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Fire Propagation and Strength Performance of Fire Retardant-Treated *Hibiscus cannabinus* Particleboard

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Abstract: The fire propagation and strength performance of kenaf (*Hibiscus cannabinus*) core particle board treated with three different commercialized fire retardants were studied using ten percent concentration of fire retardants. The fire propagation test was evaluated using performance index (I), which indicates the heat release of the tested particle boards. Physical and mechanical properties such as water absorption, thickness swelling, Modulus of Rupture (MOR), Modulus of Elasticity (MOE) and Internal Bond (IB) of the treated and untreated boards were also studied. The study showed that diammonium phosphate (DAP) was excellent in reducing the heat release of the boards followed by monoammonium phosphate (MAP) and BP® [mixture of 27-33% boric acid, 67-73% guanylurea phosphate and 0.0-4.2% phosphoric acid]. DAP and MAP were able to delay the maximum early heat release of the boards by about 15 to 16 min and 18 to 20 min, respectively compared to BP® which was only able to delay the maximum early heat release by about 10 to 15 min after ignition. The heat release of the DAP and MAP-treated particle boards started 5 min after ignition, but the heat release of the BP®-treated boards started from the beginning of the test. Boards treated with DAP were found comply with the standard ratings for thickness swelling and water absorption test. MAP-treated boards were found comply with the standard rating for MOR and were found to be the best compared to the other treated boards for MOE and IB. However, treated boards complied with the standard ratings of MOE and IB.

Key words: Kenaf, fire retardants, fire propagation, physical and mechanical

INTRODUCTION

Kenaf (*Hibiscus cannabinus*) is a fibrous plant that originally came from Western Sudan, Africa and closely related to okra and cotton (*Gossypium hirsutum* L.) (Jani *et al*., 2004). There were many researches done to prove the suitability of kenaf, as a raw material in producing useful products such as plastic and particle board. Toyota Motor Corp combined kenaf fibre with polylacetic acid, which also is made from plants, to develop kenaf-based plastic. When the plastic was burned, it released low amount of CO_2 to the environment, thus reducing the greenhouse effect (Anonymous, 2003). Researches on kenaf particle board also have been done in Malaysia. A researcher of Forest Research Institute Malaysia (FRIM) has been made a research on producing kenaf-based particle board and fibre board (Jani *et al*., 2004). It was found that kenaf particle board has good mechanical properties that surpassed the standard requirements. It was reported that particle board made from 100% Kenaf core gave superior performance than that of particle board made from 100% rubberwood, in term of Modulus of Rupture (MOR), Modulus of Elasticity (MOE), Internal Bond (IB), Thickness

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Swelling (TS) and Water Absorption (WS) (Paridah *et al.*, 2007). Particle board is a composite panel product which is produced by compressing small particles of lignocellulosic materials. Particle board is being used in the building industry. This panel is available in large panel sizes which are suitable for many uses such as furniture components and partitioning. However, for the protection of life and property from fires, information is needed for fire initiation, heat release, flame spread and generation of smoke, toxic and corrosive products to assess fire hazard and ease of fire control and extinguishment (Tewarson, 1994). This information can be obtained through fire propagation test. The first step of fire propagation is pyrolysis, where at this stage, vapors formed when a material is exposed to the fire source. Then, the vapors combined with air to form vapor-air mixture and may be ignited or auto-ignite by the heat or fire source. This stage is called ignition. The fire propagation happens when the pyrolysis moves/spread across the surface of the material (Tewarson, 1994; Abdul Rashid, 1986). Particle board is a combustible material (Abdul Rashid and Chew, 1990). The combustibility of the particle board may be reduced with flame retardants or fire retardants. Standard chemical loading for a board (50 mm and thinner board and a minimum penetration of 12 mm) recommended by American Wood Preservers Association (AWPA) Standard C 20-6 is 50 kg m^{-3}. In this study, hot and cold bath was used for treating the kenaf core particles. Three commercialized fire retardants namely diammonium phosphate, monoammonium phosphate, BP® (mixture of 27-33% boric acid, 67-73% guanylurea phosphate and 0.0-4.2% phosphoric acid) were chosen to be impregnated into the particles which later will be used to fabricate fire retardant-treated particle boards. Fire propagation performance indicates the amount of heat released and flamespread from small panels of lining material within a compartment (Rogowski, 1970; Tewarson, 1994). The heat was generated during chemical reactions during combustion process (Tewarson, 1994). Fire propagation behaviour of materials is divided into 3 categories (Tewarson, 1994). (1) In decelerating or non-propagating behaviour, the rate of fire propagation decreases with time or the heat is not broadly spread and limited to the ignition zone only. Materials with class 1 flame spread fall under this category. (2) In non accelerating behaviour, fire propagates beyond the ignition zone, although slowly. Materials with class 2 flame spread fall under this category. (3) In accelerating behaviour, fire propagates beyond the ignition zone very rapidly. Materials with class 3 flame spread falls under this category. At the same time, the mechanical and physical properties of the particle boards were also investigated to obtain valuable supportive information which may be used to add value of the fire retardant-treated particle boards to extend the usage of the treated panels.

The objectives of the study were to observe the fire propagation and strength performance of fire retardant-treated kenaf Particleboard.

MATERIALS AND METHODS

Particles Preparation, Fire Retardants and Adhesive

Kenaf core was used as raw material for the research. The raw material was received in chip form from Lembaga Tembakau Malaysia. The chips then were flaked using Kenaf Ring Flaker and were screened to get particles with size range from 1-2 mm at Wood Composite Workshop, Forest Research Institute Malaysia on March 2008. The initial moisture content of the particles (MC) was 12%. The particles were dried at 105°C to reduce the moisture content to 5% before the particles were treated with the fire retardants. Fire retardants used for the research were commercialized ammonia-formulated-phosphorous-based fire retardants namely Diammonium phosphate (DAP), Monoammonium phosphate (MAP) and boron-formulated-phosphorous-based fire retardant, BP® (mixture of guanylurea phosphate, phosphoric acid and boric acid). The fire retardants were supplied by EuroScience Pte. Ltd. and Forest Research Institute Malaysia. Urea formaldehyde was used for particle board fabrication and it was supplied by Malayan Adhesive and Chemicals Pte. Ltd., Malaysia.

Hot and Cold Bath Treatment

The hot and cold bath treatment is usually used in wood preservation industry. The hot bath heats and expands the air within the wood, forcing some of the air out. The wood is then immersed in the cold bath and the heated air contracts pulling preservative in with it. In this study, the method was modified to make it suitable with the characteristic of kenaf core. The actual treatment procedure was not suitable for kenaf core as it was excessively softened and degraded the particles. The treatment was done at Wood Composite Testing Laboratory of Forest Research Institute. Firstly, the dried kenaf core particles with 5% MC were packed into clothes and were tied to form kenaf core tea bag-like packs. About 1200 g kenaf core particles were tied in each cloth. At the same time, fire retardant solutions with 10% concentration for each chemical was prepared, by mixing boiled water with the fire retardants in the containers. Then, 4 packs of the kenaf core packs were immersed into each hot fire retardant solution and were soaked until the solution temperature reached ambient temperature. The packs were further soaked in the cooled fire retardant solutions from 15-36 min, based on the type of fire retardants used. The preliminary study showed that, kenaf core needed different cold soaking time for each fire retardant to achieve the standard dry salt retention. The kenaf core packs were cold soaked for 15 min in MAP solution, 36 min in BP® solution and 14 min DAP solution to achieve 7.19% dry salt retention (dry salt retention for 1029 g dried particles). The cold soaking time (SCR_m) was determined by doing calculation based on Fig. 1.

The calculation was done using this Eq. 1 and 2:

$$CR_m = R_1 / M \tag{1}$$

$$SCR_m = 7.19\% / CR_m \tag{2}$$

Where:

Cr_m = Dry salt retention value per min (%)

R_1 = Dry salt retention at the 1st h

M = 60 min

SCR_m = Soaking in cold bath

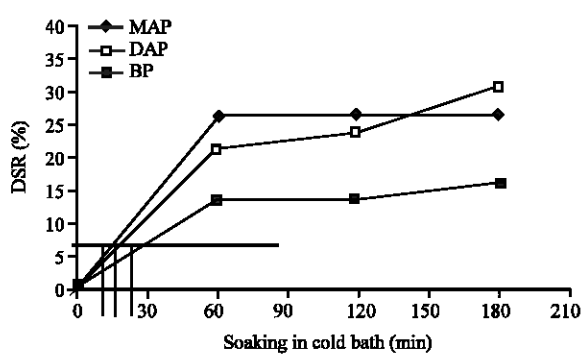

Fig. 1: Dry Salt Retention of kenaf core treated with 10% phosphorus-based fire retardants. The bolded line represents DSE = 7.19%

Table 1: Description of the particle board fabricated

Raw material	Kenaf (1-2 mm particle size)
Targeted board density	700 kg m^3
Targeted board MC	12%
Board size	(350×350×12) mm^3
Adhesive	
UF resin	12% (w/w of dried particles)
Hardener (NH_4Cl)	3% (based on resin)
Wax	1% (based on dried particles)
Flame retardants	
Diammonium phosphate (DAP)	10% (w/w of particles)
Monoammonium phosphate (MAP)	decided after preliminary test of hot and cold bath
Mixture of (BP®)	Treatment
Guanylurea phosphte (67-73%)	
Phosphoric acid (0.0-4.2%)	
Boric acid (27-33%)	

Figure 1 shows that kenaf core needed cold soaking time less than an hour to achieve 7.19% dry salt retention in each fire retardant solution. After the treatment, the treated kenaf core packs, then were taken out from the solutions, untied and were put into the oven at the temperature of 90°C until they reached 5% MC.

Particle Board Fabrication

The targeted board density was 700 kg m^{-3}. Amount of dried treated kenaf core particles to produce a board with the density of 700 kg m^{-3} was 1029 g. The description of the particle board is exhibit in Table 1. The fabrication process was completed at Wood Composite Workshop, Forest Research Institute, Malaysia. The processes started by drying kenaf core particles (treated and untreated) in an oven at temperature of 90±2°C and the MC of the particle was maintained at 5%. Then, the dried kenaf core particles were taken out from the oven, weighed to get the desired weight and directly placed into the particleboard mixer. Twelve percent (w/w of dried particles) urea formaldehyde resin mixed with 1% (based on dried particles) wax and 3% (based on resin amount) hardener was sprayed to the kenaf core particles in the particleboard mixer, which was equipped with airless spray gun. While, waiting for the kenaf core particles to mix evenly with the resin in the mixer, the polysiloxan release agent was sprayed on the surface of the caul plate to prevent the mixture from sticking with the caul plate during the hot pressing and to enhance the smoothness of the particle board. Then, wooden deckle was placed at the center of the caul plate. The moisture content of the furnish was observed using Moisture Content Calculator. The Moisture Content (MC) after the furnish was mixed with the resin was 15-20%, which was too high for particle board fabricaton. Therefore, the furnish was re-placed into the oven toachieve suitable MC for hot pressing. The furnish was left in the oven for 3 h. After 3 h, the furnish was taken out from the oven and was poured into the wooden deckle which was placed on the caul plate. The furnish was pre-pressed for 3 min for compacting purpose prior to hot pressing. Different hot pressing time was occupied for different type of fire retardant. The DAP-treated furnish was hot pressed for 9 min, the BP®-treated furnish and untreated furnish were pressed for 7 min and MAP-treated furnish was pressed for 6 min. The particle boards were conditioned in a conditioning room (65±5% RH and 20±2°C) before they were cut for testing purposes. Total of 42 boards were trimmed according to the standard requirement size and were distributed for fire propagation and strength tests.

Fire Propagation Test

The particle board size for the test was 225×225×12 mm. The test was conducted based on BS 476: part 6: 1989. The particle boards were sent to SIRIM QAS, Malaysia on December 2008 and they were tested on February 2009. No pictures were allowed to be captured during the test. One

Table 2: Calibration curve with permissible tolerances

Time from start of test (min)	Calibration curve (°C)	Tolerance
3	33	±05
5	115	±10
10	200	±12
20	245	±15

particleboard was tested at a time. The apparatus was calibrated with an asbestos board 22×22×1.5 cm. The calibration curve was obtained with permissible tolerances as shown in Table 2. The moisture content of the tested particle boards was maintained at 12% MC prior to the testing. The particle boards were tested with the face side exposed to the specified heating condition of the fire test. Firstly, the samples were heated by butane gas for 165 sec and then they were heated by electrically heated nichrome heating elements to achieve 20 min exposure time. The increase in exhaust temperature given by the burning sample for 20 min was recorded at the following interval from the start: at ½ min intervals, up to 3 min, at 1 min intervals from 5 to 10 min and at 2 min intervals from 12 to 20 min. The performance was rated by propagation index and propagation sub indices, i_1, i_2, i_3. The index of performance, I, was calculated using Eq. 3:

$$\sum_{1/2}^{3}\left(\frac{Q_m - Q_c}{10_t}\right) + \sum_{5}^{10}\left(\frac{Q_m - Q_c}{10_t}\right) + \sum_{12}^{20}\left(\frac{Q_m - Q_c}{10_t}\right) \tag{3}$$

Where:

Q_m = Temperature rise recorded for sample at time t

Q_c = Temperature rise recorded for calibration board

The I value ranges from 0 to 100 in increasing order of hazard. The calculation of the performance index was automatically performed by software which was readily equipped in the computer of fire protection section, SIRIM QAS International Sdn. Bhd. The name of the software was not mentioned in the raw reports. The software also was useful to generate temperature-time graphs, which were very essential for analyzing fire propagation of the particle boards. The I values can also predict the flamespread classification of materials. The flamespread of a material refers to the ability of a material to support the spread of the flame across the surface. It can be categorized into 4 classes namely:

- **Class 1:** Very low flamespread (165 mm)
- **Class 2:** Low flamespread (455 mm)
- **Class 3:** Medium flamespread (710 mm)
- **Class 4:** Rapid flamespread (more than 710 mm)

The above classification is based on the distance of flame covered within 10 min when the material is tested in accordance to BS 476: part 7: 1971. Materials are considered class 0 when I and i_1 are less than 12 and 6, respectively. Generally, I value of 10-25 can be considered as class 1 (very low flamespread) rating (Hall, 1975).

Physical and Mechanical Testing

The tests were conducted in accordance with British-European Standard. The physical and mechanical testing that have been conducted were static bending (BS EN 310:1993), thickness swelling and water absorption (BS EN 317:1993), internal bond (BS EN 319:1993) and density (BS EN 323:1993). The particle boards were maintained at 12% MC prior to the testing. The data were analyzed using general linear model of SPSS. The analysis was conducted according to the method reported in.

RESULTS

Fire Propagation of Kenaf Particle Board

From the current test, MAP, DAP and BP® obviously reduced the average performance index, I (Table 3) and enhanced the fire performance of the particle boards. Both MAP reduced the average performance index almost 50% compared to untreated boards and only 26.99% reduction was noted from BP®-treated particle boards. The I values for all the treatments, were less than 25 (15.6 for DAP, 16.8 for MAP and 23.8 for BP®) and these correspond to a class 1 flame spread rating or decelerating behaviour. The average performance index for untreated particle boards was 32.6 and the performance falls under class 2 flame spread rating or non-accelerating behavior. From the test, the i_1 value was reduced to less than 6 for DAP and MAP-treated particle boards (2.2 for DAP-treated and 0.1 for MAP-treated), but the i_1 value for BP®-treated particle boards was more than 6, which was 8.1.

The Temperature Rise Relationship

The average temperature-time curves of the three fire retardants are shown in Fig. 2-5. The results demonstrated that ammonium-formulated-phosphorous-based fire retardants (MAP and DAP) were able to delay the temperature rise about 5 min after the particle boards were exposed to the fire source compared to boron-formulated phosphorous-based fire retardant (BP®). The temperature rise for BP®-treated was recorded 2 min after the particle boards were exposed to the fire source. The temperature rise pattern of BP®-treated particle boards and the untreated particle boards was almost similar, but higher temperature rise was recorded from untreated particle boards. This can be seen through the size of the gap between calibration curve and the specimen average curve for the untreated particle boards (Fig. 2) compared to BP®-treated particle boards (Fig. 5). The gap was bigger for untreated particle boards. The phosphorous-based fire retardants (MAP and DAP) were also able to delay the maximum early heat release of the particle boards. The maximum early heat release for DAP-treated particle boards occurred between 18-20 min, respectively. The maximum early heat

Table 3: Fire propagation performance of kenaf core particle board

Particle board	i_1	i_2	i_3	API	FSC	MT (mm)	BD (kg m^{-3})
Untreated	15.4	13.3	3.9	32.6	Class 2	11.8	696
DAP-treated	2.2	8.5	4.9	15.6	Class 1	12.3	677
MAP-treated	0.1	11.0	5.7	16.8	Class 1	13.0	701
BP®-treated	8.1	11.3	4.4	23.8	Class 1	11.5	685

API: Average performance index (I), FSC: Flame spread classification, MT: Measured thickness, BD: Board density

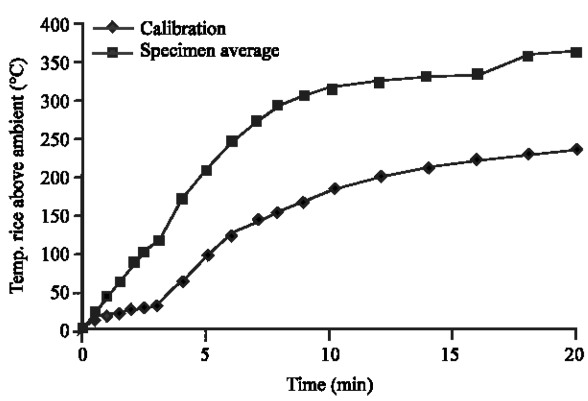

Fig. 2: Temperature-time curve of the untreated particle board

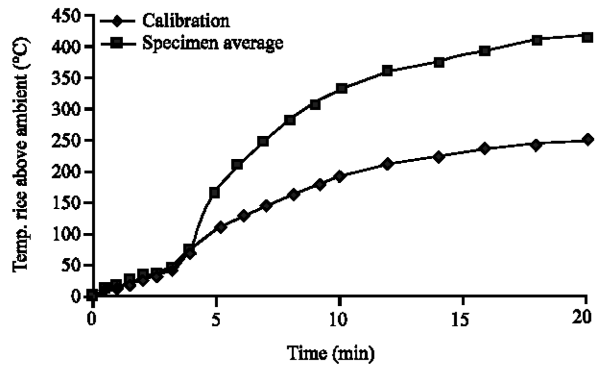

Fig. 3: Temperature-time curve of DAP-treated particle board

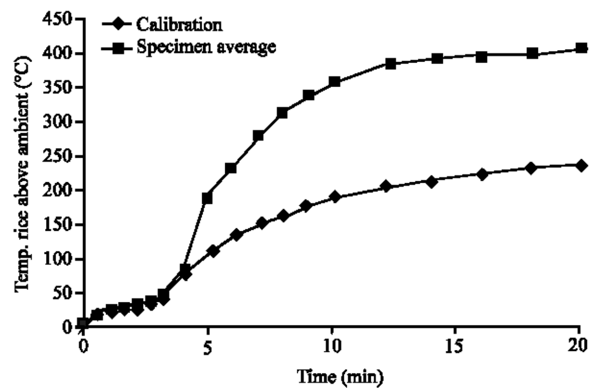

Fig. 4: Temperature-time curve of MAP-treated particle board

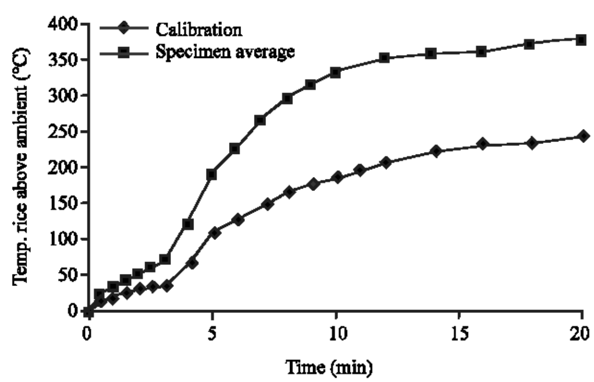

Fig. 5: Temperature-time curve of BP®-treated particle board

release for BP®-treated particle boards was almost similar with MAP-treated, where the maximum early heat release recorded for both fire retardants was between 10-15 min. The maximum early heat release for untreated particle boards was <10 min.

Physical and Mechanical Tests

The results of physical and mechanical tests are shown in Table 4. For mechanical test, MAP-treated boards were found superior, mainly for MOE and IB compared to other treated boards.

Table 4: Physical and Mechanical properties of fire retardant-treated particle boards

Sample	MOR±SD* (≥14 N mm^{-2})[a]	MOE±SD* (≥1800 N mm^{-2})[b]	IB±SD* (≥0.4 N mm^{-2})[c]	TS (%)±SD* (≤16 %)[d]	WA(%)±SD*
Control	15.95±0.454	2145.79±92.29	0.690±0.050	13.87±0.91	37.23±2.63
DAP-treated	7.651±0.473	1670.66±92.97	0.256±0.051	15.43±4.96	35.82±14.19
MAP-treated	9.151±0.470	2066.73±89.07	0.245±0.041	18.62±5.62	48.16±8.14
BP®-treated	7.173±0.455	1852.37±89.39	0.108±0.041	21.64±3.06	58.09±8.08

[a]Standard requirement of BS EN 310:1993, [b]Standard requirement of BS EN 310:1996, [c]Standard requirement of BS EN 319:1993, [d]Standard requirement of BS EN 317:1993. *Values are average of ten samples. SD: Standard deviation

The MAP-treated boards surpassed the standard requirement for MOE with average MOE value of 2066.73 N mm^{-2} and they have the highest average value for MOR, which the value was 9.151 N mm^{-2}, respectively. The DAP-treated boards were found superior compared to other treated boards for IB, TS and WA with average values of 0.256 N mm^{-2}, 15.43 and 35.82%, respectively.

DISCUSSION

The fire propagation and sub-index values, I and i_1 give a comparative measure of the amount of heat released and the flamespread from a lining material within a compartment (Rogowski, 1970; Abdul Rashid and Chew, 1990). A high value of I indicates greater contribution of heat release. If heat is the major contributor to hazard, it is defined as thermal hazard (Tewarson, 1994). The result of boron-formulated phosphorous-based fire retardant (BP®) of this study was as same as result recorded by Riem *et al*. (1971). For his study, he poured boron-based fire retardant, ammonium borate to wood fibres in powder form prior to particleboard fabrication. Then, he tested the fabricated treated particleboard with flame spread test. He found that the flame spread value was 25 or less, which the value was also falling under Class 1.

Other than that, the performance sub-index, i_1 provides an indication of ignitability and flammability of a material (Rogowski, 1970). The Malaysian Uniform Building By Laws, 1984 classified that non-combustible or materials with class 0 rating should have sub index, i_1, of 6 or less and performance index, I, of 12 or less (Abdul Rashid and Chew, 1990). According to Abdul Rashid and Chew (1990), timber-based products, except for cement board seldom achieve class 0 rating. The current test showed that MAP and DAP were efficiently reduced the subindex value lower than 6 but failed to reduce the performance index less than 12. A company from China, Jindao has tested cement bonded particle boards using fire propagation test and it was found that the particle boards were able to reduce the i_1 value less than 6 and the performance index, I less than 12 (Anonymous, 2009). The particle boards were tested with different thicknesses, from 12 to 16 mm and all of them presented same range of results. The difference of the results for the Jindao's particle boards compared to the results of current study might be caused by the difference in materials and binders used. As, for temperature-time relationship of fire propagation, the difference between the calibration and treatment curves gives a measure of heat release generated on the combustion of the specimen (Rogowski, 1970; Hall, 1975; Abdul Rashid and Chew, 1990). A maximum early heat release indicates ease of ignition and spread of flame. The heat release of the combustion of wood varies depend on the species, resin content, moisture content and other factors (Levan, 1984). The heat release happens when a material heated beyond its Critical Heat Flux (CHF) value (Tewarson, 1994). The CHF value is defined as the minimum heat flux at or below which a flammable vapour-air mixture is not generated and there is no sustained ignition (Tewarson and Ogden, 1992; Tewarson and Khan, 1988). The comparisons showed that particle boards treated with ammonia-formulated phosphorus-based fire retardants can be ignited under more severe heating conditions and the performances were superior compared to boron-formulated phosphorus-based fire retardants. The results of the current study were in a good agreement with Abdul Rashid (1986), which also studied the efficacy of MAP in reducing the heat release of particleboard. In his study, he also found that MAP-treated chipboards have maximum early heat release at 16 to 18 min. Ayrilmis *et al*. (2007) tested veneers which were treated with DAP and MAP for his study. But, he used cone calorimeter method to investigate the maximum heat release. In his study, he indicated that the heat release graphs of DAP and MAP-treated veneers produced two maximum heat release peaks when they were exposed to the fire source. When, he compared the results with the other treated veneers which were treated with borax/boric acid-based fire retardant which was also produced two maximum heat release peaks, he has found that MAP was the best in reducing the first maximum heat release. DAP was found to be effective to reduce the second maximum heat release compared to MAP and borax/boric acid. The fire retardants are hygroscopic in nature and they increase the water absorption of the treated particle boards. Yang *et al*. (2002) treated boards made from waste paper with fire retardants with retention range from 10, 15, 20 and 25%. The results of the research were the moisture content of the boards increased as the concentration of the fire retardants increased, even though the boards were not exposed to water. Based on the previous study, the water absorption of MAP-treated particle boards can be reduced by increasing the concentration to 20%. However, for boron-based fire retardant, the water absorption rate increased together with the increment of the concentration (Abdul Rashid and Chew, 1990). The longer and shorter pressing time occupied for the treated furnishes was expected to be a factor that influencing the MOR, MOE and IB of the treated particle boards. Different pressing time was applied due to the effect of fire retardants to the curing of the resin (Izran *et al*., 2008). The effect of the hot pressing length to the strength of the particle board has been investigated by Zhiyong *et al*. (2006), who fabricated medium density fibreboard with five different pressing schedules. He found that as the pressing schedule was increased from 90 to 160% the MOE value decreased from 110 to 70%. Same results were recorded by Rowell *et al*. (1997), where he tested the MOE performance of jute-based particle boards which have been hot pressed with two different pressing durations, 4 and 8 min. He recorded that particle boards pressed for 8 min had MOE value 53.3% lower than those who were pressed for 4 min. Even though, the MOE values for the treated particle boards for each chemical (except for MAP-treated boards) were lower than the standard requirement value, but still the MOE performance was sufficient, if later the boards are intended to be used as furniture components. It has been cited that the minimum MOE value for furniture, according to EN standard is 1600 N mm^{-2} (Osarenmwinda and Nwachukwu, 2007). Based on the strength performances, the particleboard also could be used for partitioning too, as strength is not a main factor to be seen in producing partition. Laminating and increase the thickness of the particleboard could be effective to enhance, not only its strength but also the fire performance, thus adding value to the fire retardant-treated panel.

CONCLUSION

The fire propagation test showed that the fire retardants were effective to reduce the heat release of the particle boards. The ammonia-formulated-phosphorous-based fire retardants performed more efficiently compared to boron-formulated-phosphorous-based fire retardant in reducing the maximum early heat release and temperature rise. At the same time, the fire retardants were also found affected the strength of the treated particle boards. All treated particle boards were not complied with the British-European standard requirements. The fire retardant hygroscopicity increased the water absorption rate, thus increased the thickness swelling of the treated particle boards. The best mechanical property results were recorded from MAP-treated particle boards and the best physical property results were recorded from DAP-treated particle boards. MAP-treated particle boards were the only particle boards that complied with standard requirement for MOE. One of the major problems of fire retardant-treated panels is the degradation of the strength overtime. Therefore, study on how to improve the strength of the fire retardant-treated particle boards should be furthered to add value to the panel.

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