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FLEXURAL PROPERTIES AND BOND-ABILITY OF UREA-FORMALDEHYDE GLUED ACETYLATED BAMBOO

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ABSTRACT

In characterising bamboo for various engineering applications, small sections of bamboo in laminated form is more convenient than round form bamboo. Utilization of bamboo strips in laminated form have great potential to supplement timber. However, dimensional instability of bamboo is a major problem. Modifying bamboo will solve the dimensional instability problem. However, modification can influence the mechanical properties and bondability. In this study we evaluated the strength and bond-ability of acetylated *Bambusa vulgaris* glued with urea formaldehyde resin. Bamboo laminate samples were subjected to acetylation by varying the acetylation temperature (100^{o}C – 140^{o}C) as well as reaction time (30 mins – 90 mins). The experimental design was 2 factor factorial in completely randomised design. The bamboo laminates were subjected to flexural as well as shear bond tests to evaluate the influence of acetylation on the strength as well as bond-ability of the bamboo laminates. The findings showed that acetylation treatment had the greatest influence on flexural MOE at 100 ^{o}C and 120 ^{o}C when the samples were acetylated for a period of 60 mins. Flexural properties of modified samples tend to improve upon acetylation except for samples modified at 120 ^{o}C and 140 ^{o}C for 90 mins and 60 mins reaction time respectively. However, no statistical variation occurred in the flexural properties of both modified and unmodified bamboo samples. Reaction temperature and time had no significant influence on the flexural properties. The MOE increased by 11.26% and 11.99% at 100 ^{o}C and 120 ^{o}C respectively where as at 90 mins reaction time for all the samples, the MOE were greatly reduced. All the bond shear test samples recorded improved shear strength compared to the control samples except samples acetylated at 100 ^{o}C and 60 mins reaction time. The greatest improvement of 45.40 % in glue line shear strength was recorded for samples acetylated at 120 ^{o}C for 30 mins while a reduction of 3.21% in shear strength was recorded at 100 ^{o}C for 60 mins. Relationship between weight percentage gain (WPG) and flexural properties and bond shear strength of acetylated bamboo showed that the MOE, MOR and bond shear strength of acetylated *Bambusa vulgaris* depend on the weight gained upon acetylation of the bamboo samples.

Keywords: Acetylation; Bamboo Laminates; WPG; Urea Formaldehyde; Bond Shear Strength

INTRODUCTION

Interest in bamboo has increased as several studies have been carried out to evaluate bamboo's physical and mechanical properties and its utilization potential as a supplemental material to wood resources (Ahmad and Kamke 2005) mainly due to alarming rates of deforestation and decreased timber yields (Kigomo, 2007). Utilization of bamboo strips in laminated form is seen to have great potential to supplement timber and therefore reduce pressure on the existing timber resources (Zheng, 2002). In characterising bamboo for various engineering applications, reformed bamboo strips are more convenient than the natural form bamboo. Bamboo laminated lumber is a newly engineered structural material that is primarily used in buildings, vehicles, ships, furniture and many more.

As with wood, the dimensional instability of bamboo can compromise the performance of other materials such as adhesives and surface coatings combined with bamboo. The problem of dimensional stability has been addressed mainly by impregnating wood with appropriate hydrophobes to bulk the cell wall thereby reducing the tendency of wood to swell or shrink excessively with changes in moisture ((Stamm 1964; Rowell, 1983; Kumar 1994). This principle can also be applied to bamboo. Similarly with wood, aside improvement in dimensional stability, modification of bamboo can influence the mechanical properties. Modifying bamboo with acetic anhydride will improve its dimensional stability aside its biological and weathering resistances and it is expected to have little effect on its strength properties (Kumar, 1994; Hill, 2006 and Rowell, 2006). Aside mechanical properties of modified wood, bonding of acetylated wood into composite products is of a particular interest. In the case of bamboo, utilization of small sections of bamboo in laminated form is more convenient than the round form bamboo (Zheng, 2002). Bamboo laminated lumber is a newly engineered structural material that is primarily used for variety of applications. If acetylated bamboo could still retain its strength and also effectively bonded, this will give bamboo great potential to supplement timber and therefore reduce pressure on the existing timber resources (Zheng, 2002).

Several studies (Hill (2006; Vick and Rowell, 1990; Vick *et al.*, 1993; Frihart *et al.*, 2004) have pointed out the negative influence of chemical modification on the mechanical as well as bonding efficiency of chemically modified products. According to Hill (2006), modification of wood can change the strength of adhesion as a result of the changes in chemical, physical and structural characteristics of wood. In the same vein, conclusions were made in some published works (Vick and Rowell, 1990; Vick *et al.*, 1993; Frihart *et al.*, 2004), that bonding performance of acetylated wood was affected by the type of resin system used. Rowell *et al.* (1987) reported that phenol-formaldehyde resin did not effectively wet and penetrate the hydrophobic surfaces of aspen flakes thereby leading to poor adhesion. Low internal bond strength and wood failure of the flake board were recorded. Narayanamurti and Handa (1953) reported losses in strength by urea-formaldehyde, casein and protein adhesives on several Indian species. However, acetylation did not affect the bond strength of resorcinol-formaldehyde and animal adhesives.

There are quite a lot of published works on strength and bonding of chemically modified wood. However, very little is currently known about strength of acetylated bamboo compared to the control as well as the compatibility of urea formaldehyde resin with acetylated bamboo. A general believe is that water-borne wood adhesives such as Urea Formaldehyde which are highly polar and have strong attractions for the hydroxyl groups of wood, will be less attracted to the less polar, hydrophobic acetylated wood with its depleted hydroxyl groups. Whereas non-polar adhesives may be more compatible with acetylated wood than normal wood (Vick and Rowell. 1990). Therefore, this study sought to assess the influence of acetylation on flexural properties and bond-ability of acetylated bamboo (*Bambusa vulgaris*) laminates glued with urea formaldehyde to further improve the utilisation of bamboo in Nigeria. In this study, Urea formaldehyde resins was used due to its , low cost, high reactivity coupled with short hot press time compared to other resin systems.

MATERIALS AND METHODS

Two to four year old *Bambusa vulgaris* culms were extracted from a naturally growing bamboo grove at Agba Forest Reserve in Ilorin, Kwara State. Agba Forest Reserve lies on Latitude 8^{o} 30'N and Longitude 5^{o} 00'E. The bamboo culms were sampled at 10% and 50% of the total height which represented the base and the middle portion of the culm. Urea formaldehyde (UF) resin (laboratory grade) was supplied by Forest Product Development and Utilization section of the Federal College of Forestry, Jos.

The experimental designed adopted for the experiment was a 2-factor factorial experiment in completely randomized design. Factor I: Reaction temperature (100 ^{o}C, 120 ^{o}C & 140 ^{o}C), Factor II: Reaction time (30, 60 & 90 minutes). The study was to evaluate the Influence of acetylation on the modulus of elasticity and modulus of rupture of acetylated bamboo and to determine the ability of UF resin to bond bamboo that had been acetylated. Effectiveness of the bonds were determined by measuring shear strength of the laminates in dry condition. Each treatment combination was replicated five times for each of the property tested.

Acetylation Treatments

The samples for the bending strength properties were cut into a dimension of 20 x 20 x 300mm while the shear bond strength were cut into a dimension of 50 x 25 x 8 mm from defect free portion of the bamboo.

All the samples were reacted with acetone for 24 hours to remove the acetic acid naturally present in the bamboo samples, they were then wipe dried and oven dried till constant weight was achieved. These weights were used as the starting weight of the bamboo samples. The oven dried samples were sorted into four groups' prior acetylation.

Each group was treated by reacting with acetic anhydride in a reactor without a catalyst or a co-solvent under an atmospheric pressure of 756mmHg. The experiments were replicated five times. The outline of the acetylation treatment is given as follows:

Acetylation at 100°C for 30 minutes, 60 minutes and 90 minutes.

Acetylation at 120°C for 30 minutes, 60 minutes and 90 minutes.

Acetylation at 140°C for 30 minutes, 60 minutes and 90 minutes.

No acetylation (Control)

Properties Determination of Acetylated Bamboo

Weight Percentage Gain

The weight percent gain (WPG) which determines the extent of the acetylation reaction was determined as:

$$WPG = \left[\frac{W_t - W_o}{W_o}\right] \times 100 \quad \ldots\ldots 1$$

Where *WPG* is the weight percent gain; W_o is the weight of oven-dried sample before acetylation; and W_t is the weight of oven-dried sample after acetylation.

Flexural and Shear Bond Strength

The bending strength of the acetylated *B. vulgaris* were tested following American Standard Method for Testing Small Clear Specimens of Timber ASTM D 3043-95 (ASTM, 1995). The samples were subjected to three point bending on the Testometric Universal Testing Machine at a cross head speed of 1.00 mm/min according to ASTM D 695-95 (ASTM, 1996). The Testometric Universal Testing Machine with machine No: 0050-01014 has Win-test analysis as embedded software for the strength analysis. The length of the modified bamboo specimens were made parallel to the grain and the samples were subjected to three point bending on the Testometric Universal Testing Machine at a cross head speed of 1.00 mm/min according to ASTM D 695-95 (ASTM, 1996). Prior testing, all the specimens' dimensions were measured for each test with digital micrometer and a steel rule and the values were entered into the machine embedded computer. Thereafter, the specimens were placed on two supporting chucks at each end and a downward force was applied at the mid span of the specimens. Based on inputs values and the axial load applied, the computer was able to produce the appropriate strength values. This procedure was applied to all modified bamboo and the control.

The samples for the shear bond strength were glued with Urea formaldehyde resin. The test joint assembly was prepared by laminating two planed strips of acetylated bamboo. The adhesive was spread on both surfaces of the two-ply laminate by hand brushing at a rate of 340 g $m^{-2.}$ After glue application, the assemblies were cold pressed at room temperature under a hydraulic press for 24 hours and at a pressure of 1.5 Nmm^{-2}. The bamboo laminates were then lay-up in unidirectional configuration (Bamboo/0°/0°/Bamboo). The samples were cold cured for 3 weeks at 27^{o}C and 65% Relative humidity. The glued samples were tested for shear strength at a loading speed of 1mm/min on a compression-loading shear machine (Universal Testometric Machine) following ASTM D 905 10. The loading was carried out until a break or separation occurred at the glue-line. Based on the axial load applied, the machine embedded computer was able to generate appropriate flexural and bond shear strength values for the bamboo samples. The data obtained were subjected to analysis of variance (ANOVA)

RESULT AND DISCUSSION

WPG of Acetylated *B. vulgaris*

The weight gain of the modified samples ranged from 1.61% to 3.67% (Table 1). Samples acetylating at 140^{o}C had the highest weight gain of 2.99% while those acetylated at 100 ^{o}C had the lowest (Table 1). Acetylating for 1 hour resulted to 3.67 % WPG (Table 1) which was the highest in this study. However, for 90 minutes which was the longest time in this study showed to have the lowest WPG of 1.61% (Table 1)

Generally, reaction time and temperature had no significant influence on the WPG of the modified samples (Table 2). However, there was increase in WPG from 100^{o}C to 120^{o}C with slight decrease in WPG at 140 ^{o}C. Likewise, influence of reaction time showed that great improvement existed in the WPG of the samples when the reaction proceeded from 30 minutes to 1 hour (Table 2).

However, there was drastic reduction in the WPG when the reaction proceeded for longer time of 90 minutes during 30 minutes reaction time. In this work, the higher the temperature of reaction, within short period, the higher the WPG which was in line with findings of Rowell (2006). However, the longer the reaction was run, the lower the WPG which was contrary to the reports of Rowell (2006). He reported that the longer the reaction is run the higher the WPG. However, he stressed that no matter how it is done, once acetylation reaches a maximum WPG of about 22% further reaction time does not increase this value.

Table 1: Mean values for Weight Gain of acetylated Bamboo

Properties	**Reaction time (mins)**	**Temperature °C**		
		100	120	140
WPG (%)	30	1.96 ± 1.53	2.88 ± 0.83	2.89 ± 1.88
	60	2.87 ± 1.08	2.41 ± 0.94	3.67 ± 1.08
	90	2.78 ± 1.72	2.95 ± 0.50	1.61 ± 0.57

Table 2: Influence of Acetylation variables on WPG of Modified *B. vulgaris*

Source of variation	**Levels**	**Weight percentage gain (WPG) (%)**
Temperature	100	2.54[a]
	120	2.75[a]
	140	2.73[a]
Time	30	2.58[a]
	60	2.99[a]
	90	2.45[a]

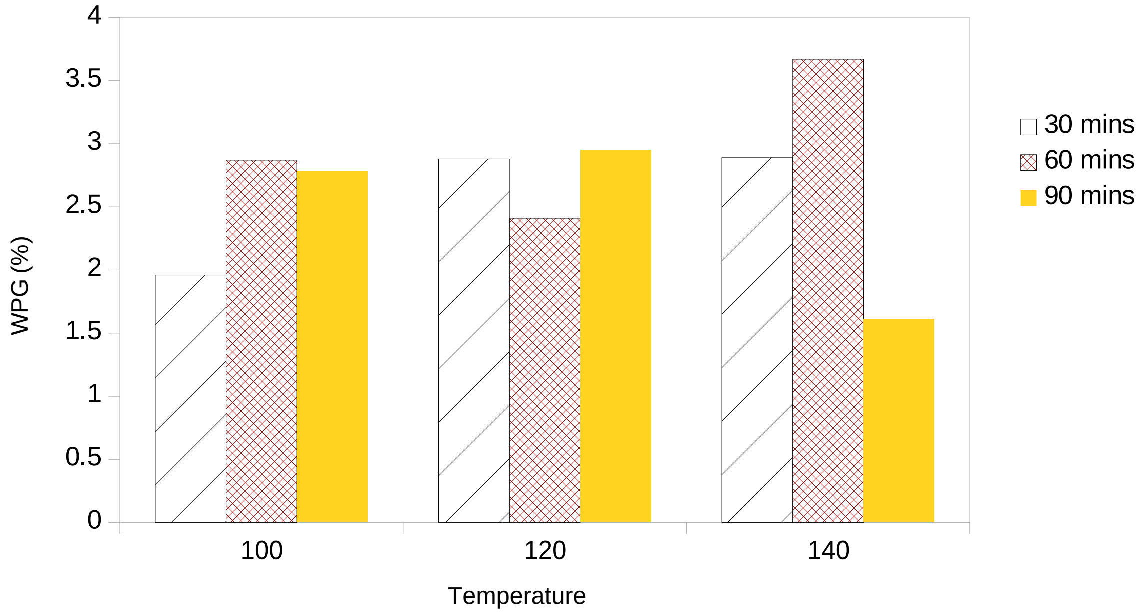

Figure 1: Influence of Reaction time and temperature on weight gain of *B. vulgaris*

Flexural Properties of Modified Bamboo

Generally, the flexural MOE and MOR of the modified bamboo were statistically similar (Table 4). However, acetylating at 100 ^oC produces bamboo with the highest MOE (4079.72 Nmm^{-2}) and MOR (65.65 Nmm^{-2}) where as the untreated samples (control) had the lowest (44.73 Nmm^{-2}) (Table 3; Figures 2 & 3). All the acetylated samples had improved flexural properties compared to the unmodified samples.

There were reductions in the MOE and MOR when bamboos were acetylated at 120^oC and 140 ^oC (Table 4). However, the MOE and MOR increased when the bamboo were acetylated from 30 to 60 minutes. When the reaction proceeded for 90 minutes, there were reductions (Figures 1 & 2). This indicates that the longer the reaction was run, the lower the strength of the modified samples. The flexural MOE of the untreated samples were greater than those acetylated for 90 minutes. This indicates that 30 and 60 minutes were best for modifying bamboo for improved strength and without loosing the strength of the bamboo.

Table 3: Mean values for MOE, MOR and Bond Shear Strength of acetylated Bamboo

Properties	Reaction time (mins)	Temperature °C		
		100	120	140
MOR Nmm^{-2}	30	63.14 ± 21.41	47.02 ± 18.42	50.13 ± 11.69
	60	65.65 ± 15.02	57.28 ± 26.09	41.52 ± 11.30
	90	58.74 ± 6.65	43.49 ± 11.85	49.23 ± 3.25
	Control		44.73 ± 16.95	
MOE Nmm^{-2}	30	3862.04 ± 1413.4	3485.41 ± 1006.49	3603.50 ± 668.95
	60	4053.12 ± 442.81	4079.72 ± 1568.29	3079.32 ± 139.97
	90	3327.31 ± 455.52	2761.26 ± 921.41	3183.03 ± 171.98
	Control		3643.06 ± 184.70	
Bond shear Nmm^{-2}	30	57.02 ± 1.13	44.42 ± 3.21	33.18 ± 1.10
	60	29.57 ± 0.29	55.06 ± 2.01	16.87 ± 0.98
	90	-	-	-
	Control		30.55 ± 0.13	

Table 4: Influence of Acetylation variables on MOE, MOE and Shear Strength of Acetylated Bamboo

Reaction variables	Levels	MOR (Nmm^{-2})	MOE (Nmm^{-2})	Shear (Nmm^{-2})
Temperature	100	62.51^a	3747.49^a	43.29^a
	120	49.26^a	3442.13^a	49.74^a
	140	49.96^a	3288.61^a	25.03^a
	Control	44.73^a	3643.06^a	30.55^a
Time	30	53.43^a	3650.32^a	44.87^a
	60	54.82^a	3737.38^a	33.83^a
	90	50.49^a	3090.53^a	-
	Control	44.73^a	3643.06^a	30.55^a

The findings of this work showed that flexural properties increased after acetylation for short. The findings of this work showed that flexural properties increased after acetylation for short reaction time. However, losses of strengths were recorded at higher temperature and longer reaction time compared to untreated samples. Acetylation treatment had the greatest influence on MOE at 100 °C and 120 ^{o}C for a period of 60 mins. The MOE increased by 11.26% and 11.99% at 100 ^{o}C and 120 ^{o}C respectively where as at 90 mins reaction time, the flexural MOE were greatly reduced. Saikia, (1999) got similar findings where the MOE of treated wood increased over the untreated ones. However, Narayanamurti and Handa (1953) reported a slight decrease in MOE of acetylated wood as compared to controls. Militz (1991) and Rowell (1991) reported slight reduction in shear strength but with no significant influence on the Bending strength and E-modulus in bending. Likewise, the MOR increased by 41.16% and 46.77% when acetylating at 100 ^{o}C for 30 and 60 minutes respectively. Dreher (1964) reported that the compression strength and hardness of chemically modified wood increased by 6-36%.

Generally, no statistical variation existed in the MOE and MOR of acetylated and unacetylated bamboo samples (Table 4). This result is similar to the findings of Rowell and Banks (1987), where the tensile strength of thin strips of pine and lime showed no significant difference in tensile strength between control and acetylated wood. Likewise, Dreher *et al.*, 1964; Larsson and Tillman, 1989; Militz, 1991; Rowell, 1991 and Akitsu *et al.*, 1993) reported no significant influence on the Bending strength and E-modulus in bending of modified wood samples.

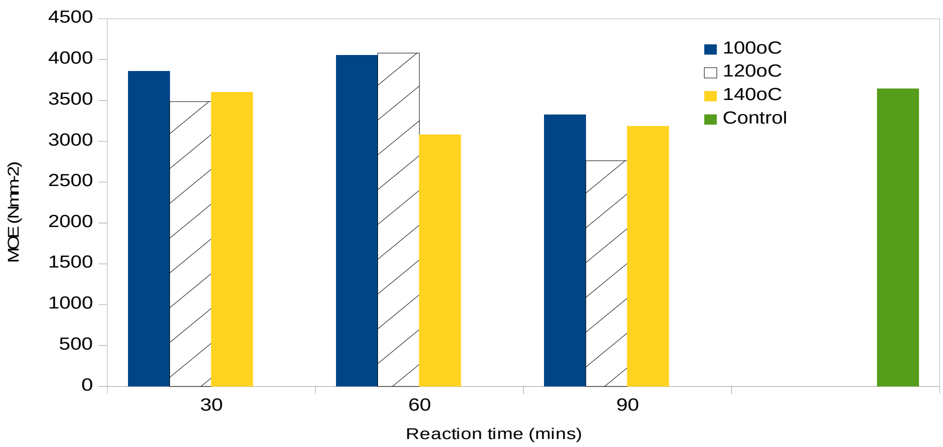

Figure 2: Influence of Reaction time on Modulus of Elasticity of acetylated Bamboo

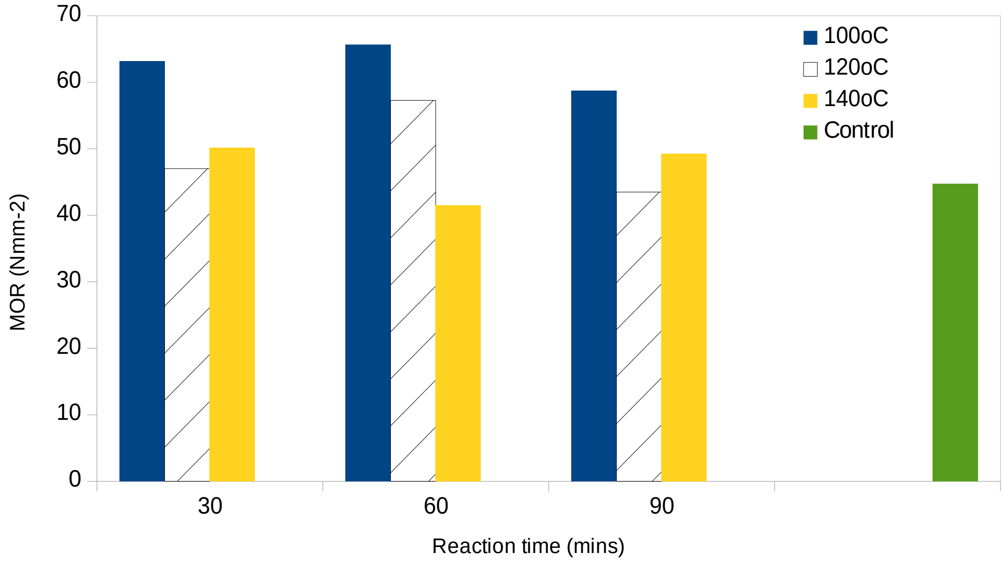

Figure 3: Influence of Reaction time on Modulus of Rupture of Acetylated Bamboo

Bond Shear Strength of Acetylated Bamboo Laminates

The result of the bondability of acetylated *Bambusa vulgaris* showed 120 ^{o}C to be the best acetylating temperature for bamboo to enhance its bondability with urea fomaldehyde resin (Table 4; Figures 1 & 2). At 120 ^{o}C, 49.74 Nmm^{-2} was recorded for the bond shear while the least 25.03 Nmm^{-2} was recorded at 140 ^{o}C. Similar to the result of the flexural MOE, the untreated samples had better bondability (30.55Nmm^{-2}) compared to the samples acetylated at 140 ^{o}C. Contrary to the result of flexural MOE and MOR, bond shear strength decreased drastically when acetylation proceeded from 30 to 60 minutes. No result was gotten for 90 minutes reaction time due to lost of samples. However, the unmodified samples had poor bondability (30.55 Nmm^{-2}) compared to the acetylated samples. The greatest improvement of 45.40 % in glue line shear strength was recorded for samples acetylated at 120^{o}C for 30 mins while a reduction of 3.21% in shear strength was recorded at 100^{o}C for 60 mins. These findings go contrary to the findings of Akitsu *et al.* (1993); Dreher *et al.* (1964); Larsson and Tillman (1989); Militz (1991) and Rowell (1991). They reported slight reduction in shear strength of wood laminates

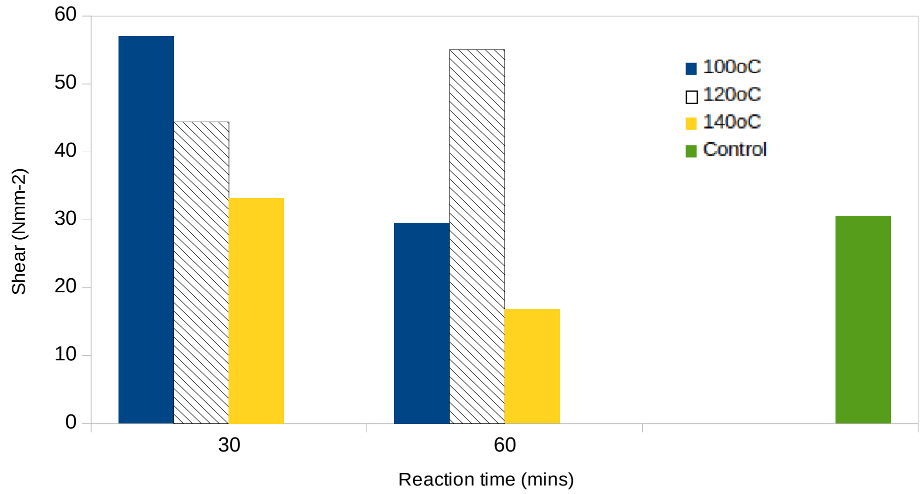

Figure 4: Influence of Reaction time on Modulus of Rupture of Acetylated Bamboo

Relationship of WPG and Flexural Properties of Acetylated *B. vulgaris*

Relationships of weight percentage gained (WPG) after acetylation and flexural properties of acetylated bamboo are shown in Figures a, b and c. The linear relationships of WPG and MOR, MOE and bond shear strength were 0.71, 0.96 and 0.51 respectively The relationships were best represented by linear regression models. The model explains 71%, 96 % and 51 % of the variation in the flexural properties and the bond shear strength respectively. The relationships were significant at p = 0.01. The regression results indicated that the MOE, MOR and bond shear strength of acetylated *B. vulgaris* depend on the weight gained upon acetylation of the bamboo samples.

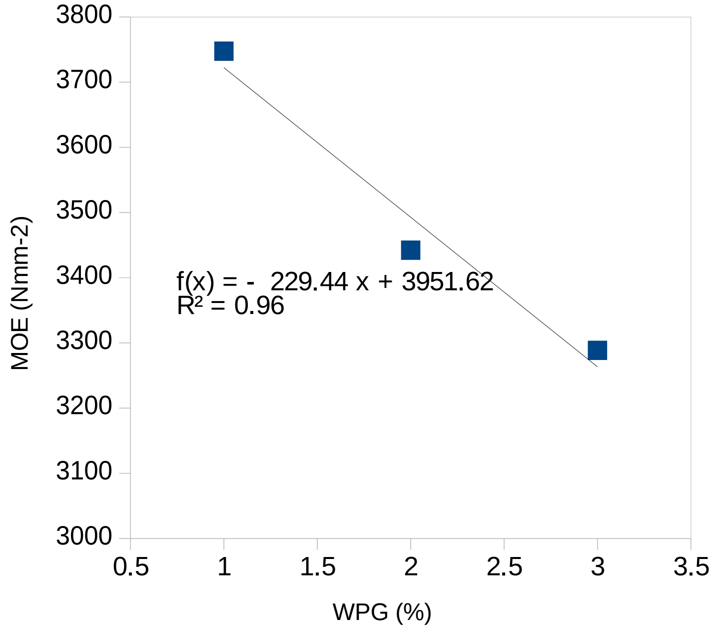

Figure 5a

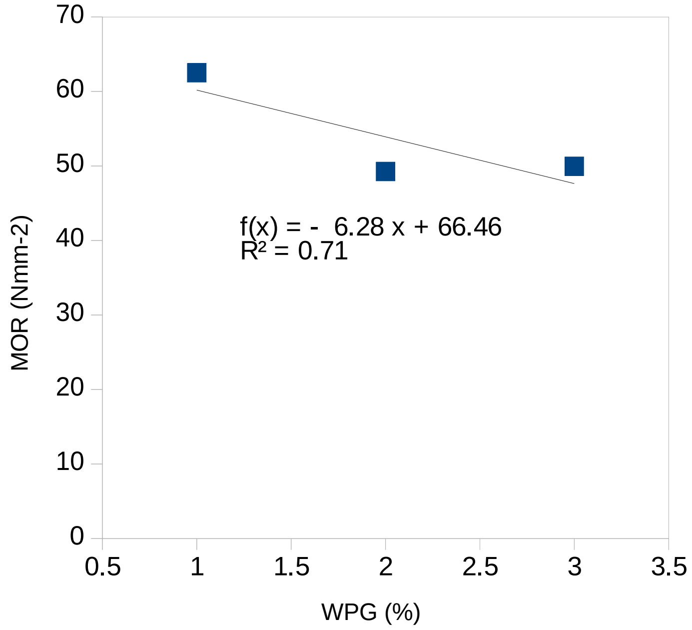

Figure 5b

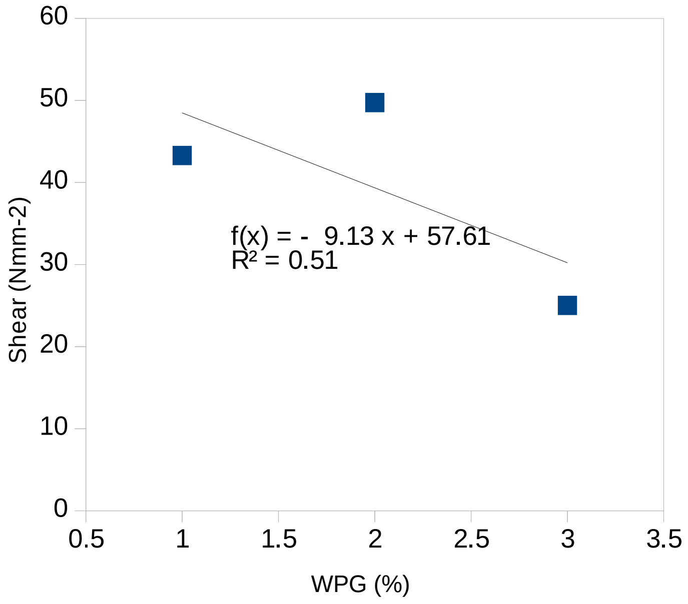

Figure 5c

Figures 5 a, b and c: Relationship of WPG with MOE, MOR and Bond Shear Strength of Acetylated *B. vulgaris* respectively

CONCLUSION

Generally, the WPG, flexural MOE and MOR as well as bond shear strength of the modified bamboo were statistically similar. The findings of this work showed that reaction time and temperature had no significant influence on the properties of modified Bamboo laminates. However, influence of reaction time showed that great improvement existed in the WPG of the samples when the reaction proceeded from 30 minutes to 1 hour. Acetylating at 100 ^{o}C produces bamboo laminates with the highest MOE (3747.49 Nmm^{-2}) and MOR (62.51 Nmm^{-2}). All the acetylated samples had improved flexural properties compared to the unmodified samples. However, losses of strengths were recorded at higher temperature and longer reaction time. 30 and 60 minutes were best for modifying bamboo for improved strength. 100 ^{o}C was shown to be the best acetylating temperature for bamboo to enhance its bondability with urea fomaldehyde resin. The regression results also showed that the MOE, MOR and bond shear strength of acetylated *Bambusa vulgaris* depend on the weight gained upon acetylation of the bamboo samples.

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