EFFECTS OF CHEMICAL ADDITIVE CONCENTRATIONS ON STRENGTH AND SORPTION OF CEMENT-BONDED BOARD

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FABIYI, J. S. 2004. Effects of chemical additive concentrations on strength and sorption of cement-bonded board. The influence of chemical additive concentration on the strength and sorption properties of cement-bonded boards (CBBs) produced from *Nauclea diderrichii* wood flakes was investigated. CBBs were made at three chemical additive concentrations: 1, 2 and 3% calcium chloride by weight of cement; three nominal board densities: 950, 1150 and 1250 kg m^{-3} and two cement-wood ratios: 1.5:1 and 2.5:1 (weight to weight basis). The modulus of rupture (MOR) and modulus of elasticity (MOE) values increased with increased chemical additive concentration. However, increase in chemical additive concentration caused reduction in water absorption (WA) and thickness swelling (TS) after 24-hours of water soaking. MOR and MOE increased while WA and TS decreased with increase in board density and cement-wood ratio. All the CBBs produced in this study meet British standard requirements for the flexural MOE property and TS performance in the presence of water. However, only the CBBs produced using chemical additive concentrations of 2 and 3% at both 1.5:1 and 2.5:1 of cement-wood ratio satisfy the British requirement.

Key words: Board density – cement-wood ratio – *Nauclea diderrichii*

FABIYI, J. S. 2004. Pengaruh kepekatan bahan tambah kimia terhadap kekuatan dan ciri erapan papan ikatan simen. Pengaruh bahan tambah kimia terhadap kekuatan dan sifat erapan papan ikatan simen (CBB) yang dihasilkan daripada kepingan kayu *Nauclea diderrichii* diselidik. CBB dihasilkan pada tiga kepekatan bahan tambah kimia: 1%, 2% dan 3% kalsium klorida mengikut berat simen; tiga ketumpatan papan: 950 kg m^{-3}, 1150 kg m^{-3} dan 1250 kg m^{-3}; dan dua nisbah simen-kayu: 1.5:1 dan 2.5:1 (nisbah berat kepada berat). Modulus kepecahan (MOR) dan modulus keanjalan (MOE) meningkat apabila kepekatan bahan tambah kimia meningkat. Bagaimanapun, peningkatan kepekatan bahan tambah kimia mengakibatkan penurunan penyerapan air (WA) dan pengampulan tebal (TS) selepas 24 jam direndam dalam air. MOR dan MOE meningkat apabila ketumpatan papan serta nisbah simen-kayu meningkat tetapi WA dan TS menurun. Semua CBB yang dihasilkan dalam kajian ini mematuhi standard British untuk sifat MOE lenturan dan prestasi TS dalam kehadiran air. Namun, hanya CBB yang dihasilkan dengan menggunakan kepekatan bahan tambah kimia 2% dan 3% pada nisbah simen-kayu 1.5:1 serta 2.5:1 mematuhi standard British tersebut.

Introduction

One of the reasons for incorporating chemical additives into cement-bonded boards (CBBs) during production is to improve the bonding of wood particles to cement. Improve bonding between wood particles and cement will definitely result in improvement of the ultimate strength of CBBs. Simatupang *et al.* (1991) stated that the addition of chemical additives and the increase of temperature of the clamped boards caused reduction in the setting time of Portland cement-bonded particleboard. Chemical additives are normally used as accelerators, which often shorten the setting time. Simatupang *et al.* (1991) emphasised that chemical additives speed up the rate of reaction of cement such that no opportunity is given for inhibitory substances to diffuse from CBBs, thereby retard the reaction.

The utilisation of wood residues as materials of value is an interesting area of research in Nigeria. During wood conversion, the equipment for wood harvesting and machining generates large quantities of wood residues such as offcut, slab, shaving and sawdust. Only about 50 to 55% of original wood becomes marketable after processing in sawmills and plywood mills (Badejo 2001). The utilisation of wood residues will definitely reduce pressure on the forest and contribute positively to the economy of the nation.

One of the potential applications of wood residues is CBB composite. The demand for wood-based panels was projected to increase from 121 000 m^3 in 1993 to 668 000 m^3 by the year 2010 (FAO 1995). CBBs have some admirable properties that make them versatile in construction industry. These properties include excellent insulating property against noise and heat, high resistance to moisture uptake and decay, high dimensional stability when exposed to extreme and fluctuating weather conditions, and high fire resistance compared with resin-bonded board (Blankenhorn *et al.* 1994, Huang & Cooper 2000). CBBs are generally accepted as reliable panels of considerable merit for house construction in areas such as roofing, decking, ceiling and cladding shuttering. CBBs are easy to erect in construction of buildings such as school, theatre, hospital and residential homes (Anonymous 1981).

Despite the admirable qualities of the CBBs, there are several problems associated with their production. A major technological problem with CBBs is that bonding of wood particles and cement is dependent on wood species (Oyagade 1998). Wood contains some extractives, which are responsible for the inhibitory effect on cement setting (Lee & Hse 1995). However, a number of treatment methods have been used to remove these extractives from wood and these include hot water extraction and chemical pretreatment, both of which are the most common (Badejo 1989).

Nauclea diderrichii is very suitable for CBBs production (Shittu 1990). The purpose of this study was to investigate the influence of chemical additive concentration levels on modulus of rupture (MOR), modulus of elasticity (MOE), water absorption (WA) and thickness swelling (TS) of CBB from *N. diderrichii* wood flakes.

Materials and methods

Wood flakes for this study were obtained from sawn timber of *N. diderrichii* at a local timber market in Ibadan, Oyo State, Nigeria. The flakes were approximately 0.52 mm thick and 30 mm long. The flakes were subjected to hot water treatment to remove water-soluble extractives. The flakes were then spread out in a conditioning room at a temperature of 20 °C and relative humidity of 65% until an average equilibrium moisture content of 12% was attained. The flakes were stored in a sealed polythene bags to maintain the moisture content prior to board production. Ordinary Portland cement was used as binder.

CBBs were produced at nominal board densities of 950, 1150 and 1250 kg m^{-3}; cement-wood ratios (weight to weight basis) of 1.5:1 and 2.5:1, and chemical additives (calcium chloride) concentration levels of 1, 2 and 3% by weight of cement. Calcium chloride was incorporated in the mixture to accelerate cement setting. The quantity of distilled water used for mixing cement and wood flakes was calculated using the formula developed by Simatupang (1979). For the production of each board, the required quantity of wood flakes, cement, calcium chloride and distilled water were thoroughly mixed until a homogenous mixture was attained. The mixture was hand felted into the mould on a caul plate. When the mould was removed, another caul plate was placed on the top of the mat before pressing. The boards were pressed to the required thickness size of 8 mm on a manual hydraulic press with a pressure of 1.23 N mm^{-2} for 24 hours. The boards were then removed from the caul plates, wrapped inside polythene bags and kept for further hardening under laboratory conditions of about 20 °C temperature and 65% relative humidity for a period of 28 days. The boards were trimmed and finally cut into sample sizes in accordance with the specification of BS 5669: Part 1 (1989). The samples were soaked in water for 24 hours after which the WA and TS were determined according to the specification of BS 5669: Part 4 (1989). MOE and MOR were also determined according to this specification.

Regression analysis was carried out to estimate the magnitude and pattern of relationships between the process variables and the board properties. Regression models were built in the following form:

$$\text{property} = a + bX_1 + cX_2 \ldots (1)$$

where,

property = MOR, MOE, WA or TS,
a, b and c = constants (a = intercepts; b and c = coefficients of X_1 and X_2 respectively),
X_1 = chemical additive concentration level, and
X_2 = observed density.

Results and discussion

Modulus of rupture

At cement-wood ratio of 1.5:1, the MOR values ranged from 3.05 N mm^{-2} at 1% additive concentration to 12.19 N mm^{-2} at 3% additive concentration (Table 1). MOR ranged from 3.29 N mm^{-2} at 1% additive concentration to 9.42 N mm^{-2} at 3% additive concentration for cement-wood ratio of 2.5:1. It is evident that increases in chemical additive concentration resulted in the increase of MOR. Calcium chloride within the range of 1 to 3% might have neutralised the effects of some extractives, which otherwise would have caused poor bonding between cement and wood flakes. The average values of MOR obtained in this study compared favourably with those of CBBs reported by other researchers (Badejo 1989, Fuwape & Oyagade 1993). MOR values for CBBs produced from 2 and 3% chemical additive concentrations at 1.5:1 and 2.5:1 cement-wood ratios satisfy the British requirement for CBBs as outlined in BS 5669: Part 4 (1989). These values are also within the range of 8.8 to 12.7 N mm^{-2} reported by Anonymous (1987).

MOR increased with increase in cement-wood ratio (Table 1). A linear relationship between MOR and combined effect of chemical additive concentration and board density is presented in Table 2. These results conform with findings by Huang and Cooper (2000). The increase in MOR may be attributed to the fact that CBBs produced at high cement-wood ratio enhance good bonding when low quantity of wood flakes is used. Good bonding is particularly imperative when coarse wood flakes are used.

MOR also increased with increase in board density (Table 1). When considering a given cement-wood ratio and a specified chemical additive concentration level such as 1.5:1 and 1, 2 or 3% respectively, increase in board density from 950 to 1250 kg m^{-3} required more quantity of wood and cement to be forced into a given volume when the mixture was pressed to the required board thickness of 8 mm. Dimensions (length, breadth and thickness) of the boards produced at the various production variables (mixing ratios, additive concentrations and board densities) were the same for the boards. Therefore, this produced well-compressed boards with better interflake contact and bonding between flakes. Hence, cement-bonded boards produced from *N. diderrichii* wood flakes at higher board density were generally higher in MOR than boards at lower density (Table 1).

Table 1 Mean values of modulus of rupture (MOR), modulus of elasticity (MOE), water absorption (WA) or thickness swelling (TS) of cement-bonded boards from *Nauclea diderrichii* wood flakes at three additives concentration (AC)

Cement-wood ratio	AC (%)	ND	OD	MOR (N mm^{-2})	MOE (N mm^{-2})	WA after 24 hours soaking in water (%)	TS after 24 hours soaking in water (%)
1.5:1	1	950	1005	3.05 ± 0.60	2924.30 ± 662.35	28.53 ± 1.56	7.61 ± 1.07
	1	1150	1176	4.97 ± 0.21	3092.00 ± 429.33	23.04 ± 1.88	7.15 ± 0.31
	1	1250	1238	5.61 ± 0.33	3479.20 ± 305.16	20.55 ± 1.50	6.50 ± 1.06
	2	950	985	5.53 ± 0.80	3662.28 ± 1163.63	21.85 ± 2.67	5.96 ± 1.35
	2	1150	1201	7.16 ± 0.33	3912.68 ± 309.12	18.04 ± 1.76	4.21 ± 1.02
	2	1250	1331	8.90 ± 0.13	4742.08 ± 201.60	12.93 ± 0.93	4.06 ± 0.85
	3	950	1014	7.63 ± 0.30	4257.13 ± 219.12	15.53 ± 1.22	3.95 ± 0.56
	3	1150	1200	8.88 ± 0.54	5252.00 ± 892.54	13.03 ± 1.07	2.76 ± 0.91
	3	1250	1275	12.19 ± 1.03	6004.95 ± 315.44	12.71 ± 1.37	2.93 ± 0.68
2.5:1	1	950	934	3.29 ± 0.73	4700.95 ± 1211.10	17.78 ± 1.29	5.21 ± 1.46
	1	1150	1168	5.62 ± 0.39	3906.03 ± 794.22	16.16 ± 0.82	4.53 ± 0.80
	1	1250	1185	6.88 ± 0.19	4723.91 ± 1091.01	13.33 ± 1.90	5.11 ± 0.32
	2	950	1008	7.28 ± 0.56	4212.38 ± 1062.00	15.10 ± 1.20	4.01 ± 0.84
	2	1150	1202	7.90 ± 0.28	4747.10 ± 1120.10	14.06 ± 1.77	2.79 ± 0.72
	2	1250	1293	9.13 ± 0.59	5183.11 ± 1011.40	10.64 ± 0.99	2.18 ± 0.26
	3	950	1011	8.48 ± 0.91	5523.28 ± 803.76	13.52 ± 1.82	2.54 ± 0.94
	3	1150	1220	9.17 ± 0.73	6249.75 ± 523.29	9.77 ± 0.94	2.05 ± 0.90
	3	1250	1337	9.42 ± 0.60	7315.11 ± 266.00	8.57 ± 0.71	2.01 ± 0.07

Each value is the mean and standard deviation of four board samples.
ND = nominal density; OD = observed density

Table 2 Linear relationships between wood-cement board properties and combined effect of chemical additive concentration (C) and board density (D)

Cement-wood ratio	$Y = a + bX_1 + cX_2$	R (%)	R^2 (%)
1.5:1	MOR = - 11.00 + 2.38C + 0.01D	94	92
	MOE = - 2044.20 + 960.08C + 3.69D	96	93
	WA = 55.26 – 4.87C – 0.02D	97	95
	TS = 14.71 – 1.88C – 0.001D	99	98
2.5:1	MOR = - 3.60 + 1.56C + 0.01D	93	87
	MOE = 665.89 + 844.87C – 2.45D	84	71
	WA = 33.20 – 1.91C – 0.01D	94	89
	TS = 9.61 – 1.22C – 0.003D	95	90

MOR = modulus of rupture; MOE = modulus of elasticity; WA = water absorption; TS = thickness swelling; D = observed density; c = Chemical additive concentration level

Modulus of elasticity

The average values of MOE ranged from 2924.30 N mm^{-2} at 1% additive concentration to 6004.95 N mm^{-2} at 3% additive concentration for cement-wood ratio of 1.5:1 and from 3906.03 N mm^{-2} at 1% additive concentration to 7315.11 N mm^{-2} at 3% additive concentration for cement-wood ratio of 2.5:1 (Table 1). Increases in chemical additive concentration and cement-wood ratio resulted in increase of MOE. From the MOE values obtained in this study, all the CBBs produced at all levels of chemical additive concentrations, cement-wood ratios and board densities satisfy the flexural MOE property of CBBs, which range between 3000 and 4000 N mm^{-2} BS 5660: Part 4 (1989). Linear relationship between MOE and combined effect of chemical additive concentration and board density is presented in Table 2. The greater rigidity of cement compared with wood contributed to the increase of MOE at larger proportion of cement to wood. Generally, MOE also increased with increase in board density (Table 1).

Water absorption

The average values of WA ranged from 12.71% at 3% additive concentration to 28.53% at 1% additive concentration for cement-wood ratio of 1.5:1 and from 8.57% at 3% additive concentration to 17.78% at 1% additive concentration for cement-wood ratio of 2.5:1 (Table 1). Increases in chemical additive concentration and cement-wood resulted in decrease of WA. A linear relationship between WA and combined effect of chemical additive concentration and board density is presented in Table 2. This finding agrees with the report by Badejo (1989). The more cement used, the thicker the coating of wood flakes. This results in better internal bond, lower springback and lesser voids in the CBBs; hence, lower quantity of water is absorbed. On a similar research work, Fuwape and Oyagade (1993) concluded that the volume of spaces in CBB has a big influence on WA. The observation made on WA in this study agrees with reports of other researchers (e.g. Oyagade 1988, Fuwape 1992).

Increase in board density resulted in decrease in WA (Table 1). WA is low at high board density level due to better interflakes contact, improved bonding between flakes and higher densification of individual flakes at high proportion of both cement and wood in a given volume.

Thickness swelling

The average values of TS after 24 hours of soaking in water ranged from 2.76% at 3% additive concentration to 7.61% at 1% additive concentration for cement-wood ratio of 1.5:1 and from 2.01% at 3% additive concentration to 5.21% at 1% additive concentration for cement-wood ratio of 2.5:1 (Table 1). Increases in chemical additive concentration and cement-wood ratio and density resulted in decrease of TS. Linear relationship between TS and combined effect of chemical additive concentration and board density is presented in Table 2. Higher dimensionally stable boards were produced with increase in chemical additive concentration. The more the quantity of cement in the board, the more the coating of the wood flakes surface with cement. This results in better internal bond, lower springback and lesser voids in the CBBs. Hence, low quantity of water is absorbed, resulting in low TS. In addition to this, increase in the cement coating of wood flakes may restrict dimensional expansion of the wood. TS values are lower than WA at the same board density, cement-wood ratio and additive concentration level. This is because TS is restricted by hygroscopic properties of wood flakes and cement (Soroka 1979). All the boards produced in this study satisfy the requirements for grade T1-cement-bonded particleboard that has low to moderate levels of performance in the presence of water as specified by BS 5669: Part 4 (1989).

Conclusions

The increase in chemical additive concentration from 1 to 3% had a significant effect on MOR, MOE, WA and TS of CBBs produced from *N. diderrichii* wood flakes. MOR and MOE of the board increased with increase in chemical additive concentration. The increase in chemical additive concentration improved the dimensional stability of the CBBs by reduction in WA and TS. Board density and cement-wood ratio also affected the MOR, MOE, WA and TS of the CBBs. The higher the board density and cement-wood ratio, the higher the MOR and MOE, and the lower the WA and TS of the CBBs at a particular chemical additive concentration. All CBBs produced in this study meet British standard requirements for the flexural MOE property and TS performance in the presence of water. However, only CBBs produced from chemical additive concentrations of 2 and 3% at 1.5:1 and 2.5:1 cement-wood ratios satisfy the British requirement.

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