Properties and Performance of Rubberwood Particleboard Treated With Bp® Fire Retardant

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Abstract

Rubberwood composites are available in many sizes and are frequently used as furniture and partitioning inputs. However they are naturally combustible and may limit its usage for other value-added products. Treating wood composites with fire retardant was one of the most effective ways to prevent such occurrence. In this study, Rubberwood (Hevea brasiliensis) particleboards were incorporated with BP® fire retardant through hot and cold soaking processes. Four different concentrations of fire retardant were applied for the study i.e., 15, 20, 25 and 30% (w/v). Treated and untreated particleboards were exposed to early burning performance test. Fire performance was assessed based on the amount of weight loss and width of burnt area formed on the boards after they were exposed to a fire source. The study shows that BP® had significantly affected the burnt area of the treated particleboards. Insignificant reductions of weight loss were recorded between 15-30% treatment concentrations. Early burning performance showed that increase of fire retardant concentration up to 25% (w/v) reduced the weight loss. There was no further weight loss reduction recorded above that concentration. The burnt area decreased as the concentration level of BP® increased. The smallest burnt area was recorded for the boards treated with 30% BP®. The addition of fire retardant had interfered slightly with the physical and mechanical properties of the treated particleboards. The physical and mechanical properties of the particleboards were adversely affected compared to untreated boards with increasing concentration of BP®.

Keywords: Early burning performance, fire retardant, rubberwood, exfoliation strength, *Hevea brasiliensis*, urea formaldehyde

1.0 INTRODUCTION

Hevea brasiliensis commonly referred to as rubberwood or heveawood has been widely accepted in Asia. Currently, there are many new fast growing plants introduced as potential substitutes for timbers from the forests, but the demand for rubberwood is still on the rise. Rubberwood is popular as a raw material for manufacturing wood composites such as particleboard and medium density fiberboard (Zaidon *et al*., 2007a; Loh *et al*., 2010; Jarusombuthi *et al*., 2010). Rubberwood composites are available in many sizes and are frequently used as furniture and partitioning inputs. However they are naturally combustible and may limit its usage for other value-added products. One of the factors that should be considered in the production of wood composites is the fire properties of the product itself.

In the United Kingdom, regulations called the UK Furniture and Furnishings (Fire) (Safety) Regulations 1988 has been established to show how important it is to know the fire properties of a product before it is introduced to the consumers. The regulations were mainly introduced to reduce the rising numbers of deaths and injuries suffered in fires started in upholstered furniture in the home, often through a dropped cigarette (Anonymous, 2009). Most of the fire deaths occur because the casualty is unable to escape from fires. Factors that often contribute to this situation are fire initiation, heat release, flame spread and generation of smoke, toxic and corrosive products, which these properties need to be controlled carefully to assess fire hazard and ease of fire control and extinguishment. There is no way to prevent the factors from happening and aggravating fire development. The only way that can be done is to reduce and delay the development, so that the consumers have enough time to escape before the fire becomes uncontrollable. Treating wood composites with fire retardant is one of the most effective ways to prevent such occurrence.

Fire retardant treatments have proven to be effective in reducing combustibility of wood-based composites (Izran *et al*., 2010; 2009a). Fire retardants can be applied in two ways, either by incorporating them into wood fibers of the composites or by spreading them on the surface through coating. Incorporating fire retardants into wood fibers provides much better protection than coating. The incorporation treatment is usually done either with or without vacuum pressure. The most common non-vacuum treatment is hot and cold bath. In this treatment, wood fibers are soaking in a heated fire retardant solution for a period of time, normally between 4-8 h, depending on the type of fibers. Highly absorbent fibers like kenaf core require shorter hot bath process as excessive hot soaking may cause the fibers to become too soft and prone to brittle (Izran, 2009b). The hot bath expands fiber cells and eliminates air in them so that the fire retardant solution can be absorbed by the cells during the following cold bath. Unfortunately, this method is rarely used commercially as it is time consuming, even though it is effective to incorporate fire retardants deeply into wood fibers.

BP® comprises of a combination of phosphoric acid and boric acid which provides insecticidal, fungicidal and fire protection properties. Like other fire retardants, many factors need to be considered for the incorporation of BP® in the manufacture of wood composites as it may also affect physical and mechanical properties. This study reports the fire performance as well as physical and mechanical properties of BP®-treated rubberwood particleboard.

2.0 MATERIALS AND METHODS

Rubberwood particles were supplied by Heveaboard Sdn. Bhd. The particles were screened to obtain fibers with length between 1-2 mm. The particles were oven-dried at 80°C until they achieved 4% moisture content. Urea Formaldehyde (UF) resin was selected as a binder and was provided by Malayan Adhesives and Chemicals Sdn Bhd.

2.1 Hot and cold bath processes

Dried rubberwood particles were treated separately with four different concentrations of BP® solutions. BP® solutions were prepared at the concentrations of 15, 20, 25 and 30% using distilled water as diluents. The solutions were prepared by heating mixture of BP® and distilled water in a tank until it reached a temperature of 70°C. The heating temperature was found to be most suitable to dilute BP® powder (Izran *et al.,*2010). When the fire retardant salts had fully dissolved, the wood particles were added into the solutions and the mixture was further heated for 24 h. The solutions containing wood particles in them were left until they reached an ambient temperature (27-30°C). The mixture was further left for another 8 h at ambient temperature. After the hot and cold soaking process, the wood particles were placed in the oven set at 70°C for 2 days to dry them down to 4-5% moisture content.

2.2 Board fabrication

The targeted board size was 300×300×10 mm (l×w×t) with a density of 750 kgm^{-3}. The board size was determined in accordance with Japanese Industrial Standard 1993. The resin loading chosen was 10% (based on oven-dried wood particles). According to the calculations made, total wood particles, hardener and resin needed to fabricate the desired boards were 602, 150 and 58 g respectively. No wax was added. Mixing was done by spraying the resin onto the wood particles in a blender equipped with airless spray gun. After the mixing stage, the furnish was scattered in a former of dimension 300 × 300 × 10 mm^3 (l × w × t) to form a mat. The mat was pre-pressed manually in a cold press and subsequently in a hot press machine at 170°C for 6 min to the targeted thickness of 10 mm. The hot-pressed boards were left to dry at a room temperature of 27°C surrounding until the resin of the boards was fully cured and were kept in a conditioning chamber with 65±2% relative humidity at temperature of 20±2°C for one week. Five boards were prepared for each treatment concentration and utilized for fire, physical and mechanical tests (4 boards for physical and mechanical tests and 1 board for fire test). The conditioned boards were trimmed and cut into specified sizes according to the standard requirement for each test.

2.3 Early burning performance test

The efficacy of the fire retardant treatment was assessed based on the percentage weight loss and width of burnt area caused by the fire. For this test, three replicates were utilized for each concentration. Both the treated and untreated samples were maintained at 12% MC, conditioned and their initial weights were measured before the test. One sample was tested at a time. The samples were inclined at 45° and the distance between the flame and the sample was set at 5 cm. The test time was set at 5 min and all the tests were conducted in a draft-free room. The samples were again left in the conditioning room until their weights were constant. Percentage total weight loss was calculated as follows (Eq. 1):

$$\text{Weight loss}\,(\%) = \frac{W_2 - W_1}{W_1} \times 100\% \qquad (1)$$

Where:
W_1 = Conditioned weight after exposure to fire
W_2 = Conditioned weight before exposure to fire

Whereas, the burnt area was calculated using Eq. 2:

$$\text{Burnt area}\,(\%) = \text{Char area}/\text{Total area} \times 100\% \qquad (2)$$

2.4 Physical and mechanical tests of particleboards

The physical (TS and D) and mechanical (MOR, MOE and EST) tests were carried out in a laboratory using the methods specified in Japanese Industrial Standard (JIS A5908 1993). The boards for the tests were trimmed at the edges and cut into required dimensions as specified in the standard (Table 1).

Table 1: Details on manufactured rubberwood particleboards

Raw material	Rubberwood particles (1-2 mm)
Targeted board density	750 kg m^{-3}
Board Size	(300 x 300 x 10) mm^3
Adhesive	
UF Resin	10% (w/w of wood particles oven dry)
Hardener (NH_4Cl)	3% (based in UF weight)
Concentrations of BP® solutions	15, 20, 25 and 30% (w/v)
Test and Sample Sizes	
Early burning performance (EBP)	(220 x 220 x 10) mm^3
Bending Strength Tests (MOR and MOE)	(230 x 25 x 10) mm^3
Exfoliation Strength Test (EST)	(50 x 50 x 10) mm^3
Density (D)	(100 x 100 x 10) mm^3

The density and MC of each cut sample was recorded. All the tests were carried out using Zwick 1400 Universal Testing Machine. All data (physical, mechanical and fire tests) were analyzed using Duncan multiple range test to determine the differences between treatment levels.

3.0 RESULTS

3.1 Early burning performance test

The results on the mean weight loss and burnt area of treated and untreated boards after exposure to fire are summarized in Table 2. Lower total weight loss indicates higher resistance against thermal degradation of fire and smaller burnt area indicates better protection to flame spread. From the results obtained, the study shows that BP® had significantly affected the weight loss and burnt area of the treated samples. The burnt area decreased as the concentration level of BP® increased. The smallest burnt area was recorded for the boards treated with 30% BP® where the percent difference to the untreated boards was -42.15%. The efficacy of the fire retardant in reducing thermal degradation by the fire can be assessed by reviewing weight loss of the samples. The weight loss of the treated and untreated samples is shown in Table 2. Insignificant reductions of weight loss were recorded between 15-30% treatment concentrations. The reductions were between 60.75-73.21% compared to the untreated boards respectively. Even though, the reductions were not significant, but there was an apparent reduction of thermal degradation brought about by the different concentrations of fire retardants.

Table 2: Mean burnt area and weight loss values of treated and untreated particleboards

Early Burning Performance Test		
Concentration (%)	Burnt area (%) ± SD	Weight loss (%) ± SD
Untreated	43.58±0.77^{a}	2.65±0.07
15	35.54±1.62 (-18.44)^{b}	1.04±0.21 (-60.75)^{b}
20	32.23±2.49 (-26.04)^{bc}	0.86±0.10 (-67.55)^{b}
25	30.32±1.18 (-30.43)^{c}	0.75±0.27 (-71.69)^{b}
30	25.21±0.67 (-42.15)^{d}	0.71±0.17 (-73.21)^{b}

[1]Means within a column followed by the same alphabets are not significantly different p≤0.05;[2]Values in parentheses are percent change over untreated and ± standard deviation

Table 3: Mean physical and mechanical values for fire retardant-treated particleboards at different concentrations compared with untreated

Concentration (%)	Physical and Mechanical Tests				
	Density ($kgcm^2$) Mean ± SD	Density($kgfcm^2$) Mean ± SD	MOE ($kgfcm^2$) Mean ± SD	EST ($kgfcm^2$) Mean ± SD	TS (%) Mean ± SD
Untreated	775.17±9.41[a]	124.28±3.85[a]	937.75±0.17[a]	3.4±0.37[a]	97.37±5.76[a]
15	764.42±13.69[a] (-1.39)	99.05±8.80[b] (-20.3)	648.49±171.89[b] (-30.85)	2.7±0.17[ab] (-20.59)	111.48±8.14[b] (14.49)
20	796.50±24.20[a] (2.75)	96.15±8.23[b] (-22.63)	1016.8±108.29[b] (8.44)	2.35±0.18[a] (-30.88)	113.09±7.03[b] (16.14)
25	842.75±18.18[b] (8.71)	82.24±10.55[b] (-33.83)	812.94±131.50[b] (-13.31)	2.16±0.11[a] (-36.47)	116.19±3.35[b] (19.33)
30	936.25±27.07[b] (17.20)	58.55±4.80[c] (-55.06)	707.37±88.55[b] (-24.57)	2.03±0.38[a] (-40.24)	115.26±4.03[b] (18.37)

[1]: Means within a column followed by the same alphabets are not significantly different at p≤0.05; [2]: Values in parentheses are percent change over untreated and ± standard deviation; MOR = Modulus Of Rupture; MOE = Modulus Of Elasticity, EST = Exfoliation Strength Test; TS = Thickness Swelling

3.2 Physical and mechanical tests

The data for physical and mechanical properties of the treated and untreated particleboards are shown in Table 3. For Modulus Of Rupture (MOR) and Modulus Of Elasticity (MOE) values, the negative signs indicate a reduction in the value of properties, while for thickness swelling and water absorption, the negative sign reflects an improvement in dimensional stability. The addition of fire retardant had interfered slightly with the physical and mechanical properties of the treated particleboards. The physical and mechanical properties of the particleboards were adversely affected compared to untreated boards with increasing concentration of BP®. The reductions for the mechanical properties (MOR, MOE and EST) were 55.06, 24.57 and 40.24%. EST or IB was often considered as an indicator of the quality of bonding and bond development within a board (Winandy *et al*., 2008). With regard to Thickness Swelling (TS), the TS values were recorded to have increment of percent change (14.49-19.33% compared to the untreated boards) from 10-25% fire retardant concentration. However, the percent change value for TS decreased to 18.37% when the concentration was 30%, even though the change was not significant. The hygroscopicity of the resin as well as the fire retardant confirmed to contribute in increasing the TS values (Izran *et al*., 2009b).

4.0 DISCUSSION

The smallest burnt area was recorded for the boards treated with 30%. This is due to boron compounds present in the formulation of BP®. Boron compound reacts with combustible gases and tar which generated by the wood particles and converting them into char. The products generated from this process, carbon dioxide and water will dilute the combustible gases, resulting in the reduction of flame spread. Furthermore, BP® also contains phosphoric acid which is also effective in aggravating char formation. Phosphorous compound can form a liquid or glossy layer, which prevents air from reaching the wood surface and at the same time helps in forming char. It has been revealed by Izran *et al*. (2009a) that BP® was as effective as Diammonium Phosphate (DAP) and Monoammonium Phosphate (MAP) in reducing flame spread; nevertheless, it took longer time to form char on the samples. This is because the amount of phosphorous compound in BP® is lower than the other two fire retardants. The efficacy of phosphorous in generating char is supported by Nussbaum (1988). His research found that charring rate of boron-based fire retardant (without added phosphorous compound) at 15% retention was 0.620 mm min^{1}, whereas for phosphorous-based fire retardant, at similar retention, the char rate was slightly greater i.e., 0.638 mm min^{1}. By looking at the processes of char formation as well as the char formation rates of the two compounds, it can be concluded that BP® exhibits two different mechanisms in providing efficient fire protection: (1) the boron compound delayed ignition in the samples, which brought delay char formation and (2) the phosphorous compound prevents spread of fire on the samples by encouraging the formation of char.

As for physical and mechanical results, the large reduction of EST indicates that the UF resin bond development was affected during hot press of board fabrication. It is probable that the bond development process may have be interfered by the mildly acidic BP® which acts as an accelerator in curing the UF resin, thus causing it to cure faster than it should (Izran *et al*., 2009a). Another possible explanation for the reduction of IB is the characteristic of BP® itself. BP® was found to be transformed into liquid at 70°C, however, gradually it will transform to its natural form (solid) as the temperature decreases to ambient temperature (Izran *et al*., 2009b). It is possible that BP® may also prevent bonding between wood particles and the resin by covering the surfaces of the particles as it transform to solid form during hot pressing. Previous studies have reported that BP® is readily found on the surface of the treated particleboards, which were conditioned for 24h following hot pressing stage (Izran *et al.,*2010). These factors are believed to cause reductions on the MOR and stiffness (MOE) of the treated boards. For TS values, Poor EST of the treated boards is assumed to affect the TS values. Previous research showed that thickness swelling has a direct relationship with internal bond or exfoliation strength. Panel with higher IB or EST values can resist the stress due to wood expansion and press opening, resulting in lower TS (Del Menezzi, 2007).

5.0 CONCLUSION

BP® was successfully incorporated in rubberwood particleboard through hot and cold bath treatment. The fire retardant treatment was effective in reducing the weight loss as well as flame spread on the surface of the boards respectively based on the early burning performance test. However this treatment has adverse effects on the physical and mechanical properties of the treated boards. Hence, studies on reducing the effects of the fire retardant to the strength and appearance of the boards should be conducted in particular, on the time needed for the cold bath treatment to allow impregnation of BP® fire retardant into the wood particles at different concentrations. This will determine the most suitable concentration to achieve standard chemical loading for BP®-treated particleboard within the shortest period of time, thus reducing treatment cost.

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