Pertanika J. Trop. Agric. Sci. 21(2): 83 - 92(1998) ISSN: 1511-3701

Incorporation of a Preservative in Particleboard: Properties and Durability

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Keywords: Particleboard, Urea formaldehyde, *Hevea brasiliensis*, Boric acid, Durability, Retention, Pycnoporous sanguineus

ABSTRAK

Asid borik (0.5% dan 1.0% w/w) dicampurkan ke dalam papan serapai kayu getah (Hevea brasiliensis) samada dengan mencampur serbuk asid borik dengan perekat urea formaldehid (UF) pada peringkat awal atau dengan menyembur larutan asid borik kepada adunan serpai semasa proses pengadunan. Dua jenis perekat UF (perekat E1 dan E2 digunakan sabagai agen perekatan. Ketumpatan sasaran papan serpai adalah 650 kg/m³. Sifat papan serpai diuji mengikut piawaian JIS A 5908-1983 dan sifat ketahanan terhadap kulat reput putih diuji mengikut piawaian ASTM D2017-71. Bebanan bahan kimia di dalam papan adalah diantara 0.42-0.47% bagi rawatan dengan 0.5% asid borik dan 0.64-0.70% bagi rawatan dengan 0.1% asid borik. Kekuatan kering modulus perpecahan (MOR) dan modulus kekenyalan (MOE) bagi papan yang telah dirawat didapati menurun dengan ketara. Penurunan sifat-sifat ini bertambah apabila tahap bebanan kimia di dalam papan bertambah. Walau bagaimanapun MOR dan MOE di dalam keadaan basah, ikatan dalaman (IB) dan pembekaan ketebalan (TS) bagi papan yang dirawat dengan kedua-dua tahap kepekatan asid borik tidak menunjukan sebarang perbezaan apabila dibandingkan dengan papan yang tidak dirawat (papan kawalan). Papan serpai yang direkat menggunakan perekat jenis E2 didadapati lebih tahan kepada kulat reput putih (Pycnoporous sanguineus) daripada papan yang direkat dengan perekat jenis E1. Kehadiran asid borik di dalam papan meningkatkan ketahanan papan terhadap kulat reput putih, dan ketahanan ini meningkat apabila bebanan bahan kimia di dalam papan meningkat.

ABSTRACT

0.5% and 1.0% (w/w) of boric acid (H_3BO_3) were incorporated in rubberwood (Hevea brasiliensis) particleboards either by initially mixing the boric acid powder with urea formaldehyde adhesive or spraying boric acid solution onto the furnish during blending. Two types of urea formaldehyde, i.e. E1-glue (maximum permissible formaldehyde emmision < 0.1 ppm) and E2-glue (maximum permissible formaldehyde emmision 0.1-1.0 ppm) were used as the bonding agent. The targeted density of the boards was 650 kg/m³. The board properties and durability against white rot fungus were evaluated in accordance with JIS A 5908-1983 and ASTM D2017-71, respectively. The chemical loading in the board was in the range of 0.42-0.47% and 0.64-0.70%, respectively when 0.5% and 1.0% of boric acid (based on the dry-weight of the particles) were incorporated in the boards. The dry modulus of rupture (MOR), dry modulus of elasticity (MOE) of the boric acid-treated boards were significantly reduced. The reduction of the properties increased as the chemical loading in the treated boards *increases. However, wet MOR and wet MOE, internal bonds (IB) and thickness swelling (TS) of treated boards at both concentration levels did not differ significantly compared to the untreated boards. Particleboards bonded with E2-glue were more resistant to white rot fungus (Pycnoporous sanguineus) than those bonded with E1-glue. The presence of boric acid significantly increased the durability of board against white rot fungus, and the resistance towards the fungus increased as the boric acid loading increases.*

INTRODUCTION

Particleboard is generally considered less susceptible to biodeterioration than solid wood (Behr 1972 and Stolley 1958), if it is used in situations where exposure to moisture is likely, biodeterioration can occur, especially for untreated board manufactured from non-durable wood species. Currently all particleboard mills in Malaysia are utilising non-durable wood species such as rubberwood (*Hevea brasiliensis*) and mixed light hardwoods (MLHW).

Improving the durability of the board by preservative treatment is one way of extending its end uses. The addition of such chemicals is necessary to increase the little inherent resistant to decay and insect attack possessed by this type of wood.

Boron compounds were chosen because they provide both the fungicidal and insecticidal properties and could be a suitable preservative for particleboard. Apart from being competitive in cost, boron compounds have low mammalian toxicity, are soluble in water, have an ability to retain the clear and light coloured finish of the treated materials and environmental friendly (Hong *et al.* 1982; Cockroft and Levy, 1973).

Many factors need to be considered for the incorporation of these compounds in the manufacture of wood composite while maintaining the standard mechanical and physical properties requirement. Gillespie (1980) stated that factors like wood species, moisture content, pressing conditions, and preservative or fire retardant treatment critically affect these properties.

This paper reports the properties and durability of boron-treated particleboard.

MATERIAL AND METHODS

Rubberwood (*Hevea brasilliensis*) chips and urea formaldehyde (UF) glue were obtained from local fibreboard mill in Negeri Sembilan and adhesive company in Selangor, respectively. Two types of urea formaldehyde resin, E1-glue, with maximum permissible formaldehyde emission < 0.1 ppm and E2-glue, maximum permissible emission 0.1 to 1.0 ppm were used as bonding agent. Orthoboric acid (H_3BO_3, ANALAR GRADE) was used as a preservative in the treatment.

Preparation of wood particles

Rubberwood chips were flaked into required dimension and then screened into size ranging from 0.5 mm to 1.0 mm. The particles collected from the screen were divided into two groups. The first group was dried to 5% moisture content (MC) and the second group was dried to 3% MC using an electric humidity chamber.

Determination of Gelation Time

Gelation time is a period of time required for the glue to form a gel at a specific temperature. In this study gelation time for the adhesive which was mixed with preservative was determined. Twenty g of UF (65.6% solids) was mixed with ammonium chloride (NH4CI, 1.5% w/w of resin solids) and boric acid (H_3BO_3, 0.5% and 1.0%, w/w of resin solids) in a beaker. The beaker and its content were submerged in boiling water and stirred until the adhesive hardened and gelled. The time that the adhesive mix took to gel was then recorded.

The gelation time recorded for the UF adhesive *per se* was about 290 s. A shorter gelation time was recorded in the mixture of UF adhesive and boric acid, i.e. 265 and 270 s, repectively for UF resin formulated with 0.5% and 1.0% boric acid. These data could be used to calculate the optimum hot press time during board manufacture.

Preparation of Particleboard

A single layer particleboard 340 mm 3 340 mm x 10 mm with targeted density of 650 kg/m^3 and final MC of ca. 10% were made. UF adhesive with two resin types (E1 and E2) each at 11% (based on oven dried weight of the particles) concentration was used as the bonding agent. E2 boards were manufactured only for board durability test. Pre-weighed rubberwood particles from each batch were blended separately. Boric acid was added to the particles by two methods. Method A: by mixing the chemical powder (0.5% and 1.0% w/w of the Oven dry (od) weight of particles) with the adhesive. The boric acid + adhesive mixture was sprayed onto the particles which had been dried to 5% MC using a pressured spray gun. Method B: spraying the furnish which had been prepared from drier particles (3% MC) with boric acid solution at both 0.5% and 1.0% dosages.

The mat forming process was carried out manually using a wooden former (340 mm x 340 mm). The particles were distributed on a stainless steel caul plate covered with a piece of teflon-fiber sheet. The furnish was spreaded uniformly within the former. Once the mat had been formed, another sheet of teflon fiber was placed on the top of the mat. The teflon-fiber sheets were used to prevent the mat from sticking the platens and to gent smooth board surface. The mat was then pressed manually and subsequently followed by hot pressed maintained at 125°C for 270 s. The stepwise pressure was applied at: step 1, 50 kg/m^3 for 150 s, step, 2, 30 kg/m^3 for 90 s and step 3, 25 kg/m^3 for 30 s. The boards were then conditioned in a conditioning room (65± 5% RH and 20±2°C) for one week before they were cut into testing specimens. The number of particleboards and treatment combination made for this study are summarised in Table 1.

Retention of boric acid in the treated particleboard

The retention of boric acid in the treated particleboard was analysed chemically using standard titration method (Anonymous 1986). Five specimens of 10 mm x 10 mm were obtained from each treated board, and were ground into sawdust and passed through number 16-mesh sieve (maximum 1 mm in size). The particles were then analysed separately following the procedure outlined in the standard (Anonymous. 1986).

Physical and Mechanical Properties of the Particleboard

The boards were trimmed at the edges and cut into the required test dimensions as shown in *Fig 1.* There was a total of 60 specimens each for static bending (dry test), static bending (wet test) tests and 30 specimens for each internal bond (IB), thickness swelling (TS), water absorption (WA) tests. All the tests were carried out using Zwick 1400 Universal Testing Machine in accordance with Japanese Industrial Standard (JIS-A-5908-1983) (Anonymous. 1983) .

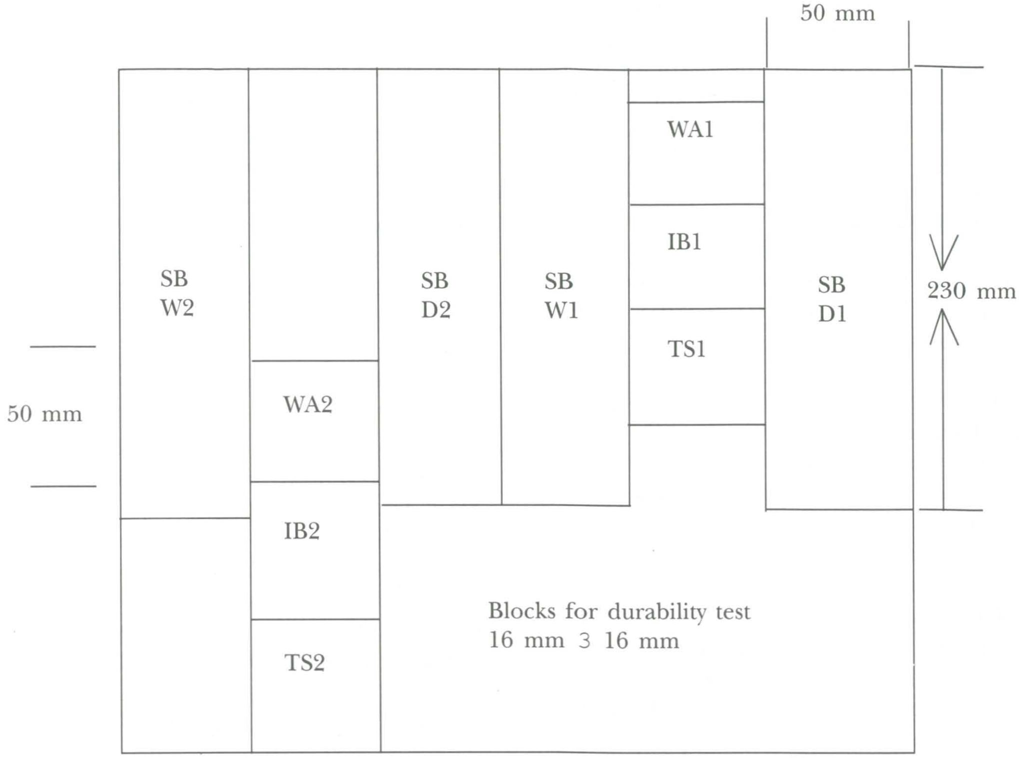
Durability of the Particleboard against Fungus

The test on durability of the treated particleboards against white rot fungus (*Pycnoporous sanguineus*) was carried out in the laboratory using the method specified in the American Standard of Testing Material (ASTM D2017-71) (Anonymous. 1972). The efficacy of the treatment was evaluated based on the percent weight loss caused by

TABLE 1
Number of particleboards and trestment combinations used in the study

Adhesive	Amount of H_3BO_3, (%, w/w)	Application of preservative		
		No. Preservative	Mix with adhesive	Boric acid solution
E1-glue	0	3		
E2-glue	0	3		
E1-glue	0.5		3	3
E1-glue	1.0		3	3
E2-glue	0.5		3	
Total		6	9	6

E 1-glue, maximum permissible emission not more than 0.1 ppm
E 2-glue, maximum permissible emission between 0.1 to 1.0 ppm



SBW = Wet static bending sample
SBD = Dry static bending sample
WA = Water absorption sample
IB = Internal bond sample
TS = Thickness swelling sample

Fig. 1 Cutting patterns of the testing specimens from each board

the degradation of the boards by the fungus. Thirty test blocks, 16 mm x 16 mm were cut from each treated and untreated boards. The blocks were conditioned in a conditioning room until they reached constant weights. Their weights were measured and the blocks were then placed in culture bottles containing white rot mycellium. The bottles together with their contents were then left in an incubating room maintained at 25±20°C and 65-75% relative humidity. At the end of the test period (after the 12th week), the test blocks were removed from the bottles, and the mycellium adhered on the surface of the blocks were brushed off. They were again left in the conditioning room until their weights were constant. The percentage weight loss from the conditioned weight before and after exposure was calculated using the following Equation:

$$\text{Weight loss (\%)} = \{(W_1 - W_2) / W_1\} \; 3 \; 100 \quad (1)$$

Where,

W_1 = Conditioned weight before exposure to fungus

W_2 = Conditioned weight after exposure to fungus

The results obtained were classified into four classes of degradation resistance: 0-10% weight loss is classified into Class A (highly resistance); 11-24% weight loss, Class B (resistance); 25-44% weight loss, Class C (moderately resistance) and above 45% weight loss, Class D (slightly/non resistance) (Anonymous. 1972).

Statistical analysis

All data were statistically analysed using one way analysis and the mean value of each property was separated using Duncan's Multiple Range Test (DMRT) to determine the differences between treatment levels.

RESULTS AND DISCUSSION

Retention of Boric Acid in the Treated Particleboards

The mean retention of boric acid in the boards was determined using standard titration method as described in Table 2. The final chemical loading for boards which were originally incorporated with 0.5% (w/w) boric acid was between 0.46-0.47% (w/w) and 0.42-0.43% (w/w) when employing method A and method B, respectively. However, a markedly lower retention was found in the boards which were originally treated with 1% (w/w) boric acid. For method A, only 0.70% (w/w) boric acid was retained in the boards while for method B, 0.64% (w/w). The lower retention values found in the treated board had been anticipated because the value was analysed based on the od weight of the board while the concentration of boric acid was prepared based on the od weight of particles.

However, it is also interesting to note that a lower retention value was recorded for treated particleboards using boric acid in the form of solution (Method B) compared to those in the form of a mixture of adhesive. The possible explanation for this is the occurrence of steam volatisation of some of the boric acid during hot pressing. It has been found that boric acid, in solution form, to some extent is volatile when dehydrated at a very high temperature, (Zaidon *et al.*1998), hence less amount of boric acid is being retained in the board. Whilst, in the other treatment most of the boric acid may have reacted with the urea formaldehyde during the mixing time and lesser amount was lost by this way as reflected by the higher retention value.

Physical and Mechanical Properties of the Particleboard

The average density, MC and the MOR and MOE for treated and untreated control particleboards are summarised in Table 3. The average density of the particleboard varied from about 581 kg/m^3 to 621 kg/m^3, i.e. markedly lower than the targeted density of 650 kg/m^3. Quite similar values (ca. 9.5%) were recorded for the final MC of the boards. The values in parentheses represent the change in properties compared to the untreated (control) boards.

The following discussion assumes that all the treated specimens have a uniform distribution of boric acid. From Table 2, the MOR and MOE values for boards tested under wet conditions did not differ significantly among the treatment groups, even though a reduction of properties was recorded as the chemical loading in the treated boards increases. The mean value for wet MOR and wet MOE for the untreated control boards were 7.89 N/mm^2 and MOE, 460.9 N/mm^2, respectively. However, when tested under dry condition, the MOR values for boards with boric acid loading ranging from 0.42-0.47% (w/w) were significantly reduced between 9.1-15.7% from 15.02 N/mm^2. While the MOR of those having higher loading (ranging from 0.64-0.70%, w/w) were reduced between 19.6-24.6%. The results also revealed that the higher the boric acid retention in the board, the higher the reduction of MOR. For dry MOE, however, the property was only affected if higher boric acid is retained in the treated board. The MOE values

TABLE 2
Mean retention boric acid-treated particleboard determined using titration method

Boric acid dosage (%, w/w)	Adhesive glue type	No. of samples	Retention of boric acid, % (w/w)	
			Method A1	Method B[2]
0.5	E1	15	0.47 (0.082)	0.42 (0.093)
1.0	E1	15	0.70 (0.013)	0.64 (0.017)
0.5	E2	15	0.46 (0.021)	0.43 (0.024)

[1]Mixing boric acid powder with adhesive before spraying the furnish
[2]Spraying the furnish with boric acid solution
Values in parentheses are standard deviation

Table 3
Mean[1] property values of particleboard treated with H_3BO_3 compared with untreated control groups

Treatment	Chemical loading (%, w/w)	MC (%)	Density (kg/m^3)	Dry MOR N/mm^2	Wet MOR N/mm^2	Dry MOE N/mm^2	Wet MOE N/mm^2
Control	0	9.22	617.3	15.02[a2]	7.89[a]	1085.8[a]	460.9[a]
Method A + 0.5% boric acid	0.47	9.54	620.5	12.71[b] (-15.7)	6.73[a] (-14.7)	981.3[a] (-9.6)	429.5[a] (-6.8)
Method A + 1.0% boric acid	0.70	9.55	580.9	11.33[c] (-24.6)	6.65[a] (-16.7)	922.3[b] (-15.1)	369.9[a] (-13.9)
Method B+ 0.5% boric acid	0.42	9.68	620.0	13.65[b] (-9.1)	6.87a (-12.9)	1036.3[a] (-4.6)	443.8[a] (-3.7)
Method B + 1.0% boric acid	0.64	9.78	608.3	12.16[c] (-19.6)	6.54[a] (-17.6)	943.6[b] (-13.1)	416.8[a] (-9.6)

[1]Mean value of 60 samples
[2]Means in the same column followed by the same letter are not significantly different (a = 0.05) using DMRT
Figures in parentheses are percent change of properties compared to untreated control.

for boards with boric acid loading of between 0.64-0.70% were reduced by ca. 17% from 1085.8 N/mm^2.

A significant reduction of MOR and MOE when tested under dry condition in the treated boards which may be attributed to one of two possibilities. Firstly, it was possibly due to the final density of the board. As seen in Table 2, the average final density obtained for the boards treated with 1.0% boric acid for both methods (i.e. 580.9 kg/m^3 for method A and 608.8 kg/m^3 for method B) was appreciably lower than the average density for the control (617.3 kg/m^3). Lehmann (1974), stated that the final board density greatly influenced the physical and mechanical properties of particleboard. Higher density particleboard generally produced boards with better strength properties. Secondly, the presence of boric acid in the board coupled with the heat from the hot press to bond the particles will hydrolyse bonds which connect the glucose units and will effectively rupture microfibrils creating shorter cellulose chains. Since most strength properties of wood are closely related to cellulose microfibril integrity will also reduce the bending strength (Ifju 1964). The higher the amount of boric acid present in the particles, the more ruptured the microfibrilsis.

A total different scenario was observed in wet bending strengths. It is known that boron compound is water soluble and it does not fix in the wood after treatment and can easily be leached out when subjected to humid condition or immersed in water. The soaking of the treated specimens prior to the static bending test would result in the leaching out some of the chemical which in turn will not significantly change the properties of the boards.

The descriptive statistics for internal bond (IB), thickness swelling (TS) and water absorption (WA) tests are given in Table 4 for the treated and untreated particleboards. The values in parentheses represent the change in mechanical properties compared to the untreated control.

From Table 4, it can be seen that the incorporation of 1.0 % boric acid significantly reduced the strength of the glue line. The IB values were lowered by 22.5% and 18.4% to 2.23 kN and 2.34 kN for those with chemical loading of 0.70 and 0.64%, respectively. For those treated with smaller amount of boric acid, the IB of the boards was not significantly affected, though a slight reduction (2.8-5.1%) was recorded. The average IB values for these boards were between 2.73 kN to 2.79 kN while the average untreated boards value was 2.87 kN.

TABLE 4
Mean[1] internal bonding and dimensional stability values of boric acid-treated particleboard compared with untreated boards

Treatment	Chemical loading (%, w/w)	Internal Bonding N/mm^2	Thickness swelling %	Water absorption %
Control	0	1.15a2	11.76a	87.3a
Method A + 0.5% boric acid	0.47	1.09a (-5.1)	13.36a (14)	80.12b (-8.3)
Method A + 1.0 boric acid	0.70	0.91b (-20.9)	11.04a (-6.0)	93.74a (7.3)
Method B + 0.5% boric acid	0.42	1.12a (-2.8)	11.47a (-4.2)	79.27b (-8.4)
Method B+ 1.0 boric acid	0.64	0.94b (-18.3)	12.75a (8.4)	89.45a (2.0)

[1]Mean values of 6 samples
[2]Means in the same column followed by the same letter are not significantly different (a = 0.05) using DMRT
Figures in parentheses are percent change of properties compared to untreated control.

Internal bond measures the particleboard bonding efficiency and indicates the compatibility of resin adhesive. In this study the incorporation of boric acid in the particleboard to some exten did not adversely affect the glue line properties. However, the IB of the boards will be reduced if larger amount of boric acid is formulated in the particleboard as reflected by the higher reduction of IB values (Table 4).

Thickness swelling (TS) measures the dimensional stability of the boards and is considered important in sizing property. The lower the TS, the better is the dimensional stability of the board. The result shows there is no definite trend in TS values of the boards with respect to concentration levels of boric acid and the treatment methods employed. This phenomenon was verified by the statistical analysis where the values for all treatment groups are not significantly different (Table 4). The TS values of the boards were in the range of 11.0 to 13.4%.

For the water absorption test, a significant reduction of about 8% was recorded for boards with boric acid loading between 4-5%. The water absorption value for the untreated particleboard was 87.33%. Suprisingly, the WA value for boards with higher chemical loading did not differ significantly when compared to the control boards.

Durability of Particleboard against Rotting Fungus (Pycnoporus sanguineus)

The average weight loss of rubberwood particleboard blocks after 12 weeks of exposure to white rot fungus (Pycnoporus sanguineus) is shown in Table 5. All control blocks were completely covered with mycelium whilst no mycelium was seen on the surface of the treated blocks. The average weight loss was 29.54% for

TABLE 5
Average weight loss of rubberwood particleboard blocks test after 12 weeks exposure to *Pycnoporous sanguineus* (white rot fungus)

Blocks	Chemical loading (%, w/w)	Weight loss (%)	Resistance class
UF-E1	0	Mean = 59.54[a1] S.D2 = 2.20 N3 = 30	C
UF-E2	0	Mean = 24.69[b] S.D = 3.76 N = 30	B
UF-E2	0.42-0.46	Mean = 5.11[c] S.D = 0.90 N = 30	A
UF-E1	0.43-1.47	Mean = 5.73[c] S.D = 1.41 N = 30	A
UF-E1	0.64-0.70	Mean = 4.59[c] S.D. = 1.97 N = 30	A

[1]Means in the same column followed by the same letter are not significantly different (p = 0.05) using Duncan' test
[2]S.D - Standard deviations
[3]N – No. of samples
UF-E 1 – Board with maximum permissible emission not more than 0.1 ppm
UF-E 2 – Board with maximum permissible emission between 0.1 & 10 ppm
A – Highly resistant with average weight loss between 0 & 10%
B – Resistant with average weight loss between 11 & 24%
C – Moderately Resistant with average weight loss between 25 & 44%

boards bonded with UF glue type E1 (max. permissible formaldehyde emmision: 0.1 to 10 ppm) and 24.69% for UF glue type E2 (max. permissible formaldehyde emmision: < 0.1 ppm). The significant difference in weight loss between E1-boards and E2-boards suggests that formaldehyde content has significant effect on the durability of the boards. Being an E2-board, more formaldehyde would be emitted when it is being exposed to humid condition. This formaldehyde would act as a barrier on the board surface, and prevent it from fungi attack. This would explain why the E2-board has lower weight loss compared to that of E1-board.

The results also revealed that a chemical loading between 0.42-0.47% has successfully reduced the degradation of the particleboards caused by the white rot fungus. The weight loss caused by the degradation was 5.11% for boards bonded with UF glue type E2 and 5.73% for UF glue type E1. A higher resistance against fungi was found as more boric acid is retained in the particleboard. This is proved by the lesser weight loss (4.59%) of board which has a chemical loading of 0.7%. With special reference to the ASTM (D2017-71) Standard (Anonymous. 1972), the boric acid-treated board can be classified into 'Highly resistance' (Class A) while untreated UF-E2 board into 'Resistance' (Class B) and untreated UF-E1 into 'Moderately resistance' (Class C).

The results found in this study are in good agreement with previous published reports (Carr 1958, William & Amburgey 1987, Grace *et al.* 1992). The authors concluded that boric acid equivalent (BAE) loading in the range of 0.4% to 1.8% (w/w) are very effective to protect wood against rotting fungi.

CONCLUSION

This study shows that a higher retention was achieved in particleboards when they were treated with boric acid in a powder form than in an aqueous solution form.

Some physical and mechanical properties of particleboard are affected by the preservative treatment. The preservative treatment did not affect the wet MOR and MOE of the boards. However, the treatment reduced the dry MOR and MOE. The glue line strength of the board was significantly reduced when higher concentration of boric acid is added. The reduction in dry MOR and MOE values of boric acid-treated particleboard may probably be due to depolymerisation of the celluolse chains.

There was no definite trend on the stability of the boron-treated board. The WA of boric acid-treated boards were not affected by the treatments.

Particleboards bonded with UF-E1 type glue (less formaldehyde content) was more susceptible to white rotting than those bonded with UF-E2 type glue (more formaldehyde content). The presence of boric acid significantly increased the durability of board against white rot fungus, and the resistance towards the fungus increased as the boric acid loading increases.

The mechanical reductions observed in this study for treated particleboards do not, in general, represent a serious detriment to use. Besides, the increase in resistivity against degradation agent will further expand the usage of the particleboards.

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