RESEARCH REPORTS

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SOME BENDING PROPERTIES OF I-JOISTS MADE WITH BIRCH LAMINATED PLYWOOD PANELS

Plywood is produced in standard size, therefore, after sawing it to the required size, a certain amount of coarse waste is generated, and the options of usage are limited due to the dimensions. Finding a way to use this coarse waste would mean increasing the amount of usable off cuts or a wasteless production, generating a product with a higher added value and limited costs of raw materials. The research looks at options to use plywood production coarse waste in the production of I-joist and wall framing that are both modern construction materials, and their utilization in construction has a good future prospect. Based on prior strength indicator tests and the specification of available coarse waste, the I-joist structure was chosen. Strength indicators of the manufactured beam samples were also tested to ensure the correct beam structures were selected. The research contains a comparison of indicator data obtained with the relevant strength indicators of I-joists produced by a different manufacturer. Comparing the stiffness EI values of the tested I-joists, they are at times lower than the relevant values of offered I-joists. It is worth mentioning that in all cases the width, depth and consecutively the cross-sectional area of the tested I-joists are slightly smaller than the relevant indicators of the offered I-joists. The indicator by which the tested I-joists are significantly lagging behind the other ones is their self-mass. When compared to LVL (Laminated Veneer Lumber) I-joists produced by "Finnjoist" having the smallest self-mass, the self-mass of the tested I-joists is 23.8% higher, but the moment of inertia is the lowest one at 49.1 cm² of the relevant values of the offered I-joists.

Keywords: birch plywood composite, I-joist, strength, modulus of elasticity, stiffness

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Introduction

It is a known fact that to produce a 1 m^3 length of plywood, approximately 2.5 to 3 m^3 of round timber is consumed [Kachalin 1984]. This proportion is so significant that plywood manufacturers have found ways to utilize the off cuts long ago. However, there are many limitations for utilizing the waste from plywood processing. It is related to plywood being a composite material, produced utilizing synthetic resin adhesive and different overlays. Here we are talking about loose waste, i.e., utilization of shavings and dust, however, there are other options in the utilization of coarse waste generated from cutting plywood in the production of necessary stock. Coarse waste maintains the same properties as plywood which enhances its utilization options. Its main disadvantage is the size. It applies especially to coarse waste generated by custom cutting and having limited cross-sectional dimensions and a length corresponding to the custom-cut plywood length. Therefore, I-joist structure has been selected for research of a more efficient utilization of coarse waste. The goal of this research is to develop technological methods for the creation of I-joists, produce the I-joists by utilizing plywood production coarse waste, and determine certain physical-mechanical properties, as well as perform the comparison of properties obtained with those of similar products from other manufacturers. Permissible stress design properties intended for use with Eurocode 5 [JJI-Joists technical manual 2010]. Thin web joists are a composite section with flanges and webs of different materials, and consequently, differing E and also EI values [Ozelton and Baird 2006]. I-joists were first produced in North America along with other new construction materials appearing as a result of the development of frame house construction technologies. In spite of their initial purpose, I-joists are universally applicable and can also be used in ceiling and roof structures and in buildings built using different technologies as well. Mass production of I-profile products began around 1980 and developed rapidly. This product soon became popular in Asia and Australia as well. However, in Europe this is a relatively new construction material. Usually for the production of I-joists, European Technical Approval ETA-06/0238, [ETA-06/0238:2011] are used. Research of the market shows that Europe is the only one of the world's most developed regions where other construction technologies and materials are preferred in the construction of low-rise wooden houses, although the utilization of I-joists have many advantages [Schuler et al. 2000].

Materials and methods

The mechanical properties of the core product of JSC Latvijas Finieris, i.e. brand Riga Ply and the plywood brands produced based on it, have been well researched and reviewed in literature. Unlike the plywood brands with a standard veneer laying scheme, for the Riga Spec 3 brand, 30 mm thick, the

mechanical property research has been performed, but is relatively limited. Research of the properties of the Riga Spec 3 plywood has been done before [Lipinskis and Spulle 2011]. A 30mm thick Riga Spec 3 plywood has been utilized in the production of I-joist flanges, while a 9 mm thick Riga Ship Ply plywood has been utilized in the production of the I-joist web. The plywood is made of birch rotary cut veneers of a thickness of 1.45 mm after drying. The plywood is glued with phenol-formaldehyde glue. The glue is mixed using resin SFŽ-3014 and a Prefere 24J688 mixture containing resins, polymerization accelerator and filler-plasticizer. The veneer gluing quality belongs to the 3. class according to EN 314-1 and EN 314-2 standards. The surface of the flange plywood elements is foiled with a phenol-formaldehyde film of the mass of 120 g m^{-2}. One face of the flange element is smooth (side F) and other (outside face of the I-joist) has wire mesh pattern (side W), to increase the abrasion resistance of the surface of the I-joist. Characterization of the plywood elements used in I-joist construction is given in table1.

Table 1. Characterization of plywood elements used in I-joist

Components of the I-joist	Veneer lay-up scheme in the direction of the longitudinal axis of I-joist*	Number of layers in plywood	Density (mean) ρ, kg m^{-3}	Moisture content (mean), %	Bending strength parallel to grain (mean), MPa
Flange	II-III-I-I-II-I-III-II	22	712	8.3	85.7
Web	-I-I-I-	7	755	7.9	138.0

*I – veneer of the grain direction parallel to the longer axis of beam; $\tilde{-}$ – veneer of the grain direction perpendicular to the longer axis of beam.
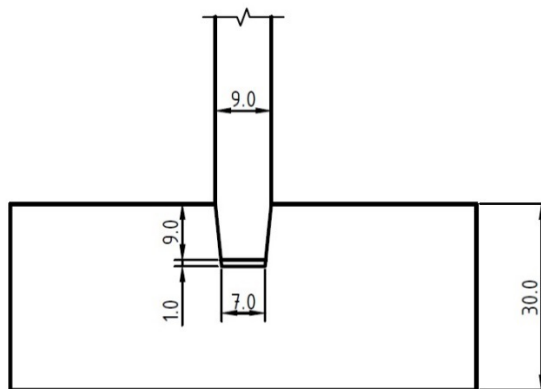

Fig. 1. Connection example flange with a thickness of 30 mm and a web thickness of 9 mm

The I-joist web is the least load carrying element, and the purpose of it is to resist tangential stress, connecting flanges along the entire I-joist length, and to increase I-joist stiffness. Web bending strength was not taken into consideration in the light gauge I-joist strength calculation methods [Karsunkin and Obrezkova 2006]. Therefore, a finger joint, (fig. 2) connection was selected for web fusing ensuring a sufficient glue joint area along the depth of the web. Between the web, the flanges and finger joints in the plywood, one component of polyurethane glue HB110 produced by Purbond® was used.
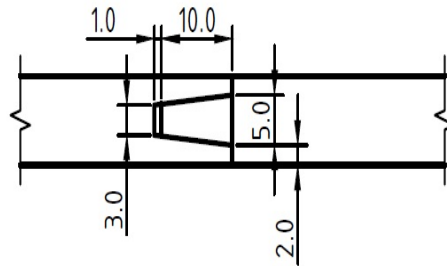

Fig. 2. Fingerjointing of the I-joist web elements

For increased adhesion of the joint of the flanges and the web. a semi-finger joint for flanges was used (fig. 3). The web with upper and lower flanges in 1/3 of the total depth was jointed figure 1. The web is a double I-joist element that can be subject to buckling during the operation. It is known that buckling has a lesser effect on bodies clamped at both ends and on bodies with higher stiffness [Lavendelis 1986; Del Menezzi et al. 2010]. Therefore, a narrow angle has been used for the finger joint in the web, in order to clamp the outer layer veneer of the web which is more buckle-resistant due to its grain direction.

The goal of this connection is to provide a connection accuracy of the fused plates, which is also important when fusing I-joist webs since their long edges are connected to flanges using a different connection. Flanges are the elements of the I-joist enduring the highest load. In practice, when fusing plywood for loaded elements, the following glue connection methods are used [Volynskii 2003]: scarf joint, butt joint, using rims on one or both sides; finger joint connection.

When utilizing a scarf joint, a connection with a large glue joint area is achieved. Due to a low angle of incidence, there is a high material consumption for this connection. This connection method is used when fusing large-size panels; therefore, there is no serial equipment to be used for fusing stock 40 to 65 mm wide. Connection with rims cannot be applied in this case since flanges to be fused must have the correct geometrical form.

Plywood fusing with finger joints is complicated since plywood is an uneven material containing glue. Moreover, accurate dimensions are very important in finger joint connections, hence also the quality of the cutting tool sharpening.

Finger joints are usually embedded in the entire depth of material which is unnecessary in the case of manufacturing I-joists, since I-joist web is connected to flanges with finger joints entering the upper part of the shelf connection. Due to the utilization of cutting tools, it would be more practical to embed finger joints only in the lower part of the shelf, whilst using a scarf joint in the upper part at a length equivalent to the length of the finger joint. This way a connection is created that can be called a combined connection (fig. 3).
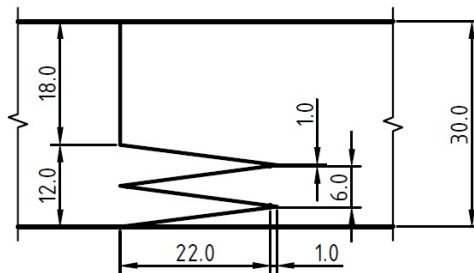

Fig. 3. Flange combined connection

It is known that the strongest glue connection can be achieved when the grain direction of the material to be glued coincides [Volynskii 2003]. In order to comply with this requirement, standard finger joints of 22×6 mm were selected. In order to establish the impact of the connection on the mechanical indicators of the product, the connection of the I-joist web should be located in the middle of the I-joist, while connections of flanges should be further away from the middle part.

At a maximum I-joist length of 6 m, it would be more practical to use coarse waste of 3080 m length for the I-joist web. In this case, the web connection would be located precisely in the middle of the I-joist.

Regardless of the length of the source material used for flanges, in a 6 m long I-joist there will be six connections of flanges: three above and three below. It is impermissible for connection spots for web and flanges coincide. Construction material strength calculation and designing methodology states that the distance between connections in the I-joist length may not be less than 600 mm.

Ten identical I-joists were created for test purposes. The I-joists were made of coarse waste of the largest volume, i.e., decisive in production volume. Flanges were made of Riga Spec 3 plywood brand coarse waste, 30 mm thick and single grain direction of several veneers, while the web was made of Riga Ply plywood brand coarse waste, 9 mm thick. The dimensions of the I-joist are indicated in the figure 4.

Connection points of I-joist elements are placed in a way that both upper and lower shelf connections, as well as the web connection would be placed in a pure bending area during the test. This way all the I-joist connections will be tested.

Before testing, all test specimens were conditioned according to the technical report EOTA TR 002 [EOTA TR 002:2000].
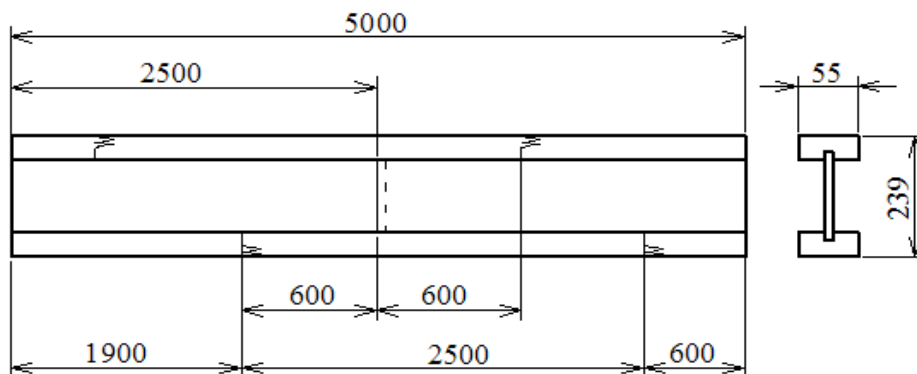

Fig. 4. Size and position of the joints of the tested I-joists

Samples were tested using a method for loading scheme described in the technical report EOTA TR 002 [EOTA TR 002:2000]. The standard prescribes the technique for detection of modulus of elasticity and flexural strength for I-joists. The basic principle of the test is detecting the flexural break strength and modulus of elasticity in two points of support. Loading from above is performed in two points in the sample. The distance between the lower support points is 18 times the depth of the sample. The distance between the loading support points is equal to 1/3 of the distance between the lower support points. The testing device Instron KN600 with a loading accuracy of ±0.1 N was used. For the material deflection measurement, the force sensor of the said device was used with a measurement accuracy of 0.01 mm. Additionally, the moment of resistance M_U and stiffness EI were calculated.

The moisture content of each sample was determined as close as possible to the location of the fracture and investigated for each sample according to EN 13183-1 [EN 13183-1:2003]

Results and discussion

Out of five pre-manufactured I-joists, peak load was detected in four. One I-joist started buckling on the side in the pure bending area, therefore loading was stopped. Buckling started at 8882 N of applied force and at 43.5 mm deflection. Additional preparation of another five I-joists was done to check if the buckling was accidental or not. After collecting the data of all ten tests only one test buckling was shown.

As anticipated, all nine other I-joists broke in the tensile shelf connection point. In three cases out of nine, when breaking the shelf at the connection point,

the breakage expanded further across the web. In one case, breakages expanded along the glue joint between flanges and web until the middle of the I-joist and along the glue joint between webs (fig. 5).

Fig. 5. Failure of I-joist

Statistical data processing results were gathered in table 2. Calculations are made using the methodology of the European Technical report [EOTA TR 002:2000]. All the characteristics were calculated using the Microsoft Excel software program.

Table 2. Results and statistical data

Characteristics	Peak load F, N	Bending strength f_b, N·mm⁻²	Modulus of elasticity E, N·mm⁻²	Max. strain w, mm
Average x_{vid}	10893	53.8	7934	48.5
Standard deviation s	577	4.13	599	3.54
Coefficient of variation v	5.3%	7.7%	7.6%	7.3%

Statistical data processing results of the tests indicate that sample production and strength indicator detection were performed correctly. This is evidenced by the fact that the coefficient of variation of both the measured indicator values are not more than 10% t.i. which is relatively small.

To prove the accuracy of selecting the I-joist structure, it is possible to compare the basic indicators with those of double T-beams already offered in the market (table 3). I-joists with similar dimensions were selected for comparison of the indicators. An oriented strand board (OSB), 10 mm thick, was used in

making all the I-joist webs. Solid timber was used in making the I-joist flanges produced by the company Nascor. Other manufacturers used Laminated Veneer Lumber (LVL), 38 and 39 mm thick, in making I-joist flanges. As mentioned before, the weakest spot in the I-joist is its lower shelf connection because flanges are fused with a finger joint connection which is intended for splicing solid timber. Therefore, it is predictable that the I-joist would break at the connection point. This connection is the determining factor of I-joist break strength. In order to make a fair comparison of mechanical properties of tested I-joists and double T-beams from other manufacturers, as well as similar construction materials, I-joist strength indicators will be calculated based on the obtained data.

Tested I-joists were produced individually with equipment different from that intended in the research, as well as using other brands of glue. Shelf connection dimensions are also different from the ones intended in the project. The upper part of connection was made straight, not angled. It was not possible to utilize a scarf joint with the available equipment; therefore, the obtained I-joist strength indicators are approximate.

Table 3. Mean values of carried research and other I-joist producers' characteristics

Producer	I-joist cross section dimension, mm	I-joist cross section area, mm, cm^2	I-joist weight, kg·m^{-1}	Moment of resistance M_U, kN·m	Stiffness $(EI)_{I-joist}$, N·mm^2·10^{12}
Tested I-ioists	55.3×239.4	49.1	4.38	8.94	0.678
Nascor	64×241	65.1	3.43	5.19	0.519
Kronopol	58×241	60.6	–	4.19	–
Finnioist	58×240	61.7	3.42	12.57	0.614
IPI	58.7×241	62.1	–	5.13	0.605
Georgia Pacific	58.7×241	62.1	4.23	4.19	0.573

The data gathered in table 3 allow us to conclude that in several cases the stiffness constant E·I values are higher in the tested I-joists than equivalent indicator values of the offered I-joists. It is worth mentioning that in all cases the width, depth and consecutively the cross-sectional area of the tested I-joists are slightly smaller than the relevant indicators of offered I-joists. Compared to previous research done by Ohashi et al. [2010] the moment of resistance of the tested I-joists were lower, but not more than 10% and the difference of stiffness was not significant.

The indicator by which the tested I-joists are significantly lagging behind the other ones is their own mass [Wood I Beam Advantages over Conventional

Lumber 2009]. When compared to I-joists produced by other producers, the self--mass of one metre is the highest one. Previous theoretical analyses indicated that web crippling performance was improved by increasing the number of web plies with the grain perpendicular to the horizontal I-joist axis [Leichti et al. 1990]. Failure test results by Ohashi et al. [2012] showed that the shear stiffness and shear capacity of the diagonal plywood web types was higher than perpendicular plywood web. In this case, further research with a diagonal plywood web could be done to increase the properties of tested I-joists.

Conclusions

1. Mean peak load of the tested I-joists was F = 10893 kN, modulus of elasticity E = 7934 N·mm^{-2} and maximum deflection 48.5 mm.
2. Mean moment of resistance of the tested I-joists M_U = 8.94 kN·m and average value of stiffness $(EI)_{\text{I-joist}}$= 0.678·10^{12} N·mm^{-2}.
3. The I-joists simple structure gives the opportunity to utilize plywood coarse waste of different dimensions.
4. Compared to other I-joist producers, the tested I-joist mass by 1 metre was the highest one, stiffness was the lowest one and the moment of resistance is comparable.
5. Research should be continued with different orientations of plywood fibres that can increase the properties of plywood I-joists.

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List of standards

EOTA Technical Report TR 002:2000 Test methods for light composite wood-based beams and columns

European Technical Approval ETA-06/0238:2011 Light composite wood-based beams and columns for structural use

EN 314-1:2005 Plywood – Bonding quality – Part 1: Test methods

EN 314-2:2000 Plywood – Bonding quality – Part 2: Requirements

EN 13183-1:2003 Moisture content of a piece of sawn timber – Part 1: Determination by oven dry method

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