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EVALUATION OF CEMENT-BONDED PARTICLE BOARD PRODUCED FROM *AFZELIA AFRICANA* WOOD RESIDUES

OLUFEMI A. SOTANNDE[1,*], ABIODUN O. OLUWADARE[2], OMAOJOR OGEDOH[1], PAUL F. ADEOGUN[1]

[1]Department of Forestry and Wildlife, Faculty of Agriculture, University of Maiduguri, Borno State, Nigeria
[2]Department of Forest Resources Management, University of Ibadan, Oyo State, Nigeria
*Corresponding Author: femsot@gmail.com

Abstract

The study was design to evaluate the physical and mechanical properties of cement-bonded particleboards produced from *Afzelia africana* wood residues. The production variables investigated were three wood particle types (flakes, flake-sawdust mix and sawdust), three chemical accelerators ($CaCl_2$, $MgCl_2$ and $AlCl_3$) and four wood-cement ratios (1:2.0, 1:2.5, 1:3.0 and 1:3.5). The accelerators were based on 2% by weight of cement used. The boards produced were subjected to physical tests such as density, percentage water absorption and thickness swelling. Mechanical properties evaluated were modulus of rupture, internal bonding strength and compressive strength. The results revealed that the type of particle used, wood-cement ratio and chemical additives had a marked influence on the physical and mechanical properties of the boards ($p < 0.05$). From quality view point, flake-sawdust composite ranked best while flake boards ranked least. Similarly, $CaCl_2$ had the best influence on the setting of the boards followed by $MgCl_2$ and $AlCl_3$. Finally, it has been shown that particle boards that satisfied the BISON type HZ requirement and ISO 8335 can be produced from *Afzelia africana* particularly at wood-cement of 1:2.5 and above.

Keywords: *Afzelia africana*, Wood flakes, Sawdust, Chemical additives, Physico-mechanical properties.

1. Introduction

Wood as a raw material contributes significantly in improving a nation's economic base, industrialization and comfort of its teeming population. Globally, the demand for wood and wood-based panel products has being on the increase.

Nomenclatures

$AlCl_3$	Aluminium chloride
$CaCl_2$	Calcium Chloride
CS	Compressive strength, N/mm^2
C_t	Cement weight, g
IBS	Internal bonding strength, N/mm^2
MC	Moisture content of wood residues, %
$MgCl_2$	Magnesium chloride
MOR	Modulus of rupture, N/mm^2
TS	Thickness swelling, %
W	Wood dry weight, g
WA	Water absorption, %
W_t	Weight of water, g
w/c	Wood-cement ratio

Greek Symbols

α	Level of significance

Abbreviations

CBP	Cement-Bonded Particleboard
ISO	International Standard Organization

In 1993, the consumption of sawn wood and wood based panel products in Nigeria was put at 2.866 and 0.121 million m^3 respectively and was projected to increase to 4.704 and 0.688 million m^3 by the year 2010 [1]. The high demand for wood and wood-based panel products in the country has resulted in over exploitation and unregulated harvesting of trees in both the natural and plantation forest leading to recent interest in lesser known timber species [2]. Despite these efforts, demand for wood products still exceeds timber supply resulting in continued cutting without replacement [3]. This imbalance between wood consumption and sustainable supply will have serious economic, social and environmental implication on the populace.

In many developing countries, Nigeria inclusive, large quantities of wood residues are generated on daily bases during wood processing without recourse for economic use. Ajayi [4] observed that only about 50-55% of the original wood harvested becomes marketable after processing in sawmills and plywood mills in Nigeria. Similarly, a critical study of sawmills scattered across the country shows that large volume of sawdust and wood flakes waste are burnt on a daily basis, thus constituting a major environmental problem [5]. Landfill disposal and burning of wood residues are becoming less acceptable, hence the need to explore the economic benefit of these residues. One way through which this can be achieved is to incorporate the wood residues into cement bonded particleboard (CBP) production. This will not only reduce environmental hazard emanating from wood waste burning but will also contribute to economic growth of the country and reduced pressure on trees from forest.

CBP are wood-based panels which are more dimensionally stable under varying relative humidity change. They are good construction materials which are of great importance to mankind and possess unique qualities over other panel products. This made it more acceptable particularly in less developed countries. The acceptance of

CPB is based on its reliability and resistance to fire, insect attack, decay and their perceived performance during natural disasters such as earthquakes and tropical storms [6, 7]. These inherent properties of CPB made it a versatile material for roofing, ceiling board, and flooring, partitioning, cladding, and shuttering [8]. However, some of the factors influencing the setting of CBP include the use of chemical accelerator, particle geometry and wood-cement mixing ratio. These factors play a major role in determining the qualities of CPB and the final end-use.

This study therefore examines the effects of different wood particle type, wood-cement mixing ratio and chemical additives on the physical and mechanical properties of cement bonded particle board produced from *Afzelia africana* wood residues.

2. Materials and Methods

2.1. Material collection and pretreatment

Green sawdust and wood flakes of *Afzelia africana* were collected from the famous Baga road timber market located in Maiduguri, Borno state in the north eastern part of Nigeria. The materials were stored in the wood utilization laboratory of the Forestry and Wildlife Department, University of Maiduguri for four months at constant room temperature to allow for break down and degradation of wood components such as glucose, lignin, and cellulose before pre-treatment. The materials were later extracted in hot water at a constant temperature of 85°C to ensure further breakdown of inhibitory sugar compounds. The extracted materials were separately air dried inside controlled ambient for two weeks to attain approximately 12% moisture content prior to use.

2.2. Board formation and testing

The experimental design adopted is shown in Table 1. The required amount of sawdust and flakes needed to make every single board was dry-mixed thoroughly with cement based on specified w/c ratio. Chemical additives, ($CaCl_2$, $MgCl_2$ and $AlCl_3$) prepared as 2% by weight of cement was dissolved in water, sprinkled on wood-cement composite and mixed into uniform matrix free lump. The amount of water used was computed using the formula shown below:

$$W_t = 0.60C_t + (0.30 + MC)W \quad (1)$$

where Wt is weight of water (g), C_t is cement weight (g), MC is moisture content of wood residues (%) and W is wood dry weight (g).

Table 1. The Experimental Conditions for the Manufacture of Wood-Cement Boards.

Production variables	Specifications
Wood particle type	Flakes + Sawdust (1:1), Flakes, Sawdust
Wood-cement ratios (w/c)	1:2.0, 1:2.5, 1:3.0, 1:3.5
Chemical additives (2%)	$CaCl_2$
Board size, cm	30 × 30 × 1
Board density target, g/cm^3	1.2

The stock was hand formed in wooden mould of 30 cm × 30 cm, placed on metal plate and covered with polythene sheet. Thereafter, the mat was guarded with four 1 cm stoppers at the edges and pre-pressed with a wooden press. The pre-pressed mat was covered with another polythene sheet after which the upper metal plate was placed. Five replicates were prepared for each production batch. The mats were later cold pressed in a 5 tones hydraulic jack press for 24 hours. After the pressing cycle, the boards were de-moulded and allowed to cure at room temperature for a month. Each of the production batches was replicated five times based on wood particle type, chemical additive and w/c mixing ratios.

Thereafter, the boards produced were trimmed, cut into specimen sizes of 20×20cm and subjected to tests in accordance with the procedures stipulated in ASTM D 1037-93 [9]. The board density, thickness swelling (TS) and percentage of water absorption (WA) were determined manually while the internal bonding strength (IBS), modulus of rupture (MOR) and compressive strength (CS) of the boards was determined using Otto Wolpert-Werke GMBH D-6700 universal testing machine.

2.3. Statistical analysis

A 3×3×4 factorial experiment in a Completely Randomized Design was used. The main factors considered were; material type (flake, flake-sawdust and sawdust), chemical additive ($CaCl_2$, $MgCl_2$ and $AlCl_3$) and the wood-cement ratio (1:2.0, 1:2.5, 1:3.0 and 1:3.5). Duncan Multiple Range Test was used at 95% probability level to test the significance of treatment means.

3. Results and Discussion

3.1. Effect of production variables on board densities

The analysis of variance for the physical characteristics of the boards is summarized in Table 2. It was observed that difference in wood particle type and blending ratio had a marked effect on board density ($p < 0.05$), but variations in chemical additive does not ($p > 0.05$). Board density varied from 1.17 g/cm^3 to 1.22 g/cm^3 with an average of 1.20 g/cm^3 (Table 3). The flake-sawdust boards produced at w/c ratio of 1:3.5 had the highest density of 1.32g cm^{-3} while the least density of 1.01 g/cm^3 was obtained in flake boards produced at w/c ratio of 1:2. The reason for the increase in density with w/c ratio might be due to the quantity of cement in the mixture which is denser than wood fibres. It can thus be concluded that density of wood-cement board is a function of the quantity of the cement in the mix. The observed high density of flake-sawdust boards could be attributed to the heterogeneous nature of the particles which enhanced bonding and filling of void spaces in the boards. This became apparent in the higher density of 1.21 g/cm^3 obtained in sawdust boards compared to 1.17 g/cm^3 obtained in flakes boards. Thus, smaller wood particles tend to bond better with Portland cement than bigger particles in wood-cement composites [10].

Meanwhile, the introduction of chemical additives enhanced the setting of the boards as expressed in the varying densities. The highest density was obtained when $CaCl_2$ was used while the least density was obtained in wood-cement composites produced without any chemical additives (Fig. 1). The densities of all the boards produced are in the range of ISO requirement of not less than 1 g/cm^3 [11] and maximum density of 1.25 g/cm^3 of BISON wood-cement boards [12].

Table 2. Analysis of Variance of the Effect of Production Variables on Board Density, Water Absorption and thickness swelling.

Sources of variation	Df	Density (g/cm^3)	WA (%)	TS (%)
Wood material type (MT)	2	16.22*	8.55*	7.01*
W/C ratio (w/c)	3	211.47*	120.25*	39.75*
Additive (A)	3	2.15^{ns}	3.13*	6.93*
MT x W/C	6	4.27*	3.97*	12.71*
MT x A	6	0.98^{ns}	2.39^{ns}	5.16*
W/C x A	9	4.30*	3.62*	4.28*
MT x W/C x A	17	1.46^{ns}	1.95^{ns}	4.96*
Error	97			
Total	143			

* = Significant, ns = Not significant

Table 3. Influence of Wood Particle Type on Physical Properties of the Boards.

Variables		Density (g/cm^3)	WA (%)	TS (%)
Particle type				
Flakes (F) + Sawdust (S)		1.22*	22.35*	1.92*
Flakes (F)		1.17*	27.88*	2.75*
Sawdust (S)		1.21*	22.39*	2.09*
Wood-cement ratios				
F + S	1:2.0	1.11	31.06	2.27
F + S	1:2.5	1.18	25.78	1.65
F + S	1:3.0	1.27	12.63	1.41
F + S	1:3.5	1.32	8.52	0.97
F	1:2.0	1.01	44.07	4.66
F	1:2.5	1.14	33.19	2.51
F	1:3.0	1.23	14.77	1.82
F	1:3.5	1.32	13.34	1.62
S	1:2.0	1.09	36.63	3.41
S	1:2.5	1.19	25.89	1.92
S	1:3.0	1.25	11.12	1.46
S	1:3.5	1.29	10.49	1.26

*Values with the same alphabets in each column are not significantly different at α = 0.05

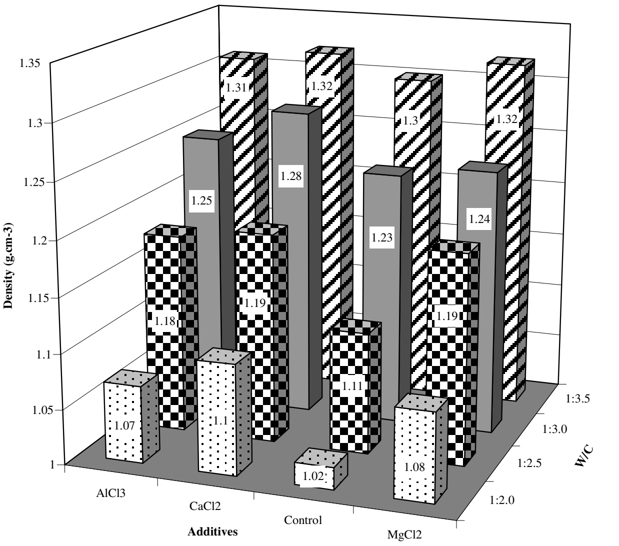


Fig. 1. Effect of Chemical Additives and w/c Ratio on Board Density.

3.2. Effect of production variables on WA and TS of the boards

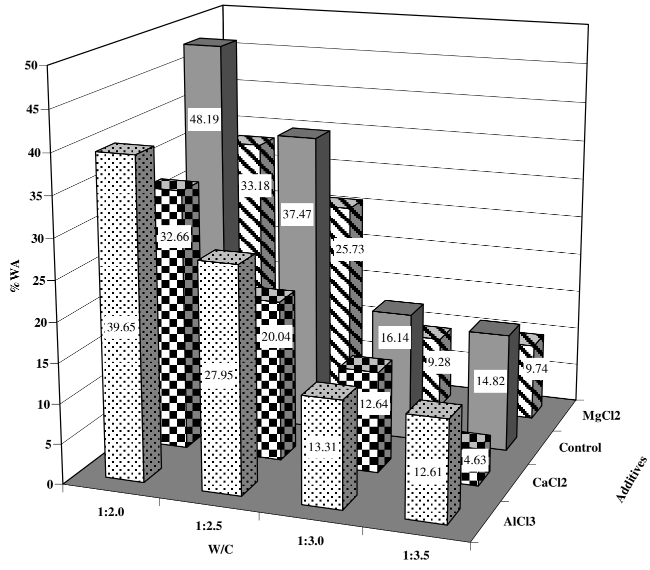
Water absorption (WA) and Thickness swelling (TS) are physical properties related to dimensional stability of the boards. They give an idea of how wood-cement boards behave when used under severe humidity conditions. They are especially important in boards for external use.

Table 2 shows that the type of wood particle used, w/c ratio and chemical additives significantly influenced water absorption of the boards ($p < 0.05$). After 120 hours of immersion, the highest water absorption of 27.88% was obtained in flake boards while flake-sawdust boards had the least (Table 3). The observed high percentage water absorption in flakes-cement bonded composite could be attributed to difficulty in compression and presence of void spaces in the boards which allowed water intake. Meanwhile, when the w/c ratio was varied, an inverse relationship was established between the cement content of boards and the %WA. The use of chemical additives also played some inhibitory role on the %WA, Fig. 2(a). Boards produced with chemical additives had significantly lower % WA compared to boards produced without chemical additives.

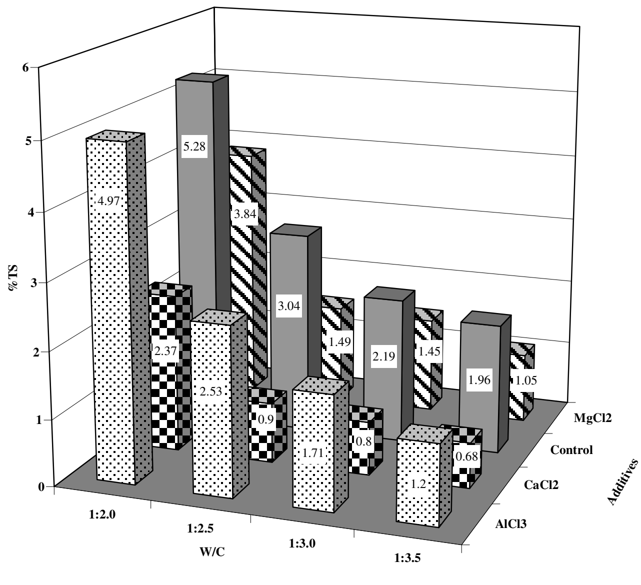
The thickness swelling (TS) of the boards followed the same trend with %WA (Table 2 and 3). It was evident that the presence of more irregular void spaces in flake board enhanced water absorption which influenced %TS [13]. This assertion was corroborated by Lee [14] in which he stated that the presence of many voids in the boards allowed internal swelling. Apart from particle geometry, the TS of the boards were also influenced by w/c ratio (Table 3) and chemical additives, Fig. 2(b). In general, higher cement content in the boards lowers thickness swelling likewise the use of flake-sawdust mixture. The implication of this is that, wood particles in boards produced from lower wood-cement ratios are not encapsulated by cement which resulted in lower bonding and higher TS [15]. From this study, ISO 8335 requirement for TS of wood-cement boards of less than 2% [11] was met when the w/c was greater than 1:2.0 in both flakes-sawdust and sawdust boards and at 1:3.0 in flake boards (Table 3).

3.3. Effect of production variables on internal bonding strength (IBS) of the boards

The result of analysis of variance presented in Table 4 shows that the type of wood particle used and w/c ratios had a marked effect on IBS of the boards ($p < 0.05$). Flake-sawdust boards had average IBS of 0.50 N/mm^2 closely followed by 0.41 N/mm^2 obtained in sawdust boards while flake boards had the least with an average value of 0.37 N/mm^2 (Table 5). The highest value obtained in flake-sawdust composite is attributed to the absence of void space in the board which enhanced the strength. The bonding strength of the boards increased with increase in cement component of the boards. This is in agreement with earlier studies by Eusebio et al. [16] and, Zhou and Kamdem [17]. Wang and Sun [18] and Papadopoulos *et al*. [19] also observed that density of particleboards and wood components significantly influenced the particleboard strength properties. Meanwhile, all the chemical additives positively influenced the bonding strength of the boards (Fig. 3). Such influence accounted for the observed higher IBS of the boards compared to when no additive was applied. The sawdust and flakes-sawdust boards met BISON type HZ of 0.4 N/mm^2 internal bonding strength of wood-cement composite [12]. However, the standard was not met in flake boards until w/c ratio was increased to 1:3.0.



(a)



(b)

Fig. 2. Effect of w/c Ratio and Chemical Additives on (a) %WA and (b) %TS of the Boards.

Table 4. Analysis of Variance of the Effect of Production Variables on Strength Properties of the Boards.

Sources of variation	Df	IBS (N/mm)	MOR (N/mm)	CS (N/mm)
Wood material type (MT)	2	3.40*	0.478ns	4.657*
w/c ratio (W/C)	3	2.95*	0.654ns	60.514*
Additive (A)	3	0.92ns	0.773ns	3.845*
MT × W/C	6	0.82ns	1.242ns	4.431*
MT × A	6	1.89ns	1.180ns	1.218ns
W/C x A	9	0.98ns	1.148ns	6.388*
MT × W/C × A	17	0.68ns	1.028ns	3.710*
Error	97			
Total	143			

* = Significant, ns = Not significant

Table 5. Effect of Wood Particle Type on Strength Properties of the Boards.

Variables		IBS (N/mm^2)	MOR (N/mm^2)	CS N/mm^2)
Particle type				
Flakes (F) + Sawdust (S)		0.50[a]	11.64[a]	15.16[a]
Flakes (F)		0.37[b]	9.57[a]	12.55[b]
Sawdust (S)		0.41[ab]	5.81[a]	15.00[a]
Wood-Cement ratios				
F + S	1:2.0	0.45	11.15	9.08
F + S	1:2.5	0.49	15.45	10.6
F + S	1:3.0	0.51	10.92	17.6
F + S	1:3.5	0.59	9.54	24.7
F	1:2.0	0.19	6.33	8.34
F	1:2.5	0.34	5.88	8.71
F	1:3.0	0.42	5.64	13.3
F	1:3.5	0.45	5.38	19.9
S	1:2.0	0.33	9.64	9.45
S	1:2.5	0.40	12.83	10.3
S	1:3.0	0.45	8.33	16.9
S	1:3.5	0.51	7.49	23.3

*Values with the same alphabets in each column are not significantly different at $\alpha = 0.05$.

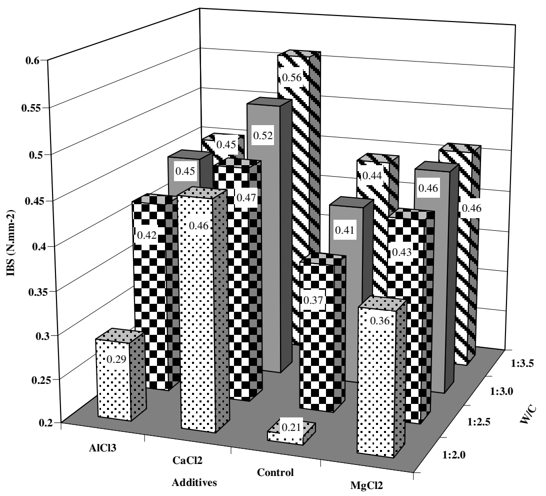


Fig. 3. Effect of Chemical Additives and w/c Ratio on IBS of the Boards.

3.4. Effect of production variables on modulus of rupture (MOR) of the boards

The type of wood particle used and w/c ratios had no marked effect on MOR of the boards produced (Table 4). Nevertheless, flakes-sawdust boards had the highest average MOR of 11.64 N/mm^2 while the least MOR was obtained in flake boards, 5.81 N/mm^2 (Table 5). The reason for high MOR in flakes-sawdust boards could be attributed to the random distribution of the particles in the composites. Thus, it could be concluded that heterogeneous particle sizes tend to enhance bending strength properties of wood-cement composites as oppose to the use of single particle of larger size. Meanwhile, when the w/c ratio was increased from 1:2.0 to 1:2.5, MOR of the boards also increases. However, further increase in the cement component of the boards beyond 1:2.5 resulted in decrease in MOR of the boards (Table 5). Similar trend was observed when the effect of the chemical additives on wood-cement mixture was considered (Fig. 4). This could be attributed to the higher proportion of wood in the board which enhanced the flexural property. When wood occupies more volume in the board, the areas of stress concentration around the component particles are more diffused, resulting in increased applied stresses [20]. Apart from in flake board, MOR of the flake-sawdust and sawdust composite met the minimum of 9.0 N/mm^2 set by BISON type HZ for wood-cement board.

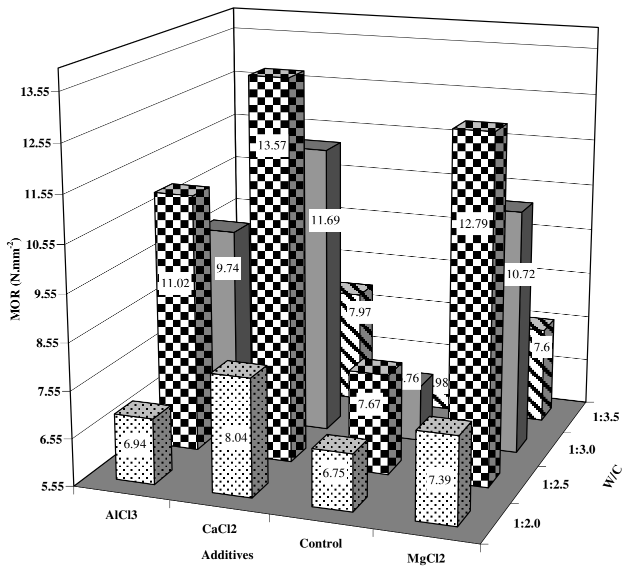


Fig. 4. Effect of Chemical Additives and w/c Ratio on MOR of the Boards.

3.5. Effect of production variables on compressive strength (CS) of the boards

The compressive strength of the boards varied significantly depending on the type of wood particle, w/c ratio and chemical additive used (Table 4). The average compressive strength ranged from 12.55 N/mm^2 in flake boards to 15.16 N/mm^2 in flake-sawdust boards (Table 5). These values fell short of the compressive strength of neat cement. According to Gong et al. [21] the compression strength values required for material to be used as pavements ranged from 20-25 N/mm^2. The reason for this according to Bentur and Mindness [22] could be attributed to the fact that wood fibres are generally not used to improve the compression of wood-cement bonded composite, though a small improvement in strength may sometimes result from their use. The role of wood particles in cement board was to control cracking and alter the behaviour of the composite once the matrix has cracks [23]. The high strength of flake-sawdust composite could be attributed to the distribution of the flakes and sawdust in the composite which eliminate the void spaces as much as possible. This became apparent when the interaction between the chemical additives and the mixing ratio is considered (Fig. 5). Thus, all the composites; flake board (19.9 N/mm^2) flake-sawdust board (24.7 N/mm^2) and sawdust board (23.3 N/mm^2) compared favourably with cement composites used for pavements when the w/c ratio was increased to 1: 3.5.

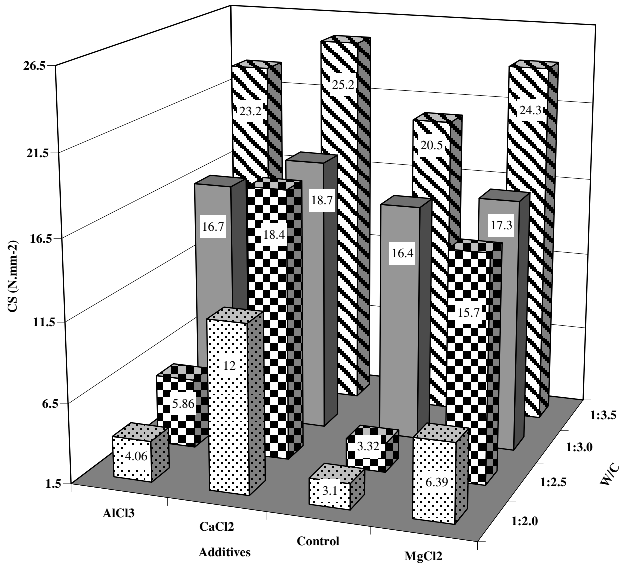


Fig. 5. Effect of Chemical Additives and w/c Ratio on CS of the Boards.

4. Conclusions

The physical and mechanical properties of cement-bonded particleboards produced from *Afzelia africana* wood residues were evaluated. This was done using three wood particle types (flakes, flake-sawdust mix and sawdust), three chemical accelerators ($CaCl_2$, $MgCl_2$ and $AlCl_3$) and four wood-cement ratios (1:2.0, 1:2.5, 1:3.0 and 1:3.5). At the end of the investigation, the following conclusions were drawn.

- The increase in cement content of the boards and introduction of chemical additives lowers the water absorption and thickness swelling of the boards.
- Except MOR, increase in cement content of the boards and addition of chemical additives significantly influenced the board density, internal bonding and compressive strength.
- From the quality view point, flake-sawdust composite ranked best followed by sawdust and flake boards respectively. Similarly, $CaCl_2$ had the best influence

on the setting of the boards followed by $MgCl_2$ and $AlCl_3$ respectively while boards produced without any chemical additive ranked least.

- Finally, it has shown that particle boards that satisfy BISON type HZ requirement and ISO 8335 can be produced from *Afzelia africana* particularly at wood-cement of 1:2.5 and above.

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