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Effects of the Treated Chemicals on the Flexual and Physical Properties of Fire Retardant Treated Particleboards [*1]

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耐火處理 파티클 보오드의 휨強度와 物理的 性質에 미치는 藥劑의 影響[*1]

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要　　約

本 硏究는 耐火処理 파티클보드의 휨強度와 物理的 性質을 調査検討함으로서 耐火処理 파티클보드의 製造可能性을 究明하고져 実施하였다.

本 硏究에서는 木材파티클을 5, 10, 15, 그리고 20%濃度의 황산암모늄과 미나리스(Minalith)溶液에 沈漬시킨후 乾燥시켜서 製造하였다. 製造된 파티클보드의 휨強度와 物理的 性質을 調査한 結果에 따르면 휨強度에서 破壞係數와 弾性係數는 韓國工業標準規格 KS F 3104의 type 100水準(100kgf/cm², 1.5 × 10⁴kgf/cm²)을 만족 시켰으나 두께膨脹率은 모두 이 規格水準(12%)에 이르지 못하였다.

또한 剝離抵抗은 미나리스의 15와 20%濃度의 경우를 除外하고는 모두 韓國工業標準規格 KS F 3104의 type 100 水準(1.5kgf/cm²)을 凌駕하였다.

Summary

This research was performed to investigate the manufacturing possibility of the particleboard treated with commercial fire retardant chemicals. Laboratory test boards at this investigation were made from particles treated by soaking into 5, 10, 15, and 20 percent concentration solutions of ammonium sulfate and Minalith before resin was applied. According to the results, MOR (modulus of repture) and MOE (modulus of elasticity) in flexure exceeded type 100 (100 kgf/cm^2, 1.5 × 10^4 kgf/cm^2) of the Korean Industrial Standard (KS F 3104). Except for 15 and 20 percent chemicals concentrations of Minalith, every internal bond stress values met type 100 (1.5 kgf/cm^2) of KS F 3104. However thickness swelling values of fire retardant treated particleboards were not reached in the Standard (12%).

1. Introduction

Wood based materials, plywood and laminated board, have been largely used for panels. Especially plywood requires large diameter logs to manufacture. Decrease in such large diameter log production increases making flake, wafer, saw kerf and particleboards which can be produced with unprocessed forest products, industrial wood residues

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and wood chips. Wood based structural particleboards have been limited in some applications for building constructions because of their flammability. A trend by fire protection is recently toward the use of fire retardant particleboards. This can seriously affect the market for particleboard products because many are used as decorative and structural materials in house and other buildings.

There are essentially two methods in producing fire retardant particleboard – pressure impregnation into the board or pretreatment of the particles before the board is formed. Pressure impregnation of the board has several economic disadvantages because these disadvantages outweigh its advantages. At present two methods of particle treatment before the board is formed may be considered by wood scientists – addition of the chemicals in the resin spray or particle treatment prior to resin application. The latter appears to be more desirable than the former because mixing of the fire retardant chemicals within the resin spray permits them to act as catalyst for the resins themselves.

From the above conception, the latter method was selected at this investigation and carried out to know the effect of treated chemicals on the flexural and physical properties of fire retardant treated particleboard.

2. Literature Reviews

The earliest reference to fire retardants for wood reported in Chemical Abstracts occurs in Vol. 1 (1905), refered to a mixture of ammonium phosphate and boric acid. Considerable researches on fire retardant treatments for wood and wood based materials have been conducted in the United States, Canada, Europe and elsewhere since 1905. But there has been a little investigation on fire retardant treatments for particleboards even the developed countries.

Fire retardant flakeboard from treated flakes by Arsenault (1964) was investigated. His tests showed that a promising fire resistant flakeboard can be made by treating aspen flakes with a chemical solution before the binder resins are applied. Syska (1969) reported that in fire retardant treatments for particleboard the most critical problem pointed out by him was the adverse effect of the treatment chemicals on the resin binders, which resulted in severely lowering board strengths. He concluded that the resins were being catalyzed by the fire retardant chemicals and were setting before the press was closed. However Shen and Fung (1972) reported a simple and effective method for making fire retardant particleboard. This process involves the hot-pressing of fire retardant chemicals into the particleboard through surface impregnation with suitable temperature, pressure, and pressing time. The surface flammability of the particleboard was substantially reduced by this method with relatively less fire retardance than that required by the conventional treatment.

Fire retardant treatments for dry formed hardboards were reported by Myers and Holmes (1975). This investigation of 21 chemical treatments has shown that the fire performance of dry formed hardboard could be improved. Two promising fire retardant treatment formulations, disodium octaborate tetrahydrateboric acid and dicyandiamide-phosphoric acid formaldehyde were selected for commercial trials. A commercial application of fire retardants to dry formed hardboards by Myers and Holmes (1977) was investigated. In this study the boards treated with disodium octaborate tetrahydrate-boric acid had low smoke development and high strength and linear stability. Because of the board's low leach resistance, the treatments are not necessarily suited for exposure to high moisture. The boards treated with sodium octaborate tetrahydrate-boric acid and dicyandiamide phosphoric acid formaldehyde met the acceptance flamespread criteria for Class B with flamespread values under 75.

By the above studies the effects of chemicals on flexural and physical properties of fire retardant treated particleboard were not clearly reported until present. Accordingly we are going to disclose these unclear chemicals effects of flexural and physical properties on fire retardant treated particleboard.

3. Materials and Procedure

3.1. Materials

3.1.1. Wood chip

Wood chip made of meranti log residues at Daesung Lumber Industrial Company in Incheon, Korea, were prepared. They were coarse chips passed through a 4 mm screen and retained on a 2.5 mm screen.

3.1.2. Selection of fire retardants

- o Ammonium sulfate $(NH_4)_2SO_4$
- o Minalith
  - diammonium orthophosphate $(NH_4)_2HPO_4$ .... 10 percent
  - ammonium sulfate $(NH_4)_2SO_4$ .... 60 "
  - sodium borate (anhydrous) $Na_2B_4O_7$ .... 10 "
  - boric acid H_3BO_3 .... 20 "

Minalith was formulated according to the Standards of the American Wood Preservers' Association (1976) and U. S. Forest Products Laboratory (1974).

3.2. Procedure

3.2.1. Fire retardant treatments

After drying to approximately 6 percent moisture content, the particles were treated by soaking in aquous solutions with the chemical concentration of 5, 10, 15, and 20 percent solids respectively during 2 hrs. The particles were then redried to approximately 8 percent moisture content again.

3.2.2. Board manufacture

A total of 17 particleboards was made – 6 boards (2 chemicals X 3 replications) for each of the 4 treatment systems and 3 control boards. For comparison purpose, 3 parallel laminated products and 3 cross laminated products were made in the same thickness as the particleboards. Particleboard manufacturing conditions were:

Board size: 0.8 cm by 15 cm by 20 cm

Binder: 10 percent Urea formaldehyde liquid resin (based on oven dry weight of particles)

Additive: 1 percent wax emulsion (based on oven dry weight of particles)

Mat moisture content: 19 percent

Press temperature: 150°C

Press time: 7 mins.

Closing time: 1 min.

Pressing schedule: 40 kg/cm^2 for 3 mins., 35 kg/cm^2 for 2 mins. and 25 kg/cm^2 for 2 mins.

3.2.3. Testing the particleboards

After conditioning at 13°C and 48 percent relative humidity for about 10 days, the boards manufactured were cut into the specimens for modulus of rupture (MOR) and modulus of elasticity (MOE) in flexure, internal bond stress, thickness swelling, moisture content and density. The testing procedures were performed according to KS F 3104.

3.2.4. Statistical analysis

An analysis of variance was made to determine the effects of chemicals treatments on MOR and MOE in flexure, thickness swelling, internal bond stress, moisture content and density. The experiment was designed with a 2 by 3 by 4 factorial with split plot design. Regressions between chemicals concentration and flexual and physical properties were also analyzed.

4. Results and Discussion

Fire retardant treatment of wood is performed by soaking or impregnating with various water soluble chemical solutions. According to Koch (1972) and U. S. Forest Products Laboratory (1974), the minimum retentions of fire retardant chemicals must be fairly high to be effective, ranging from 2.5 to 5.0 pounds of dry chemicals per cubic foot of wood near the surface. Figure 1 shows the results of retentions of fire retardant chemicals according to solution concentration of 5, 10, 15, and 20 percent chemicals by weight. Except for 5 percent solution concentration, mean retentions of fire retardant chemicals are within or above the range of 2.5 to 5.0 lb/ft^3 [1.134 to 2.268 kg/(30 cm)^3] on dry chemicals basis.

The flexural and physical properties of the particleboards with these chemical retentions are as

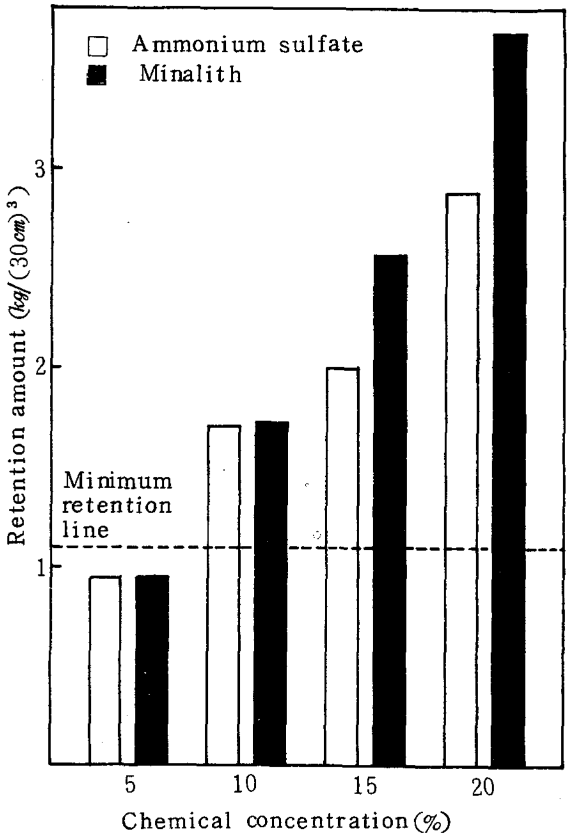

Figure 1. Retentions of fire retardant chemicals according to solution concentration.

follows.

4.1. Modulus of rupture in flexure

Table 1 shows the results of the ANOV (analysis of variance) for MOR in flexure of all specimens tested. The results of L. S. D. test are shown in Table 2. Difference at 5% level was found between chemicals of ammonium sulfate and Minalith. The values of MOR in flexure of the particleboards treated with ammonium sulfate were greater than those of Minalith. Considerable differences at 1% level were found between non-treatment (control) and treatments of both chemicals according to solution concentrations. Modulus of rupture in flexure of ammonium sulfate treated boards was reduced about 36 percent compared with the control boards, that of Minalith treated boards about 46 percent, and mean MOR in flexure of both chemicals reached in about 41 percent. Accordingly it was known that MOR of fire retardant particleboard showed greater reduction percentage than that of fire retardant plywood and solid wood by the past studies of King and Matteson (1961), Jessome (1962), and Gerhards (1970). This result agrees with the studies by Arsenault (1964) and Syska (1969). But every average values of MOR in treated boards met the Standard (type 100) of KS F 3104. The two curved lines are drawn

Table 1. F ratios of each properties computed by split plot design

Properties / S. V.	MOR	MOE	Internal bond stress	Thickness swelling	MC	Density
A	59.059*	2.209	50.967*	214.880**	34.476**	13.729
B	17.947**	6.719**	48.990**	122.922**	6.515**	2.188

A : main plot → chemicals B : sub plot → treatment systems

* : significance at 5 % level ** : significance at 1 % level.

in Figure 2 from the data of MOR and chemicals concentrations. In the trend of MOR plotted by regression in both chemicals treated boards, ammonium sulfate decreases to 10 percent chemicals concentrations but after 15 percent increases with the increase of concentration, and Minalith decreases to 15 percent but after that increases with the rise of concentration. Significance of these regressions were shown at 5 percent level in ammonium sulfate and at 1 percent level in Minalith. The modulus of ruptures of parallel veneer laminated and cross veneer laminated boards were considerably above that of the treated particleboards.

4.2. Modulus of elasticity in flexure

The results of the ANOV for modulus of elasticity in flexure of all specimens tested are shown in

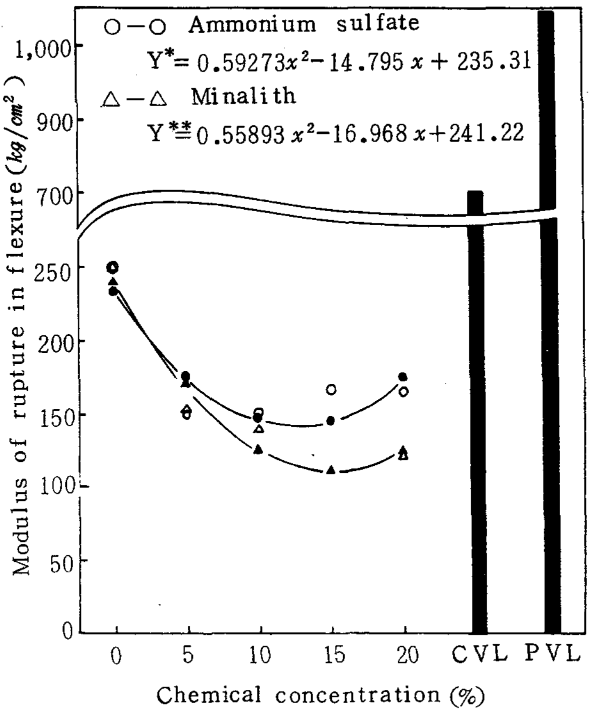

Figure 2. Relationship between modulus of rupture in flexure and chemicals concentration.

* CVL : Cross veneer laminated board
PVL : Parallel veneer leminated board.

Table 1. Table 2 shows the results of L. S. D. test. No statistical difference was found between the chemicals of ammonium sulfate and Minalith, but at 1 percent level were found between non-treatment (control) and treated particleboards of both chemicals according to solution concentrations. Modulus of elasticity in flexure of ammonium sulfate treated boards was reduced 25.6 percent for the control boards, that of Minalith treated boards 23.9 percent, and average MOE in flexure of both chemicals 24.7 percent. Accordingly it was known that MOE of fire retardant particleboard showed greater reduction percentage than that of fire retardant plywood and solid wood by the studies of King and Matteson (1961), Jessome (1962), and Gerhards (1970), and that of fire retardant particleboard by the past studies of Arsenault (1964) and Syska (1969). However all values of MOE in flexure of non-treatment and treated board satisfied the Standard (type 100) of KS F 3104. The two curved lines are drawn in Figure 3 from the data of MOE and chemicals concentrations. In the trend of MOE plotted by regression in both chemicals treated boards, ammonium sulfate decreases to 10 percent chemicals concentrations, but after that

Table 2. Difference between average values of the properties

1) Modulus of rupture in flexure of treated particleboard (kg/cm^2).

Concentration / Chemicals	A	B	C	D	E	Mean
C1	247.63	150.14	150.76	167.25	165.56	176.27
C2	247.63	153.44	139.75	112.96	123.14	155.38
Mean	247.63	151.79	145.26	140.11	144.35	165.83

LSD [(C1)−(C2)] = 11.692　　LSD [(A)−(B)] = 37.525

LSD [(C1A)−(C1B)] = 53.068　　LSD [(C1A)−(C2B)] = 48.528

A : 0%　B : 5%　C : 10%　D : 15%　E : 20% (solution concentration)

C1 : Ammonium sulfate　　C2 : Minalith

* Each value is an average of 3 specimens.

increases to 20 percent chemicals concentration, and Minalith decreases to 10 percent but after 15 percent increases with the rise of concentration. The regression of ammonium sulfate and Minalith showed significance at 5 percent level. The MOE of the particleboards was considerably below that of parallel veneer and cross veneer laminated boards made for comparison.

4.3. Internal bond stress

Table 1 shows the results of the ANOV for internal

2) Modulus of elasticity in flexure of treated particleboard (10^4 kg/cm^2)

Concentration / Chemicals	A	B	C	D	E	Mean
C1	2.83	1.82	1.92	2.20	2.48	2.25
C2	2.83	2.41	2.03	1.77	2.40	2.29
Mean	2.83	2.12	1.98	1.99	2.44	2.27

LSD [(C2)–(C1)] = 0.111 LSD [(A)–(B)] = 0.485
LSD [(C1A)–(1B)] = 0.686 LSD [(C1A)–(C2B)] = 0.621.

3) Internal bond stress of treated particleboard (kg/cm^2).

Concentration / Chemicals	A	B	C	D	E	Mean
C1	3.22	1.94	1.94	1.67	1.69	2.09
C2	3.22	1.90	1.54	1.44	1.32	1.88
Mean	3.22	1.92	1.74	1.56	1.50	1.99

LSD [(C1)–(C2)] = 0.126 LSD [(A)–(B)] = 0.349
LSD [(C1A)–(C1B)] = 0.494 LSD [(C1A)–(C2B)] = 0.455.

4) Thickness swelling of treated particleboard (%).

Concentration / Chemicals	A	B	C	D	E	Mean
C1	9.94	25.89	28.52	38.09	38.61	28.21
C2	9.94	39.30	45.80	48.46	65.29	41.76
Mean	9.94	32.59	37.16	43.27	51.95	34.99

LSD [(C2)–(C1)] = 3.977 LSD [(B)–(A)] = 4.923
LSD [(C1B)–(C1A)] = 6.962 LSD [(C1B)]–(C2A)] = 7.133.

5) Moisture content of treated particleboard (%)

Concentration / Chemicals	A	B	C	D	E	Mean
C1	6.53	6.00	6.06	6.00	5.90	6.10
C2	6.53	6.11	6.79	6.82	6.78	6.60
Mean	6.53	6.05	6.43	6.41	6.34	6.30

LSD [(C2)–(C1)] = 0.373 LSD [(A)–(B)] = 0.244
LSD [(C1A)–((C1B)] = 0.346 LSD [(C1A)–(C2B)] = 0.456.

6) Density of treated particleboard (g/cm³)

Chemicals \ Concentration	A	B	C	D	E	Mean
C1	0.82	0.83	0.84	0.88	0.90	0.85
C2	0.82	0.82	0.79	0.79	0.85	0.81
Mean	0.82	0.82	0.82	0.84	0.87	0.83

LSD [(C1)−(C2)] = 0.046 LSD [(B)−(A)] = 0.052
LSD [(C1B)−(C1A)] = 0.074 LSD [(C1B)−(C2A)] = 0.078

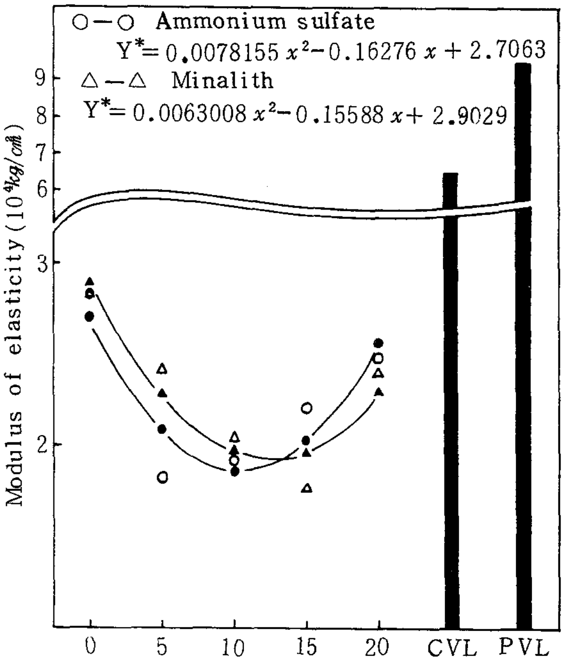

Figure 3. Relationship between modulus of elasticity in flexure and chemicals concentration.

bond stresses of all specimens tested. Average internal bond stress values for various treatments were shown in Table 2 and compared in Figure 4. Difference at 5 percent level was found between chemicals of ammonium sulfate and Minalith, and also differences at 1 percent level were found between non-treatment (control) and treated particleboards of both chemicals according to chemicals concentrations. Internal bond stress of ammonium sulfate treated boards was reduced 43.78 percent compared with the control boards, that of Minalith treated boards 51.86 percent, and average internal bond stress of both chemicals 47.82 percent. Therefore it was known that the internal bond stresses of ammonium sulfate and Minalith treated boards were considerably below that of the control board. A minimum acceptable value for the Korean Standard (type 100) of KS F 3104 is 1.5 kg/cm². Except for 15 and 20 percent chemicals concentrations of Minalith, every internal bond stress values were satisfactory for this Standards. Similar results were reached in the study by Arsenault (1964). The two curved lines of regressions are drawn in Figure 4 from the data of internal bond stresses and chemicals concentrations. The two regressions of ammonium sulfate and Minalith treated boards showed significance at 1 percent level. The internal bond stresses of two kinds of veneer laminated boards showed similar average values compared to the treated particleboards adversely with the results of MOR and MOE in flexure.

4.4. Thickness swelling

The results of the ANOV for thickness swelling of every specimens tested are shown in Table 1. Average thickness swelling values for various treatments are shown in Table 2, and these results were compared in Figure 5. Difference at 1 percent level found between chemicals and treatment systems. Each regression of ammonium sulfate and Minalith treated boards was drawn in Figure 5 from the data of thickness swelling and chemicals concentrations. They showed significance at 1 percent level. A minimum acceptable value for the Standard (type 100) of KS F 3104 is below 12 percent. Except for the control boards, all thickness swelling values

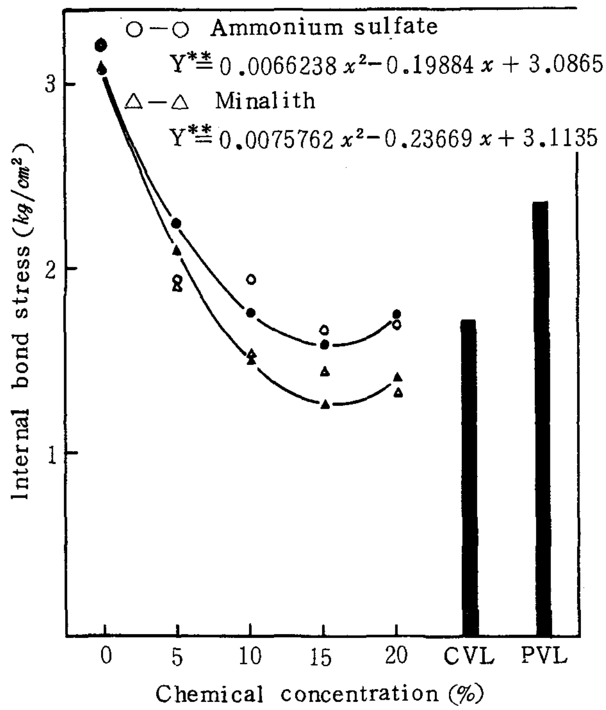

Figure 4. Relationship internal bond stress and chemicals concentration.

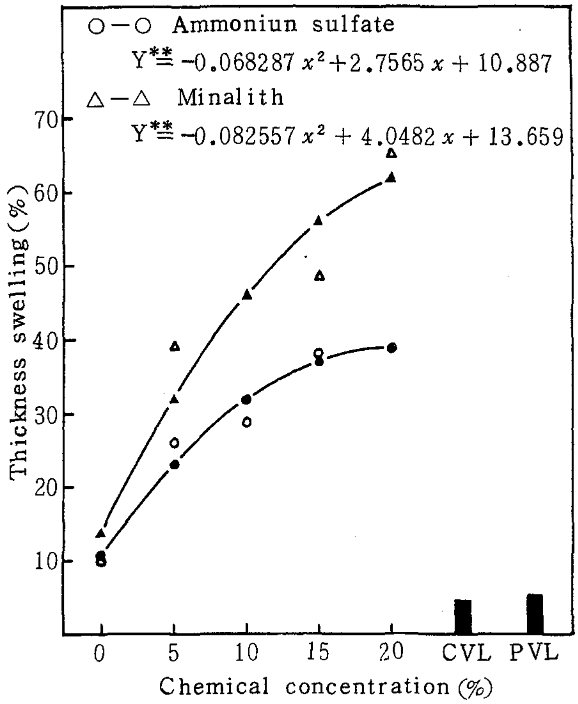

Figure 5. Relationship between thickness swelling and chemicals concentration.

were not reached in the Standard. Based on the results from this study, the authors conclude that thickness swelling properties should be improved. Especially thickness swelling values of Minalith were greater than those of ammonium sulfate. As pointed out in the past study by Arsenault (1964), this phenomenon seems that hydrophilic salts in Minalith added hygroscopicity to the particleboards, and also because both chemicals act as catalysts for the resins, and reduce the working life of the resin, an increase in solution concentrations may have resulted in considerable increase in thickness swelling values. The values of compared veneer laminated boards were below those of the control particleboards.

4.5. Moisture content and density

The results of the AOV for moisture content and density of all specimens tested are shown in Table 1. Average moisture content and density values for the various chemicals concentration of treatments are shown in Table 2 and compared in Figure 6 and 7. Moisture content showed statistical difference at 5 percent level between solution concentrations, and at 1 percent level between treatment systems. The regression of moisture content of ammonium sulfate treated boards showed negative significance at 1 percent level while that of Minalith treated boards shows no significance. This seems to be owing to the hydrophilic salts in Minalith. Density showed no significance. The regression of density of ammonium sulfate treated boards showed significance at 5 percent level while that of Minalith treated boards no significance. Although the target density of the boards was 0.8 g/cm^3, average values of all boards were 0.83 g/cm^3. But the differences were negligible. The moisture contents of veneer laminated boards were above that of the particleboards. The density of veneer laminated boards were below that of the particleboards.

5. Conclusions

This experiment was conducted to investigate the flexural and physical properties of the fire retardant particleboards. The particleboards were

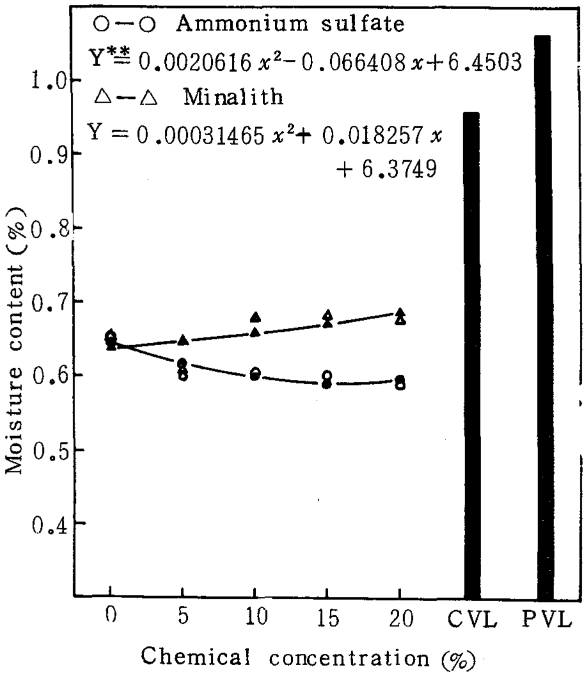

Figure 6. Relationship between moisture content and chemicals concentration.

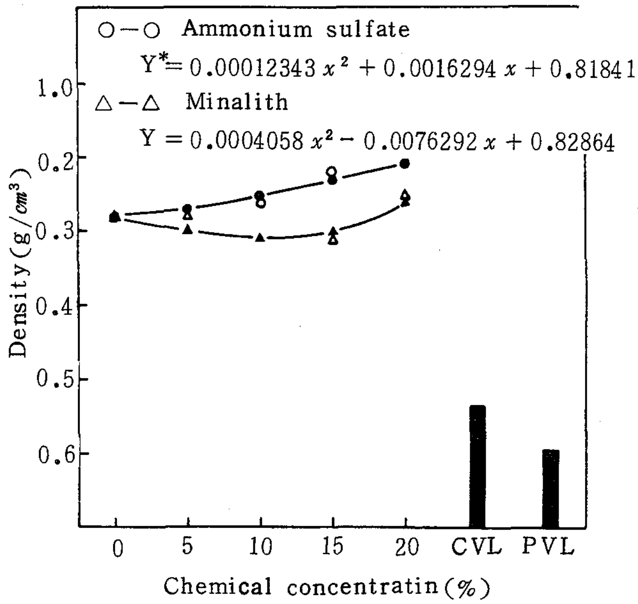

Figure 7. Relationship between density and chemicals concentration.

produced with chips which soaked in the solution concentrations of 5, 10, 15, and 20 percent ammonium sulfate and Minalith.

The findings of this study may lead to conclusions as below:

1. MOR and MOE in flexure exceeded the Standard (type 100) of KS F 3104.
2. MOR and MOE in flexure of ammonium sulfate treated boards were reduced 36 and 25.6 % for the control boards while those of Minalith treated boards 46 and 23.9 %.
3. Except for 15 and 20 percent chemical concentrations of Minalith, every internal bond stress values met the Standard (type 100) of KS F 3104.
4. Except for the control boards, all thickness swelling values were not reached in the Standard of KS F 3104.
5. The moisture content of ammonium sulfate and Minalith treated boards showed contrary results because of hydrophilic salts in Minalith.

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