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Effect of adding Urea Formaldehyde in Polyvinyl acetate on the bending properties of Finger jointed Wood sections

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ABSTRACT
Effect of adding urea formaldehyde in polyvinyl acetate on the bending properties of finger jointed sections of Eucalyptus hybrid when joined with such a glue mixture is reported. It is observed that as the UF content in the mixture increases from 20 % to 80 %, the MOR values of the jointed sections significantly increase from 17.4 N/mm² to 45.5 N/mm². At 80 % proportion of UF in the mixture, the MOR value actually approached that obtained with PVA alone. The MOE values did not vary significantly. Overall, it is found that UF is a better adhesive to finger joint Eucalyptus sections.
Key words: Bending strength, Finger joint, Poly Vinyl Acetate, Stiffness, Urea Formaldehyde

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INTRODUCTION

In finger jointing of wooden pieces, the finger profile parameters and the adhesive used are two major parameters which play important roles in deciding the strength of the joint. Enough of works have been reported on both aspects. The efficiency of a joint also depends on the wood species that is being used. The bonding properties of cell components in wood influence the bonding method, the geometric shape and size of pieces and also the conditions to which the joined pieces will be exposed while in use [15]. Albino *et al.* [1] found that the bond strength had a strong dependence on the position of the stem from where *Eucalyptus grandis* samples were prepared. Bustos *et al.* [6] reported that the finger-joint of high flexural and tensile performance can be produced by using an Isocyanate type of adhesive. Obucina *et al.* [16] showed through their studies that an excessive increase in the quantity of adhesive in the adhesive film results in reduction of the glued joint's strength. One of the most common adhesive used by wooden industries is the Poly Vinyl Acetate (PVA). However, this adhesive has been shown to be inferior to Urea Formaldehyde (UF) in the case of Eucalyptus [13]. There have been reports of this adhesive's better performance as a wood adhesive by adding Melamine Formaldehyde (MF) and Melamine Urea Formaldehyde (MUF) [11]. Qiao *et al.* [18] have also reported on the improved water resistance of PVA by blending it with MUF. Against this background a study was conducted to investigate the effect of adding UF to PVA on the strength of finger joints made from Eucalyptus.

MATERIAL AND METHODS

Sample sections of *Eucalyptus* hybrid were cut from kiln-seasoned (upto 10-12 %) planks using a circular saw. The sections were selected from visually inspected defect free portions. Approximately 51 mm thick planks were used for making the samples. The number of

samples in each set ranged from nine to fifteen. The sample sizes were kept as of roughly 50 x 50 mm^2 cross section with 750 mm length.
A commercial finger shaping machine fitted with a cutter set yielding fingers of 20 mm length, 5 mm pitch and 1 mm tip thickness was used in the study. For joining the fingers, a commercial Urea Formaldehyde (UF) resin and Poly Vinyl Acetate (PVA) adhesives were used. The UF adhesive was prepared from the UF resin powder by mixing it with 2% of ammonium chloride (NH_4Cl) hardener and making an aqueous solution with 57.6 % solid content. Apart from using these two adhesives individually, mixtures of these two adhesives were also prepared in four ratios of PVA:UF (80:20, 60:40, 40:60 and 20:80) to investigate the effect of mixing UF in PVA. The adhesives were applied to all fingers using a brush after shaping the fingers. Subsequent to adhesive application, the sections on which fingers were profiled were mated 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. The jointed samples were cured at room temperature for at least 48 hours. Prior to the bending measurements, the samples were given a light planning to remove any surplus adhesive.
The static bending measurements on the jointed samples were carried out on a Universal testing machine following the broad directions laid down in Indian standards (IS-1708) [5]. Central loading was adopted to make the bending measurements. The loading was done in a horizontal mode to the jointed specimens with fingers being parallel to the face on which the load was applied. The span of the test was kept at 700 mm. The load was applied continuously such that the movable head moved at 2.5 mm per minute and deflections were noted against applied loads until the joint failed. From the load-deflection graphs on a spread sheet, the load and deflection 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:

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

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

Where
P = Load at limit of proportionality (N)
P' = Maximum load at which the 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)
All statistical analyses were performed using SPSS statistical package.

RESULTS SAND DISCUSSION
The bending parameters (MOR and MOE) of finger jointed sections of Eucalyptus obtained with the adhesive combinations used are given in table 1. The corresponding efficiencies calculated with respect to the values obtained with 100 % PVA adhesive also are presented in the table

Table 1: Bending parameters of Eucalyptus finger jointed sections with different ratios of UF mixed in PVA

PVA:UF ratio	MOR (N/mm²)	MOR Efficiency*	MOE (N/mm²)	MOE Efficiency*
100:0	45.7 (5.3)		10211 (1758)	
80:20	17.4 (4.4)	38.1	9327 (3026)	91.3
60:40	27.3 (6.5)	59.7	9672 (1601)	94.7
40:60	39.9 (7.2)	87.3	9747 (616)	95.5
20:80	45.5 (7.2)	99.6	11155 (3463)	109.2
0:100	53.3 (5.5)	116.6	11508 (1211)	112.7

*Efficiencies are calculated with respect to values obtained with PVA alone

One can observe from the above table that the MOR values progressively increase by adding increasing amounts of UF to the adhesive combination. However, by using PVA alone, the bending strength is not far different from that obtained with highest concentration of UF (PVA:UF = 20:80) in the mixture. On the whole UF gives better MOR values as against the PVA. This is consistent with a previous report on Eucalyptus sections when joined with a profile having shorter fingers than the one used in the present study wherein just 30.2 N/mm^2 was reported with UF and only 20.5 N/mm^2 was reported with PVA [12]. The effect of finger profiles on the strength was illustrated in that study which is again proven in this study where a different profile has yielded better strength values with both the adhesives. It is already well reported that usually longer fingers yield better bending strengths. Ayarkawa *et al.* [2] used two profiles with similar pitches and tip thicknesses but with different finger lengths. They found that the longer fingers consistently resulted in higher bending strengths irrespective of the different end pressures they used for joining. The increase in finger-joint strength with increasing finger length is a common result reported [17, 8].
The efficiencies illustrate the effect of adding UF to the mixture on the bending strength. This is illustrated in fig. 1.

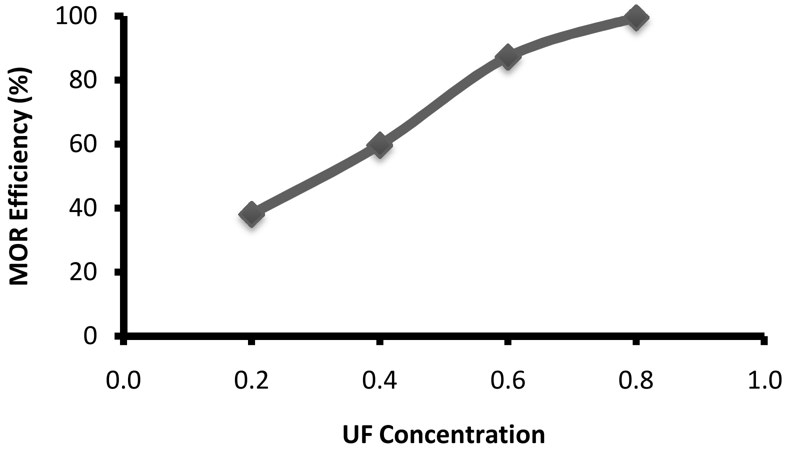

Fig. 1: Effect of concentration UF in the mixture on the bending strength efficiency

The MOE values too seem to show an increasing trend with increasing UF concentrations. The values are range from 9327 N/mm^2 for 20 % UF in the mixture to 11155 N/mm^2 with 80 % UF in the mixture. However, a look at the efficiencies of the MOE of the joints reveals that all values are above 90 %. High and sometimes better MOE by finger jointed sections of *Eucalyptus* with UF adhesive with a different finger profile [19]. The MOE efficiencies are illustrated in fig. 2.

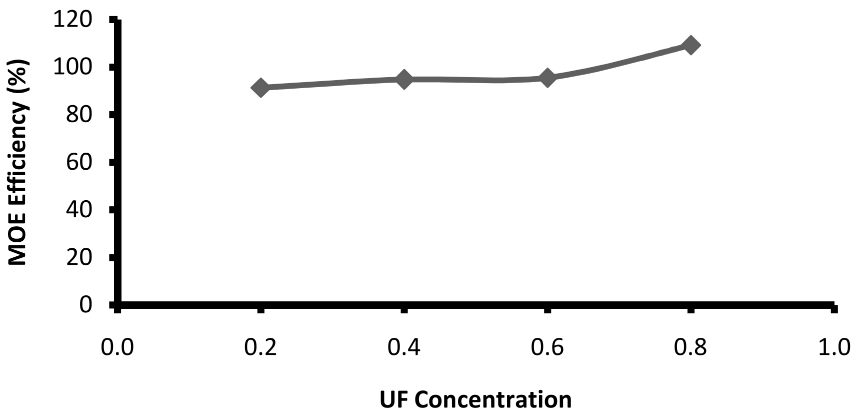

Fig. 2: Effect of concentration UF in the mixture on the MOE efficiency

Fig. 2 illustrates that though there is an increase in the MOE efficiencies with increasing UF concentration in the mixture, in general all the joints have retained high efficiency values. Ayarkawa *et al.* [2] reported high MOE for finger jointed African hardwoods.

The individual strength and MOE values obtained for the 69 samples used in the study (39 joined with the mixture of the adhesives and 15 each with either adhesive alone) were analysed to clearly understand the variations using One Way ANOVA. The results are presented in table 2.

Table 2: ANOVA of MOR and MOE of finger jointed samples

Source of variation	Parameter	df	Mean Square	F	p
Adhesive		5	2021.5	56.78	<0.001
Error	MOR	63	35.6		
Total		68			
Adhesive		5	8983384	2.11	
Error	MOE	63	4264743		0.076
Total		68			

Table 2 shows that the MOE values do not differ significantly for all the jointed sets of samples. From table 1 we have already seen that the actual MOE values range from 9327 N/mm^2 for 20 % UF in the mixture to 11508 N/mm^2.

Very high MOE efficiencies have been reported for finger joints glued with different adhesives for many wood species in literature. The elastic properties are reported to be more a property of the wood rather than the adhesive bond [7]. The scarf portions of the joint help in minimising wood material discontinuities. This is expected to help the mechanical properties of the jointed sections to be not dependent on the adhesive used to very great extents. In the case of *Eucalyptus benthamii* also, similar MOE for two different (PVA and polyurethane-based) adhesives has been reported for finger jointed sections. In mango wood, higher MOE value was reported with UF adhesive and one of the profiles (F1) used in the study than that of clear wood specimens [14]. The good retention of MOE of finger jointed African hardwood sections using resorcinol-formaldehyde adhesive up to about 83-98 % of the individual clear sections depending on the wood density and with a finger length of 18 mm also has been reported [2]. They attributed this to the fact that stiffness being a more global phenomenon is not very sensitive to joint properties. Ayarkwa *et al.* [3] reported no significant effect of glue type on the modulus of elasticity in both bending and tension in African hardwoods. Even different finger profiles could not affect the MOE of *Populus alba* and *Abies alba* when finger jointed with PVA [10]. Very high MOE efficiencies in the range of 114-129 % were reported for mango wood with the same adhesives but with a very different finger profile [14]. MOE of finger jointed samples of Beechwood joined using 10 mm long fingers and PVA was found to be unaffected compared to even unjointed samples [20].

Table 2 however, very clearly shows that the MOR (bending strength) values do differ significantly for the samples that were joined with different adhesives/adhesive combinations. This is quite clear from the efficiencies of MOR of the samples that were joined with different UF concentration in the mixture (fig. 1).

To understand the individual behaviour, all the 69 MOR values were subjected to Duncan's homogeneity test which grouped the values into five subsets. These are given in table 3.

Table 3: Duncan's subsets for the MOR values

PVA:UF ratio	**Number of samples**	**MOR (N/mm^2) Subsets**				
		1	**2**	**3**	**4**	**5**
80:20	10	17.4				
60:40	10		27.3			
40:60	10			39.9		
20:80	9				45.5	
100:0	15				45.7	
0:100	15					53.3
Sig.		1.000	1.000	1.000	0.923	1.000

One can see that as the UF proportion in the mixture increases, the MOR values increase and approach the value provided by PVA alone. However, UF gives the maximum MOR. Follrich *et al.* [7] have explained that glues like UF are capable of diffusing into the cell walls where their curing leads to an increased hardness of the cell wall resulting in higher joint strength. On the other hand, adhesives like PVA can only penetrate into the lumens but not into the cell walls. Thus with high proportions of PVA, the contribution in the adhesion due to presence of the glue becomes minimal. With a heavy contribution of UF in the mixture (PVA:UF = 20:80), the joint is just able to match the strength of un-mixed PVA. With a reduction of UF in the mixture, the adhesive is probably not diffusing into the cell walls. In addition, different Eucalyptus spp. were shown to have 2-3 µm fibre wall thickness compared to 8-14 µm lumen diameter [4].

CONCLUSIONS

It is observed that as the UF content in the mixture increases from 20 % to 80 %, the MOR values of the jointed sections significantly increase from 17.4 N/mm^2 to 45.5 N/mm^2. At 80 % proportion of UF in the mixture, the MOR value actually approached that obtained with PVA alone. However, sstrengthening PVA by mixing the adhesive with a stronger resin like UF seems to be not possible with finger joints. UF is a much better glue for finger jointing of Eucalyptus. Though the bending strength gets reduced by PVA, the stiffness of the joint remains unaffected either adhesive or its mixture is used to finger-joint Eucalyptus.

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