One of the most important aspects in the glued laminated timber manufacture is the execution of the finger joints used to compose the laminas in the desired length. However, in Brazil, there are not many studies about the evaluation of finger joints and adhesives used with reforestation species for the production of structural elements of glulam. On the other hand, the alternative adhesive research is important to reduce the final cost of the product and for better aesthetic results. The objective of this work is to evaluate the performance of timber joints glued with castor oil based polyurethane adhesive. For this, tensile tests of timber laminas of Pinus SP species had been carried out, in structural size, using laminas made with this adhesive, and using comercial adhesive, and in laminas without finger joints, for comparison. The results indicate that the polyurethane adhesive presents a suitable performance to be used in the manufacture of laminas for glulam.

**Keywords:** Castor oil based polyurethane adhesive; glued laminated timber; GLULAM.

1. **Introduction**

One of the factors known on the wood when compared with other materials of construction it is the high variability of the values of the mechanical properties of the diverse species used for structural ends (Machado, 2000).

At another time, when wood was amply offered, they were used with big transversal sections in structural applications with recognized quality (in terms of physicist-mechanical properties), simply by the origin. Consequently, after decades of irrational use, the today available wood comes each time more from reforestations (with fast growing species), originating wood with a lot of defects.

Glued laminated timber (glulam) is presented as one technique to make possible the wooden use of reforestation with structural purposes, while defects as knots and fissures disable the use of entire pieces. This technique consists in to glue blades that were jointed previously by means of finger jointing process. Today the finger jointing is used frequently to produce glulam.

These joints present a discontinuity of the material and consequently are considered potentially fragile regions. In this way, the joints in glulam represent, among others, one of the most important factors of the characteristics of strength of the glulam structural members (Macêdo, 1996).

For a good performance, the choice of an adhesive with good strength and exterior wet use durability is basic. So the adhesive that produces a good jointing between the materials (Carrasco, 2004) must be compatible with the adherent.

The phenol resorcinol formaldehyde adhesive assures good gluing with high strength mechanical and exterior wet use resistance, but it presents an unfavorable factor: very expensive, arriving to represent about 30% of the glulam total cost, in Brazil. This fact contributes to become the glulam a little competitive material in Brazil.

The effect of the glue type in the properties of tension and bending of finger joints was studied in hardwoods in Africa (Obeche, Makore, Moabi) using phenol resorcinol formaldehyde adhesive, melamine formaldehyde and isocyanates (polyurethanes) (Ayarkwa et al., 2000). The results indicated that the type of glue had a significant effect, statistically, on the strength in tension and
bending of the finger joints, in three tropical species. The performance of three types of glue seems to be related to the density of the wood, in inversely proportional way.

The adhesives based on isocyanate, such as polyurethanes, are gaining acceptance in the North America for many structural and not structural applications. The gluing with these adhesives presents high strength to the creep, to the moisture, to the treatments with exposition to the heat and, moreover, the cure can be made in ambient conditions. For these reasons, the polyurethane adhesive is a viable alternative for applications in finger jointing lumber (Bustos et al., 2003).

The behavior of castor oil polyurethane adhesive was analyzed in beams of glued laminated timber, made of Pinus caribea var. hondurensis and Eucalyptus Grandis species, and evaluating its efficiency in the lamination of beams and its behavior in the rupture of the structural elements (Azambuja, 2000; Henriques de Jesus, 2000). As conclusion, the new variety of adhesive previously presented achieved the normative resistance characteristics; however, exists the necessity of a bigger time of cure compared with the conventional adhesive (phenol resorcinol formaldehyde).

2. Materials and Methods

2.1 Materials

The adhesives used in the research are detailed following:

- The experimental castor oil polyurethane adhesive is supplied for the KEHL industry of rubber and polymers. The adhesive is originated from oil vegetal (Ricinus Communis) and consisted of a poliol and a prepolymer. The adhesive studied is made of two components, and is made of the natural and renewable resources. It has the cure in the ambient conditions, is not aggressive to the man and the environment, and it is produced by the national technology. The two components must be mixed in opportune ratios for each case, depending on the application and the necessities of the techniques. The castor oil polyurethane adhesive produce totally transparent bond lines, enhancing structural appearance. It does not have solvent and formaldehyde emission during the process of production and in the finished wooden product.

- Phenol resorcinol formaldehyde adhesive is supplied by the Chemical ALBA industry and known in Brazil as CASCOPHEN RS. It is a synthetic resorcinol-formaldehyde-based liquid adhesive in an aqueous/alcoholic solution. It has two components, one of which a reddish-brown resin (CASCOPHEN RS), and the other one is hardener (PREPARADO ENDURECEDOR FM), which is a beige powder. After mixed, these two components result in a high-performance glue, which is water-proof (cold or boiling), resistant to several organic solvents, fungi and exterior wet using.

The wood chosen for the research was the species Pinus Hondurensis - caribea Pinus hondurensis (softwood). The specie was chosen by to have low density, that it propitiates for good gluing, beyond the fact of this wood being proceeding from reforestation areas.

For the evaluation of the finger jointing lumber was made 50 finger jointed assemblies (25 for each type of adhesive) with finger joints of 28 mm long 8 and 25 finger jointed specimens that had been manufactured without finger joints, for comparison with nominal dimensions of the 3,5 x 7,5 x 200 cm and with moisture content of the group of specimens to 12%.

2.2 Grading rules applied to lumber

Two different methodologies are used to evaluate wooden structural members in real size: visual grading and mechanical grading.

The set of wood had been classified, firstly, with discarding of the pieces with extreme warping, steep slope of grain, compression failures, decay, pitch pockets, or stress risers due to errors in specimen preparation that can invalidate the results of the tests.
Later a visual grading was made applying the described method of visual grading for the Southern Pine Inspection Bureau (SPIB, 1994) and following the restrictions of norm AITC 117 (AITC 117, 2001).

According to recommendations of AITC 117 was made a mechanical grading of the wooden blades. This methodology evaluates the influence of the defects (visible and not visible) directly in mechanical properties and is considered the best form to evaluate the possible interaction of defects. The applied technique was transverse vibration that determined the bending rigidity of the material.

2.3 Pressure of glue in the finger jointing lumber and strength test

The finger jointing lumber had been glued under the pressure of 9 MPa, in function of the length of the finger and the wood density. With this gluing pressure the fissure of the 5mm superior extension in the deep of the fingers had not occurred. The gluing pressure time was 40 seconds, following the recommendations of the norm DIN (DIN 68 140, 1971). The efficiency of the adhesives was evaluated using parallel tension to the grain strength test, according to ASTM (ASTM D198, 1984). The equipment for strength test in structural dimensions members was the Metriguard with capacity to 1000 kN, model 422.

3. Results, discussion and conclusions

The efficiency of the adhesives: the experimental castor oil polyurethane adhesive and phenol formaldehyde, in finger jointing reforestation lumbers, was evaluated by means of tension parallel to the grain tests by means of statistical methods. Table 1 lists the average values of the strength test for evaluating structural adhesives for finger jointing lumber.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Sample size</th>
<th>Mean</th>
<th>Minimum confidence interval</th>
<th>Maximum confidence interval</th>
<th>Standard deviation</th>
<th>Coefficient of variation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resorcinol formaldehyde</td>
<td>25</td>
<td>55,60</td>
<td>51,43</td>
<td>59,77</td>
<td>9,90</td>
<td>17,81</td>
</tr>
<tr>
<td>Castor oil</td>
<td>25</td>
<td>45,67</td>
<td>41,89</td>
<td>49,44</td>
<td>8,96</td>
<td>19,62</td>
</tr>
<tr>
<td>Control (No finger joints)</td>
<td>25</td>
<td>79,50</td>
<td>69,17</td>
<td>89,84</td>
<td>24,52</td>
<td>30,84</td>
</tr>
</tbody>
</table>

The effects of the variables were determined using the MINITAB 14 software program. A two-way analysis of variance tests the equality of populations means when classification of treatments was made by two variables. For this procedure, the data were balanced (all cells had been with the same number of observations) and variables were fixed. The first variable (1 to 3) was type of the adhesive. The second variable (1 to 25) was achieved by mean of Modulus of elasticity (MOE) of pieces. Each group, with the same second variable, has 3 specimens with the MOE approximately equals. The treatments were (1) experimental castor oil polyurethane adhesive, (2) phenol formaldehyde adhesive and (3) specimens without finger joints.

With this model, the variance equality can be verified by means of the histogram of residuals graphics, by means of the graphs of residuals versus fitted values and the normality of the distribution of the results by graphs of normal probability plot of the residuals. A comparison of averages between equal size samples for the method of Tukey was effected. The test of normality of the residuals shown that the residues follow a normal distribution and that the variance is constant; the points are dispersed uniformly around zero.

By means of the statistical analysis can be concluded that exists statistical significant difference of MOR among the three studied treatments. It can be observed by the average of tension strength in the control specimens is 79,50 MPa; and 55,60 Mpa and 45,7 MPa, respectively for the adhesives:
phenol resorcinol formaldehyde and experimental castor oil polyurethane. The adhesives presented the following efficiencies of gluing: 69.93% and 57.48%, respectively in comparison with specimens without finger jointing lumber.

The experimental castor oil polyurethane adhesive showed an efficiency of gluing of 82.19% in relation to the phenol resorcinol formaldehyde, which is widely used in the lumber industries. A comparison of averages between these adhesives was effected and can be concluded that exists statistical significant difference in the average MOR for two adhesives.

The types of failure that occurred in finger jointed specimens due to tension loading were classified in accordance to the failure mode classification of tested specimens of the ASTM (ASTM D 4688, 1999). The phenol resorcinol formaldehyde adhesive presented the mode 4 (mostly tensile wood failure at the finger joint roots or scarf tips and with high overall wood failure and little failure of any kind along the joint profile), in the majority of the cases. On the other hand the experimental castor oil polyurethane adhesive showed two predominant ruptures models: type 4 and 3 (this one correspond to the failure mostly along the joint profile but with some failure at the finger roots or scarf tips and good overall wood shear failure along the joint profile surface).

As final conclusion, the viability of use of the experimental castor oil polyurethane adhesive can be affirmed, in the manufacture of finger joint lumber, in terms of structural performance.

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4. References


