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A Comparative Study on the Mechanical Properties of Plywood treated with Several Fire-Retardant Chemicals(II)[1]

— Effect of Platen Temperature in Press Drying on the Static Bending Strenght of Treated Plywood —

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數種 耐火藥劑로 處理된 合板의 機械的 性質에 관한 比較硏究(II)[1]

—熱板乾燥時 熱板温度가 處理合板의 휨強度에 미치는 影響—

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要 約

熱板温度가 耐火藥劑로 處理된 合板의 再乾燥 後 曲強度에 미치는 影響을 調査하기 위해 두께 3.5mm 메란티合板을 黃酸암모늄, 第一인산암모늄, 第二燐酸암모늄 그리고 混合藥劑인 硼砂 • 硼酸 및 미나리스 等 5種의 耐火劑의 20% 水溶液에 9時間동안 浸漬處理한 다음, 各各 熱板温度 90°C, 120°C 및 150°C를 適用한 段階別 乾燥方式으로 乾燥하여 曲強度試驗을 行하였다.

比例限界에서의 應力, 彈性係數, 破壞係數 및 比例限界까지의 單位體積當 일 等을 調査한 바, 水分處理對照區의 경우, 熱板温度 120°C까지 維持되던 強度가 150°C에 이르러서는 현저한 減少傾向을 나타내었으나, 耐火藥劑處理合板은 150°C까지 熱板温度가 上昇함에도 不拘, 強度가 維持되었으며 일부 藥劑處理의 경우엔 오히려 增加하는 樣相도 보여주었다.

乾燥速度와 強度維持의 側面을 고려할 때, 바람직한 熱板乾燥温度는 150°C 였으며 耐火藥劑中 補強效果가 가장 좋은 藥劑는 硼砂 • 硼酸이었다.

Summary

Soaking treated in 20% aqueous solutions of $(NH_4)_2SO_4$, $(NH_4)H_2PO_4$, $(NH_4)_2HPO_4$, $Na_2B_4O_7$-H_3BO_3 (60:40) and Minalith, the mixed salts for 9 hrs, the wet 3.5mm meranti (*Parashorea* spp.) plywoods were press-dried at 90, 120 and 150°C and put to static bending test to examine the influence of redrying temperature on the strength of fire-retardant treated plywoods in flexure.

While water-soaking treatment (control) showed serious reduction in Stress at proportional limit, MOE, MOR, Work per unit volume at 150°C, all the fire-retardant treatments maintained bending strength even at

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150°C and showed rather increased values in case of some chemicals.

In view of drying rate and maintenance of strength, the most pertinent platen temperature was 150°C and Borax-Boric acid was the predominant fire-retardant in this study.

Key words: fire-retardant plywood, soaking treatment, press drying, static bending strength, stress at proportional limit, MOE, MOR, Work per unit volume to proportional limit.

Introduction

Fire-retardant treatment on interior construction materials has been indispensable for the prevention aginst a disastrous fire. PB, HB and plywood are popular building because of their good workabilities and esthetic faces. Naturally it is inevitable to treat these parel products with fire-retardants.

Mechanical properties of wood and wood based panel products are generally affected by hydrolysis and thermal decomposition from the soaking treatment followed by hot press drying. Fire-retardants treated plywoods are expected conserve their strength to some extent in comparison with water treated plywoods relatively.

Maclean (1951) reported that steaming or press drying reduced the weight and strength of wood. Jessome (1962) examined the mechanical properties of fire-retardant treated douglas fir, red pine and their plywoods. Gerhards (1970) studied the effect of drying method (air drying, indoor drying, kiln drying) on the bending strength of the treated solid woods and LVL (laminated veneer lumber). It was reported by Schaffer (1973) that the tensile strength of heated wood had decreased inactively until 175°C but dropped abruptly over this point. Troughton, *et al.* (1974) found that the strength reduction of wood was due to hydrolysis and oxidation by heat treatment in the order of steaming, hot-pressing and kiln heating. Wangaard (1979) proved 0.6 – 1.0% reduction rate per 1°C of strength and Gerhard (1979) ascertained high temperature drying caused the reduction of 18% in tensile strength and 10% in MOE.

The present study was undertaken to examine the effects of chemical type and the temp. of platen regarding to the drying rate on the bending strength of thin fire-retardant plywoods.

Materials and methods

Preparation and conditioning of samples

3.5mm meranti (*Parashorea* spp.) plywoods for exterior use were purchased and cut into size of 15cm by 15cm. Samples with no defects as starved joint, knots and scars were screened and conditioned in the laboratory of 65% RH and 15°C for 2 weeks.

The number of sample used in this experiment was 108 sheets in total, the product of 6 (chemical type including water) x 3 (platen temp.) x 6 (replication).

Fire-retardant chemicals and others

Fire-retardant chemicals used in this soaking treatment were tabulated in table 1.

Table 1. Fire retardant chemicals and their compositions

Chemical type	Composition (grade)	
Ammonium sulfate	$(NH_4)_2SO_4$ (GR)	
Ammonium phosphate, mono basic	$NH_4H_2PO_4$ (GR)	
Ammonium phosphate, di basic	$(NH_4)_2HPO_4$ (GR)	
Borax-Boric acid	$Na_2B_4O_7$ (GR)	60%
	H_3BO_3 (GR)	40%
Minalith	$(NH_4)_2HPO_4$ (GR)	10%
	$(NH_4)_2SO_4$ (GR)	60%
	$Na_2B_4O_7$ (GR)	10%
	H_3BO_3 (GR)	20%
Water (control)	plain tap water	

A 5 liter beaker to which thermometer attached was employed as soaking bath and set in the cabinet to maintain the constant solution temperature. And a hot press of 48cm by 48cm (Area), 0–350°C (temp. range), 70,000 kg (max. press.) and about

15cm ram diameter was used to redry the wet sample plywoods.

Fire-retardant treatment and press drying

15cm by 15cm plywoods were treated in the specially devised soaking bath as stated above for 9 hrs. Hot (60°C) and cold (11°C) soaking treatment (6:3) was applied to 3 single salts, $(NH_4)_2SO_4$, $(NH_4)H_2PO_4$ and $(NH_4)_2HPO_4$ to maximize the absorption. But only hot soaking for 9 hrs was applied to the mixed salts, Borax-Boric acid and Minalith treatment because of immiscibility and low solubility of their compositions in cold solution. Plywood samples had been controlled to 12.69 – 12.74% M.C. before soaking.

Fire-retardant treated plywoods were redried between aluminium cauls in hot press at 90, 120 and 150°C of platen with the intervals of 5, 2 and 0.5 min. between platen openings in each platen temperature according to Chen's cyclic step-drying method (1978).

Press drying terminated about at 10% M.C., the target point counted backward from the weight of samples weighed during the drying process.

Static bending test

Redried samples were prepared into the size of 2.54cm (W) by 15cm (L) and loaded on the universal testing machine under the operating condition shown in table 2.

Table 2. Operating condition of static bending test

Item	Condition
Span length (L)	8.5 cm
Sample thickness (h)	3.5 mm
Sample width (b)	2.54 cm
Max. load	25 kg
Load speed	10mm/min
Chart speed	100mm/min

We calculated four mechanical data, i.e., Stress at proportional limit (S_{pl}), MOE, MOR and Work per unit volume to proportional limit (W_{pl}) from table 2. and fig. 1.

The calculation formulae are as follows.

$$S_{pl} = 3P_{pl} \cdot L/2bh^2$$

$$MOE = P_{pl} \cdot L^3/4D_{pl}bh^3$$

$$MOR = 3P_u \cdot L/2bh^2$$

$$W_{pl} = P_{pl} \cdot D_{pl}/2V$$

wh, D_{pl} : deflection at proportional limit

P_{pl} : load at proportional limit

P_u : max. load

V : volume.

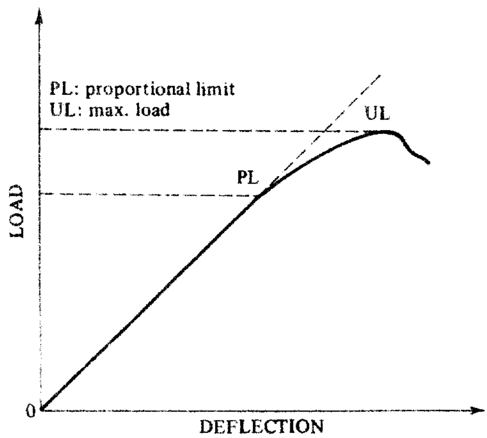

Fig. 1. Load-deflection curve in flexure.

Results and discussion

Chemical retention and drying rate

According to Lee and Kim's (1982) study, it took at least about 9 hrs in soaking method to get the effective chemical retention proposed by Koch (1972).

Table 3. shows the mean chemical retention

Table 3. Mean chemical retention in 9hr-soaking treated plywoods

Chemical type (20% aq. soln.)	Absorbed content [kg/(30cm)^3]	Chemical retention [kg/(30cm)^3]
Ammonium sulfate	6.317	1.263
Ammonium phosphate, mono basic	6.766	1.353
Ammonium phosphate, di basic	6.657	1.331
Borax-Boric acid	6.132	1.226
Minalith	4.529	0.906
Water (control)	8.320	–

among 5 chemicals in 9 hr-soaking treated plywoods. Our guess about the result was right. Borax-Boric acid and Minalith showed the lowest retention coming up to our expectations. This result was deemed to be caused by their incomplete miscibilities and only hot soaking.

Table 4. Drying rate of soaking treated plywoods by platen temp. (m.c. %/min.)

Chemical type \ Platen temp.(°C)	90	120	150
Ammonium sulfate	1.287	5.803	26.230
Ammonium phosphate, mono basic	1.712	7.126	28.901
Ammonium phosphate, di basic	0.980	8.939	24.298
Borax-Boric acid	0.594	3.609	27.744
Minalith	0.743	3.024	16.230
Water (control)	2.040	10.744	31.112

We also found from table 4 that the drying process had the analogous mechanism as absorption process. While it took 40-50 min or 10±3 min. to reach the target point at 90 or 120°C, only 3 min. was enough to get this point in case of 150°C. Without any serious diminution in mechanical strength, it will be desirable to redry the wet plywoods at 150°C. The results of static bending test on the fire-retardant treated plywoods with discussion are as follows.

Stress at proportional limit (S_{pl})

Table 5. showed that there was high statistical significance among the chemicals in S_{pl} value of fire-retardant treated plywoods. Fig. 2. also represented the obvious difference among 5 chemicals and control in S_{pl} value. As seen in fig. 2., however, the fire-retardant plywoods treated with chemicals were hardly affected by the temperature of platen in press drying. S_{pl} values of the chemicals treated

Table 5. Mechanical data for fire-retardant treated plywoods from static bending test

Chemical type, A	Platen temp.(°C),B		ɔpl (kg/cm²)	MOE (kg/cm²)	MOR (kg/cm²)	Wpl (kg-cm/cm³)
Ammonium sulfate	90		210.36	21387.4	354.07	.061
	120		193.29	19472.5	310.65	.057
	150		199.75	20934.5	306.32	.053
		mean	**201.13**	**20598.1**	**323.68**	**.057**
Ammonium phosphate, mono basic	90		156.49	14791.6	258.92	.050
	120		170.55	16527.9	284.60	.051
	150		192.24	18996.5	329.52	.055
		mean	**173.07**	**16772.0**	**290.92**	**.052**
Ammonium phosphate, di basic	90		174.87	16672.8	279.82	.055
	120		188.39	17370.9	297.18	.058
	150		203.77	18311.5	320.52	.062
		mean	**189.01**	**17451.8**	**299.17**	**.058**
Borax-Boric acid	90		219.75	17347.6	327.0	.082
	120		218.81	17626.2	292.19	.081
	150		273.00	24087.8	384.82	.091
		mean	**237.19**	**19687.2**	**334.67**	**.085**
Minalith	90		206.93	18625.3	325.13	.072
	120		203.79	16330.9	305.93	.071
	150		216.35	18618.5	316.73	.075
		mean	**209.02**	**17858.2**	**315.93**	**.073**
Water (control)	90		153.06	18063.3	290.35	.039
	120		151.58	17684.1	283.81	.041
	150		127.28	15274.1	250.69	.033
		mean	**143.97**	**17007.2**	**274.95**	**.038**

Chemical type, A	Platen temp.(°C),B	*Spl* (kg/cm²)	MOE (kg/cm²)	MOR (kg/cm²)	Wpl (kg-cm/cm³)
Sub plot (B) mean	90	**186.91**	**17814.7**	**305.88**	**.064**
	120	**187.73**	**17502.1**	**295.73**	**.064**
	150	**202.06**	**19370.5**	**318.05**	**.068**
F-value	A	50.654**	7.735**	5.920**	92.547**
	B	2.096	2.082	1.316	.519
	AxB	4.003**	3.889**	4.590**	1.072
L.S.D. (0.05, 0.01)	A_1-A_2	(13.06, 17.67)	(1629, 2204)	(26.6, 36.0)	(.005, .007)
	B_1-B_2	(9.63, 12.83)	(1135, 1512)	(15.9, 21.2)	(.005, .007)
	$A_1B_1-A_1B_2$	(23.59, 31.42)	(2780, 3703)	(39.1, 52.1)	(.013, .017)
	$A_1B_2-A_2B_1$	(23.27, 31.14)	(2794, 3741)	(41.6, 55.7)	(.012, .016)

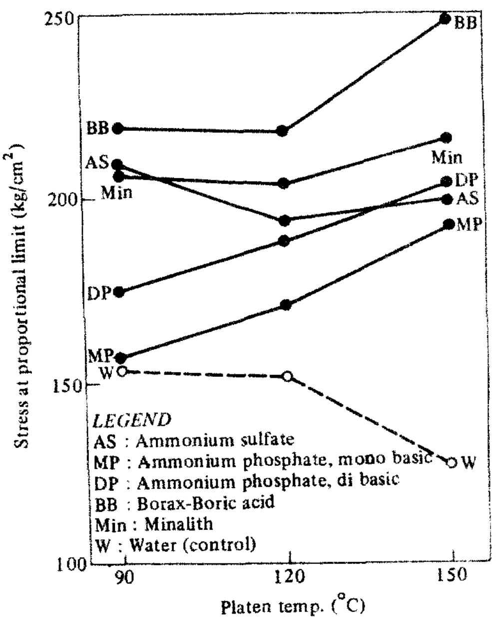

Fig. 2. Effect of platen temperature on the stress at proportional limit (*Spl*) of the redried plywoods among fire-retardant chemicals.

plywoods maintained and rather increased even at 150°C but that of water treated plywood (control) decreased abruptly at 150°C by the effect of thermal decomposition of wood constituents. Borax-Boric acid showed the more excellent *Spl* value than any other chemical.

Modulus of elasticity (MOE)

According to table 5., MOE values of fire-retardant treated plywoods also showed statistical difference with high significance among the fire-retardants. But there was no significance (at 5% level) among the temperatures of platen. In other words, the platen temperature did not influence on the MOE value of chemical treated plywoods but water treated plywoods.

As expected, water treated plywoods were deeply hurt at 150°C of platen but chemical treated plywoods sustained or elevated their strength even at 150°C. Not only Borax-Boric acid but also Ammonium sulfate excelled the rest chemicals in MOE value owing to its high melting point (approx.

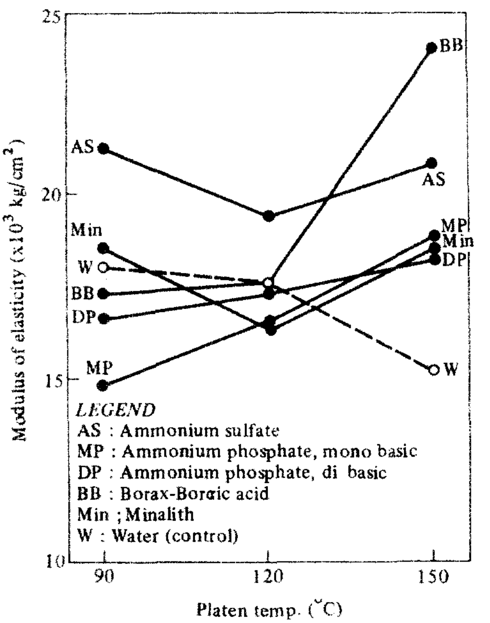

Fig. 3. Effect of platen temperature on the modulus of elasticity (MOE) of the redried plywoods among fire-retardant chemicals.

280°C).

Modulus of rupture (MOR)

MOR values of fire-retardant treated plywoods showed the similar tendancy to that of MOE values. They were different from one another with high significance (table 5) but all of them except control had no relation with the temperature of platen in press drying. Water treated plywoods were also affected by high temperature (150°C) to be the lowest MOE value in all the treated plywoods. Borax-Boric acid also showed the highest MOR value. Borax is the natural principal form of Boron which is the lightest member of the Group III elements. And H_3BO_3 (m.p. : 170.9°C, sp.gr.= 1.5172) is prepared by the action of strong acids on borax into crystallization. Its property strengthening fire-retardant treated plywoods even at the higher temperature is inferred from the crystallinity and the synergism between Borax and Boric acid.

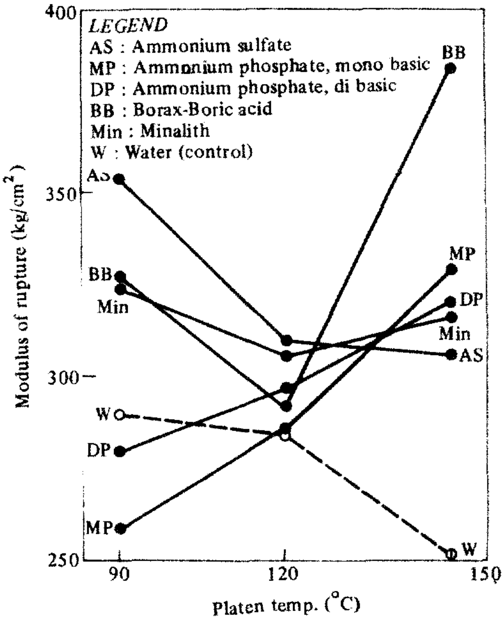

Fig. 4. Effect of platen temperature on the modulus of rupture (MOR) of the redried plywoods among fire-retardant chemicals.

Work per unit volume to proportional limit (W_{pl})

The changing aspect of W_{pl} values of treated plywoods according to the rise of platen temperature was as like as the case of S_{pl}. Undoubtly there were wide difference among the chemicals and all the chemical treatments surpassed the water treatment in W_{pl} value at all temperatures.

The temperature-dependency of W_{pl} value was the lowest level with the minimum F-value (0.519) as shown in table 5. Two mixed chemicals, Borax-Boric acid and Minalith held the higher ranks in order by means of their good synergic effects. And water treatment crawled at the bottom in W_{pl} value.

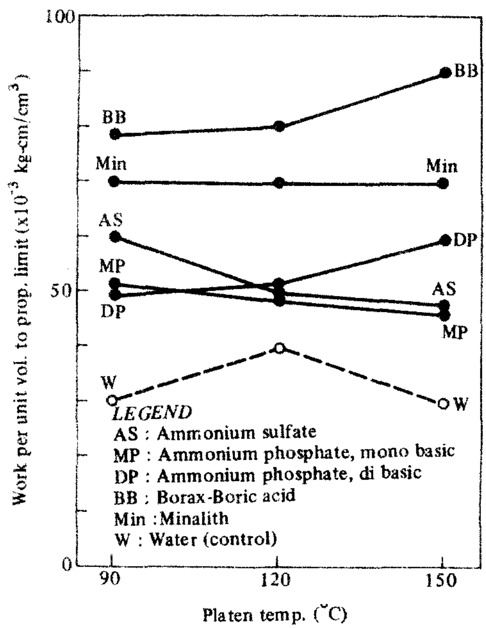

Fig. 5. Effect of platen temperature on the work per unit volume to proportional limit (W_{pl}) of the redried plywood among fire-retardant chemicals.

Conclusion

We employed the ordinary soaking and press drying process which is the widespread and practical method in wood preservation industry to manufacture fire-retardant plywood. We also carried this experiment to compare the effect of the type of fire-retardant chemicals and platen temperature in press drying on the static bending strength of fire-retardant treated plywoods manufactured by the above-stated method.

The conclusion of the study got from the basis of results and discussion is as follows.

All the chemical treatments stood high above water treatment and Borax-Boric acid treatment showed the highest value in four mechanical data, that is, S*pl*, MOE, MOR and W*pl*. And while water treatment (control) showed serious reduction in the four data at 150°C, 5 fire-retardant treatments maintained the bending strength even at 150°C and showed rather increased values in one or two chemical treatments. We could fix 150°C and Borax-Boric acid for the most proper platen temp. and fire-retardant in view of drying rates and maintenance of strength in this study.

Literature cited

1. Chen, P. Y. S. 1978. Press drying black walnut wood: Continuous drying *vs*. step drying. Forest Prod. Jr. 28(1):23-25.
2. Gerhards, C. C. 1970. Effect of fire-retardant treatment on bending strength of wood. U.S. D.A. Forest Service, Res. Pap. FPL-145.
3. Gerhards, C. C. 1979. Effect of high-temperature drying on tensile strength of Douglas fir 2 by 4's. Forest Prod. Jr. 29(3): 39-46.
4. Jessome, A. P. 1962. Strength properties of wood treated with fire-retardants. Forest Prod. Res. Branch, Canada Dept. of Forestry Rpt. No. 193:12p.
5. Koch, P. 1972. Utilization of southern pines. Pard II: 1111-1128, Agriculture Handbook No. 420, USGPO, Washington, D. C.
6. Maclean, J. D. 1951. Rate of disintegration of wood under different heating conditions. Amer. Wood Preserv. Assoc. Proc. 47: 155-169.
7. Schaffer, E. L. 1973. Effect of pyrolitic temperature on the longitudinal strength of dry Douglas fir. Jr. of Testing and Eval. 1(4): 319-329.
8. Troughton, G. E. and L. R. Lozon. 1974. Heat effects on tensile properties of Douglas fir and white spruce thin sections. Wood Sci. 7(2):116-122.
9. Wangaard, F. F. 1979. Wood: Its structure and properties. The Pennsylvania State University, University Park, Pa.
10. 李鉤宇, 金鍾萬. 1982. 合板의 耐火處理와 熱板 乾燥에 關한 硏究. 목재공학 10(1):5-37.