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Physical and Mechanical Properties of Portland Cement-Bonded Flakeboards Fabricated from *Macaranga gigantea* and *Neolamarckia cadamba*

Noor Azrieda, A. R.[1], Razali, A. K.[2], Rahim, S.[1] and Izran, K.[3]*

[1]*Biocomposites and Wood Protection Programme, Forest Research Institute Malaysia, 52109 Kepong, Selangor, Malaysia*
[2]*Faculty of Applied Sciences, Universiti Teknologi Mara, 40400 Shah Alam, Selangor, Malaysia*
[3]*Advanced Processing and Design Programme, Forest Research Institute Malaysia, 52109 Kepong, Selangor, Malaysia*

ABSTRACT

This study evaluated the properties of cement-bonded flakeboards made from wood of pioneer forest species, namely, Kelempayan (*Neolamarckia cadamba*) and Mahang (*Macaranga gigantea*). The wood species were first evaluated for their compatibilities with cement by looking at their effects on the hydration rate of the cement. The properties of the flakeboards were tested using ASTM D 1037-99. An analysis of variance was carried out to study the effects of accelerator types and concentrations and flake lengths on the boards. There was no significant interaction between the wood species, but there was a significant relationship between the differences of accelerator types and concentrations and flake length at $p<0.05$. Generally, boards treated and fabricated with higher concentration of accelerator and longer flakes had superior performance. The mechanical properties [internal bond (IB), modulus of rupture (MOR), screw withdrawal (SWD) and modulus of elasticity (MOE)] of the boards were significantly influenced by the length of the flake and accelerator concentration — the longer the flake, the higher the accelerator concentration, the better the strength would be. For Kelempayan, the greatest values of MOR, IB, SWD and MOE which were influenced by flake length were 100mm Kelempayan at 1.5% $MgCl_2$ (9.5 MPa), 100 mm Kelempayan at 1.5% $MgCl_2$ (0.37 MPa), 100 mm Kelempayan at 2.5% $MgCl_2$ (519.4 MPa) and 100mm Kelempayan at 1.5% $MgCl_2$ (3329 MPa), respectively. As for the influence of accelerator concentration, the greatest mechanical values were observed from 75 mm Kelempayan at 2.5% $CaCl_2$ (7.47 MPa), 75 mm Mahang at 2.5% $MgCl_2$ (0.38 MPa), 75 mm Mahang at 2.5% $CaCl_2$ (425.51 MPa) and 75 mm Kelempayan

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E-mail addresses:
azrieda@frim.gov.my (Noor Azrieda, A. R),
eastrun84@gmail.com (Izran, K.)
* Corresponding author

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at 2.5% $CaCl_2$ (3001 MPa), respectively. However, reverse results were recorded for the physical properties of Kelempayan flakeboards added with magnesium chloride ($MgCl_2$).

Keywords: Accelerator type and concentration, pioneer species, flake length, strength

INTRODUCTION

Deforestation has become a big issue for many countries throughout the world. In Malaysia, since the British colonial rule in 1956, the Malaysian economy has involved the expansion of commodity and production. This expansion led to exploitation of natural resources which had divided the economy into two parts, namely, the primary sectors (agriculture, forestry, mining, and fishing) and secondary sectors (manufacturing and construction). The economic growth since that time has caused the demand of the secondary sector higher than the supply of the primary sector (Coutts, 2007). Thus, to meet the demand of the secondary sector, forests were exploited excessively and this led to deforestation. Deforestation rate increases year by year and has never stopped until today, as claimed by Butler (2006). To prevent further deforestation that might have caused many other bigger problems, such as erosion and global warming, government called the wood-based product manufacturers to reduce the usage of wood from the forests and to switch to crops which could be utilized as alternative raw materials in producing wood-based products. It was found that kenaf (Izran *et al.,* 2009), sesenduk (Khairul *et al.,* 2009), engkabang and *Acacia mangium* (Izran *et al.,* 2010a; Mohd Hamami *et al.,* 1998) and coconut (Khairul *et al.,* 2009a) are suitable to be further promoted and industrialized in order to create a sufficient material supply for the wood-based product manufacturers. Pioneer species can also be highlighted to form wider alternative material selection for the manufacturers. Pioneer species is a species that is first to establish itself in an area which was previously devastated by flood, plowing and fire (Anon, 2011). Two promising pioneer species that can be commercialized due to their fast-growing ability are mahang (*Macaranga spp.*) and kelempayan (*Neolamarkia cadamba*). However, information regarding these species is rather limited, and hence, creates obstacles in promoting and utilizing them efficiently.

Cement-bonded boards are readily available and accepted in Europe, United States, Russia and Asia, mainly for roofs, walls and floors. There is a number of researcher which previously carried out on the strength of boards with different types of raw materials and particle geometries (Del Menezzi *et al.,* 2007; Mohamad Hamami *et al.,*1998; Guntekin & Sahin, 2009). These researchers have proven that the boards possess better advantages compared with ones which are produced from organic resins in terms of strength and durability. Therefore, this study attempted to use mahang and kelempayan as raw materials for cement-bonded flakeboards. The effects of several parameters such as accelerators and flake length on the mechanical and physical properties of the flakeboards were also studied. Accelerators were incorporated into the flakeboards to enhance the compatibility between the flakes and cement.

MATERIALS AND METHODS

Preparations of the Mahang and Kelempayan Flakes

Mahang gajah (*Macaranga gigantea*) and Kelempayan (*Neolamarckia cadamba*), which were extracted from Gua Musang Forest District, Kelantan, were used for this purpose. The binder used was Ordinary Portland Cement (OPC). Through a hydration test, these two species have been found to be better able to trigger the hydration rate of the binder than the other selected pioneer forest species, namely, Memeh, Langian, Terap and Melembu (Noor Azrieda *et al.,* 2010). The hydration rate was evaluated through temperature-time relationship. The most compatible species to be mixed with Ordinary Portland Cement (OPC) should achieve the highest temperature within a short period of time. It is because the higher the temperature, the faster the hardening of the cement is (Barron, 2010).

Firstly, the timbers were cut into billets in a length of 18”. Then, they were debarked and shredded to flakes using a shredding machine which is available at Duralite (M) Sdn. Bhd. The initial moisture content of the flakes was 70%. The flakes were soaked in water to remove wood extractives which might affect the cement setting. The description of the boards is listed in Table 1.

According to the calculation made, 1.08 kg of flakes, 2.16 g of cement and 0.814 kg of water were required to form a board with a dimension of 450 (l) x 450 (w) x 12 (t), as depicted in Table 1.

TABLE 1
Description of the fabricated cement-bonded flakeboards

Raw material	Mahang gajah and kelempayan
Flake length	75 mm and 100 mm
Targeted board density	750 kgm^{-3}
Board size	(450 × 450 × 12) mm^3
Binder	Ordinary Portland Cement (OPC)
Accelerator types and concentrations:	Calcium chloride ($CaCl_2$) and Magnesium chloride ($MgCl_2$) at 1.5 and 2.5% concentrations besed on cement weight
Material ratio (Cement:Wood:Water	2:1:1

Target density: 800kgm^{-3}

Manufacture of cement-bonded flakeboards

The flakes of those species were oven-dried to reduce the MC to 12 ± 2%, and also hit using a hammermill. After that, the flakes were screened, and only those in the length of 75 mm and 100 mm were selected. They were then blended separately with the cement during board fabrication process. For Mahang, only flakes with 75 mm length were chosen, but for Kelempayan, both the lengths were used. Prior to blending, the flakes were soaked in water for 24 h. Calcium chloride ($CaCl_2$) and magnesium chloride ($MgCl_2$) were used as accelerators. The binder was mixed separately with two different accelerators at two different concentrations, namely, 1.5 and 2.5% (w/w), to enhance the compatibility between the flakes and the binder. The concentrations were selected based on the hydration test of the OPC mixed with the accelerators and wood flakes (Noor Azrieda *et al.,* 2010). The test revealed that the accelerator concentrations greater than 2.5% gave no effects to the hydration of the OPC. Therefore, to cut cost, the accelerator concentrations from 1.5% to 2.5% were chosen.

The flakes and the binder were mixed in a blender for 20 min and the mixture was put into a former made from metal in a 450 x 450 mm size. The top and the bottom of the mat were covered with caul plates and pressed at 413685.43 Pa pressure to 12 mm thickness. Then, the mat which was placed between the caul plates was clamped and left for 24 h in a conditioning chamber at a temperature of 60±2ºC and a relative humidity of 65±2% to let the flakeboards hardened. The hardened flakeboards were left clamped to cure for 28 days before they were trimmed to standard sizes for the physical and mechanical tests (Table 2) in accordance with ASTM D 1037-99 (ASTM D-1037, 1999). The clamps were removed from the cured flakeboards prior to the trimming. Hence, a total of 72 flakeboards were utilized for the tests. The experimental design is presented in Fig.1.

TABLE 2
Standard sample sizes for the physical and mechanical tests in accordance with ASTM D 1037-99 with 12mm thickness

Type of Testing	Standard size
Bending strength	300 x 75 mm
Internal bond	50 x 50 mm
Screw withdrawal	75 x 75 mm
Thickness swelling	50 x 50 mm
Density	300 x 75 mm

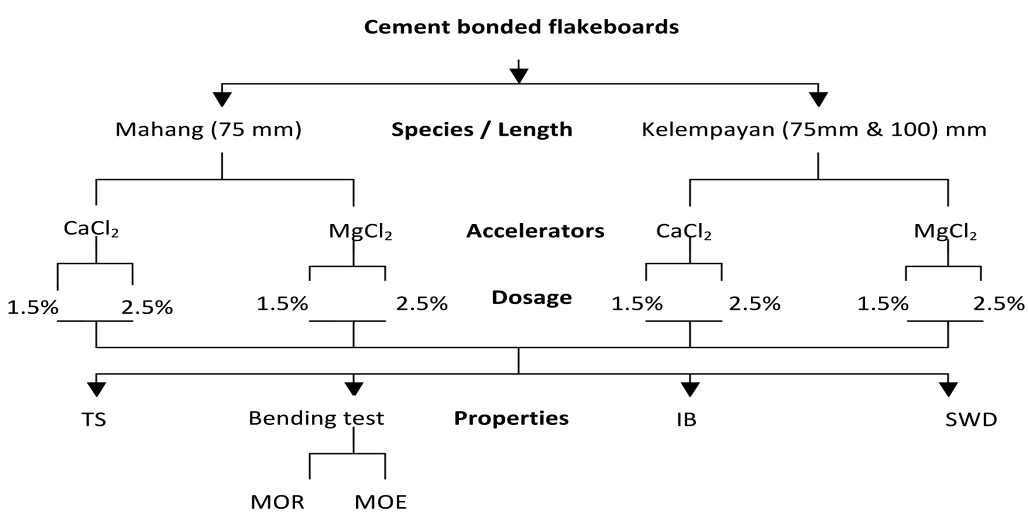

Fig.1: The Experimental Design

Statistical Analysis

An analysis of variance (ANOVA) and mean separation using the least significant difference (LSD) method were carried out to evaluate the effects of flake length, accelerator type and concentration on the strength and dimensional stability of the boards. The ANOVA is available in Statistical Package for the Social Sciences (SPSS).

RESULTS AND DISCUSSION

Performances of the Cement-bonded Flakeboards

The density obtained from the fabricated flakeboards range from 800kg/m^3 to 850kg/m^3. By comparing the data presented in Table 3, it has been determined that accelerator type and concentration are significantly influencing the performances of the flakeboards. Although the influence of flake length was not significant, it was found that the performances increased in line with the increase of flake length. The influence of flake length was only observed for kelempayan. Flakeboards made from 75 mm kelempayan which were added with 1.5% $CaCl_2$ had the mean values for MOR, MOE, IB with 6.9, 2761 and 0.24 MPa, respectively. The SWD mean value was 367.5 N. Higher values were observed for 75 mm kelempayan added with 2.5% $CaCl_2$, whereby the mean values were 7.47, 3001, and 0.33 MPa for MOR, MOE, IB and 367.6 N for SWD. A similar pattern was recorded for 75 mm kelempayan treated with $MgCl_2$. The values increased with the increase of the accelerator concentration from 1.5% to 2.5%, but the values were lower than that of which was added with $CaCl_2$. The values of MOR, MOE and IB for 75 mm kelempayan added with 1.5% $MgCl_2$ were 6.78, 2752 and 0.19 MPa, whereas SWD was 339.1 N. Slightly higher values were found for those added with 2.5% $MgCl_2$. The values were 6.83, 2906, 0.26 MPa and 377.2. For instance, kelempayan flakeboards improved its MOR between 2.86 to 22.03% and MOE between 5.06 to 17.33% when 100 mm flakes were used. On the contrary, the flakeboards added with $CaCl_2$ (100 mm kelempayan) experienced reduction on SWD for both the concentrations (-12.38% for 1.5% $CaCl_2$ and -3.23% for 2.5% $CaCl_2$) as compared with those 75 mm kelempayan flakeboards. However, the values increased with the additions of $MgCl_2$ (18.84% for 1.5% $MgCl_2$ and 27.38% for 2.5% $MgCl_2$).

The use of the accelerators did have significant effects on the boards' MOR, IB and SWD (Table 3), which were made from 75 mm mahang flakes. The accelerators have insignificant effects on MOE, even though there were some increments recorded (2616 MPa for 1.5% $CaCl_2$, 2669 MPa for 2.5% $CaCl_2$) and (2248 MPa for 1.5% $MgCl_2$ and 2684 MPa for 2.5% $MgCl_2$). The results of the mahang flakeboards indicated that higher performances were achieved with higher accelerator concentration. By comparing 75 mm mahang flakeboards and 75 mm kelempayan flakeboards, the 75 mm kelempayan flakeboards were apparently superior to the 75 mm mahang flakeboards. However, SWD of the mahang flakeboards was better than that of kelempayan flakeboards.

TABLE 3
The physical and mechanical values of mahang and kelempayan

	Kelempayan				Mahang			
	$CaCl_2$		$MgCl_2$		$CaCl_2$		$MgCl_2$	
	1.5%	2.5%	1.5%	2.5%	1.5%	2.5%	1.5%	2.5%
	75 mm Mean±S.D				75 mm Mean ± S.D			
MOR	6.90±0.53[a]	7.47±0.39[b]	6.78±0.35[c]	6.83±0.36[d]	6.31±0.52[a]	6.52±0.24[a]	5.31±0.23[b]	6.84±0.29[b]
MOE	2761±91.16[a]	3001±76.39[b]	2752±60.01[c]	2906±96.49[d]	2616±71.60[a]	2669±61.48[a]	2248±84.34[a]	2684±100.36[a]
IB	0.24±0.02[a]	0.33±0.02[b]	0.19±0.01[c]	0.26±0.01[d]	0.36±0.01[a]	0.37±0.01[a]	0.32±0.01[b]	0.38±0.01[b]
SWD	367.5±17.12[a]	367.6±14.08[b]	339.1±19.01[c]	377.2±28.42[d]	374.73±14.03[a]	425.51±18.51[a]	348.96±16.78[b]	404.62±15.58[b]
TS	1.84±0.16[a]	1.95±0.69[b]	2.14±0.08[c]	2.41±0.09[d]	1.91±0.09[a]	1.79±0.07[b]	2.09±0.11[c]	1.91±0.08[d]
	100 mm							
MOR	7.4±0.59[a]	7.69±0.74[b]	9.5±0.75[c]	8.76±0.44[d]				
MOE	3041±138.1[a]	3161±138[b]	3329±262.6[c]	3168±162[d]				
IB	0.21±0.14[a]	0.24±0.01[b]	0.37±0.03[c]	0.30±0.02[d]				
SWD	322±22.49[a]	355.7±30.92[b]	417.8±16.35[c]	519.4±14.37[d]				
TS	2.11±1.96[a]	1.98±0.15[b]	1.67±0.09[c]	1.81±0.16[d]				

[1]Means within a row followed by the same alphabets under each species are not significantly different at $p \leq 0.05$, [2]MOR=modulus of rupture (MPa), MOE=modulus of elasticity (MPa), IB=internal bond (MPa), SWD=screw withdrawal (N), TS= thickness swelling.

According to MS 934, the standard requirement values for MOR, MOE, and IB are 9MPa, 3000 MPa and 0.5 MPa, respectively. As shown in Table 3, the flakeboards made from 100mm kelempayan that surpassed the standard value of MOR were only those added with 1.5 % $MgCl_2$. Meanwhile, none of the flakeboards made from 75mm flakes for both the species recorded to have higher MOR mean values than the standard. Amazingly for MOE, the mean stiffness values of all the flakeboards made from 100mm kelempayan were found to be greater than the standard value. The results are in line with the findings of a previous study (Badejo, 1988), whereby the longer and the thinner the flakes, the stronger, the stiffer and more dimensional stability the cement-bonded particleboards would become. A similar MOE performance was exhibited by the flakeboards fabricated from 75mm kelempayan mixed with 2.5 $CaCl_2$. Unfortunately, the IB value for the flakeboard of each species, flake length, accelerator type and concentration obviously failed to meet the standard requirement. It was quite surprising as the IB values were even lower than fibre-reinforced particleboards formed with polymer resins (Izran *et al*., 2009b; Paridah *et al.,* 2009). Perhaps, this is due to the properties of OPC, which is high viscosity and less watery compared to polymer resins. This was expected to limit the spread of the OPC on the surfaces of the flakes, and hence affected interfacial bonding between flakes. The relationship of IB with thickness swelling is discussed further in the next section.

Thickness Swelling

Thickness swelling is to measure the dimensional stability of the flakeboards. Lower thickness swelling value indicates a more stable board. As stated in the MS 934 standard, the standard mean TS value should be less than 2%. The Kelempayan flakeboards that had met the standard requirement were those made from 75mm kelempayan added with 1.5% $CaCl_2$ (1.84%) and 2.5 $CaCl_2$ (1.95%), 100mm kelempayan added with 2.5% $CaCl_2$ (1.98%), 1.5% $MgCl_2$ (1.67%) and 2.5% $MgCl_2$ (1.81%). Meanwhile, the Mahang flakeboards showed impressive TS results because none of the flakeboards had TS value more than 2%, except for those added with 1.5% $MgCl_2$.

Previous research has found that thickness swelling has a direct relationship with internal bond. In particular, a panel with higher IB values can resist the stress due to wood expansion and press opening, resulting in lower TS (Del menezzi *et al.,* 2007). The results derived for the flakeboards made from 75 mm and 100 mm flakes of Kelempayan contradict with the findings of Del Menezzi *et al.* (2007). The increase of the IB values for each concentration and type of the accelerator did not reduce the TS for the 75 mm and 100 mm Kelempayan flakeboards. However, the findings are applied for the mahang flakeboards (0.36MPa IB with 1.91% TS for 1.5% $CaCl_2$; 0.37MPa IB with 1.79% TS for 2.5% $CaCl_2$) and (0.32MPa IB with 2.09% TS for 1.5% $MgCl_2$; 0.38MPa IB with 1.91% TS for 2.5% $MgCl_2$). Such improvement was expected due to the enhancement in the mahang flakes themselves as a result of the cross-linking with Ordinary Portland Cement (OPC). Mahang was found as the most compatible species to be mixed with OPC (Noor Azrieda *et al*., 2010). This was expected to enhance the bond between the mahang flakes and the binder, and thus reduced the effect of moisture to the dimensional stability of flakeboards made from that particular species. In the analysis by Noor Azrieda *et al*. (2010), kelempayan was found to be less compatible with OPC due to its high sugar and starch contents. This may explain the inefficiency of kelempayan flakeboards in reducing thickness swelling.

CONCLUSION

Kelempayan and Mahang were found as suitable materials for producing cement-bonded flakeboards. Accelerator concentration and type were two of the most important parameters for flakeboards fabrication, as they improved the cement setting, and increased the strength of the flakeboards. A higher concentration of accelerators exhibited better strength performance. Conversely, dimensional stability was reduced when the concentrations were increased especially for Kelempayan added with 2.5% $MgCl_2$. The length of flakes apparently improved the strength and dimensional stability of those added with $CaCl_2$, but contradicting results were obtained for the dimensional stability of those treated with $MgCl_2$. Overall, 100 mm long flakes produced stronger flakeboards as compared to those made of 75 mm long flakes. Thus, it is suggested that the compatibility between the wood species and the binder be improved to enhance the cross-linking between both mediums, as poor bonding has been identified as the main factor for the poor performance of the cement-bonded flakeboards. This could possibly be achieved by adding compatibilizers such as maleic anhydride (MAH) and grafted polyethylene (PE-g-MAH) into the wood-accelerator-cement mixture prior to pressing and curing processes. Nonetheless, a further study on the addition of compatibilizers should be conducted to examine whether or not the compatibilizers can solve the problem.

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