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Exploratory studies on bending strength enhancement of finger jointed timber sections using high nanoclay concentrations in the adhesive

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Abstract
This paper tries to investigate the possibility of using nanoclay as a filler in Urea Formaldehyde (UF) adhesive to finger-joint short pieces of *Melia azedarach* wood. Three relatively high (4%, 5% and 6%) concentrations of nanoclay were attempted in the study. The study showed that all three concentrations were able to effectively enhance the bending strengths by 25% to 32% compared to sections joined only using UF. However, all the three concentrations resulted in similar strengths. Comparing with the bending strength of clearwood sections reported in literature, the MoR efficiency could be enhanced from 59% to 79.8% by addition of nanoclay. The addition of nanoclay did not contribute to any significant change in the MoE values. The study illustrates the advantage of using nanoclay as a filler in UF to enhance the bending strength of finger jointed sections of *M. azedarach* short pieces leading to value addition.

Keywords: Bending strength, finger-joint, *Melia azedarach*, MoE, nanoclay, urea formaldehyde

Introduction
Wood as a resource has innumerable benefits and utility. With advancement of scientific interventions and modern day technology, the issue of conservation of this resource has grasped all branches of science. One such branch that has gained access into wood utilization in recent times is nano-science. With the advent of nanotechnology, nanoparticles with a particle size of 1 to 100 nanometers have proven to enhance the properties of various lignocellulosic materials. Nanoclay is being used as tool of investigation for improving the quality of wood composites and reducing volatile emissions from such products (Ismita *et al*. 2018) [13]. Even though the structure of nanoclays and their nature is being explored for decades, their exact definition is an ongoing subject of debate (Fernandes *et al*. 2014; Uddin 2008) [7, 24]. The flexural properties of composites obtained from 5 phc (parts per hundred compounds) nano-magnesium oxide added resins were reported to increase significantly (Kiaei *et al.* 2017) [15]. Bardak *et al.* (2017) [2] could improve the bending and tension strengths of the mortise and tenon joints by adding TiO_2 and SiO_2 nano-fillers in to the PVAc matrix in 1% and 2% concentrations. Studies have shown use of nanoparticles to prepare fungal resistant coatings for wood that protect wood from fungal attack (Shukla *et al.* 2019) [22]. Strength of particle boards has been reported to increase by adding nanoclay in the resin (Ismita and Chavan 2017) [12].

Finger-jointing has proven to be one successful technique to effect savings in mills and workshops apart from value addition. In a finger-joint, finger tips are positioned in a straight line oriented vertically with respect to the edges of wood pieces. Thus the two pieces are in contact through the shorter contact vector (Habipi *et al.* 2015) [10]. These finger joints are well-bonded using adhesive polymers. Finger joints of mango wood joined with UF adhesive resulted in near 100% bending strength efficiency (Kishan Kumar *et al*., 2015) [16]. Finger jointed sections of *M. azedarach* exhibited more than 60% efficiency in bending strength compared to corresponding unjointed solid wood (Kumar *et al.*, 2017). *Melia azedarach* is of very high value and is found over a very wide range of habitats in Australia, including semiarid areas (Lowry *et al.* 1997) [19] This species has been widely cultivated as an ornamental and shade tree, as it is well adapted to warm climates,

poor soils, and seasonally dry conditions (Harrison *et al.* 2003) [11]. Studies on finger joints of wood sections of this tree have recently been reported (Singh *et al*., 2017; Kumar *et al*., 2017) [23].

Against this background, the present preliminary study investigates the effects of nanoclay added UF resin in relatively high concentrations (4% to 6%) on the flexural properties of finger jointed sections of *Melia azedarach.*

Materials and methods

Sample sections were cut from kiln-seasoned (10-12%) 51 mm thick planks of *M. azedarach*. Adequately long sections for jointing purposes were cut from the planks. Twenty eight samples were prepared for the bending measurements. These were divided into four sets of seven samples each. The sample sizes were roughly 50 x 50 mm^2 in cross section and 750 mm in length. A finger profile of 20 mm length, 5 mm pitch and 0.8 mm tip thickness was used to profile fingers on a commercial finger shaping machine. Urea Formaldehyde (UF) adhesive with 57.6% solid content was prepared as reported earlier (Kumar *et al*., 2017).

A commercial nanoclay containing metallic oxides {(0340399) [1332-58-7] Clay Nanopowder (Nano Clay) Part-C} was used in the study as nanofiller. This nanoclay, for different concentrations was mixed with distilled water in a beaker by gentle stirring using a glass rod to break any kind of lumps formed. After 10 minutes of stirring, the solution was placed in a Loba-Life (3.5 l) Ultrasonic Water Bath. The sonicated solution was added to UF resin powder in water such that the concentrations of the nanoclays were 4%, 5% and 6% of the dry UF resin powder.

The four adhesives thus prepared (with no nanoclay content, and with nanoclay in three concentrations) were applied to all profiled fingers using a brush. Each set had seven replications. These sets were designated as NC0 (UF without nanoclay), NC4 (UF with 4% nanoclay), NC5 (UF with 5% nanoclay) and NC6 (UF with 6% nanoclay). The finger profiled sections were joined and pressed at an end-pressure of 6 N/mm^2 on a pneumatic press. The samples were made in such a way that the joints occupied their central position and these were cured at room temperature for at least 48 hours. Prior to the bending measurements, the samples were planed lightly to remove any adhesive ooze out.

The static bending measurements on the 28 finger-jointed samples were carried out on a Universal testing machine as described elsewhere (Kumar *et al*., 2017). A span of 700 mm was adopted for the bending tests. From the load-deflection graphs on a spread sheet, the load (P) and deflection (D) at the limit of proportionality were recorded.

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

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

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

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 (without nanoclay) was used as controls for comparison purpose. Statistical analyses were carried out using SPSS software.

Results and Discussion

All the twenty eight finger jointed samples failed at the joint during the bending measurements suggesting that that the strengths of the jointed sections are less than that of the clear woods of *M. azedarach* (Lara-Bocanegra *et al*. 2017) [18]. The bending strengths (MoR) of the seven samples of *M. azedarach* in this study which were joined with UF alone (NC0) ranged from 22.3 N/mm^2 to 40.2 N/mm^2 with a mean of 31.2 ± 7.1 N/mm^2. This value is very close to the reported value of 27.9 N/mm^2 for finger jointed samples of this wood species (Singh *et al*., 2017) [23].

The MoR values obtained for samples finger jointed with UF containing nanofiller samples yielded bending strength values of 39.5 ± 6.4 N/mm^2 (NC4), 42 ± 7.2 N/mm^2 (NC5) and 41.8 ± 5.6 N/mm^2 (NC6) for 4%, 5% and 6% nanoclay concentrations respectively. Thus an increase in the MoR is indicated for the nanoclay added jointed sections. The mean MoE of samples without nanoclay (NC0) was 5499 ± 901 N/mm^2. The means of MoE values for nanoclay added sections were 6652 ± 637 N/mm^2 (NC4), 6310 ± 1535 N/mm^2 (NC5) and 5935 ± 410 N/mm^2 (NC5). The MoE values thus, do not seem to exhibit any pattern.

The 28 values each of MoR and MoE were analyzed through one-way ANOVA to look for any differences. The results of the analyses are shown in table 1.

Table 1: ANOVA of flexural parameters 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	183.1	4.190	0.016
	Error	24	43.7		
MoE	NC Concentrations	3	1706144	1.824	0.170
	Error	24	935329		

Table 1 reveals that the bending strength values do show significant differences with concentrations of nanoclay in the resin used to join the sections. Hence, Duncan's homogeneity test was performed on the 28 MoR values 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
NC0	7	31.2	
NC4	7		39.5
NC6	7		41.8
NC5	7		42.0
Sig.		1.000	0.504

Table 2 clearly indicates the effect of adding nanoclay to the UF resin in enhancing the bending strength of the finger joints of this wood. However, interestingly, there is no effect of increasing the nanoclay concentration at these levels. The strengths due to 4-6% addition of nanoclay in the resin are similar to each other. Moya *et al.* (2015) [21] reported that there is no significant increase in dry shear resistance when 1% and 1.5% nanoclay (montmorillonite) was added to UF resin when studying the bond strength of *Carapa guianensis.* However, there was an increase in percentage wood failure suggesting better bonding. In another study, the shear strength of joints of sugar maple (*Acer saccharum*) and black spruce (*Picea mariana*) at dry state increased by addition of 1% nanoclay (montmorillonite) in PVAc by 10% (Kaboorani and Riedl, 2011) [14]. However, further increase in nanoclay concentration did not improve the shear strength. Improvement in the bonding strength of oak has been reported by the addition of SiO_2 nanoparticles in UF whereas TiO_2 failed to give enhanced strength (Bardak *et al.*, 2018) [3]. Thus arriving at an appropriate nanofiller and an optimum concentration of the same is still an ongoing effort. Improvements in the adhesion strength are usually attributed to the good interactions between nano-fillers and polymer matrix of the resin (Zhai *et al.* 2008, Bardak *et al.* 2016) [26, 4].

It would be interesting to look at the actual levels of enhancements achieved in MoR through nanoclay addition. Though the MoR values of nano-filled samples are grouped together in table 2, the actual increases over the value obtained with UF alone are shown in figure 1.

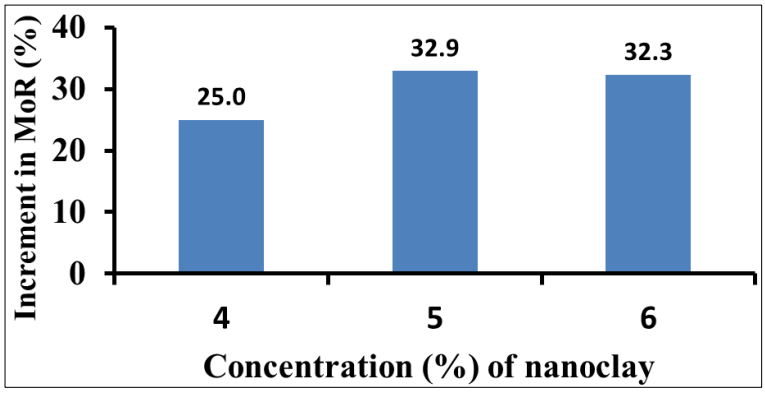
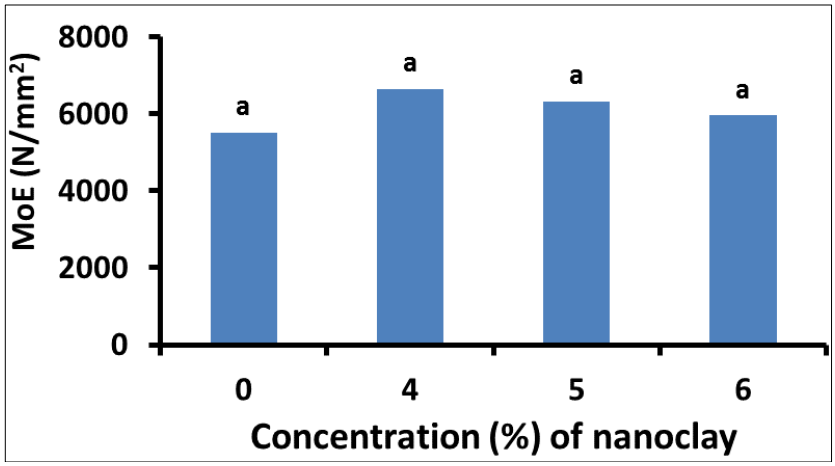


Fig 1: Percent increase in bending strengths of UF joined sections due to nanoclay addition

Figure 1 reveals a 25% increase in the MoR of NC4 samples over NC0 samples. For NC5 and NC6 samples, these increments are around 32%. A report on the improvements in maximum bending moment capacity due to addition of 2% nano SiO_2 in PVAc matrix were in the range of 19.3% to 25.3% for mortise and tenon furniture joints of beach, oak and plywood sections (Bardak *et al*., 2017) [2].

The reported MoR value of *M. azedarach* with no joints (clear wood) is 52.6 N/mm² (Kumar *et al*., 2017). With the value of 31.2 N/mm² obtained in the present study with UF alone, the MoR efficiency works out to 59.3%. It is pertinent to note that by adding nanoclay as a filler into UF, this efficiency enhanced to a range of 75.1-79.8%. This fact points to value addition to the technique of finger jointing.

Table 1 indicates that there is no significant differences between the MoE values of all the four sets (p=0.17). The MoE values against different nanoclay concentrations are shown in figure 2.



Note: The alphabets on the bars show the levels of significance

Fig 2: MoE of finger jointed sections against nanoclay concentrations

From fig. 2, it is evident that the MoE values of all sets are around 6000 N/mm^2 and slight increase in the nanoclay added specimens are found insignificant from table 1. High MoE retention by finger jointed sections of three African hardwoods were reported (Ayarkawa *et al.* 2000) [1]. They attributed this to the fact that bending strength being a local phenomenon is more sensitive while stiffness being more global is less sensitive to joint properties. The elastic properties are reported to be more a property of the wood rather than the adhesive bond (Frihart, 2005) [8]. In many 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 two different (PVAc and polyurethane-based) adhesives has been reported for finger jointed sections (Martins *et al.*, 2013) [20]. Very high MoE efficiencies in the range of 114-129% were reported for mango wood with UF and PVAc adhesives with a different finger profile (Kishan Kumar *et al.* 2015) [16]. MoE of finger jointed samples of Beech wood joined using 10 mm long fingers and PVAc was found to be unaffected compared to clear samples (Vassiliou *et al.* 2007) [25]. In an interesting study on commercially available finger jointed wood of Burma teak (adhesive unknown), it was found that the elasticity retention was about 98.4% with respect to solid wood (Danawade *et al*. 2014) [5]. These results illustrate the lesser influence of adhesive on the elasticity of finger joints.

Conclusions

The study illustrates that addition of nanoclay in 4% to 6% concentrations can improve the bending strength of finger jointed *Melia azedarach* sections substantially. Given the fact that finger joints use very small amounts of adhesive, this is a clear indication of value addition of such sections. MoR values in the levels of 31 N/mm^2 without nanofiller addition could be brought up to the range of 39 N/mm^2 to 42 N/mm^2 by addition of nanoclay in the Urea Formaldehyde adhesive in these concentrations. One important observation is that at these levels of nanoclay loading, no concentration effect could be found. The elasticity, as is usual with finger joints, remained unaffected by the adhesive with or without nanoclay addition.

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