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(RESEARCH ARTICLE)

Bending strength enhancement of finger joints by inclusion of nanoclay in low concentrations into Urea formaldehyde adhesive

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Abstract

Results on the effects of using nanoclay as filler in Urea Formaldehyde (UF) adhesive to finger-joint short pieces of *Melia azedarach* wood are reported in this paper. Three relatively low (0.5%, 1% and 1.5%) concentrations of nanoclay containing metallic oxides were used in the study. The results are indicative of the fact that all three concentrations were able to effectively enhance the bending strengths by 22% to 58% compared to sections joined using UF with no added nano-filler. A nanoclay concentration of 1% of UF resin powder weight resulted in the highest bending strength of 50.3 N/mm^2. Comparing with the MoR of clearwood sections reported in literature, the efficiency could be enhanced from 51.7% up to a range of 63% to 81.8% by addition of nanoclay. The addition of nanoclay did not result in any significant changes in the MoE values of the finger jointed sections. The study demonstrates the value addition that can be brought to finger jointed sections of *M. azedarach* using nanoclay in low concentrations as filler in UF to enhance the bending strength of short pieces without compromising on the stiffness.

Keywords: Finger-joint; *Melia azedarach*; MoE; MoR; Nanoclay; Urea Formaldehyde

1. Introduction

The strength of the finger-joint is one of the reasons for its extensive use in timber joinery world-wide. Traditionally, these are considered as a series of scarf joints separated by low-strength butt joints [1]. This technique's success is due to the fact that end grain to end grain direct contact is reduced by using thin finger tips. The two wood pieces are ultimately in contact through the shorter contact vector [2]. The geometry of the finger profile plays an important role in deciding the strength of the joint since it decides the areas available for adhesive application [3]. Apart from the finger geometry, a suitable adhesive is the most important requirement for good joint strength. This led to a situation wherein most of the research works in finger joints were on the effectiveness of various adhesives for different wood species [4,5]. A large number of adhesives have been found to be successful with different tree species. Mango wood finger jointed with Urea Formaldehyde (UF) adhesive yielded 100% bending strength efficiency [1]. However, finger jointed sections of *M. azedarach* resulted in less than 50% efficiency in bending strength compared to its unjointed solid wood when a profile with thicker finger tips was used [6]. The performance of UF with Eucalyptus sections was equally unsatisfactory [7]. It thus became imperative that suitable adhesive combinations should be investigated for such hardwood species for obtaining strong finger joints.

Nano-fillers possess large surface areas and have high reactivity. This property has been utilised to enhance the physical and mechanical properties of wood composites and reducing emissions from such products [8]. Bardak *et al.* reported improvement in the bending and tension strengths of the mortise and tenon joints by adding TiO_2 and SiO_2 nano-fillers in to the Polyvinyl Acetate (PVAc) matrix [9]. Taking a cue from such studies, nanofiller addition to UF was tried successfully to enhance the bending strengths of short sections of *Melia azedarach* [10,11]

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Given this background, the present study tries to find out if nanoclay addition to UF resin in relatively low concentrations (0.5%, 1% and 1.5%) can enhance the bending strength of finger jointed sections of *Melia azedarach* which usually does not provide joints of very high strength with UF alone. The main utility of this hardwood species is as timber which is of medium density and ranges in colour from light brown to dark red. The utilization of this extends from manufacturing of boxes and crates, fixtures, furniture to plywood [12].

2. Material and methods

About 51 mm thick planks of *M. azedarach* which were kiln-seasoned to 10-12% moisture content were used to prepare samples for the study. Firstly sufficiently long sections for jointing purposes were cut from the planks so that the resulting jointed samples will be about 750 mm long. A total of thirty two finger jointed samples were prepared for the estimation of flexural properties. These 32 samples were divided into four groups containing eight samples each. The sample sizes were roughly 50 x 50 mm^2 in cross section. Fingers of 20 mm length, 5 mm pitch and 0.8 mm tip thickness were profiled on a commercial finger shaping machine. Urea Formaldehyde (UF) adhesive with 57.6% solid content was prepared using commercial STRONGBOND-P-101G as reported earlier [7].

The nano-filler used in the study was a commercial nanoclay containing metallic oxides {(0340399)[1332-58-7] Clay Nanopowder (Nano Clay) Part-C}. This nanoclay was mixed in required amount of distilled water in a beaker and gentle stirring by a glass rod was adopted to avoid any kind of lump formation. After this, the solution was sonicated using SKL 1200D ultrasonicator for 15 minutes using a 10 mm probe. The sonicated dispersion was added to the required amounts of UF resin powder slowly (with simultaneous stirring with a glass rod) such that the concentrations of the nanoclays were 0.5%, 1.0% and 1.5% of the dry UF resin powder without adding the hardener. These mixtures were homogenized using Dynaken WT 500 Homogenizer at 20000 rpm for 10 minutes or till no visible lumps could be detected. The required hardener [7] was mixed to the adhesives just before applying to the fingers.

The four sets of UF resins thus prepared (with three nanoclay concentrations, and without nanoclay) were applied to all profiled fingers using a brush and were joined and pressed at an end-pressure of 6 N/mm^2 on a pneumatic press. The samples were prepared such that the finger joints occupied their central positions. Subsequent to pressing, the samples were cured at room temperature for at least 48 hours. The four sets of samples thus prepared were designated as NC0 (UF without nanoclay), NC0.5 (UF with 0.5% nanoclay), NC1 (UF with 1% nanoclay) and NC1.5 (UF with 1.5% nanoclay). After curing, all the samples were given a light planing so that any adhesive ooze out could be removed.

The static bending measurements on the 32 finger-jointed samples were carried out on an automatic Universal testing machine as described elsewhere [7]. The span of the test was kept at 700 mm irrespective of the thickness of the samples. Since the maximum thickness of any sample was ~ 50 mm, a span of 14 times or more than the thickness was ensured. The load (P) and deflection (D) at the limit of proportionality were read from the load-deflection graphs on a spread sheet for each sample.

The flexural parameters Modulus of Rupture (MoR) and Modulus of Elasticity (MoE) were calculated for each sample using the following formulae:

$$MOR = \frac{3P'l}{2bh^2} \text{ N/mm}^2 \qquad (1)$$

$$MOE = \frac{Pl^3}{4Dbh^3} \text{ N/mm}^2 \qquad (2)$$

Where

P = Load at limit of proportionality (N)

P’ = Maximum load at which the sample/joint failed (N)

l = Span of sample (mm)

b = Breadth of sample (mm)

h = Height (thickness) of sample (mm)

D = Deflection at limit of proportionality (mm)

The set joined with UF alone (NC0) was used as controls for comparison purpose. Statistical analyses were carried out using SPSS package.

3. Results and discussion

All the thirty two finger jointed samples showed failure at the joint during the bending measurements. This suggests that that the strengths of the jointed sections are less than that of the clear woods of *M. azedarach* [13]. The bending strengths (MoR) of the eight samples which were joined with NC0 (UF without nanoclay) ranged between 27.3 N/mm^2 and 34 N/mm^2 with a mean of 31.8 ± 2.8 N/mm^2. The reported value of MoR of samples finger jointed with a similar profile and UF is 32.7 N/mm^2, 31.4 N/mm^2 and 31.2 N/mm^2 for this species [10,11,12].

The mean MoR values obtained for samples finger jointed with UF containing nanofiller were 41.2 ± 9.5 N/mm^2 (NC0.5), 50.3 ± 6.2 N/mm^2 (NC1) and 39.0 ± 6.4 N/mm^2 (NC1.5) respectively for 0.5%, 1% and 1.5% nanoclay concentrations. Thus an accountable increase in the MoR is indicated due to nanoclay addition in UF. The mean MoE of samples without nanoclay (NC0) was 6533 ± 1389 N/mm^2. The means of MoE values for nanoclay added samples were 6121 ± 746 N/mm^2 (NC0.5), 6322 ± 798 N/mm^2 (NC1) and 5798 ± 423 N/mm^2 (NC1.5). The MoE values thus, do not seem to result in appreciable increase due to nano addition. To understand the actual significance of the nano addition, all the 32 individual MoR and 32 MoE values were analysed through one-way ANOVA. The results of the analyses are summarized in table 1.

Table 1 ANOVA of MoR and MoE of finger jointed sections with and without nanofiller in the UF resin

Bending parameter	Source of variation	df	Mean Square	F	p
MoR	NC concentrations	3	465.8	10.467	<0.001
	Error	28	44.5		
MoE	NC Concentrations	3	782293	0.948	0.431
	Error	28	825399		

Table 1 clearly indicates that the MoE of the jointed sections do not show any significant differences for the four different adhesive preparations used ($p>0.05$). The values obtained are indeed similar to those reported in literature with UF. Singh et al. [14] reported a value of 6568 N/mm^2 for this species with UF adhesive but with another profile which had lesser number of fingers in the joint. An almost similar value of 6752 N/mm^2 was reported with UF but with a profile similar to the one used in the present study [12]. After nano clay addition in different concentrations, MoE values in the range of 5499 N/mm^2 to more than 9000 N/mm^2 have been reported [10,11]. In most of the studies, the MoE of finger jointed sections usually do not vary much from the values of even unjointed sections. In the case of *Eucalyptus benthamii*, similar MoE for PVA and polyurethane-based adhesives has been reported for finger jointed sections [15]. The elasticity usually is determined by the wood rather than the adhesive bond [16]. Finger jointed African hardwoods also did not exhibit any significant effect of glue type on the MoE in bending [17].

On the other hand, table 1 indicates significant differences in bending strength values of the jointed sections. Hence, the 32 MoR values were tested for Duncan's homogeneity and the results are given below in table 2.

Table 2 Duncan's subsets for MoR values of finger jointed samples

Nanoclay concentration	Number of samples	Subsets of MoR (N/mm2)		
		1	2	3
NC0	8	31.8		
NC1.5	8		39.0	
NC0.5	8		41.2	
NC1.0	8			50.3
Sig.		1.000	0.513	1.000

Table 2 clearly indicates a positive effect of adding nanoclay to the UF resin by enhancing the bending strength of the finger joints of this wood. However, the strengths due to 0.5% and 1.5% addition of nanoclay in the resin are similar to each other. A scan of the literature on effect of increasing concentrations of nano-fillers points to the fact that the positive effects usually disappear after an optimum concentration possibly due to agglomeration. For instance, no significant increase in dry shear resistance was reported when 1% and 1.5% montmorillonite nanoclay was added to UF resin in a study on the bond strength of *Carapa guianensis* [18]. However, there was an increase in percentage wood failure indicating the role of the nano-filler in causing better bonding. The shear strength of joints of *Acer saccharum* (sugar maple) and *Picea mariana* (black spruce) at dry state increased by 10% through addition of 1% nanoclay (montmorillonite) in PVAc [19]. They also reported no further improvement in the shear strength due to increase in nanoclay concentration. The changes in the pH and viscosity of adhesive due to nanoclay addition can affect the positive effects of nano-filler addition in UF [20]. Types of nanoparticles also affect the performance of nano-added resins. Bonding strength of oak improved by the addition of SiO_2 nanoparticles in UF whereas TiO_2 did not yield enhanced bond strength [21]. Better adhesion strength due to nano-addition in the resin is usually attributed to the good interactions between nano-fillers and polymer matrix of the resin [22,23].

It would now be interesting to assess the actual levels of improvements achieved in MoR through nanoclay addition in three concentrations in the UF resin. The MoR values of samples joined with nano-added UF are grouped in two subsets with 1% showing highest values in table 2. The actual percentage increases over the value obtained without nanoclay (UF alone) are shown in figure 1.

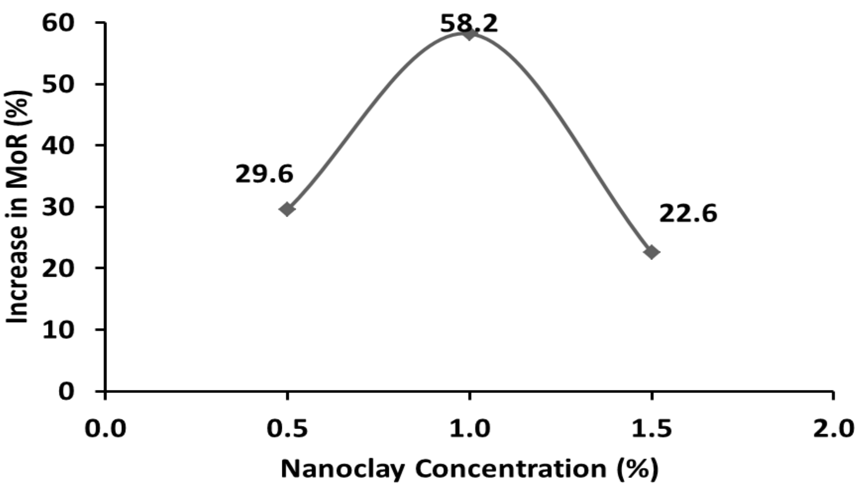

Figure 1 Percent increase in MoR of UF joined sections due to nanoclay addition

Figure 1 reveals a 22.6% to 29.6% increase in the MoR for NC1.5 and NC0.5 samples respectively over NC0 samples. Table 2 has grouped the actual MoR values corresponding to these two concentrations together. For NC1 samples, the increment is 58.2%. Addition of 2% nano SiO_2 in PVAc matrix resulted in improvements of maximum bending moment capacity in the range of 19.3% to 25.3% for mortise and tenon furniture joints of beach, oak and plywood sections [24]. Lap shear strengths of Scots pine and poplar wood also have shown improvements by addition of nanocellulose fiber in the matrix of PVAc [25]. However, the improvement shown by 1% in the present study is lesser than that reported in an earlier preliminary study [10]. Hence it is imperative that the investigations in this direction need to be substantiated further.

A value of 61.5 N/mm^2 for MoR was reported for clear wood sections of *M. azedarach* [6]. The value of 31.8 N/mm^2 obtained in the present study with UF alone works out to an efficiency for MoR of 51.7%. Looking at the MoR values obtained by adding nanoclay as a filler into UF (Table 2), this efficiency has enhanced to a range between 63.4% and 81.8%. This fact points to value addition to the technique of finger jointing through the use of nanoclay in the adhesive.

As discussed earlier (table 1), the MoE values did not show any significant differences between them. The reported value of MoE of clear wood of this species is 7776 N/mm^2 [6]. With the mean values of MoE obtained for finger jointed sections, the efficiencies works out to 84% for NC0, 78.7% for NC0.5, 81.3% for NC1 and 74.6% for NC1.5 respectively. These are high and acceptable levels reported for finger joints in general. High MoE retention by finger jointed sections of three African hardwoods has already been reported irrespective of the finger geometry and end pressure used to press the fingers [26]. They attributed the difference in the behaviour of MoR and MoE to the fact that MoR being a local phenomenon is more sensitive while stiffness being more global is less sensitive to joint properties. MoE efficiencies in the range of 114-129% were reported for mango wood with UF and PVAc adhesives with a different finger profile [1]. MoE of Beech wood samples finger jointed with 10 mm long fingers and glued with PVAc was found to be similar as that of clear samples [27]. Commercially available finger jointed wood of Burma teak (joined with unknown adhesive) was found to show 98.4% elasticity retention with respect to solid wood [5]. Thus, the lesser effect of adhesive on the elasticity of finger joints is well reported. More importantly, nano-addition, which caused better joint strength, has also retained the elasticity by more than 75% making it a useful technique for finger jointing.

4. Conclusion

The study demonstrates that addition of nanoclay in 0.5% to 1.5% concentrations improves the bending strength of finger jointed *Melia azedarach* sections substantially compared to sections joined with UF containing no nanoclay. Since finger joints use very small amounts of adhesive, nano addition at such low concentrations giving improvements is a proof of value addition. MoR values of sections joined with nanoclay addition could be enhanced by 22% to 58% compared those which were joined with UF which had no nanofiller in the resin. Overall, 1% nanoclay addition yielded the best improvement in MoR. The elasticity remained unaffected by the UF adhesive with or without nanoclay addition.

Compliance with ethical standards

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Disclosure of conflict of interest

There is no conflict of Interest among any parties in this research article.

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