



## Role of different gluing areas in deciding the bending strength of finger jointed timber

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### Abstract

A study was undertaken to investigate the role of different gluing areas on the bending strength properties of wooden finger joint. Three different profiles were used in the study. It was found that the profile with the largest total tip area resulted in lowest bending strength in spite of its good finger length. The profile with shortest finger resulted in better bending strength due to its total lower tip area. It was concluded that, to get improved strength properties, the total area contributed by the finger tips involved in the finger-joint requires reduction. It was inferred that the classical approach of considering parameters of single finger needs reconsideration.

**Keywords:** Finger joint, finger profile, static bending, tip area, urea formaldehyde.

### Introduction

Any wooden section's strength requirements depend on the end-use it is being prepared for. Utilizing short sections of pieces of waste wood through the technique of finger-jointing can lead to wood's economic utilization thus reducing mill waste. The finger parameters deciding the strength of a finger joint are finger length (L), finger tip thickness (t), finger slope (S) and pitch (P). Traditionally, evaluation of strength of wooden finger joints has been mainly on temperate species<sup>1,2</sup>. Limited reports on hardwoods only are available in literature. Ayarkawa et al. reported how the finger geometry affects the strength of finger joints made using three African hardwoods<sup>3</sup>. Most works available in literature are on the determination of tensile and bending strengths of sections of different wood species joined through finger-jointing<sup>4,6</sup>. There is a report on the structural performance with different finger configurations<sup>7</sup>.

As a general notion, strength of any adhesive joint is supposed to increase with increasing the gluing area when the adhesive used and curing conditions remain the same. Finger joints consist of sloping areas and areas of the tips of individual fingers. Hence it would be interesting to look at the role of total glue joint area, the sloping area in the joint and the tip area in the joint separately. Though effect of finger geometries (t, P, Land S) have been studied by many authors<sup>8-10,1</sup> to correlate their roles with the joint strength, the role of areas is only scarcely reported<sup>11</sup>. A report on the possibility of reducing the tip area to enhance the compression strength of finger joints of Eucalyptus is worth mentioning<sup>12</sup>.

With this background, an effort was made to understand the differences in the various areas involved in a finger-joint and their possible effect on the flexural parameters with three

different finger-shaping profiles on Eucalyptus hybrid wood. For jointing purpose, the usually reliable Urea Formaldehyde (UF) adhesive was used. As far as its strength, toughness and weight are concerned, Eucalyptus is classified as a moderate timber<sup>13</sup>. It has comparable working quality index as teak<sup>14</sup> and it is used for packing cases, furniture, dunnage pallets, crates, doors etc. It is pertinent to note that usefulness of finger jointing technique in Eucalyptus hybrid with polyurethane based glue has already been demonstrated where more than 47 % efficiency in the tensile strength of jointed samples was reported<sup>15</sup>.

### Materials and methods

Sections of *Eucalyptus* hybrid were cut from seasoned (up to 10-12%) planks. Sections with adequately length were cut for profiling fingers. Defect free sections were selected from visual inspection. Planks of nearly 60 mm thickness were used for preparing the samples. 750 mm long samples with nearly 50 x 50mm<sup>2</sup> cross section were prepared.

Three sets of finger profiling cutters designated as F1, F2 and F3 were used in the study. These were mounted on a finger shaping machine to shape fingers of three different finger-parameters. Urea Formaldehyde resin in powder form was mixed with 2% ammonium chloride (NH<sub>4</sub>Cl) as hardener to prepare the adhesive to join the fingers. The aqueous solution thus prepared had a solid content of 57.6 %. A brush was used to spread the adhesive on all fingers. Subsequent to application of the adhesive, a pneumatic pressing vice was used to mate the profiled fingers at an end-pressure of 6 N/mm<sup>2</sup>. It was made sure that the finger-joints occupied the central position of each jointed sample. Such jointed samples were allowed to cure for 48 hours at room temperature. Any adhesive ooze out on any such jointed sample was removed by giving a light planing to the

sample. 15 samples each were made with the three profiles. However, during joining on the pressing vice, two samples were damaged and hence only 14 samples each were available for profiles F1 and F3.

The individual tip area of a finger (with tip thickness  $t$ ) on a sample of width  $SW$  is calculated as,

$$T = SW * t \tag{1}$$

For a finger of Length ( $L$ ) and Pitch ( $P$ ), the slope ( $S$ ) is given by

$$S = \frac{(P - 2t)}{2L} \tag{2}$$

Then the joint area which is on the side of a finger is

$$A_{js} = SW * \sqrt{L^2 + L^2 S^2} \tag{3}$$

Only one of the two sloping sides of a particular finger is considered to calculate this. The second such side of that finger is naturally justified by the finger on the other section which mates with it. The area of the tip ( $T$ ) and the area of the sloping side ( $A_{js}$ ) which take part in the gluing process and the other parameters of any particular finger profile are shown in Figure-1.

Thus, the total glued joint area ( $A_j$ ) is the total of area of sloping side ( $A_{js}$ ) and the area of the tip ( $T$ ).

$$A_j = T + A_{js} \tag{4}$$

The finger parameters ( $L$ ,  $P$  and  $t$ ) of the three profiles were measured on random fingers of the samples made with each profile before applying the glue.

The static bending (SB) measurements on the clear and jointed samples were carried out on a Universal testing machine following Indian Standards<sup>16</sup>. The span of the test was kept at 700mm. The load was applied continuously throughout the test such that the movable head of the testing machine moved at 2.5 mm per minute. The loads and corresponding deflections were noted until the joint failed. The load and deflection at limit of proportionality were noted from the load-deflection graphs using standard procedure<sup>11</sup>.

The Moduli of Rupture (MOR) and Elasticity (MOE) were estimated as:

$$MOR = \frac{3P'L}{2bh^2} \text{ N/mm}^2 \tag{5}$$

$$MOE = \frac{PL^3}{4Dbh^3} \text{ N/mm}^2 \tag{6}$$

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 and discussion

The mean values of finger parameters measured on fingers of the profiled sections before applying the adhesive are given in Table-1.

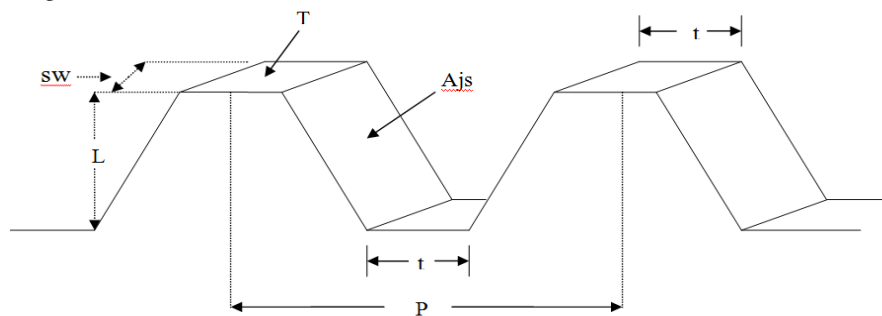


Figure-1: Areas and finger parameters.

Table-1: Parameters of the three finger profiles used.

Profile	No of fingers	Length (L) mm	No of fingers	Pitch (P) mm	No of fingers	Tip thickness (t) mm	Slope (S)
F1	200	19.18(0.07)	75	6.65(0.15)	200	1.5 (0.04)	0.1
F2	200	19.83(0.08)	75	4.8(0.1)	200	0.83(0.02)	0.08
F3	200	13.25(0.12)	75	3.91(0.05)	200	0.64(0.03)	0.1

Note: values in the parenthesis give the Standard Deviations.

Table-1 shows that the three finger profiles F1, F2 and F3 have different geometries. It can be clearly seen that profiles F1 and F2 have almost similar lengths whereas profile F3 has shorter length. In the case of pitch and tip thickness, all three profiles are different which is generally dependent on cutter thickness. These random values which were taken from profiled samples were analyzed to check for their similarity/ dissimilarity in the mean values. The analysis showed that each of the three finger parameters are indeed significantly different for each of the three profiles ( $p < 0.001$ ). The Duncan's homogeneity test showed that the finger lengths followed a pattern of  $F2 > F1 > F3$ . Interestingly, the pitch and tip thickness followed a pattern of  $F1 > F2 > F3$ . The tip thickness of F1 is more than 2 times that of F3. Moreover, the two profiles F1 and F3 have similar slopes while F2 has fewer slopes (calculated with Eqn. 2). This situation would lead to different areas at the finger tips (Tip area T) and sloping area (SA) resulting in different total gluing areas for the fingers of each profile. A look at the different values of pitch ranging from 3.91mm to 6.65mm suggest that for a given cross section, the number of fingers that would involve in completing the joint would also be different (higher the pitch, lower the number of fingers). When the numbers of fingers involved in the joint is also taken into account, the gluing areas need to be calculated separately for each profile.

For this, the exact number of finger tips and sloping surfaces involved in the prepared samples (approximately 50 mm x 50 mm cross section) were estimated on random samples. The results are given in Table-2.

Table-2 illustrates the role of pitch in contributing to the glue joints in a standard sample of 50X50 mm<sup>2</sup> cross section. On a first look, it might seem that since F3 provides nearly double the

number of finger tips than F1, the fingertip areas (T) involved in a joint would always be higher for F3. However, let us actually calculate these for a standard sample width of 50 mm using the formula given in the previous section (Equation-1). The total tip areas in these cases would be:

For F1  $13 \times 50 \times 1.5 = 975 \text{mm}^2$   
 For F3  $25 \times 50 \times 0.64 = 800 \text{mm}^2$

**Table-2:** Numbers of fingertip joints and sloping joints involved in a finger joint of samples.

Profile	Number of fingertip joints	Number of sloping joints
F1	13	14
F2	19	20
F3	25	26

We see that in spite of having only 13 finger tips in the joint, F1 still involves more tip area in a joint than F3 due to its very high tip thickness. (The tip joints are considered limiting factors since they contribute to weaker butt portions). This illustrates that it is essential that one calculates the actual areas involved in a joint to find out the effect of areas on the joint strength.

Considering this background, the behavior of the various areas in a joint for the three profiles was analyzed for the fingers profiled for static bending studies.

The results obtained on various areas and static bending parameters obtained with the three finger profiles for the 43 samples used in the study are given in Table-3.

**Table-3:** Various areas and SB parameters of samples joined with UF adhesive using the three profiles.

Profile		Sample width SW (mm)	Area of Finger Tips T (mm <sup>2</sup> )	Finger Sloping areas A <sub>js</sub> (mm <sup>2</sup> )	Total area A <sub>j</sub> (mm <sup>2</sup> )	MOR (N/mm <sup>2</sup> )	MOE (N/mm <sup>2</sup> )
F1(14)	Mean	51.51	1004.43	13900.26	14904.69	39	10241
	SD	0.57	11.18	154.79	165.97	4.5	2391
	CV (%)	1.11	1.11	1.11	1.11	11.5	23.3
F2(15)	Mean	51.23	807.96	20384.32	21192.28	56	11731
	SD	0.41	6.43	162.22	168.65	7.08	1203.24
	CV (%)	0.80	0.80	0.80	0.80	12.6	10.2
F3(14)	Mean	51.69	826.96	17894.29	18721.25	59	12348
	SD	0.44	6.99	151.25	158.24	8.99	1981.53
	CV (%)	0.85	0.85	0.85	0.85	15.2	16.0

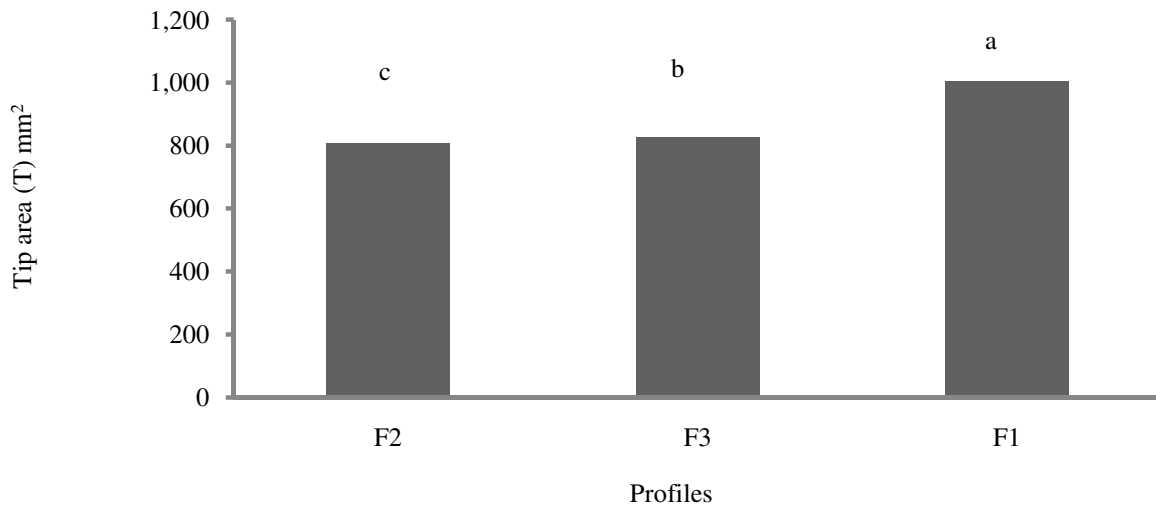
Note: values in the parentheses give the number of samples used. SD stands for the standard deviation and CV stands for the Coefficient of variation.

Table-3 indicates that the total tip areas in the joints of the samples are least (807.96 mm<sup>2</sup>) for F2 and highest (1004.43 mm<sup>2</sup>) for F1. Similarly, the total of sloping surface area is highest (20384.32 mm<sup>2</sup>) for F2 and least (13900.26mm<sup>2</sup>) for F1. Thus, these two areas seem to yield contrasting results. By adding up both the tip and sloping areas, we would get the actual gluing area in a joint. With 21192.28 mm<sup>2</sup>, this is highest for F2 whereas F1 presents the least with 14904.69 mm<sup>2</sup>. Interestingly, F3 which has similar slope (Table-1) as F1 always occupies a position between F1 and F2 as far as areas are concerned. It would be interesting to see how these areas behave statistically.

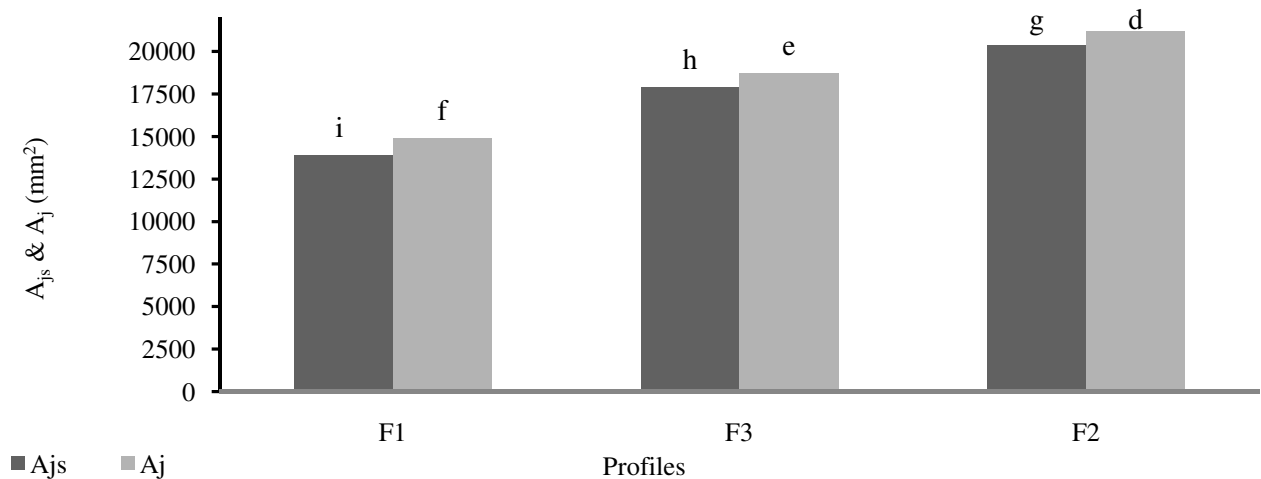
One way ANOVA conducted on these areas suggested that these areas are indeed significantly different (p < 0.001). Further analysis using Duncan’s homogeneity test placed these areas

into three distinct subsets. The results obtained are shown in Figures-2 and 3.

It can be seen that from Figure-2 that the mean of total tip areas in a joint follows a pattern of F1>F3>F2 which is different from the result that was obtained for tip thicknesses with single finger. The highest tip thickness of F1 (1.5 mm) has indeed resulted in the highest total tip area. But the lowest total tip area is being provided by F2 and not by F3 which had the least tip thickness of 0.64 mm (Table-1). This amply illustrates the reason for accounting for all fingers in a joint when gluing areas are being highlighted. The fact that even by using half long fingers can result in much less reduction (~26 %) in contact area in a finger-joint due to the effect of other parameters was demonstrated earlier<sup>17</sup>.



**Figure-2:** Distribution of total tip areas (T) of the three profiles.



Note: Different alphabets on the bars in figures 2 and 3 represent different levels of significance.

**Figure-3:** Distribution of total sloping and gluing areas (A<sub>js</sub> and A<sub>j</sub>) of the three profiles.

From Figure-3, it can be seen that in the case of sloping and total gluing areas, the three profiles follow a similar pattern with  $F2 > F3 > F1$ . Thus, considering only the total gluing areas, jointed sections with F2 are expected to provide maximum strengths. This is further supported by the lowest tip areas this profile has provided. Hence, let us now look at the SB results obtained.

None of the finger jointed samples failed in wood completely away from the joint implying that the strengths of the jointed sections are less than that of the clear wood of Eucalyptus<sup>18</sup>. The reported value of MOR of joint-free Eucalyptus specimen is 89 N/mm<sup>2</sup>. In the present study, the mean MOR values were 39 N/mm<sup>2</sup> for samples with finger profile F1 and 56 N/mm<sup>2</sup> for F2 and 59 N/mm<sup>2</sup> for profile F3. The mean MOE also followed a similar order with values of 10241 N. mm<sup>2</sup>, 11731 N/mm<sup>2</sup> and 12348 N/mm<sup>2</sup> respectively for F1, F2 and F3. The lowest values obtained with F1 are consistent with the earlier discussion on areas. However, the maximum values do not seem to be concurrent with that discussion. Hence, the calculated values of all the individual 43 samples were analysed using One-way ANOVA. This showed that both MOR and MOE values are significantly different ( $p < 0.001$  for MOR and  $p = 0.017$  for MOE). The Duncan's homogeneity test was conducted on these values and the grouping of the subsets obtained is given in Figure-4.

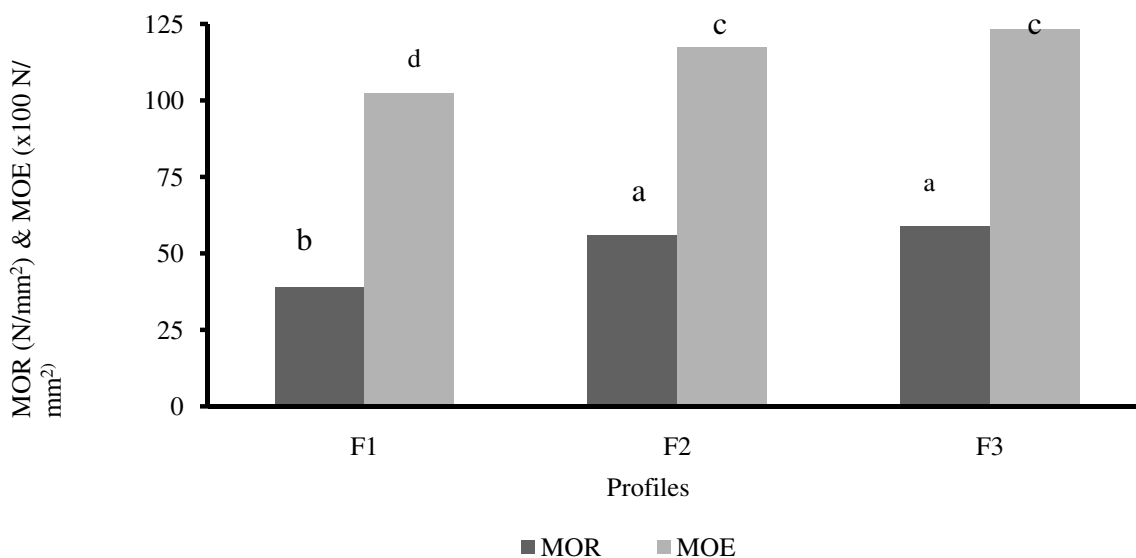
It can be seen from Figure-4 that both the parameters [MOR and MOE] are grouped into two subsets with the values for F1 occupying the least valued group. This is consistent with the areas in Figures-2 and 3 wherein the total and sloping areas are least for F1. The profile F1 had the maximum tip areas. These tips contribute a series of butt joints which even if they are well-bonded result in very low strength<sup>11</sup>. Selbo had suggested reducing the ratio of tip thickness to pitch for enhanced strength

of the joint<sup>10</sup>. The values of this ratio are 0.23, 0.17 and 0.16 for F1, F2 and F3 respectively in this study. Thus Selbo's suggestion is found valid in our study. Strickler recommended virtual knife edged finger tips for better strength<sup>8</sup>. However, in our study it is seen that by reducing the tip thickness from 0.83 mm (F2) to 0.64 mm (F3), the strength values have not significantly improved (fig 4). Ayarkawa *et al.* carried out studies on two finger profiles with different finger lengths but both having equal pitches and equal tip thicknesses<sup>5</sup>. They reported that with different end pressures used to mate the fingers, the longer fingers always resulted in higher bending strengths. The increase in finger-joint strength with increasing finger length is a common result reported<sup>19,20</sup>. However, in our study, the shortest finger (F3) also resulted in higher strength along with the longest fingered profile (F2).

It can be inferred that it is necessary to account for all the fingers (total areas involved) in a finger joint when efforts are made to improve the joint strength by manipulating the finger parameters.

### Conclusion

The tip thickness of a finger profile alone does not decide the extent of the total area of tips of fingers in a finger-joint. To get improved strength properties, the total of areas of all finger-tips involved in the joint requires to be kept to minimum. In a similar fashion, long fingers can result in low total gluing areas in a joint depending on the pitch. Profile with the largest total tip area resulted in lowest bending strength whereas the profile with shortest finger resulted in better bending strength. The approach of considering parameters of only one finger needs a re-look in manufacturing cutters that can yield better bending strengths.



Note: Different alphabets on the bars in figures 2 and 3 represent different levels of significance.

**Figure-4:** Bending parameters of the samples joined using the three profiles.

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