



Physical and Mechanical Properties of Flame Retardant-Treated *Hibiscus Cannabinus* Particleboard

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Abstract

Physical and mechanical properties of flame retardant-treated kenaf particleboards were studied using physical tests such as water absorption, thickness swelling and mechanical tests such as modulus of rupture (MOR), modulus of elasticity (MOE) and internal bond (IB). The kenaf core particles were treated with 10% concentrations of three types of flame retardants namely diammonium phosphate ($(\text{NH}_4)_2\text{HPO}_4$), monoammonium phosphate (NH_4HPO_4) and BP® [mixture of 27-33 % boric acid, 67-73 % guanylurea phosphate and 0.0-4.2 % phosphoric acid]. The study showed that DAP-treated particleboards complied with the thickness swelling and water absorption of British-European standard [BS EN 317:1993] requirements. BP®-treated particleboards were found to have performance values superior than the British-European standard requirement values for MOR [BS EN 310:1993] and MOE [BS EN 310:1996]. MAP-treated particleboards surpassed the standard requirement value for IB [BS EN 319:1993]. However, all treated particleboards complied with the standard requirement value of MOE except DAP-treated particleboards. The untreated particleboards complied with all the standard requirements of the physical and mechanical tests. Overall, the flame retardants affected the physical and mechanical properties of the kenaf core particleboard

Keywords: Kenaf, Fire retardants, Hot and cold, Water absorption, Thickness swelling, Modulus of rupture, Modulus of elasticity, Internal bond

1. Introduction

There are many studies have been done around the world to prove that kenaf can be used to produce kenaf-based composites with acceptable physical and mechanical properties. It has been reported by Paridah et al (2004) and (2009) that kenaf core-based particle boards were able to give better MOR, MOE, internal bond, thickness swelling and water absorption performances than that of rubberwood-based particleboards. Muehl et al (1999) studied the strength of kenaf-based particleboard with the influences of different amount of resin and wax used to the strength of the particleboards. He found out that the mechanical performance of kenaf-based particleboards could be improved with the reduction of wax and increase of resin loading. However, the increase of the resin loading caused the particleboards to have poor water absorption and thickness swelling performance. Kenaf also has been used as a raw material to produce kenaf-based plastic polymer composite which have superb strength performances. Based on the research done by Mohamad Zharif (2008), where he tested the kenaf-based polymer composite with seven different mechanical tests such as fractural modulus, fractural strength, impact strength, tensile strength, yield strength, elongation at break and tensile

modulus. He recorded in his report that the kenaf-based polymer composite had superb performance for all the tests and surpassed the ASTM standard requirements for those mechanical tests. The results were in a good agreement with Jalaludin (2001). With the evidences shown above, kenaf is no doubt can be utilized in many ways for composite industries. Particleboard is a structural material made of wood fragments, such as chips or shavings, which are mechanically pressed into sheet form and bonded together with resin (Anon, 2000). Other definition of particleboard is panel from dry wood particles that have been sprayed or dusted with a binder resin, and are bonded together with resin and heat (Charles, 1986). Particles for the particleboards can be made from almost any type of wood, whether whole logs or log residues such as trimmings and shavings from lumber or plywood manufacturing (Charles, 1986). This panel is available in large panel sizes which are suitable for many uses such as furniture components and partitioning. This engineered panel is often modified to many high-value products for different situations of usages such as fire-retardant treated particle board (for fire protection purposes), moisture resistant particle board (for outdoor use), thin particle board (for furniture industry), high density particle board (for flooring). The fire resistance of the composite is very important nowadays, especially when the composite is used as structural components. The primary objective of a fire-resistant structural design is to maintain the structural integrity during a fire for a sufficient period so that all the occupants may safely evacuate, firemen may extinguish the fire, and the loss of property may be minimized (Park *et al.*, 2004). According to Abdul Rashid *et al.* (1990), particleboard is a combustible material. Previous studies revealed that treating particleboards with flame retardants were effective to reduce the combustibility and heat release of the panel (Abdul Rashid *et al.*, 1990; Izran *et al.*, 2008a, 2009a and 2009b). Most of the strength and physical properties of the treated particleboards however, were sharply reduced. Improper curing of the adhesive was identified as the cause for the poor performance of boards. This was attributed to the interference caused by the dry salt retention during manufacture of the boards (Izran *et al.*, 2009b and Zaidon *et al.*, 2007). Other than the dry salt retention, the buffering capacity of the material used was also proved to cause the improper curing of the resin (Izran *et al.*, 2008b). This paper reports the mechanical and physical properties of flame retardant-treated *Hibiscus cannabinus* core particleboards.

2. Materials and Method

2.1 Particle preparation and treatment

Kenaf core was used as raw material for the research. The kenaf core is light and porous, having a bulk density of 0.10 – 0.20 g/cm³. It can be crushed easily into light-weight particles. Kenaf core has cellulose and lignin content as same as wood [31-33% cellulose and 23-27% lignin] and it has higher content of hemicellulose than wood (Paridah *et al.*, 2009). The raw material was supplied in chip form by Lembaga Tembakau Negara (LTN), Malaysia. The chips then were flaked and screened into 1–2 mm. The particles were dried at 105±2°C to reduce the moisture content to 5% before the particles were treated with the fire retardants through hot and cold bath soaking process. Flame retardants used to treat the particles 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 27-33 % boric acid, 67-73 % guanlyurea phosphate and 0.0-4.2 % phosphoric acid]. Adhesive used in this study was urea formaldehyde (UF) supplied by Malaysian Adhesive Company Sdn. Bhd., Shah Alam. For the treatment, dried kenaf core particles firstly, were hot soaked in the flame retardant solutions (dissolved with water to 10% concentration) for 10 minutes at the temperature of 70°C and were left to ambient temperature. Then the particles were cold soaked for 15 minutes in MAP solution, 36 minutes in BP® solution and 14 minutes DAP solution to achieve 7.19 % dry salt retention (dry salt retention for 1029 g dried particles to produced a particleboard with 700 kg/m³ as targeted density) to meet the standard requirement. Standard chemical loading for a board (50mm and thinner board and a minimum penetration of 12mm) recommended by American Wood Preservers Association (AWPA) Standard C 20-6 is 50kg/m³ (Anon, 1968). The flame retardant concentration, dry salt retention and cold soaking time were determined through preliminary studies (Izran *et al.*, 2008c).

2.2 Particleboard fabrication

The targeted board density was 700 kg/m³. Amount of dried kenaf core particles to produce a board with that density was 1029 g. The parameters used for manufacture of the particleboards are exhibit in Table. 1. Firstly, the dried treated kenaf core particles were taken out from the oven and were weighed to get the desired weight. Then, the particles were directly placed into the particleboard mixer. Urea formaldehyde resin mixed with wax and hardener was sprayed to the kenaf core particles in the particleboard mixer, which was equipped with airless spray gun. The moisture content of the furnish was 20%, which was higher than the targeted moisture content, therefore the furnish was re-dried for three hours to 12% MC. The re-dried furnish was then formed in a former, pre-pressed and subsequently pressed in a hot press at 160°C. The pressing time for each treatment varied from 6 to 9 minutes. Variations in pressing time for different flame retardant treatments were occupied based on the effect of flame retardant to the gelation time of the resin reported by (Izran *et al.*, 2008b and Izran *et al.*, 2009c). The DAP-treated furnish was hot pressed for 9 minutes, the BP®-treated furnish and untreated furnish were pressed for 7 minutes and MAP-treated furnish was pressed for 6 minutes. Prior to

cutting into testing blocks, all boards were conditioned at 20°C and 65% relative humidity until equilibrium, i.e 12%. Total of three boards for each treatment were trimmed according to the standard requirement size and were distributed for the strength tests.

2.3 Mechanical and physical property evaluation

The tests were conducted in accordance with British Standard EN. The physical and mechanical testing 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).

2.4 Data adjustment using ANOCOV

The densities of the particleboards were found to be in the range of 590 kg/m³ to 780 kg/m³. Due to that, an adjustment using analysis of covariance (ANOCOV) was performed to correct for expected differences in physical and mechanical properties due to the difference of density value (Zaidon *et al.*, 2008). Density was chosen as a covariate variable and adjusted means were separated using Least Significance Different (LSD) method.

3. Results and Discussions

3.1 Mechanical and Physical Properties of treated and untreated particleboards

The adjusted data for physical and mechanical properties of treated and untreated particleboards are demonstrated in Table 2. 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.

3.1.1 Mechanical Property Evaluation

The MOR values for particleboards treated with DAP; BP® and MAP were reduced by 54.61%, 38.95% and 52.86% respectively, which are significantly lower compared to the untreated particleboards. The MOR value of the untreated particleboards was 15.74 N/mm². The MOR values for the MAP and DAP-treated particleboards were found to be lower than the BP®-treated particleboards. However for MOE, treatment using BP® did not affect the MOE of the particleboards as the stiffness value of the particleboards was 3.72% higher than the untreated particleboards. The MOE value for the untreated particleboards was 2066 N/mm². The treatments using DAP and MAP, both caused reduction of the MOE of the particleboard by 19.96% and 10.34% from the original stiffness. 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 particleboards. Different pressing time was applied due to the effect of fire retardants to the curing of the resin (Izran *et al.*, 2008b and 2009c). It was also suspected that strength loss occurred during chemical treatment and subsequent redrying of the panel (White and Sweet, 1992). The percent relative change in MOR and MOE is exhibit in Figure 1. More than 50% reductions were recorded for IB values of all treated particleboards. The reductions were 63.29% for the DAP-treated particleboards, 64.59% for the BP®-treated particleboards and 84.39% for the MAP-treated particleboards from the IB value of the untreated particleboards, which was 0.69N/mm². The percentage of reduction for each treatment is present in Figure 2. The reductions of the IB values for the treated particleboards may be attributed to insufficient or over sufficient curing of the resin. It was indicated that, flame retardants affected the pH glue line which slows down or aggravates up the polymerization reaction rate (Izran *et al.*, 2008b and 2009c). Thus, modifications on the hot pressing time and temperature were required to fully cure the resin.

3.1.2 Physical Properties Evaluation

With regards to physical properties, all flame retardant-treated particleboards exhibit higher thickness swelling (15.43%-21.64%), compared to the untreated boards (13.87%). Thickness swelling is to measure the dimensional stability of the particleboards. Lower thickness swelling value indicates a more stable board. The results show the flame-retardant treatments reduced the dimensional stability of the particleboards. In general, all flame retardant treatments increased the water absorption of these particleboards except for particleboards treated with DAP. Flame retardants are hygroscopic in nature and with that characteristic; they increased the water absorption of the treated particleboards. The percent relative change of thickness swelling and water absorption against the untreated particleboard is presented in Figure 3. Muehl *et al.* (1999) treated boards made from waste paper with flame 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. The water absorption of MAP-treated particle boards can be reduced by increasing the concentration to 20 %. However, for boron-based flame retardant, the water absorption rate increased together with the increment of the concentration (Abdul Rashid *et al.*, 1990).

4. Conclusions

The findings from this study revealed that flame retardant treatments significantly affect the physical and mechanical properties of the kenaf core particleboards. The flame retardants were found to affect the curing of the resin and

modification on the hot pressing time was occupied to be sure that the resin is fully cured and compact particleboards could be produced. The BP®-treated particleboards performed the best in the mechanical tests even though the IB value for the particleboards was slightly 1.31% lower than the DAP-treated particleboards. In fact the MOE performances of the BP® particleboards were better than the untreated particleboards. The reductions of the mechanical properties were expected caused by the hot pressing temperature, time and subsequent re-drying of the particleboards. Physical properties were dominated by the DAP-treated particleboards. The DAP-treated particleboards were having the lowest thickness swelling value compared to the other treated particleboards. It is interesting to note here that the water absorption of the DAP-treated particleboards was lower than the untreated particleboards. As a whole, the treatment system used in this study may be suitable for the manufacturing of flame retardant-treated particleboard from kenaf core. Further study on improving the mechanical and physical performances of the treated particleboards should be conducted to expand the usage of the particleboards. Besides, the increase in resistivity against thermal degradation will further expand the usage of the panels.

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Table 1. Parameters used for manufacture of the particleboards

Raw Material	kenaf (1-2 mm particle size)
Targeted board density	700 kg/m ³
Targeted board MC	12%
Board Size	(350 x 350 x 12) mm ³
Adhesive	
UF resin	12% (w/w of dried particles)
Hardener (NH ₄ Cl)	3% (based on resin)
Wax	1% (based on dried particles)
Flame retardants	
1. diammonium phosphate (DAP)	10% (w/w of particles) decided after preliminary test of hot and cold bath Treatment
2. monoammonium phosphate (MAP)	
3. Mixture of BP®:	
i) guanylurea phosphate (67-73%)	
ii) phosphoric acid (0.0-4.2%)	
iii) boric acid (27-33%)	

Table 2. Adjusted mean mechanical and physical values and percent change in properties for flame retardant-treated particleboards compared to untreated

Performance	Standard requirements	Board density (kg/m ³)	Flame retardant treatments			
			Control ± S.D	DAP ± S.D	BP® ± S.D	MAP ± S.D
MOR (N/mm ²)	≥ 14N/mm ²	701.68	15.74 ^a ±	7.14 ^b ±	9.61 ^c ±	7.42 ^{bd} ±
Change (%)			1.70	1.06	2.39	0.86
IB (N/mm ²)	≥ 0.4N/mm ²	678.28	0.69 ^a ±	0.26 ^b ±	0.25 ^{ba} ±	0.11 ^c ± 0.41
Change (%)			0.50	0.51	0.41	0.11 ± 0.41
MOE(N/mm ²)	≥1800N/mm ²	701.68	2066 ^{ac} ±	1670.06 ^b	2145.79 ^a	1852.37 ^{bc}
Change (%)			297.69	± 378.31	± 565.34	± 229.93
TS (%)	≤ 16 %	NA	13.87 ±	15.43 ±	21.64 ±	18.62 ±
Change (%)			0.91	4.96	3.06	5.62
WA	NA	NA	37.23 ±	35.82 ±	58.09 ±	48.16 ±
Change (%)			2.63	14.19	8.08	8.14
				(-3.79)	(35.91)	(29.36)

¹Means within a row followed by the same alphabets are not significantly different at p≤0.05,

²Percent change over untreated and ± are standard deviations, ³Values are adjusted mean of ten samples

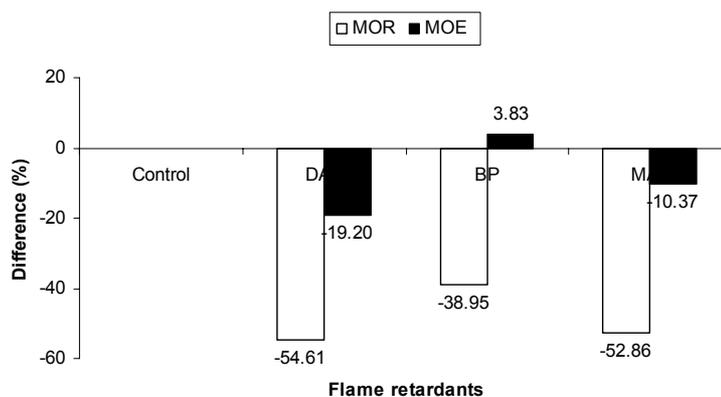


Figure 1. Percent relative change in MOR and MOE against the untreated

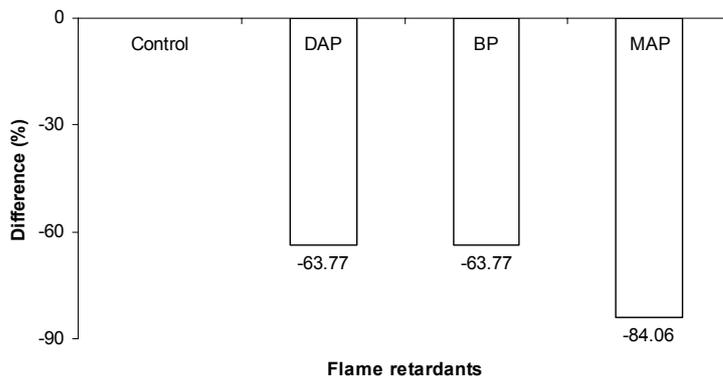


Figure 2. Percent relative change in internal bond against untreated

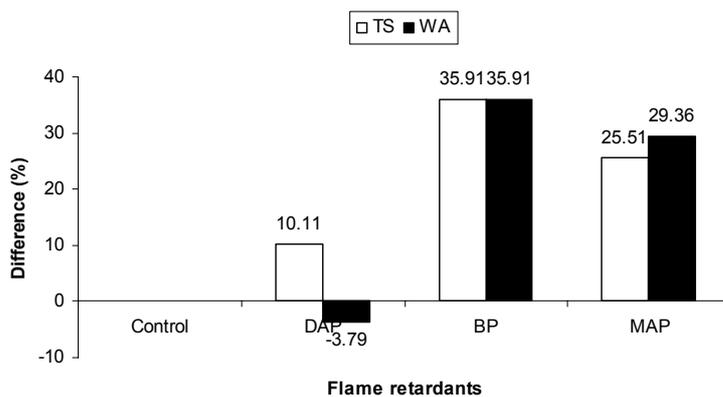


Figure 3. Percent relative change in thickness swelling and water absorption against untreated