Dimensional Stability of Cement-Bonded Boards Manufactured with Coffee Chaff[*1]

Babatunde AJAYI[*2†]

ABSTRACT

Coffee chaff for manufacturing of the 6 mm thick cement-bonded boards was obtained from a coffee processing industry at Omuo-Ekiti, in Ekiti State, Nigeria. Boards were produced with three levels of cement to coffee chaff ratio of 1.5:1, 2.5:1 and 3.5:1; and at three levels of mixing curing reagent of 2.0%, 2.5% and 3.0%. Three dimensional properties of thickness swelling (TS), water absorption (WA) and linear expansion (LE) were investigated after 48 hours immersion in water. The mean values obtained for TS, WA and LE ranged from 0.46% to 1.47%, from 11.52% to 24.00%, from 0.19% to 0.35%, respectively. The most dimensionally stable boards were produced at the highest mixing levels of curing reagent and cement to coffee chaff ratio of 3.0% and 3.5:1, respectively. The coffee chaff is suitable as raw material for the manufacture of cement-bonded composites and it would be able to stimulate and activate the use of other agro-byproducts for the manufacture of value-added panels.

Keywords : thickness swelling, water absorption, linear expansion, coffee waste, cement-bonded board

1. INTRODUCTION

The mismanagement of forest biodiversities gives rise to economic wastes. These are arisen from the over-exploitation of virgin and artificial plantation, or the under-utilization of these wood species. This indiscreet attitude to forest management gave lot of concerns to wood scientists and technologists the impetus to stimulate a new concept and approach towards finding alternative sources of raw materials to meet the demands of forest industries at present and in future.

The bulk of the volume of wood wastes generated in Nigeria was estimated to be about 1.72 million m^3 (Badejo and Giwa, 1985) and amounted to 2.32 million m^3 (Badejo, 1990). Between 1996 and 2001, wood wastes generated in Ondo State alone amounted to 0.57 million m^3 (Ajayi, 2001). A lot of research activities have been poured into the use of wood only as the source of raw materials for cement-bonded particleboard manufacture (Ajayi 2000, Badejo 1999, Simatupang and Geimer 1990, Lee 1991, Fuwape and Fuwape 1995). As a result of mismanagement and deficit supply of wood resources to fill this gap already created.

*1 Received on March 12, 2006; accepted on July 20, 2006.
*2 Department of Forestry and Wood Technology Federal University of Technology, P.M.B 704, Akure, Ondo State, Nigeria.
† Corresponding author : Babatunde AJAYI (babatundeajayi2000@yahoo.com)

Agricultural wastes have been considered as suitable raw materials for cement-bonded composites but have not been significantly utilized. These include bagasse (Sandermann, 1970, Simatupang *et al* 1993), maize stalk (Ajayi, 1982) and banana stalk with sawdust (Ajayi, 2003a). The wastes generated from the agricultural byproducts of Nigeria are often perceived as va lueless. The use of such raw materials for cement bonded -board production and other value-added wood products will increase the industrial and economic development (Ajayi, 2003a). The new products will promote the establishment of agricultural byproducts use on a large scale and would be able to boost an economy of agricultural society.

Because of the high cost of synthetic resin binders, and heat energy in particleboard manufacture, the need to find an alternative source to synthetic binder becomes apparent (Ajayi 2000). Hence, cement is being used as a binding agent in cement-bonded particleboard manufacture (Ajayi 2000, Ajayi 2003b, Oyagade 1994, Hawkes and Cox 1992).

Despite superior performance of cementbonded composites, many wood species and agricultural residues may not bond adequately together with cement. This is due to the presence of chemical substances which inhibit the proper setting and curing of cement binder (Ajayi 2003b, Fuwape 1992, Ajayi 2003a, Biblis and Lo 1968). These chemical substances include sugars, starches, hemicelluloses and such extractives as phenolic compounds (Biblis and Lo 1968, Blankenhorn *et al* 1994, Lange, *et al* 1989). In order to prepare the raw materials suitable for board manufacture, the pretreatment of these substances become inevitable so as to remove the water soluble chemical substances and improve the bonding ability of cement binder with wood or agricultural residues. Hot water treatment is one of the simple and effective methods of removing and reducing these inhibitory substances.

Coffee fruit is a drupe, composed of a yellow and pulpy mesocarp which encloses the two seeds. The ripe fruits are harvested and dried in open air for 4~5 weeks. Thereafter the fruits were processed and the chaff is separated from the seeds either by machine or pounded on a smooth concrete floor. The chaff is dumped close to processing site and burnt.

This study is aimed to examine the suitability of coffee chaff for cement-bonded board manufacture and to examine the effect of production variables on the dimensional stability of the boards.

2. MATERIALS and METHOD

The raw material used for this work (coffee chaff) is a byproduct derived from processed dried coffee seeds. The coffee chaff was collected from the processing industry and transported to the Wood Products Laboratory of the Forestry Research Institute of Nigeria, Ibadan. Firstly, the coffee chaff was dried in the open air for 7 days for reduction of the moisture content and the breakdown of the chemical substances in it. Thereafter, the chaff was put inside an aluminum pot and immersed in hot water at temperature of $80^{o}C$ for one hour. Hot water containing the leached chemicals was drained off; thereafter the hot water-treated chaff was soaked in cold water for 20 minutes. Pretreated chaff was air-dried for 14 days to moisture content of approximately 12% prior to use.

The following production variables were used:

i. Cement to coffee chaff ratio: 1.5:1.0, 2.5:1.0, 3.5:1.0
ii. Mixing level of curing reagent ($CaCl_2$): 2.0%, 2.5% and 3.0%

Manufacturing conditions were as follows:

- Board dimension: 6 mm (T)×350 mm (W)×350 mm (L)
- Pressing pressure: 1.23 N/mm^2
- Moisture content of coffee chaff: approximate 12%.
- Board density : 1200 kg/m^3

For the production of each board, the quantity of cement and coffee chaff, calcium chloride and water were weighed, and mixed together thoroughly in order to prevent the formation of cement/coffee chaff lump.

The mixture was allowed to stand for three minutes before it was uniformly hand-formed into a mat inside a wooden mold and placed on a metal plate covered with polythene sheet. The top press plate was also covered with polythene sheet before it was placed on the mat. This covering was done to prevent the sticking of the metal plates on the mat formed.

The mould was pre-pressed, stacked together and transferred to the hydraulic press and cold-pressed for 24 hours. Thereafter, boards were removed and placed inside a polythene bag and sealed up for 4 weeks for curing and hardening of boards. Then, boards were subsequently trimmed into test samples of 152 mm ×152 mm square. These boards were immersed in cold water at room temperature for 48 hours. thickness swelling (TS) water absorption (WA) and linear expansion (LE) properties were investigated in accordance with the test procedures specified in ASTM D 1037 (1978). Data collected were analysed using a computer software programme. Least significant difference test was performed to determine if significant differences existed between sample means at 0.05 significance level.

3. RESULTS and DISCUSSION

This study has initiated concerted research efforts to examine the suitability of using various agricultural byproducts for boards composites manufacture in Nigeria. This will serve as a poverty alleviation initiative, provide panel product needs for housing development and conserve the depleting wood resources.

3.1. Thickness Swelling

The mean values of thickness swelling are presented in Table 1. The values ranged between 0.46% and 1.47%. Cement to coffee chaff ratio and curing reagent's mixing level showed a profound effect on the reaction of boards to water. As the cement to coffee chaff ratio and curing reagent's mixing ratio increased, the thickness swelling values decreased. This finding is supported by the works of Ajayi (2000, 2003a), Simatupang *et al* (1991), and Fuwape (1994). Boards produced at the highest cement to coffee chaff ratio of 3.5:1.0 and curing reagent's mixing level of 3.0% were most dimensionally stable. The high values of thickness swelling at low cement to wood ratio were due to scanty coating of cement on wood flakes, and poor internal bonding which allowed swelling of the wood component of boards (Fuwape 1992, Ajayi 2000). As the cement and $CaCl_2$ content increased, the wood flakes were more thoroughly coated. This affected boards' compression behaviours and also increased the compression strength of boards (Ajayi 2000).

The result of the analysis of variance in Table 2 shows that there were significant differences in the thickness swelling of boards with cement to coffee chaff ratio, whereas such comparison with curing reagent's mixing level and the interaction of these two factors were not significantly different ($P < 0.05$). That is, the interaction between curing reagent's mixing level and cement to coffee ratio has no significant effect on thickness swelling. The result of multiple difference range test in Table 3 shows that there was a significant difference between the thickness swelling of boards with cement to coffee chaff ratio of 3.5:1.0 and 1.5:1.0 only. There was no significant difference in thickness swelling of boards between any of the curing reagent's mixing level.

3.2. Water Absorption

The relationship of the boards' water absorption to cement-coffee chaff ratio and curing reagent's mixing level was similar to that of thickness swelling after soaking in water for 48 hours. The water absorption mean values obtained ranged between 11.52% and 24.00% (Table 1). It was observed that as the cement to coffee chaff ratio and curing reagent's mixing level increased, the water absorption values decreased. This observation is corroborated by the findings of Ajayi (2003a), Geimer *et al* (1993), Kwon and Geimer (1998), Fuwape (1992) and Ajayi (2000). Thus it may be possible to manufacture high water resistance boards by increasing the cement to coffee chaff ratio and curing reagent's mixing level. As a result of these, the most dimensionally stable boards were those produced at the highest cement to coffee chaff ratio and curing reagent's mixing level of 3.5:1 and 3.0%, respectively.

Statistical analysis of the data revealed significant differences in the water absorption of the boards with cement to coffee-chaff ratio, curing reagent's mixing level and the two-factor interactions. This shows that the combination of the two factors at various levels will affect the water absorption of the boards consistently. The result in Table 3 shows that significant differences exist in the water absorption of boards with cement-coffee chaff ratio of 3.5:1 and 2.5:1; 2.5: 1 and 1.5:1; and 3.5:1 and 1.5:1, but significant difference only occurred in water absorption of boards with curing reagent's mixing level of 3.0% and 2.0%; 2.5% and 2.0%. No significant difference was present between 3.0% and 2.5%.

3.3. Linear Expansion

Table 1 shows the results of linear expansion. The linear expansion behaviour of boards is

Table 1. Thickness swelling, water absorption and linear expansion of boards from coffee waste

Cement to Coffee Chaff Ratio	Mixing Level of Curing Reagent (%)	Thickness swelling (%)	Water absorption (%)	Linear expansion (%)
1.5:1	2.0	1.47±0.31	24.00±3.06	0.35±0.02
	2.5	1.42±0.38	17.94±3.08	0.31±0.03
	3.0	1.11±0.39	16.96±2.18	0.33±0.05
2.5:1	2.0	1.05±0.59	16.41±0.75	0.31±0.00
	2.5	1.00±0.49	14.49±0.82	0.30±0.00
	3.0	0.96±0.39	13.52±0.80	0.28±0.01
3.5:1	2.0	0.81±0.35	13.45±1.39	0.25±0.01
	2.5	0.76±0.58	13.15±0.84	0.23±0.01
	3.0	0.46±0.21	11.52±0.66	0.19±0.00

Values are means of three replicates

very similar to those of thickness swelling and water absorption tests. The linear expansion mean values ranged between 0.22% and 0.32% after 48 hours soak in water. Similarly both the cement to coffee chaff ratio and curing reagent's mixing level had strong effect on linear expansion of boards. The boards became more stable as the cement to coffee chaff ratio and curing reagent's mixing level increased. A similar observation was made by Badejo (1986). Boards manufactured at the highest cement to coffee chaff ratio of 3.5:1 and curing reagent's mixing level of 3.0% were most stable. The result revealed that the mean values for linear expansion were lower than the two other properties (thickness swelling & water absorption). This shows that the reaction of cement-bonded boards to water immersion may be due to high resistance of board to movement in a linear direction. The analysis of variance in Table 2 shows that both cement-coffee chaff ratio and curing reagent's mixing level had significant effect on linear expansion of boards, whereas the interaction of both factors had no significant effect on linear expansion of boards. This implies that consistent result will always be obtained regardless of the level of interaction.

Table 3 shows the result of multiple difference range tests. Significant differences exist between the linear expansion of boards with cement-coffee chaff ratio of 3.5:1 and 2.5:1, 2.5:1 and 1.5:1, and 3.5:1 and 1.5:1, respectively. Also significant differences in the linear expansion of boards occurred only between boards with curing reagent's mixing level of 3.0% and 2.0%, 2.5% and 2.0%, respectively, whereas no significant difference in the linear expansion of boards was present between curing reagent's mixing level of 3.0 and 2.5%.

4. CONCLUSION

This study assessed the possibility of using coffee chaff for the manufacture of cement-bonded composites. The study has indicated that cement-bonded particleboards using coffee waste can be manufactured. The study reveals that thickness swelling, water absorption and linear expansion decreased as the cement-coffee chaff ratio and curing reagent's mixing level increased. It also shows that there was a positive correlation between the dimensional stabil-

Table 2. The analysis of variance of thickness swelling, water absorption and linear expansion of coffee chaff-combined cement-boards

Source of Variation	Degree of Freedom	F values		
		Thickness swelling	Water absorption	Linear expansion
Coffee chaff-combined with cement	2	7.16*	47.68*	79.08*
Mixing level of curing reagent	2	1.33ns	15.54*	9.15*
Coffee chaff combined with cement and mixing of curing reagents	4	0.17ns	3.43*	2.23ns
Error	27			
Total	36			

* denotes significant at $P < 0.05$ and ns means not significant at $P < 0.05$

Table 3. Multiple difference range test for thickness swelling, water absorption and linear expansion of coffee chaff - combined cement boards

FACTORS	LEVELS	Thickness swelling	Water absorption	Linear expansion
Cement to Coffee Chaff Ratio	3.5:1	0.68[a]	12.71[a]	0.22[a]
	2.5:1	1.00[ab]	14.81[b]	0.30[b]
	1.5:1	1.33[b]	19.63[c]	0.33[c]
Mixing level of curing reagent	3.0	0.84[a]	14.00[a]	0.27[a]
	2.5	1.06[a]	15.19[a]	0.28[a]
	2.0	1.11[a]	17.95[b]	0.30[b]

Data marked by the same letter are not significantly different at 0.05 level of significance.

ities and the production variables at boards manufacture. Increase in cement-coffee chaff ratio had significant effect on thickness swelling, water absorption and linear expansion. Whereas increase in curing reagent's mixing level only had significant effect on water absorption and linear expansion. In this study, boards produced at the highest levels of cement-coffee ratio of 3.5:1 and curing reagent's mixing level of 3.0% were found to be the most stable boards. Dimensionally stable boards can be produced from coffee chaff with Portland cement after hot water treatment and such boards could be used as alternative to sawn timber for construction works.

REFERENCES

1. Ajayi, B. 1982. Investigation of the physical strength properties of maize stalk-based particleboard. HND, Thesis; Schl. of Forestry, For. Res. Inst. of Nigeria, Ibadan, Nigeria.
2. Ajayi, B. 2000. Strength and dimensional stability of cement-bonded flakeboard produced from *Gmelina arborea and Leucaena leucocephala* Ph.D. Thesis, Federal University of Technology, Department of Forestry and Wood Technology, Akure, Nigeria. 176p.
3. Ajayi, B. 2001. Wood waste management inforest industries. *Journal of Tropical Forest Resources* 17(2) 91~102pp.
4. Ajayi, 2003a: Assessment of the dimensional stability of cement-bonded particleboard from post-harvest banana stems residues and sawdust. In Proc. World Forestry Congress, 21st - 28th September 2003 at Quebec City, Canada. Vol. A. pp157.
5. Ajayi, B. 2003b. Short term performance of cJement-bonded hardwood flakeboards. *Journal of Sustainable Tropical Agricultural Research* 8: 16~19.
6. American Society for Testing and Materials 1978. Standard methods of evaluating the properties of wood-base fibre and particle panel materials. ASTM Desig. D1037-78. Philadelphia, Pennsylvania.
7. Badejo, S.O.O. and S. A. Giwa. 1985. Volume assessment and economic importance of wood waste utilisation in Nigeria. Technical Report No. 50. Forestry Research Institute of Nigeria, Ibadan.
8. Badejo, S.O.O. 1990. Sawmill wood residues in Nigeria and their utilization. Invited paper, Proceedings of National Workshop on Forestry Management Strategies for Self-sufficiency in Wood Production. Forestry research Institute of Nigeria, Ibadan, 12th - 15th June 1990.
9. Badejo, S.O.O. 1999. Influence of process variables on properties of cement-bonded particleboards from mixed tropical hardwoods. Ph.D. thesis, Fed. Uni. Of Tech., Dept. of For. and Wood Tech. Akure, Nigeria. 255pp.
10. Biblis, E. J. and C. F. Lo. 1968. Sugars and other wood extractives: effect on the setting of

southern pine cement mixtures. *Forest Prod. J.* 18(8): 28~34.

11. Fuwape, J. A. 1992. Sorption properties of wood-cement particleboard as influenced by cement/wood ratio. *J. Ind. Acad. Wood Sci.* 23(1): 1~9.
12. Fuwape J. A. 1994. Compatibility of tropical wood residue with Portland cement-*Journal of Timber Development Association (India)* Vol. XL. No. 4.
13. Fuwape, J. A and I. A. Fuwape. 1995. Technical assessment of three-layer cementwood particleboard. *Nigeria J. Forestry* 24 (1and 2): 57~60.
14. Geimer, R. L, M. R. Souza, A. A. Moslemi, and N. H. Simatupang. 1993. Carbon-dioxide application for rapid production of cement-bonded particleboard. *In Moslemi, A.A. (Ed) Inorganic Bonded wood and Fiber Composite materials.* Vol.3 Forest Prod. Res. SOC. Madison, WIS. pp 31~41.
15. Hawkes, A. J. and D. R. S. Cox. 1992. A small-scale process for manufacturing wood-wool cement slabs in developing countries Bulletin 49. Natural Resources institute. 38pp.
16. Kwon, H. E and R. L. Geimer. 1998. Impact of steam pressing variables on the dimensional stabilization of flakeboard. *Forest Prod. J.* 48 (4):55~61.
17. Lange, H., M. H. Simatupang, and Neubauer, A. 1989. Influence of latent hydraulic binders on the properties of wood-cement composite. In Proc. 1st Int. Conf. On Fiber and Particleboard. Bonded with inorganic Binders, Forest prod. Soc. Madison Wis. pp 48~52, in Moslemi A.A. (Ed).
18. Lee, A. W. C. 1991. The latest developments in the cement-bonded wood excelsior (wood wool) board industry. In: Proc. Second International Inorganic Bonded Wood and Fiber Composite Materials. Forest Prod. Res. Soc. Madison. Wis. pp. 103~107.
19. Oyagade, A. O. 1994. Compatibility of some tropical hardwood species with Portland cement. *Journal of Tropical Forest Science* 6(4) 387~396.
20. Sandermann, W. 1970. Technical processes for the production of wood-wool cement boards and their adaptation for the utilization of agricultural residues. UNIDO. ID/ WG.83/4, 1970.
21. Simatupang, M. H. and R. L. Geimer. 1990. Inorganic binder for wood composites: feasibility and limitations. In: Proc. of Wood Adhesive Symposium. Forest Prod. Res. Soc. Madison, Wis. pp 169~176.
22. Simatupang, M. H., A. Kasim, N. Seddig, and M. Smid. 1991. Improving the bond between wood and gypsum. Proc. Second Int. Inorganic Bonded Wood and Fiber Composite Materials. For. Prod. Res. Soc. Madison Wis. pp.61~69. In Moslemi AA. (Ed).
23. Simatupang, M. H., Rahim Sudin, and J. S Suh. 1993. The carbon-dioxide injection method. An environmentally friendly process to fabricate cement-bonded boards from oil palm trunk. Conf. on Forestry and Forest. Prod. Res. 1993. Kuala Lumpur, Malaysia. pp 117~127.