Wood Sci. Technol. 22:357–370 (1988)

Wood Science and Technology

Effect of flake geometry on properties of cement-bonded particleboard from mixed tropical hardwoods

S. O. O. Badejo, Ibadan, Nigeria

Summary. Laboratory scale cement-bonded particleboards were made from mixed particles of three tropical hardwoods. Boards were three-layered comprising of 2 mm thick sawdust face and 4 mm thick core layers made from flakes of three lengths – 12.5 mm, 25.0 mm and 37.5 mm and two thicknesses of 0.25 mm and 0.50 mm. The panels were fabricated at three density levels of 1,050 kg/m^3, 1,125 kg/m^3 and 1,200 kg/m^3. From the statistical factorial analysis carried out, flake length, flake thickness and board density had significant effects at 1% level of propability on the properties of the tested panels. Mean MOR ranged from 5.22 to 11.15 N/mm^2; MOE –2,420 to 4,820 N/mm^2; water absorption and thickness swelling following 144 hours soak in water, 32.95 to 46.00% and 0.35 to 5.47% respectively. The longer and thinner the flakes, the stronger, stiffer and more dimensionally stable the experimental cement-bonded particleboards. Similarly, the higher density panels generally exhibited higher strength values in terms of MOR and MOE and were more dimensionally stable. MOR, MOE, water absorption and thickness swelling were found to be highly correlated with flake length, flake thickness and panel density. Correlation coefficients (R) for these relationships were 0.888 to 0.986 for the combined variables; and 0.574 to 0.992 for the individual factors. In all the cases tested, the regression relationships were linear.

Introduction

Particle geometry relates to size dimensions of particles used for the production of particleboard. Reported literature abound on its effects on properties of resin-bonded particleboards (Post 1958, 1961; Turner 1954; Brumbaugh 1960; Gatchell, Heebink 1964; Gatchell et al. 1966; Lehmann 1974; Moslemi 1974; Shuler, Kelly 1976; Maloney 1977; Vital et al. 1980). Results from most of these studies have established that flexural and stiffness in bending as well as dimensional stability of boards improve with increase in flake length used for board production. Similarly, unlike the wood-wool cement boards where adequate studies have been reported on wood raw materials screening, suitability tests and consequent follow-up board manufacture from different wood raw material types (Sandermann et al. 1960; Kollmann 1963; Sandermann, Kohler 1964; Pinion 1968; Das, George 1969; Wong, Ong 1982; Raczkowski et al. 1983; Schubert, Wienhaus 1984; Hofstrand et al. 1984; Moslemi, Lim 1984; Lee 1984, 1985; Lange, Simatupang 1985; Zhengtian, Moslemi 1985), only limited published studies have been found on cement-bonded particleboards in general (Vermaas

1974; Prestemon 1976; Kawamura et al. 1979; Xia 1982) and in particular the effect of particle dimensions on properties of such boards (Iida, Yamagishi 1983).

Furthermore, most of the available informations on cement-bonded particleboards are those obtainable in technical literature (Bison 1981; Elten 1981; Canali 1981) and most of these are based on use of temperate wood raw materials. Commercial wood-cement board production in general is less preferred from tropical hardwoods due to presence of chemical substances inhibitory to the setting of the cement binder. These have been identified as sugars and wood extractives mostly phenolic and other water soluble substances (Sandermann et al. 1960; Davis 1966; Weatherwax, Tarkow 1967; Biblis, Lo 1968; Zhengtian, Moslemi 1985). Panels made from such woods usually crumble into bits immediately following removal from the press. Also for this similar reason, commercial board production is generally not made from mixed wood raw materials. Only species which have been tested and found suitable are used. Unlike the wood-wool cement boards however, production of cement-bonded particleboards offers a lot of advantage with regard to raw materials requirement. Ligno-cellulosic raw materials ranging from roundlogs, small size timbers and logging wastes (Sandermann 1970; Chittenden et al. 1975; Simatupang et al. 1978; Bison 1981; Elten 1981); manufacturing wastes such as slab wastes from sawmill, peeler cores from veneer and match factories (Badejo 1983, 1986); and agricultural residues such as bagasse (Sandermann 1970; Canali 1981) have been indicated as possible raw materials. Production of cement-bonded particleboard is therefore possible in areas of depleted wood resource but where large volume of industrial wood wastes are produced, as well as areas of limited wood resource but which generate large volume of agricultural residues like bagasse and cotton stalk. In Nigeria for example, sawmill sizes are relatively very small and slab wastes from these small size mills are lumped together during sawnwood processing. Because of the increasing scarce wood raw material supply in recent years, there has been an increasing emphasis on wood wastes utilisation in the country. In a situation similar to that of Nigeria therefore, problems will no doubt be encountered with sorting and segregation of these wastes if they were to be used for wood-cement board production. Within the past seven years, the Forestry Research Institute of Nigeria has concentrated research efforts on use of mixed tropical hardwood species found in the country for production of cement-bonded particleboards.

Based on the above reasons, this study was initiated to provide baseline information on strength properties of cement-bonded particleboard manufactured on a laboratory scale from mixed particles of three tropical hardwood species; as well as how such properties are related to the geometry of the particles used.

Experimental

The three tropical hardwood species used for this investigation are *Triplochiton scleroxylon* K. Schum, *Khaya ivorensis* A. Chev. and *Terminalia superba* Eng. and Diels. Both the coarse sawdust and slab wastes of these species were collected from a local sawmill operating a horizontal CD-6 headrig machine. After collection, the coarse sawdust of each species was sieved with a 2-mm mesh sieve in order to remove too fine materials which were not appropriate for board production. The wood particles which collected on the 2-mm mesh were again sieved with a 6-mm mesh in order to remove oversize and bark inclusions. The wood materials which finally passed out of the 6-mm mesh sieve were finally used for the surface layer of the experimental panels. These were blended together in equal proportion from the three hardwood species. The sawdust mix was then pre-treated with hot water at a temperature of 50 °C and air dried to a moisture content of about 12% prior to use.

On the other hand, the slab wastes from each of the three hardwoods were debarked and cut on a circular saw into small lumber sizes measuring 60 cm in length and 50 mm in width for proper handling on the machine used for flake production. They were then fed through a tenoning machine used at the woodworking laboratory of the Forestry Research Institute of Nigeria, Ibadan. The tenoning machine carried scoring knives which produced uniform flakes of pre-determined length and thickness. Flakes from the three hardwood species were then blended together in equal proportion, pre-treated with hot water at a temperature of 50 °C and thereafter air dried to a moisture content of 12% prior to use.

The following production variables at the indicated levels were used for the production of the experimental cement-bonded particleboard:

1. Board core flake thickness 0.25 mm and 0.50 mm.
2. Board core flake length 12.5 mm, 25 mm and 37.5 mm.
3. Board densities at levels of 1,050 kg/m^3, 1,125 kg/m^3 and 1,200 kg/m^3 (oven-dry basis).

The above experimental design was therefore a $2 \times 3 \times 3$ factorial layout. Six panels of flake length and thickness were produced for each of the three board density levels applied in the study. Other production factors were held constant for each panel. These were the wood particles' moisture content of 12%, cement to wood particles mixing ratio of 2.5:1.0, hot water pretreatment of the wood particles at a temperature of 50 °C and additive concentration from calcium chloride applied at 3% of the cement weight in the board.

For panel fabrication, the quantity of wood required to make a panel was weighed out and manually mixed in a container with the needed amount of water into which had been dissolved the quantity of chemical additive required for the mixing. The amount of water used was based on the formula proposed by Simatupang (1979). After ensuring that the wood particles were well coated with the additive solution, the required quantity of cement was slowly added while mixing continued until a homogenous wood-water-cement mix was formed. These mixing procedures were separately carried out for the sawdust and flake core layers of the fabricated panels. The wood-cement mixes were then hand formed into mats with the flake-cement mix forming the central core layers of the boards and half of the sawdust-cement mix comprising each side of the two face layers. The formed panels were thereafter pressed cold on a hydraulic press to the required thicknesses of 6 mm and sizes of 30 cm $\times$ 30 cm with a pressure of 1.23 N/mm^2 for a 24-hour period. The quantity of raw material requirements for board formation were calculated in such a way that following pressing the core and the two surface layers thicknesses were at a ratio of 2:1. This procedure was followed in line with two other previous studies where it was shown that increased proportion of flakes in cement-bonded particleboard panels manifested in improved panel properties relating to modulus of rupture and modulus of elasticity (Badejo 1987 a, 1987 b).

Following the 24-hour pressing cycle, the panels were stripped off the caul plates and kept inside polythene bags for 48 hours and thereafter trimmed and cut to the required test specimen sizes in accordance with the ASTM Standard D 1937-78. They were then put back in the bags for another 20 days in order to allow for full curing of the cement binder. Thereafter, they were removed from the bags and conditioned under a temperature of $70 \pm 2\,^{\circ}F$ and relative humidity of $60 \pm 2\%$ for at least three weeks prior to testing. The bending strength test was carried out on a Tensometer machine while the water soak tests were done following prolonged soaking in water for 144 hours. The prolonged soaking in water was considered essential in the study in view of the exterior use to which wood-cement boards are put most, especially for roofing and wall cladding.

Results and discussion

The compiled averages of the test results for each of the 18 experimental treatments are listed in Table 1. Also the test results as evaluated in a $2 \times 3 \times 3$ factorial analysis of variance with four replications are presented in Table 2.

As Table 1 shows, moduli of rupture and elasticity for the 18 experimental treatment combinations used in the study ranged from 5.22 to 11.15 N/mm^2 and 2,420 to

Table 1. Compiled averages for mechanical and dimensional stability tests performed on cement-bonded particleboards made from three mixed tropical hardwood species. WA = water absorption; TS = thickness swelling

Flake length mm	Flake thickness mm	Planned board density kg/m^3	Estimated board density[a] kg/m^3	Static bending		Dimensional stability[b]	
				MOR N/mm^2	MOE N/mm^2	WA %	TS %
12.5	0.25	1,050	1,025	6.57	2,920	43.00	3.02
25.0	0.25	1,050	1,032	7.69	3,540	37.80	1.20
37.5	0.25	1,050	1,028	9.40	3,960	34.60	0.88
12.5	0.25	1,125	1,055	8.18	3,400	42.70	2.49
25.0	0.25	1,125	1,070	9.27	3,740	37.10	1.12
37.5	0.25	1,125	1,074	9.83	4,350	33.80	0.69
12.5	0.25	1,200	1,250	9.18	3,660	40.20	1.56
25.0	0.25	1,200	1,238	10.24	4,010	36.40	0.50
37.5	0.25	1,200	1,150	11.15	4,820	32.95	0.35
12.5	0.50	1,050	1,000	5.22	2,420	46.00	5.47
25.0	0.50	1,050	1,040	7.13	2,810	44.30	2.12
37.5	0.50	1,050	1,020	8.46	3,160	42.65	1.16
12.5	0.50	1,125	1,060	6.41	2,740	44.55	3.91
25.0	0.50	1,125	1,068	8.68	3,090	40.85	1.33
37.5	0.50	1,125	1,134	9.76	3,520	39.85	1.10
12.5	0.50	1,200	1,245	7.11	3,150	43.00	2.40
25.0	0.50	1,200	1,185	9.78	3,290	37.30	0.90
37.5	0.50	1,200	1,174	10.75	3,930	36.90	0.75

[a] Based on 4 samples per treatment combination
[b] Estimated after 144 hours soak in cold water

Table 2. Factorial analysis of variance for testing the effects of flake length, flake thickness and panel density on properties of cement-bonded particleboards made from mixed particles of three tropical hardwoods

Source of variation	Degrees of freedom	Mean MOR	Square MOE	Values (MS)	
				WA	TS
Flake length (L)	2	47.08 [b]	5.014 [b]	2.59 [b]	37.25 [b]
Flake thickness (T)	1	14.98 [b]	8.792 [b]	3.02 [b]	11.94 [b]
Board density (D)	2	31.60 [b]	2.734 [b]	0.78 [b]	9.16 [b]
L × T	2	3.02	0.121	0.19	2.60 [b]
L × D	4	0.33	0.066	0.01	1.73 [b]
T × D	2	0.05	0.002	0.17	0.76 [b]
L × T × D	4	0.31	0.011	0.04	0.043
Error	54	2.04	0.331	0.21	0.12

[b] Significant at 1% level of probability

For purposes of factorial analysis of variance, the MOE data in Table 1 were reduced by a factor of 1,000 while the water absorption was reduced by a factor of 10 in order to reduce the magnitudes of MS values shown above

4,820 N/mm^2 respectively. These mean modulus of rupture (MOR) and modulus of elasticity (MOE) values obtained for the study conform quite favourably to figures reported in past studies. From his studies on 18 mm thick cement-bonded particleboards produced from selected softwood species, Dinwoodie (1978) reported mean MOR of 11.3 N/mm^2 and MOE of 4,900 N/mm^2. From data taken from Bison technical literature, MOR range values of 8.8 to 12.7 N/mm^2 and MOE mean value of 2,940 N/mm^2 were reported for 18 mm thick cement-bonded particleboards made from varying number of wood raw materials. The maximum mean MOR of 11.5 N/mm^2 and MOE of 4,820 N/mm^2 obtained in this study originated from panels made with the longest flake length of 37.5 mm and the smaller thickness of 0.25 mm.

As listed in Table 2, the levels at which the flake length, flake thickness and board density were used in the study experiment had significant effects on MOR and MOE. No two-way or three-way significant interactions were found between and among these three variables used for board production. The use of longer flakes manifested in production of stronger and stiffer panels in static bending. Similarly, MOR and MOE increased as panel density increased. On the other hand however, boards made with thicker flakes were found to be inferior to those made from thinner flakes. These results conform with previously published studies on resin-bonded particleboards (Post 1958; Brumbaugh 1960; Shuler, Kelly 1976). These results were graphically illustrated in Figs. 1 and 2.

As shown in Table 1, variations existed between the planned and estimated densities of the experimental panels. Measured variations in mean density of treatments belonging to the same density class ranged from 1.0 to 4.8% for those panels fabricated with planned density of 1,050 kg/m^3, 0.8 to 4.4% for those that originated from the density level of 1,125 kg/m^3 and 3.2 to 7.1% for the 1,200 kg/m^3 dense panels. One probable cause of variation could be attributed to the human error introduced during the mat formation. Since at this formation stage the wood-cement-water mixes were

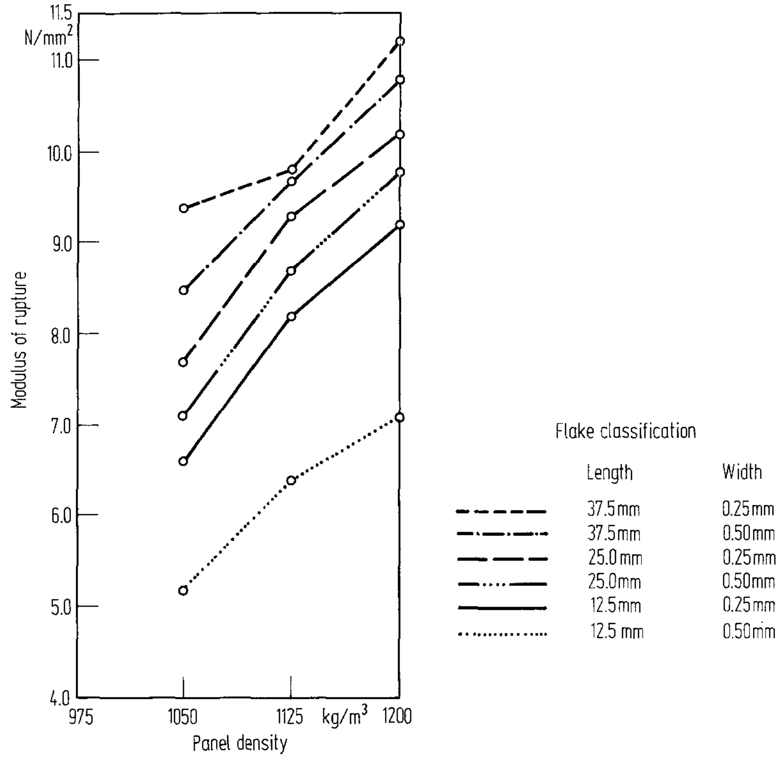

Fig. 1. Influence of flake geometry and panel density on modulus of rupture of cement-bonded particleboards fabricated from mixed particles of three tropical hardwood species

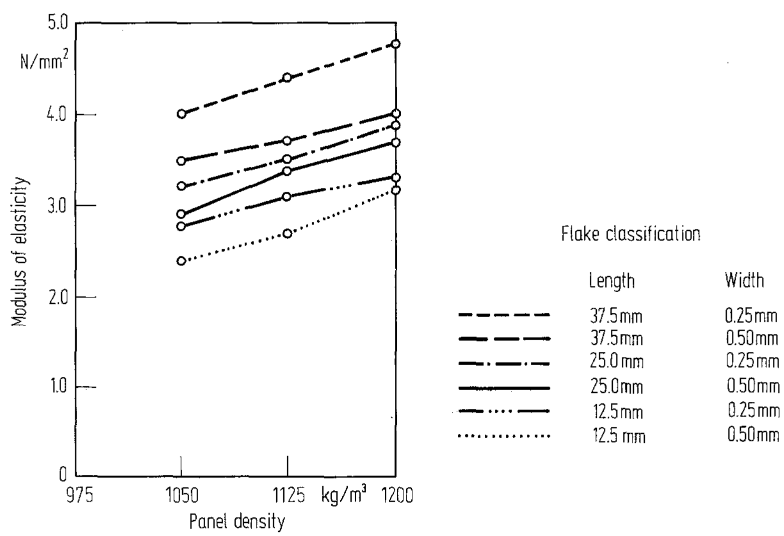

Fig. 2. Influence of flake geometry and panel density on modulus of elasticity of cement-bonded particleboards fabricated from mixed particles of three tropical hardwood species

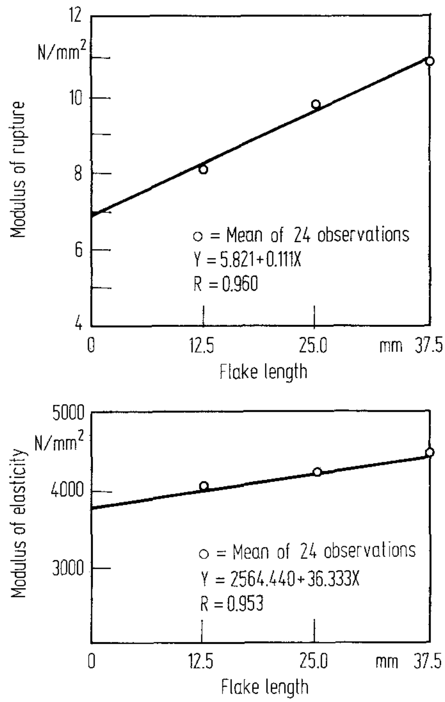

Fig. 3. Regression between modulus of rupture, modulus of elasticity and flake length

manually spread, it was not technically possible to ensure evenly distributed materials which consequently led to production of panels of non-uniform thickness. These variations not withstanding however, it was statistically possible to establish regression relationship for the static bending data.

Regression analyses were performed to determine relationship between the significant factors and the moduli of rupture and elasticity. Flake length, board density and flake thickness were highly correlated with MOR and MOE of the experimental cement-bonded particleboards. Flake length and board density were positively correlated with MOR and MOE and these relationships were linear as shown in Figs. 3 and 4. Flake thickness on the other hand, was negatively and linearly correlated with MOR and MOE (Fig. 5). The equation that relates MOR to the three production variables used in the study experiment is shown below with R value of 0.971:

$$Y = -9.954 - 3.618\,X1 + 0.111\,X2 + 0.152\,X3; \; R = 0.971,$$

where Y represents the dependent variable, MOR and X1, X2 and X3 represent the independent variables of flake thickness, flake length and board density respectively. Similarly, the multiple regression analysis performed on the study data also shows that MOE is related to the three factors from the equation given below, with R value of 0.986:

$$Y = -1{,}449.72 - 2{,}795.56\,X1 + 36.33\,X2 + 4.5\,X3; \; R = 0.986,$$

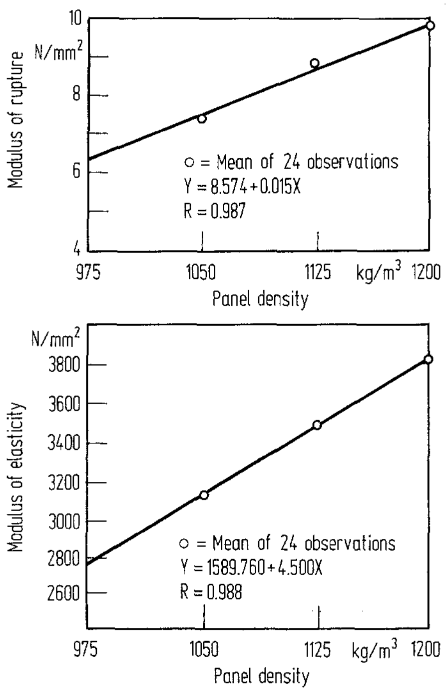

Fig. 4. Regression between modulus of rupture, modulus of elasticity and panel density

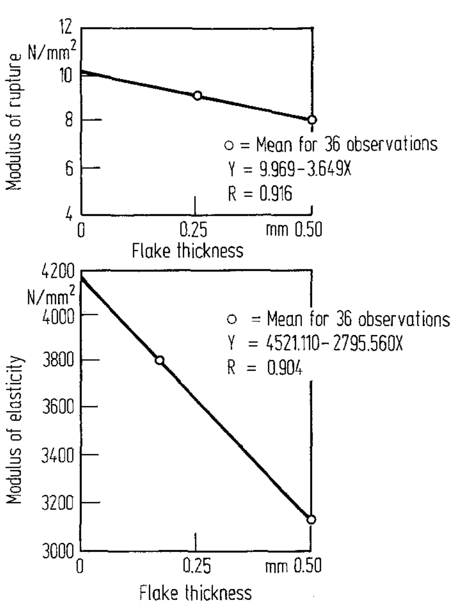

Fig. 5. Regression between modulus of rupture, modulus of elasticity and flake thickness

where Y is the dependent variable, MOE and X1, X2 and X3 represent flake thickness, flake length and board density respectively. For the two cases of MOR and MOE, the multiple regression performed were highly significant at 1% level of probability (Table 3).

As shown in Table 1, the compiled averages for the water absorption and thickness swelling tests ranged from 32.95 to 46.00% and 0.35 to 5.47% respectively following prolonged soak in water for 144 hours. Prestemon (1976) reported mean water absorption range values of 28.08 to 65.77% for 25 mm thick cement-bonded particleboards made from sawdust of two temperate wood species (oak and elm) following 24 hours soak in cold water. Mean thickness swelling range values of 0.67 to 3.60% were similarly reported in the same study. Also, Dinwoodie (1978) reported average thickness swelling value of 0.75% for 18 mm thick cement-bonded particleboard made from selected softwood species which were tested only after 24 hours soak in water. When the prolonged soaking for 144 hours used in this study is therefore taken into consideration, the water absorption and thickness swelling results appeared to have performed satisfactorily.

As listed in Table 2, the factorial analysis of variance performed on the water absorption test data showed that flake length and flake thickness were significant factors at 1% level of probability, while the board density was only significant at 5%. No significant interaction was found between and among the three production variables used. As illustrated in Fig. 6, mean water absorption values decreased with longer flakes. Similarly, the ability of the fabricated panels to take up moisture under prolonged soak in water decreased with increased panel density. On the other hand however, water absorption increased with thicker flakes. These findings tend to follow previously published studies for resin-bonded particleboards (Brumbaugh 1960; Vital et al. 1980). Regression analysis showed that water absorption was correlated with the three production variables. Flake length and board density were negatively correlated with water absorption while flake thickness was positively correlated. The multiple regression equation that relates water absorption with the three production variables is shown below with R value of 0.945:

$$Y = 66.972 + 16.388\,X1 - 0.258\,X2 - 0.024\,X3; \quad R = 0.947,$$

where Y is the dependent variable water absorption, and X1, X2 and X3 represent flake thickness, flake length and board density respectively. The regression was highly significant at 1% level of probability.

The pattern followed by the factorial analysis of variance of the thickness swelling data was different from the other three tests. Flake length, flake thickness, panel

Table 3. Regression analysis to show the correlation of board properties with flake length, flake thickness and board density

Source of variation	Degrees of freedom	Mean MOR	Square MOE	Values (MS)	
				WA	TS
Regression	3	14.15[b]	20.13×10^{5} [b]	79.71 b	7.89[b]
Residual	14	0.18	12.15×10^{3}	1.97	0.45

[b] Significant at 1% level of probability

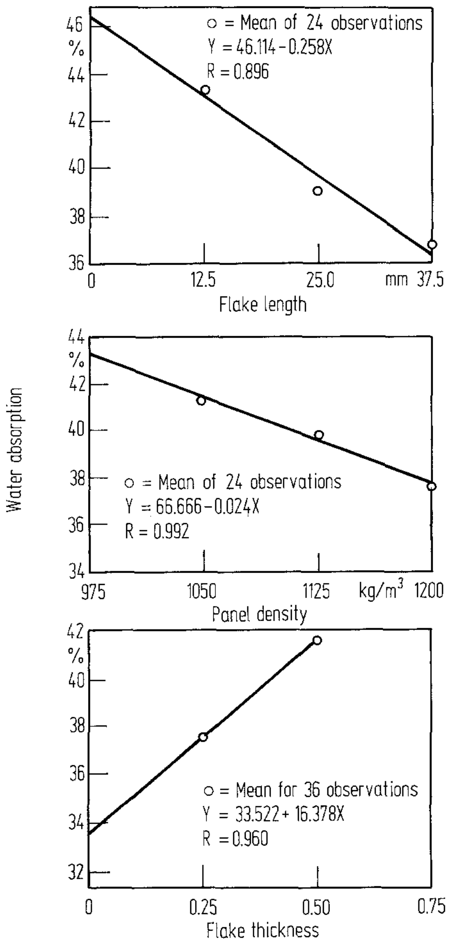

Fig. 6. Regression between water absorption and flake length, panel density and flake thickness

density and three two-way interactions involving flake length and thickness; flake length and density; and flake thickness and density were found significant at 1% level of probability. Thickness swelling mean values decreased with longer flakes and at higher panel density but increased with thinner flakes. It means in effect that the longer and thinner the flakes used for production of the experimental cement-bonded particleboard panels, the more dimensionally stable these boards produced from them. This result simularly tend to follow previously published data on resin-bonded particleboard (Brumbaugh 1960; Gatchell et al. 1966; Vital et al. 1980). As shown in Fig. 7, both flake length and panel density were positively correlated with thickness swelling while flake thickness was negatively correlated. The multiple regression equation that related thickness swelling with the three production variables is given as follows with R value of 0.888:

$$Y = 12.055 + 3.258\,X1 - 0.093\,X2 - 0.008\,X3, \quad R = 0.888,$$

where Y is the dependent variable thickness swelling, and X 1, X 2 and X 3 represent flake thickness, flake length and board density respectively. The regression was highly significant at 1% level of probability (Table 3).

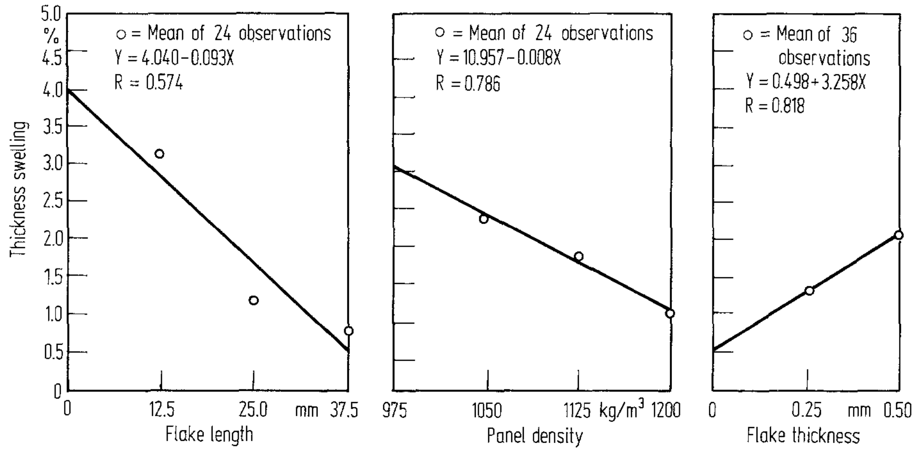

Fig. 7. Regression between thickness swelling and flake length, panel density and flake thickness

From the study's experimental data, the most favourable panel in terms of strength, stiffness, water absorption and thickness swelling are those fabricated with wood particle flakes having a length of 37.5 mm, a thickness of 0.25 mm and bonded to a panel density level of 1,200 kg/m^3.

Conclusion

From the limited data collected in this study and the consequent statistical analysis made, the following conclusions are drawn:

1. It was technically feasible on a laboratory scale to fabricate cement-bonded particleboards from mixed flake particles (for core layer) and sawdust (for face layer) of the three tropical hardwood species used in the study. These are *Triplochiton scleroxylon, Khaya ivorensis* and *Terminalia superba.*

2. Panels fabricated at increasing board density were generally stronger, stiffer and more dimensionally stable under prolonged soak in water for 144 hours.

3. Use of longer flakes significantly increased MOR and MOE in static bending and improved dimensional stability relating to water absorption and thickness swelling.

4. MOR and MOE in static bending were significantly reduced by the use of thicker flakes. Use of thicker flakes also manifested in significantly increased water absorption and thickness swelling of the experimental boards.

5. The longer and thinner the flakes, the stronger, stiffer and more dimensionally stable the cement-bonded particleboards produced from them.

6. There was a high degree of correlation between MOR, MOE, water absorption and thickness swelling and each of the the three production factors (flake length, flake thickness and panel density) used for experimental investigation.

7. More research studies on cement-bonded particleboard production from mixed hardwood species in general and tropical woods in particular are however recommended.

References

Badejo, S. O. O. 1983: Preliminary study on the utilisation of Nigerian sawmill sawdust for the production of water-proof cement-bonded ceiling boards. Proceedings, 13th Conf. of For. Assoc. of Nigeria, Benin, Nov.

Badejo, S. O. O. 1986: Developments in Forest Products Research in Nigeria. Seminar Series, Vol. 2, 11 p. Forestry Research Inst. of Nigeria, Ibadan

Badejo, S. O. O. 1987a: Trial production and testing of cement-bonded particleboard from mixed tropical hardwoods (to be published)

Badejo, S. O. O. 1987b: Influences of three production variables on properties of cement-bonded particleboard from mixed tropical hardwoods (to be published)

Biblis, C. J.; Lo, C. 1968: Sugars and other wood extractive effects on the setting of southern pine cement mixtures. Forest Prod. J. 18 (8):28–34

Bison-Werke Co. 1981: Building board installations. Factors of machines. Technical Information Bulletin

Brumbaugh, J. 1960: Effects of flake dimension on properties of particle-boards. Forest Prod. J. 10: 243–246

Canali, K. G. 1981: Building boards installations. Factory of machines. Technical Information Bulletin

Chittenden, A. E.; Hawkes, A. J.; Hamilton, H. R. 1975: Wood-cement systems. Background paper, World Consultation on wood-based panels. FAO/UNDP/FO/WC. WBP/75, New Delhi, India

Das, A.; George, J. 1969: Suitability of some Indian timbers for Portland cement bonded wood-wool boards. J. of Timber Dev. Assoc. of India. 15: 21–26

Davis, T. C. 1966: Effect of blue stain on setting of excelsior cement mixtures. Forest Prod. J. 16(6): 49–50

Elten, Eng. Co. 1981: Elten plants for building boards and production lines for wood-cement boards. Technical Information Bulletin and private visit

Gatchell, C. J.; Heebink, B. G. 1964: Effects of particle geometry on properties of moulded wood-resin blends. Forest Prod. J. 14: 501–506

Gatchell, C. J.; Heebink, B. G.; Hefty, F. V. 1966: Influences of component variables on properties of particleboards for exterior use. Forest Prod. J. 16: 46–59

Hofstrand, A. D.; Moslemi, A. A.; Garcia, J. F. 1984: Curing characteristics of wood particles from nine northern rocky mountain species mixed with Portland cement. Forest Prod. J. 34(2): 57–61

Iida, N.; Yamagishi, K.; Kitazawa, M.; Takahashi, T.; Namioka, Y. 1983: The manufacture of wood-cement boards using species which inhibit cement hardening VI. The effect of chip length and orientation. J. Hokkaiddo Forest Prod. Res. Inst., No. 372

Kawamura, Y.; Mamada, S.; Ishii, K. 1979: On the production of 3-layered wood-based cement board with unsuitable species. Bulletin, Niigata Univ. Forestr. No. 12: 65–72

Lange, H.; Simatupang, M. H. 1985: Herstellung von zementgebundenen Fichten- und Pappelspanplatten – Wechselwirkungen von fünf Einflußfaktoren und ihre Wirkung auf die Plattenfestigkeit (Manufacture of wood-cement from Norway spruce and poplar particles. Interaction of five factors and their effect on board strength). Holz Roh-Werkstoff 43: 229–236

Lee, A. W. C. 1984: Physical and mechanical properties of cement-bonded southern pine excelsior board. Forest Prod. J. 34(4): 30–34

Lee, A. W. C. 1985: Bending and thermal insulation properties of cement-bonded cypress excelsior board. Forest Prod. J. 35(11/12): 57–58

Lehmann, W. F. 1974: Properties of structural particleboards. Forest Prod. J. 24(1): 19–26

Maloney, T. M. 1977: Modern particleboard and dry process fibreboard manufacturing. Miller Freeman Publications, San Francisco, CA

Moslemi, A. A. 1974: Particleboard Vol. I. Southern Illinois Univ. Press, Carbondale

Moslemi, A. A.; Lim, Y. T. 1984: Compatibility of southern hardwoods with Portland cement. Forest Prod. J. 34(7/8): 22–26

Pinion, L. C. 1968: Trials on home grown timbers for wood-wool cement-building slabs. Timber Trade J. 265(4): 27–29

Post, P. W. 1958: Effect of particle geometry and resin content on bending strength of oak flakeboard. Forest Prod. J. 8: 317–322

Post, P. W. 1961: Relationship of flake size and resin content to mechanical and dimensional properties of flake board. Forest Prod. J. 11: 34–37

Prestemon, D. R. 1976: Preliminary evaluation of a wood-cement composite. Forest Prod. J. 26(2): 43–45

Raczkowski, J.; Krauss, A.; Pacha, R. 1983: Setting of cement in the presence of scots pine wood affected by brown stain. Holzforsch. Holzverwert. 35: 40–43

Sandermann, W. 1970: Technical processes for the production of wood-wool cement boards and their adaptation to the utilisation of agricultural residues. UNIDO ID/WG.83/4, 1970

Sandermann, W.; Kohler, R. 1964: Über eine kurze Eignungsprüfung von Hölzern für zementgebundene Werkstoffe. (A short test of the aptitudes of woods for cement-bonded materials). Holzforschung 18: 53–54

Sandermann, W.; Preusser, H. J.; Schweers, W. 1960: Studien über mineralgebundene Holzwerkstoffe – III. Mittlg.: Über die Wirkungen von Holzinhaltsstoffen auf den Abbindevorgang bei zementgebundenen Holzwerkstoffen (Studies on mineral bonded wood materials. The effects of wood extractives on the setting of cement-bonded wood materials). Holzforschung 14(3): 70–77

Schubert, B.; Wienhaus, O. 1984: Die Messung des Temperaturverlaufes der Zementhydratation als Prüfmethode für die Herstellung von Holz-Zement-Werkstoffen (Measurement of the course of hydration temperature as a test method in the manufacture of wood-cement products). Holztechnologie 25: 118–122

Shuler, C. E.; Kelly, R. A. 1976: Effect of flake geometry on mechanical properties of eastern spruce flake-type particleboard. Forest Prod. J. 26(6): 24–28

Simatupang, M. H. 1979: Der Wasserbedarf bei der Herstellung zementgebundener Holzspanplatten. Holz Roh-Werkstoff 37: 379–382

Simatupang, M. H.; Schwarz, H. G.; Bröker, F. W. 1978: Small scale plants for the manufacture of mineral-bonded wood composites. Special paper. 8th World Forestry Congress, FID-II/21-3, Jarkata, Indonesia

Turner, H. D. 1954: Effect of particle size and shape on strength and dimensional stability of resin-bonded wood particle panels. Forest Prod. J. 4: 210–223

Vermaas, C. H. 1974: Duripanel cement-bonded particleboard – Economic aspects of production and marketing. World Consultation on wood-based panels. FAO/WCWBP/75, Document No. 23

Vital, B. R.; Wilson, J. B.; Kanarek, P. H. 1980: Parameters affecting dimensional stability of flakeboard and particleboard. Forest Prod. J. 30(12): 23–29

Weatherwax, R. C.; Tarkow, H. 1967: Effect of wood on the setting of Portland cement: Decayed wood as an inhibitor. Forest Prod. J. 17(7): 30–32

Wong, W. C.; Ong, C. L. 1982: Compatibility of timber species with Portland cement. Malaysian Forester 45(1): 87–93

Xia, Y. Z. 1982: Effects of different ratios between raw materials on the properties of a 3-layered oriented cement-bonded structural particle-board

Yamagishi, K.; Kasai, A.; Komazawa, K.; Nunomura, A. 1980: The manufacture of wood-cement boards using species which inhibit cement hardening. I. The effects of pre-treatment of larch particles with oil and chemical. Report Hokkaiddo Forest Prod. Research Inst. No. 342, p. 6–10

Zhengtian, L.; Moslemi, A. A. 1985: Influence of chemical additives on the hydration characteristics of western larch wood-cement-water mixtures. Forest Prod. J. 35(7/8): 37–43

(Received December 7, 1987)

S. O. O. Badejo
Forest Products Research Division
Forestry Research Institute of Nigeria
P.M.B. 5054
Ibadan, Nigeria