OPTIMISING TREATMENT SYSTEM FOR KENAF (*HIBISCUS CANNABINUS)* PARTICLEBOARD WITH FIRE RETARDANTS

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IZRAN K, ZAIDON A, BEYER G, ABDUL RASHID AM, ABOOD F & RAHIM S. 2010. Optimising treatment system for kenaf (*Hibiscus cannabinus)* particleboard with fire retardants. Particleboard is widely used for panelling, partitioning and ceiling in buildings. The treatment of this material to improve fire performance is not an exception. A study was carried out to determine the fire performance of kenaf particleboard treated with phosphorous-based fire retardants. Kenaf core particles were first treated separately with 8 and 10% solutions of monoammonium phosphate (MAP), diammonium phosphate (DAP) and a mixture of boric acid, guanylurea phosphate and phosphoric acid (BP®) using hot and cold bath processes. The soaking time needed to achieve the standard dry salt retention, i.e. 50 kg m^{-3} was determined. Particleboards from these treated kenaf particles were fabricated and their fire performance evaluated. Using 8% treating solution, it took about 36, 21 and 48 min of immersing in cold bath to achieve the standard retention requirement for MAP, DAP and BP® respectively but for 10% concentration, the times were slightly shorter, i.e. 15, 20 and 35 min respectively. Among the three phosphorous formulations, BP® showed the best performance in improving the insulation and integrity of kenaf particleboard when exposed to fire. This is followed by MAP and DAP. BP®-treated board was the last to ignite compared with the other two boards.

Keywords: MAP, DAP, BP, hot and cold bath, fire resistance, early burning performance

IZRAN K, ZAIDON A, BEYER G, ABDUL RASHID AM, ABOOD F & RAHIM S. 2010. Pengoptimuman sistem rawatan papan serpai kenaf (*Hibiscus cannabinus*) dengan bahan perencat api. Papan serpai contohnya yang dijadikan panel, pembahagi dan siling telah digunakan secara meluas dalam pembinaan bangunan. Rawatan bahan ini untuk meningkatkan prestasi api bukanlah sesuatu yang asing. Kajian telah dijalankan untuk menentukan prestasi api papan serpai kenaf yang dirawat dengan menggunakan bahan perencat api yang berasaskan fosforus. Partikel teras kenaf telah dirawat secara berasingan menggunakan monoammonium fosfat (MAP), diammonium fosfat (DAP) dan campuran asid borik, guanilurea fosfat dan asid fosforik (BP®) pada kepekatan 8% dan 10% melalui proses rendaman panas dan sejuk. Sistem rawatan yang optimum untuk mendapatkan retensi garam kering yang diperlukan iaitu 50 kg m^{-3} juga telah dikenal pasti. Papan serpai dihasilkan daripada partikel kenaf yang telah dirawat ini dan prestasi apinya telah diuji. Pada kepekatan 8%, partikel kenaf memerlukan tempoh rendaman sejuk masing-masing selama lebih kurang 36 min, 21 min dan 48 min untuk mencapai retensi garam kering bagi MAP, DAP dan BP®. Bagaimanapun, pada kepekatan 10%, tempohnya lebih singkat iaitu 15 min untuk MAP, 20 min untuk DAP dan 35 min untuk BP®. Antara tiga formulasi fosforus ini, BP® menunjukkan prestasi terbaik dalam memperbaiki insulasi dan integriti papan serpai kenaf apabila didedahkan kepada api. Ini diikuti oleh MAP dan DAP. Papan serpai yang dirawat dengan BP® paling sukar terbakar berbanding papan yang dirawat dengan bahan perencat yang lain.

INTRODUCTION

Kenaf has been found to be a potential raw material for wood composites. Mechanical properties of kenaf particleboard and fibreboard surpass the EN standard requirements (Mohamad Jani *et al.* 2004, Izran *et al.* 2009b, c). It was also reported that particleboard made from kenaf core has superior physical and mechanical properties than those of rubberwood (Paridah *et al.* 2007). Kenaf core particles can also be treated with fire retardants to produce particleboards which have abilities to reduce the spread of flame and the release of heat when exposed to fire (Izran *et al.* 2009a).

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Particleboards for the building industry come in many sizes and densities which are suitable for many uses such as ceilings, partitioning and panelling. In order to be used in high rise buildings, particleboard must comply with the fire resistance requirements of building regulation, i.e. the Uniform Buildings by Laws 1984. Therefore, treatment to improve the fire performance of these boards is necessary to comply with the building regulation. Attempts to treat particleboard with fire retardants have been carried out through brushing, spraying, dipping, soaking, pressure treatment, hot and cold bath, and diffusion treatments (Abdul Rashid & Chew 1990, Baharuddin 2002). A 50-mm or thinner solid sawn lumber must achieve a standard chemical loading of 50 kg m^{-3} with a minimum penetration of 12 mm (Anonymous 1963). The fire performance of a material for building construction is assessed through fire resistance and early burning tests. Fire resistance provides a means of quantifying the ability of an element to withstand exposure to high temperatures based on insulation which is influenced by integrity criteria (British Standard 1987). Once a particleboard has achieved integrity failure, automatically the insulation evaluation will be stopped. However, the insulation failure can happen before integrity failure, therefore, it is best to assess the failure too. For early burning test, the three important variables measured are ignition time of an element, percentage of weight loss and char formation after exposure to source of heat.

The aim of this study was to evaluate the fire resistance and early burning performances of particleboards made from kenaf core particles treated with phosphorous-based fire retardants. The optimum treatment system so as to meet the standard retention requirement for the fire retardants was first studied. For this, kenaf particles were treated separately with 8 and 10% solutions using hot and cold bath treatments. The optimum time of cold soaking to obtain the desired minimum retention requirement for each treating solution was determined. This is to ensure that the required amount of fire retardants is determined and to avoid excessive or insufficient amounts of fire retardant in the treatment. Excessive amount of fire retardant will only unnecessarily add cost to the treatment. On the other hand, if a small amount is used, the dry salt standard retention (DSR) will be very low and may not meet the standard requirement.

MATERIALS AND METHODS

Chips from kenaf core were used as raw material and these were obtained from the National Tobacco Board, Malaysia. Fire retardants used were diammonium phosphate (DAP), monoammonium phosphate (MAP) and a mixture of guanylurea phosphate, phosphoric acid and boric acid (BP®). Urea formaldehyde resin obtained from the Malayan Adhesive & Chemicals Sdn Bhd was used as the binder. Kenaf chips were flaked using a ring flaker and screened to obtain particles with sizes of 1–2 mm. The particles were dried in a standard industrial oven at approximately 80 °C until a moisture content of 3 to 5% was reached. Fire retardant solutions of 8 and 10% concentrations (w/v) were prepared separately.

Hot and cold bath treatments

Kenaf particles were treated separately with fire retardant solutions using hot and cold bath treatments. The time required to immerse particles to achieve the minimum DSR in each board, i.e. 50 kg m^{-3}, was determined. Particles (5 g) (Wi) were placed on a piece of cloth which was then tied using a rubber band. Four packs were prepared for each treatment. The packs were then immersed into a beaker filled with hot fire retardant solution. The beaker was then heated using a hot plate at 70 °C for 10 min after which the beaker was placed in a fume hood until the solution reached ambient temperature. An hour later, one pack of each treatment was taken out of the beaker, dried and its weight (Wf) measured. This was repeated for the rest of the packs at hourly intervals. The DSR was calculated using equation 1.

$$\text{DSR (\%)} = [(Wf - Wi)/(Wi)] \times \text{concentration (\%)} \quad (1)$$

The DSR was then converted to kg m^{-3} to obtain the standard minimum retention, i.e. 50 kg m^{-3}. From the graph of DSR (%) versus time of soaking (h), it was determined that 997 g of dried particles were needed to produce a particleboard of 350 × 350 × 12 mm. Subsequently, the amount of dry salt (kg) required for each board was calculated using equation 2.

$$\text{DSR (50 kg m}^{-3}\text{)} = \text{dry salt weight/particleboard volume} \quad (2)$$

From the above equation, the weight of dry salt required for each board was 74 g (i.e. 7.42%). Having found this, the soaking time of particles to achieve the desired requirement retention for each solution was estimated through the plotted graph.

Board fabrication

Single-layer treated and untreated particleboards were fabricated using specifications shown in Table 1. The treated furnish was blended with 12% urea formaldehyde for approximately 15 min to ensure uniform distribution of the adhesive. Moisture content of the furnish was maintained at 12% to avoid blistering during hot pressing and also because fire retardants used in the treatment were hygroscopic. Furnish with excess moisture was dried again in an oven at 80 °C. The furnish was then formed in a wood deckle, pre-pressed and subsequently hot pressed at 180 °C. The time for pressing was determined by gelation time of the admixture of adhesive and fire retardants (Zaidon *et al.* 1998, Zaidon *et al.* 2008, Izran *et al.* 2009d). It was found that the pressing time of DAP-treated furnish was 12 min, BP 10 min, MAP 9 min and untreated furnish, 10 min. The hot press was performed stepwise using four cycles of pressure starting from 130, followed by 90, 70 and 50 kg cm^{-2}.

Fire resistance test

The test was conducted in a fire furnace based on BS 476: Part 22 (British Standards Institution 1987). Samples of 350 × 350 × 12 mm were used in this test. Before testing, the weight, thickness, length and width of the boards were measured. Cement was used to attach the board to the frame of the furnace. One board was tested at a time. Three thermocouples were attached to each board and the ends of the thermocouples were connected to a recorder which measured the temperature of the unexposed (i.e. the part of the board which was not exposed to the fire source in the furnace) face of the board. The temperature of the furnace was also recorded using thermocouples in the furnace.

The initial temperatures of the furnace were 27–30 °C and temperature increments were recorded at intervals of 5 min until the temperature of the unexposed face achieved 183 °C (insulation failure) or the board collapsed (integrity failure). The temperature–time relationship during the test was calculated using equation 3 (British Standards Institution 1987).

Table 1 Description of the fabricated particleboard

Raw material	Kenaf core particles
Targeted board density	700 kg m^{-3}
Targeted board moisture content	12%
Board size	350 × 350 × 12 mm
Adhesive	
UF resin	12% (w/w of board)
Hardener (NH_4Cl)	3% (based on resin)
Wax	1% (based on oven-dried particles)
Fire retardant • Diammonium phosphate (DAP) • Monoammonium phosphate (MAP) • Mixture of (BP®): 67–73% guanylurea phosphate, 27–33% boric acid and 0–4.2% phosphoric acid	DSR 7.42% (w/w particles)
Hot press temperature	180 °C
Hot pressing time	9–12 min, dependent on the treated particles

$$T = 345 \log (8t + 1) + T_o \quad (3)$$

where

T = furnace temperature at time t min

T_o = ambient temperature

After burning, physical changes of the exposed and unexposed faces of boards were examined to evaluate the failure of integrity and insulation.

Early burning performance

All samples (200 × 200 × 12 mm) were oven dried at 103 ± 2 °C overnight and their oven-dry weights (Wb) were determined. Prior to testing, 1 ml ethanol was dispersed at the centre of each untreated and treated boards. Each board was then placed inclined at 45°, 3 cm above a Bunsen burner and the time taken for the board to ignite was recorded. The combustion on the surface of the board was left for 2 min after which the char area was measured and the sample reweighed (Wa). These data were used to calculate the percentages of burnt area and weight loss (equations 4 and 5).

$$\text{Weight loss (\%)} = \frac{Wb - Wa}{Wb} \times 100 \quad (4)$$

$$\text{Burnt area (\%)} = \frac{\text{Char area}}{\text{Sample area}} \times 100 \quad (5)$$

RESULTS AND DISCUSSION

Hot and cold bath treatments of kenaf particleboard

The DSR versus the time of cold soaking is illustrated in Figures 1 and 2. Results showed that during the first hour, for 8% solution, DAP was the highest amount of retardant absorbed by particles, followed by MAP and BP®. On the other hand, for 10% solution, particles absorbed MAP the most, followed by DAP and BP®. Soaking times required to reach the standard retention requirement of 7.42% DSR were 36, 21 and 48 min for MAP, DAP and BP® respectively (Figure 1) for treatments using 8% solutions and 15, 20 and 35 min respectively for the 10% treatment solution (Figure 2). These showed that shorter cold soaking time could be achieved from the 10% concentration compared with the 8%. Therefore, particles soaked in the 10% concentration were chosen for board fabrication.

Fire resistance performance of kenaf particleboard

Tables 2 and 3 summarise the fire properties of treated and untreated boards. Figures 3 to 6 show temperature curves of the furnace for each tested board. The furnace temperature curves can be used to observe the relationship between temperature increment and time in

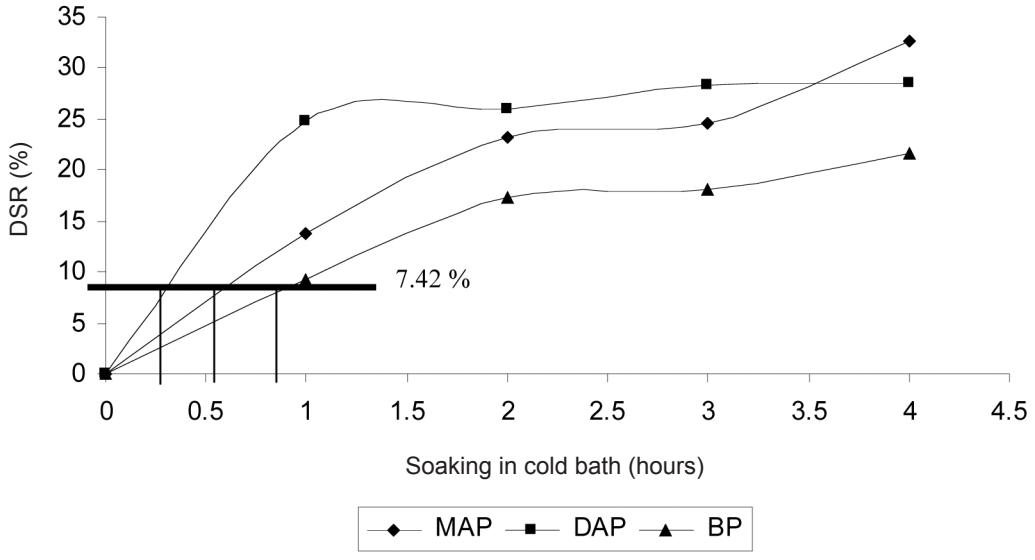

Figure 1 Dry salt retention (DSR) of kenaf particles treated with 8% solutions of MAP, DAP and BP using hot and cold bath processes

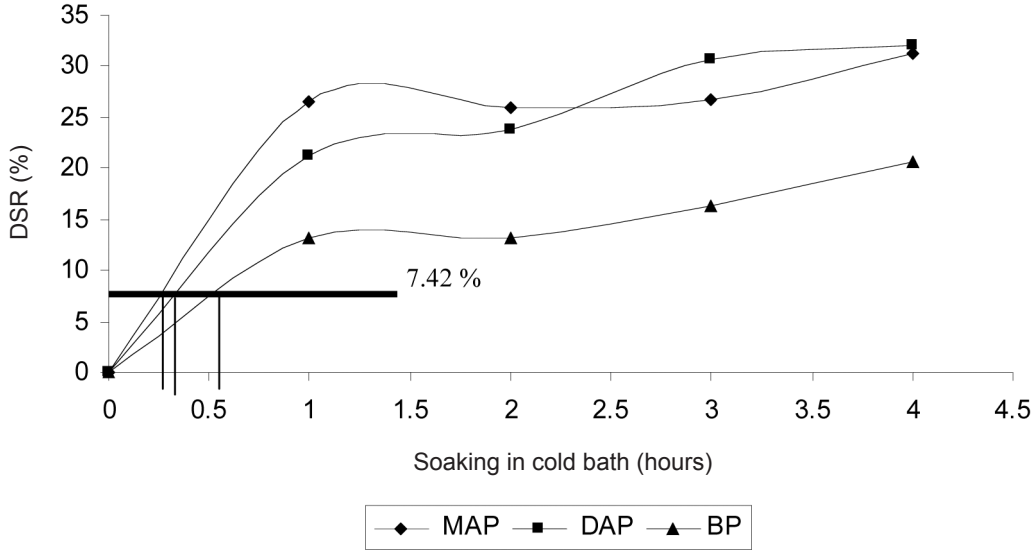

Figure 2 DSR of kenaf particles treated with 10% solutions of MAP, DAP and BP using hot and cold bath processes

Table 2 Fire resistance performance of treated kenaf particleboard

Particleboard	CTEF (min)	CTUF (min)	Insulation (min)	Integrity (min)	TIAF (°C)
Untreated	7	11	13	13	182
DAP-treated	8	12	15	15	183
MAP-treated	13	16	18	19	244
BP®-treated	15	17	18	18	331

CTEF = Charring time at the exposed face; CTUF = charring time at the unexposed face;
Insulation = time at insulation failure; Integrity = time at integrity failure
TIAF = temperature at integrity failure

Table 3 Early burning performance test of treated kenaf particleboard

Particleboard	Ignition time (s)	Burnt area ± SD (%)	Weight loss ± SD (%)	Board density (kg m^{-3})
Untreated	50	18.43 ± 3.9	0.99 ± 0.3	586
DAP-treated	100	15.83 ± 2.0	0.97 ± 0.4	447
MAP-treated	100	14.28 ± 1.3	0.55 ± 0.2	472
BP®-treated	120	8.52 ± 2.6	0.69 ± 0.3	537

Data are averages of three samples

the furnace during the tests. Four curves were generated for each test; three curves were calibrated curves, namely, specified upper limit temperature (SULT), specified standard temperature (SST) and specified lower limit temperature (SLLT) and one curve was the actual burning temperature (ABT), i.e. temperature of the furnace during the test. To ensure accuracy of assessment, ABT should be between SULT and SLLT and needs to be almost similar with the SST and this was observed in this study. This indicated that the temperatures of the furnace were not influencing the accuracy of the fire resistance results obtained.

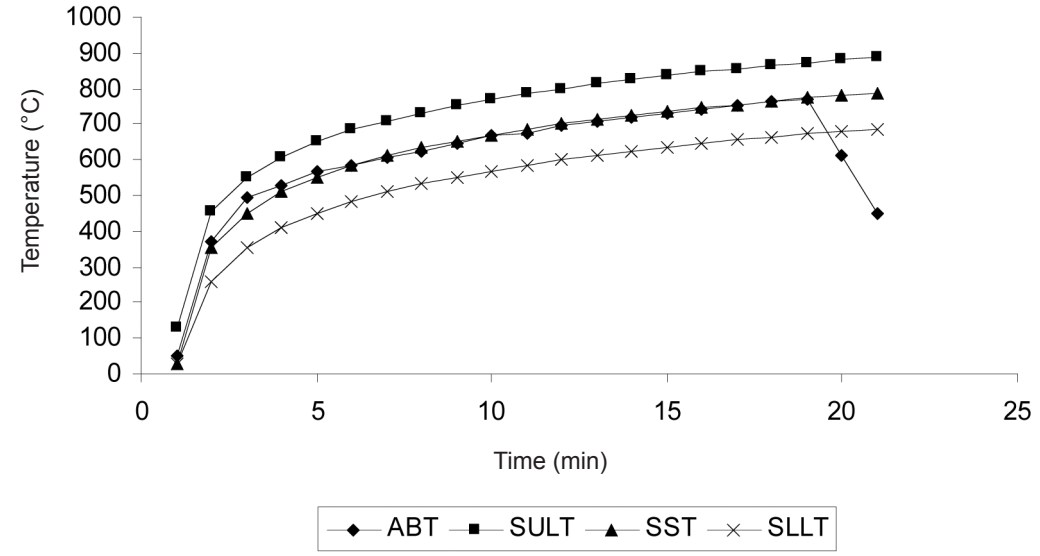

Figure 3 The furnace temperature for the DAP particleboard; ABT = actual burning temperature; SULT = specified upper limit temperature; SST = specified standard temperature; SLLT = specified lower limit temperature

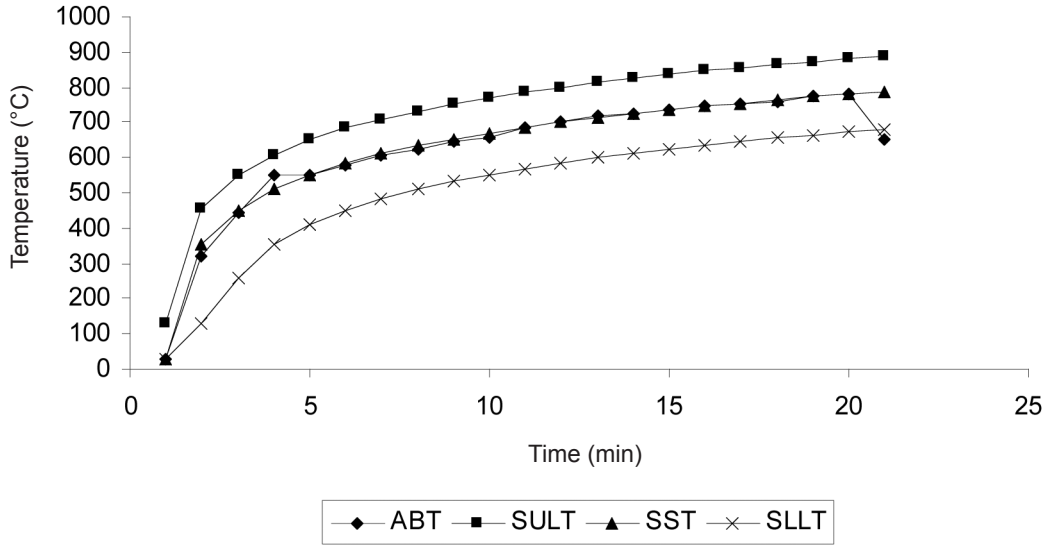

Figure 4 The furnace temperature for the BP®-treated particleboard; ABT = actual burning temperature; SULT = specified upper limit temperature; SST = specified standard temperature; SLLT = specified lower limit temperature

Untreated board could only maintain insulation and integrity for 13 min after exposure to fire. The temperature at integrity failure was 182 °C (Table 2). The exposed part of the board started to darken within 7 min of exposure and was completely burnt at the 11th min. By this time, char started to establish on unexposed surface at the top of the board and after 13 min, the surface started to ignite and continuous flaming was observed for more than 10 s.

The DAP-treated board experienced integrity failure after 15 min of exposure to fire (Table 2). The board collapsed as the temperature of the unexposed surface increased to 183 °C. Darkening at the exposed surface started after 8 min, while charring at the unexposed surface began after 12 min. Flaming on the unexposed surface also continued for more than 10 s. Insulation (18 min) and integrity (19 min) performances of MAP-treated board were higher than the

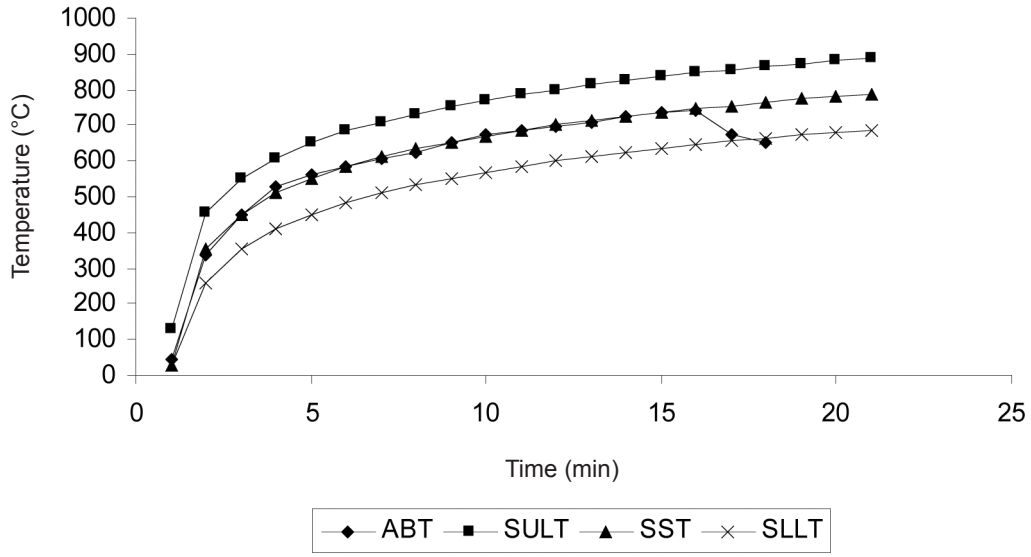

Figure 5 The furnace temperature for the untreated particleboard; ABT = actual burning temperature; SULT = specified upper limit temperature; SST = specified standard temperature; SLLT = specified lower limit temperature

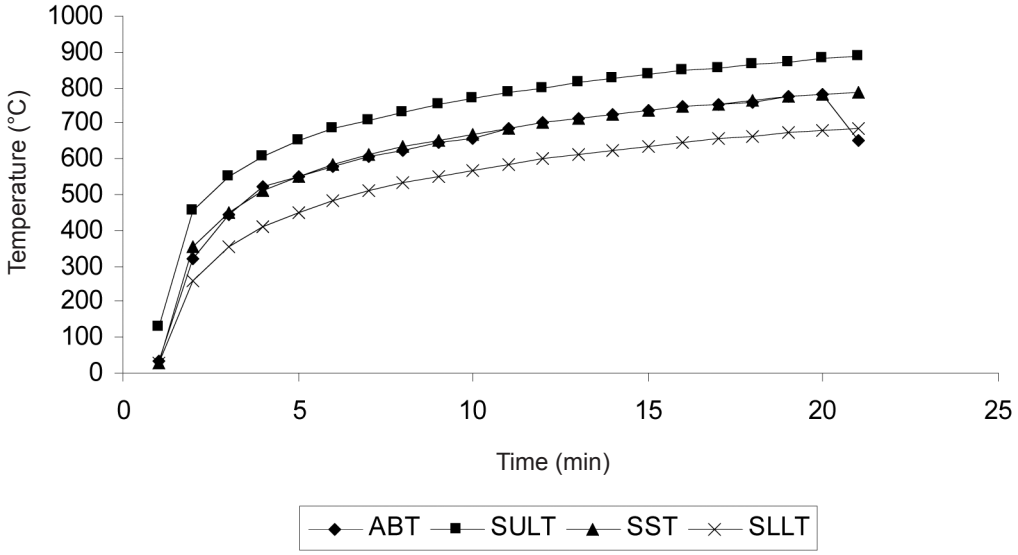

Figure 6 The furnace temperature for the MAP-treated particleboard; ABT = actual burning temperature; SULT = specified upper limit temperature; SST = specified standard temperature; SLLT = specified lower limit temperature

untreated and DAP-treated boards. At 244 °C, the temperature at integrity failure for MAP-treated board was also higher than DAP- and untreated boards but inferior to BP®-treated boards. Char started to form at the centre of the board after 16 min and ignition occurred after 19 min with continuous flaming for more than 10 s. For BP®-treated board, both insulation and integrity criteria were maintained up to 18 min of exposure to flame. However, integrity failure was observed at a much higher temperature, i.e. 331 °C. Charring at the unexposed surface occurred after 17 min exposure to fire.

In the early burning performance, MAP- and DAP-treated boards each took 100 s to ignite whereas for BP®-treated board, 120 s (Table 3). Ignition time for untreated board was 50 s. BP-treated board had the smallest burnt area, i.e. 8.5% of the total exposed area, while for MAP- and DAP-treated boards, the burnt areas

were 14.3 and 15.8% respectively. Untreated board had 18.4% of burnt area (Table 3). With regard to weight loss due to burning, there was no difference between DAP-treated and untreated boards (~1%) but the other two boards showed lesser weight loss, i.e. 0.6% for MAP- and 0.7% for BP®-treated boards.

The tests revealed that fire performance of kenaf particleboard improved when treated with phosphorous-based fire retardants. BP® showed the highest efficacy followed by MAP and DAP indicating that boron formulated fire retardants performed better than phosphorous-based fire retardants. This is in agreement with findings by Abdul Rashid and Chew (1990). Boron compound is able to penetrate into particles of boards and provide complete protection of the material, thus, prolonging the time taken for heat to transfer through the cross-section of the board (Kolowski & Wladyka 2001).

Results of this study also showed that a shorter time is needed to cause charring in the board that had a higher percentage of phosphorous. Char formed faster on DAP- and MAP-treated boards compared with the BP®-treated board. This is because phosphorous accelerates the formation of char mass from cellulosic material and suppresses flammable volatiles (Grexa & Kiosk 1992, Ishihara 1992). Thus, the higher content of phosphorous in MAP-treated and DAP-treated boards compared with BP®-treated board may contribute to the shorter time for charring. Boron compound reacts with combustible gases and tar generated by kenaf particles and converts them into carbon char. The by-products generated from this process, namely, carbon dioxide and water will dilute the combustible gases, resulting in reduction of flame spread (Levan & Tran 1990).

CONCLUSIONS

Fire retardant can be successfully incorporated in kenaf particleboard through treatment of particles using hot and cold bath treatments. Using 8% treating solutions, it took about 21 to 48 min of immersing in the cold bath to achieve standard retention requirement but for 10% concentration, it took slightly shorter time, i.e. 15 to 35 min. The three fire retardants studied were effective in improving fire resistance and early burning performance of kenaf particleboards. Treated boards had insulation and integrity performances between 15 and 19 min compared with 13 min for untreated board. BP® and MAP performed better than DAP in improving insulation and integrity of the board. BP®-treated board ignited least readily when compared with the rest of the boards. MAP and DAP aggravated the formation of char on the surface of the boards when exposed to fire compared with BP®. MAP formulation is better than BP® only in terms of weight loss after burning.

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