Fig. 21 Distortion process of decorative laminates overlaid particle board exposed to high and low humidity condition.

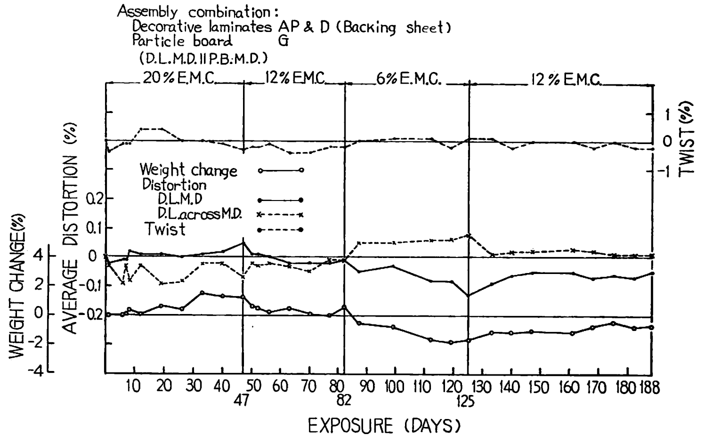


Fig. 22 Distortion process of decorative laminates overlaid particle board exposed to high and low humidity condition.

throughout the exposing period.

It seems to be one more reason for their small distortion that they had smaller weight changes than those of the other specimens, as can be seen in Table 12. Since the backing sheet E showed high equilibrium moisture content in high humidity condition as shown in Table 5, the laminated board which was combined with the backing sheet E had high weight change in 20% EMC, but generally the specimens for backing sheet had smaller weight change than other specimens. Therefore, the moisture sorption or desorption of the particle board in inner layer is sufficiently restrained by the outer layers within the exposing period in this study. This also seems to be a reason why they had small distortions.

Consequently, it was recognized that when the particle board is overlayed by the decorative laminates, the laminated board might naturally have small distortion during moisture sorption and desorption occasioned by laminating the backing sheet which resembles the surface material.

Conclusion

In this study the distortion of the decorative laminates overlaid particle board has been discussed in relation to the basic properties of the materials and actual distortion. Finally, the real condition of the distortion and the countermeasure for obviating the distortion will be considered in the following:

Since the equilibrium moisture contents show a remarkable difference between the decorative laminates and the particle board, the swelling or shrinkage of both materials must be compared with the absolute value of swelling from 6% EMC to 20% EMC or shrinkage from 20% EMC to 6% EMC. The value of the swelling and the shrinkage in both materials are as shown in Tables 6 and 7. The decorative laminate which consists of many melamine resin and phenolic resin impregnated papers had a high value in swelling and shrinkage beyond expectation. The particle board had relatively no difference depending on direction in swelling and shrinkage except for special cases, but the decorative laminate was affected by an anisotropy of paper as a base material, and always had higher swelling or shrinkage in across the machine direction than in the machine direction. Especially, the swelling of the decorative laminate AP in across the machine direction was four times that of the machine direction. Even in the other specimens the swelling in across the machine direction showed twice or three times that of the machine direction. This is responsible for the difference of distortion of laminated board in the machine and across the machine direction. The decorative laminates in across the machine direction had a maximum shrinkage throughout both materials. This is also responsible for creating the big distortion during moisture desorption.

If the surrounding conditions do not change, even a one-side overlaid board has not a big distortion consequent upon decreasing the moisture movement within the board depending on the adhesive moisture immediately after laminating. In the case of using urea resin as an adhesive, therefore, it is necessary for the adhesive to be a high solid resin and for an extender to have wheat flour added. Moreover, it is also necessary to decrease the moisture which is absorbed to the decorative laminates and particle board, by means of decreasing the glue spread. For this reason, it seems to be effective to use rubber type adhesive.

It is evident from the results mentioned previously that the one-side overlaid board inevitably has a distortion with change of the surrounding conditions. In order to decrease the distortion as much as possible, it is a matter of course that the surface of board should be balanced in dynamics as well as moisture sorption or desorption by laminating a backing sheet which is similar to the surface material. If it is impossible to use the backing sheet because of its expensiveness, although the surface of board does not balance in dynamics, the back side should be covered with a plywood or at least a moisture retardant paint as polyurethane. Thus, by means of restraint of moisture sorption or desorption from the back side, most of the distortion of the laminated board can no doubt be decreased.

As will be apparent from the findings in this study, the machine directions of the anisotropic particle board and decorative laminates are best when intersected perpendicularly in laminating, otherwise unexpected distortion results. In order not to complicate the stress relation due to swelling and shrinkage, it is necessary to arrange the machine directions of both materials parallel, regardless of whether the back side is treated or not.

When compared with the positive or negative tendency (direction) of the actual distortion, the computed value of the distortion which was analyzed for only one direction as a simple beam generally coincided with the measured value, except for a special instance. The absolute value of the distortion occasioned the relatively big error in across the machine direction during moisture desorption. This seems to be affected by the movement in the machine direction and also seems to be caused by simplification of analysis in distortion. But it is conceivable that the distortion of the laminated board can be computed by the equation (10) as a simple analysis with tolerable accuracy. Especially, the positive or negative tendency of distortion can be quite accurately predicted by measuring only the swelling and shrinkage of the materials beforehand.

Consequently, when overlaying, more similar materials in swelling or shrinkage between the decorative laminates and particle board should be combined by measuring the properties of both materials in the machine and across the machine direction beforehand. The decorative laminate as AP which has a remarkable difference between the machine and across the machine direction in swelling and shrinkage should be avoided for overlaying. On the other hand, the decorative laminate as AF which has relatively less difference between the direction in swelling and shrinkage should be used. In respect to the particle board, it is desirable to select more isotropic material.

Summary

Physical and mechanical properties of several typical particle boards and decorative laminates on the market were measured. Simultaneously, at the time when the particle board was overlayed by the decorative laminates, distortion of laminated board depending on moisture sorption and desorption was mathematically analyzed and the computed value of distortion was substantiated experimentally. The results of the study showed that the distortion of one-side overlaid board can be predicted by measuring the swelling, shrinkage and YOUNG's modulus of the components beforehand, and how to prevent the distortion of one-side overlaid board.

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パーティクルボードに関する研究 (XI)

オーバーレイ・パーティクルボード製造技術に関する研究 (第2報)

メラミン化粧板オーバーレイ・パーティクルボードの反り

岩　下　　睦[1]
アンドリュウ・エム・スタシェフスキー[2]

概　　要

パーティクルボードにメラミン化粧板をオーバーレイして家具の天板が作られることが多いが，特に片面張りの場合にそりになやまされる。この報告は市販の代表的なパーティクルボードとメラミン化粧板の物理的，弾性的性質を測定し，同時に，それらの材料を2層にはり合わせた場合の吸湿，脱湿による板のそりについて理論的に解析し，そりの計算値を実験的に検討した。

その結果，メラミン化粧板片面オーバーレイボードのそりは，まえもって構成要素の膨張率，収縮率，引張りヤング率を知ることによって予想しうることがわかった。

なお，その反りの防除法についても考察が加えられた。

(1) 木材部材質改良科材質改良研究室長・農学博士
(2) オーストラリア林産研究所合板接着科研究員・日豪科学技術交流留学生