Effect of Soaking/Oven-Drying on Mechanical and Physical Properties of Birch (Betula spp.) Plywood

The objective of this study was to explore some of the physical and mechanical properties of 9-layer birch (Betula spp.) plywood with the addition of phenol-formaldehyde glue, in cases in which the cutting edges of the samples are coated with the damp-proof mastic Fibergum, and in case in which they remain unprocessed (uncoated), following a total of ten cycles of soaking/oven-drying. The properties to be determined were the bending strength (BS), modulus of elasticity in bending (MOE), thickness swelling (TS) and restore dimensions (RD), which were tested according to the European standards (EN). A linear-fractional equation and linear relationship were used for the approximation of any change in the physical and mechanical properties of the samples depending upon the number of soaking/oven-drying cycles. It was shown that the values of the properties investigated were most affected by the first soaking and drying cycle. Thereafter, BS and MOE levels decreased smoothly at a low rate, but the values of TS became stabilised. The BS and MOE values for the wet samples with coated cutting edges were higher than when they were uncoated, as the moisture levels in the former case were lower. After the first soaking of the samples with coated cutting edges, the retention values were as follows: BS at 52.8 % and 66.7 % for the major and minor axes, respectively, with the same applying to MOE at 61.9 % and 64.2 %, while TS was at 105.2 %. To clarify the phenomenon that causes a decrease of the properties, the face plies and edge structures of the initial dry samples and of the samples after the first, second and ninth soaking/oven-drying cycles were studied using the X-Ray technique.

Keywords: plywood; bending strength; modulus of elasticity; thickness swelling; restore dimensions; moisture content; X-Ray technique

SAŽETAK • Cilj ovog istraživanja bio je odrediti neka fizička i mehanička svojstva furnirske ploče od brezovine (Betula spp.) izrađene od devet slojeva furnira i uz dodatak fenol-formaldehidnog ljepila. Uzorci čiji su rubovi premazani za vlagu nepropusnim premazom Fibregum i uzorci s nepremazanim rubovima namakani su i sušeni u sušioniku tijekom deset ciklusa. Prema europskim standardima, ispitivana su ova svojstva ploče: čvrstoća na savijanje, modul elasticnosti, debljinsko bubrenje i vraćanje dimenzija uzoraka. Za aproksimaciju promjena fizičkih i mehaničkih svojstava uzoraka ovisno o broju ciklusa namakanja i sušenja u sušioniku primijenjeni su linearna frakcijska jednadžba i linearni odnos. Utvrđeno je da je na vrijednost ispitivanih svojstava najviše utjecao prvi

1 Authors are researchers at Estonian University of Life Sciences, Institute of Forestry and Rural Engineering, Tartu, Estonia.
2 Author is researcher at Tallinn University of Technology, Tartu College, School of Engineering, Tartu, Estonia.
3 Author is researcher at Estonian University of Life Sciences, Institute of Technology, Tartu, Estonia.
1 INTRODUCTION

1. UVOD

As a wood-based material, the physical and mechanical properties of plywood are affected by moisture. Plywood is a highly valued construction material, one which is used more widely than other wood-based panels in conditions that involve outdoor exposure. To be able to determine the average moisture of wood and plywood samples, a continuous moisture measurement (CMM) set-up was developed (Van den Bulcke et al., 2011). With a similar set-up, an adapted electrical moisture measurement method was introduced by Li et al., (2013) to measure internal moisture levels in plywood.

In practice, weathering conditions with alternating soaking and drying cycles can reduce the mechanical properties of plywood. Li et al., (2016) studied moisture behaviour and structural changes in different layers of plywood specimens that had been exposed to outdoor weather conditions for approximately one year. It became apparent that moisture distribution in plywood was not homogeneous in outdoor conditions. In some plywood types, the second layer can accumulate a significant amount of rain, and long rainy periods and cloudy weather can cause the inner plywood layers to retain high moisture levels. The glue line between the plies was not ruptured after one year of outdoor exposure. River (1994) studied outdoor aging (at a point between 7 to 12 years) in wood-based panels (including one panel of 5-ply, Douglas fir, and marine graded commercial plywood) and its correlation with accelerated aging in the laboratory. The plywood panel that was the subject of the study belonged to a group of panels with the highest levels of resistance to outdoor exposure, managing to retain 99.6 % and 48.6 % of their initial bending strength (BS) (modulus of rupture, MOR) after one year and ten years, respectively. Significant correlations (Pearson’s and Spearman’s correlation coefficients >0.90) were found between MOR after cyclic boil-dry (BD) aging and MOR after outdoor aging (River, 1994).

For companies that are involved in producing plywood, quality control is essential for the commercialization of this type of wood. As it has already been established that a wood product will have insufficient levels of strength and dimensional stability during the course of changing moisture levels, it is reasonable to investigate some of the mechanical and physical properties of plywood depending upon the number of soaking/oven-drying cycles.

The objective of this paper was to study changes in BS, MOE, and TS after ten soaking/oven-drying cycles, with the investigation involving the cutting forehead and the facet edges of the samples being coated with the damp-proof mastic Fibergum, see Master’s thesis (Kruus, 2016). In the earliest studies, the cutting edges remained unprocessed (uncoated) - see Master’s theses (Kasepuu, 2014 and Sooru, 2015).
Approximated experimental data used a linear-fractal expression for the investigated BS, and MOE, and the linear relationship between TS and RD depending upon the number of soaking/oven-drying cycles. Also, the statistically significant (p<0.05) coefficient of variation (CV) was estimated and calculated in percentages for average values according to EVS EN 326-1:2002. The effects of soaking/oven-drying have been clarified in terms on the face plies and edge structure of the samples evaluated by means of the X-Ray technique.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

Three 9-layer commercial uncoated Wisa birch (Betula spp. grown in south-eastern Estonia) plywood moisture-proof panels with nominal dimensions of 3000 mm × 1500 mm × 12 mm were produced by UPM-Kymmene, Otepää, Estonia. Engineered hardwood plywood panels were commonly glued together with phenol-formaldehyde resin (PF) as the selected wood adhesive (Manufacturing Process of Veneer and Plywood). The dimensions of each test sample (290 mm × 50 mm × 12 mm) for BS and MOE were marked out from larger panels and were cut out in the parallel direction (II - major axis) and perpendicular direction (T - minor axis) to the face ply grain. Experiments were carried out with eleven series (with a minimum of twelve samples in a series), the first of them (dry) added also to the calculations for soaked samples. The cutting forehead and the facet edges of the test samples, as extracted from the two panels, were coated with the damp-proof mastic Fibergum, and those from the third panel remained unprocessed (uncoated). All samples were divided into two groups. One group of samples was tested in a wet (soaked) state, while the second group was tested in a dried state. The test samples were placed in a tank of room temperature water (22 ± 2) °C for a period of 24 hours. The samples were dried (over 48 hours) in a ventilated drying box at (65 ± 2) °C and after that, they were conditioned in a climatic chamber at a relative humidity level of (65 ± 5) % at (21 ± 2) °C. The dimensions and weight of the bending test samples were measured immediately after they were taken out of the water tank or the climatic chamber, in order to determine their TS, RD and MC (using the weighing method) according to the EVS-EN 317: 2000 and EVS-EN 322: 2002 standards. The dimensions of the samples were measured using a digital calliper with an accuracy of 0.01 mm and a screw gauge (Mitutoyo 293-805) with an accuracy of 0.001 mm (EVS-EN 325: 2002); the weight of the samples was measured by means of an electrical balance, a Kern PLB 1000-2 with an accuracy of 0.01 g and samples were tested immediately. The computer-controlled mechanically-actuated universal testing machine, an Instron 3369, was also used. Deflection values for a determination of the modulus of elasticity were measured by means of an optical gauge (Advanced Video Extensometer 2663-821). Samples for determining BS and MOE were tested following the three-point flatwise bending test in accordance with the EVS-EN 310:2002 standard. A load was applied at a constant rate so that failure occurred in (60 ± 30) seconds.

In order to be able to evaluate BS and MOE at static flexion in the directions of the II-major axis and T-minor axis in relation to the grain on the face plies, the process formulated by (Sooru et al., 2015) was realised and calculated according to the EVS-EN 310:2002 standard. Calculation for the coefficient of the variation of the measurements was carried out according to the EVS-EN 326-1:2002 standard.

Dimensional stability (swelling in thickness) was determined prior to the bending test in the middle zone of the samples (for more details see Figure 1b in Sooru et al., 2015).

The following linear-fractional function (equilateral hyperbola) was used to approximate the experimental data obtained for the properties investigated, depending upon the number of soaking/oven-drying cycles (Lille et al., 2013 and Sooru et al., 2015)

\[ Y(x) = (d \cdot (Y_i - Y_f) / (cx + d)) + Y_f \]

in which \( Y_i \) and \( Y_f \) are the calculated initial \( (x = 0) \) and final values \( (x = \infty) \) of the properties investigated, while \( x \) is the number of cycles, and \( c \) and \( d \) are constants.

The initial and final values of the properties and constants should be determined so that the measured experimental data are approximated in the best possible way by minimising the square of error (least squares regression). This problem was solved by using the Mathcad 15.0 programme with the regression function \( genfit(vx, vy, vg, F) \). The following assumptions were made for the mathematical expressions (the values of BS and MOE versus the number of soaking/oven-drying cycles): the approximation curve, first, cuts ordinate; and second, making it possible to determine the limit values, in which BS and MOE stabilise.

The formula (1) also makes it possible to predict, to a certain extent, the mechanical and physical properties of the samples when their values are known after the application of a small number of soaking/oven-drying cycles (between two and three). The relationship between TS and RD depending upon the number of cycles is approximated in the best way possible by minimising the square of error, by using the software, MS Excel, with the results being reached by means of regression analysis function found by the programme. The YXLON FF35 CT computed tomography system was applied for an X-Ray investigation of the structure of plywood.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Following a degree of room temperature water absorption (22 ± 2) °C by the test samples after a soaking time of 24 hours, the average moisture was about (25.3 ± 1.7) % and (40.0 ± 4.0) % for the coated and unprocessed cutting edges, respectively. Coating the cutting edges of the test samples inhibited water ab-
sorption considerably. After drying, the average moisture was \((7.7 \pm 1.8)\%\).

The mean values obtained for one cycle of \(BS\) and \(MOE\) in the directions of the II-major axis and T-minor axis are presented in Figure 1, for oven-dry \((7.7 \pm 1.8)\%\) and wet \((25.3 \pm 1.7)\%\), where the cutting edges are coated with mastic, and in Figure 2, for wet \((40.0 \pm 4.0)\%\), (for oven-dry, see more in Sooru et al., 2015), where the cutting edges have remained unprocessed.

All mean values in the experimental data were approximated by means of Eq. 1 and are presented as curves of the calculated values of the properties investigated and their constants. Also, the coefficient of variation (CV) for the mean values was calculated in percentages.

---

**Figure 1** Dependence of \(BS\) (marked as \(f_m\)) and \(MOE\) (marked as \(E_m\)) on the number of soaking/oven-drying cycles, mean values from experimental data with CV and curves of approximation.

**Slika 1.** Ovisnost čvrstoće na savijanje i modula elastičnosti o broju ciklusa namakanja i sušenja u sušioniku, srednje vrijednosti iz eksperimentalnih podataka s koeficijentima varijacije i aproksimacijskim krivuljama.
The experimental data for all the properties studied tended to fluctuate to a moderate extent as the plywood had been produced from heterogeneous wood material and the plies had natural flaws and knots. Consequently, after 24 hours of soaking, when the cutting edges were coated and water absorption through them was blocked, the moisture (25.3 ± 1.7) % was about 15 % lower than in the samples with unprocessed cutting edges (40.0 ± 4.0) %. On the other hand, considering that the barrier, which had been provided by the glue used for the bonding of the plies, inhibits the absorption of water through the faces, moisture levels in the panels with significantly larger dimensions was lower than in the samples with unprocessed (uncoated) cutting edges. It was shown that the direction of the face grain direction plays an important role in some properties of structural plywood panels. The BS and MOE values differed significantly depending upon whether they were measured in parallel or perpendicular to the samples. The determined values of the properties investigated for the samples of the T-minor axis fluctuated more than those for the samples of the II-major axis. For the parallel samples, the direction of the experimental load in relation to the face grain was tangential (T), while the direction of the internal load in relation to the face grain was longitudinal (L); for the perpendicular samples, the situation was the opposite. The tensile strength in the T direction of European beech wood was many times lower than in the L direction. It can be seen that the proposed Eq. 1 approximated the experimental data quite satisfactorily. It should be noted that the values for the calculated percentages are taken from the approximation curves and are presented in Table 1.

Figure 2 Dependence of BS and MOE on the number of soaking/oven-drying cycles, mean values from experimental data and curves of approximation

Slika 2. Ovisnost čvrstoće na savijanje i modula elastiĉnosti o broju ciklusa namakanja i sušenja u sušioniku, srednje vrijednosti iz eksperimentalnih podataka i aproksimacijske krivulje
The linear relations between mean values for one cycle of TS and RD, depending upon the number of soaking/oven-drying cycles are presented in Figure 3.

The TS was 5.2 % and 7.1 % at a moisture of about (25.3 ± 1.7) % and (40.0 ± 4.0) %, respectively, while the thickness RD in the dried samples at a moisture of (7.7 ± 1.8) % was 98.6 %. The reduction in TS may indicate a volume decrease of the face plies due to plastic deformation during the first soaking period and also to manufacturing residues (including particles and dust) in the plywood, which were washed off during the soaking cycle.

The TS for the plywood did not change significantly after the first soaking/oven-drying cycles (7.7 ± 1.8) %. This phenomenon has been noted in the case of wood. Swelling in wood, which is also similar to swelling in plie as a wood product, takes place below the fibre saturation point (FSP) (about 30 %), at which the

Table 1 Mean values for BS, MOE, TS and RD for dry and moist test samples and residual values of wet samples versus dry samples

| Moisture, axis / Sadržaj vode, osi | Dried / Sušeni, % | Soaked / Namakani, % |
|------------------------------------|------------------|----------------------|
|                                    | Major II | Minor T | Major II | Minor T | Major II | Minor T |
| Mean values / Srednje vrijednosti, N/mm² |          |          |          |          |          |          |
| Bending strength Čvrstoća na savijanje | initial | 98.0     | 66.5     | 98.5     | 66.4     | 91.4     | 67.4     |
|                                   | final     | 74.3     | 54.9     | 48.5     | 39.5     | 38.7     | 24.5     |
| Modulus of elasticity Modul elastičnosti | initial | 10130 | 6387 | 10130 | 6387 | 9539 | 5662 |
|                                   | final     | 8494     | 5630     | 5484     | 3942     | 5049     | 3364     |
| Mean residual values vs those obtained from initial dry samples, % | Major II | Minor T | Major II | Minor T | Major II | Minor T |
| After first cycle BS | 80.0 | 92.5 | 52.8 | 66.7 | 46.8 | 48.0 |
| Nakon prvog ciklusa MOE | 91.9 | 90.9 | 61.9 | 64.2 | 57.3 | 62.1 |
| Final BS | 75.8 | 82.6 | 49.2 | 59.5 | 42.3 | 36.4 |
| Završno MOE | 83.8 | 88.1 | 54.1 | 61.7 | 53.9 | 35.3 |
| Thickness swelling / Debljinsko bubrenje % | 5.2 | 7.1 |
| Restore dimension/ Povrat dimenzija | 98.6 |
Figure 4 X-Ray images of texture of samples: a) face plies; b) middle edge in parallel with II-axis; c) in parallel with T-axis; purveyance dry (0 cycle), and after the first, second and ninth soaking/oven-drying cycle.

Slika 4. Rendgenske slike teksture uzoraka: a) slojevi lica; b) srednji rub paralelno s osi II; c) paralelno s osi T; suho (0 ciklusa), nakon prvoga, drugoga i devetog ciklusa namakanja i sušenja u sušioniku.
The mechanical and physical properties of 9-layered birch plywood after soaking/oven-drying cycles were investigated according to European standards. Experiments were carried out with eleven series, with a minimum of twelve samples in a series.

After the first soaking at a moisture level of (25.3 ± 1.7) %, the retention values were as follows: BS at 52.8 % and 66.7 % for the major and minor axes, respectively, with the same applying to MOE at 61.9 % and 64.2 %, while TS was at 105.2 %. At a moisture of (40.0 ± 4.0) %, the retention values were as follows: BS at 46.8 % and 48.0 % for the major and minor axes respectively, with the same applying to MOE at 57.3 % and 62.1 %, and with TS at 107.1 %.

After the first soaking and drying test (with a moisture of (7.7 ± 1.8) %), the retention values were as follows: BS at 80.0 % and 92.5 % for the major and minor axes, respectively, with the same applying to MOE at 91.9 % and 90.9 %, and with RD at a thickness of 98.6 %.

The proposed analytical function satisfactorily approximated the BS and MOE experimental data, depending upon the number of soaking/oven-drying cycles.

The results of the X-Ray investigations showed that the causes of abrupt change in the properties of the plywood samples were rapid water sorption-desorption and the related swelling-shrinkage of the face plies on the plywood in restrained elongation conditions.

The analysis, as presented here, is limited to data obtained from the aforementioned experiments.

Acknowledgements – Zahvala

The X-Ray investigations for the current study were supported by the European Regional Fund, project No. 2014-2020.4.01.16-0183, Smart Industry Centre (SmartIC).

5 REFERENCES

1. Dieste, A.; Krause, A.; Bollmus, S; Militz, H., 2008: Physical and mechanical properties of plywood produced with 1,3-dimethylol-4,5-dihydroxyethylenurea (DMDHEU)-modified veneers of Betula sp. and Fagus sylvatica. Holz als Roh- und Werkstoff, 66 (4): 281-287. https://doi.org/10.1007/s00107-008-0247-3.
2. Cosereanu, C.; Lica, D.; Curtu, I.; Lunguleasa, A.; Cismaru, I.; Brenci, L.; Fotin, A., 2010: Mechanical Testing of Beech Veneer Sandwich Composites. In: Proceeding of 7th Internation DAAAM Baltic Conference. Industrial Engineering, Tallinn, Estonia.
3. Hiziroglu, S., 2017: Dimensional Changes in Wood. Oklahoma Cooperative Extension Service. http://pods.dasnr.okstate.edu/docushare/dsweb/Get/Rendition-7237/NREM-5009web.pdf.
4. Kasepuu, K., 2014: Effect of plywood soaking and drying cycles on mechanical and physical properties. MSc Thesis, Estonian University of Life Sciences, Tartu, Estonia (in Estonian). https://dspace.emu.ee/xmlui/bitstream/handle/10492/1751/Kaido_Kasepuu_MA2014.pdf?sequence=3&isAllowed=y.
5. Kruus, S., 2016: Changes in physical and mechanical properties of moisture resistant birch plywood after soaking and oven-drying cycles. MSc Thesis, Estonian University of Life Sciences, Tartu, Estonia (in Estonian). https://dspace.emu.ee/xmlui/browse?type=author&value=Kruus%2C+Silver.
6. Li, W. Z.; Van den Bulcke, J.; De Windt, I.; Van Loo, D.; Dierick, M.; Brabant, L.; Van Acker, J., 2013: Combining electrical resistance and 3-D X-ray computed tomography...
phy for moisture distribution measurements in wood products exposed in dynamic moisture conditions. Building and Environment, 67: 250-259. https://doi.org/10.1016/j.buildenv.2013.05.026.
7. Li, W. Z.; Van den Bulcke, J.; De Windt, I.; Dhaene, J.; Van Acker, J., 2016: Moisture behavior and structural changes of plywood during outdoor exposure. European Journal of Wood and Wood Products, 74 (2): 211-221. https://doi.org/10.1007/s00107-015-0992-z.
8. Lille, H.; Kõo, J.; Ryabchikov, A.; Reitsnik, R.; Veinthal, R.; Mikli, V.; Sergejev, F., 2012: Investigation of residual stresses and some elastic properties of brush-plated gold and silver coatings. Key Engineering Materials, 527: 125-130. https://doi.org/10.4028/www.scientific.net/KEM.527.125.
9. Lipinskis, I.; Spulle, U., 2011: Research of mechanical properties of birch plywood with special veneer lay-up schemes. Drewno, 54 (185): 109-118.
10. Zalemanis, A.; Zudrags, K.; Japins, G., 2018: Birch plywood sample tension and bending property investigation and validation in solidworks environment. In: Proceeding of 24th International Scientific Conference Research for Rural Development, Jelgava, Latvia, 1: 103-110. https://doi.org/10.22616/rdr.24.2018.016.
11. River, B. H., 1994: Outdoor aging of wood panels and correlation with laboratory aging. Forest Products Journal, 44: 55-65.
12. Sooru, M., 2015: Variation in mechanical and physical properties of birch plywood after soaking/oven-drying cycles. MSc Thesis, Estonian University of Life Sciences, Tartu, Estonia (in Estonian). https://dspace.emu.ee/xmlui/bitstream/handle/10492/2171/Marko_Sooru_2015MA_MT_%c3%a4istikst.pdf?sequence=1&isAllowed=y.
13. Sooru, M.; Kasepuu, K.; Kask, R.; Lille, H., 2015: Impact of soaking/oven-drying cycles on the mechanical and physical properties of birch plywood. IOP Conference Series: Materials Science and Engineering, 96: 012075. https://iopscience.iop.org/article/10.1088/1757-899X/96/1/012075/pdf.
14. Van den Bulcke, J.; Van Acker, J.; De Smet, J., 2009: An experimental setup for real-time continuous moisture measurements of plywood exposed to outdoor climate. Building and Environment, 44 (12): 2368-2377. https://doi.org/10.1016/j.buildenv.2009.03.021.
15. Van den Bulcke, J.; De Windt, I.; Defoirdt, N.; De Smet, J.; Van Acker, J., 2011: Moisture dynamics and fungal susceptibility of plywood. International Biodeterioration & Biodegradation, 65 (5): 708-716. https://doi.org/10.1016/j.ibiod.2010.12.015.
16. ***Estonian Centre for Standardization, EVS EN 326-1, 2002: Puitplaadid. Prooviivõtt, lõikamine ja kontrol. Osa 1: Prooviivõtt, katsekehad lõikamine ja katsetutemusteväljandamine. Wood-based panels. Sampling, cutting and inspection. Part 1: Sampling and cutting of test pieces and expression of results.
17. ***Estonian Centre for Standardization, EVS EN 317, 2000: Puutlaastplaadid ja puutiidplaadid. Pundumise määramine paksuses pärast leotamist. Particleboards and fibreboards. Determination of swelling in thickness after immersion in water.
18. ***Estonian is a Country of Forest – Statistics/Estonian Timber. https://estoniantimber.ee/statistics/ (Accessed Nov. 10, 2018).
19. ***Estonian Centre for Standardization, European Standard EVS EN 310: 2002: Puitplaadid. Paindeelastusmodul ja paindetugevus määramine. Wood-based panels. Determination of modulus of elasticity in bending and of bending strength.
20. ***Estonian Centre for Standardization, EVS EN 322, 2002: Puitplaadid. Niskussisaldusluse määramine. Wood-based panels – Determination of moisture content.
21. ***Estonian Centre for Standardization, EVS EN 325, 2012: Puitplaadid. Katsekehad mõõtmete määramine. Wood-based panels. Determination of dimensions of the pieces.
22. ***Manufacturing Process of Veneer and Plywood/Estonian Timber. https://estoniantimber.ee/best-practices/manufacturing-process-of-veneer-and-plywood/ (Accessed Nov. 10, 2018).
23. ***Finnish birch plywood – Metsä Wood. Retrieved from: www.metsawood.com/.../plywood/birch-plywood/.../Birch-plywood.asp (Accessed Nov. 10, 2018).
24. ***Finnish Forest Industries Federation, 2002: Handbook of Finnish plywood. Kirjapaino Markprint Oy, Lahti, Finland. https://www.metsateollisuus.fi/uploads/2017/03/30041750/887.pdf (Accessed Nov. 10, 2018).
25. ***Plywood Manufacturing: Global Markets to 2022. Aug. 2018. Report 173 pages. BCC Research LLC. BCC Research LLC, 49 Walnut Park, Building 2, Wellesley, MA 02481, US.
26. ***Plywood Market: Global Demand Analysis & Opportunity Outlook 2023. Report, ID: 261. April, 2019. Research Nester. 77 Water Street 8th Floor, New York 10005, US.
27. ***Plywood Market: Strong Demand for MR Grade Plywood to Drive Growth: Global Industry Analysis 2013 – 2017 and Opportunity Assessment 2018 – 2028. 2018-11-12, 400 pages. Future Market Insights. 3rd Floor, 207 Regent Street, London W1B 3HH, United Kingdom.
28. ***UN 2016. Food and agriculture organization of United Nations. Global forest products: facts and figures, 2017/03/30041750/887.pdf (Accessed Nov. 10, 2018).

**Corresponding address:**
Prof. MIHKEL KIVISTE PhD
Tallinn University of Technology (Taltech)
Tartu College
School of Engineering
Puiestee 78, 51008 Tartu, ESTONIA
e-mail: mihkel.kiviste@taltech.ee