EFFECTS OF BOARD DENSITY ON BENDING STRENGTH AND INTERNAL BOND OF CEMENT-BONDED FLAKEBOARDS

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AJAYI, B. & BADEJO, S. O. O. 2005. Effects of board density on bending strength and internal bond of cement-bonded flakeboards. Single-layered cement-bonded flakeboards were manufactured in the laboratory using two exotic tropical hardwood species, *Gmelina arborea* (G) and *Leucaena leucocephala* (L) and a combination of the two species at equal percentage (G + L). Boards were made to three densities of 1000, 1100 and 1200 kg m^{-3} and with homogenous particle size of 50 × 2.5 mm in length and thickness respectively. The effects of board density on modulus of rupture (MOR) and internal bond (IB) of each species were investigated. MOR ranged from 7.7 to 9.8 N mm^{-2} and 5.0 to 6.4 N mm^{-2} for boards made from *G. arborea* and *L. leucocephala* respectively. MOR for boards composed of equal quantities of both species (G + L) ranged from 5.5 to 8.9 N mm^{-2}. The IB values for G, L and G + L ranged from 0.11 to 0.16, 0.06 to 0.08 and 0.08 to 0.12 N mm^{-2} respectively. MOR was positively correlated with board density, unlike IB. Hence, boards from *G. arborea*, the lower density species, were stronger than those made from *L. leucocephala* or a combination of the two species. MOR of boards at different densities and species were significantly different, whereas there was no significant difference in the IB of boards at different densities.

Key words: *Gmelina arborea* – *Leucaena leucocephala* – additive concentration – mixing ratio – modulus of rupture

AJAYI, B. & BADEJO, S. O. O. 2005. Kesan ketumpatan papan terhadap keteguhan lentur dan kekuatan dalam bagi papan tatal simen. Papan tatal simen satu lapisan dibuat di makmal menggunakan dua spesies kayu keras tropika dan eksotik, *Gmelina arborea* (G) dan *Leucaena leucocephala* (L) dan campuran kedua-dua spesies pada nisbah yang sama (G + L). Papan dijadikan dalam tiga ketumpatan iaitu 1000 kg m^{-3}, 1100 kg m^{-3} dan 1200 kg m^{-3} dengan saiz partikel homogen sepanjang 50 mm dan setebal 2.5 mm. Kesan ketumpatan papan terhadap modulus kepecahan (MOR) dan kekuatan dalam (IB) setiap spesies dikaji. MOR berjulat antara 7.7 N mm^{-2} hingga 9.8 N mm^{-2} untuk *G. arborea* dan antara 5.0 N mm^{-2} hingga 6.4 N mm^{-2} untuk *L. leucocephala*. MOR untuk papan yang mengandungi kedua-dua spesies berjulat antara 5.5 N mm^{-2} hingga 8.9 N mm^{-2}. IB untuk G, L dan G + L masing-masing berjulat antara 0.11 N mm^{-2} hingga 0.16 N mm^{-2}, antara 0.06 N mm^{-2} hingga 0.08 N mm^{-2} dan antara 0.08 N mm^{-2} hingga 0.12 N mm^{-2}. MOR berkorelasi positif dengan ketumpatan papan tetapi korelasi sedemikian tidak diperhatikan untuk IB.

Jadi, papan daripada *G. arborea* iaitu spesies berketumpatan rendah lebih kuat daripada papan daripada *L. leucocephana* atau daripada campuran kedua-dua spesies. MOR papan pada ketumpatan berlainan dan spesies berlainan berbeza dengan berertinya. Tiada perbezaan IB diperhatikan untuk papan pada ketumpatan berlainan.

Introduction

Cement-bonded wood composite board was first developed in Europe in 1900 and consisted of wood particles bonded with magnesite. Since then, Portland cement has become the main binding agent used in the production of cement-bonded boards and the production of such boards has become commercially important worldwide. In developed countries, production is at a mature stage with plants operating in several countries including Russia, Japan, Germany, France, United Kingdom, Malaysia, Turkey and Australia (Simatupang *et al.* 1993). However, research has shown that fast-growing plantation hardwood species can be used for manufacture of cement-bonded composite board such as *Gmelina arborea* (Badejo 1999, Ajayi 2000, Eusebio *et al.* 2002a, Eusebio *et al.* 2002b) and *Leucaena leucocephala* (Ajayi 2000).

Research interests in cement-bonded boards are increasing in developing countries. For example in Nigeria commercial production of fanciful cement-bonded ceiling board has commenced at the Wood Products Centre of the Forestry Research Institute of Nigeria. This interest in cement-bonded boards can be attributed to the widespread availability of major raw materials mainly wood and cement as well as the simplicity and availability of technology for board production. The cement-bonded boards produced in Nigeria are considered to be suitable for building, construction works, partitioning, floor tiles and ceiling. Their acceptability rests on the qualities associated with cement-bonded wood composites, namely good dimensional stability, high resistance to insect attack, decay and fire, good insulation properties and good nailing ability (Eltomation 2000). Wood-cement composites are well suited as major components of low cost housing and the lack of adequate housing in Nigeria could stimulate further interest in the development of cement-bonded boards. Various grades of building materials will need to be produced to meet future demands of the construction and residential building sectors.

The high cost of resins and machinery necessary for the production of resin-bonded boards, which are an alternative to cement-bonded boards in some applications, is another point in favour of cement-bonded wood composites (Ahn & Moslemi 1980, Simatupang & Geimer 1990, Simatupang *et al.* 1991, Oyagade 1994, Badejo 1999, Ajayi 2000).

In order to assure local markets of the strength properties of wood-cement composites, there is a need to provide information of the strength properties of boards and ensure that they meet accepted standards. This study was designed to provide such information and to determine the effects of board density and species on bending and internal bond strength of boards made from two plantation hardwood species, *G. arborea* and *L. leucocephala*, that were available in Nigeria.

Materials and methods

Materials

The samples of *G. arborea* and *L. leucocephala* were obtained in logs of 1 m length with diameters ranging from 150 to 200 mm from Ekiti State Government Office, Ado-Ekiti and Forestry Research Plantation at the Federal University of Technology, Akure respectively. The logs were debarked manually and transported to the Wood and Wood Products Laboratory of the Forestry Research Institute of Nigeria, Ibadan. They were stored under cover in the laboratory for three months to allow seasoning and depletion of wood sugar. Sugars are capable of inhibiting the setting of cement and it is important to reduce their concentration in wood before manufacture of wood cement composites.

Logs were sawn into slabs using circular saw and then cut into billets. Flakes measuring 50 (length) × 2.5 mm (thickness) in size were produced. The basic density of each wood species was determined using wood block samples measuring 250 × 75 × 150 mm. The volume of each wood block was estimated based on dimension. The density of each wood sample was calculated by dividing the weight of each sample by the corresponding volume.

Flakes from each wood species were separately pre-treated with hot water at 60 °C for 50 min. After soaking, the leachate containing soluble wood extractives was drained and flakes were then soaked in cold water for 10 min, and the leachate later drained off. Flakes were then air dried for 14 days until they attained a moisture content of 12%.

The following variables were used for production of cement-bonded flakeboard:

- Board density of 1000, 1100 and 1200 kg m^{-3}
- Wood raw materials comprising *Gmelina* (G), *Leucaena* (L) and a combination of the two at equal weight ratio (G + L).

Other production factors kept constant were

- Mixing ratio of cement/wood 2:1
- Additive concentration (calcium chloride) of 1.5%
- Board thickness of 6 mm
- Moisture content of wood flakes 12%

Board manufacture

According to each treatment combination of board density and species, the required quantity of wood flakes was weighed and placed in a plastic mixing bowl. The required solution of calcium chloride and water was added uniformly and blended together. The required quantity of Portland cement was added and thoroughly mixed together until a mixture free of lumps was obtained before forming into mat.

Cement-wood mixtures were placed inside a wooden mould of 350 × 350 mm. The hand-formed mat was placed on metal plate, covered with polythene sheet and pre-pressed using plywood cauls. The top of the formed mat was covered with polythene sheet and a metal plate and transferred to a hydraulic press. Mats were pressed to the required thickness using a pressure of 2.23 N mm^{-2} for 24 hours. Boards were then removed from the press and kept inside sealed polythene bags for 28 days to allow curing of cement. The edges of boards were subsequently trimmed and boards were cut into test specimens and conditioned in controlled environment at room temperature (20 °C) and 65 ± 2% relative humidity for 21 days.

A tensiometer machine was used to test the bending strength of boards. Each specimen of 194 × 50 mm board was supported equally at two points with parallel metal rollers to ensure that crushing of the specimen at the end points did not occur during testing. The points of contact between specimen and roller were 17 mm away from the two ends. Specimens were loaded using a rounded metal bar at their centre perpendicular to the face of the test piece over their whole width. For internal bond (IB), a block of hardwood (*Afzelia africana*) measuring 90 × 50 × 25 mm in thickness and later reduced by 3 mm in thickness and 20 mm in length with a bulging surface of 50 × 50 mm equivalent to the size of test specimen was clearly bonded with epoxy glue to the faces of specimens. The loading features were attached to the head of testing machine. Thereafter, force was applied perpendicularly to the faces, and the centre of load passed through the centre of each specimen. Loading was continuous at uniform speed until failure occurred within the test specimen. Modulus of rupture (MOR) and IB of the boards were assessed based on the test procedure described in ASTM (1978).

The statistical design for the experiment was 3 × 3 factorial in completely randomised design. Each treatment combination of the board was replicated thrice thereby making the total number of specimens tested to be 27.

Results and discussion

Density

Gmelina arborea and *L. leucocephala* had densities of 480 and 690 kg m^{-3} respectively.

Modulus of rupture

MOR ranged from 7.68 to 9.75 N mm^{-2}, 5.00 to 8.67 N mm^{-2} and 5.49 to 8.93 N mm^{-2} for boards made from *G. arborea, L. leucocephala* and a combination of the species respectively. The G boards were stronger than L and G + L boards (Table 1). Boards made from G + L were stronger than L board. The range of MOR values obtained here compared favourably with those reported, i.e. 4.7 to 10.7 N mm^{-2} (Simatupang *et al.* 1993) and 9.0 to 15.0 N mm^{-2} (Kossatz *et al.* 1994). Board density in addition to wood species had a significant effect on the MOR of boards. The MOR increased with increasing board density. This agreed with the findings of Oyagade (1990), Geimer *et al.* (1993) and Fuwape (1995). It may be possible to produce stronger (and heavier) boards by increasing board density. The greater compression ratio and bonding within high density boards made from *Gmelina* probably accounted for their relatively high strength properties (Ajayi 2000).

Table 1 Modulus of rupture and internal bond of cement-bonded flakeboards as influenced by board density

Species	Density (kg mm^{-3})	MOR (N mm^{-2})	IB (N mm^{-2})
Gmelia arborea	1000	7.68	0.16
	1100	8.84	0.12
	1200	9.75	0.11
Leucaena leucocephala	1000	5.00	0.08
	1100	5.15	0.07
	1200	8.67	0.06
Gmelina + Leucaena	1000	5.49	0.12
	1100	8.12	0.10
	1200	8.93	0.08

Table 2 Least significant difference (LSD) for modulus of rupture and internal bond

Factor	Level	MOR	IB
Species	*Gmelina arborea*	8.76 a	0.12 a
	Leucaena leucocephala	6.41 b	0.12 a
	Gmelina + Leucaena	7.51 ab	0.08 a
Density (kg mm^{-3})	1000	6.19 a	0.12 a
	1100	7.37 a	0.11 a
	1200	9.12 b	0.10 a

Means followed by the same letter are not significantly different at the 0.05 probability level.

Lower compression ratio and level of inter-flakes contact in L board resulting in weaker bonds and the presence of voids probably accounted for the lower strength of the boards. Table 2 shows that there is significant difference ($p < 0.05$) in the MOR of the *G. arborea, L. leucocephala* and their combination. There was no significant difference in the MOR of boards with densities of 1000 and 1100 kg m^{-3} but significant differences occurred between boards with the highest density and those of lower densities.

Internal bond

The values for IB ranged from 0.11 to 0.16 and 0.06 to 0.08 N mm^{-2} for boards made from *G. arborea* and *L. leucocephala* respectively (Table 1). Boards made from a combination of the two species were weaker than G board but stronger than

L board. Failures generally occurred within the central core of the boards and at the interfacial layer between wood flakes and inorganic binder. While MOR was positively correlated with density, the reverse was the case for IB. Ajayi (2000) obtained similar results in his study. This trend contrasted with findings reported for resin-bonded boards, where increases in board density cause increases in internal bond strength (Maloney 1977, Place & Maloney 1977). The low IB strength of L board may be attributed to coarse, rough surfaces and the presence of voids within the core of boards. The smaller flakes produced by the flaking of *L. leucocephala* may have provided insufficient contact area for effective bonding to resist the tensile forces applied during IB testing. In the case of G board, flakes were larger and well compressed within boards, which aid better inter-flakes surface contact and little or no voids within boards. Board surfaces were also smoother and all of these factors may have contributed to the higher strength of the G board compared with L and G + L boards. *Gmelina arborea* (480 kg m^{-3}) produced boards with superior internal bond characteristics to *L. leucocephala* (690 kg m^{-3}) probably because it is a low density wood and is less dense than *Leucaena*.

The presence of powdery substance was observed on the surface of all the boards. The L board contained greater quantities of this substance than the G + L and G boards. The powdery substance is indicative of inadequate bonding and hydration of cement due to the influence of extractives in the wood (Ajayi 2000). Consequently, low quality boards were produced. There was no significant difference in the IB of the different boards irrespective of species and board density.

Conclusions

Cement-bonded flakeboards were produced from two exotic plantation hardwood species and a mixture of the two species at equal weight ratio. Boards made from *Gmelina* were stronger than those made from *Leucaena* or a combination of both. The L board had the lowest strength properties. There was a positive correlation between the density of boards in the range 1000–1200 kg m^{-3} and MOR whereas the opposite was the case for IB. This study has provided baseline information on strength properties of two common fast growing plantation hardwood species in Nigeria. The strength properties of the boards indicated that the species could be used in the production of cement-bonded flakeboard in Nigeria. Such boards could serve as an alternative to sawn timber.

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