EFFECT OF CASSAVA FLOUR AS UREA-FORMALDEHYDE ADHESIVE EXTENDER ON THE BONDING STRENGTH OF PLYWOOD

N. S. A. Derkyi [1], D. Sekyere [1], N. A. Darkwa.[2] and J. G. Yartey.[1]

[1] *Forestry Research Institute of Ghana, Council for Scientific and Industrial Research, KNUST P. O. Box 63, Kumasi. Ghana Email: dertch@csir-forig.org.gh.*
[2] *Faculty of Renewable Natural Resources, KNUST, Ghana*

ABSTRACT

Extenders are added to adhesive formulations to reduce resin utilization leading to cost savings. In this work, urea-formaldehyde resin was synthesized in the laboratory and cassava flour was added to the urea-formaldehyde resin in adhesive mix formulations for interior plywood manufacturing using a laboratory press. These formulations were compared with similar ones using wheat flour as extender. There were five extension levels (15.6, 31.2, 46.8, 62.4 and 78.1%) and three pressing times (4, 5 and 6 minutes). The results indicate that the effect of extender type on plywood bonding strength was not significant, while the level of extension has highly significant effect on the plywood bonding strength. The higher the level of resin extension, the lower the plywood bonding strength. The physicochemical properties of the synthesized resins and formulations, are reported.

***Keywords*: Formulation, synthesized resin, extension level, physicochemical properties, Brookfield viscometer.**

INTRODUCTION

Urea-formaldehyde adhesives (UF) are the condensation products of unsubstituted urea and formaldehyde. They are usually two-part systems, consisting of the resin and hardening agent. They are also available as spray-dried powders with incorporated hardener. The latter is activated by mixing with water. Fillers and extenders are also added. The most common application of urea-formaldehyde adhesives is in plywood manufacture. They are however not suitable for exterior applications or extreme temperatures (Petrie, 1977; Rayner, 1965; Shields, 1984). These limitations are evidenced for example, in strength losses of UF bonded joints; irreversible swelling of UF bonded composite panels and formaldehyde release (Higuchi and Sakata, 1979; Myers, 1985; Ebewele *et al*., 1991; Edoga, 2001; Edoga, 2002). Pizzi (1983) and Savla (1977) have discussed amino resins including ureas in considerable detail.

Wood adhesive extenders are amylose compounds with some protein content that have adhesive action and contribute to the rheological properties of the glue mix. The physico-chemical properties of these extenders are very important to establish. For instance, high ash, high crude fat and high fiber contents pose unpredictable viscosity problems and increase wash water requirement. Protein has been found to influence the water taking capacity of flour (Robertson, 1977). The government of Ghana is promoting greater production of processed wood products for markets in Europe, the United States, and South Africa. Ghana is a competitive supplier to the growing world market of veneer sheets and plywood. Potential value-added wood exports include handicrafts; finished and semi-finished furniture, mouldings and machined wood; flooring; door, window, and cabinet frames and panels; and paper and paperboard (Graffham *et al.* 1997).

The paperboard and plywood industries of Ghana are significant users of starch, flour and starch-based products. In 1996 the paperboard industry used 420 tons of starch-based adhesives in the manufacture of corrugated board. In the same period the plywood industry used 1,134 tons of starch and 1,200 tons of food grade wheat flour as extenders for synthetic wood glues. The paperboard and plywood industries account for 37% of the market for starch and starch-based products in Ghana (Graffham *et al.* 1997).

The plywood industry in Ghana comprises eight large-scale factories, which use imported synthetic resin-based glues in the manufacture of plywood sheets. These glues cost US$2,220/tons. To reduce costs, synthetic glues are mixed with an extender that can be either imported maize starch (US$650/tons) or food grade wheat flour (US$500/tons). Typically 50 kg of synthetic glue will make 55-60 1/8" plywood sheets, with an extender this increases to 80-85 sheets of 1/8" plywood sheets. For each 50 kg batch (of synthetic glue), either l0 kg of maize starch or 25 kg of wheat flour is required (Graffham *et al.* 1997). Several factories in Ghana have tried locally produced cassava flour and starch as extenders but have found these to be of poor quality and discontinued their use. The problem was that locally produced flour was not milled properly, they were insufficiently dried and contained many insoluble impurities that caused blistering in the plywood sheets. One manufacturer claims that local flour caused his percentage of rejects to rise from 1 to 7% (Graffham *et al.* 1997).

Cassava is a root crop which is abundant in the tropics and is a very important food crop in Ghana. Utilization of cassava on industrial scale is emerging and the industrial products which can be obtained from cassava are starch and cassava flour. High Quality Cassava Flour (HQCF) is produced from quality cassava varieties from Ghana under strict good manufacturing practices (GMP).

One of the main changes that has occurred in wood construction in the last 50 years has been the adoption of glue technology, to bond structures together and to make wood available in a more stabilized, laminated sheet form as plywood. Plywood mills in Ghana use wheat flour as extender in the adhesive mix for plywood production. Wheat as a commodity is not grown in Ghana and is therefore imported. Its market price keeps soaring-up because it has competing uses. It is used in Ghana as a food source particularly for bread and pastries making in addition to its use as extender in plywood mills. The aim of this work was to determine the effect of cassava flour, a local material as extender in adhesive mix for plywood manufacture.

MATERIALS AND METHODS

Materials

High quality cassava flour was supplied by Amasa Agro Processing Company Limited in Accra and wheat flour was purchased from a local market. Rotary-cut veneers were obtained from Logs and Lumber Limited, a local plywood processing mill in Kumasi. All chemicals used were of analytical grade purchased from BDH chemicals, Poole, England.

Methods

Urea Formaldehyde Resin Synthesis

A UF resin was synthesized in a 4-L glass reactor following the general cook procedure similar to that outlined previously by Savla (1977). The laboratory-synthesized UF resin (Table 2) was characterized based on the gel time, viscosity, pH, free formaldehyde, and solids content. For each parameter, average value of three readings was taken.

Formulation of Adhesive Mix

By using a modified formulation of Savla (1977), each plywood adhesive mix (Table 1) was formulated by adding a portion of the required amount of water to the resin followed by gradual addition of extender while stirring with a speed regulated stirrer. The rest of the water was added with the stirrer still running. Once a homogenous solution was obtained, the hardener was also added under agitation. Mix viscosity was measured with a Brookfield Viscometer Model LVF, spindle number 2 and 3 at 12 rpm.

Laboratory Plywood Manufacture

Three-ply plywood were prepared using veneer sheets of area 30 cm × 30 cm and 3 mm thickness from Otie (*Pycnanthus angolensis*) as face and back and Ceiba (*Ceiba pentandra*) as core. Each of the adhesives was applied to the veneers, conditioned to 12% moisture content, with a roller coater at a spread rate of 1.7g/cm^2 of single glueline. The spread panels were then pressed at 120°C and a pressure of 1.0 MPa at varying pressing times of 4, 5 and 6 minutes to obtain plywood of thickness 9.2 mm. The total assembly time, which includes the time from first adhesive application until hot-pressing, was 30 minutes.

Experimental Design

In the adhesive bond quality evaluation (dry and wet tests), a 2 × 5 × 3 factorial experiment in completely randomized design (CRD) was employed: 2 types of extender × 5 adhesive extension levels × 3 pressing times. This makes a total of 30 treatment combinations. The extenders used were cassava flour and wheat flour; The extension levels were 15.6%, 31.2%, 46.8%, 62.4% and 78.1% based on resin solids and the plywood pressing times were 4, 5 and 6 min. Adhesive mix without extender served as a control.

Statistical Analysis

The viscosities, solids content and pH of the adhesive mix and the shear strength of the plywood bond data were determined by the American Standards for Testing Materials (ASTM) procedures and evaluated using analysis of variance in SPSS 11.0 package.

Table 1: Adhesive mix with different extension levels

Components	*Parts by Weight (pbw)*					
	Level of Extension, E (%)					
	E_0	E_1	E_2	E_3	E_4	E_5
UF, 64% resin solids	100	100	100	100	100	100
Extender[a]	0 (0)	10 (15.6)	20 (31.2)	30 (46.8)	40 (62.4)	50 (78.1)
NH_4Cl	5	5	5	5	5	5
Water	5	20	35	50	65	80

Numbers in parentheses refer to percent adhesive extension based on resin solids.
[a] Refers to cassava flour or wheat flour.

Table 2: Properties of synthesized Urea-Formaldehyde Resin

Gel time (min)	Viscosity (cP)	Free Formaldehyde (mg/l)	Solids Content (%)
60	3403.33 (45.09)	0.28	64

Value in parenthesis represents standard deviation.

Table 3: Properties of adhesive mix with cassava and wheat flour extenders

Level of extension		*Viscosity (cP)*	*Solids content (%)*
Extension with cassava flour	E_1	3296.66 (45.09)[e,f]	57.90 (0.10)[e]
	E_2	3093.33 (90.18)[c,d]	54.80 (0.10)[d]
	E_3	3000.00 (60.00)[c]	52.53 (0.06)[c]
	E_4	2806.66 (70.24)[b]	50.70 (0.20)[b]
	E_5	2490.00 (85.44)[a]	49.40 (0.20)[a]
Extension with wheat flour	E_1	3300.00 (50.00)[e,f]	58.00 (0.10)[e]
	E_2	3210.00 (85.44)[d]	54.80 (0.10)[d]
	E_3	3100.00 (40.00)[c,d]	52.60 (0.30)[c]
	E_4	3000.00 (80.00)[c]	50.80 (0.10)[b]
	E_5	2800.00 (10.00)[b]	49.50 (0.30)[a]

Values bearing the same letter in a column are not significantly different at the 5% level by LSD Values in parenthesis represent standard deviation.

RESULT AND DISCUSSION

Physicochemical Properties of the Adhesives

The properties of the synthesized urea-formaldehyde resin and formulated adhesive mix with cassava and wheat flour extenders are presented in Tables 2 and 3 respectively. The processing of thermosetting resins requires understanding of the rheology and the polymerization reaction kinetics during cure. The gel time is one of the most important kinetic characteristics of curing, because it describes the attainment of certain critical conversion responsible for the transition from liquid to solid state of the curing process (Vilas *et al*., 2000). The gel point is characterized by the appearance in the reactive system of a macromolecule with an infinitely large molecular weight.

Rheological properties such as the viscosity can be directly correlated to the evolving physical and mechanical properties during resin cure (Hu *et al*., 2001). From Figure 1, it is observed that the viscosity of adhesive mix decreases with increasing extension levels. Apparently, decreasing solids content causes decrease in viscosity. Viscosity and solids content of the adhesive formulations are significantly different for the various extension levels (Table 3). Solids content were however not significantly different for the two types of extenders (Table 3).

A serious drawback of urea formaldehyde resin is the emission of the hazardous formaldehyde during cure (Kim, 2001; El-Naggar *et al.*, 2001; Pizzi *et al.*, 2001). It is important therefore to determine the formaldehyde emission from synthesized urea-formaldehyde resins. The formaldehyde emission level of 0.28 mg/L for the synthesized resin (Table 2) is within the acceptable emission range of 0.3 mg/L according to International Standards Organization, ISO 12460 – 4 standard, and therefore not of serious environmental consequences.

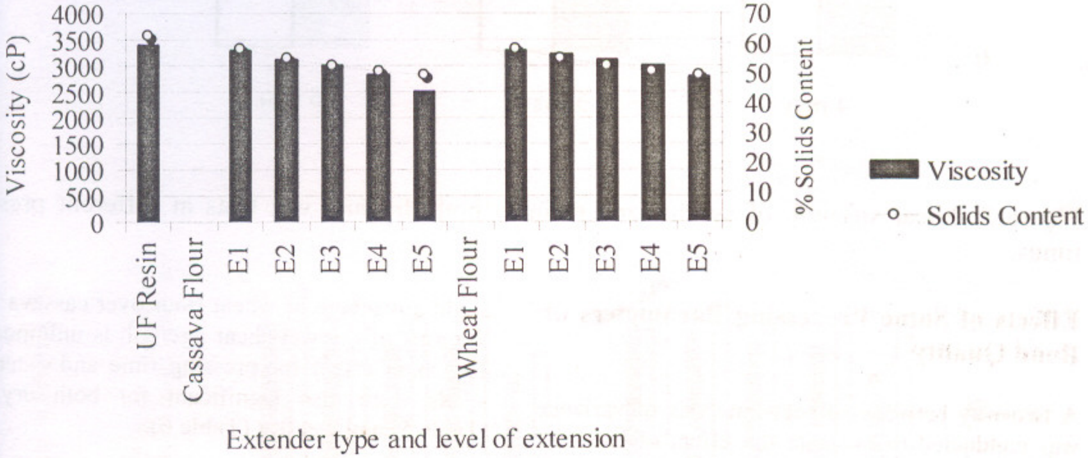

Figure 1: Variation of viscosity with solids content for type of extender and level of extension

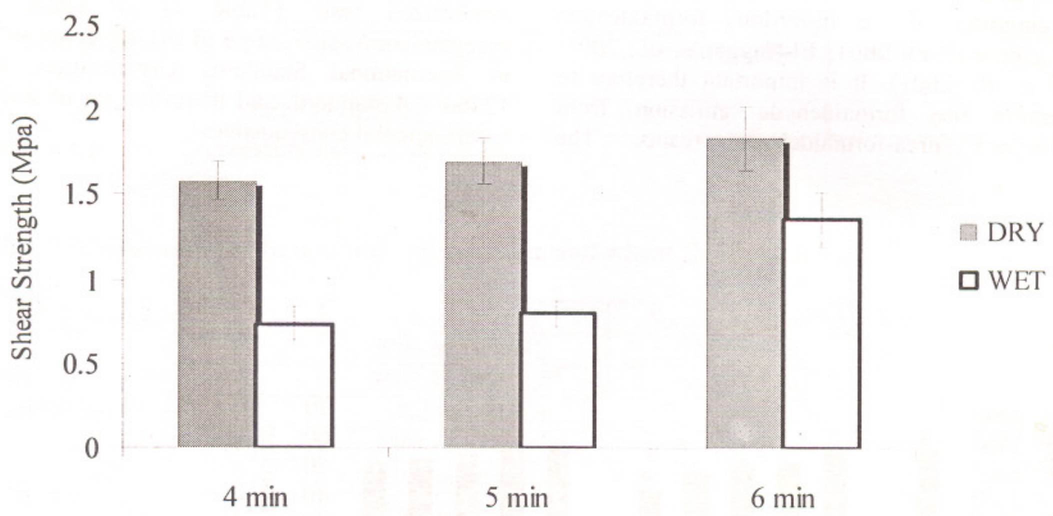

Figure 2: Shear strength of synthesized resin in both dry and wet tests at different pressing times.

Effects of Some Processing Parameters on Bond Quality

A two-way between-subjects analysis of variance was conducted to evaluate the effect of extender type, extension level and pressing time on plywood bond strength. The between-subjects factors were type of extender, with two levels (cassava flour and wheat flour); percentage extension, with five levels (15.6, 31.2, 46.8, 62.4 and 78.1%) and pressing time with three levels (4, 5 and 6 minutes). The alpha level was 0.05. A significant main effect was found for extender type in the case of wet test but not dry test (Table 4). Thus, the performance of both cassava flour and wheat flour in terms of dry shear strength were comparable, but not comparable in wet shear strength where wheat flour had a better performance than cassava flour. Since UF is for interior application in plywood manufacture, the slight advantage of wheat flour over cassava flour in terms of the wet shear strength is unimportant. The main effect for pressing time and extension levels were also significant for both dry test (Table 5) and wet test (Table 6).

Table 4: Effect of extender type on the shear strength of plywood samples

Type of Extender	Treatment Means (MPa)	
	Dry Shear Strength	Wet Shear Strength
Cassava Flour	1.399[a]	0.688[a]
Wheat Flour	1.401[a]	0.835[b]

Values bearing the same letter in a column are not significantly different at the 5% level by LSD.

The pressing time and levels of adhesive extension were highly significant in the dry shear strength but not the type of extender nor the interaction of the main factors (Table 5). Thus, the performance of both cassava flour and wheat flour in terms of dry shear strength were comparable. The dry shear strength of the plywood samples was not affected although resin solids of the adhesive mixes decreased with increasing extension. It follows that the available resin in the adhesive mixes at varying levels of extension was sufficient to bond the veneers as observed by Chan and Dionglay, (1996).

As in dry shear strength, the effects of pressing time and levels of adhesive extension were highly significant in wet shear tests. However, type of extender was significant contrary to the dry test (Table 6). Higher extension levels with cassava flour caused a sharper decrease in wet shear strength compared to wheat flour extension. Apparently, wheat flour extended adhesive mix offers a better moisture tolerance to plywood bond than cassava extended adhesive mix. Shear strength increased as pressing time increased in both the dry test (Figure 3) and wet test (Figure 4), indicating better polymer curing at higher temperatures.

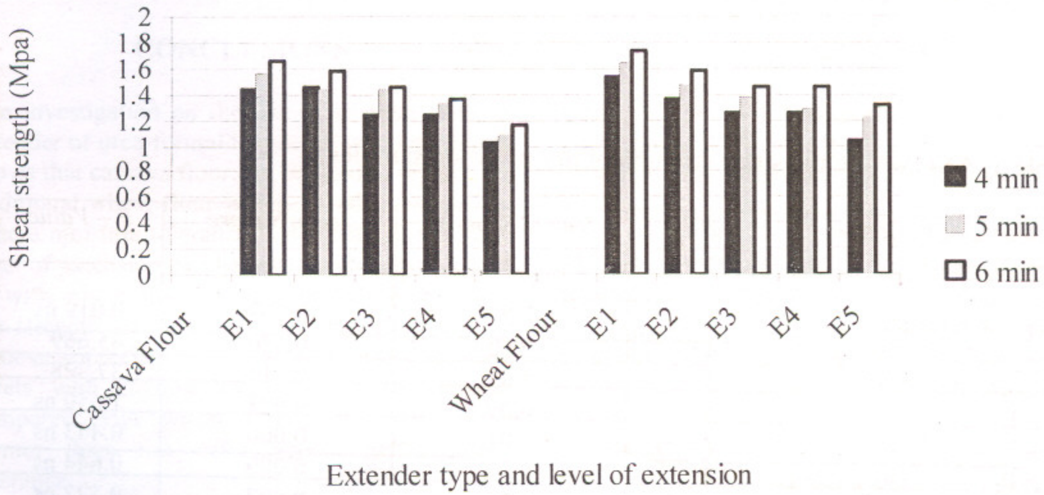

Figure 3: Effect of extender type and level of extension on dry shear strength of plywood bond at different pressing times

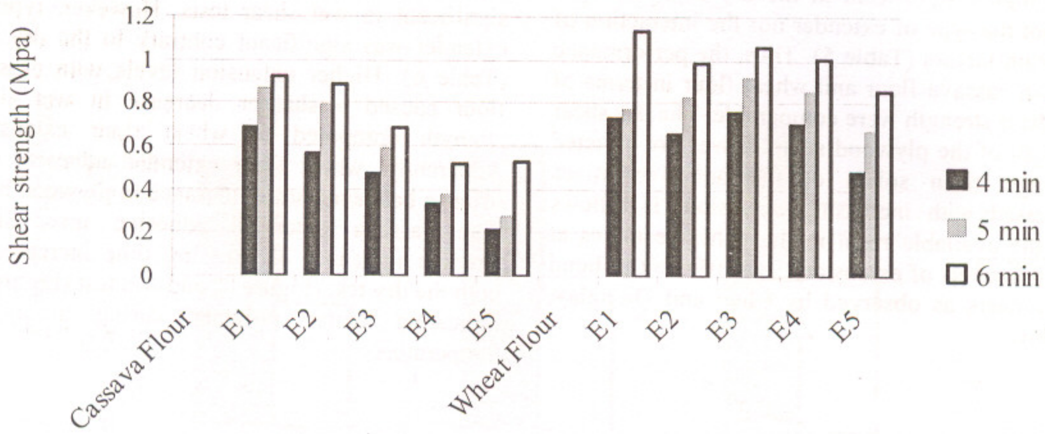

Figure 4: Effect of extender type and level of extension on wet shear strength of plywood bond at different pressing times.

Table 5: ANOVA on the shear strength of dry plywood samples

Source of Variation	*df*	*Sum of Squares*	*Mean Square*	*F – Value*
Type of extender (T)	1	0.003	0.003	0.019 ns
Extension level (E)	4	2.50	0.626	45.669 [¤]
Pressing time (P)	2	1.02	0.511	37.328 [¤]
T × E	4	0.09	0.023	1.650 ns
T × P	2	0.01	0.006	0.443 ns
E × P	8	0.07	0.009	0.644 ns
T × E × P	8	0.06	0.007	0.522 ns
Error	120	1.64	0.014	
Total	149	299.40		

[¤] - significant at 0.05 level of confidence
ns – not significant

Table 6: ANOVA on the shear strength of wet plywood samples

Source of Variation	*df*	*Sum of Squares*	*Mean Square*	*F – Value*
Type of extender (T)	1	0.67	0.67	43.53 □
Extension level (E)	4	0.45	0.11	7.34 □
Pressing time (P)	2	2.37	1.18	76.87 □
T × E	4	0.65	0.16	10.54 □
T × P	2	0.05	0.03	1.68 ns
E × P	8	0.13	0.02	1.11 ns
T × E × P	8	0.14	0.02	1.12 ns
Error	120	1.85	0.01	
Total	149	94.8		

□- significant at 0.05 level of confidence
ns – not significant

CONCLUSIONS

The investigation on the use of cassava flour as extender of urea-formaldehyde plywood adhesives shows that cassava flour can be used to replace the traditional wheat flour which is rather expensive. Where moisture tolerance is not critical, the same level of extension can be made with cassava flour as with wheat flour without materially reducing the strength of the adhesive-bond. However, to achieve appreciable moisture tolerance, extension levels with cassava flour should be reduced compared with wheat flour extension as the former does not offer appreciable moisture tolerance.

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