

Advanced Adhesive Technologies for Structural Joints

Emily J. Lee, Liam M. Patel

University of Materials Science, Boston, USA

Abstract—The industrial process adds to engineering wood products features absent in solid wood, with homogeneous structure and reduced defects, improved physical and mechanical properties, bio-deterioration, resistance and better dimensional stability, improving quality and increasing the reliability of structures wood. These features combined with using fast-growing trees, make them environmentally ecological products, ensuring a strong consumer market. The wood I-joists are manufactured by the industrial profiles bonding flange and web, an important aspect of the production of wooden I-beams is the adhesive joint that bonds the web to the flange. Adhesives can effectively transfer and distribute stresses, thereby increasing the strength and stiffness of the composite. The objective of this study is to evaluate different resins in a shear strain specimens with the aim of analysing the most efficient resin and possibility of using national products, reducing the manufacturing cost. First was conducted a literature review, where established the geometry and materials generally used, then established and analysed 8 national resins and produced six specimens for each.

Keywords—Engineered wood products, structural resin, wood joist.

I. INTRODUCTION

ENGINEERED wood products (EWPs) are industrial products which have the main features of sustainability, quality control, safety, efficiency structures, aesthetics, and various uses. One of engineered wood product that stood out are the wood I-joist, which can be produced from the junction of more than one wood composite, using the best properties of each one. Wood I-joist beam occupy a prominent place, because of possibility utilization of wood from planted forests and is a sustainable material, its main features are, light material, high stiffness and strength, reliability, low power consumption for its production and cost-effective when compared to solid wood beams.

A critical part of wood I-joist is the web-to-flange joint, the stiffness and strength is directly related to the material used and an efficient connection. Recently, the developments of improved adhesives and construction techniques have led to the development of I-joist beams industry.

II. BRIEF LITERATURE REVIEW

A. Wood

The wood has been widely used due to its high structural capacity, aesthetic value, great strength, low energy consumption for its production, easily obtained material and renewable source. The regeneration cycle, can easily exceed the volume that is being used. Regarding the reforestation trees, with increasing demand, lower value trees could be fully utilized if targeted for composite products.

B. Wood I-Joists

I-beams are composite structural members that are manufactured using sawn solid wood or structural composite lumber flanges and structural panel webs. The web-to-flange joint are bonded together with adhesives, forming the cross-sectional shape of an "I".

Composite wood are becoming more prevalent in structural system, and they are expected to become even more important.

Wood I beams can be manufactured with different dimensions and therefore different rigidities and strengths. In flexion, the flanges are subjected to axial forces and the web is subjected to shear stress, predominantly. Fig. 1 shows some beams with different heights [1].



Fig. 1 Wood I-joists

Three hundred thirty million meters of I-beams are made annually [2]. In Brazil, the technology of the I-beams has been explored in the academic area with several studies; in the construction industry is still underutilized.

C. Web-to-Flange Joint

An important part of I-joist is the web-to-flange joint. Many different concepts have been introduced to ensure good shear performance, easy fabrication and gluing, improve the ability to transmit concentrated loads without crushing, guarantee of stiffness and strength, avoid splitting the flange stock when either the flange or web changes dimensions, and enhance product uniqueness.

The connection by metal pins is not rigid, causing a reduction of the strength and stiffness [3].

Due to the large development of new materials, building systems and structural systems, the studies of connections between structural elements have been important to the improvement in sizing, considering that the transmission of stresses and deformations in the structure are largely dependent upon the behaviour of these connections, [4].

Reference [5] provides some models of web-to-flange joint and use of OSB or plywood for the web. Fig. 2 details the geometry of connections.

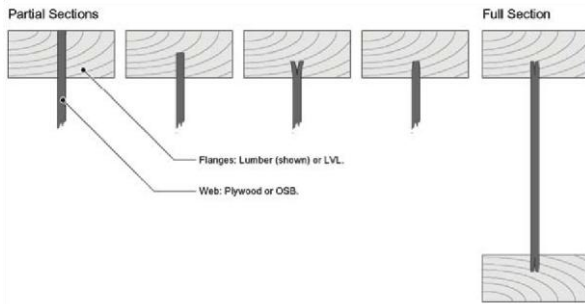


Fig. 2 Web-to-flange joints models and materials

The union in flange-web joints and in a length of the flange and web are the main challenges for the production of wood "I" beams and see being studied frequently in search of better geometry, strength and ease of production. The behaviour of the "I" beams pasted depends on a number of parameters including geometrical and mechanical characteristics of components [6].

D. Resins

The American Society for Testing and Materials (ASTM) defines an adhesive as a substance able of holding materials together by surface attachment. Adhesion is the state in which two surfaces are held together by interfacial forces, which may be valence forces, interlocking action, or both. Valence forces are forces of attraction produced by the interactions of atoms, ions, and molecules that exist within and at the surfaces of both adhesive and adherent. Interlocking action, also called mechanical bonding, means surfaces are held together by an adhesive that has penetrated the porous surface while it is liquid, then anchored itself during solidification. [7].

Although individual producers may write their own specifications for adhesives used in the manufacture of wood I-joists, adhesives are generally in compliance with standard specifications for durable structural uses such as ANSI/AITC A190 for flange-end joints, ASTM D2559 for web-web and flange-web connections, and PS 1-83 or APA PRP-108 for plywood veneer bonding. Phenol-formaldehydes and phenolresorcinols are the main-stays of the industry, although some melamine adhesives are also used for flange-web bonding [8].

New adhesives studies were realized with demethylated Kraft Lignin (DKL), by-product in the production of dimethyl sulfoxide from kraft lignin, and a polyethylenimine (PEI). In this study, a wood composite bonded with this new DKL-PEI adhesive system were very strong and very water resistant. The DKL-PEI adhesive were readily prepared and used to bond maple veneer. The DKL-PEI adhesives can be completely cured at 120 °C and 5 minutes [9].

A wooden I-joist can have up to five different adhesives in its construction. Can be used a different resin for wood laminated flanges, finger joined with a melamineformaldehyde adhesive and glued together with a phenolresorcinol-formaldehyde and polymeric. The web can be OSB and is often produced using both phenolformaldehyde and polymeric diphenylmethane diisocyanate adhesives and the final I-joist by attachment of the

strandboard to the flange. Each of these resins has different chemistries, conditions in temperature uses, time, and is subjected to different forces during uses [10].

III. MATERIAL AND METHODS

Through the literature reviewed was identified materials commonly used in I-beams, Pinus for flanges and OSB for the web. To evaluate the mechanic behaviour of web-to-flange joints is needed, in addition to theoretical analysis, conducting laboratory tests, were performed specimens in full scale. This check was made in *Pinus taeda* wood to verify the validity of the model under study. To the OSB values were provided by the manufacturer.

A. Used Materials

Was used *Pinus taeda* in the flanges, as they are from reforested areas, low density, low cost, wide availability in this region, and potential production in the country. For the web was used structural OSB Home Plus 9.5 mm thick manufactured by LP Brasil in southern Brazil.

The use of epoxy-based resins enables lower cost manufacturing of composite beams, therefore, makes it necessary to check resistance, identifying the one with the reliability, ease of implementation and cost benefit. This research was analysed 8 different structural resins, namely: Cascophen RS-216M synthetic structural resin, based on Resorcinol-Formaldehyde and epoxy based resins: COMPOUND (fluid), COMPOUND (Gel), RHEOPOX (average flow), MSET EP (Handle normal), MSET EP (Slow Take) Sikadur 32 and Sikadur 32 (Gel).

B. Push-Out Shear Tests

To establish the test methods of connection systems, as well as other factors involved, we sought the association of positive characteristics observed in different situations reported in the literature review, since the Brazilian NBR 7190 (1997) does not show the specimen test. The shear test specimen dimensions were established according to the height of Ibeam, 241 mm wide and 250 mm length. To evaluate the webto-flange joint were produced 6 shear specimens for each resin to determine if the web could slip in the flange joint when loaded, and to identify the best performance, lower cost and easy production by resins, using the rectangular geometry groove. Fig. 3 shows the specimen dimensions.

These tests are designed to analyses the bonding strength as the gluing adhesion for each resin, checking if there was displacement in binding or web breakage by shear. *Pinus taeda* parts which compose the tables were processed and cut at specified to produce specimens measured. To production all specimens, a mortising machine was used to notch the flange and connect to the web. The flanges solid wood was benefited in laboratory and then was made grooves for each specimen. Fig. 4 shows the mortising machine during production of the rectangular groove.

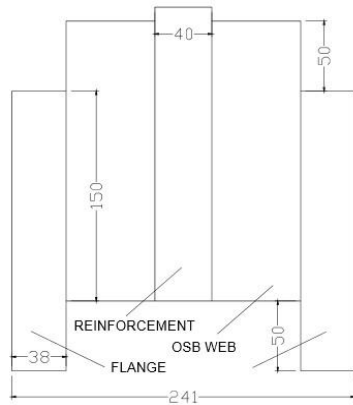


Fig. 3 Specimen dimensions



Fig. 4 Mortising machine producing the rectangular groove

The flanges were selected by obtaining a material with a minimum of imperfection and tested on the flexural modulus, density and humidity control between 12 to 14%, like Brazilian Code “NBR 7190 – Design of Timber Structures” [11]. Epoxy based resins were applied with spatula because of the consistency and Resorcinol-Formaldehyde were applied with paint-brush.

To ensure a perfect union in web-to-flange joint, the specimens were pressed, as shown in Fig. 5.



Fig. 5 Specimens on pressing apparatus

To prevent OSB crushing, the web was reinforced on both sides with pieces of solid wood of *Pinus taeda* glued onto the OSB with the same resin used in connection. Fig. 6 shows the web-to-flange joint specimen with reinforcement.



Fig. 6 Web-to-flange joint specimen with reinforcement

Tests were conducted until OSB web failure, and the failure mode was recorded. The objective of this test was to analyze if the web could slip in the flange joint when loaded, identifying the resin without adhesion or if the OSB web tore in shear. Fig. 7 shows the specimen in shear tests machine.



Fig. 7 Specimen in shear test machine

IV. RESULTS AND DISCUSSION

The specimens were all made with the same geometry, rectangular model, since this test is intended only to verify the shear strength of the joint.

Table I shows the average results from all resins tests.

The specimen that slid in the joint was produced with resins MSET EP (Slow take) and Sikadur 32, they are considered not rigid for structural elements. For the other resins, the web-to-flange joint did not slip during all tests and tore in shear near joint, demonstrating higher strength and stiffness. Fig. 8 shows one of those tests.

TABLE I
RESULTS FROM SHEAR TESTS

Resins	Average Load (kN)	Standard Deviation (kN)	Rupture Mode
--------	-------------------	-------------------------	--------------

Cascophen	31,15	1,82	Tore in shear
Compound Fluid	23,47	1,87	Tore in shear
Compound Gel	28,10	2,10	Tore in shear
Rheopox (Average flow)	25,00	1,89	Tore in shear
M-Set EP (Handle normal)	31,75	1,90	Tore in shear
M-Set EP (Slow take)	24,12	1,72	Slid in the joint
Sikadur – 32	26,60	2,80	Slid in the joint
Sikadur – 32 Gel	30,38	1,87	Tore in shear



Fig. 8 OSB tore in shear near application line

V. CONCLUSION

The workability of the resin is essential for the production of I beams and quality of the joints. All epoxy-based adhesives had difficulties in application due to the fluidity. The possibilities of using a brush-paint to apply the resin Cascophen make this the best option, ensuring ease of specimen preparation, while maintaining high performance and reliability of the joint connection.

REFERENCES

- [1] P. Fisette, "The evolution of engineered wood I-joists (Department of Natural Resources Conservation. Building Materials and Wood Conservation)," Amherst, MA: University of Massachusetts, 2006.
- [2] R. J. Ross, J.R. Erickson, *I-Joists* (Natural Resources Research Institute). Madison, WI: University of Minnesota Duluth, 2006, chapter 7.
- [3] J. L. N. Góes, *Nailed Timber Beams with I Composed Section*. (Dissertation Msc. in Structural Engineering), São Carlos School of Engineering, University of São Paulo, 2002.
- [4] G. C. Stamato, C. J. Calil, *Resistance of inlay of plywood*. (Dissertation Msc. In Structural Engineering), São Carlos School of Engineering, University of São Paulo, 2002, Book, n. 18, p. 49-76.
- [5] Engineered Wood System. *APA Understanding Engineered Wood Products – Construction Guide*. Form N° E30, Tacoma, WA, United States, 2007.
- [6] Racher, P., Bocquet, J. F., Bouchair, A. *Effect of web stiffness on the bending behaviour of timber composite I-beams*. Universidade de Blaise Pascal, Campus de Cêzeaux – França, 2005.
- [7] Forest Products Laboratory. *Wood Handbook – Wood as an engineering material*. Gen Tech. Rep. FPL-GTR-110. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 463p, 1999.
- [8] R. J. Leichti; R. H. Falk; T. L. Laufenberg, *Prefabricated wood I-Joist: an industry overview*. Forest Product Journal, v.40, n.3, pp. 17, 1990.

