

BENDING PROPERTIES OF WOOD I-JOIST MADE WITH PINUS (*PINUS SP.*) AND CURUPIXÁ (*MICROPHOLIS VENULOSA*) FLANGES

Shiba GK¹, Del Menezzi CHS^{1,*}, de Melo RR² & Souza MR³

¹Department of Forest Engineering, Faculty of Technology, University of Brasília, PO Box 04357, 70904-970, Brasília-DF, Brazil

²Department of Agronomic and Forestry Sciences, Federal University of the Semi-Arid Region, 59625-900, Mossoró-RN, Brazil

³Forest Products Laboratory, Brazilian Forest Service, Brasília, 70000-000, Brazil

*cmenezzi@unb.br

Submitted March 2017; accepted October 2017

This study aimed to evaluate the bending properties of I-joist made with medium density fiber (MDF) panel web and flanges of *Pinus* sp., curupixá (*Micropholis velunosa*) and combined flanges. The tests comprised 21 beams, being 7 for each group. The join between flange and web was provided by single component polyurethane (PU) structural adhesive in 200 g m⁻². The beams were tested to determine the modulus of rupture (f_m) and modulus of elasticity (E_M) in static bending. The pinus beams showed a mean value of 6638 N mm⁻² for E_M and 19.6 N mm⁻² for f_m , while curupixá beams showed values of 12190 N mm⁻² and 22.6 N mm⁻², respectively. The E_M and f_m values for composite beams were in between the figures described above, i.e. 9027 N/mm² and 20.5 N/mm². There was a significant difference for E_M among the beams with pinus flanges and curupixá flange. However, the f_m was not affected by the type of flange used. It was observed that at least 1/3 of the failure occurred between the flanges and the web joint, especially in beams made with curupixá, which prevented the beam from reaching its maximum static bending resistance. It was concluded that produced beams reached static bending values close to I-joists, but was higher due to low compatibility between the studied tropical timber and the utilised adhesive.

Keywords: Wood engineered products, bending beam properties, structural adhesive, modulus of rupture, modulus of elasticity

INTRODUCTION

I-joist profile composed of wood are products widely utilised in North America mainly in construction of buildings and homes (Fisette 2000). In the United States, engineered wood products (EWP) is replacing the lumber in large-scale, especially for roofs and floor manufacturing (Santos et al. 2009). However, these products are unfamiliar in Brazil due to the large availability of wood in the domestic market and lack of product standardisation. The EWP have non-adequate importance because the consumers tend to use solid wood instead of purchasing a technologically worked product, due to habit and lack of information about their advantages.

These I-joist profile, unlike solid wood parts, have its predefined characteristics and limitations, owing to its development and laboratory testing. This raises the possibility of maximising the usage of wood, avoiding unnecessary expense on wood

quantity, and without risking structure safety. A structural panel that will support two flanges or tables is part of a EWP set, consisting of a slender web joint of solid wood or other engineered products, for example, glued laminated veneer lumber (LVL). The join is performed with perfect grooves fit, made in flanges with the web and fixed with structural adhesive. Mounting allows different sizes to meet the project request. This joint provides geometry that brings many advantages especially in mechanical properties i.e. stiffness, resistance to bending moment and shearing (Jahromi et al. 2006, Morrissey et al. 2009). Santos et al. (2009) and Campos et al. (2012) address the buckling in I-beams. Owing to its slender and considerable spans, these beams present high lateral instability, resulting in failure. The main failure modes observed were web buckling or upper flange compression due to buckling.

According to The Engineered Wood Association, the I-Joist profile is highlighted as an exclusive category in the EWP classification (APA 2012). It is considered the second generation of EWP due to its efficient design and highlight in the world market (Pedrosa et al. 2005). It is utilised in many countries that use wood as a base material for construction of houses and buildings. The I-Joist profile is utilised to support floors and ceilings and it has great environmental and economic advantage because they are manufactured with a smaller amount of raw material compared to massive beams. Its reduced web thickness, slenderness and height gains lead to a large inertia around the axis (Bender & Lang 1993, Fiset 2000). At the edges, where the beam is required in stress to enter flanges or tables function, the I-Joist has a favorable geometric shape to withstand maximum compression at the upper part and tension in the lower part of the beam. The beam is manufactured by gluing a central piece (web) along with two flanges on the edge, thus giving stiffness and resistance to shearing and bending moment (USDA 2010, Santos et al. 2009).

The flanges can be a solid wood or LVL. It is divided in accordance to beam specifications, and then machined, where grooves are opened to fit the web. These grooves must be as accurate as possible to avoid non-fit or span problems that may interfere in the adhesive spreading during bonding process. They have similar upper and lower dimensions and withstand compression and tension stress. Thus, it is possible to use different species in each of the flanges for large response and beam efficiency, and the flanges must have a higher stiffness than the web (Pedrosa et al. 2005, Santos et al. 2009).

Structural panels generally utilised in the web are plywood, oriented strand board (OSB) or medium density fiber (MDF), which give enough strength to the beam. They are responsible for beam height, which is an important factor in respect of dimensions and deflection resistance (Pedrosa et al. 2005). The panels are sawn in exact dimensions, thus providing stability to the beam and material economy.

MATERIALS AND METHODS

Wood I-Joist

A total of 21 I-Joist profiles were produced with 2.750 mm length using MDF panel as web. Two

species were utilised for flanges, *Micropholis venulosa* (curupixá) and *Pinus sp.* Seven beams were composed with curupixá in the upper flange and pinus in the lower flange. Among the 14 remaining beams, seven were composed with curupixá flanges and seven others with pinus flanges. Two MDF boards from Fibrapla company were acquired for web manufacturing with dimensions of 1830 mm width, 2750 mm length and 9 mm in thickness. These plates were sawn into 21 parts of 150 mm width and 2750 mm length, and stored in a cool room until installation. Following species macroscopic identification, four curupixá plates were acquired for flanges with dimensions of 60 mm × 400 mm × 3000 mm and 21 pinus beams with dimensions of 70 mm × 70 mm × 3000 mm. All parts were stored in a cool room for 15 days, and then cross sectioned into parts of 50 mm × 50 mm and 2750 mm length. The flanges were then machined to 10 mm width and 15 mm depth for fitting cutter manufacturing. A single component polyurethane structural adhesive (Cascola PU), 200 g m⁻², was used to join the flanges in the web for multi-material bonding.

Assembling

The edges of MDF boards were sanded to activate bonding surface. The area of each glue line was 0.11 m². A total of 22 g of PU adhesive was weighed using an electronic scale with 0.01 g resolution. The adhesive was spread with a wooden stick until homogenous. After adhesive spreading, the flanges were fitted in the web and pressed using four clips, two at the edges and two at the central portion. The pressing has a load of 4000 kg force for a duration of 5 hours. Beam dimensions are shown in Figure 1.

Experimental analysis

Beam experimental analysis was performed according to standard procedures, ASTM D 198 and ASTM D5055 (ASTM 2013, 2014), with static bending test of four points, where two were supports and two were load application. The rupture load and deflection were obtained in this test. The test system was installed on a concrete beam reaction. The test was performed using a Pavitest hydraulic machine (model C-4070) until beam rupture. The load was measured using a 20 ton capacity load cell. The deflection was measured using a 50 mm LVDT Schlumberger

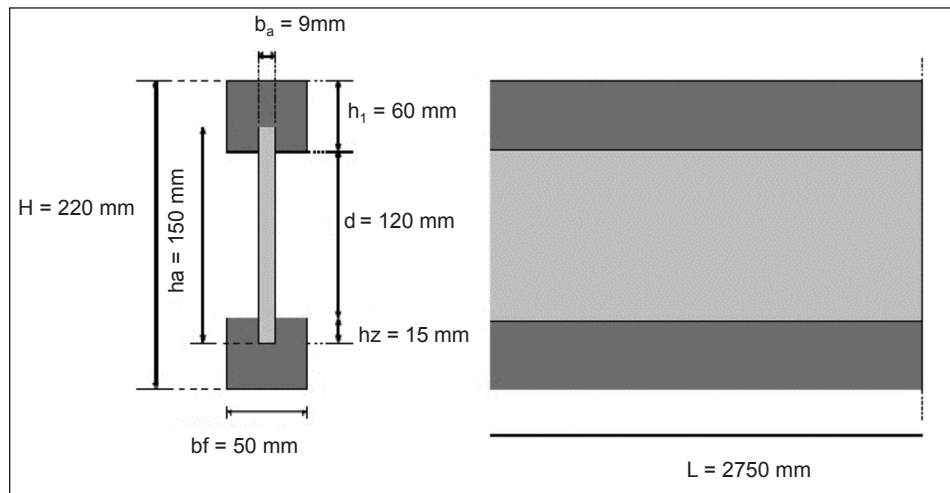


Figure 1 I-Joist nominal dimensions and its structural elements

transducer, coupled to a metal bar and attached to the neutral axis of the beam. Data was collected using AqDados 7.02 software of two channels, ADS0500 IP data acquisition integrated system, which registers the applied load and the deflection at each second of test. The collected data were statistically analysed using SPSS software V17 (2004), for discrepant data removal, obtaining means, standard deviation and variance. Variance analysis (ANOVA) was performed following the Tukey HSD test, and the treatments compared.

First, a metal bar was fixed by screw at 50 mm from the beam edge, at neutral beam line without any contact, to avoid interference with deflection measurement by LVDT. The bar extends across the beam requiring an apparent modulus of elasticity, since its non-deformation was considered in terms of shearing. The beams were supported by parts with bearings to avoid crushing effect. A part, with two separated actuators at 650 mm and positioned at 1000 mm from each beam edge, was utilised in load application. Thus the relation between the beam height and the distance between support and loading application was 1:4.54, characterising the beam as short (ASTM 2013). The test schedule is represented in Figure 2. All tests were performed between 10 and 20 minutes at 5.98 mm min⁻¹ speed (ASTM 2014).

Equations 1, 2 and 3 determined modulus of elasticity, the maximum bending moment and modulus of rupture of the tested beams:

$$E_M = \frac{P' \times a \times (3L^2 - 4a^2)}{48 \times I \times \delta} \quad (1)$$

$$E_{max} = \frac{Prup \times a}{2} \quad (2)$$

$$f_M = \frac{M \times y}{I} \quad (3)$$

where EM = modulus of elasticity of the I-Joists, N mm⁻²; P' = 4000 N; L = distance between the supports, mm; a = distance between supports and load applied, mm; I = moment of inertia, mm⁴; δ' = deformation caused in P'; M = bending moment, N mm; Prup = rupture load, N; fM = rupture modulus, N mm⁻²; y = distance between neutral line and the edges, mm.

The failure mode of the beams was visually analysed according to ASTM (2013) standard, which defines the main failures and large occurrence in beams with I profile (Figure 3).

RESULTS AND DISCUSSION

To calculate the moment of inertia, 21 beams were measured. As the difference between them was minimal, the beam nominal dimensions were considered (Figure 1), thus, the moment of inertia was calculated as 3.84 × 10⁷ mm⁴ for all beams.

Mechanical evaluation of beams

Figure 4 shows the bending properties of all beams, i.e. modulus of elasticity, maximum bending moment, rupture load and modulus of rupture. Two statistically discrepant data (VC4 and VP6) were removed for statistical

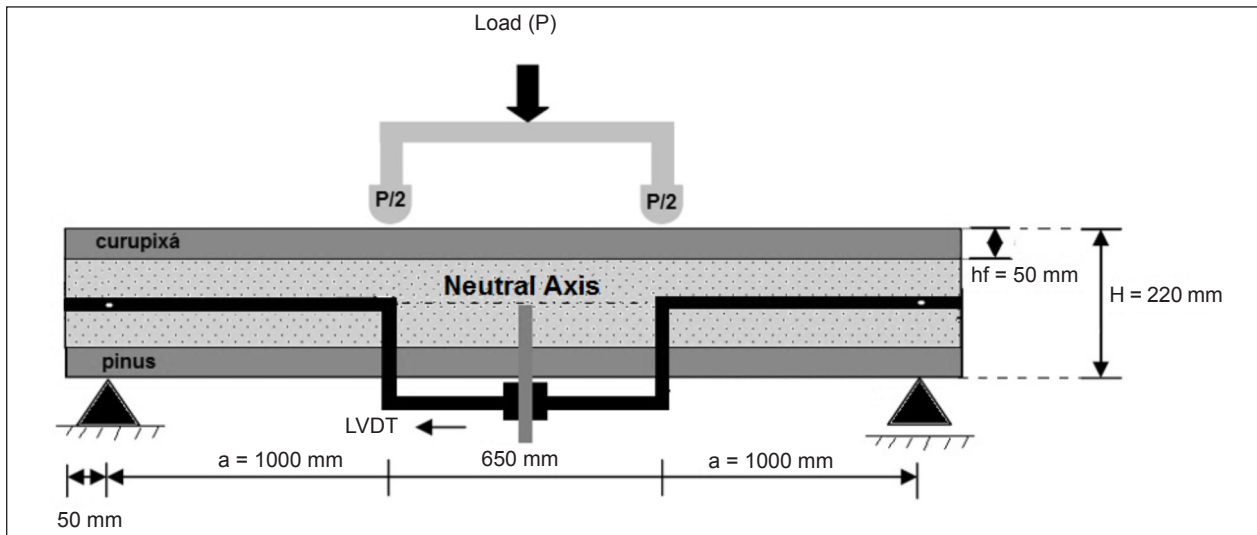


Figure 2 4-point static bending testing schedule

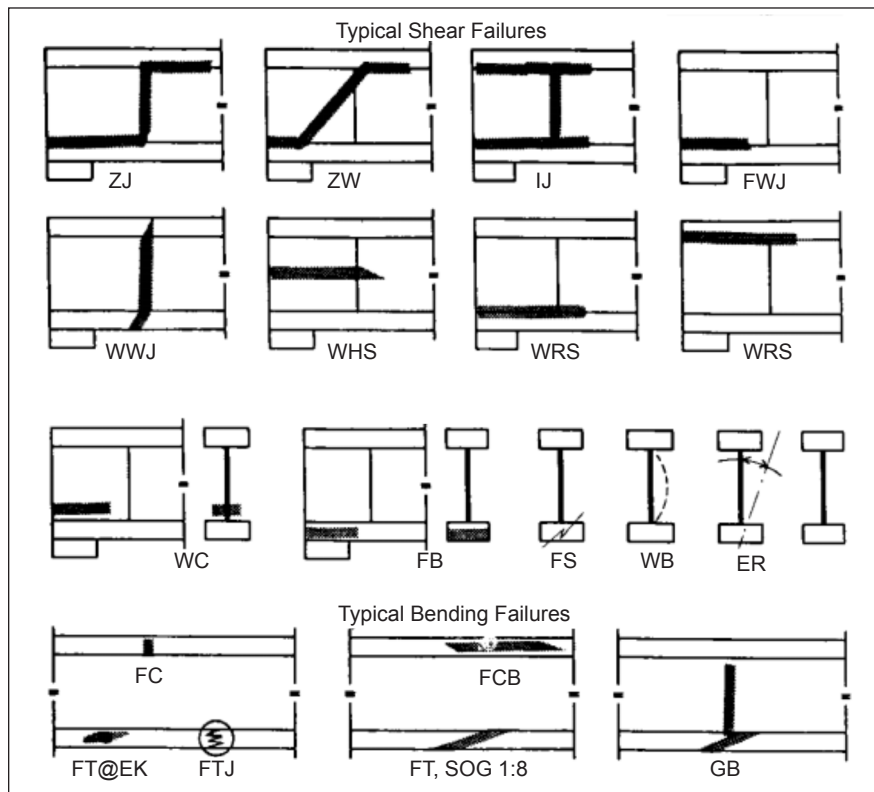


Figure 3 Failure codes for full-scale tests (ASTM D5055 2013)

purposes. The variance analysis indicated significant differences among treatments for modulus of elasticity, separating them into two groups. The first group indicated non-significant difference between pinus beams and composite beams and the second group indicated non-significant difference between curupixá beams and composite beams. Thus, there is a clear

statistical difference in modulus of elasticity between pinus beams and curupixá beams. There was no statistical difference between the three treatments for the modulus of rupture, thus the species had no influence on beams bending strength (Figure 4).

There was no difference in the modulus of rupture, although expected. Statistical

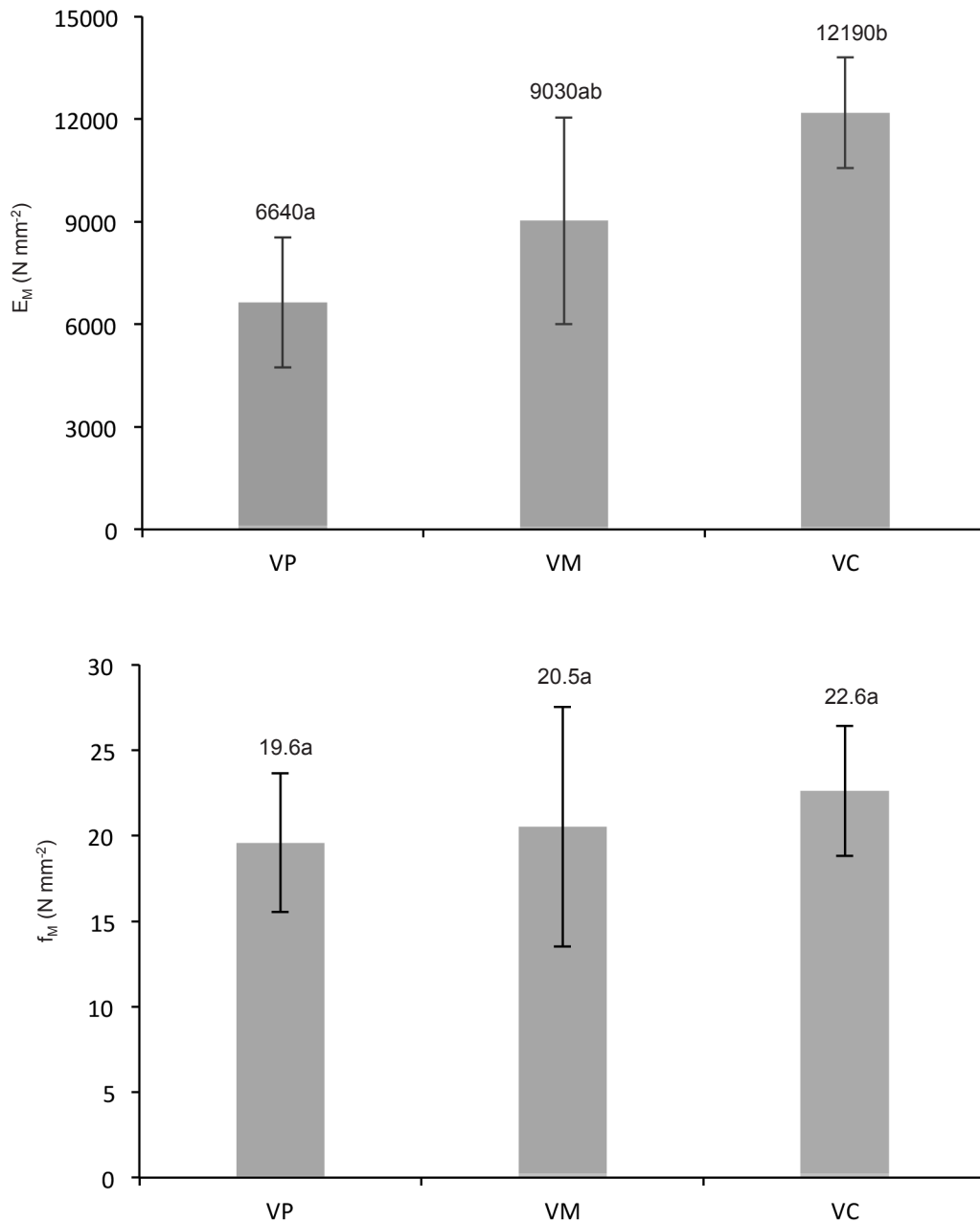


Figure 4 Modulus of elasticity and modulus of rupture of the tested wood I-joists; VP = less rigid treatment, VM = two species combination, VC = more rigid treatment

significant difference between modulus of elasticity treatments were non-significant. This may be explained by the fact that the adhesive failure was the main reason for restricting load capacity. Most of the curupixá beams failed in the glue line by imposing a limit on the beams strength, as observed in the visual evaluation. Values obtained in this study corresponded with previous research studies on I-joists with tropical hardwood (Chu et al. 1993, Jamaludin et al. 2005, Jahromi et al. 2006, Santos et al. 2009, Del Menezzi et al. 2010, Campos et al. 2012).

Statistical results indicated the successful species combination, clearly demonstrating the species influence regarding beams stiffness. The modulus of elasticity average of less rigid treatment (VP) is close to half of the modulus of elasticity of the more rigid treatment (VC). Two species combination (VM) resulted in an modulus of elasticity close to the average of the other two treatments, indicating that species combination in I-beam flanges resulted in modulus of elasticity average of composite beams for one of the species. The load and deflection data were plotted graphically which indicated how

much load is required to deform 1 mm. Thus at 10000 N, the VC3 beam, presented a deformation of 8.9 mm and the VP3 showed 14.78 mm.

Visual evaluation of the beam failure

According to ASTM (2013) classification, failures occurred in I-beams with curupixá flanges were typical shearing and glue line failures. The VC1, VC2 and VC5 beams showed typical shearing failures, classified according to the standard as rupture mode (ZW). This classification is performed to shearing failure in the web at angle next to 45°, not necessarily passing through a web-web join. Such a situation was non-existence in this study since all the beams were made with web in a single piece. The VC3, VC4, VC6 and VC7 beams had failed in the glue line, classified as no glue transfer (NGT) by the standard. Although there was proper spreading of the adhesive, the transfer between the surfaces did not occur. The non-transfer may be due to insufficient adhesive as recommended by the manufacturer for the species. The flange/web joint sliding generated a typical bending failure except in VC4 (Figure 5).

The failures in the pinus I-beams were four typical cases of shearing and three caused by

bending, according to ASTM (2013). The typical failure mode occurred due to the presence of node in the pulled flange, a typical pinus genus characteristic. The VP1, VP2, VP3 and VP4 beams showed typical shearing failure, classified as ZW, characterised by breaking at 45° of the web. In VP5, VP6 and VP7 beams flange failure in tension (FT) type occurred. Failure by flange tension is typical of beam under bending action. In VP6, the failure occurred due to grain slope near the node, located in the lower flange, which resulted in beam brittle rupture, described as prior to test (PTT) and slope-of-grain (SOG) in the standard. In VP5 and VP7 beams, the failure was FT with brittle characteristic.

The failures of I-beams composite had five different classifications according to ASTM (2013) (Figure 5). The VM1 and VM4 beams were broken due to compression failure by bending the upper flanges, with lateral buckling of the part, indicating deficiency in the amount of side supports on the beam, classified as flange buckling failure (FCB). In the beams, essays were utilised for side supports. The VM3 and VM6 beams showed failure classified as FT, which according to the standard are failures by tension. In VM3, the failure was caused by the presence node in the lower flange, observed before the test,



Figure 5 Rupture mode (ZW) observed for curupixá flanged wood I-joist

resulting in brittle rupture of the beam, classified as prior to test (PTT). In VM6, the failure by tension was caused by glue line failure of the upper flange, classified as NGT. The VM2 beam failure was caused by web compression failure, classified as flange failure in flexural compression (FC). The VM6 beam was the only one that failed by shearing due to vertically web failure being classified as ZJ. The VM7 beam had no flanges or web failures and failure only happened on the glue line, classified as NGT, featuring an adhesive transfer failure to the surface (Figure 6).

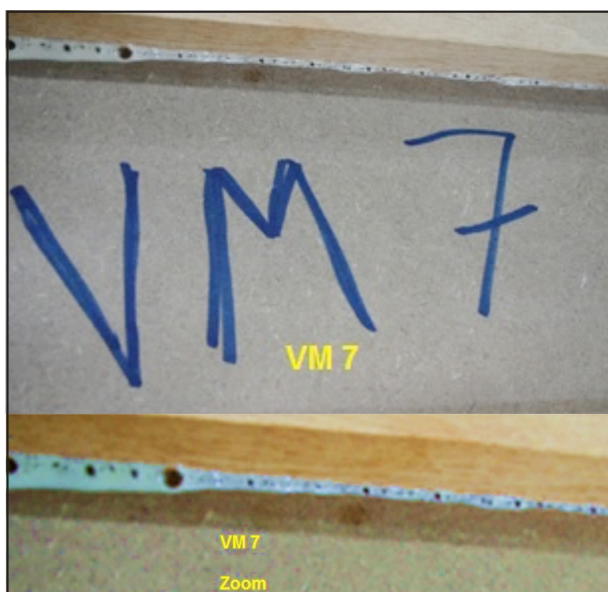


Figure 6 Evidence of glue-line shear of curupixá flanged wood I-joists

According to ASTM (2013), the tested beams were considered short, explaining the fact that 38.1% of tested beams presented a typical shearing failure. Most failures caused by bending (33.33%) occurred due to the presence of defects in the lower flange observed before the beam test (PTT) or due to adhesive failure (NGT). Compared to Campos et al. (2012), the tested beams showed large improvement in side stability, where side buckling of the beam occurred only in 2 essays (9.5%), due to alteration in flanges dimensions. The addition of 10 mm on each side of the flange cross section (50 mm × 50 mm) resulted in increasing beam height and base width, consequently of the inertia (I), making the beam more robust and stable.

CONCLUSION

The results were satisfactory for pinus, regarding modulus of elasticity and modulus of rupture. The tests were affected by adhesive for curupixá, which proved to be the limiting factor for modulus of rupture. Curupixá beams showed good modulus of elasticity. The species utilised in the flanges significantly influenced the modulus of elasticity in the beam with I profile, indicating that species combination influence I-beam stiffness proportionately. Species combination had no significant influence on the modulus of rupture. The adhesive proved inadequate for structural utilisation in curupixá sp. (*Micropholis venulosa*).

REFERENCES

- APA (THE ENGINEERED WOOD ASSOCIATION) 2012. *Performance Rated I-Joists*. The Engineered Wood Association, Tacoma.
- ASTM. 2013. *ASTM D5055-05 – Standard Specification for Establishing and Monitoring Structural Capacities of Prefabricated Wood I-Joists*. American Society for Testing and Materials, Denver.
- ASTM. 2014. *ASTM D198-99 - Standard Test Methods of Static Tests of Lumber in Structural Sizes*. American Society for Testing and Materials, Denver.
- BENDER DA & LANG JDS. 1993. *Wood Products for Engineered Structures: Issues Affecting Growth and Acceptance of Engineered Wood Products*. Forest Products Society, Madison.
- CHU YP, MOHD RH & CHONG YT. 1993. Strength of plywood web box beam. *Journal of Tropical Forest Science* 5: 492–511.
- CAMPOS MBES, DEL MENEZZI CHS & SOUZA MR. 2012. Flexural properties of wood I-joists flanged with tropical hardwoods. *Journal of Tropical Forest Science* 24: 369–378.
- DEL MENEZZI CHS, SANTOS AML & BORTOLETTO JR G. 2010. Flexural properties of I-beams made from nondestructively tested LVL-flanges. Paper presented at the 11th World Conference on Timber Engineering, Riva del Garda.
- FISSETTE P. 2000. The Argument for I-joists: new products and increased competition make superior I-joist performance available at solid-lumber prices. *Fine Homebuilding Magazine* 129: 70–73.
- JAHROMI AB, ZHANG B, HARTE A, WALFORD B, BAYNE K & TURNER J. 2006. Investigating the Structural Performance of Multi-webs I-beams. *Journal of the Institute of Wood Science* 17: 148–158.
- JAMALUDIN MA, NORDIN K & AHMAD M. 2005. *Strength Properties of Engineered I-Joist Made From Laminated Veneer Lumber (LVL), Solid Wood, Oriented Strand Board (OSB) and Plywood*. FPL General Technical Report No.163. USDA Forest Service, Madison.
- MORRISSEY GC, DINEHART DW & DUNN WG. 2009. Wood I-joists with excessive web openings: an experimental

- and analytical investigation. *Journal of Structural Engineering* 135: 655–665.
- PEDROSA AL, IWAKIRI S & MATOS JLM. 2005 Produção de vigas estruturais em perfil I com painéis de madeira reconstituída de *Pinus taeda* L. e *Eucalyptus dunnii* Maiden. *Floresta* 35: 443–449.
- SANTOS AML, DEL MENEZZI CHS & BORTOLLETO JUNIOR G. 2009. Comportamento teórico e experimental de vigas de madeira em perfil I: efeito de alma na resistência, rigidez e deslocamento vertical. *Scientia Forestalis* 37: 131–141.
- USDA (UNITED STATES DEPARTMENT OF AGRICULTURE). 2010. *Wood Handbook: Wood as Engineering Material*. 2nd Edition. Forest Products Laboratory (FPL), United States Department of Agriculture (USDA), Washington.