PART 2.– INFORMATION ABOUT PROJECT

2.1. Project Nr.2

Title	***Innovative and multifunctional composite materials for sustainable buildings***
Project leader's name, surname	Kaspars Kalniņš
Degree	Dr.sc.ing.
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2.2. Tasks and deliverables

(List all tasks and deliverables that were planned for reporting period, list responsible partner organizations, give status, e.g. delivered/not delivered)

Development of sandwich panels from raw resources available in Latvia – birch plywood. Developed product should maintain stiffness/strength comparing to the conventional plywood boards meanwhile assuring weight saving and improving impact resistance, vibration damping and heat isolation properties.

Tasks of the project

- Experimental investigation of separate sandwich panel components as experimental investigation of finished prototypes
- Development of design methodology based application of FEM and validated numerical models.
- Laboratory scale sandwich panel prototyping and development of recommendations for manufacturing scale-up

Time frame for the core tasks is given in Annexes 2A

In addition, specific tasks related to completing core tasks of each Project parts are defined in every Period of the Project corresponding to the calendar year.

Nr.	Tasks	Deliverable	Responsible partner	Status
1	Plywood sandwich panels with I-type stiffeners and improved vibration damping and impact properties	Report (technology/models) 27.05.2016.	K. Kalnins, Institute of Materials and Structures, RTU	In progress
2	Quality control and characterisation of load bearing capacity	Report (method) 30.01.2017.	K. Kalnins, Institute of Materials and Structures, RTU	In progress

3	Design guidelines for plywood panels with I-type stiffeners	Report (method) 30.09.2017.	K. Kalnins, Institute of Materials and Structures, RTU	In beginning
4	Prototyping method for plywood panels with I-stiffener core	Report (method) 28.02.2017.	K. Kalnins, Institute of Materials and Structures, RTU	In beginning
5	Manufacturing scale-up	Report (recommendations) 30.12.2018.	K. Kalnins, Institute of Materials and Structures, RTU	In beginning
6	Evaluation on domestic economic impact	Report 30.12.2018.	K. Kalnins, Institute of Materials and Structures, RTU	In beginning

In case of non-fulfilment provide justification and describe further steps planned to achieve set targets and results

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2.3. Description of gained scientific results

(Describe scientific results achieved during reporting period, give their scientific importance)

Time frame for the Core task 1 is given in Appendix 2-A.

Tasks allocated for 2st reporting period	Core achievements
WP-1: Elaboration of physical properties of polyurethane foam for determination of thermal conductivity/vibration and impact absorption for multifunctionality of sandwich I-core panels.	***Performed experimental investigation on vibration damping and impact resistance on the plywood sandwich panels with vertical stiffeners and foam core.***
The aim of current task was to assess vibration damping and impact properties of polyurethane foam. A dedicated reference birch plywood panels and sandwich panels with various core materials as cork, polystyrene, polyisocyanurate and natural rubber has been produced and tested. A major contributor as JSC "Latvijas Finieris" and Meža Nozares kompetences centrs (Forestry competence centre of Latvia) has been given by providing a series of specific reference and various core specimens. This synergy brought a large database of plywood fracture and damage properties as well as vibration damping and impact resistance ones. The vibration damping properties extracted from natural frequencies and modal tests of series of specimens with different core types has been achieved. A laser scanning equipment POLYTECH PSV400 has been employed. Specimens were attached to the steel frame with cables to achieve non-affecting free-free boundary conditions. Full-field mobile scanning head makes non-contact acceleration measurements on specimen surface at all frequency spectrum. Besides acquiring natural frequencies, one advantage of modal analysis set up is a determination of modal damping factor (loss factor) according to ASTM E756. General trend in Figure 1. shows only a small increment of loss factor comparing to reference birch plywood. However more significant tendency is a decrease of loss factor for sandwich panels with foam filler, comparing with reference one. Most obvious reason for this trend is additional stiffness reinforced by foam core. Acquired results also possess high scatter of experimental values which	

could be reduced by increasing number of tested panels.

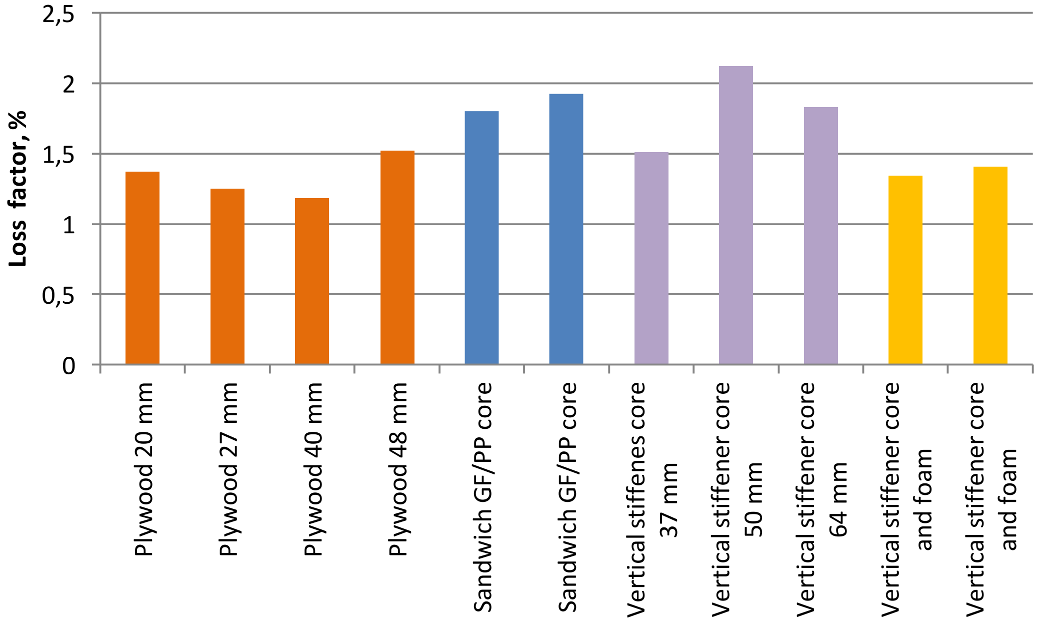

Figure 1. Loss factor for natural-frequency for reference and sandwich panels

In order to evaluate the impact load resistance of plywood sandwich panels with different core types a series of tests of low velocity impact has been conducted on INSTRON Dynatup 9250HV drop tower. Test procedure and specimen dimensions have been taken according to standard NF B51-327 - Plywood Dynamic Punching Test. The resistance to cracking and penetration should be determined by measuring the height of mass falling on square shaped specimen. Obtained results confirmed that impact resistance of specimens is heavily dependent on impact location – hit on stiffener our in between the stiffeners for stiffened sandwich panels. Much less energy is needed to perforate specimen skin between stiffeners comparing to impact directly on stiffener - difference between the impact on stiffener and between stiffeners varies at least twice. Penetration energy for rib-stiffened sandwich-specimens with and without core foam filler is at least doubled the magnitude.

WP-2: Extension of design methodology for sandwich panel design based on simulations of finite element method and optimisation of obtained physical results. Initial verification of test results and validation of produced prototypes and scale up structures.	***Validation of the numerical model by 4-point bending and thermal conductivity tests***

The aim of current task was to initiate numerical simulations in order to estimate theoretical advantages of polyurethane filled sandwich panel thermal and stiffness properties versus birch plywood.

A thermal model of the cross-section numerically represented in a 2D model with PLANE55 elements. Steady state analysis with loads applied to the temperature on lower and upper nodes of the mesh. Results in Table 1 shows that numerical analysis has a capability to forecast effective thermal conductivity; however, it shows lower values than in case of experimental tests by Linseis FHM 300 apparatus.

Table 1. Comparison of experimental and numerical results

Number of stiffeners	Effective thermal conductivity, mW/m·K		Δ,%
	Experimental result	Numerical result	
3	68.3 (0.4)	56.5	17.3
4	73.5 (2.1)	58.4	20.5

In addition a set of bending tests on INSTRON 8802 has been conducted to verify and to confirm the maturity of numerical model. The comparison of load/deflection curves is given in Figure 2 align to test set up of plywood polyurethane foam sandwich panel.

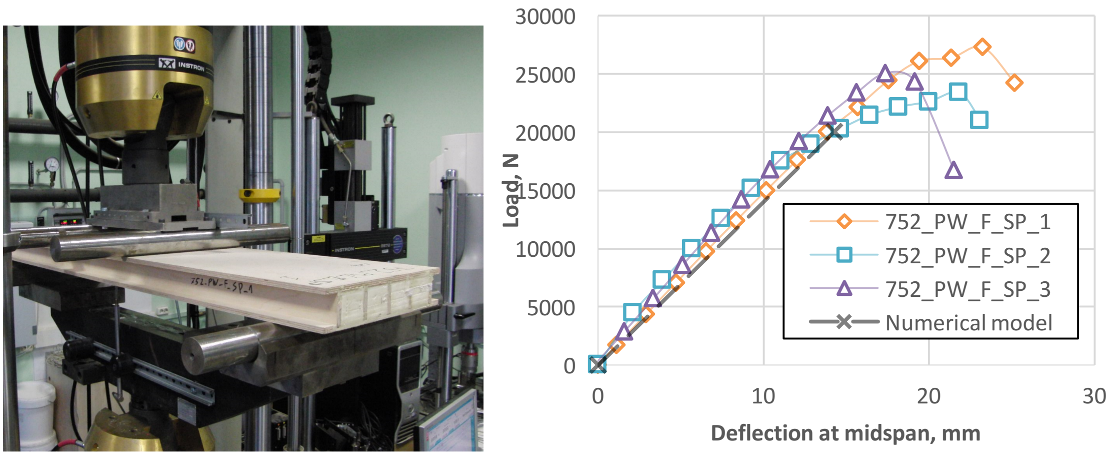

Figure 2. Test set-up and load/deflection curves for rib stiffened panels

WP-3: Laboratory scale-up prototyping of developed sandwich panels, extension of chemical composition of polyurethane foam composition for improved adhesion and workability.	***Several series of preliminary prototypes of stiffened sandwich panels with various polyurethane foam core has been produced.***

The focus of current task was to assess the most appropriate polyurethane foam applicability and corresponding recipe. Moreover in order to deliver preliminary prototypes a risk assessment was required for further improvement of production equipment and technology.

Initially a special attention was given to renewable raw materials in order to obtain high density PU foams. From thermo gravimetric (TGA) analysis of PU foam material tall oil (TO) based polyols were selected to develop two type rigid PU foams, polyurethane foams with isocyanate index 110 and polyisocyanurate (PIR) foams with isocyanate index 250. TO polyol contains teritary amine groups what gives autocatalytic properties for PU foam formulation. Such polyol is more suitable for PIR foam production, also PIR foams have higher thermal stability which is desired property for materials that will be used in potential fire hazard risk applications. The developed PU/PIR foams were analysed using TGA equipment and mass loss curves in nitrogen atmosphere were obtained. The first mass los step at 190 ºC in TGA curves is related to evaporation of liquid flame retardant - TCPP. For PU foams with isocyanate index 110 mass loss of soft segment degradation products is seen at 260 ºC. Such degradation stem is not seen for PIR foams with isocyanate index 250 because it is highly crosslinked polymer materials with small soft segment content. The degradation products of hard segments are released at 335 ºC and final release of heavy aromatics and pyrolysis products is seen at 390-470 ºC. This study confirmed that there are available solutions for fire retardant sandwich panel development.

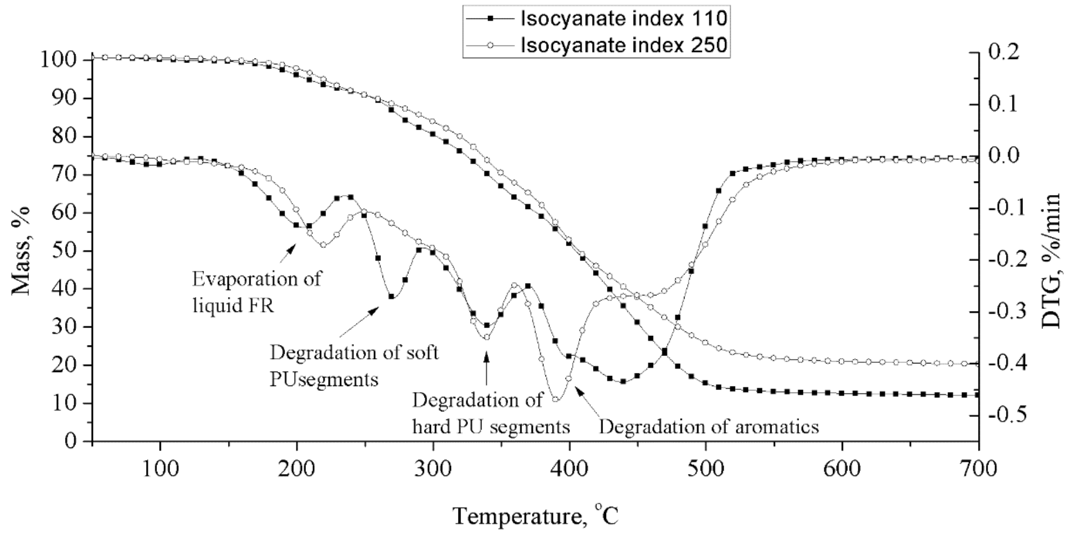

Figure 3. Thermo-gravimetric curves for specimens with different isocyanine index

PU foam (made of partially renewable components) has been filled in sandwich panels with vertical stiffeners to improve heat insulation properties. Foam mixing and filling tasks have been made on adjusted equipment in cooperation with Latvian State Institute of Wood Chemistry. The main challenge was providing of sufficient flatwise pressure to prevent face movement during chemical reaction of the foam. Achieved results (cross sections with and without foam) shown in Figure 4 shows that foam filling technology could be improved to make foam structure more uniform in next trials.

Figure 4. Sandwich panel initial prototype with and without polyurethane foam.

2.4. Further research and practical exploitation of the results

(Describe further research activities that are planned, describe possibilities to practically exploit results)

WP-1*:* Elaboration of physical properties of polyurethane foam for determination of thermal conductivity/vibration and impact absorption for multifunctionality of sandwich I-core panels.

Main results in 2nd review period

- Produced a database of impact resistance test results for reference plywood boards.
- Produced a database of impact resistance test results of plywood sandwich panels with and without foam core filler.
- Produced a database of vibration damping properties for reference plywood panels
- Produced a database of vibration damping properties for reference plywood specimen's panels with and without foam core filler.

Further work:

- A database of various density foam core adhesion and thermal conduction properties.

WP-2: Extension of design methodology for sandwich panel design based on simulations of finite element method and optimisation of obtained physical results. Initial verification of test results and validation of produced prototypes and scale up structures.

Main results in 2nd review period

- Performed experimental validation of numerical models based of FEM.
- Evaluated and verified stiffness of rib-stiffened panels with and without foam filler.
- Performed experimental validation of thermal models based for effective thermal conductivity.

Further work direction:

- Further validation of the numerical model also introducing failure criteria
- Improving input data quality for better model performance

WP-3: Laboratory scale-up prototyping of developed sandwich panels, extension of chemical composition of polyurethane foam composition for improved adhesion and workability.

Main results in 2nd review period

- Prototyped several series of rib stiffened sandwich panels with various core wall and surface thickness. A demo movie available on IMATEH web page.
- Performed DTG tests of some foam mixtures

Further work direction:

- Improvement of foam infusion technology.
- Development of high density PU foam system with open pore structure.
- To perform adhesion tests on foam and plywood interface part specimens.

Further prototype sandwich panel specimens with open pore structure.

2.5. Dissemination and outreach activities

(Describe activities that were performed during reporting period to disseminate project results)

Publications:

1. Labans E., Jekabsons G., Kalnins K., Zudrags K., Rudzite S., Kirpluks M., Cabulis U. Evaluation of plywood sandwich panels with rigid PU foam-cores and various configurations of stiffeners, In Proceedings of 3th International Conference "Optimization and Analysis of Structures", 2015, 45-52
    a. file:///C:/Users/Diana/Downloads/Edgars.pdf

Conferences:

1. Kirpluks M., Kalnbunde D., Cabulis U. High functionality polyols from rapseed oil as raw material for polyurethane thermal insulation, Baltic Polymer Symposium, Sigulda, Latvia, September 16-18, 2015;
2. Labans E., Jekabsons G., Kalnins K., Zudrags K., Rudzite S., Kirpluks M., Cabulis U. Evaluation of plywood sandwich panels with rigid PU foam-cores and various configurations of stiffeners, 3th International Conference "Optimization and Analysis of Structures", Tartu, Estonia, August 23-25, 2015.

Presentations:

1. K. Kalniņš K., E. Labans, U. Cābulis, M.Ķirpļuks, Synergies between Framework Programe 7 and VPP – in development of sandwich apnels. Week of innovative regions. WIRE 2015. June 3-5, Riga, Latvia
2. K.Kalnins, A.Čate - Innovative and Multifunctional Composite Materials for Sustainable Buildings, Innovative Materials for the Development of the Baltic Region National Economy, Dec.16, Rīga http://conference.birti.eu/agenda.
3. E. Labans, K. Kalniņš., Japins, G, Zudrags., K., Rudzite, S. Smart sandwich structures of plywood and GF/PP. EuroNanoForum 2015, June 10-12, Riga, Latvia

Doctoral thesis:

1. E.Labans "Integration and optimisation of multifunctionality for plywood sandwich construction". Scientific supervisor – K. Kalniņš, current status – submitted to Latvia Science Academy defence scheduled for spring 2016.
2. M. Kirpluks "Properties of Polyurethane foam composites with nano particles from renewable sources". Scientific supervisor – U. Cabulis. Estimated time of defence – spring of 2017

Master thesis:

1. D. Kalnbunde „ High functionality polyols from rapseed oil as raw material for polyurethane thermal insulation". Latvia University, master thesis in chemistry. Scientific supervisor – U. Cabulis

Web page

Updated IMATEH home page http://imateh.rtu.lv/ with detailed information about publications, attended events and main results.

Leader of the project No. 2 ______________________Kaspars Kalnins___________________

(signature and transcript)

(date)