목재공학 12(2) : 20～26. 1984(原著)
Wood Sci. & Tech. 12(2) : 20～26. 1984

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

– Effect of Soaking Time on the Static Bending Strength 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 關한 比較研究(I)[1]

— 處理合板의 휨強度에 미치는 浸漬時間의 影響 —

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要　　約

耐火處理된 合板의 內部에 殘存하고 있는 耐火藥劑의 種類 및 그 量이 合板 特有의 長點인 휨 強度에 어떠한 影響을 미치는 가를 調査하기 爲해 黃酸 암모늄(Ammonium sulfate), 第一燐酸 암모늄(Ammonium phosphate, mono basic), 第二燐酸 암모늄(Ammonium phosphate, di basic), 그리고 複合藥劑인 硼砂・硼酸(Borax-Boric acid) 및 미나리스(Minalith) 等 5種의 耐火劑를 20% 水溶液으로 調製한 다음 3.5mm 메란티 合板을 3時間부터 12時間 동안 3時間 間隔으로 浸漬處理를 한 後 120℃의 熱板으로 再乾燥하여 휨 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, 藥劑處理한 合板의 경우가 水分處理合板(對照區)에 比해 大部分 높게 나타났으며 硼砂・硼酸 處理合板의 경우가 4部門에서 共히 가장 높은 値를 보여주었다. 그리고 處理時間이 延長됨에 따라, 즉 藥液의 吸收量(藥劑 殘存量)이 增加함에 따라 휨 強度는 大體的으로 向上하는 것으로 나타났다.

強度的 側面이나 浸漬處理時 發生하는 缺陷 등을 考慮할 때 複合藥劑인 硼砂・硼酸이 가장 바람직한 合板用 耐火處理藥劑로 사료되는 바이다.

Summary

This study was carried out to investigate the influence of chemical type and its retention in the fire-retardant treated plywoods on the static bending strength, a property peculiar to plywood. Being soaked in 20% aqueous solution of $(NH_4)_2SO_4$, $NH_4H_2PO_4$, $(NH_4)_2HPO_4$, Borax-Boric acid and Minalith for 3 to 12 hours at three-hour intervals and redried at 120°C in hot press, the treated plywoods were put to static bending test.

The values of chemical treated plywoods in Stress at proportional limit, Modulus of elasticity, Modulus

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1 接受 4月 16日 Received April 16, 1984.
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of rupture and Work per unit volume to proportional limit were widely higher than those of water treated plywoods(control) and Borax-Boric acid treatment showed the highest value in the four mechanical data. And the bending strength of fire-retardant treated plywoods increased with the extension of soaking time or the increase of chemical retention in themselves. Borix-Boric acid was the desirable fire-retardant for thin plywood in view of mechanical strength and soaking defects in this study.

Key words: fire-retardant treated plywood, static bending test, stress at proportional limit, modulus of elasticity, modulus of rupture, work per unit volume to proportional limit.

Introduction

Plywood chiefly used for interior finish work has pretty high inflammability and can cause big fire disaster, so it is inevitable to treat plywood with fire-retardants.

Soaking method is occasionally used in manufacturing the fire retardant plywood and redrying problem without serious physico-chemical defects comes to the front of us in this method. Lee and Kim (1982) reported that the soaking treated plywoods had been dried in rather short time by hot press drying method. They also showed that chemical retention in fire-retardant treated plywoods increased with the increase of soaking time. Lee and Chung (1983) treated 5.25 mm-meranti (*Parashorea* spp.) plywood with $(NH_4)_2HPO_4$ by hot/cold soaking method and redried the soaked plywoods at 160°C in 2.5 to 4 minutes.

There have been many experiments on the effect of fire-retardant treatment on the mechanical properties of wood and rather thick wood based panel products. King and Matteson (1961), Jessome (1962) and Percival and Suddarth (1971) treated plywood and solid wood with fire-retardants and tested the mechanical strength on the treated panals. Juneja (1972) treated wood and veneer with chemicals and exploited a stable fire-retardant. Jain, *et al.* (1975) studied the effect of the assorted fire-retardant chemicals on the strength of the treated wood and plywood. Gerhard (1970) showed how the drying method (air drying, indoor drying and kiln drying) had influenced on the bending strength of wood and LVL (laminated veneer lumber). Chung and Lee (1984) also performed the static bending test on $(NH_4)_2HPO_4$ treated plywoods which had been redried in hot press to investigate the effect of platen temp. on the strength of soaking treated 5.25mm plywood.

The present study was undertaken to examine the influence of the chemical type and retention amount in the treated thin plywood on its bending strength in flexure.

Materials and methods

Sample plywoods and conditioning

Meranti (*Parashorea* spp.) plywoods for exterior decoration on the market were used in this experiment of which the size was 120 cm (W) by 240 cm (L) and 3.5 mm(T). Parts of the purchased plywoods which had defects as starved joints, knots and scars was eliminated and the remainder was cut into the size of 15 cm by 15 cm and conditioned in the laboratory of 65% RH and 15°C for 2 weeks.

The number of total plywood samples was 144 sheets, the product of 6 (chemical type including water) × 4 (soaking time) × 6 (replication).

Fire-retardant chemicals and others

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

A 5 liter beaker to which thermometer attached was employed as soaking bath and set in the temp. adjustable cabinet to maintain the solution at constant temperature. And hot press which had the spec of 48 cm by 48 cm (platen area), 350°C (max. temperature), 70,000 kg (max. press.) and about 15 cm dia. ram was used to

Table 1. Fire retardant chemicals and their compositions

Chemical(composition)		Grade	Concentration(%)
Ammonium sulfate $(NH_4)_2SO_4$		Reagent	20
Ammonium phosphate, mono basic $NH_4H_2PO_4$		Reagent	20
Ammonium phosphate, di basic $(NH_4)_2HPO_4$		Reagent	20
Borax-Boric acid		Reagent	20
$Na_2B_4O_7$	60%		
H_3BO_3	40%		
Minalith		Reagent	20
$(NH_4)_2HPO_4$	10%		
$(NH_4)_2SO_4$	60%		
$Na_2B_4O_7$	10%		
H_3BO_3	20%		
Water(control)		Plain water	

redry the soaked plywood samples.

Fire-retardant treatment and press drying

Using the specially devised soaking bath as stated above, 15 cm by 15 cm plywoods were treated through the process as shown in table 2. to get the minimum chemical retention proposed by Koch (1972).

Because of the immiscibility of their compositions in cold solution, only hot soaking method was applied to the case of Borax-Boric acid and Minalith. Plywood samples had been controlled to 12.69-12.74% moisture content before soaking.

Table 2. Treating processes by fire retardant chemical solutions

Chemical solution \ Treating time(hrs)	3	6	9	12
Ammonium sulfate	Hot* soaking	Hot soaking	Hot and** cold bath	Hot and cold bath
Ammonium phosphate, mono basic	Hot soaking	Hot soaking	Hot and cold bath	Hot and cold bath
Ammonium phosphate, dibasic	Hot soaking	Hot soaking	Hot and cold bath	Hot and cold bath
Borax-Boric acid	Hot soaking	Hot soaking	Hot soaking	Hot soaking
Minalith	Hot soaking	Hot soaking	Hot soaking	Hot soaking
Water	Hot soaking	Hot soaking	Hot and cold bath	Hot and cold bath

* soaking in the solution at 60°C

** After hot soaking at 60°C, last 3hrs cold soaking at 11°C.

Fire-retardant treated plywoods were redried between aluminium cauls in hot press under the condition of 120°C platen temp. and 3.52 kg/cm^2 pressure. Drying was progressed according to Chen's cyclic step-drying method (1978) and terminated about at 10% M.C., the target point counted backward from the weight of samples weighed during drying process.

Static bending test

2.54 cm(W) by 15 cm(L) samples parallel to core grain were prepared for bending test and loaded on the Shimatzu universal testing machine under the operating condition shown in table 3.

Table 3. Operating condition of static bending test

Item	Condition
Maximum load	25 kg
Load speed	10 mm/min
Chart speed	100 mm/min
Sample thickness	3.5 mm
Sample width	2.54 cm
Span length	8.5 cm

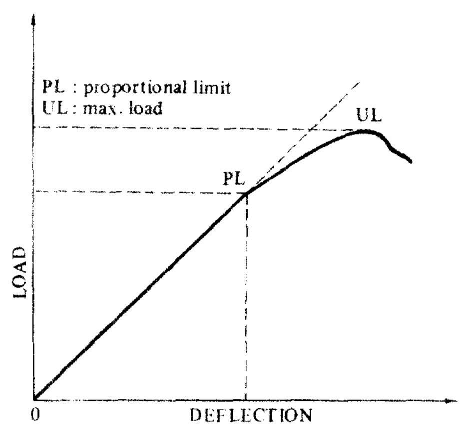

Fig. 1. Load-Deflection curve.

By the load-deflection curve(Fig. 1) from the static bending test, we calaulated four mechanical data, i.e., stress at proportional limit(S_{pl}), modulus of elasticity(MOE), modulus of rupture(MOR) and work per unit volume to proportional limit(W_{pl}).

The calculation formulae are as follows.

$S = 3P_{pl}L/2bh$

$MOE = P_{pl}L/4D_{pl}bh$

$MOR = 3P_u L/2bh$

$W = P_{pl}D_{pl}/2V$

wh, D_{pl}: deformation at proportional limit

P_{pl}: load at proportional limit

P_u : maximum load

V : volume

Results and discussion

As the soaking time increased for 3 to 12 hours, fire-retardant solution absorption and chemical retention in treated plywoods also increased gra-

Table 4. Mean and L.S.D. value from split plot design analysis of treated plywoods in flexure

Chemical, A	Soaking time, B	S_{pl} (Kg/cm^2)	MOE (Kg/cm^2)	MOR (Kg/cm^2)	W_{pl} (Kg-cm/cm^3)
Ammonium sulfate	3	148.25	1674.98	271.55	0.0371
	6	160.56	16651.62	278.04	0.0402
	9	173.61	16196.07	280.70	0.0482
	12	193.26	19472.45	310.65	0.0500
	Mean	**168.92**	**17198.78**	**285.23**	**0.0438**
Ammonium phosphate, mono basic	3	163.89	15533.92	288.62	0.0451
	6	186.37	18262.98	320.20	0.0501
	9	188.89	17878.77	328.59	0.0508
	12	170.32	16527.92	284.60	0.0520
	Mean	**177.40**	**17050.89**	**305.50**	**0.0497**
Ammonium phosphate, di basic	3	177.75	18913.82	286.11	0.0487
	6	189.24	17803.79	317.81	0.0500
	9	185.86	17871.35	302.26	0.0518
	12	188.39	18037.61	297.18	0.0588
	Mean	**185.31**	**18156.64**	**300.84**	**0.0520**
Borax-boric acid	3	195.45	17130.20	294.71	0.0658
	6	217.34	18818.85	319.15	0.0701
	9	241.17	20398.75	352.00	0.0753
	12	218.81	17626.17	292.19	0.0841
	Mean	**218.91**	**18493.50**	**314.51**	**0.0721**
Minalith	3	204.61	17236.15	290.70	0.0641
	6	199.15	16936.93	308.24	0.0651
	9	187.85	16745.10	262.89	0.0671
	12	203.79	16330.93	305.93	0.0675
	Mean	**198.85**	**16812.28**	**291.94**	**0.0662**
Water (Control)	3	152.72	14919.42	273.69	0.0391
	6	162.74	17241.57	281.78	0.0380
	9	142.08	16436.10	251.90	0.0350
	12	151.58	17684.09	283.81	0.0360
	Mean	**152.28**	**16570.29**	**272.79**	**0.0370**
Sub-plot mean	3	173.78	16701.41	284.23	0.0571
	6	185.90	17619.29	304.29	0.0584
	9	186.58	17587.70	296.39	0.0567
	12	187.71	17613.20	295.73	0.0581
F-value	A	**34.630****	**3.883***	**8.989****	**90.135****
	B	**2.398**	**.656**	**1.012**	**2.640**
	AxB	**2.907**	**1.422**	**1.980**	**3.618**
L.S.D. value (0.05, 0.01)	A_1-A_2	(11.43, 15.47)	(1138.21, 1439.90)	(14.56, 19.70)	(.004, .006)
	B_1-B_2	(8.37, 11.10)	(1112.86, 1475.99)	(16.25, 21.55)	(.003, .005)
	A_1B_1-A_1B_2	(20.49, 27.18)	(2725.95, 3615.41)	(39.80, 52.78)	(.008, .011)
	A_1B_2-A_2B_1	(21.11, 28.16)	(2620.56, 3488.43)	(37.41, 49.76)	(.009, .011)

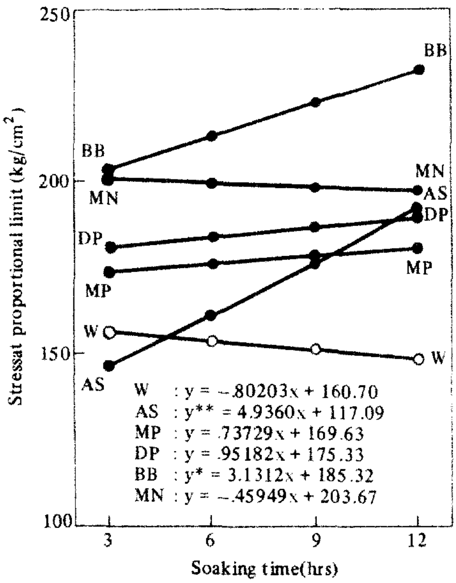

Fig. 2. Regression curves for the effect of soaking time on the stress at proportional limit (S_{pl}) of treated plywood in flexure among 5 soaking chemicals.

dually and every fire-retardant chemicals except Borax-Boric acid caused the soaked plywoods to swell up to some extent by the action of NH_4 group. The soaking treated plywoods were redried to reach the target point in 10 minutes or so at 120°C.

The results of the static bending test on the fire-retardant treated plywood samples are shown with discussion as follows.

Stress at proportional limit(S_{pl})

Table 4. and fig. 2. show the stress at proportional limit of the treated plywoods soaked in 5-chemicals and water. As seen in table 4., there was very significant difference among fire-retardant chemicals and their effects were compared graphically against one another. Borax-Boric acid treated plywoods were most excellent in S_{pl} and their values increased significantly with the extension of soaking time. Water treated plywoods were lower than any other chemical treatment and their S_{pl} values decreased slightly with the increase of soaking time. But fire-retardant treated plywoods were far from decreasing and in case of Ammonium sulfate treatment S_{pl} value increased steeply, instead.

Modulus of elasticity(MOE)

The MOE of fire-retardant treated plywoods also showed statistic significance among the chemicals but the changing aspect was somewhat different from the case of S_{pl} with the lapse of soaking time as seen in fig. 3.

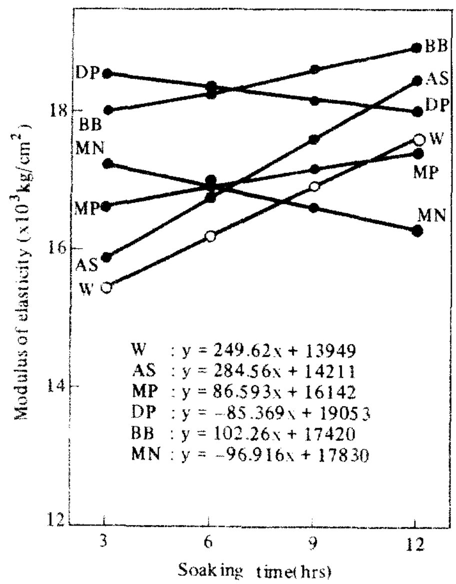

Fig. 3. Regression curves for the effect of soaking time on the modulus of elasticity (MOE) of treated plywoods in flexure among 5 soaking chemicals.

The tendency of variation in MOE was not constant among 5 fire-retardant chemicals, in other words, the values of chemicals in MOE were incoherent with the extension of soaking time, but there were no statistic significance within all treatments. The values of fire-retardant chemical treated plywoods were superior to those of water treatment except Minalith treated plywoods and Borax-Boric acid also showed the highest MOE value in the same manner in case of S_{pl}.

Modulus of rupture(MOR)

There was highly significant difference in MOR values among fire-retardant chemicals, too. And their MOR values hardly changed with the soaking time except Ammonium sulfate treatment which showed abrupt increase with statistical significance. As expected, the MOR value of Borax-Boric acid treated plywoods was the highest and water treatment showed the lowest MOR value. No particular change in the order in MOR values among chemicals was observed comparing with S_{pl} values.

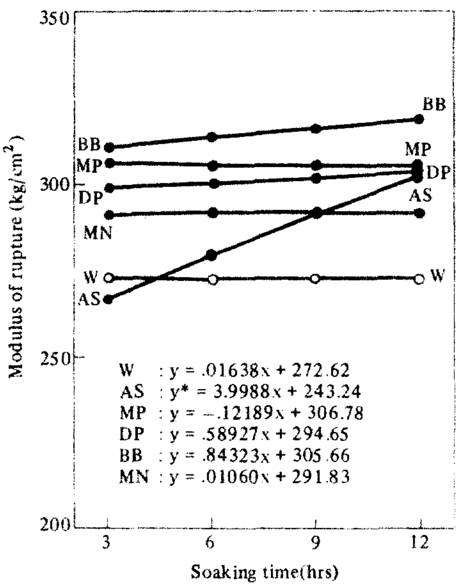

Fig. 4. Regression curves for the effect of soaking time on the modulus of rupture (MOR) of treated plywoods in flexure among 5 soaking chemicals.

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

W_{pl} values also differed from one another with high significance among fire-retardant chemicals. And all the chemical treated plywoods excelled water treated plywoods in W_{pl} value and increased with the increase of soaking time. Especially Borax-Boric acid and Ammonium sulfate treatment showed highly significant increase, on the other hand, water treated plywoods decreased and remained in the lower position compared with any chemical treatment. Borax-Boric acid treated plywoods also had the superlative value in work per unit volume to proportional limit.

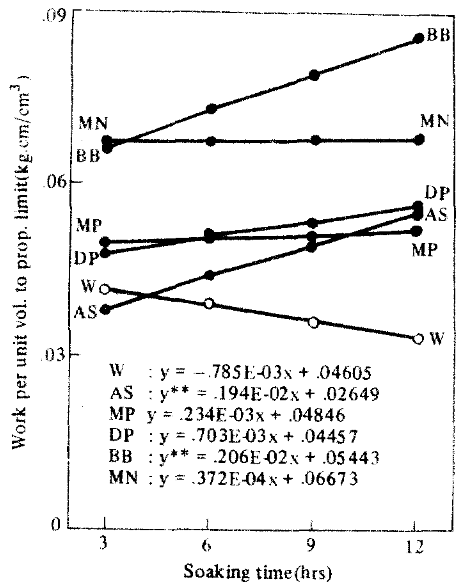

Fig. 5. Regression curves for the effect of soaking time on the work per unit volume to proportional limit (W_{pl}) of treated plywoods in flexure among 5 soaking chemicals.

Conclusions

The ordinary soaking treatment and hot press drying process have been the widespread and practical method for manufacturing fire-retardant treated plywood. This study was carried out to compare the effect of the type of five-retardant chemicals and retention in treated plywoods on their own static bending strength which had been manufactured by the above-stated method. From the basis of results and discussion, we got the following conclusions.

The values of chemical treated plywoods were generally higher than those of water treated plywoods and Borax-Boric acid treated plywoods showed the highest values in four mechanical data, that is, S_{pl}, MOE, MOR and W_{pl}. And the bending strength of treated plywoods increased with the extension of soaking time or the increase of chemical retention in themselves.

Borax-Boric acid was thought as the desirable fire-retardant chemical for thin plywood in view of mechanical strength and soaking defects in this study.

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