Technological Properties of Cement-Bonded Composite Board Produced with the Main Veins of Oil Palm (*Elaeis guineensis*) Particles

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The effects of main veins of palm (*Elaeis guineensis*) particles and the amount of $CaCl_2$ on the mechanical and physical properties of cement-bonded composite boards (CBCBs) were investigated in this study. Homogenous CBCBs were produced with main veins palm particles content at three levels of 10, 15, or 20 wt.% and $CaCl_2$ at three levels of 0, 3, or 6 wt.%. Other manufacturing parameters consisting of pressure and time for cold-press, material dry weight, and panel dimensions were kept constant. The flexural strength, flexural modulus, internal bonding, water absorption, thickness swelling, and the thickness of CBCBs after 2 and 24 h immersion in distilled water were determined. The results indicated that increased amount of lignocellulosic particles caused a decrease in the mechanical properties of the CBCBs. The increase in calcium chloride up to 6 wt.% improved mechanical properties of the CBCBs. The panels manufactured with 10 wt.% *E. guineensis* particles and 6 wt.% $CaCl_2$ showed the most favorable physical and mechanical properties.

Keywords: Cement-bonded composite board; Palm; Calcium chloride; Physical and mechanical properties

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INTRODUCTION

Agricultural wastes such as sugarcane bagasse, arhar stalks, date palm midrib, flax, babacu shell, vegetable fibers, vine stalks, wheat straw, and rice husk ash have been used as filler in the manufacture of wood-cement boards (Aggarwal 1995; Almeida *et al.* 2002; Ntalos and Grigoriou 2002; Papadopoulos and Hague 2003; Roma *et al.* 2008; Nemli *et al.* 2009; Nasser *et al.* 2011; Nasser 2012; Bahurudeen *et al.* 2015). These raw materials have been used as substitutes for mineral aggregates and solid woods from natural forests (Savastano *et al.* 2000; Karade *et al.* 2001; Almeida *et al.* 2002; Semple *et al.* 2002; Li *et al.* 2004; Abdel-Kader and Darweesh 2010).

In order to remove chemical substances, pre-treatment of lignocellulosic particles with cold or hot water as well as the addition of $CaCl_2$ or $MgCl_2$ is required (Rahim *et al.* 1995; Olorunnisola 2008; Ashori *et al.* 2011; Zhou and Li 2012). Furthermore, there are many factors that affect the properties of cement-bonded composite boards (CBCBs), such as the effect of exothermic behavior during the hydration process (Hachmi *et al.* 1990; Semple *et al.* 2002; Okino *et al.* 2004). Generally, lowering the amount of inhibitory extractives diffuse into the cement paste is beneficial for the wood-cement compatibility.

In addition, hemicellulose, starch, sugar, tannins, and lignin, each to a varying degree, affect the cure rate and ultimate strength of these composites (Nazerian *et al.* 2011). The compatibility between wood particles and cement can be enhanced by the incorporation of chemical additives (Wei and Tomita 2001; Okino *et al.* 2004). The setting of cement can be delayed when composite panels are made using plant fibers, and the hemicelluloses, starch, sugar, tannins, certain phenols, and lignin appear to be responsible for this delay (Aggarwal *et al.* 2008; Nasser *et al.* 2011).

Some lignocellulosic species used in the production of wood-cement boards do not react well with cement because of extractives (Moslemi *et al.* 1983; Vaickelioniene and Vaickelionis 2006; Aggarwal *et al.* 2008). The effects of extractives can be overcome by adopting suitable measures such as cold water extraction and/or using an accelerator such as calcium chloride ($CaCl_2$) (Almeida *et al.* 2002; Okino *et al.* 2004; Aggarwal *et al.* 2008; Olorunnisola 2009). A dose of 2% $CaCl_2$ by weight of cement inhibits the adverse effects of 1% extractives of arhar stalks (Aggarwal *et al.* 2008). Moreover, particle size and amount have great effects on the mechanical (MOR, MOE, IB) and physical (water absorption, dimensional stability) properties of CBCBs (Semple *et al.* 2002; Aggarwal *et al.* 2008; Ajayi and Olufemi 2011; Marzuki *et al.* 2011; Nasser *et al.* 2011).

The oil palm tree is a common species in tropical countries. The veins of the oil palm are not efficiently used in industrial applications. Based on the extensive literature search, there is limited information on the potential utilization of oil palm veins in the production of cement-bonded composites. This study examined the suitability of using oil palm (*E. guineensis*) main veins as lignocellulosic filler and $CaCl_2$ for manufacturing CBCBs. The mechanical and physical properties of the manufactured boards were determined.

EXPERIMENTAL

Materials

The oil palm lignocellulosic particles (PLPs) were prepared from pruned branches of palm after the separation of its leaflets; the main veins (Fig. 1) were chopped using laboratory drum chipper, Pallmann PHT 120x430 to obtain suitable chips and changed to flack by Pallmann PZ8 ring flicker.

Fig. 1. The main veins of oil palm used CBCBs as palm lignocellulosic particles

The PLPs passing through a 1 mm × 1 mm sieve were mixed with the additive ($CaCl_2$) in three levels. The type 2 Portland cement was manufactured by Zabol Cement Industries Company (Sistan Cement Plant, Sistan, Baluchestan province, Iran). This cement type was modified to increase the concrete strength against sulfate attack and decrease hydration temperature. The curing time of this cement was slower than that of type 1 Portland. Additionally, the hydration process was performed at low temperature. For this reason, this cement type is suitable for concrete in tropical regions.

Three different levels of the PLPs (10, 15, or 20 wt.%) and calcium chloride additive (0, 3, or 6 wt.%) based on the dry weight of cement (Table 1) were used in the production of experimental composites. Other factors such as cement type, thickness of composites, and press conditions were kept constant (Table 2).

Production of Cement-Bonded Composite Boards

Aluminum sheets with dimensions of 450 mm × 450 mm and wooden mold with dimensions of 400 mm × 400 mm × 70 mm were used in the production of cement-bonded composite boards (CBCBs). The PLPs were wetted with water plus calcium chloride solution. For all the CBCB specimens, the water to cement ratio was maintained at 0.5. After 15 min of manual mixing (Nazerian *et al.* 2011), the cement-wood water mixture was uniformly spread in a wooden mold. Nine types of panels were produced under laboratory conditions (Table 1).

Table 1. The Different Treatments for the Experimental Panels (Types of Produced CBCBs)

Cement-bonded Composite Board Code	Palm Lignocellulosic Particles (wt.%)	Cement (wt.%)	Calcium Chloride (wt.%)
PLP10%-C90%-CC0% *	10	90	0
PLP10%-C90%-CC3%	10	90	3
PLP10%-C90%-CC6%	10	90	6
PLP15%-C90%-CC0%	15	85	0
PLP15%-C90%-CC3%	15	85	3
PLP15%-C90%-CC6%	15	85	6
PLP20%-C90%-CC0%	20	80	0
PLP20%-C90%-CC3%	20	80	3
PLP20%-C90%-CC6%	20	80	6

* PLP: Palm lignocellulosic particles; C: Cement; CC: Calcium chloride

Table 2. Constant Variables Used in the production of CBCBs

Cement Type	Thickness (mm)	Density (kg m^{-3})	Press Conditions			Conditioning or Watering Time (day)
			Compression (MPa)	Time (h)	Temperature (ºC)	
Type 2 Portland	15	1100	3.80	12	20	28

A total of 27 mats with dimensions of 400 × 400 mm were manually formed prior to pressing. Cold pressing (Burkle LA-160, Burkle, Germany) took place under an initial pressure of 3.80 MPa, to a 15 mm thickness, after which the boards were retained in compression for 12 h. The target board density was 1100 kg m^{-3}. To minimize the cement capillary desiccation and enhance hydration, the boards were misted with distilled water and then wrapped in cellophane before storing for curing at 20 ºC and 65% relative humidity for a month. The schematic of production process of cement-bonded composite board are shown in Fig. 2.

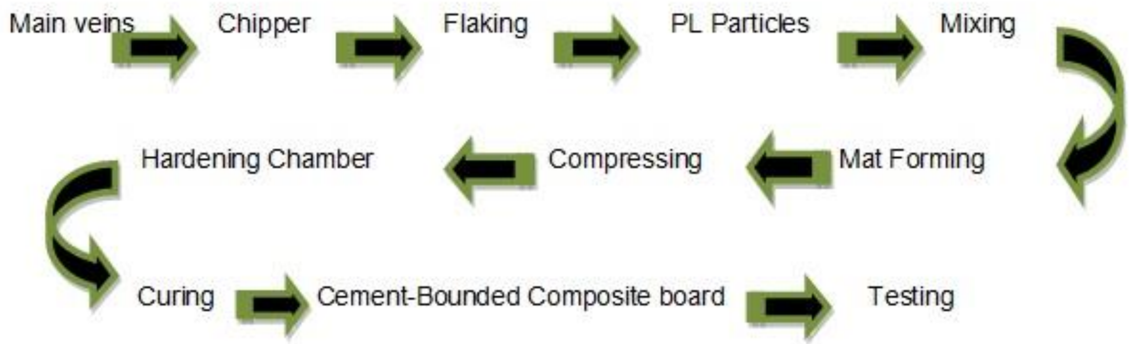


Fig. 2. Production process of cement-bonded composite board

Measuring of Mechanical and Physical Properties

The CBCBs were tested for mechanical properties including MOR (modulus of rupture), MOE (modulus of elasticity), IB (internal bonding), and physical properties including density, WA (water absorption), and TS (thickness swelling, after 2, and 24 h immersion in water) according to the DIN 68763 (1990) standard. The Instron Universal Testing Machine (model 1186) (Canton, MA, USA) was used for testing of the specimens (Fig. 3). Three replicates were tested for each treatment and the average values were obtained from them.

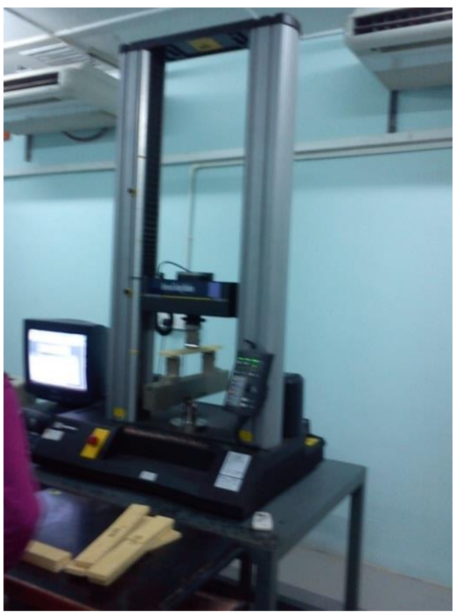


Fig. 3. The Instron Universal Testing Machine for flexural testing of the composite board

The MOR and MOE of the CBCBs specimens were calculated using the following equations,

$$MOR = \frac{3PL}{2BH^2} \tag{1}$$

$$MOE = \frac{P1L^3}{4BH^3Y1} \tag{2}$$

Where, P (N) is the maximum load of rupture, L (mm) is the spam length, B (mm) is the width of specimen, H (mm) is the thickness of specimen, $P1$ (N) is the load in the proportion limit, and $Y1$ (mm) is the change of length in the proportion limit.

In order to measure the IB property of CBCBs specimens, the specimens were glued to a metal plate using a thermosetting or heat-curing (hot melt) resin or adhesive. The cold water flow was used for cooling and complete curing of adhesive. After 2 hours the tensile test as indicator of internal bonding of boards were performed. The Instron Universal Testing Machine (model 1186) (Canton, MA, USA) was used at a loading speed of 2 mm/min. The IB of specimens were calculated using the following equation,

$$IB = \frac{P}{A} \tag{3}$$

Where, P (N) is the load of rupture, and A (mm^2) is the area of specimens.

The determination of 2 hours and 24 hours water absorption (WA) and thickness swelling (TS) tests were performed according to ASTM D 1037 (1998). Water absorption test was conducted by immersing the CBCB specimens in a deionized water bath at 25 ºC for different time durations. After going through the 2 hours, 24 hours immersion process, the specimens were taken out from water and the surfaces were dried using a clean dry cloth. The specimens were reweighed to the nearest 0.1 mg within 1 min of removing them from the water. The specimens were weighed regularly at 2 hours, 24 hours exposure. The water absorption of each specimen was calculated by the weight difference.

Water absorption (%) was determined according to,

$$\text{Water absorption (\%)} = \frac{Wf - Wi}{Wi} \times 100 \tag{4}$$

Where, W_i is the initial weight and W_f is the final weight. Likewise, the thickness swelling (%) was calculated as,

$$\text{Thickness swelling (\%)} = \frac{Tf - Ti}{Ti} \times 100 \tag{5}$$

Where, T_i is the initial thickness and T_f is the final thickness.

Statistical Analysis

An analysis of variance was conducted ($p < 0.05$) to evaluate the effect of the PLPs and $CaCl_2$ on some physical and mechanical properties of CBCBs. Significant differences among the average values of the CBCB specimens were determined using Duncan's multiple range test.

RESULTS AND DISCUSSION

Effect of Palm Particles and $CaCl_2$ on MOR, MOE, and IB Values

The significance of different combinations of palm particles and $CaCl_2$ as well as their interaction on the MOR, MOE, and IB values of the produced CBCBs are given in Table 3.

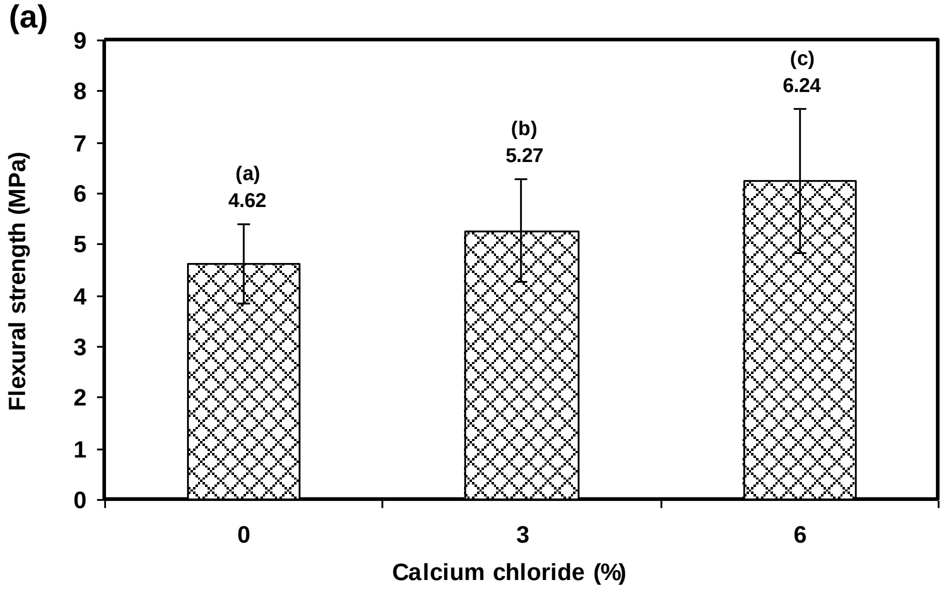
Table 3. ANOVA for the Independent and Dependent Effects of Palm Particles and $CaCl_2$ on MOR, MOE, IB, Density, Water Absorption, and Thickness Swelling after 2 and 24 h of CBCBs

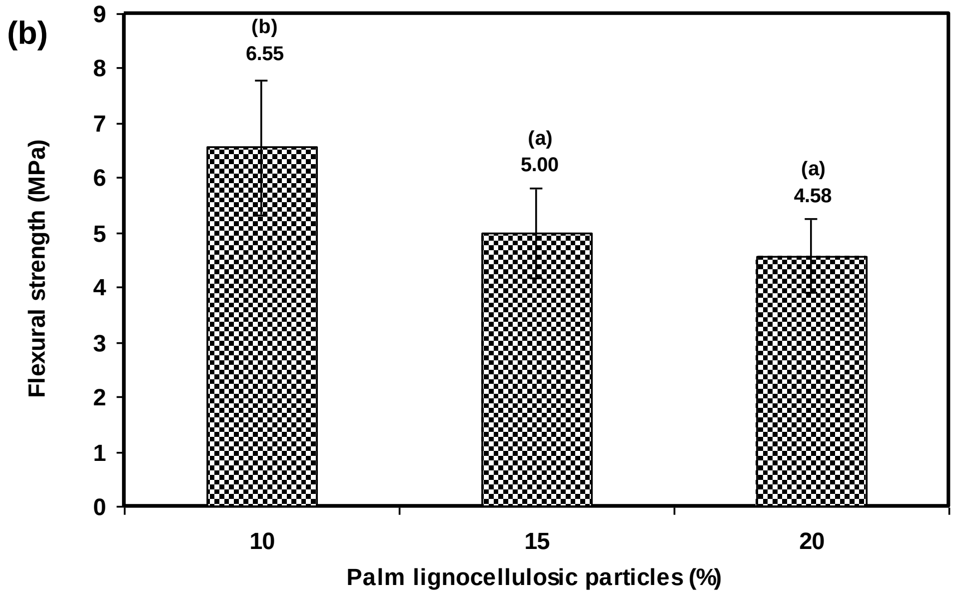
	MOR	MOE	IB	Density	WA 2 h	WA 24 h	TS 2 h	TS 24 h
CC	*	*	*	*	*	*	*	*
PLP	*	*	*	ns	*	ns	*	*
CC * PLP	Ns	*	*	ns	*	*	*	*

* Significant at α = 5% level; ns: Non significant

With increased $CaCl_2$ from 0% to 6%, the MOR of the CBCBs increased from 4.62 MPa to 6.24 MPa. In contrast, with the increased amount of the particles from 10% to 20%, the MOR values significantly decreased from 6.55 MPa to 4.58 MPa (Fig. 4).

(a)





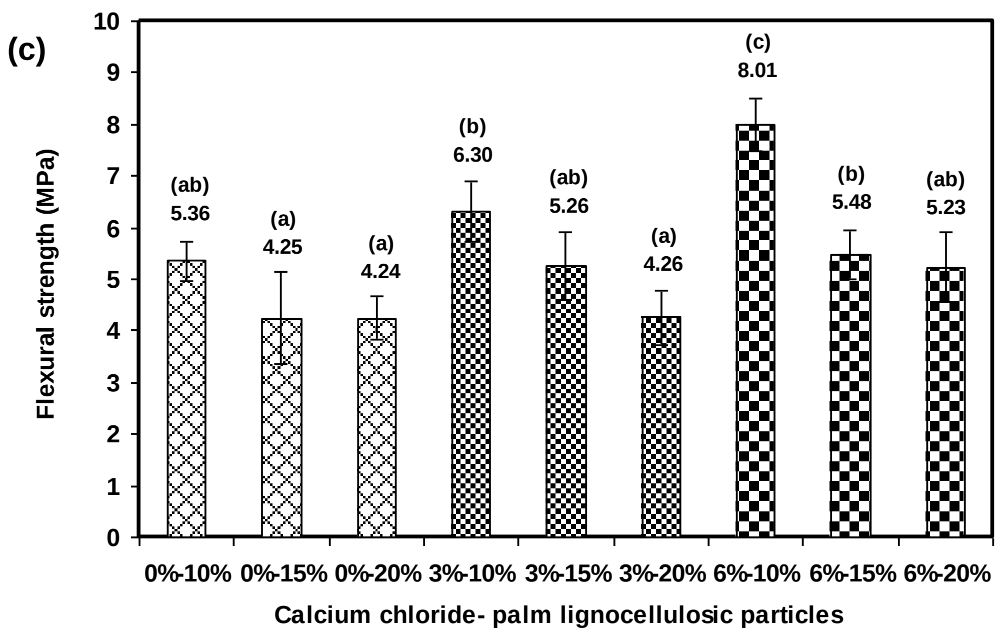


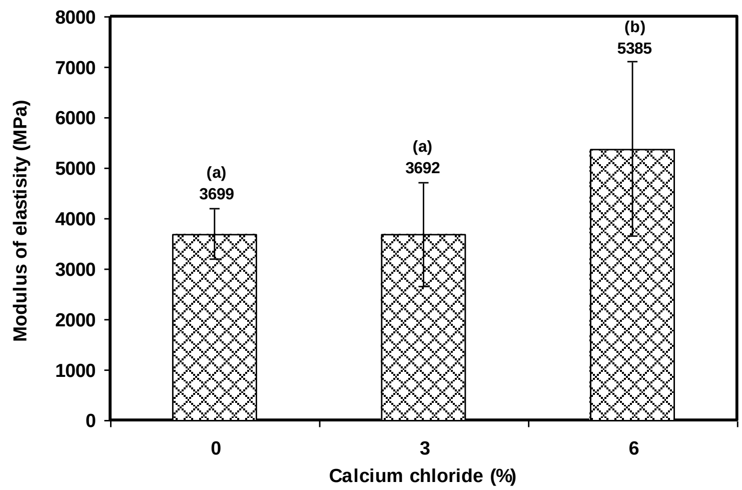
Fig. 4. Effect of palm particles and $CaCl_2$ amounts on the MOR values of the produced CBCBs. (a) Flexural strength *versus* amount of calcium chloride without palm-lignocellulosic particles. (b) Flexural strength *versus* amount of palm-lignocellulosic particles without calcium chloride. (c) Flexural strength *versus* amount of calcium chloride – palm-lignocellulosic particles. Different letters in each column indicate a statistical difference ($p < 0.05$) among the composite groups.

The best combination for the MOR (8.01 MPa) was found in the specimens containing 6% $CaCl_2$ and 10% particles. The further addition of the particles up to 20% reduced the MOR to 4.24 MPa at 0% $CaCl_2$. The decrease in MOR at higher particle content could be due to the increases in the composite porosity, as well as the reduction in the particle-matrix interfacial area (Aggarwal *et al.* 2008). However, all the values were found to be lower than the minimum requirements (9.0 MPa) of the ISO 8335-1987 (1987) and BS 5669-1989 (Part 4 Specifications) (1989) standards. However, the combination of 6% $CaCl_2$ with 10% particles (8.01 MPa) nearly reached the minimum requirements (ISO 8335-1987 (1987)).

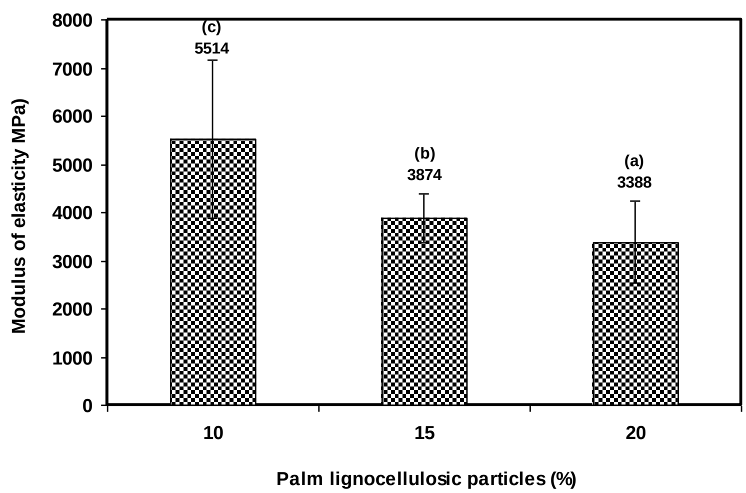
As shown in Fig. 5, the CBCBs with 6% $CaCl_2$ had the highest MOE value (5385 MPa) and the lowest MOE value with 0% $CaCl_2$ (3699 MPa). The highest value was reached at 10% particles (5514 MPa). The best combination was found in the specimens with 6% $CaCl_2$ and 10% particles (7656 MPa), and the lowest value was found in the specimens with the combination of 3% $CaCl_2$-20% particles (2399 MPa). The MOE value of 6% $CaCl_2$ with 10% particles exceeded the standard requirement (3.0 GPa) (ISO 8335-1987 (1987)).

ANOVA analysis showed that there were significant dependent effects of palm particles, $CaCl_2$, and their combination on the IB values of CBCBs (Table 3). As shown in Fig. 6, the best values of IB strength were recorded in boards with 6% $CaCl_2$ (0.41 MPa) and 10% particles (0.46 MPa) or with the combination of 6% $CaCl_2$ and 10% particles (0.52 MPa). Furthermore, the addition of up to 20% particles increased the volume of particles and reduced the volume of matrix, which caused lower IB strength (Aggarwal *et al.* 2008).

(a)



(b)



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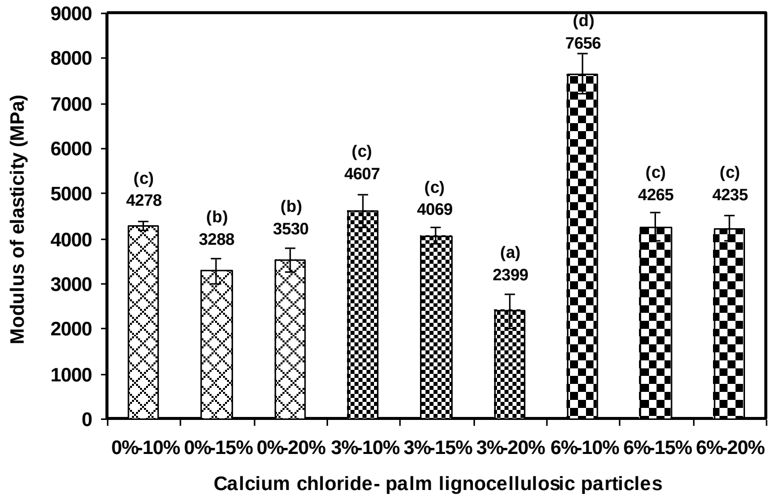
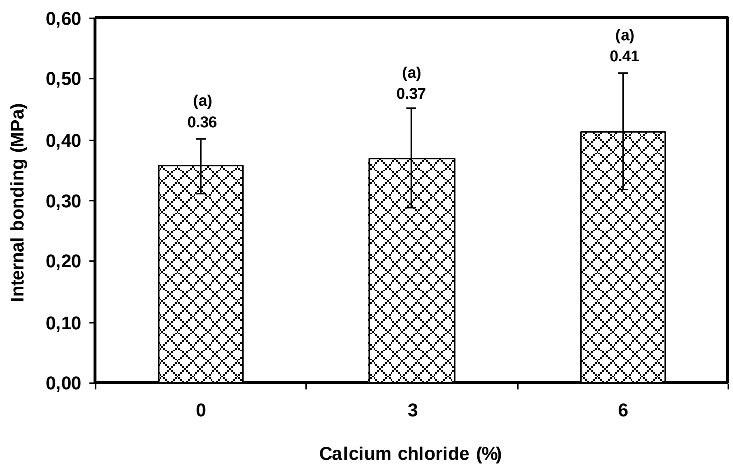


Fig. 5. Effect of palm particles and $CaCl_2$ amounts on the MOE values of the produced CBCBs (a) Modulus of elasticity in bending *versus* amount of calcium chloride without palm-lignocellulosic particles. (b) Modulus of elasticity in bending *versus* amount of palm-lignocellulosic particles without calcium chloride. (c) Modulus of elasticity in bending *versus* amount of calcium chloride - palm-lignocellulosic particles. The different letters in each column indicate that there is statistical difference ($p< 0.05$) among the composite groups.

(a)



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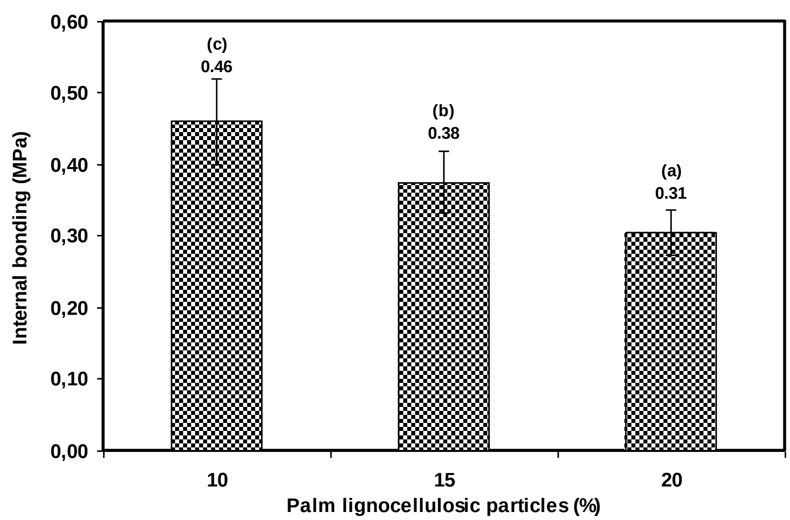

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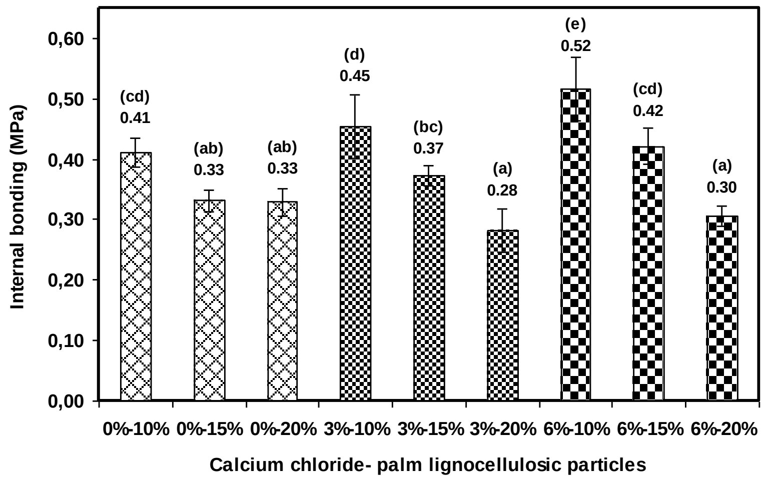


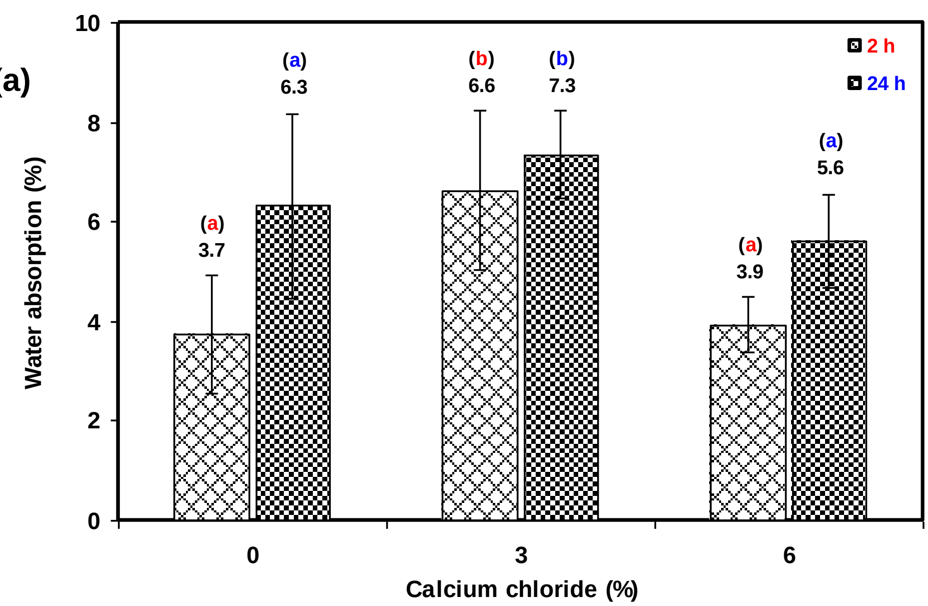
Fig. 6. Effect of palm particles and $CaCl_2$ amounts on the IB values of the produced CBCBs. (a) Internal bonding strength *versus* amount of calcium chloride without palm-lignocellulosic particles. (b) Internal bonding strength *versus* amount of palm-lignocellulosic particles without calcium chloride. (c) Internal bonding strength *versus* amount of calcium chloride - palm-lignocellulosic particles. The different letters in each column indicate that there is statistical difference ($p < 0.05$) among the composite groups.

The IB strength values were close to or exceeded the requirement standard (0.45 MPa). The interfacial area between the particles and cement matrix was reduced with increased particle amount. This could be due to increased particle-to-particle interaction, which decreased the bonding with cement and subsequently lowered the strength properties (Aggarwal *et al.* 2008).

Water Absorption of CBCBs after 2 and 24 h

The 2 h WA of the specimens was significantly affected by the amount of particles in the CBCB specimens (Table 3). However, after 24 h immersion in water, there was no significant effect of the amount of the particle on the WA of the specimens.

(a)



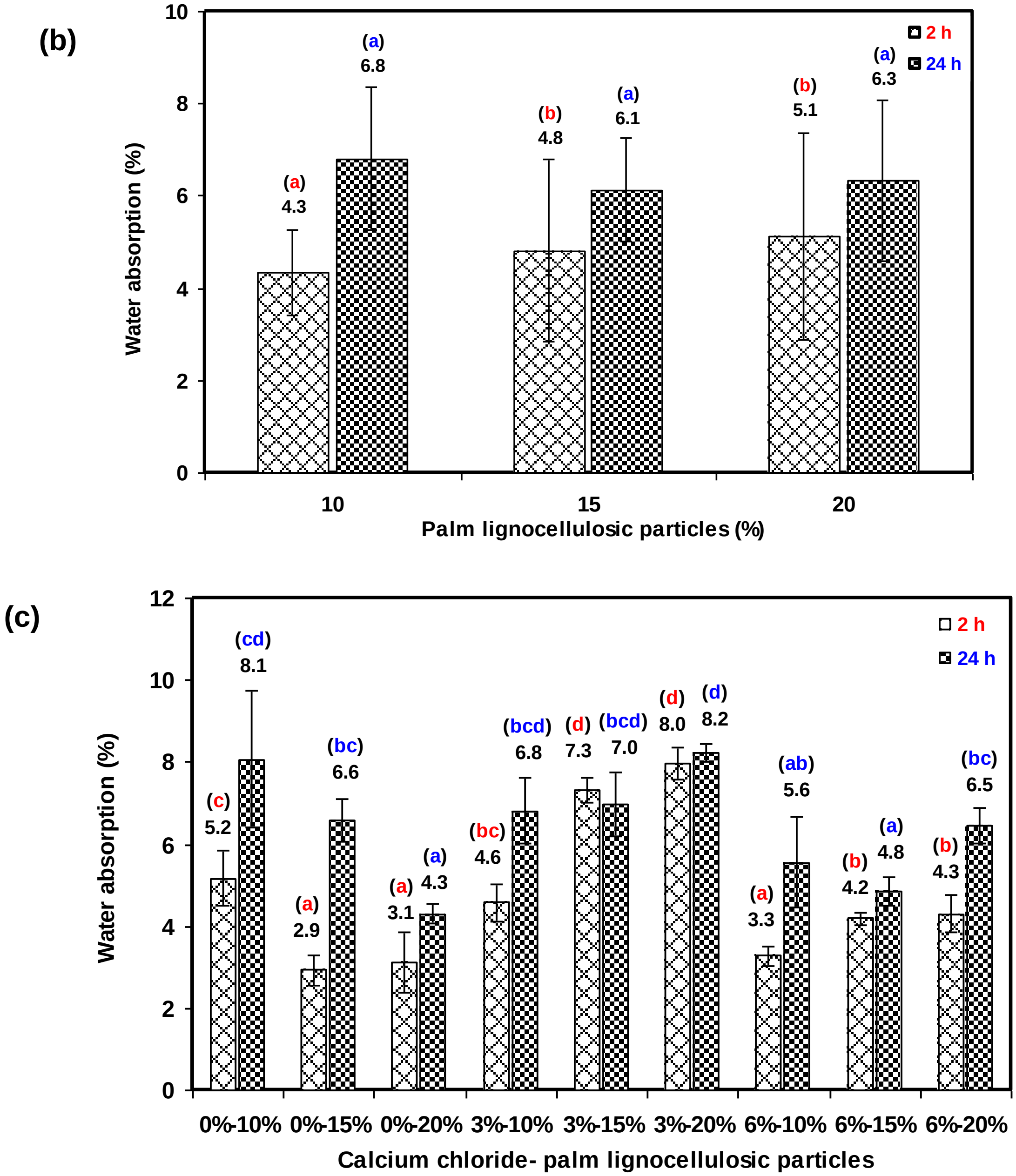


Fig. 7. Effect of palm particles and $CaCl_2$ amounts on the WA values of the produced CBCBs after 2 and 24 h soaking in water. (a) Water absorption *versus* amount of calcium chloride without palm-lignocellulosic particles. (b) Water absorption *versus* amount of palm-lignocellulosic particles without calcium chloride. (c) Water absorption *versus* amount of calcium chloride - palm-lignocellulosic particles. The different letters in each column indicate that there is statistical difference ($p< 0.05$) among the composite groups.

As shown in Fig. 7, the highest WA value after 2 h was found in the CBCB specimens (6.6%) treated with 3% $CaCl_2$, followed by the CBCB specimens manufactured with 20% particles (5.1%) and 10% particles (WA 4.3%). As for the combination treatments, the highest value was found in the CBCB specimens produced with 3% $CaCl_2$ and 20% particles (WA 8%). The lowest values were found in the CBCB specimens with 0% $CaCl_2$ (WA 3.7%), followed by 10% particles (WA 4.3%). The combined treatments of 0% $CaCl_2$-15% particle, 0% $CaCl_2$-20% particle, and 6% $CaCl_2$-20% particle had the WA values of 2.9%, 3.1%, and 4.3%, respectively.

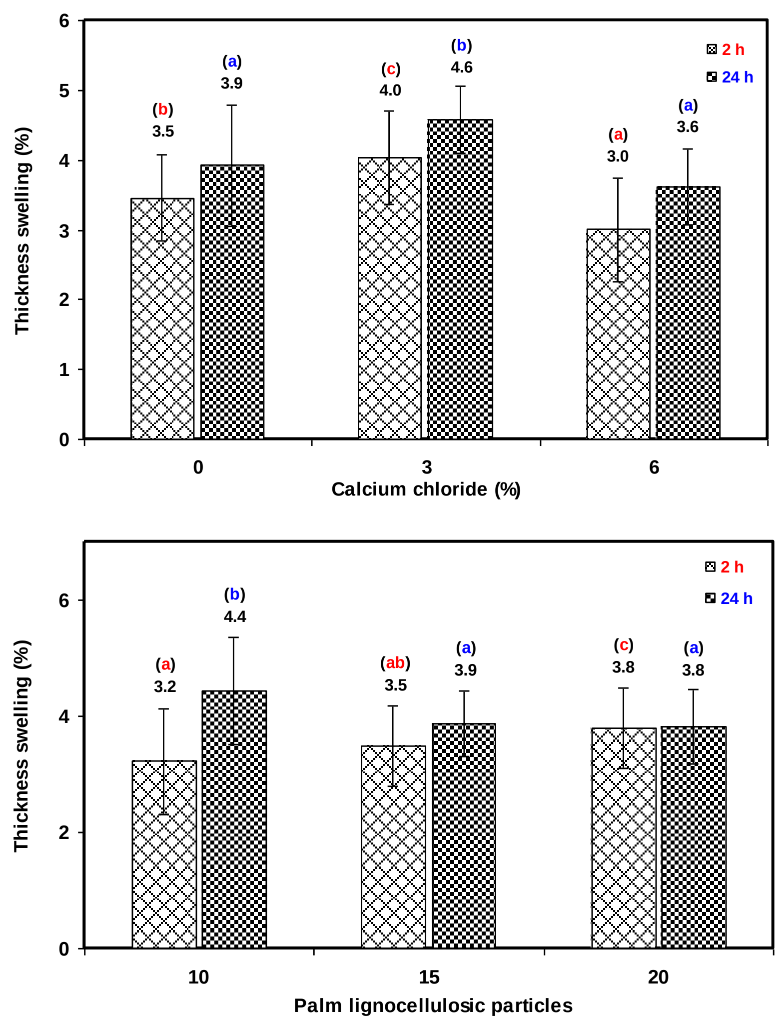
After 24 h (Fig. 7) immersion in water, the highest values of WA were found in the CBCB specimens manufactured with 3% $CaCl_2$ (WA 7.3%), CBCB specimens manufactured with 10% particles (WA 6.8%) and 20% particles (WA 6.3%), and the combination treatment of 3% $CaCl_2$ and 20% particles (WA 8.2%). The lowest values were found in the CBCB specimens manufactured with 6% $CaCl_2$ (WA 5.6%), followed by 15% particles (WA 6.1%) and 20% particles (WA 6.3%) and the combined treatments of 0% $CaCl_2$-20% particles (WA 4.3%).

Thickness Swelling of Boards after 2 and 24 h

All the treatments significantly affected the 2 h and 24 h thickness swelling (TS) of the CBCB specimens (Table 3). The lowest 2 h TS value (3%) was found in the specimens with 6% $CaCl_2$, followed by 10% particles (3.2%), and 6% $CaCl_2$ with 10% particles (TS 2.2%), respectively. After 24 h (Fig. 8) immersion in water, the lowest TS value (3.6%) was found in the specimens with 6% $CaCl_2$, followed by 20% particles (3.8%) and 0% $CaCl_2$ with 15% particles (3.3%).

(a)

(b)



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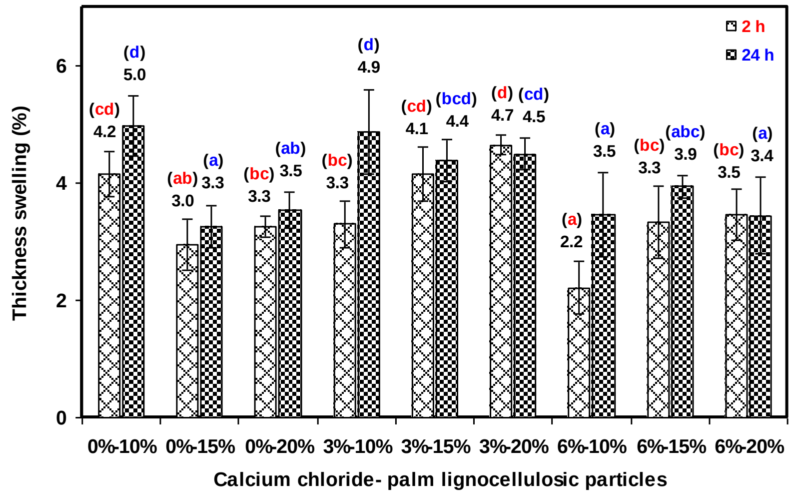
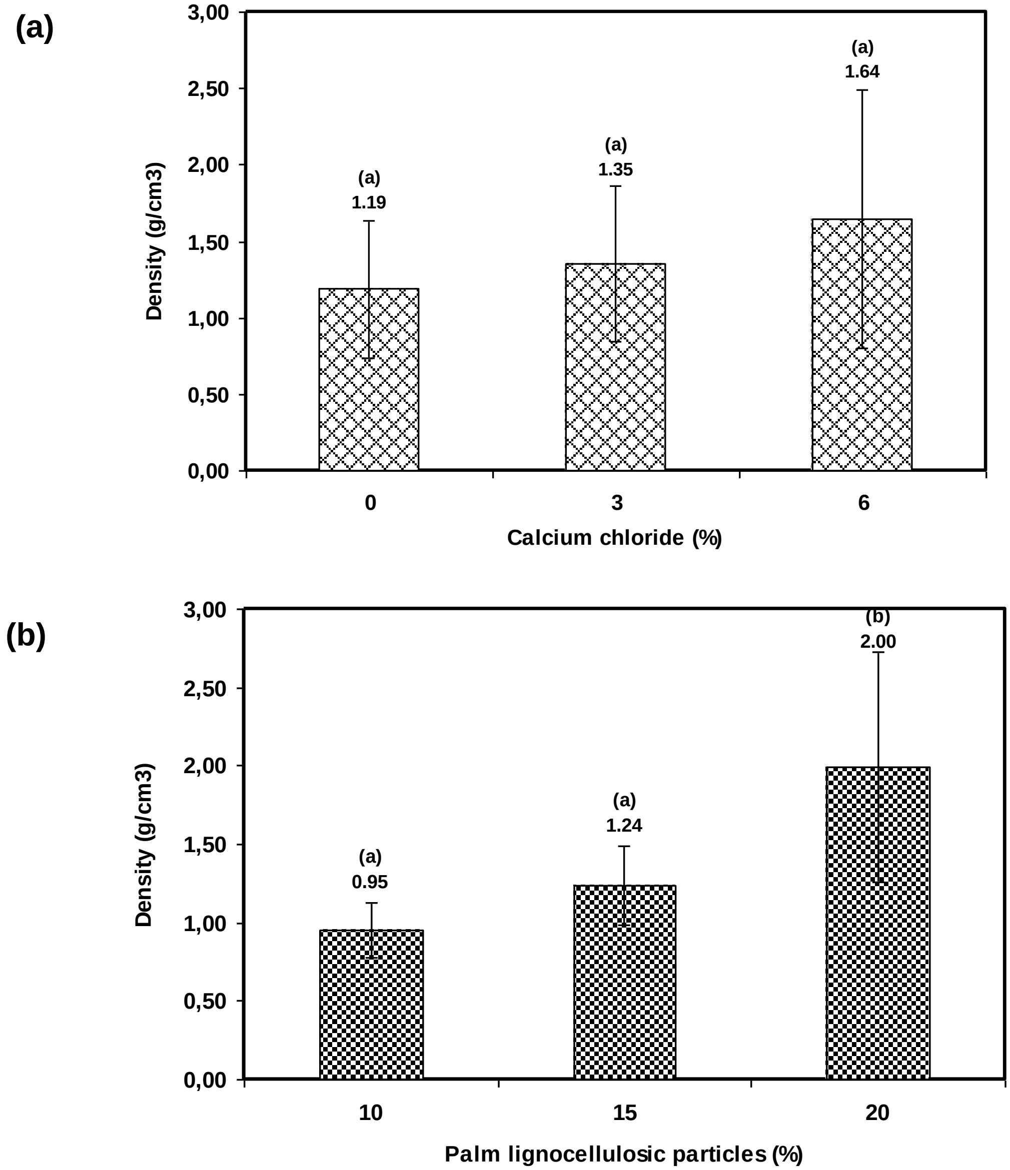


Fig. 8. Effect of palm particles and $CaCl_2$ amounts on the TS values of the produced CBCBs after 2 and 24 h of soaking in water. (a) Thickness swelling *versus* amount of calcium chloride without palm-lignocellulosic particles. (b) Thickness swelling *versus* amount of palm-lignocellulosic particles without calcium chloride. (c) Thickness swelling *versus* amount of calcium chloride - palm-lignocellulosic particles. The different letters in each column indicate that there is statistical difference ($p < 0.05$) among the composite groups.

The treatment of 6% $CaCl_2$ with 10% particles (TS 2.2%) was nearly reached the maximum requirement of ISO 8335-1987 (1987) (max. 2.0%). The WA and TS values of the CBCB specimens increased directly with time of water soaking from 2 to 24 h. After 24 h, the mean values of WA and TS were in agreement with those reported previously (Wei and Tomita 2001; Papadopoulos and Hague 2003; Okino *et al.* 2004). In addition, the denser panels having lower void spaces in the structure are expected to absorb less water (Guler and Ozen 2004; Roma *et al.* 2008).

Board Density

The $CaCl_2$ amount had a significant effect on the density of CBCB specimens (Table 3). With the increase in the $CaCl_2$ amount from 0 to 6%, the density of CBCB specimens increased from 1.19 to 1.64 g cm^{-3}, respectively (Fig. 9a).


(a)
Density (g/cm3)
3,00
2,50
2,00
1,50
1,00
0,50
0,00
(a)
1.19
(a)
1.35
(a)
1.64
0
3
6
Calcium chloride (%)
(b)
Density (g/cm3)
3,00
2,50
2,00
1,50
1,00
0,50
0,00
(a)
0.95
(a)
1.24
(b)
2.00
10
15
20
Palm lignocellulosic particles (%)

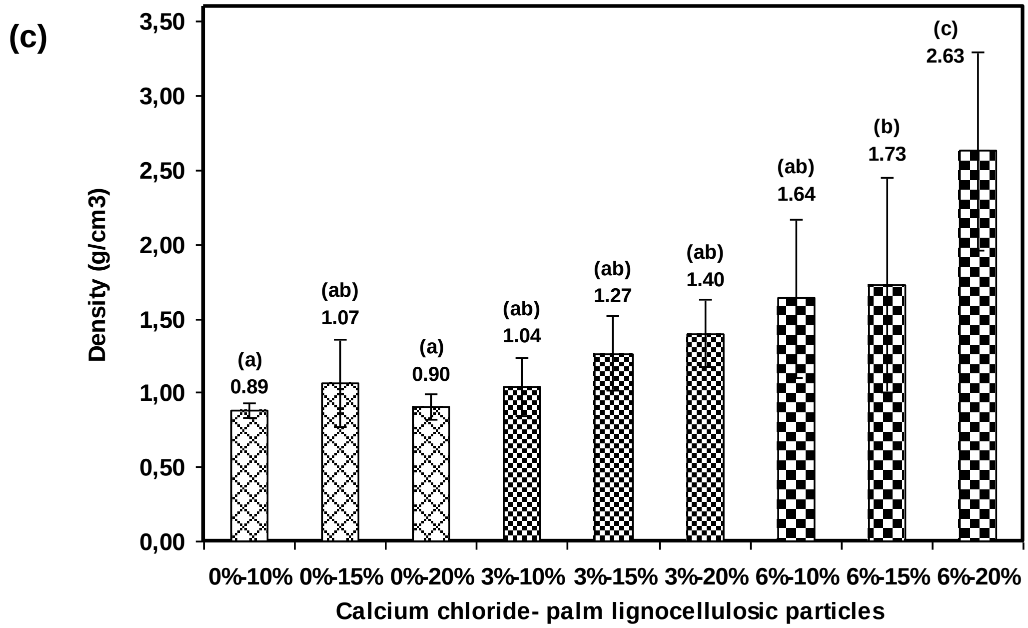


Fig. 9. Effect of amount of palm particles and $CaCl_2$, and $CaCl_2$-palm particles on the density of the produced CBCBs. (a) Density *versus* amount of calcium chloride without palm-lignocellulosic particles. (b) Density *versus* amount of palm-lignocellulosic particles without calcium chloride. (c) Density *versus* amount of calcium chloride - palm-lignocellulosic particles. The different letters in each column indicate that there is statistical difference ($p< 0.05$) among the composite groups.

Even with increase in the particle amount from 10 to 20%, there were no significant differences between densities with values of 0.95 g cm^{-3} and 2.00 g cm^{-3}, respectively (Fig. 9b). The lowest value was found in specimens with 0% $CaCl_2$-10% particles (0.89 g cm^{-3}) while the highest value was found in the specimens with 6% $CaCl_2$-20% particles (2.63 g cm^{-3}) (Fig. 9c). These values meet the ISO 8335-1987 (1987) standard requirement of a density above 1.00 g cm^{-3}

The dimensional stability of the CBCB specimens improved with increasing $CaCl_2$ content from 0 to 6%. The mechanical (IB and MOR) and physical properties (WA and TS) of the CBCB specimens increased with increasing density of the boards. These findings are consistent with previous studies. For example, Nasser and Al-Mefarrej (2011) reported that the date palm midrib particles were reclassified to suitable for wood-cement panels production under limited conditions (T_{max} value was 54.23°C and the C_A value was 75.73%) by the addition of 3% $CaCl_2$ as an accelerator to the untreated particles. In other studies (Moslemi *et al.* 1983; Mohamed 2004), the addition of 3% $CaCl_2$ to the mixture of cotton stalks and bagasse particles slightly improved the maximum hydration temperature for the untreated particles. Generally, the main veins of palm particles could be suitable for the production of cement-wood particleboards after the addition of $CaCl_2$ (Sandermann and Kohler 1964; Okino *et al.* 2004). Ferraz *et al.* (2011) reported that the coir fiber (*Cocos nucifera* L.) was a suitable raw material for cement-bonded composites as physical and mechanical properties were enhanced by the addition of 4% $CaCl_2$. However, 2% of aluminum sulfate and magnesium chloride significantly improved bending and tensile strengths of cement-bonded particleboard made from presoaked oil palm stems in comparison with calcium chloride, and there was no significant effect of particle size (Rahim *et al.* 1995).

CONCLUSIONS

1. The results indicated that increased amount of main veins of palm particles caused a decrease in the mechanical properties of the CBCBs. However, the combination treatment of 6 wt.% $CaCl_2$ with 10 wt.% particles (8.01 MPa) nearly reached the minimum requirements of ISO 8335 (1987) standard. The increase in the $CaCl_2$ up to 6% resulted in improved mechanical properties of the CBCBs.
2. The mean values of the studied parameters showed that the MOR, MOE, and IB of CBCB specimens increased directly with the increases of the $CaCl_2$.
3. The dimensional stability of the CBCB specimens improved directly with increasing $CaCl_2$ content from 0 to 6 wt.%. The lowest value of WA after 2 h was found in the specimens with 0 wt.% $CaCl_2$-15 wt.% particles (2.9%) and 0 wt.% $CaCl_2$-20 wt.% particles (4.3%) after 24 h.
4. The board thickness decreased with the increasing amount of particles. The lowest TS values after 2 h and 24 h were found in the CBCB specimens manufactured with 6% $CaCl_2$-10% particles (2.2%) and after 24 h with 0% $CaCl_2$-15% particles (3.3%).
5. The most favorable formulation of CBCB based on physical and mechanical properties tested consisted of 90 wt.% of cement + 10 wt.% of main veins palm particles + 6 wt.% of $CaCl_2$.

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