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SYNERGISTIC INFLUENCE OF FLAME RETARDANT ADDITIVES AND CITRIC ACID ON THE FUNCTIONAL PROPERTIES OF RICE HUSK/WOOD BLENDED PARTICLEBOARDS

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ABSTRACT

The selected functional properties of rice husk/wood blended particleboards which include thermal analysis, limiting oxygen index, morphological analysis, and mechanical properties have been investigated. Rice husk/wood particleboards were produced with one step hot press casting technique using citric acid to improve the compatibility in the particleboards with calcium oxide and aluminum oxide as flame retardants. The results showed improvement in the mechanical properties, flame retardancy, and thermal stability with the addition of flame retardants to the particleboards. The aluminum oxide synergy with citric acid in rice husk/wood particleboards gave the best flame retardancy.

Keywords: Flame retardants, mechanical properties, particleboards, physical properties, thermal properties, waste natural fiber.

INTRODUCTION

The increasing population of humans with the sustainability development oriented in the modern era will demand more structures of construction materials. Rise in the manufacture of construction materials has also led to increasing in greenhouse gas emission and diminution of natural assets. Agro-industrial lignocellulosic

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wastes have been used as a new economic social and environmental alternative material for particleboards production due to the increasing number of it in the agricultural wastes (de Lima Mesquita *et al.* 2018). Furthermore, it is possible to have a combination of wood with other lignocellulosic materials to manufacture environmentally friendly products without reducing their quality.

According to de Melo *et al.* (2014), rice husk (*Oryza sativa*) is highly potential for particleboards utilization among most agricultural by-products. It has been one of the major waste products from the agricultural industry of the producing countries. Due to the high quantities of silica, cellulose and lignin in rice husk couple with other useful reinforcement properties, rice husk is used in the construction industry (Temitope *et al.* 2015, Battegazzore *et al.* 2018). The presence of a high concentration of amorphous silica determines the pozzolanic effect, which exhibits cementations properties of rice husk. Also, the use of rice husk ash which contains high amorphous silica eventually improves the strength and durability of concrete (Sulaiman *et al.* 2018).

Rubberwood (*Hevea brasiliensis*) trees were initially planted for their latex. When the trees reached an age of over 25 years, the old mature trees are felled for replanting as the latex production decrease (Jamil *et al.* 2013). Hence, the rubberwood logs are therefore used for the manufacture of a variety of products, such as particleboards, medium density fiberboards (MDF), plywoods, laminated veneer lumbers (LVL) and so on, due to its favorable medium-density-hardwood and natural light color (Loh *et al.* 2010). They also stated that, due to the unattractive price of rubber and conversion of rubber plantation to oil palm plantation, the rubber plantation area was decreasing and the supply of rubberwood was subsequently reduced. Thus, the study focused on the incorporation of rice husk and rubberwood particles into particleboards production.

Presently, urea and phenol based formaldehyde are commercially used as particleboards binder in manufacturing (Sulaiman *et al.* 2016, Cèsar *et al.* 2017). However, formaldehyde-based resins are not environmentally friendly and also constitute health disorders that contain harmful chemical substances (Suraya *et al.* 2018). Previous work monitored with the aid of FTIR spectra by Umemura *et al.* (2012) showed that there was a reaction between citric acid and wood bark given rise to the formation of ester linkage involved in the reaction between the carbonyl groups and the hydroxyl groups of the citric and wood. Kusumah *et al.* (2016) reported the result of the characterization of particleboards manufactured from the combination of sorghum bagasse and citric acid.

Building fire resistance awareness has been increased to ensure the safety of occupants at the same time provide sufficient time for fireman to extinguish the fire and minimize property loss (Umemura *et al.* 2012). Flame retardants can be classified into two categories, which are additive flame retardants and reactive flame retardants. The use of mineral flame retardant in particleboards has resulted in the separation of lignocellulosic particles and has also reduced the thermal conductivity of the particleboards, which subsequently led to flame retardancy (Cèsar *et al.* 2017, Zhao *et al*. 2017). Mineral fillers used to decrease the flammability of the substances are carbonates or hydroxides. According to Hull *et al.* (2011), aluminum hydroxide decomposes endothermically to form aluminum oxide (Al_2O_3) that releases water vapor that dilutes the radicals in the flame, whereas the alumina residue builds up to form a shielding effect for the blazing polymer.

To the best of the author's knowledge, there is no report on the use as a flame retardant additive of a particleboards characteristic made of citric acid hybridized rice husk/wood particles reinforced with aluminum oxide (Al_2O_3) and calcium oxide (CaO). The main objective of this study was therefore to assess and evaluate the synergistic effects of citric acid and flame retardant additive on the functional properties of particleboards made from hybridized rice husk/wood particles. The produced particleboards will be evaluated for their changes in functional groups and morphological characteristics, limited oxygen index and thermal properties, as well as physical and mechanical properties, so that the targeted minimum required standard for particleboards is met.

MATERIALS AND METHODS

The rice husk used for this study was from Kilang Beras Bernas Paya Keladi, Kepala Batas Pulau Pinang, Malaysia while the wood particles consist of rubberwood obtained from Hevea Board Berhad, Negeri Sembilan, Malaysia. The rice husk and wood particles used for this study were a ratio of 50:50. The adhesive used was citric acid obtained commercially from R&M Chemicals, while the flame retardant additives used in this research were aluminum oxide (Al_2O_3) and calcium oxide (CaO), which were purchased from Bendosen Laboratory Chemicals.

Preparation of raw materials and production of particleboards

Both the rice husk and wood particles were grounded to reduce the size to less than 10 mm with the aid of Riken Grinder. An oven-dried weight of the raw materials which equivalent to 800 kg/m^3 targeted density of particleboards was prepared. 10 % (w/w) Al_2O_3 and CaO powder were each added into the particleboards production formulation in order to have flame retardant properties, and mixed together with a citric acid solution. Three formulations as shown in Table 1 were used. The particleboards were prepared according to Hashim *et al.* (2011) and Kusumah *et al.* (2016) with slight modification. The design of the casting mold was to prepare particleboards in six replicates each and maintained a uniform density of 800 kg/m^3 according to the formulation shown in Table 1 in a wooden mold. The cast was initially pre-pressed by cold press followed by hot pressing at 5 MPa pressure for 20 min. The thickness of the particleboards was controlled by 10 mm steel bars placed at the side before subjected to the hot press by the hot press machine.

Table 1: Formulation for particleboards preparation.

Materials	Agro waste (g)		Fire retardant %		Citric acid (CA)	Total (g)	Distilled water (mL)
	Rice husk	Wood Particles	Aluminum oxide (Al_2O_3)	Calcium oxide (CaO)			
Control	179,87	179,87	-	-	-	359,74	50
	163,52	163,52	30,56	-	-	357,60	50
	163,52	163,52	-	30,56	-	357,60	50
10 % CA	163,52	163,52	-	-	30,56	357,60	50
	149,89	149,89	28,02	-	28,02	355,82	50
	149,89	149,89	-	28,02	28,02	355,82	50
20 % CA	149,89	149,89	-	-	56,03	355,81	50
	138,36	138,36	25,86	-	51,72	354,30	50
	138,36	138,36	-	25,86	51,72	354,30	50

Characterization of particleboards properties

The possible changes on the morphological outlay of each particleboards were monitored with Thermo Scientific Scanning Electron Microscopy (SEM). The samples were prepared as reported by Hashim *et al.* (2011) and examined on the SEM model of FEI Quanta FEG 650. FT-IR Spectrophotometer of IRPrestige-21 from Shimadzu was used to monitor the various functional groups existing in each type of particleboard sample. The particleboards were grounded into a pellet with an addition of potassium bromide (KBr) and scanned through a wavelength of 500 cm^{-1} - 4000 cm^{-1} under nitrogen. The spectra results were compared and analyzed. The limiting oxygen index (LOI) was carried out according to standard ASTM D2863-08 (2008) with a dimension of 8 cm × 1 cm × 0,5 cm. Thermal analysis of all produced particleboards will be run using Mettler Toledo TGA/SDTA851^e thermogravimetric (Mettler Toledo Corp, Switzerland). About 10 mg of each sample was put in an aluminum pan and burn under a nitrogen atmosphere at starting temperature of 30 °C to 930 °C with a heating rate of 20 °C/min.

All the particleboards were prepared according to the Japanese Industrial Standard JIS A5908-03 (2003) for evaluation of physical and mechanical properties. The mechanical tests of modulus of rupture (MOR) and internal bond (IB) strength were executed with the aid of Universal Instron testing machine System Model UTM-5582 operational on a load cell capacity of 10^3 kg. The physical tests were evaluated on ten specimens, weighed to an accuracy of 0,01 g from each panel include for density, water absorption (WA) and thickness swelling (TS) after the samples have been immersed in water for 24 h. Flame retardant properties showed by Al_2O_3 and CaO additives respectively were evaluated for the control sample with 10 % citric acid and 20 % citric acid particleboard respectively. The data generated were analyzed for the significant differences using the Tukey test. Particleboards without the addition of citric acid and additives were used as a control sample.

RESULTS AND DISCUSSION

Functional groups assessment

The Fourier Transform Infrared Spectroscopy (FTIR) as shown in Figure 1 revealed the transmittance of the particleboards samples at a range of 500 cm^{-1} - 4000 cm^{-1} wavenumbers. The FTIR spectra were used to monitor the presence and disappearance of functional groups that exist in the particleboards before and after addition of different percentage of citric acid and the flame retardant additives, (Al_2O_3 or CaO). The FTIR showed general similarities in the spectra images of both the control and the reinforced particleboards. The spectra results show a significant broad absorption band appearing between the region of 3414 cm^{-1} – 3426 cm^{-1}, indicating OH and/or NH stretching for all the samples, as also reported by Hashim *et al.* (2011). Meanwhile, peaks around 2300 cm^{-1} - 2400 cm^{-1} indicated the presence of carbon dioxide (CO_2), which resulted from the measuring condition.

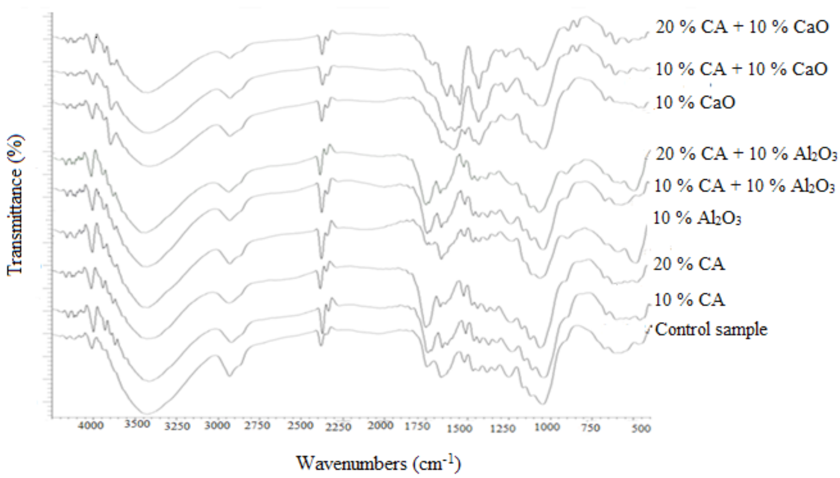

Figure 1: FTIR spectra of particleboards incorporated with different percentages of flame retardants.

Absorption band existing around 1738 cm^{-1} was attributed to C=O stretching resulting from the carbonyl group or the resultant ester group occasion with the citric acid addition (Giridhar *et al.* 2017, Umemura *et al.* 2013) which the intensity of the band increased with the increase of citric acid addition in the particleboards. The particleboards bonded with 20 % CA possessed lower transmittance than those added without citric acid. The analysis result was supported by the previous works that bonding mechanism was the formation of ester linkages between carbonyl groups from citric acid with hydroxyl groups from wood and rice husk particles (Seo *et al.* 2016). As a result, citric acid acts as a cross linking agent by reacting with the hydroxyl group of the natural fibers in accordance with the development of the ester linkages which contribute to the good physical properties of particleboards. This would reduce the hygroscopicity of the lignocellulosic and result in good dimensional stability of the final product (Vukusic *et al.* 2006). This was strongly supported by the improvement of the physical and mechanical properties of the particleboards produced.

From the figure, the spectra of particleboards with the addition of 10 % Al2O3, showed an absorption peak around 667 cm^{-1} which was associated with the stretching of Al-O-Al groups that are part of aluminium oxide network (Orellana *et al.* 2014). The presence of Al-OH group appeared around 1420 cm^{-1} was not significantly observed in Figure 1. Furthermore, the particleboards with the addition of 10% CaO showed spectra with a sharp peak at 3644 cm^{-1} due to the O-H stretching vibration for monomeric form of Ca(OH)2 when CaO hydrated with the moisture present in particles during the board manufacturing process (Bakovic *et al.* 2006). Spectra of particleboards with the addition of 10 % CaO was showed in the figure, in which a peak at 511 cm^{-1} corresponded to Ca-O symmetric vibration (Galvan-Ruiz *et al.* 2007). In this study, a mixture of rice husk and wood particles has been used in particleboards production. Silica is highly present in rice husk, where the entire outer layer of the rice husk surface was almost covered by silica (Jamil *et al.* 2013). From the figure, the intense absorption peaks at a region of 1038 cm^{-1} - 1111 cm^{-1} were observed. The peaks at 1100 cm^{-1} and 480 cm^{-1} are due to the stretching vibrations and flexion of the Si-O-Si bonds (Orellana *et al.* 2014).

Evaluation on the microstructure of samples

The distribution of rise husk, wood particles and additives such as Al_2O_3 and CaO in the particleboards was observed and shown in Figure 2. The rice husk has a cylindrical rough and hollow structure, which might become a barrier during adhesive application (de Melo *et al.* 2014) whereas wood particles showed well compacted cross-sectional arrangement. Morphology of particleboards made from a mixture of rice husk and wood particles without citric acid added, clearly exhibited that particles were loosely packed to one another and there are some voids that can be observed as shown in Figure 2a.

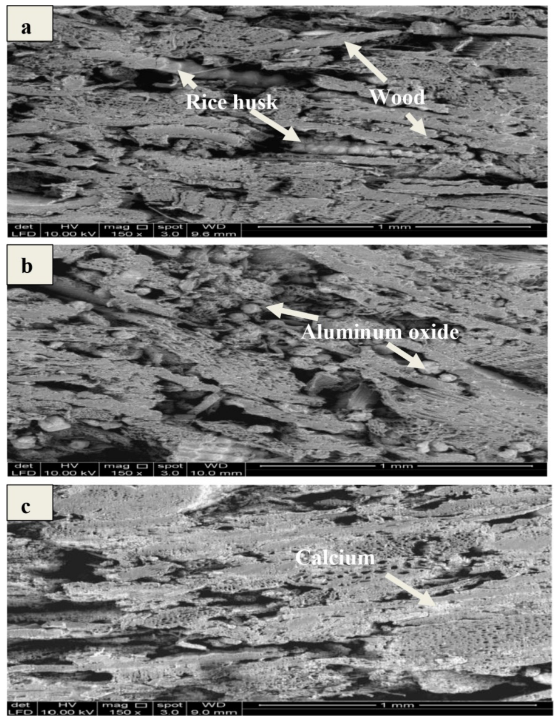

Figure 2: SEM micrographs of (a) particleboards from mixture of rice husk and wood particles (b) addition of 20 % citric acid + 10 % Al_2O_3 and, (c) with addition of 20 % citric acid + 10 % CaO at 150X magnification.

From Figure 2b, Al_2O_3 was detected in the particleboards as granulated size without melting during particleboards manufacture as its melting point is very high. The addition of 10 % Al_2O_3 in the particleboards which was randomly distributed in the particleboard mixture can be expected. The Al_2O_3 additive filled the void spaces between the mixture of rice husk and wood particles. The compactness of the particleboard was improved with the citric acid addition as a binder and Al_2O_3 additive. Particleboard sample added with 20 % CA and 10 % CaO (Figure 2c), showed no obvious granulated CaO additives on the cross-sectional surface. The small fine CaO powder is seen as homogeneously dispersed on the cross-sectional surface of the particleboards sample. However, these particles have a great tendency to form agglomerates which could affect the final performance of particleboards especially the mechanical properties of the particleboards as shown in the SEM micrograph.

Limiting oxygen index (LOI)

The LOI value of all particleboards is tabulated in Table 2. In this study, aluminum oxide (Al_2O_3) and calcium oxide (CaO) was added to the particleboards as flame retardants additive. LOI was used to measure the least volume of oxygen concentration in a mixture of oxygen and nitrogen that required supporting the flaming combustion process of a sample. This means that there is a positive correlation between flame retardant and the amount of oxygen to burn it. This indicated that the addition of the additives to the binderless particleboards made the particleboards less flammable. The incorporation of flame retardants into the binderless particleboards raised LOI value. This is supporting evidence that the additives enhanced the flame-retardant properties of the particleboards. Particleboards incorporated with 20 % CA + 10 % Al_2O_3 exhibited the highest LOI at 58 % followed by 20 % CA + 10 % CaO of 48 %.

Table 2: LOI of all particleboards from mixture of rice husk and wood particles.

Particleboards	Limiting Oxygen Index (LOI) %
Control sample	20,48
10 % Aluminum oxide (Al_2O_3)	38,65
10 % Calcium oxide (CaO)	36,72
10 % Citric acid (CA)	37,61
10 % CA + 10 % Al_2O_3	47,75
10 % CA +10 % CaO	45,45
20 % CA	43,86
20 % CA + 10 % Al_2O_3	57,97
20 % CA + 10 % CaO	48,04

Overall, the addition of both additives, CaO and Al_2O_3 and also citric acid into the binderless particleboard has increased the flame retardancy. According to Jia *et al.* (2015), materials having LOI values greater than 26 % will show self-extinguishing behaviors and considered to be good flame retardant. In this study, the optimum condition of CaO to act as a flame retardant at 20 % has met the requirement of physical and mechanical properties according to Type 8 of JIS A 5908-03 (2003) Standard. Although aluminum-based additives have been widely investigated and used as flame retardant additives, the addition of citric acid content has enhanced the properties of Al_2O_3 as a flame retardant in this study. According to Hull *et al.* (2011), loadings of 5-20 % of inert fillers which acting as flame retardants, have an inconsequential influence on the LOI, as over 80 % inert filler loading will make effective flame retardant.

Thermal degradation through thermogravimetric analysis (TGA)

The TGA device was employed to monitor the thermal degradation reaction of the particleboards and also to determine the mass loss or gain due to decomposition or loss of volatile matter. Figure 3 showed the weight loss (TG) curves and the derivative thermogravimetric (DTG) curves of all types of particleboards produced. For all the particleboards samples, weight loss was observed at temperatures up to 100 °C due to moisture loss at the initial stage. The major degradation of lignocellulose fibers began at temperatures above 250 °C and ended at temperatures below 500 °C (Elbasuney 2017). The decomposition of cellulose and hemicellulose occurred at a temperature range of 190 °C -360 °C (Saari *et al.* 2020), while the decomposition of lignin was between 180 °C -500 °C (Poletto 2017).

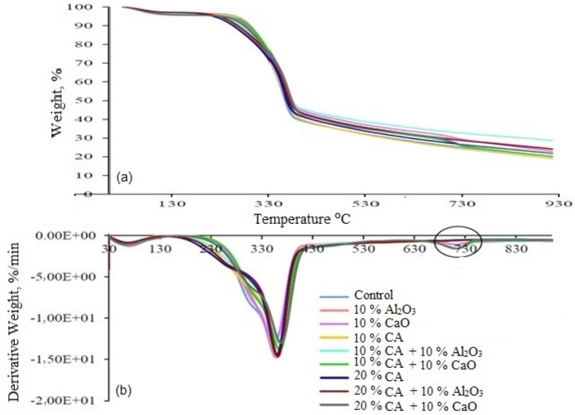

Figure 3: (a) TGA and (b) DTG curves of all particleboards from mixture of rice husk and wood particles with addition of citric acid as natural binder and Al_2O_3 and CaO as flame retardant additives.

From Figure 3, TG curves for particleboards with the addition of 10 % CaO showed further weight loss at a temperature around 700 °C. The first weight loss between 264 °C and 538 °C was attributed to the decomposition of the organic matter meanwhile the next loss in weight occurred between 538 °C and 721 °C was due to the calcium oxide (CaO) decomposition releasing carbon dioxide into the atmosphere (Abdul Khalil *et al.* 2018). Moreover, the addition of CaO as a flame retardant in this study, might re-carbonated at temperature 600 °C but this reaction is very slow.

The particleboards with the addition of 10 % Al_2O_3, showed no obvious difference on DTG curves when compared with other particleboards. Particleboards added with 10 % CA and 10 % Al_2O_3, showed the lowest percentage of weight loss with an increased temperature up to 930 °C. This was due to Al_2O_3 that formed a protective layer to protect the fibers that present in the particleboard. This was more clearly seen in Figure 3 that particleboard with the addition of 10 % Al_2O_3 is thermally stable at the highest temperature compared with others. However, with increased addition of 10 % CA + 10 % Al_2O_3 and 20 % CA + 10 % Al_2O_3 thermal stability of the particleboard was enhanced. This was supported by the results obtained in limiting oxygen index (LOI) evaluation that increased for 20 % CA + 10 % Al_2O_3 particleboard.

Dimensional stability of the particleboards

Results of the physical properties of the prepared particleboards are shown in Table 3. The average density, percentages of both water absorption (WA) and thickness swelling (TS) content of particleboards at various formulations were presented. The TS of the different panels varied from 6,83 % to 42,90 % and the WA ranged from 34,40 % to 92,01 %. The WA and TS value decreased dramatically when citric acid is added from 0 % to 10 % and 20 % into the particleboards panel. The hygroscopicity of lignocellulosic particles caused swelling when the particleboards immersed in water. The lignocellulosic particles spring back by releasing the built-in compressive forces that have been undergone during board manufacturing (Nagieb *et al.* 2011). According to Umemura *et al.* (2012), citric acid is used as a water resistant adhesive. Thus, with the increasing percentage of citric acid (CA) used to bond the particles, the TS and WA of the particleboards were accordingly reduced. This was obviously showed that the addition of citric acid resulted in an improvement in dimensional stability of particleboards (Widyorini *et al.* 2014).

Table 3: Physical properties of the particleboards.

Particleboards	Density (g/cm^3)	Water absorption (WA, %)	Thickness swelling (TS, %)
Control sample	0,80 ± 0,012	$92,01 \pm 3,92^f$	$42,90 \pm 1,09^g$
10 % Al_2O_3	0,80 ± 0,011	$80,31 \pm 3,75^e$	$40,29 \pm 1,03^f$
10 % CaO	0,80 ± 0,011	$56,27 \pm 3,89^d$	$35,52 \pm 1,09^e$
10 % CA	0,80 ± 0,017	$43,87 \pm 3,88^b$	$9,49 \pm 0,95^b$
10 % CA + 10 % Al_2O_3	0,80 ± 0,018	$48,90 \pm 2,42^c$	$9,46 \pm 0,90^b$
10 % CA + 10 % CaO	0,80 ± 0,010	$51,03 \pm 2,49^c$	$25,23 \pm 0,97^d$
20 % CA	0,80 ± 0,016	$38,66 \pm 3,51^a$	$6,92 \pm 1,14^a$
20 % CA + 10 % Al_2O_3	0,80 ± 0,010	$34,40 \pm 3,36^b$	$6,90 \pm 1,02^a$
20 % CA + 10 % CaO	0,80 ± 0,009	$39,17 \pm 3,97^c$	$9,83 \pm 1,12^c$

± Values in parenthesis represent the standard deviation while different lower-case letters in superscript represent statistical significance and same lower case letters indicate a similarity of differences ($p < 0,05$).

When the average density of the particle board of 800 kg/m^3 was maintained, there was an observed relatively high WA and high TS in control particleboard panels compared with the particleboards reinforced with flame retardant additives and further dropped as the additives increased. While the control particleboards have the highest WA and TS values of 92,01 % and 42,90 % respectively, the particleboard with additives (20 % CA + 10 % Al_2O_3) recorded the least percentage WA and TS of 34,40 % and 6,90 % respectively. This is due to the improved compatibility of fiber particles, binders and additives. The presence of additives is expected to inhibit water penetration in the particleboards and increase as the additive increases, resulting in low WA and TS values. The high TS and WA values show that there are relatively more empty spaces in the binderless particleboards. The requirement set out in JIS A5908-03 (2003) Type 8 standard for particleboards is less than 12%. In this study, all particleboards with the addition of 10 % and 20 % of CA (excerpt 10 % CA + 10 % CaO) capable of meeting the TS standard, thus showing that the addition of CA will increase the dimensional stability of the particleboards.

Mechanical properties

Table 4 summarizes mechanical properties which include the internal bond (IB) and average modulus of rupture (MOR) of the rice husk/wood-based particleboards with and without additives. Despite the consistent density value of the particleboards, the presence of compatibilizing agent and the inclusion of flame-retardants additives show a positive impact on the MOR and the IB of the prepared particleboards. The results revealed the least value of 6,23 MPa and 0,91 MPa of MOR and IB strength respectively for the binderless particleboards which is higher than the value obtained for kenaf core binderless particleboards (Xu *et al.* 2004). However, the value is lower than the value obtained for oil palm trunk (OPT) with polyhydroxyalkanoates addition to the binderless particleboard (Baskaran *et al.* 2012) and oil palm trunk with the addition of sucrose and fructose binderless particleboards (Lamaming *et al.* 2013). The highest values of MOR and IB strength were obtained from rice husk/wood blended with 20 % citric acid + 10 % Al_2O_3 formulated particleboards.

This observation is ascribed to the excellent role of citric acid in ensuring good compatibility of the binder and flame retardant addition as shown in the SEM image (Figure 2). However, these reinforced particleboards exhibit better mechanical properties performance compared to binderless particleboards. Both MOR and IB strength also show a significant increase than those of the binderless particleboards. In addition to improving flame retardants, flame retardant additives have been reported to improve the mechanical properties of reinforced materials. From the result in Table 4, the particleboards reinforced with the combination of flame-retardant substances (Al_2O_3 + CaO) fulfilled the minimum requirements of 8,0 MPa of MOR and all particleboards have passed 0.15 MPa of IB for Type 8 JIS A5908-03 (2003).

Table 4: Mechanical properties of the particleboards.

Particleboards	Density (g/cm^3)	Water absorption (WA, %)	Thickness swelling (TS, %)
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10 % CaO	0,80 ± 0,011	56,27 ± 3,89^{d}	35,52 ± 1,09^{e}
10 % CA	0,80 ± 0,017	43,87 ± 3,88^{b}	9,49 ± 0,95^{b}
10 % CA + 10 % Al_2O_3	0,80 ± 0,018	48,90 ± 2,42^{c}	9,46 ± 0,90^{b}
10 % CA + 10 % CaO	0,80 ± 0,010	51,03 ± 2,49^{c}	25,23 ± 0,97^{d}
20 % CA	0,80 ± 0,016	38,66 ± 3,51^{a}	6,92 ± 1,14^{a}
20 % CA + 10 % Al_2O_3	0,80 ± 0,010	34,40 ± 3,36^{b}	6,90 ± 1,02^{a}
20 % CA + 10 % CaO	0,80 ± 0,009	39,17 ± 3,97^{c}	9,83 ± 1,12^{c}

± Values in parenthesis represent the standard deviation while different lower case letters in superscript represent statistical significance and same lower case letters indicate a similarity of differences ($p < 0,05$).

CONCLUSIONS

Awareness of ecological values and interest in renewable materials have created a demand for agro based building products. The present research study revealed the potential of the rice husk/rubber wood particles in the building and furniture industry as partial or full replacement of wood particleboards. Therefore, in this research, the particleboards were developed from a mixture of rice husk/wood particles with the addition of citric acid and aluminum oxide (Al_2O_3) or calcium oxide (CaO) have been investigated. Based on the results obtained, the citric acid found to be a potential natural adhesive to replace synthetic adhesive as it improved the functional properties of particleboard from rice husk/wood particle mixtures. Particleboards from the mixture of rice husk and wood particles, were produced a target density of 800 kg/m^3 in order to achieve the JIS A5908-03 (2003) standard. LOI evaluation, shows that both CaO and Al_2O_3 exhibited good performance with an increase of citric acid content. Particleboard with 20 % CA and 10 % Al_2O_3 possessed better flame-resistant properties and even thermally stable. Overall, particleboards from a mixture of rice husk and wood particles with 20 % CA in addition to both formulas with 10% Al_2O_3 (LOI of 58 %) and 10% CaO (LOI of 48 %) exhibited strong flame resistance properties. The addition of a combination of flame-retardant substances (Al_2O_3 + CaO) increased particleboards strength and met the minimum physical and mechanical property specifications in compliance with Type 8 of JIS A5908-03 (2003) Standard. The results clearly suggest that, with minor modification, the application of rice husk/rubber wood particles in building construction is feasible and effective.

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