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Research Paper

Influence of the Composition on the Exploitation Properties of Combined Medium Density Fibreboards Manufactured with Coniferous Wood Residues

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Abstract

One of the main disadvantages of medium density fibreboards (MDF) in comparison with particleboards is the higher price of the panels, due to the energy-intensive defibration process.
Studies on the possibilities for replacing a part of the wood fibre mass in the composition of MDF with coniferous sawmill residues (shavings) obtained from bandsaw, are presented in this article. The experimental plan is designed using the McLean and Anderson method for studying the properties of multi-component systems in the presence of constraints on the components. The content of coniferous wood shavings varies up to 40%. The panels are manufactured with a density of 720 kg.m^{-3}. The content of urea-formaldehyde resin varies from 8 to 14% in order to compensate the negative effect of the inclusion of coniferous wood shavings in the composition of the manufactured MDF panels. The main exploitation properties of the panels are determined. Experimental and statistical models on the influence of the studied factors are obtained by applying stepwise regression and optimization is performed in order to acquire the best exploitation properties of MDF panels.
As a result of the study it was determined that in order to achieve the values of MDF properties, required by the respective standards, the maximum permissible content of coniferous wood shavings should be up to 10.6%, in which case the content of urea-formaldehyde resin should be above 10%. If the content of urea-formaldehyde resin is below 10%, the maximum permissible content of coniferous wood shavings should be up to 5%.

Keywords: medium-density fibreboards (MDF), wood fibre mass, coniferous wood residues, statistical models

1. INTRODUCTION

The principles embedded in the circular economy are now emphasized in almost all manufacturing processes and product design. This has introduced several innovative concepts i.e. the bioeconomy, the bio-based society and the green economy that are now changing the strategic planning of many industrial companies [16].

The woodworking and furniture industries represent a sustainable, innovative and environmental economic sector, using a natural and renewable raw material and thus play a vital role in the development of green economy. Nowadays these wood-based industries, including the fibreboard sector, are facing an increased competition for wood resources from the renewable energy sector, due to the current legislative measures for promoting the use of wood for producing bioenergy to meet the respective renewable energy targets and by the development of innovative bio-based products [14]. Maximization of resource efficiency is a key objective to implement a circular economy and to face the challenges of increased demand for wood and wood-based products. To meet these demands sustainably requires action in a variety of areas, from the sustainable management of forests, to the more resource efficient use of wood in society. One of the leading principles is the so-called cascading use of wood resources: *"the efficient utilisation of resources by using residues and recycled materials for material use to extend total biomass availability within a given system"* [21].

The wood-based industries produce significant amounts of waste and residues. According to some authors [13] 26 million tonnes of post-consumer wood (wood products that are disposed at the end of their life cycle, e.g. wooden furniture, window frames and wood-based panels, packaging, doors, windows, various construction materials, etc.) was generated in Europe in 2010. Taking into account these figures it is

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important to create different applications for the previous waste and residue materials while considering environmental and economic factors. Large quantities of wood wastes are also produced in the course of primary and secondary wood processing, including bark, sawmill shavings, slabs, off-cuts, rejects, wood chips and saw dust. These types of waste, sometimes called wood processing residues, are produced at industrial facilities and are easily collectable and reusable as feedstock for wood-based composite industry [7; 17; 20]. The total amount of wood processing residues in the EU28 was 178.7 Mm^3 in 2010, of which 82.3 Mm^3 were sawmill residues [21]. These residues represent an untreated and clean wood resource that can be used materially in the pulp and panel industry. The industrial reuse of wood resources will contribute greatly to the supply of raw material and will enhance the competitiveness of wood-based composite materials.

Fibreboards are a composite wood-based material with a dispersed phase of wood fibres and a composite matrix phase formed by the adhesion and cohesion bonds of the panels [1; 3].

Fibreboard production ranks second of all wood-based composites worldwide, outpaced only by the production of plywood and glued-laminated timber. The growth in the production of fibreboards for the period 2011 - 2015 was 45%, due mainly to the increased production of MDF panels, which accounted for 80% of the total production of fibreboards [30].

The defibraiton (disintegration of wood to free fibres) is one of the most energy-intensive processes in the production of this type of wood-based panels and has an important role in forming the final product costs [6; 9; 15]. Therefore, the design of exploitation properties of panels can be effectively performed by regulating the parameter values of the wood fibre mass incoming to the upper flow [8; 19]. When determining the raw material characteristics both the impact on the exploitation properties and production costs should be taken into consideration [12]. The reduction of product costs can be achieved by including wood industry residues in the composition of panels which do not need to go through the defibration process. The wood shavings, resulting from the primary and secondary wood processing with a bandsaw, represent a typical raw material for that purpose [2].

At present this type of wood processing waste and residues is mainly used in the production of wood pellets [4] and briquettes [11;18], as well as in the wood chemical industry for production of bioethanol [10]. It should be noted that the possibilities for utilization of wood shavings in one of the fastest-growing industries, namely the production of MDF panels, has not been sufficiently studied yet.

The adhesion bonds are of great importance in the production of fibreboards by dry processing method [5; 8]. The active area of contact between the fibres is reduced by including wood shavings in the composition of fibreboards, which can be compensated to some extent by increasing the bonding agent content.

The use of soft wood from deciduous tree species is recommended in the production of panels by dry processing method. The most widely used bonding agent is the urea-formaldehyde resin [5].

The present research is aimed at studying the possibilities of replacing a part of the wood fibre mass in the composition of combined medium density fibreboards (MDF) manufactured from poplar (*Populus alba* L.) with coniferous sawmill residues (shavings) from Scots pine (*Pinus sylvestris* L.) and the respective influence on the exploitation properties of the panels.

2. MATERIALS AND METHODS

The combined medium density fibreboards (MDF) were produced in laboratory conditions from wood fibre mass and coniferous sawmill residues (shavings). The wood fibre mass was obtained in factory conditions according to the Asplund method by using the *Defibrator* L-46 equipment. The wood fibre mass had a pulp freeness of 11° ShR and a bulk density of 29 $kg.m^{-3}$.

The coniferous wood shavings had a bulk density of 145 $kg.m^{-3}$. The fractional composition was as follows: fraction over 2.0 – 1.24%; fraction 2.0/1.0 – 25.71%; fraction 1.0/0.8 – 6.67%; fraction 0.8/0.5 – 34.2%; fraction 0.5/0.315 – 19.0%; fraction 0.315/0.2 – 9.25%; saw dust – 3.94%.

The wood shavings and fibres were dried to the uniform moisture content of 6%.

The studies on the influence of the composition on the exploitation properties of combined fibreboards manufactured with coniferous wood shavings were implemented by applying the simplex grid experimental plans with a twofold constraint of the factors using the McLean and Anderson method [22]. The experimental matrix is presented in Table 1.

Table 1. Matrix of the experiments

№	Wood shavings content X_1	Content of urea-formaldehyde resin X_2	Content of fibres in absolute dry state X_3
1.	0.4	0.14	0.46
2.	0	0.08	0.92
3.	0.4	0.08	0.52
4.	0	0.14	0.86
5.	0.2	0.11	0.69
6.	0	0.11	0.89
7.	0.2	0.14	0.66
8.	0.2	0.08	0.72

The area of factor variation, corresponding to the above matrix, is presented on Fig. 1.

The panels were manufactured with a density of 720 $kg.m^{-3}$. The content of coniferous wood shavings was altered from 0 to 40%. The content of urea-formaldehyde resin was altered

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Table 2. Results for the exploitation properties of combined fibreboards

№	Content of wood shavings X_1	Content of urea-formaldehyde resin X_2	Content of fibres in absolute dry state X_3	Bending strength f_m, N.mm^{-2}	Internal bond strength f_t, N.mm^{-2}	Swelling in thickness G_t, %	Water absorption A, %
1.	0.4	0.14	0.46	16.93	0.37	22.68	84.77
2.	0	0.08	0.92	21.55	0.21	25.87	60.26
3.	0.4	0.08	0.52	14.15	0.26	25.84	100.03
4.	0	0.14	0.86	24.22	0.32	19.49	50.73
5.	0.2	0.11	0.69	20.43	0.25	26.28	79.81
6.	0	0.11	0.89	25.35	0.38	19.74	37.37
7.	0.2	0.14	0.66	19.68	0.40	21.56	58.83
8.	0.2	0.08	0.72	17.01	0.23	28.07	101.20

Table 3. Regression models for determining the influence of coniferous wood shavings and urea-formaldehyde resin on the exploitation properties of combined fibreboards

Property	Bending strength f_m, N.mm^{-2}	Internal bond strength f_t, N/mm^{2}	Swelling in thickness Gt, %	Water absorption A, %
Coefficient B_1	-48.729	0.595	–	82.098
Coefficient B_2	-3548.362	–	52.246	-242.394
Coefficient B_3	-31.044	–	36.146	85.524
Coefficient B_{12}	4705.522	–	–	–
Coefficient B_{13}	–	-0.465	50.000	226.065
Coefficient B_{23}	4572.727	3.206	-146.805	–
Coefficient B_{123}	-320.826	–	–	–
Determination coefficient R^2	0.985	0.610	0.861	0.865
Calculated value of the Fisher criterion F_{calc}	28.012	6.791	9.010	8.497
Critical value of the Fisher criterion F_{cr}	19.296	5.786	6.591	6.591

from 8 to 14% in order to compensate the negative impact of the inclusion of coniferous wood shavings in the composition of the manufactured MDF panels.

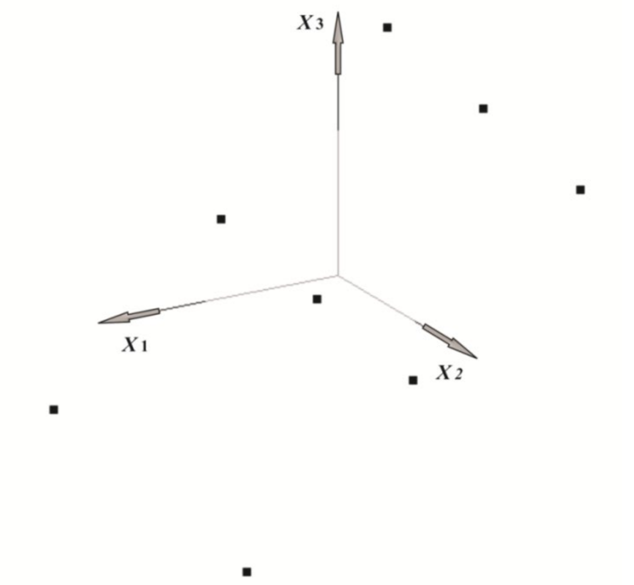

Fig. 1 Area of factor variation applying two-fold factor constraints for studying the influence of composition on the exploitation properties of combined fibreboards manufactured with coniferous wood shavings

The paraffin content was 1% of the absolutely dry wood. The additives were added for a period of 50 s by using a laboratory mixer at the speed of 850 min^{-1}. The pressing was performed on a laboratory press PMS CT 100, Italy. The hot pressing factor was 30 s.mm^{-1} of the panel thickness. The panels were manufactured with a thickness of 8 mm. The pressing temperature was 200° C. The hot pressing regime was as follows: I stage - pressure P = 4 MPa (15% of the whole cycle); II stage - pressure P = 2.0 MPa (15% of the whole cycle); III stage - pressure P = 0.8 MPa (50% of the whole cycle); IV stage - pressure P = 1.5 MPa (20% of the whole cycle).

The combined fibreboards were manufactured in laboratory conditions within the specified constraints. The properties of the panels were determined in accordance with the requirements of the applicable European standards in the respective field [23; 24; 25; 26; 27; 28]. The internal bond strength is determined to trace the bonding quality between the fibrous elements and between the fiber elements and the wood shavings.

The data was processed using specialized software (QstatLab) and stepwise regression at 1000 interactions was applied for determining the optimal values of the panel components.

3. RESULTS AND DISCUSSION

The summarized results for the exploitation properties of combined fibreboards with variation of the values (levels) of the coniferous wood shavings and urea-formaldehyde resin in accordance with the adopted experimental matrix are presented in Table 2.

The determination coefficient is used as a measure for determination of the approximation. The values of the regression coefficients, determination coefficient, calculated (F_{calc}) and critical (F_{cr}) value of the Fisher criterion, showing the regression models about the influence of the composition on the different exploitation properties of combined fibreboards, are presented in Table 3.

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3.1 Analysis of the obtained experimental results for the bending strength of the panels

The influence of coniferous wood shavings and urea-formaldehyde resin on the exploitation properties of combined fibreboards manufactured of poplar and coniferous wood shavings is presented on Figure 2. By increasing the percentage of coniferous wood shavings up to 40% and reducing the content of urea-formaldehyde resin from 14 to 8%, a decrease of the bending strength values of the combined fibreboards is determined – from 25.3 to 14.2 N.mm^{-2}, i.e. as the result of the content variation of the boards there is a significant, more than 1.8 times, change in bending strength of the panels.

The optimal (maximum) value of the bending strength with a planned constraint of 23 N.mm^{-2} [29] for the value of the property which corresponds to the standard requirements for MDF panels with a predetermined board thickness is presented on the figure. The maximum value is reported at 11.59% urea-formaldehyde content, 0% wood shavings content and 88.38% content of poplar wood fibres. In order to achieve the requirements for the bending strength of fibreboards, the content of coniferous wood shavings can be increased up to 26% while the urea-formaldehyde content should be above 12%. When the binder content is 8%, the requirements for the bending strength of the panels could be achieved at the maximum permissible content of wood shavings up to 5%.

If the wood shavings content is increased above 10%, a significant deterioration of the bending strength values is observed which should be compensated by an increased binder content.

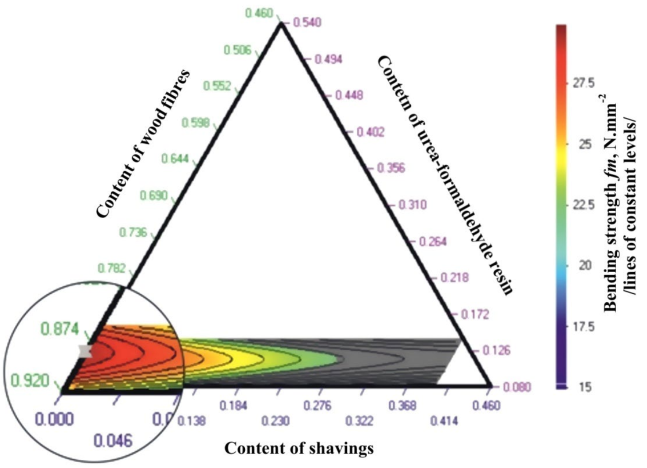

Fig. 2 "Composition-property" diagram for the bending strength of combined fibreboards manufactured with coniferous wood shavings

3.2 Analysis of the obtained experimental results for the internal bond strength of the panels

The graphical interpretation of the results for the influence of the composition on the internal bond strength of combined fibreboards manufactured of poplar wood and coniferous wood shavings is presented on Figure 3. The rage of variation of the examined property at the different panel compositions is from 0.21 to 0.40 N.mm^{-2}, i.e. the internal bond strength is decreased 1.9 times. The optimal (maximum) value of the internal bond strength of the manufactured combined fibreboards is also presented on the figure. The maximum value is determined at 14% content of urea-formaldehyde resin and without wood shavings in the composition of the panels. The greatest gradient of the property decrease is determined when increasing the wood shavings content above 10% and reducing the urea-formaldehyde content below 12%, respectively (transition to the orange zone of the graph).

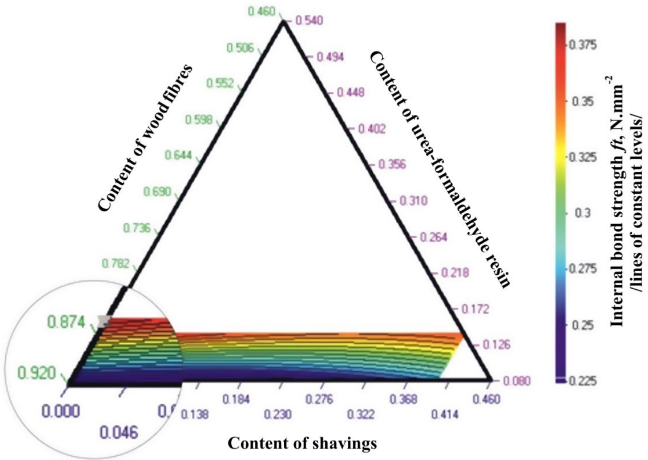

Fig. 3 "Composition-property" diagram for the internal bond strength of the combined fibreboards manufactured with coniferous wood shavings

3.3 Analysis of the obtained experimental results for the swelling in thickness and water absorption of the panels

The graphical interpretation of the dependence of the swelling in thickness of combined fibreboards manufactured of poplar wood and coniferous wood shavings is presented on Figure 4 by the "composition-property" diagram. The swelling in thickness of the panels varies from 19.5 to 28% within the studied range of factor variation, i.e. the swelling in thickness of the panels deteriorates 1.4 times by the increased content of coniferous wood shavings. The minimum value of the examined property is determined at 14% binder content and without coniferous wood shavings.

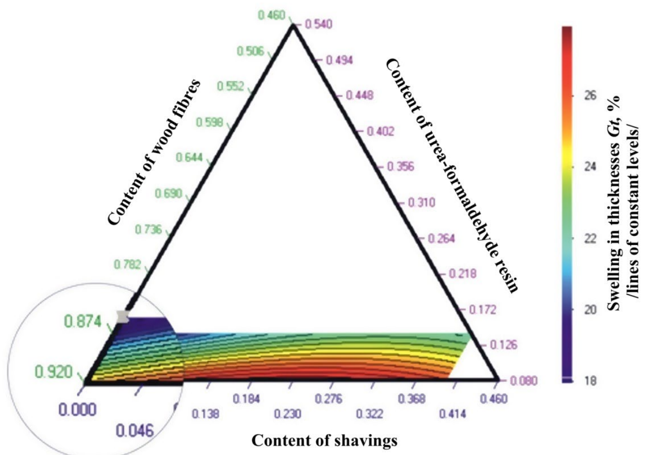

Fig. 4 "Composition-property" diagram for the swelling in thickness of the combined fibreboards manufactured with coniferous wood shavings

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Upon analysis of the regression model and the graph, a distinct deterioration (increase) of the studied property is observed with the increase of wood shavings content above 10% and reduction of the bonding agent content below 12% (transition from the dark to light blue area of the graph).

The graphical representation of the influence of the panel composition on the water absorption of the panels is shown on Figure 5.

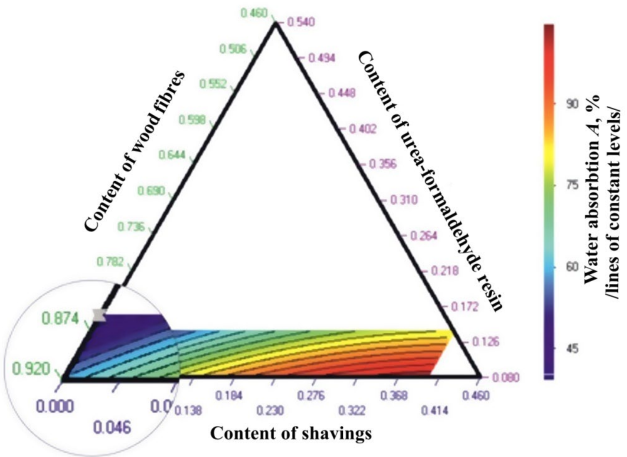

Fig.5 Composition-property" diagram for the water absorption of the combined fibreboards manufactured with coniferous wood shavings

The water absorption of the panels varies within the range from 101.2 to 37.4 %. The most significant deterioration of all studied exploitation properties is determined for the water absorption (2.7 times) as the result of the addition of coniferous wood shavings and reduction of the binder content.

The optimal value of the property is obtained at 14% content of urea-formaldehyde resin without the inclusion of wood shavings.

Regarding the water absorption of the panels two main dividing values of the wood shavings content are determined, after which a significant deterioration or increase of the values of the studied property is reported. The first significant increase of the gradient is observed after exceeding the value of 10% wood shavings content and the second one – above 26% wood shavings content. As for the binder content a significant deterioration of the values of the water absorption is determined at reduction below 12%.

4. CONCLUSIONS

After conducting the present research and analysing the obtained experimental results for the influence of the composition on the exploitation properties of combined fibreboards manufactured of poplar wood and coniferous wood shavings, the following main conclusions can be drawn:

1) A significant deterioration of the studied exploitation properties of the panels is determined after including coniferous wood shavings in the composition of poplar fibreboards due to the decreased area of active contact between the fibrous elements;
2) As a result of the variation of coniferous wood shavings from 0 to 40% and reduction of the urea-formaldehyde content from 14% to 8%, the decrease in bending strength and internal bond strength of the panels is almost twice;
3) The negative impact on the swelling in thickness of the panels, resulting from the increased coniferous wood shavings content and reduced urea-formaldehyde content, is 1.4 times; the most significant influence of the composition of the panels is determined for their water absorption where a deterioration of 2.7 times is reported;
4) Regarding the influence on the exploitation properties of combined poplar fibreboards manufactured with coniferous wood shavings, the percentage contribution to the latter should be no more than 26%; after exceeding the 10% wood shavings content the minimum urea-formaldehyde content should be 12%;
5) When the urea-formaldehyde content in the composition of the combined fibreboards is up to 10%, the maximum content of coniferous wood shavings should not exceed 5%.

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REFERENCES

[1] Ayrilmys N, Yurttas E, (2017) Effect of core layer fiber size and face to core layer ratio on properties of three layered fiberboard. BioResources 12(4):7964-7974.

[2] Bello RS (2017) Characterization of Sawdust Produced from Circular, Chain and Band Sawing Machines. Bioprocess Engineering. Vol. 1, No. 1:21-29.

[3] Benthien JT, Bahnisch C, Heldner S, Ohlmeyer M (2014) Effect of fiber size distribution on medium-density fiberboard properties caused by varied steaming time and temperature of defibration process. Wood and Fiber Science 46(2):175-185.

[4] Bergström D, Israelson S, Öhman M, Dahlquist SA, Gref R, Boman C (2008) Effects of raw material particle size distribution on the characteristics of Scots pine sawdust fuel pellets. Fuel Processing Technology 6.

[5] Thoemen H, Irle M, Sernek M (2010) Wood-Based Panels an Introduction for Specialists. Brunel University Press.

[6] Hellström LM, Carlberg T, Engstrand P, Gradin PA, Gregersen ØW (2012) Evaluation of collimated chipping technology for reducing energy consumption in mechanical pulping. Journal of Science & Technology for Forest Products and Processes 2(3).

[7] Hillring B, Canals G, Olsson O (2007) Market for recovered wood in Europe - an overview. In: Gallis Ch (ed) Management of recovered wood. University Studio Press, Thessaloniki.

[8] Htun M, Salmén L (1996) The importance of understanding the physical and chemical properties of wood to achieve energy efficiency in mechanical pulping. Wochenbl. Papierfabrik 124: 232-235.

[9] Hua J, Chen G, Xu D, Shi SQ (2012) Impact of termomechanical refining conditions on fiber quality and energy consummation by mill trial. BioResources 7(2):1919-1930.

[10] Irawati D, The utilization of sawdust for ethanol production. http://repository.ipb.ac.id/handle/ doi: 123456789/9013. (accessed 17 May 2014).

[11] Kupolati WK, Grassi St, Frattari A (2012) Environmental Greening through Utilization of Sawdust for Production of Bricks. OIDA International Journal of Sustainable Development, Vol. 4, No. 12:63-78.

[12] Li J, Pang S, Scharpf EW (2012) Modeling of thermal energy demand in MDF production. Forest Prod. J. 57(9):97-104.

[13] Mantau, U. (2012) Wood Flows in Europe. Commissioned by CEPI: Confederation of European Paper Industries, and CEI-Bois: European Confederation of Woodworking Industries.

[14] Mantau U. (2010) Wood resource balance results - is there enough wood for Europe? In: Mantau U et al (ed) Euwood - Real potential for changes in growth and use of EU forests. Final report, Hamburg:19–34.

[15] Martínez A, Huber CD, Pinkl S, Mahrdt E, Teischinger A, Müller U (2017) Dynamic Compression: A Novel Technique to Reduce Energy Consumption during Wood Fiber Production. BioResources 12(4):7376-7394.

[16] McCormick K, Kautto N (2013) The bioeconomy in Europe: an overview. Sustainability 5:2589–2608.

[17] Merl AD, Humar M, Okstad T, Picardo V, Ribeiro A, Steierer F (2007) Amounts of recovered wood in COST E31 countries and Europe. In: Gallis Ch (ed) Management of recovered wood. University Studio Press, Thessaloniki:79–116.

[18] Pushpa J, Pramod Y (2012) Briqueting of saw dust. Applied Mechanics and Materials Vols. 110-116:1758-1761.

[19] Shi JL,. Zhang SY, Riedl B (2006) Multivariate modeling of MDF panel properties in relation to wood fiber characteristics, Holzforschung. 60(3):285-293.

[20] Vefago LHM, Avellaneda J (2013) Recycling concepts and the index of recyclability for building materials. Resour Conserv Recycl 72:127–135.

[21] Vis M, Mantau U, Allen B (Eds.) (2016) Study on the optimised cascading use of wood. No 394/PP/ENT/RCH/14/7689. Final report. Brussels:337.

[22] Wang Z, Ye W, Chu I, Ong ShP (2016) Elucidating Structure–Composition–Property Relationships of the β-SiAlON:Eu2+ Phosphor. Chemistry of Materials.

[23] EN 310: 1993 "Wood-based panels - Determination of modulus of elasticity in bending and of bending strength".

[24] EN 316:2009 "Wood fibreboards - Definition, classification and symbols".

[25] EN 317:1993 "Particleboards and fibreboards - Determination of swelling in thickness after immersion in water".

[26] EN 319:1993 "Particleboards and fibreboards - Determination of tensile strength perpendicular to the plane of the board".

[27] EN 322:1993 "Wood-based panels - Determination of moisture content".

[28] EN 323:1993 "Wood-based panels - Determination of density".

[29] EN 622-5:2009 "Fibreboards - Specifications - Part 5: Requirements for dry process boards (MDF)".

[30] Global production and trade of forest products in 2016 http://www.fao.org/forestry/statistics (accessed 05 January 2018).