

Experimental and Numerical Identification of Veneers Mechanical Properties

Edgars Labans, *Riga Technical University*, Kaspars Kalninsh, *Riga Technical University*,
Olgerts Ozolinsh, *Riga Technical University*

Abstract. Computational modelling is an effective tool for development of innovative solutions from cross-ply laminates such as plywood. In order to assure accuracy of such method predetermined material properties should be evaluated. Moreover numerical simulations should be validated with the physical experiments under various loading conditions. The aim of current research was to determine elastic properties for individual veneer specimens in order to evaluate the input data for further plywood products analyses using FEM commercial code ANSYS. Therefore more than 250 unidirectional veneer specimens with different thicknesses have been tested. These acquired values have been verified using FEM analysis and afterwards used in validation of bone shaped plywood tension test specimens. Some conclusion has been drawn to narrow down the confidence bounds for mechanical properties to be used in design of plywood panels.

Keywords: veneer mechanical properties, plywood, tension tests, ANSYS

INTRODUCTION

Due to continuous supply and demand as well as established processing traditions for wood products the plywood industry, remains one of the most perspective industries in Latvia [1]. Nevertheless to withstand the future competition for innovative wood products solutions, elaboration of the designs and production technologies are demanded. Currently perspective research area is associated with plywood sandwich panel designs which could be made from high quality plywood outer plates and low density material or modified plywood as core structure.

Finite element method (FEM) codes like ANSYS [2] or ABAQUS [3] are utilised by all industries to automate the design process and to simulate the complex behaviour of products under various load conditions. Therefore parametric numerical model allows reducing the designing costs associated with prototype manufacturing and testing [4]. However in order to run FEM simulation, a real single ply – veneer [5] material properties are required. Such material properties (Young modulus, Poisson's coefficient and ultimate strength) reported in respectable literature [6,7] is for traditional stacking sequence for plywood thus adequate for theoretical calculations and not suitable for FEM analyses. Evidently for a single layer modulus of elasticity is more affected by micro cracks [8] appearing after peeling process and hot pressing, thus obtained material properties has larger scatter and are less robust to be used in numerical simulations.

The mechanical properties obtained from unidirectional veneer specimen tests has been incorporated and validated in multilayer bone shaped plywood specimen numerical and experimental tests. Acquired values will be used for further research as input data to improve accuracy of plywood sandwich panel parametric model in ANSYS environment.

Veneer specimens

To determine veneer mechanical properties, more than 250 test specimens have been produced at the Lignums factory (AS "Latvijas Finieris") according to the plywood manufacturing practice.

The specimen production process has been initiated with preparation of the test plates and the clamping plates. In total of four full scale (600 x 900 mm) plywood plates had been produced to cover the full range of the test requirements. Specimen production was realized in same way as plywood manufacturing process, initiated with glue covering and then cold preloading following the compression in the hot press at 140°C degree temperature. The first plate was made out from dried single veneer sheet, with average thickness of $T1=1.55$ mm. The second plate was made from single veneer sheet compressed in the hot press with average thickness $T1=1.46$ mm. The third plate produced from two veneers and glued together using the hot press, thus average thickness $T1=2.7$ mm. The same process has been used to produce the last - three layer plate with average thickness of $T1=4.03$ mm. Before the final plate assembly, additional clamping plates have been added at the ends of these specimens to secure fastening zone protection against the local stresses. Clamping plates was produced from one veneer ply and attached perpendicularly to the specimen fibre direction. The specimen geometrical characteristics (Figure 1.) has been made according to ASTM D3039 [9] for composite laminate tension test where length $L=300$ mm, width $B=20$ mm, 25 mm and 30 mm. The Cover plate length $L1$ is 100 mm. Were produced specimens with longitudinal and perpendicular wood fibre orientation to specimen length. In total of 220 specimens where tested with longitudinal wood fibre orientation where 120 specimens had width of 20 mm, 60 specimens had width 25 mm and 40 specimens had width 30 mm. Besides additional 50 specimens with perpendicular orientation of the fibres and width 20 mm has been tested.

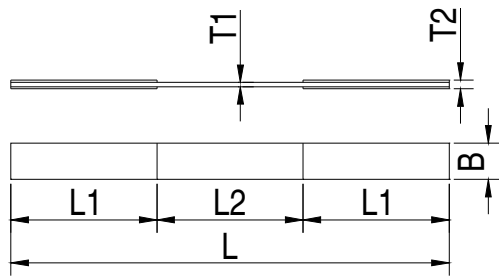


Fig. 1. Geometry of veneer specimen

Some manufacturing difficulties have been reported during the manufacturing process of the specimens, in particular once one side was assembled with the adhesive clamping plates and compressed, significant bending deformations occurred from unbalanced load distribution. To glue another clamping plate from other side, base plate has been straighten by loading addition thick plywood plates on it. As clamping plates was glued on slightly bent surface, thus displacement of 1 – 15 mm from predicted position occurred. After final specimen production phase the discrepancies were observed like clamping plates was not fully attached lesser specimens has been cut than initially designed.

Moreover to validate acquired mechanical properties from unidirectional specimens additional 28 bone shaped plywood specimens have been tested in tension according to NF B 51-123 [10] (dimensions at Fig.2). Such specimens are used by AS “Latvijas Finieris” for quality control of plywood’s ultimate stresses and for determination of modulus of rigidity.

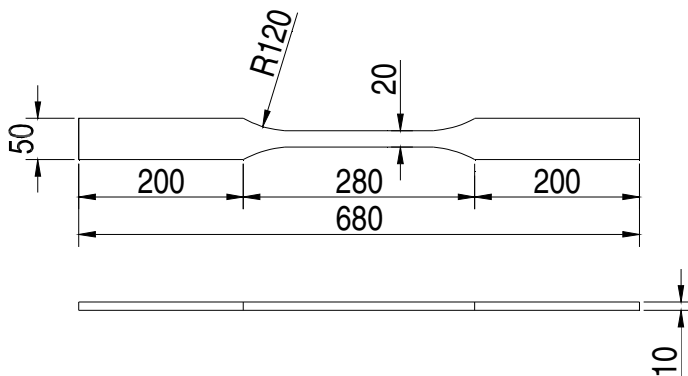


Fig.2. Geometry of plywood specimen

Experimental set-up

All tension tests has been realised at the Riga Technical University in the Institutes of Materials and structures testing laboratory. The universal testing equipment INSTRON 8802 (see. Fig. 3.) and INSTRON 8872 (see. Fig.4.) (for specimens with perpendicular fibres direction) has been used. More detailed technical specification can be found in www.ims.rtu.lv.



Fig.3. Specimen tension test on INSTRON 8802

The distance between the clampings/grips $L2$ has been assumed to be constant 100 mm and all tests was realised with loading speed of 1mm/min until ultimate failure. To measure the specimen deformation on the ZWICK Z100 (Fig. 4) testing machine were used laser extensometer BTC-EXOWMST.H01 and grip displacement measurements, the load measured was measured by standard 10kN load cell. To verify the test results the INSTRON 8802 testing machine was utilised where deformations was measured using INSTRON 2620 series dynamic extensometer [11] together with the grip displacement readings. The specimen dimensions as well as failure mode was recorded for each test sample.



Fig. 4. Specimen tension test on ZWICK Z100

The same testing procedure was realised on 7-ply plywood tension specimens (12 with longitudinal outer fibres and 16 with perpendicular outer fibres). The NF B 51-123 [10] test setup is shown in Figure 5 together with the dynamic extensometer.

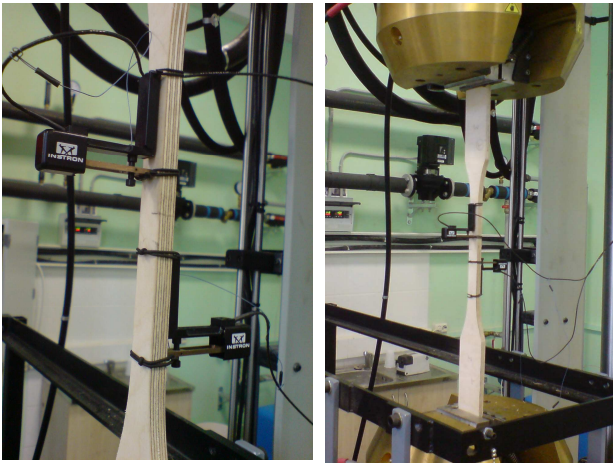


Fig. 5. Plywood specimen tension test on INSTRON 8802

Testing verification

Some testing inconsistencies revealed by performing tension tests, in particular the laser extensometer on ZWICK Z100 (Fig.6) machine are lacking robustness when plywood specimens are tested. This is due to wood specimen fibre alignment what creates numerical discrepancy once relative displacements have been registered. The wood microheterogeneous structure cause trapping of the laser measurement once the fibres start to open and unparallel cracks propagate along the specimen. As sketched in figure 7, once micro crack separate the laser measuring zone, the laser probe can not be used for measurement as the same measurement are have bidirectional movement. This leads to the principle that results can not be retrieved from such specimen tests. (Fig. 8). An alternative engineering solution would be to attach the paper labels which would cover the local micro crack propagation and global deflection could be measured.

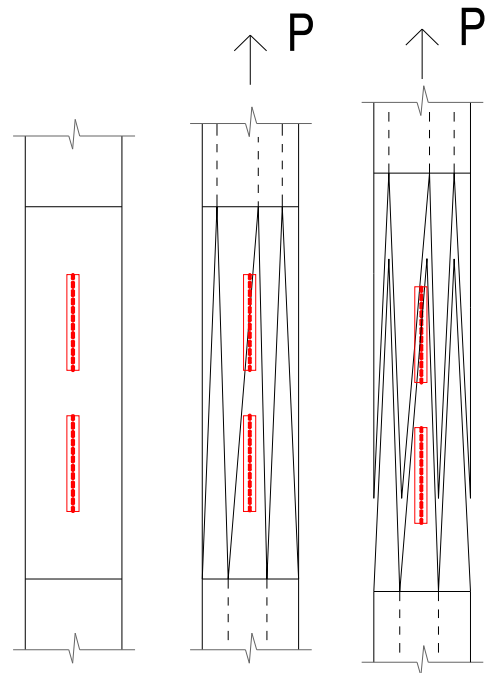


Fig. 7. Laser extensometer measuring zones (red dots) and tension behaviour of wood micro cracks under tension load

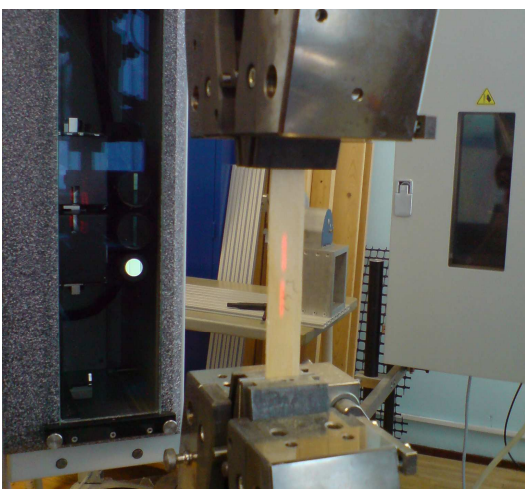


Fig. 6. ZWICK Z100 laser extensometer measuring the plywood specimen

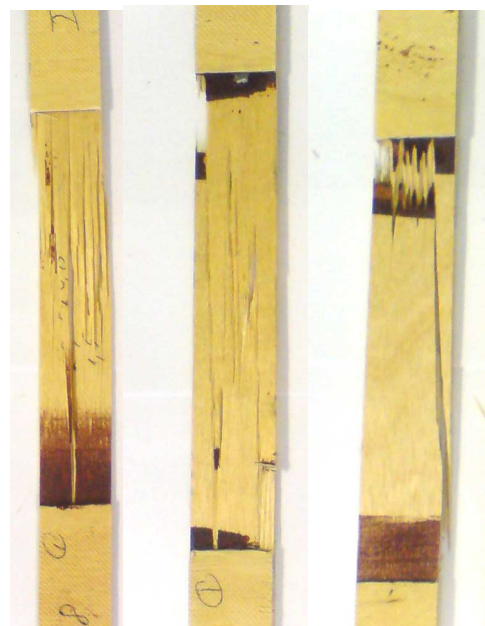


Fig. 8. Specimen failure mode cases misleading the laser extensometer measurements

Furthermore testing verification revealed that grip sliding can be observed on ZWICK Z100 machine which cause up to four times displacement discrepancies if the load cell displacement readings are used. Therefore by performing initial calculations for modulus of elasticity a modulus of elasticity has been recorded three times lower than average

value associated with plywood specimens – 10 GPa. Nevertheless the results from an extensometer and load cell on INSTRON 8802 test equipment had practically no distortion which is due hydraulic grip anti sliding properties. This resulted that extracted data from ZWICK Z100 machine was used solely for determination of the ultimate stresses, because ultimate force was validated with measurement from the INSTRON 8802. The servohydraulic test supremacy is associated with specimen fastening system which by increment of applied load increases the pressure on test specimen. Considering that load for specimen destruction is not high (about 5 % of machine power) complete specimen clamping during loading process might not be reached. Using INSTRON 8802 machine such fault wasn't observed because of automatic fastening plates pressing with pre-defined load.

RESULTS AND DISCUSSIONS

By performing specimen's tension tests modulus of elasticity and breaking tensile stress and also maximal and minimal values of these properties has been estimated. For specimens with wood fiber orientation parallel to the specimen longitudinal direction, values of elasticity's modulus are shown in Table 1.

TABLE 1

Modulus of elasticity for specimens with parallel orientation of fibres [GPa].

Type of specimen	Specimen width, mm		
	20	25	30
Laminated	Avg.		16.96
	Max - Min		max.17.51 min.16.49
1 ply compressed	15.97	15.66	14.54
	max.17.06 min.14.58	max.17.53 min.14.77	max.14.86 min.14.32
1 ply	15.19	14.61	13.99
	max.16.32 min.13.68	max.15.10 min.14.04	max.14.96 min.12.21
2 ply	14.36	14.22	13.95
	max.15.60 min.13.17	max.14.63 min.13.86	max.14.37 min.13.73
3 ply	13.26	13.39	11.99
	max.13.21 min.12.45	max.13.55 min.13.18	max.12.22 min.11.65

Values from table 2 were used to make graphic of dependency modulus of elasticity from specimen cross section dimensions (Fig. 9.)

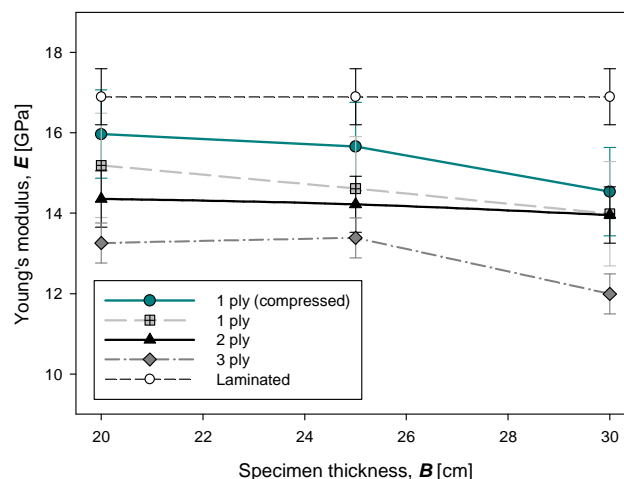


Fig.9. Modulus of elasticity versus specimen thickness

Average value of modulus of elasticity is 14.81 GPa. For specimens with fibre orientation perpendicular longitudinal direction, average modulus of elasticity is 0.5GPa. It has been achieved that the greatest modulus of elasticity are for 1-ply specimen impregnated with glue and produced under the pressure. By increasing thickness of the specimen, the modulus of elasticity decreases until average value of 13.26 GPa. It could be explained by wood defects appearing in thicker specimen's cross-section. Similar tendency to decrease modulus of elasticity gives the increasing width of specimens from 20 mm to 30mm. Most robust results from all specimens have specimens made from 2 unidirectional veneers – difference between modulus of elasticity for specimens with 20 mm and 30 mm width vary only 3.5 %. For other specimens results difference between specimens with various width from 5-15 %.

Average breaking tensile stress for specimens with fibers orientation parallel to specimen longitudinal direction is 125 MPa (maximal value 149 MPa, minimum 104 MPa). Breaking stress has tendency to increase with specimen width, difference between specimens with 20 mm and 30 mm thickness about 10 %. To summarise an average values of acquired modulus of elasticity for plywood specimens are as follows: for specimens with outer fibers direction longitudinal 9.75 GPa (maximal value 11.39 GPa, minimum 8.07 GPa), for specimens with outer fibre direction perpendicular to specimen length average value of elasticity's modulus 8.14 GPa (maximal value 10.20 GPa, minimum 5.52 GPa)

Average breaking tensile stress for specimens with fibres orientation parallel to specimen longitudinal direction is 72 MPa, for specimens with perpendicular fibre orientation 54 MPa.

FEM ANALYSIS

Using FEM commercial code ANSYS v.11 [2] has been simulated tension tests for 7-layer plywood specimens with extended endings as shown in (fig. 10). Initial unidirectional specimen simulation results have been verified with physical tests in order to estimate finite element mesh density. The

bone shaped specimen has been modelled using ANSYS 4-node shell element SHELL 181. It was assumed that each ply has thickness of 1.35 mm. Plywood stacking sequence has been modelled assuming that each layer is perpendicular to the upper and lower one, as plywood consists of an odd number of plies.

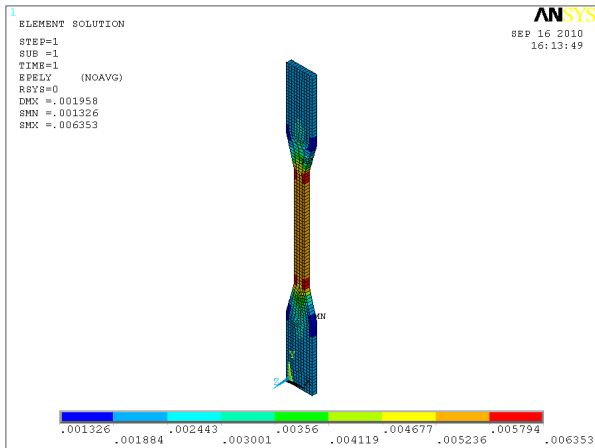


Fig. 10. Plywood specimen FEM model

For robustness analysis mechanical properties has been used as variable parametrical input data. An average values of bi-directional Young modulus, Poisson's ratio and shear modulus were assumed as – 16 GPa for E_x in fibres longitudinal directional and 0.5 GPa for E_y in perpendicular direction. In order to asses the robustness of the numerical and physical tests the load/strain field plot has been drawn as shown in (Fig. 11, 12). The field describe the min. and max. bounds between the experimental and numerical results and an overlapping are outlines the concurrence between them. It may be observed a slight underestimation by FEM analysis when similar min/max values are used.

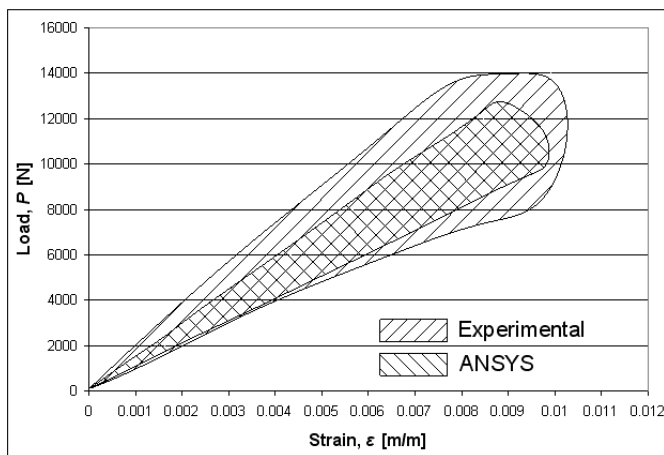


Fig. 11. Load and strain curves for plywood specimens with perpendicular orientation of the outer wood fibres

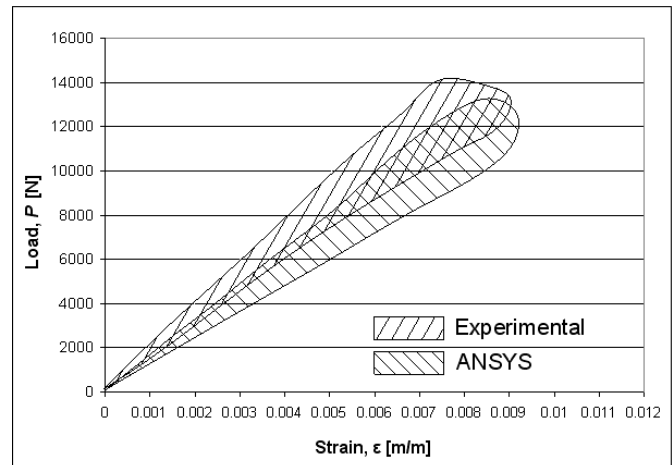


Fig. 12. Load and strain curves for plywood specimens with longitudinal orientation of the outer wood fibres

NUMERICAL CALCULATION

Effective modulus of elasticity E_{ef} using numerical calculation could be determined analytically by using equation (1).

$$E_{ef} = \sum_{i=1}^n \frac{A_i}{A} E_i \quad (1)$$

A_i – cross-section area for each layer

A – cross-section area of plywood structure

E_i – modulus of elasticity for individual layer

It has been assumed that all plies have similar thickness and modulus of elasticity for longitudinal wood fibre orientation - 16 GPa and for perpendicular to fibre orientation - 0.5 GPa. Acquired effective modulus of elasticity for plywood specimens with longitudinal orientation of outer fibres - 9.36 GPa, for specimens with perpendicular orientation of outer fibres – 7.14 GPa. It should be noted that there is no dispersion of results, because area relation of perpendicular and parallel plies remains constant. In addition average values of analytically acquired values have been compared with numerically and experimentally acquired results are shown in (fig. 13).

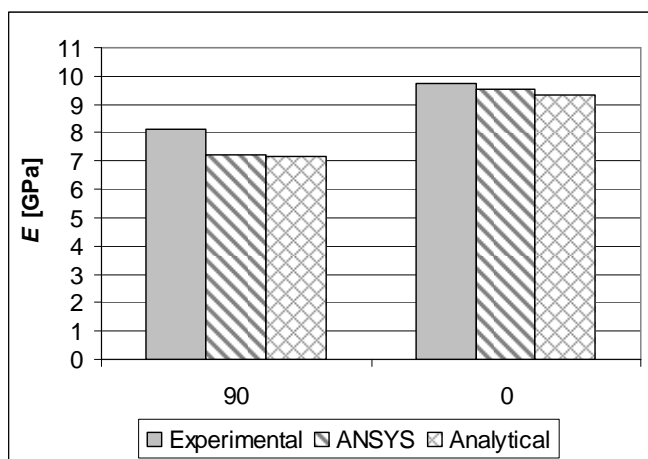


Fig.13. Comparisons of modulus of elasticity

As illustrated in Figure 13, results for specimens with longitudinal orientation (0) of outer wood fibres has low variations resulting in 4 % discrepancy. Meanwhile specimens with perpendicular orientation (90) of outer wood fibres have significant difference between experimental and numerical values of modulus of elasticity resulting in 12 % discrepancy. This could be explained by wide dispersion of experimental results once specimens with perpendicular stacking sequence are tested.

CONCLUSIONS

The unidirectional veneer mechanical properties has been extracted by performing tension tests for the small size veneer specimens, which served as input data for validation between the plywood bone shaped numerical and physical results. Acquired accuracy range using these values of modulus of elasticity was in range of 5-15 %. During physical experiments it has been noticed that laser extensometers from ZWICK Z100 testing machine are not suitable for wood specimen testing. Further physical tests should be performed to determine precise influence of Poisson's ratio and values for shear modulus in order to improve and to optimize parametrical model of plywood sandwich panels.

Edgars Labans, Kaspars Kalniņš, Oļģerts Ozoliņš. Finiera mehānisko īpašību eksperimentāla un skaitliska identifikācija

Datorsimulāciju izmantošana mūsdienās kļuvusi par efektīvu līdzekli inovatīvu uz saplākšņa un citu līmētu materiālu bāzes veidotu produktu izstrādē. Taču, lai nodrošinātu šādas metodes precizitāti, nepieciešami materiāla īpašību pētījumi, kā arī skaitlisko simulāciju validācija ar eksperimentāliem rezultātiem dažādos slodzes apstākļos. Dotā darba mērķis ir noteikt atsevišķu finieru elastīgās īpašības, lai to vērtības varētu izmantot kā ievaddatus turpmāku saplākšņa produktu izstrādei uz galīgo elementu bāzes (GEM) veidotā datorprogrammā ANSYS. Darbā tika veikti laboratorijas testi vairāk nekā 250 dažāda biezuma un platuma finiera paraugiem ar atšķirīgu šķiedru orientāciju. Iegūtās vērtības tika verificētas, izmantojot GEM aprēķinu kaula formas saplākšņa parauga stiepes datorsimulācijai. Tādiem pašiem paraugiem tika veikti arī laboratorijas testi, lai pārbaudītu aprēķina rezultātus. Pētījuma rezultātā tika noteiktas finiera mehānisko īpašību robežvērtības, kuras var pielietot saplākšņa produktu skaitliskos aprēķinos. Izmantojot iegūtās vērtības, tika novērtēts skaitlisko aprēķinu konfidences intervāls salīdzinājumā ar laboratorijas eksperimentiem.

Эдгарс Лабанс, Каспарс Калниньш, Ольгертс Озолиньш. Экспериментальная и численная идентификация механических свойств шпона

Использование компьютерных симуляций является эффективным средством для разработки инновативных материалов на базе фанеры и других клееных материалов. Но для того, чтобы обеспечить точность такого метода, нужны исследования свойств материала и верификация компьютерных симуляций с лабораторными исследованиями. Цель работы - определить эластичные свойства шпона, используя образцы небольшого размера, и использовать полученные данные как вводимые данные для параметрической модели сэндвич-панели с гофрированным ядром в коммерческом пакете МКЭ ANSYS. Было проверено свыше 250 образцов шпона разной толщины и ширины. Валидация параметрической модели была произведена с использованием МКЭ расчета для образца фанеры на растяжение. Для таких же реальных образцов был произведен тесты в лабораторных условиях. В результате исследования были выявлены механические свойства материала, подходящие для проектирования продуктов из фанеры. Используя полученные данные, был определен интервал точности расчетов по сравнению с лабораторными экспериментами.

REFERENCES

1. **Zudrags K., Kalnins K., Jekabsons G., Ozolins O.** Bending properties of plywood I-core sandwich panel. The Nordic-Baltic Network in Wood Material Science and Engineering. *In: Proceedings of the 5th meeting*, Copenhagen, (2009), 169-175.
2. *ANSYS Version 11. User Manual*, Papenburg, USA, (2009).
3. *ABAQUS Online Documentation: version 6.8/ Dassault Systemes*, (2008)
4. **Mackerle J.** *Finite element analyses in wood research: a bibliography*. Wood science and technology (2005) 39: 579-600
5. **Wu Q, Cai Z, Lee JN.** Tensile and dimensional properties of wood strands made from plantationsouthern pine lumber. *For Prod J* (2005) 55(2):87-92.
6. *Wood Handbook: Wood as Engineering material. Specialty treatments*. General Technical report 113. US Department of Agriculture, Forest service, Forest products laboratory, Madison, Chapter 4, 4-6, (1999).
7. *ENV 1995-1-2:1994, Eurocode 5 Design of timber structures – Part 1-1: General – Common rules and rules for buildings*. European Committee for Standardization (CEN), Brussels, Belgium (1994)
8. **Sturzenbecher R., Hoffstetter K., Bogensperger T., Schickhofer G., Eberhardsteiner J.** *Development of high performance strand boards: engineering design and experimental investigation*. In: Wood science and technology (2010) 44: 13-29
9. *ASTM D3039 / D3039M - 08 Standard Test Method for Tensile Properties of PolymerMatrix Composite Materials*.
10. *NF B 51-123, Wood-based panels, Détermination du module d'élasticité en traction et de la résistance à la traction parallèle aux faces*, (1987)
11. http://www.instron.co.uk/wa/acc_catalog/prod_list.aspx?cid=828&cname=Dynamic%20Axial%20Clip-on%20Extensometers (29.sept. 2010)

Edgars Labans Born in Ludza 1986, currently M.sc. student at Riga Technical University faculty of civil engineering. Main research interest associated with wood based material and structural design.
E-mail: edgars.labans@rtu.lv

Kaspars Kalnins Born in Riga 1980, graduated from Riga Technical University earning Ph.D in solid mechanics. Main research interest associated with composite material numerical analysis, optimisation and physical testing.
E-mail: kaspars.kalnins@sigmanet.lv

Oļģerts Ozolins Born in Riga 1975, graduated from Riga Technical University earning Master degree in civil engineering. Main research interest associated with composite material numerical analysis and physical testing.
E-mail: olģerts@bf.rtu.lv